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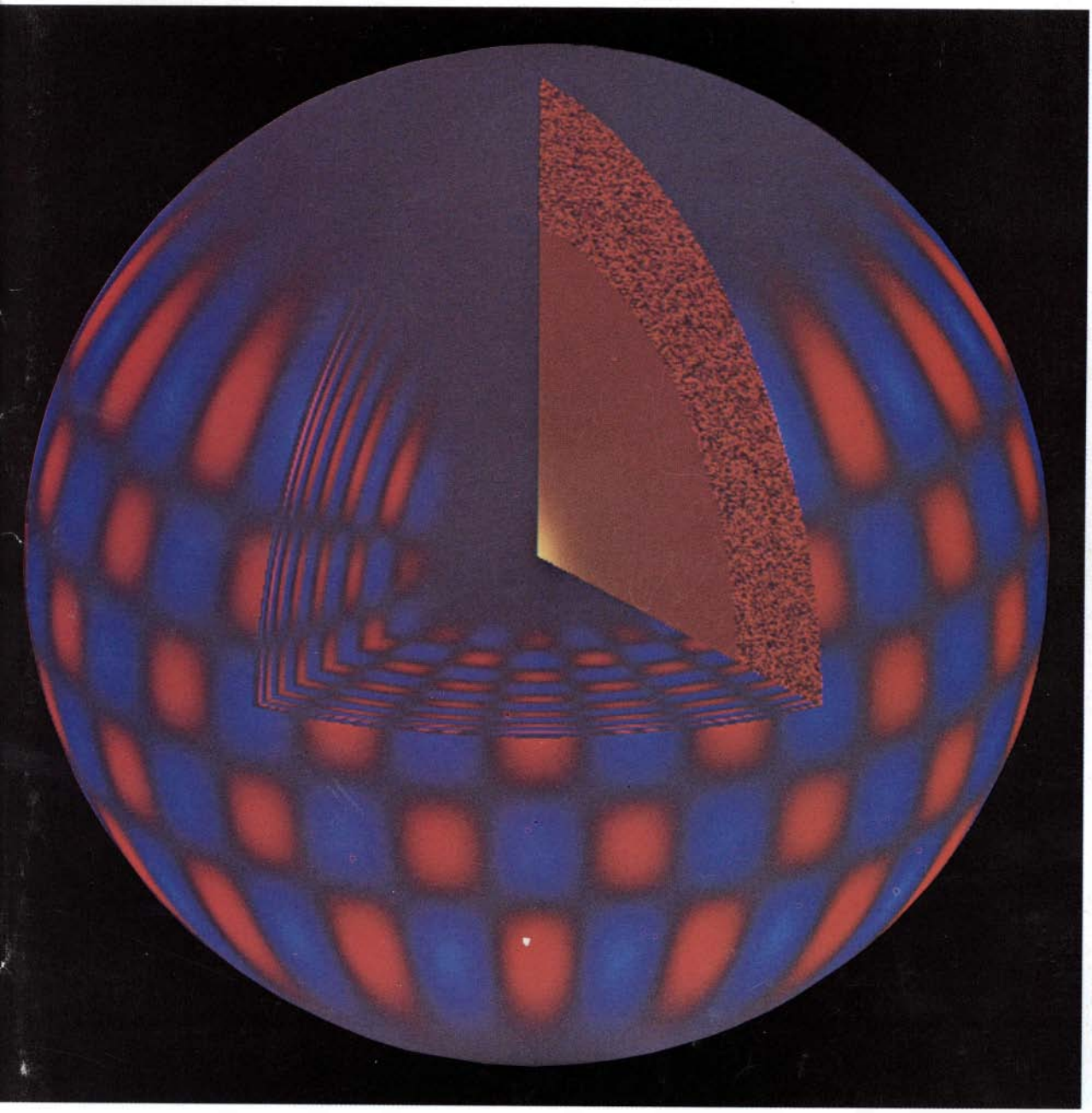

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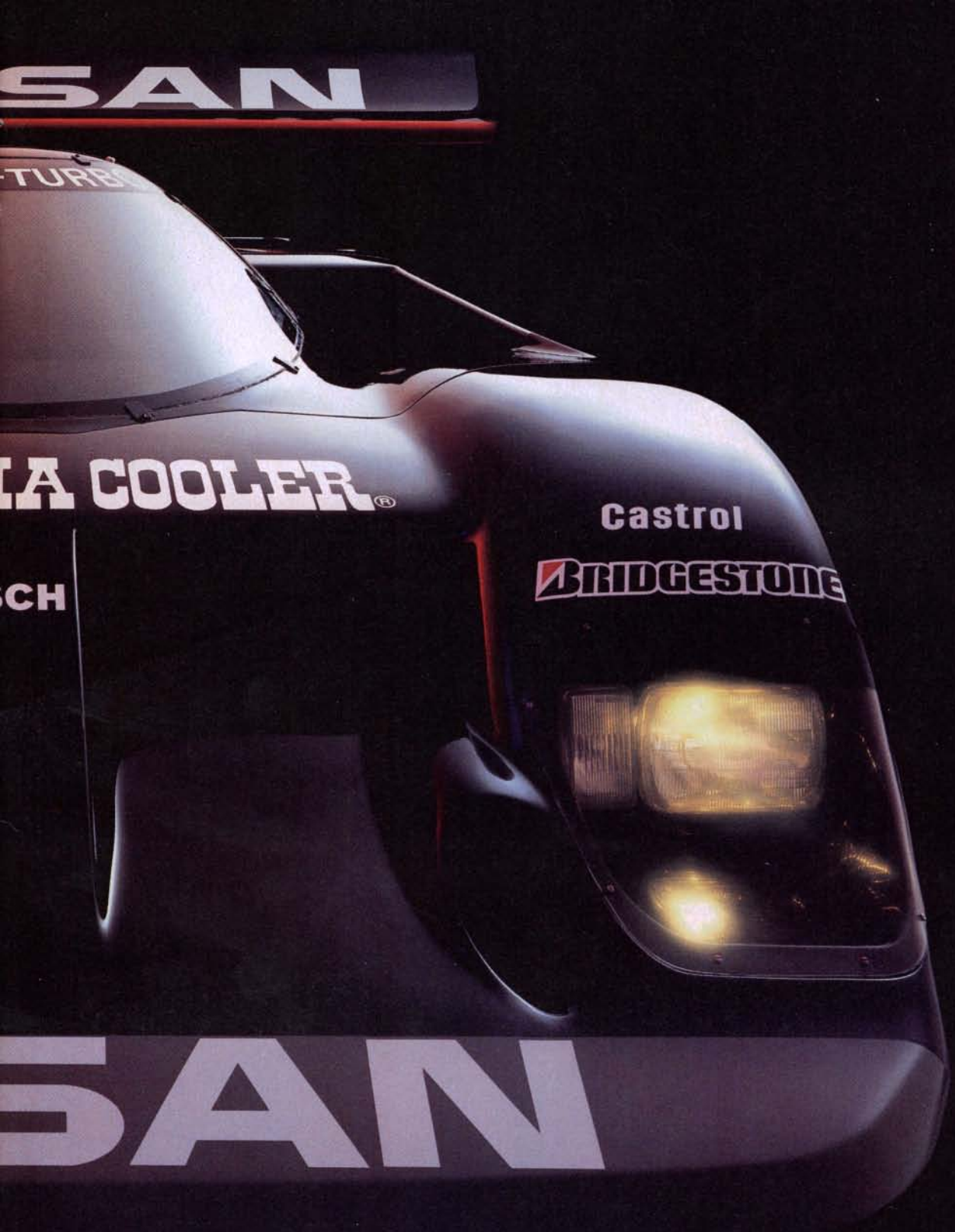

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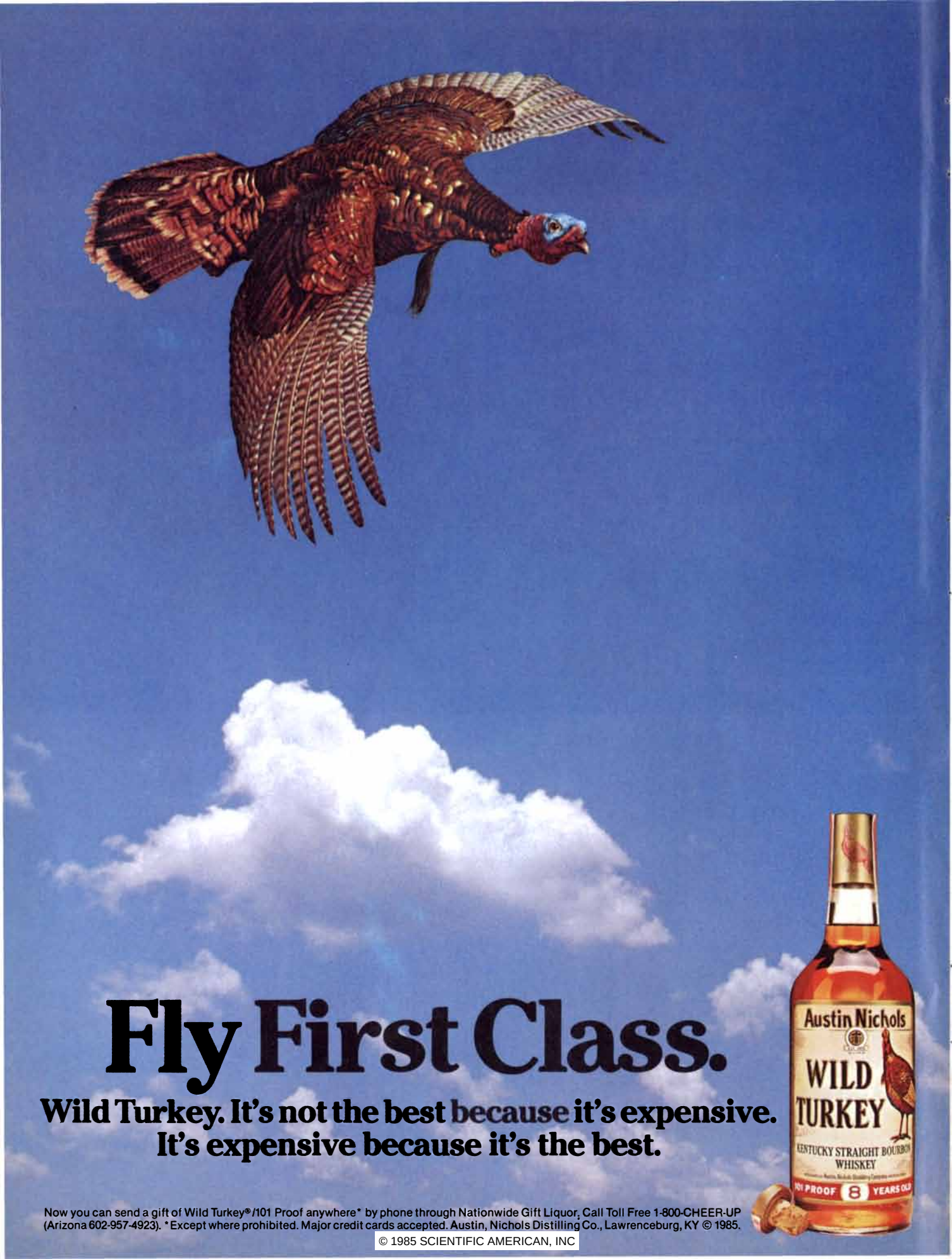

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ARTICLES

DEPARTMENTS

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THE COVER

The computer-generated image on the cover represents a three-dimensional acoustic wave resonating in the interior of the sun. Like sound waves moving through the air, solar acoustic waves move through the gaseous sun in the form of alternating zones of compression and rarefaction. At the same time they displace solar gases: regions shown in red are momentarily receding with respect to the viewer and regions in blue are approaching. Although such waves resonate deep within the sun, they generate oscillations at the surface that can be detected from the earth (see "Helioseismology," by John W. Leibacher, Robert W. Noyes, Juri Toomre and Roger K. Ulrich, page 48). Temperature, composition and motions deep in the sun influence the oscillation frequency. Hence the motions yield insight into conditions in the solar interior, whose distinct regions are shown on one face of the cutaway.

THE ILLUSTRATIONS

Cover image by John W. Leibacher and John Harvey, National Solar Observatory

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LETTERS

To the Editors:

The mysterious "*colliviaria*" mentioned by A. Trevor Hodge ["Siphons in Roman Aqueducts," SCIENTIFIC AMERICAN, June] aroused my interest. Hodge states that "the word does not appear elsewhere in Latin, so that there is no telling from the name what the devices were." It is possible to speculate on the design and use of the *colliviaria* if the word is broken down into its roots and engineering demands of the water system are considered.

Colliviaria breaks down into *colligo,* which means to fasten together or to connect, and *via,* which means a road or passage. This suggests that the *colliviaria* was a manifold that brought together the pipes in the siphon.

Such a manifold would make the system easier to control and maintain. Any section of pipe that developed a leak could easily be closed for repairs. Since all the pipes would be connected to the manifold, any section on the intake side could be repaired along with any section on the output side. Only the volume of water supplied by one pipe would be lost....

As Hodge mentions, a difficult and dangerous task in designing a siphon system is avoiding water hammers, shock waves that occur when a stream of water abruptly stops moving. Water hammers could severely damage the large, soft lead pipes of the Roman siphon as the pipes were being filled. Once the first pipe was filled a manifold would have helped to "soften the blow" by allowing other pipes to be filled from the bottom.

JOSEPH A. MURRAY

Plainfield, Vt.

To the Editors:

One of the mysteries explored by Hodge, namely the "*colliviaria,*" which "must be put in to relieve air pressure," is similar to one I ran across in a new engineering project.

In the final check of instrumentation at a wastewater treatment plant, I found the volume of the final effluent changing from "no flow" to about two million gallons per day regularly with a two-minute cycle. When I asked for an explanation, the engineer in charge told me that he had "overlooked the vent pipe, which must be put in to relieve the air pressure."

This installation had a pipe that descended with a nearly vertical inclination from the final clarifier and then ran horizontally under a road and up again to the chlorination basin. The velocity in the nearly vertical down leg formed a vortex that carried air with the flow of water. The vortex could not be maintained in the horizontal run, and so the air tended to accumulate. When enough air had accumulated, it would escape up the pipe, causing the flow to stop until the air was cleared. When we added a small vent pipe, which ran upward from the beginning of the horizontal pipe to an elevation above the influent level, the flow was stabilized.

GEORGE DAVIS

Birmingham, Ala.

To the Editors:

Hodge is puzzled by the meaning of *colliviaria* because its translation indicates the need to release air at the bottom of an inverted siphon—which he describes as nonsense.

Perhaps the Romans knew more about air entrapment in inverted siphons than Hodge realizes. Almost 40 years ago I had the opportunity to observe the bottom elbow of the Mitchell Creek siphon, part of a gravity irrigation system near Manson, Wash. This siphon is a heavy steel pipe that drops approximately 244 meters to carry water across Mitchell Creek Canyon.

As we approached the siphon we were at first puzzled and then alarmed at a tremendous surging sound. On close approach the sound proved to be emitted by the pipe, which was literally shaking the ground.

Evidently water rushing down the intake section of the pipe entrained air, which the velocity of the water prevented from escaping. The air was forced under increasingly high pressure to the elbow, where it was discharged explosively in bursts; in the process it caused air hammer.

The Romans, with their soldered lead pipes, would indeed have done well to provide air escapement under such circumstances, and it seems more than likely that the *colliviaria* was precisely what the translation indicates.

The diagram on page 116 of the June issue shows the system as it would appear when water was available to immerse the pipe inlets fully. But when the water supply was insufficient to fill the intake, air would be trapped by the water pouring down the pipe and some means of release would be necessary if the fragile pipes were to survive.

AUSTIN POST

Tacoma, Wash.

To the Editors:

Two weaknesses have inhibited discussion of the siphon question. First, lack of space limits exposition and makes it hard to meet readers' comments fully. The question of air in the siphon has caused a lot of discussion, however, and so here are two brief points:

1. The argument referred to a siphon in normal operation, not to one being filled or drained (when procedures and conditions are quite different).

2. Air pockets *can* be a problem if air is entrained, but Roman siphon pipes drew water from low in the header tank, far below surface level, and should have entrained little air.

The second weakness is endemic to all study of ancient technology: historians are weak in engineering, engineers know little history—and the two hardly ever meet anyway. The opportunity to help bridge the gap in a forum such as this is a rare privilege. As a classical archaeologist, I therefore cordially welcome all letters from the technically qualified on the siphon question, and here and now appeal for more of them, in the hope that some real step forward in scholarship may come from an infusion of new ideas.

Those interested are again referred to my longer article in *Papers of the British School at Rome* [see "Bibliography," SCIENTIFIC AMERICAN, June]. In particular I would welcome bright ideas on the siphon at Aspendos in Turkey. See also Norman A. F. Smith's "Attitudes to Roman Engineering and the Question of the Inverted Siphon," in *History of Technology* (Volume 1, pages 45–71; 1976).

Letters should be addressed directly to me.

A. TREVOR HODGE

Department of Classics
Carleton University
Ottawa K1S 5B6
Canada

EDITOR'S NOTE

Through inadvertence final changes in "The Topology of Mirages," by Walter Tape (SCIENTIFIC AMERICAN, June) were not submitted to the author. A corrected version of the article is available without charge in the offprint series. Any reader who would like a copy may write to W. H. Freeman and Company, 4419 West 1980 South, Salt Lake City, Utah 84104.

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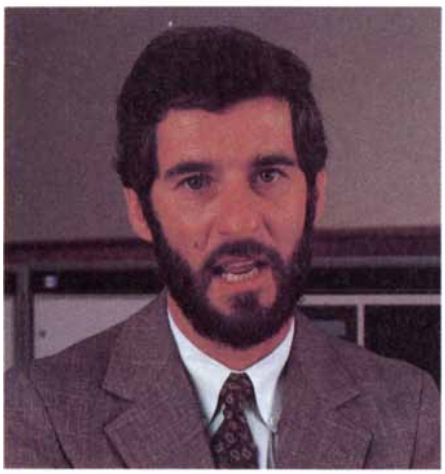

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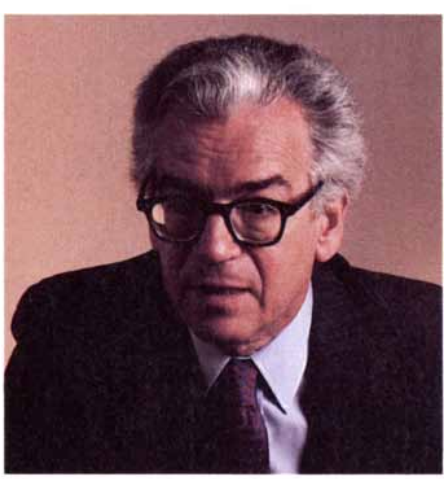

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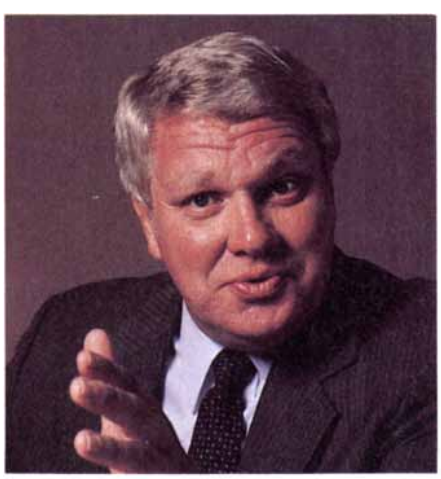

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"Sound-on-film, which revolutionized motion pictures in the theater, promises to do the same in the amateur- and home-movie field with the introduction of the first amateur sound camera with which anyone can now make his own 'talkies.' The new camera utilizes film 16 millimeters wide with sprocket holes on one side only and a narrow track on the other side for recording the sound."

"Economies in time that will result in increased yields through proper fertilization of agricultural fields are made possible through a new soil-analysis device originated in Honolulu. Laborious chemical tests that normally take weeks to complete are replaced by a method requiring but a few minutes. Complete plotting of the necessary fertilization of every part of a field can be secured while time is still available to make use of the information for the benefit of the then growing crop."

"Sodium hexametaphosphate has been found to possess properties that make it a useful adjunct to soap when washing with 'hard' water. B. H. Gilmore of the Mellon Institute of Industrial Research has conducted an extended investigation of the role of this salt in sequestering calcium and magnesium ions. By removing these ions from solution without precipitation, the curdling effect of hard water upon soap is completely inhibited and all of the soap is held in solution to exercise its full detergent effect."

"It is sometimes stated that fuel economy in airline operations is unimportant. Reliable statistics for the year 1934 tell a different story: number of passengers, 537,637; miles flown, 42,622,619; gallons of gasoline used, 21,991,782. The average number of miles per gallon is thus 1.94. Passenger miles per gallon is given as 7.23. Figuring fuel costs at 11 cents per gallon means that fuel costs are 1.52 cents per passenger mile. The average airline fare in the United States is six cents per mile. Thus the fuel cost is 25 percent of the passenger revenue. There is no doubt that an increase in engine efficiency and the use of a cheaper fuel would help the lines considerably."

"We think of airplanes as aging even more quickly than automobiles, yet the Bureau of Air Commerce of the Department of Commerce says that the useful life of an airplane frequently exceeds five years. As many as 169 civilian airplanes now in service in this country were built in 1926 or earlier."

SCIENTIFIC AMERICAN

SEPTEMBER, 1885: "Probably no former event in the history of yacht racing has attracted so much attention as the trial for the championship between British and American yachts in the vicinity of New York. The race was for the possession of the prize cup won by the yacht *America,* in a contest with a fleet of British yachts off Cowes, England, in 1851. The New York Yacht Club has held the cup under a deed of gift from the original owners of the *America,* under the condition of its remaining a perpetual challenge cup. The race, between the *Puritan* of the United States and the *Genesta* of Great Britain, has finally been accomplished, and the victory of the sloop in both trials leaves the cup still in America's possession."

"The cholera has taken strong hold in Spain and on the southerly coast of France this year; every succeeding report from the infected regions indicates the gradual spreading of the disease, and the mortality is becoming frightfully great. The season is so far advanced that the apprehension of the disease's spreading to these shores this year has about subsided. That it will cross the ocean and visit us next year is more than probable; therefore municipalities and individuals should not relax their efforts to put the streets in good order and their houses and grounds in cleanly condition."

"By a recent enactment of the Pennsylvania legislature boys under fourteen years of age, and all women and girls, are prohibited from being employed in the coal mines of that State. It is estimated that the law covers nearly one-half of the whole number of slate pickers in the mines, at which boys are sometimes employed when only six years of age, and that it also includes a good proportion of the mule drivers and door tenders. It has required many years of agitation to get the law passed, and its enforcement now is causing no little excitement in the mining regions. Yet society undoubtedly owes it to itself to see that these little ones are at school instead of being thus early predestined to a life of ignorance."

"Reduced postage and other causes have increased the correspondence of the world. Less than fifty years ago the average number of letters received by each person per annum was only 3 in the United Kingdom, and it is now 37 letters and 4 postal cards. The most recent reliable ascertained comparison (for 1882, when the average was 35 in Great Britain) gives the average per head in the United States as 21; Germany, 17; France, 16; Italy, 7, and Spain, 5."

"Mr. Gaston Tissandier, in company with Mr. J. Ducom, has recently been making some experiments in photography from a balloon, and the results obtained were highly satisfactory. The photographic apparatus employed was arrayed upon the edge of the car in such a way as to pivot upon its axis, and to be kept in a vertical position."

Photography from a balloon

THE AUTHORS

FRANK VON HIPPEL, DAVID H. ALBRIGHT and BARBARA G. LEVI ("Stopping the Production of Fissile Materials for Weapons") are physicists at Princeton University's Center for Energy and Environmental Studies (CEES). Von Hippel, who is also a professor at Princeton's Woodrow Wilson School of Public and International Affairs, obtained his B.S. in physics from the Massachusetts Institute of Technology and earned his D.Phil. in theoretical physics as a Rhodes Scholar at the University of Oxford. Immediately before going to Princeton he was a resident fellow at the National Academy of Sciences; previously he had worked at several university and Government laboratories. Von Hippel is a past chairman of the Federation of American Scientists (FAS) and is currently on the board of directors of *Bulletin of the Atomic Scientists.* Albright is a research assistant at both the CEES and the Washington office of the FAS. His B.S. and M.S. in mathematics are from Wright State University; he also has an M.S. in physics from Indiana University. In 1981 and 1982 he was a consultant at the Environmental Policy Institute, and afterward he taught physics at George Mason University. In 1983 he joined the staff of the FAS on a part-time basis while acting as consultant to several other institutions. Albright became affiliated with the CEES in 1984. Levi has a B.A. in physics from Carleton College and an M.S. and Ph.D. in physics from Stanford University. She is a contributing editor of *Physics Today,* whose staff she first joined in 1969 as an associate editor. From 1970 to 1976 she was a lecturer in mathematics and physics at Fairleigh Dickinson University; from 1977 to 1981 she was a lecturer in physics at the Georgia Institute of Technology. Levi joined the research staff of the CEES in 1981.

JOHN W. LEIBACHER, ROBERT W. NOYES, JURI TOOMRE and ROGER K. ULRICH ("Helioseismology") share a common interest in the physical structure of the sun. Leibacher is associate astronomer at the National Solar Observatory. He has an A.B. and a Ph.D. in astronomy from Harvard University, where he also had fellowships. Before taking his present position in 1983, he worked at various astrophysical laboratories, including the Laboratoire de Physique Stellaire et Planétaire in France. Noyes is professor of astronomy at Harvard and an astrophysicist at the Smithsonian Astrophysical Observatory. His bachelor's degree is from Haverford College (1957) and his Ph.D. is from the California Institute of Technology (1963). Since 1962, when he joined the Harvard faculty, he has been affiliated with the Smithsonian Observatory. From 1973 to 1980 he was associate director of the Center for Astrophysics there. He is codiscoverer of the "five-minute" oscillations of the sun. Toomre is professor in the department of astrophysical, planetary and atmospheric sciences of the University of Colorado at Boulder; he is also a fellow of the Joint Institute for Laboratory Astrophysics there. He did his undergraduate work at the Massachusetts Institute of Technology and then went on to get his Ph.D. from the University of Cambridge in 1967. Before going to the University of Colorado in 1971, he spent some time at the National Aeronautics and Space Administration's Institute for Space Studies and on the mathematics faculty at New York University. Ulrich is professor of astronomy at the University of California at Los Angeles. His degrees are from the University of California at Berkeley: a bachelor's degree in chemistry (1963) and a doctorate in astronomy (1968). Before joining the U.C.L.A. faculty in 1970, he had worked on the solar-neutrino problem at Caltech.

PETER ALBERSHEIM and ALAN G. DARVILL ("Oligosaccharins") will be the director and associate director respectively of the Complex Carbohydrate Research Center to be founded next month at the University of Georgia. Albersheim was graduated from Cornell University in 1956 with a B.S. in plant pathology; he received a Ph.D. in biochemistry from the California Institute of Technology in 1959. After several postdoctoral appointments he went to Harvard University, where he taught for five years. In 1964 he joined the faculty of the University of Colorado at Boulder, becoming professor of molecular, cellular and developmental biology in 1970. Darvill got a B.Sc. in plant biology at Wolverhampton Polytechnic in 1973 and a Ph.D. in plant physiology from the University College of Wales in 1976. Since then he has been at the University of Colorado, first as a postdoctoral research associate and recently as associate professor, also in the department of molecular, cellular and developmen-

tal biology. Albersheim and Darvill gratefully acknowledge the long-term support of their work by the U.S. Department of Energy.

JAMES E. ROTHMAN ("The Compartmental Organization of the Golgi Apparatus") is professor of biochemistry at the Stanford University School of Medicine. He became interested in cellular biochemistry as an undergraduate majoring in physics at Yale College. He received his Ph.D. from the Harvard Medical School in 1976. After two years as a postdoctoral fellow at the Massachusetts Institute of Technology he joined the faculty at Stanford. Rothman is on the editorial board of several journals, including *Science* and *Cell*.

JOHN H. SINFELT ("Bimetallic Catalysts") is a senior scientific adviser in the Corporate Research Science Laboratories of the Exxon Research and Engineering Company. He earned his B.S. in 1951 from Pennsylvania State University and went on to the University of Illinois at Urbana-Champaign for graduate study in chemical engineering. Immediately after getting his Ph.D. in 1954, he began work at Exxon. Sinfelt maintains his academic ties through active collaboration in university research projects.

ROBERT R. JACKSON ("A Web-building Jumping Spider") is senior lecturer in the zoology department of the University of Canterbury in New Zealand. He was born and educated in the U.S., where he did his undergraduate work at North Carolina State University and received his doctorate in zoology from the University of California at Berkeley in 1976. After a year of postdoctoral research with the North Carolina Department of Mental Health, he moved to New Zealand, where he now teaches animal behavior and evolutionary biology. Jackson began the studies described in his article as a visiting fellow in the neurobiology department of the Research School of Biological Sciences at the Australian National University.

MICHAEL T. MOTLEY ("Slips of the Tongue") is professor of communicology in the rhetoric department at the University of California at Davis. His B.A. and M.A. degrees were awarded by the University of Texas in 1965 and 1967 respectively. He became interested in psycholinguistics while he was a graduate student in Texas, and he decided to study verbal slips while he was working on his doctorate in communication at Pennsyl-

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vania State University, where he got his Ph.D. in 1970.

THOMAS D. SEELEY, JOAN W. NOWICKE, MATTHEW MESELSON, JEANNE GUILLEMIN and PONGTHEP AKRATANAKUL ("Yellow Rain") bring diverse skills to their joint investigation of yellow rain. Seeley is associate professor of biology at Yale University. He earned an A.B. in 1974 at Dartmouth College and a Ph.D. in 1978 from Harvard University. Before joining the Yale faculty he spent a year living in the mountain forests of Thailand studying the ecology of the native honeybees. Seeley has continued his investigations of honeybees, focusing on their social behavior. Nowicke is curator and palynologist in the botany department at the National Museum of Natural History of the Smithsonian Institution. She received both her A.B. in zoology (1959) and her Ph.D. in botany (1968) from Washington University in St. Louis. In 1972 she was appointed by the Smithsonian Institution to establish a palynology laboratory in its botany department. Meselson is professor of biochemistry and molecular biology at Harvard University. A graduate of the University of Chicago, he obtained his Ph.D. in physical chemistry from the California Institute of Technology in 1957. He stayed on at Caltech after completing his graduate studies, first as a postdoctoral fellow and then as assistant professor. He joined the Harvard faculty in 1960. In addition to his primary work in molecular genetics, Meselson has long been involved in issues pertaining to chemical and biological weapons. Guillemin is associate professor of sociology at Boston College. She received her bachelor's degree at Harvard University in 1968 and her Ph.D. in sociology from Brandeis University in 1973. She has written widely in the field of anthropology, particularly on American Indians. At present Guillemin does research in medical sociology. Akratanakul is associate professor of entomology at Kasetsart University, Kamphaeng Saen Campus, in Thailand. After completing his undergraduate study in his own country, he came to the U.S., where he earned an M.S. degree in 1975 at Oregon State University and a Ph.D. in 1977 from Cornell University. In addition to his scientific interest in Asian honeybees he has helped to develop the beekeeping industry in Thailand. Akratanakul has also served as a consultant in apiculture development for the Food and Agriculture Organization of the United Nations.

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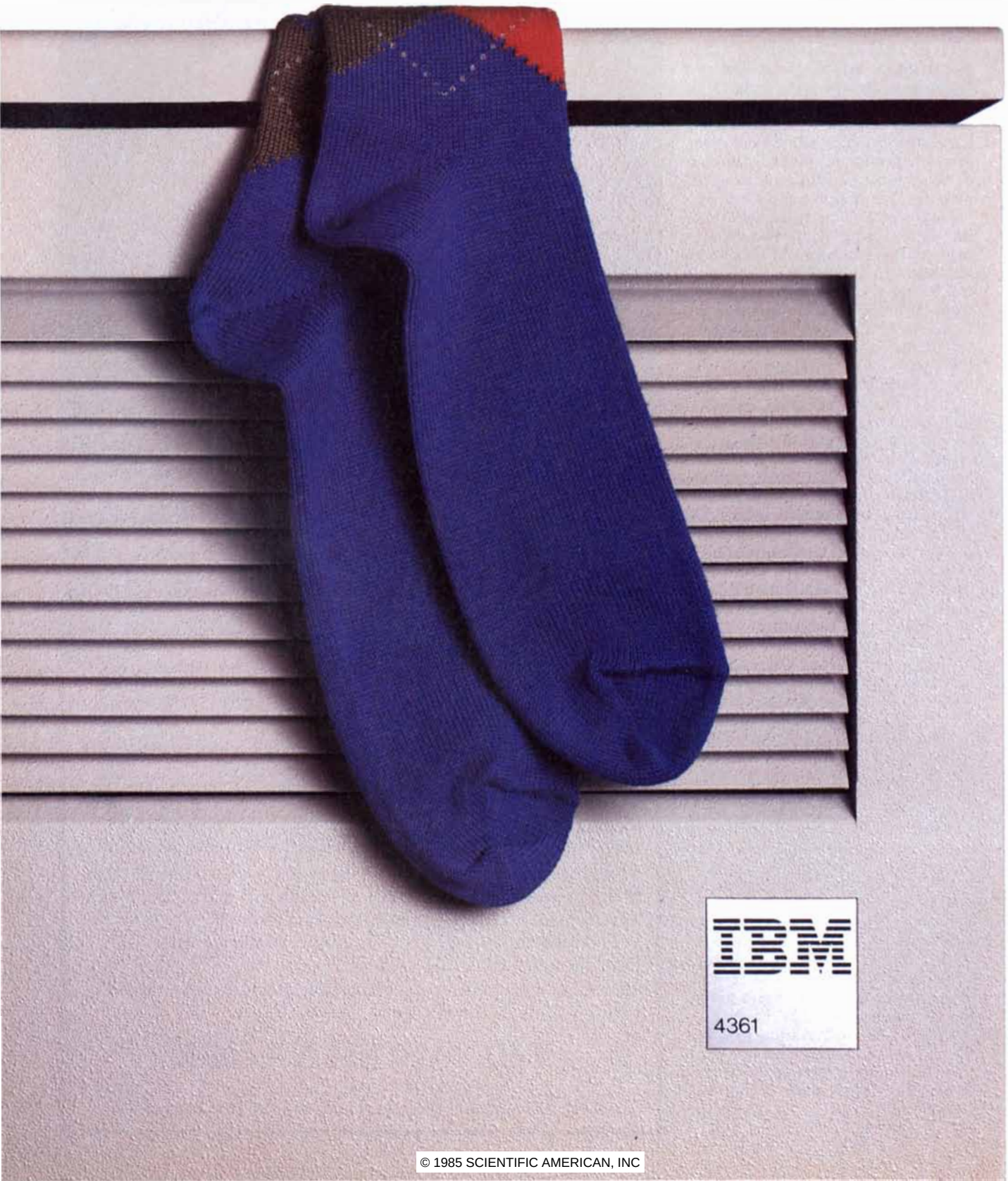

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COMPUTER RECREATIONS

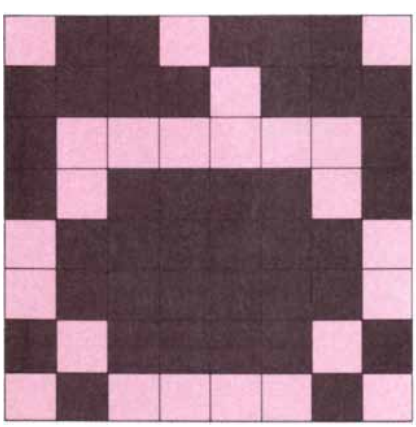
At Bell Labs work is play and terminal diseases are benign

by A. K. Dewdney

The line between work and play at the AT&T Bell Laboratories in Murray Hill, N.J., is impossible to draw. Curious, occasionally serious games emerge from the laboratory as the natural overflow of a spontaneous and astonishing wellspring of scientific creativity. Cases in point are the Blit terminal and CRABS, a crustacean recreation that sometimes complicates use of the Blit.

Developed four years ago at the Murray Hill facility by Rob Pike and Bart Locanthi, the Blit (as they affectionately called it) was a preliminary version of the Teletype Corporation's new DMD 5620 terminal. The Blit and its Teletype incarnation are multiprogramming terminals.

On a visit to the laboratories last fall I was invited by Pike to see the DMD 5620 in action. On terminals of this type (which I shall hereafter simply call Blit terminals) the display screen can be divided into windows, which sometimes overlap. Each window acts as if it were a miniature screen in its own right; specifically each displays the output of a separate program. The programs can run on the terminal's own built-in microprocessor or they can run on the Blit's host computer. An expanse of gray texture covers unused parts of the screen.



The basic crab icon displayed in a grid

Three programs occupied the windows before us. In one window was an experimental text editor undergoing tests. In the second window another text editor displayed text from the first program. In the third window a debugging program operated on the experimental editor. All three programs ran on the Blit's own microprocessor. As Pike demonstrated the tremendous usefulness of this multiprogram system a number of crablike icons appeared at the top of the screen, scuttled to the boundary of a window and began to nibble at it. Seeing my distraction, Pike explained: "Ah yes. Here come the crabs. Just for fun we downloaded the CRABS program from the host computer."

The Blit's host computer was running UNIX. One of the most popular operating systems ever developed, UNIX is the creation of Kenneth L. Thompson, a Bell Laboratories investigator who shared the Turing award in 1983 with Dennis M. Ritchie, a Murray Hill colleague.

I watched in fascination as the crabs (some 30 in all), having eaten away the boundary of one window, proceeded to devour the text within. "How do you stop them?" "You can't." "Yes, but how do you stop them?"

CRABS, written by Luca Cardelli and Mark Manasse in 1982, is a deliberate violation of the design rules of the Blit terminal's multiprogramming system. The program in each window is intended to be self-contained and protected from the programs running in other windows. Once the Blit terminals had been distributed throughout the Murray Hill laboratories, Cardelli and Manasse found the temptation to break these rules irresistible.

By the time Pike had reviewed this brief history all the windows on the screen had been thoroughly nibbled. In fact, they resembled the pages of a recently discovered medieval manuscript. The texts were so tattered that it was impossible for Pike to describe what was happening in the windows.

Pike explained that the original terminal got its name from bitblt, a low-level graphics operator of surprising range and versatility. "Bitblt" is a contraction of bit-boundary block transfer. The term applies to a procedure that directs the movement of information within the terminal's memory. Specifically, bitblt transfers the contents of one rectangular set of memory locations into another. In the process it may perform simple logic operations on these contents.

Part of the Blit terminal's memory consists of a 100,000-byte subsystem that is devoted to the display screen. A continuous electronic scan translates each bit of this memory into a light or dark point on the display screen. In the process it converts a one-dimensional array of memory locations into a two-dimensional display of its contents. Because storage and display differ in their dimensionality the locations corresponding to a single rectangle on the screen are scattered throughout memory in the form of separate blocks of consecutive locations; each block corresponds to a horizontal line in the rectangle. The collection of all locations in all the blocks constitutes a rectangular set. It is bitblt's task to manipulate such rectangular sets.

To operate a multiprogramming environment successfully the Blit terminal requires a hefty amount of offscreen memory for the use of any programs currently running on the screen. The Teletype DMD 5620 terminal, for example, devotes 900,000 bytes to the purpose. Here too rectangular sets are essential; bitblt is called on frequently to transfer the contents of a set in offscreen memory into a rectangular set of screen memory. For example, a certain rectangular set in offscreen memory contains the letter *A*. Each time a program displays *A* as part of its textual output, bitblt is called on to transfer this rectangular set into screen memory so that the character can appear.

Hardware memory scanning is the principal feature of the frame-buffer approach to graphic terminal design. Frame buffers are now coming into general use, even in the personal-computer market. Witness the MacIntosh.

In the traditional approach to graphics, memory is consulted more sporadically. The display of a drawing, for example, is managed through a list of points, lines and other pictorial elements. When the drawing is to be displayed, its list is scanned. Simple pictures can be scanned quickly because

they have short display lists; the display of complex pictures, however, may require too much time.

The pattern of bits that occupies a given rectangular set in memory is called a bitmap. Each bitmap produces a specific image on the screen, either a character, an icon or some other graphic element. The CRABS program, for example, uses certain offscreen bitmaps that give rise to various forms of the tiny crustaceans. The following string of 0's and 1's represents a crab, 1's designating black and 0's green:

01101110...11110111...100000-
01...10111101...01111110...01-
111110...10111101...01000010

Readers who want to imitate bitblt by hand may draw an 8-by-8 square grid. The string above will then represent a rectangular set in offscreen memory and the square grid will represent part of screen memory. Scan both the string and the grid one bit at a time and copy the string into the grid. Reproduce the grid in a small section of the screen by blackening each square containing a 1; squares containing a 0 are pale. The image of a crab emerges [*see illustration on opposite page*].

I noted above that any part of the screen not within a window has a gray texture that is really a pattern of dots. When the crabs first invaded Pike's Blit screen, they wandered through the gray texture until they encountered a window, which they began to eat. At the time Pike had said, "Gray is road for crabs. They don't eat their road." Indeed, crabs do not eat anything; they pave it over. When CRABS moves one of its protégés, it checks the area just ahead of the crab and, if it is not already gray, makes it so. It then moves the crab onto the newly grayed location. The bitblt operator makes both procedures possible.

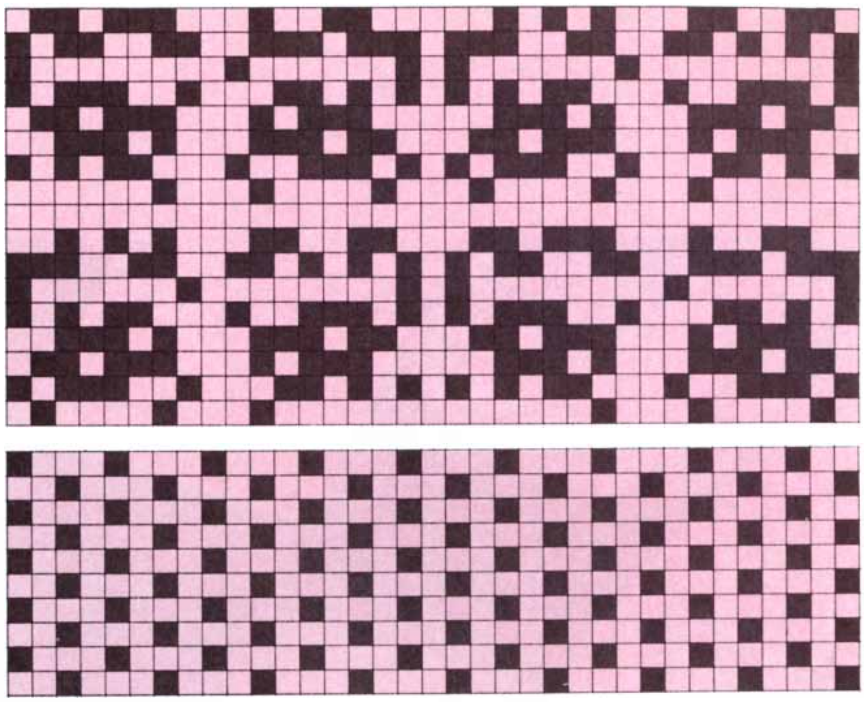
In its simplest form bitblt replaces each bit d in the destination bitmap by the corresponding bit s in a source bitmap. In shorthand the operation is written as a replacement:

$$d \leftarrow s .$$

A nongray area is made gray by using bitblt in this form. The area just ahead of the crab is the destination bitmap and an offscreen bitmap containing gray texture is the source bitmap.

Next CRABS moves the crab; it erases the crab from its present position and redraws it in a new position. To carry out these operations bitblt is used in a more sophisticated form, summarized in the following notation:

$$d \leftarrow s \oplus d .$$



Crab bitmaps perforated with holes accommodate eight possible placements on gray texture

Here each destination bit is replaced by its combination with the corresponding source bit under the logic operator called XOR($\oplus$): d will become 1 if and only if either s or d (but not both) already has that value. The use of the XOR operator is convenient for both erasing and redrawing a crab. Unfortunately bitblt in this form cannot use the solid crab icon produced by the pencil exercise described above.

Consider what happens, for example, if the standard solid crab bitmap is XORed onto gray texture: when a dot of gray (a 1) is XORed by any portion of the crab body (also a 1), the result is a green hole ($1 \oplus 1 = 0$). If the body already has a hole in that position, however, the result is black ($1 \oplus 0 = 1$). This accounts for the strange appearance of the eight special crab bitmaps actually used by CRABS to move its charges [*see illustration above*]. Each bitmap represents a crab with a pattern of holes already punched in it. There are eight possible placements of a crab on gray texture; the patterns reflect these placements.

CRABS moves a crab by first erasing it and then redrawing it. To erase a crab the XOR version of bitblt maps the appropriately holed crab bitmap onto the destination crab. The destination crab disappears except for the gray texture dots the XOR operator perforce leaves behind. To draw a crab bitblt employs XOR to draw another appropriately punched crab onto the destination area. The crab appears intact because its holes match perfectly the gray texture to be accommodated.

The algorithm used by the CRABS program controls each crab by means of five steps:

1. Erase the crab from its previous position.
2. Determine a new position.
3. If the new position does not occupy a gray site, make it gray, reset the position and choose a new random velocity.
4. Draw the crab in its new position.
5. Randomly alter the velocity of the crab. Return to step 1.

Naturally, the crabs move sideways. Thus a new position is always on one side or the other of a crab. The new position is determined by the crab's current direction and its speed. Both quantities are subject to changes that are essentially random in step 5. There are many possible directions; speed can vary from one pixel to seven pixels per move.

During my discussion with Pike the crabs had first appeared at the top of the screen. Then they had wandered in a generally downward direction through the gray areas. When they arrived at a window, they nibbled their way into it. The nibbling was most evident because tiny gray patches steadily replaced the clean background. The effect was unmistakable and compelling; it was as if paper were being incrementally devoured to reveal an underlying gray surface.

Step 3 of the CRABS algorithm reinforces the illusion by causing the crab to bounce away from the area just nib-

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bled, as though it were sitting back for a moment to digest before going off in search of more food. The random nature of the crab's movement causes the window to be eaten away across a respectably ragged front. Without this feature the screen would more closely resemble the work of burrowing insects. The randomness also provides more time to react to the invasion.

As we watched the crabs eating their way into the windows on his Blit terminal, Pike described the varied reactions of colleagues who encountered the multitude of tiny appetites for the first time. In some cases the introduction was arranged clandestinely: while someone was momentarily away one of the merrier spirits at the Murray Hill facility would start CRABS on the innocent's terminal.

Since the Blit terminal is equipped with a mouse, which controls a cursor on the screen, a hapless victim might try to use the device to swat at the crabs. The ploy is doomed because crabs find the cursor as delectable as the text. Between bites the cursor regenerates. Hence although the crabs could be slowed down in this way, they could not be stopped, and windows would continue to disintegrate.

The victim might try to cover the crabs with a window. This too would slow them down, but a crab trapped under a window would nibble away a gradually expanding area around itself and eventually break free.

Again I asked Pike how the crabs can be stopped. This time he relented: "Turn off your terminal and restart it." The maneuver is effective, but it does mean logging into the host computer all over again.

Cardelli and Manasse, the authors of CRABS, recount the program's genesis in an informal memorandum. Fascinated by the Blit terminal's design rules, they analyzed possible violations. They also consulted Pike, who gave them the requisite software fragments. The two programmers found that some of the possible violations of the terminal's design rules could actually be useful. An example is the LENS program, which magnifies a portion of the screen. (The LENS window can be seen magnifying crab-infested text in the illustrations on these two pages.) LENS is a violation because a window's process should not have direct access to the contents of another window.

Originally Cardelli and Manasse had planned to emulate a video game called QIX but invented instead a program called MEASLES: little balls floated about the screen in the gray areas between windows. Initial tests quickly showed that measles could be controlled by slapping a window on them. The authors clearly empathized with their creations: "Suddenly those poor trapped measles have nowhere to go, no gray area to run to. They are frozen, paralyzed with terror, and buried underneath a window."

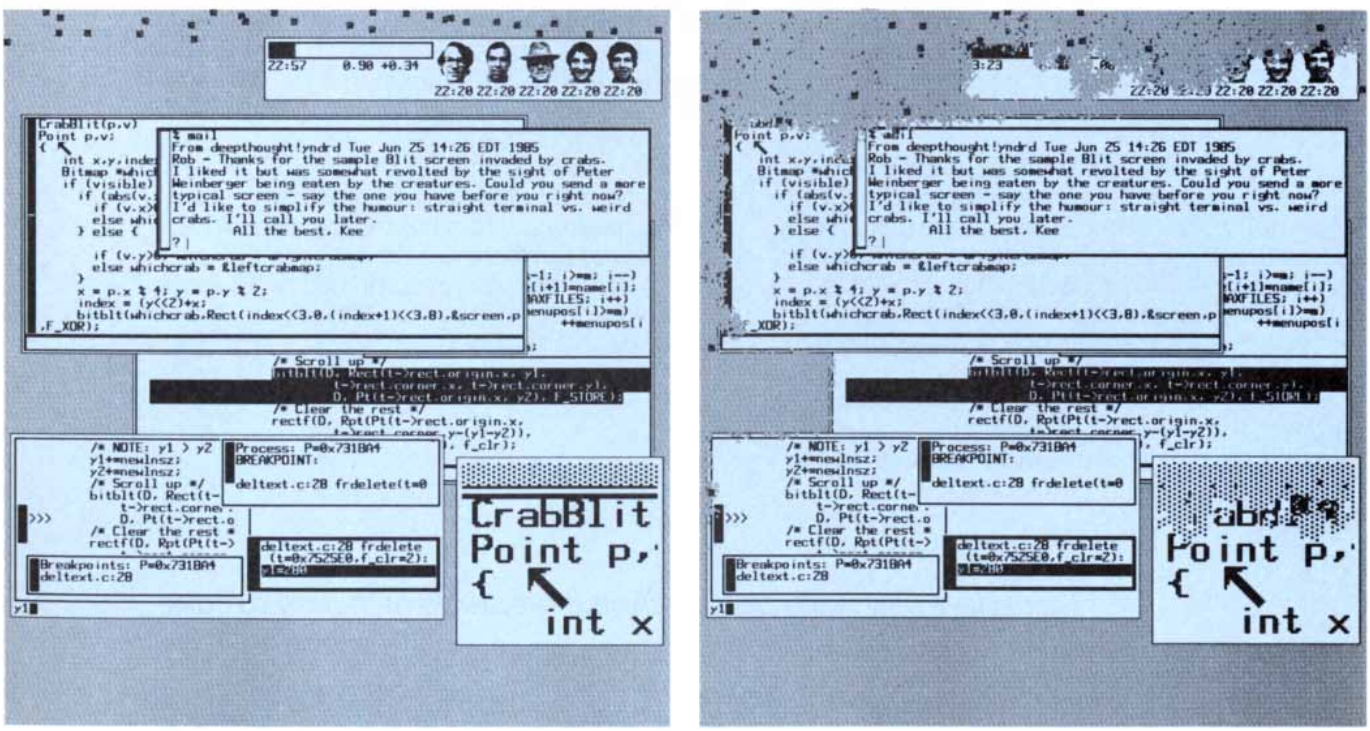
Their initial solution was to make each trapped measle flash in an effort to annoy its human captor. This program was called ANGRY MEASLES.

Angry measles, however, were nothing compared with the next program to suggest itself: Why should the measles not eat their way out of windows? The resulting program was called HUNGRY MEASLES. Cardelli writes: "The new version . . . had quite a different character. It wasn't cute, it was awesome."

Someone watching the program said the measles resembled tiny crabs. Cardelli and Manasse implemented the icon and CRABS was born. Other programs, including one that leaves bird and animal tracks all over the screen, followed in the wake of CRABS.

The victims of the pranks have fought back. There was a program called SQUISHCRABS that examined the Blit memory for evidence of the CRABS program. On finding it, SQUISHCRABS would kill the program and convert every crab on the screen into a blob. Unfortunately a change in terminal software made SQUISHCRABS ineffective.

Evidence of yet other recreations abounds at Murray Hill. I was introduced to a program called AUTOPUNNER written by Ron Hardin. This program converts an English text into a string of phonemes, which are regrouped, converted back into English words and displayed in the form of a new text. The result (after some human intervention) sounds like strangely de-



Blit terminal screen displaying the output of five programs is attacked by crabs.

mented free verse. Take, for example, this distortion of *Peter Piper:*

Better buy perfect Topeka beagle buffers
Topeka beagle buffers sputter fiber beaks
Effeter fiber beaks abetted feeble puppies
Worst Topeka beagle puppies feature viper-pique.

A more focused recreation is the attempt to program a computer to play chess. The 1980 world computer-chess championship was won by Belle, a special-purpose computer and program developed at the Murray Hill laboratories. Ken Thompson and Joe Condon are its creators. (I hope to discuss this and other current computer-chess programs in a future column.)

The chess computer, devoted to recreation, neatly brings the discussion back to the creative tension between work and play. A widespread attitude among computer scientists is aptly stated by Alan J. Perlis, professor of computer science at Yale University, in the recently published book *Structure and Interpretation of Computer Programs,* by Harold Abelson, Gerald Jay Sussman and Julie Sussman.

"I think it's extraordinarily important that we in computer science keep fun in computing. When it started out, it was an awful lot of fun." But, Perlis believes, the fun became dulled by demands that computer scientists focus too sharply on the nuts and bolts of their dreams and designs. Such concerns more properly belong to those who guide the evolution of discovery into productive devices. "We began to feel as if we really were responsible for the successful, error-free perfect use of these machines. I don't think we are. I think we're responsible for stretching them, setting them off in new directions, and keeping fun in the house."

The fun and productiveness of computer science lies precisely in the sense of development, the unfolding of ideas that seem to come half from people and half from the machines themselves. It is even possible to suggest that in the absence of such fun there is little real progress.

I cannot end this article without a final mention of the Blit terminal and its bitblt operator. Pike has suggested two intriguing puzzles that demonstrate the power and flexibility of bitblt. Readers should imagine themselves to be equipped with the two versions of bitblt mentioned earlier; one replaces the destination bitmap by the source bitmap. The other carries out the XOR operation in the process.

Clear a rectangle. Without resorting to a special 1-filled offscreen bitmap use bitblt in either the replacement form or the XOR form to clear a specific rectangle on the screen.

Rotate an image. An $n \times n$ square image occupies the upper lefthand corner of a $2n \times 2n$ Blit screen. Use bitblt to rotate the image 90 degrees. Assume that the screen is otherwise blank.

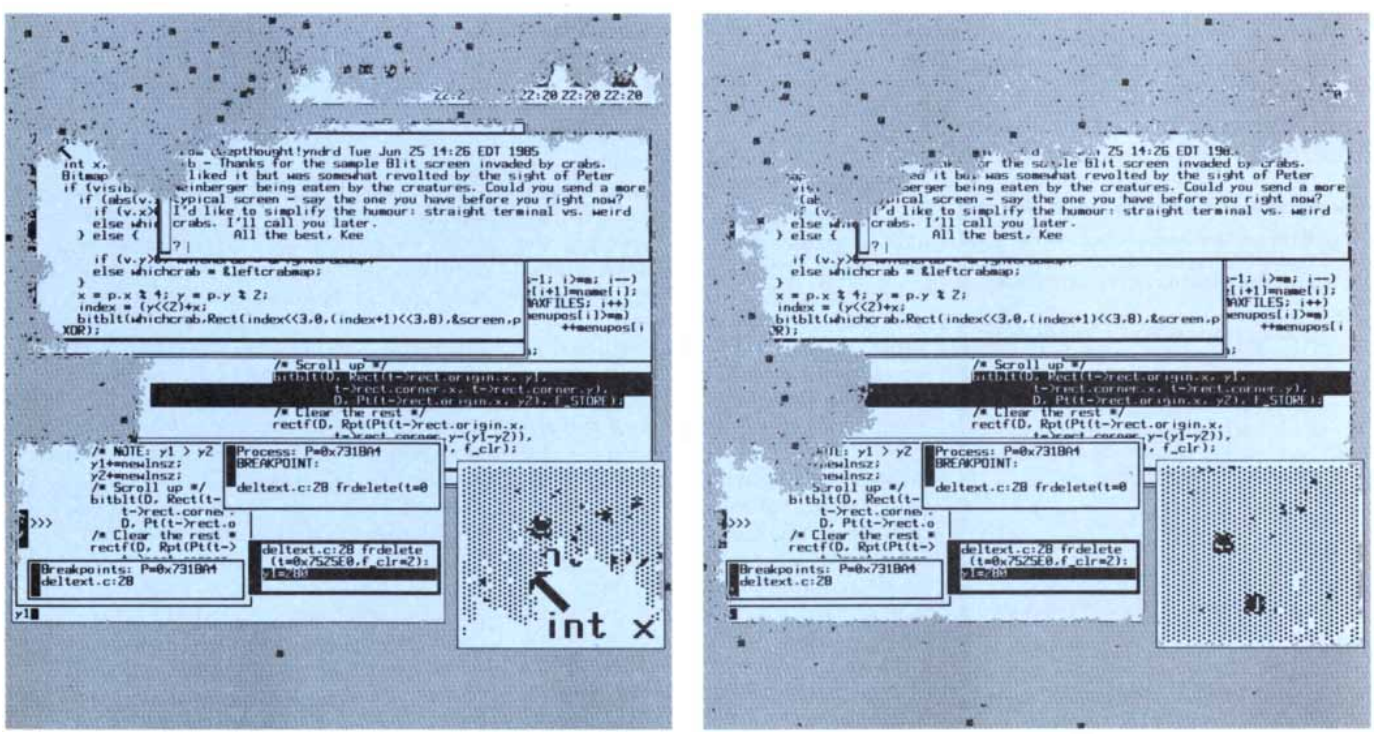
In the first problem one is not allowed to assume anything about the appearance of the screen outside the rectangle. In such a case what bitmap could possibly serve as the source?

In both problems the effect of bitblt on a given rectangle (no matter what its shape) is counted as a single operation. The first problem can be solved with one bitblt and the second with $3n + 1$. Can anyone find a faster way?

In the June column I invited readers to propose elegant arguments supporting the proposition that Jos Wennmacker's maneuver actually finds the longest path in a tree made of string. Two hanging operations, I said, are enough to isolate a longest path. First, pick up the tree by any of its vertexes and dangle it. Second, pick up the tree again by the vertex that hangs lowest and dangle it once more. The longest path runs from the held vertex to the one that now hangs lowest.

The foregoing description implicitly assumes that the tree has only one longest path. In fact there could be several paths equal in length that are longer than the other paths. Consequently in both steps there could be several vertexes from which to choose; in these circumstances one vertex can be picked arbitrarily.

I received far more arguments than



A user can abort such an attack by shutting off the terminal and logging in again

I expected. It seems reasonable to advance kudos to the following creators of elegant arguments. All are in close contention: John J. Bartholdi III of Atlanta, Ga., Nachum Dershowitz of Urbana, Ill., William B. Lipp of Milford, Conn., David G. Mead of Davis, Calif., and Johan van Benthem of Groningen, Holland. As readers will suspect, all but Lipp are connected with universities: the Georgia Institute of Technology, the University of Illinois at Urbana-Champaign, the University of California at Davis and the State University of Groningen.

"Elegance" to me means a combination of clarity and brevity. In the context of this column it also means a minimum of notation, inequalities and equations. So it was that Bartholdi emerged as a relatively clear winner:

"Let H be the held point, L the lowest point. Claim: L must be one end of the longest path.

"Proof: Let $A \neq L$ be another end of the longest path. Now the longest path leaving A consists of an 'up' portion followed by a 'down' portion. But the 'up' portion is no longer than from A to H and the 'down' portion is no longer than from H to L. Thus A to L must be a longest path.

"Now holding the point L must result in A dangling the lowest, by the same reasoning."

The argument is more intuitive than it is rigorous. It is convincing because it suggests a mental picture in which the up and down portions of the longest path containing A hang beside the path from H to L and, in a sense, do not quite measure up. Making the argument precise doubles its length.

The first gadget discussed in the June column used a board, some nails and rubber bands and a long, smooth rod to determine the best fit of a straight line to several data points. Drive the nails into the board to represent the points, I instructed, then slip a rubber band over each nail and over the long rod. Release the rod when it is in approximately the right position and watch it shiver into equilibrium.

I stated that the rod's final position minimized the total energy of the system (correct) and that the sum of the orthogonal lengths from the rod to the nails was therefore minimized (incorrect). I was thinking of the formula for force, in which extension of the rubber bands would be the main factor. As many readers pointed out, however, energy stored in each rubber band is proportional to the square of the extension. My shame at being thus caught up was more than compensated for by the realization that Marc Hawley's gadget was much closer to computing the least-squares formula than I realized. The only important difference that remains lies in the distances. To calculate least-squares regression the rubber bands must stretch vertically and not at right angles to the rod (unless the rod is horizontal).

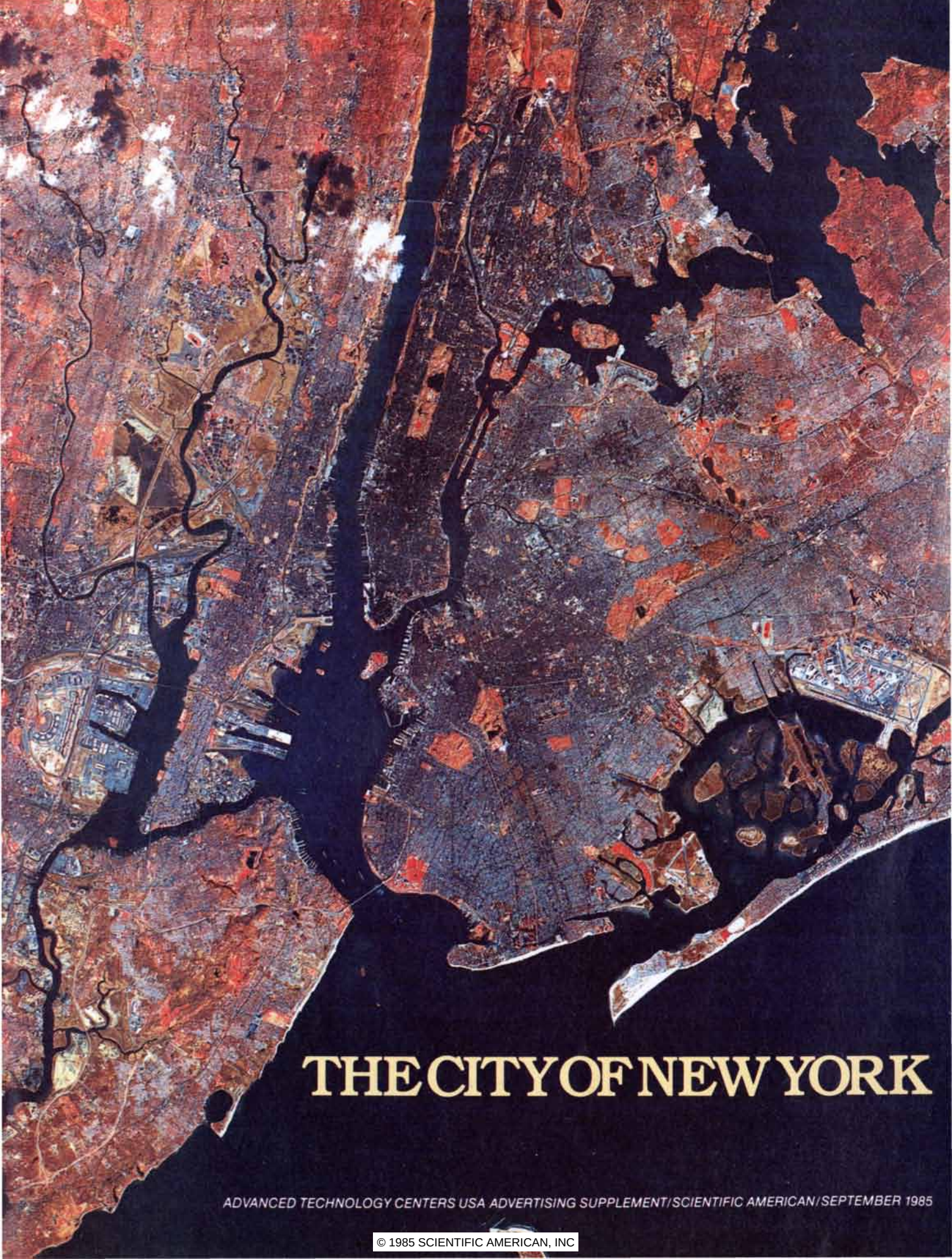
Several readers noted that the rubber bands must be ideal in the sense of having no slack length. This defect can be remedied by one of two means: Charles Dillingham, Jr., of New York, N.Y., replaces the nails with thin cylinders that have a point at one end. The cylinders are equal in length to the unstretched rubber bands. Each band is attached to the pointed end inside the cylinder. The band does not become extended until it is pulled outside the other end and looped around the rod. Robert B. Finucane of Waterbury, Vt., fixes the problem by recessing each elastic in holes that pierce the board at each data point.

There was little criticism of the hydraulic cubic-equation solver except for a mix-up noted by a few readers: the cubic and squared terms are contributed by the suspended cone and paraboloid respectively, not the other way around. A straightforward exercise in calculus confirms this.

I suspect it will be some time before the subject of analog gadgets is revisited in this column. Let me therefore give, by way of a parting shot, the cardboard real estate gadget sent in by Allan Lazar of Teaneck, N.J.

Lazar uses a discarded box from a grocery store and a postal scale to check "the accuracy of the size of real estate tracts having an irregular outline." He traces a map of the property onto a flat cardboard sheet and cuts it out with a pair of scissors. He then weighs both the sheet and a square of the same kind of cardboard scaled to represent an acre. Dividing the first weight by the second yields a good estimate of the acreage of the tract.

So many results from PINT programs around the world have continued to pour in that I am obliged to publish one more grand average. This includes all 1,000-shot estimates of pi received since the first grand average was computed for the July column. Over the two-month period of accumulation I watched as the steadily accumulating average sank as low as 3.129. Things brightened somewhat when mail from Europe and Asia began to bring the average up again. I am particularly grateful to a large contingent of participants who read *Spektrum der Wissenschaft* (the German-language edition of *Scientific American*). Thanks to them the average is now accurate to two decimal places when it is rounded. There were 126 usable letters and the second grand average stands at 3.137.



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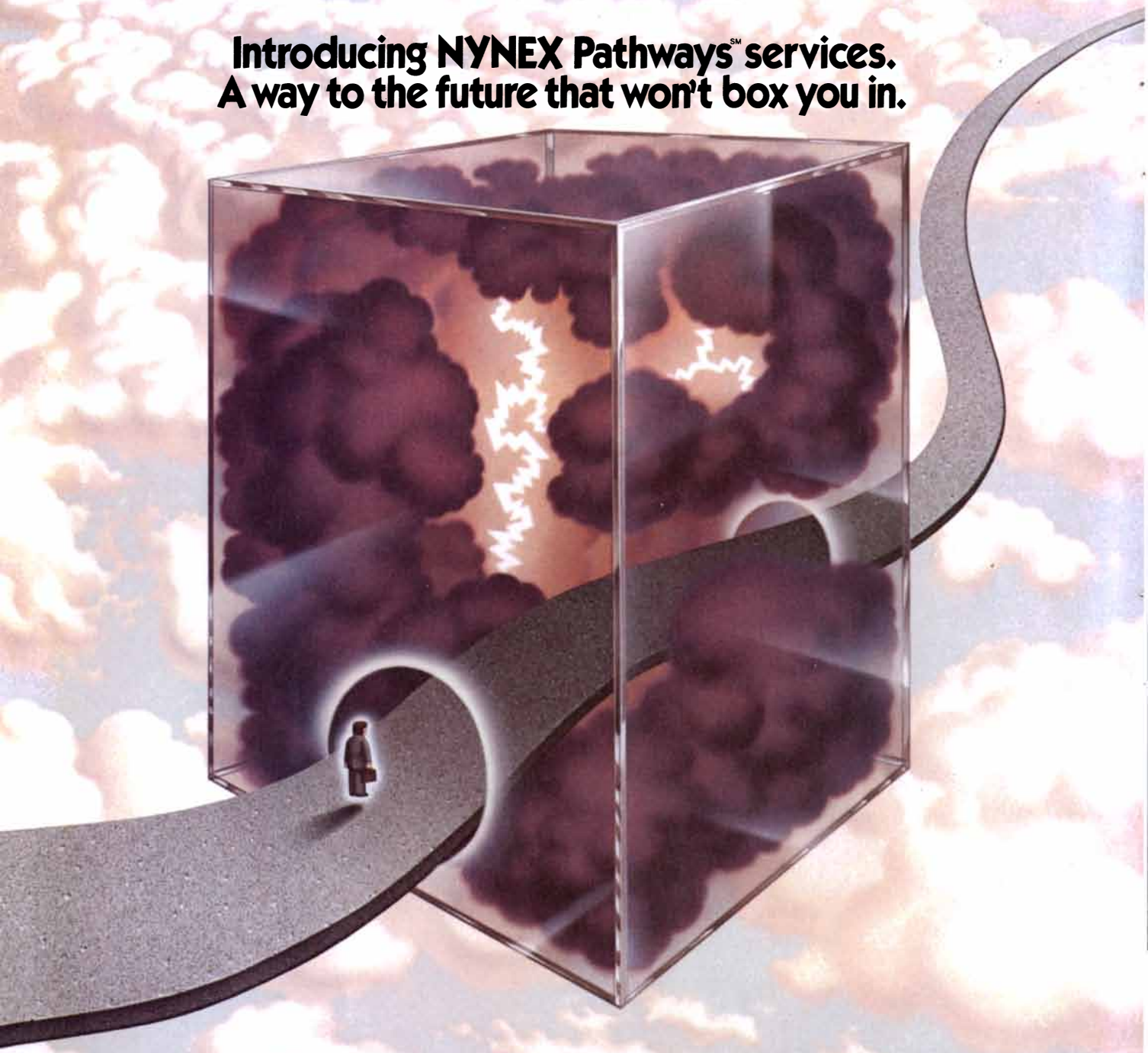

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NYNEX

New York City has made a striking comeback from the vicissitudes of the 1970's, to emerge as the urban success story of the 1980's. It is now the world's leading financial center and the U.S. capital of information-related industries. It is growing fast as a leader in telecommunications, biotechnology and other areas of high technology.

At the same time, New York City has stabilized its previous loss of traditional manufacturing jobs and is starting to attract a wide variety of production operations in new industrial parks and renovated older buildings.

Part of the dramatic recovery can be attributed, of course, to upward trends in the international economy and to the city's traditional strengths, but the city's business community, administration, labor force and utilities have united in a cooperative effort to make the city an attractive place to do business for all types of operations.

The city now offers a number of innovative programs, including tax incentives and active relocation help, to attract and keep businesses within the five boroughs. Consolidated Edison Company and Brooklyn Union Gas Company have pitched in with incentive programs of their own to aid business growth.

Perhaps most important, New York City is now more attractive than ever to the best and brightest talent in the professions and the arts, creating a force for innovation that would be hard to match anywhere else.

"This is a city of pride and promise," says Edward I. Koch, New York's colorful, outspoken mayor. "The new industries that are growing here are young and fast-paced, and so are their people. New York's got what they need —and vice versa."

Universities Spark Growth

A key ingredient in New York City's burgeoning high-technology industries is its network of renowned universities and medical centers. Stretching along a three-mile corridor on Manhattan's East Side are such leading institutions as Memorial Sloan-Kettering Cancer Center, Cornell University Medical College, New York University School of Medicine and Rockefeller University.

Several of these have committed themselves to backing incubator facilities for new high-technology companies in adjoining research and development parks. Columbia University, for example, is developing Audubon Research Park, a center for new business developments in the health sciences, next to the Columbia Presbyterian Medical Center on Manhattan's Upper West Side.

The Cooper Union for the Advancement of Science and Art is one of the few tuition-free private institutions in the country. It offers degrees in architecture, art and engineering. The engineering department is very active in partnerships with small, generally high-tech firms on using applied research toward process and product development. "There is a tremendous potential here for engineering skills and medicine to interact in pioneering work," says Jameel Ahmad, director of research at the Cooper Union Research Foundation.

Leading Biotechnology Center

New York City is the hub of a region that has long been the national leader in pharmaceutical research and production. For example, eight of the 17 pharmaceutical companies ranked in a recent Fortune 500 survey are headquartered in New York and neighboring New Jersey. Manhattan is home to two of the largest: Bristol-Myers and Pfizer.

Thus the city is well positioned to attract a major share of the growing biotechnology industry. Besides the well-known corporate giants located here, a number of smaller entrepreneurial firms have been launched.

Among the most successful is Enzo Biochem, Inc., which was started in 1978 by a group of scientists and businessmen in Manhattan's downtown SoHo (south of Houston Street) neighborhood. One of the first of the genetic engineering enterprises to go public, Enzo Biochem has reached annual sales of more than $5 million.

"We're just a few minutes away from about 10 major medical and educational institutions," says Barry W. Weiner, executive vice president. "Our people feel they are still in the mainstream of science."

High-Tech Industrial Parks

All of New York City's boroughs are joining in the commitment to high-technology development. At Polytechnic Institute of New York's main campus in Brooklyn, MetroTech, an ambitious 16-acre urban industrial park, will be built adjacent to the school, one of the nation's foremost engineering institutions.

MetroTech's research and office development will be geared to the needs of telecommunications and computer-related operations. "New York City is probably the largest user of telecommunications and computer technology in the country," says George Bugliarello, president of Polytechnic. "As research and development move more and more into the information age, interaction between professionals becomes more important and the density of cities like New York becomes more significant. The huge concentration here of financial institutions and corporate headquarters makes it a very attractive market for producers of technology."

MetroTech, for example, is expected to attract small firms and the back-office operations of larger companies in some 2.6 million square feet of commercial space. These operations will have close access to all of Polytechnic's facilities, including an array of computerized data bases.

One of the nation's leading telecommunications training centers, Polytechnic is the first to offer a master's program in telecommunications management. This leadership role is one outgrowth of faculty and student association with some of the world's most sophisticated users of telecommunications technology. Polytechnic people are frequently consulted by the financial and corporate community in setting up telecommunications systems.

Among the institutions Polytechnic serves is Manufacturers Hanover Trust Company.

"At Polytechnic and elsewhere in New York we have access to high-quality people and state-of-the-art technology," says Roberta Frackman, vice president for telecommunications at Manufacturers Hanover. "We're very eager to take advantage of new developments in technology, and New York is where they come onto the market first."

Frackman also points out the advantage of working in close proximity to a large community of telecommunications professionals. "You can find out who's doing what in five minutes here in Manhattan. Telecommunications professionals here share a great deal of useful information."

Telecommunications Advances

New York City is expanding its already formidable telecommunications capabilities. NYNEX Corporation, which includes New England Telephone and New York Telephone, is using innovative technologies to extend digital capabilities to homes and offices. In 1984, NYNEX put in more than 26,000 miles of fiber-optic cable, for a year-end total of about 57,000 fiber miles. Digital switching and fiber-optic pathways make it possible to convey information quicker and at less cost.

Telecommunication capabilities are also being extended with the construction of the world's first custom-designed satellite-communications center and office-park complex. Located on Staten Island, the Teleport provides a large-scale array of satellite-earth stations linked by a fiber-optic network to the area's major business centers. The integrated office park features "intelligent" buildings with modern facilities in a controlled, secure environment.

Partners in the 200-acre Teleport include Merrill Lynch Telecommunications, Inc., the City of New York, and the Port Authority of New York and New Jersey.

City and State Aids

The Koch administration now offers a wide range of financial and tax incentive programs, some of them specially geared to the needs of high-technology firms. It is making the programs as free of bureaucratic red tape as possible.

A major resource for companies relocating within or moving into the city is the Office of Business Development, which has a growing reputation as a "one-stop shopping center" for company requirements. To help a company locate, the office maintains a computerized "space bank" with detailed listings of some 80 million available square feet of commercial facilities in all five boroughs.

Among financing programs available are a revolving loan program under which debt instruments can be issued at around 70 percent of the current bank prime rate, triple-tax-exempt bonds and federally backed Urban Action grants.

The city administration has made an increasing commitment to direct help in keeping and attracting businesses. The city's Public Development Corporation, for example, took an active role in finding a location in lower Manhattan for the expansion needs of Shearson Lehman Brothers, which had considered moving part of its operations to New Jersey.

The administration also stresses that it is committed to the growth of all types of businesses. "We want to maintain and expand a broad base of jobs in both the manufacturing and services sectors," says Alair A. Townsend, deputy mayor for finance and economic development. "That will prevent dependence on a small number of industries and provide jobs for New Yorkers whatever their level of education and skills."

Venture Capital

New York City, acknowledged as the world's financial capital, is, of course, a major center of venture capital. Besides the hundreds of sources available in the private sector, other sources are steadily developing. For example, the New York State Business Venture Partnership, backed by state employee-pension funds, has earmarked $60 million for investments in new advanced-technology businesses in New York City and the state.

The partnership is managed by New York City – based Rothschild, Inc., which itself is a world leader in biotechnology venture capital. "We have reviewed more than 125 deals and are negotiating with several entrepreneurs," says Douglas S. Luke, Jr., Rothschild's manager of the New York State Business Venture Partnership. "We're very excited about the opportunities here."

New York City Partnership

While New York City's administration is actively promoting economic development, the city's business leaders are recognizing that they too have an important stake in maintaining healthy growth. As a result, business people are increasingly involved in many aspects of civic affairs.

One of the most active business groups is the New York City Partnership, led by Chairman David Rockefeller, former chairman of the Chase Manhattan Bank, and President Frank Macchiarola. The partnership, established in 1979, set as its overall goal "to make New York City a better place in which to live, to work and to conduct business."

The partnership is made up of the New York Chamber of Commerce and Industry, the Economic Development Council, and a 120-member board representing all five boroughs and comprising the leaders of both large and small businesses, as well as heads of universities and civic organizations.

Since its formation, the partnership has targeted key problem areas for improvement, including youth employment, education, transportation, housing, safety and government effectiveness. Among its more visible efforts have been:

- Under the partnership's Summer Jobs Program, corporate sponsors have donated several million dollars worth of executive time and talent to help develop jobs for young people and to match them with appropriate employers. More than 100,000 jobs have been developed through the program.
- Under the Housing Partnership, substantial private resources have been made available to help build more in-city moderate- and middle-income housing. About 1,200 housing units have been created through the program.

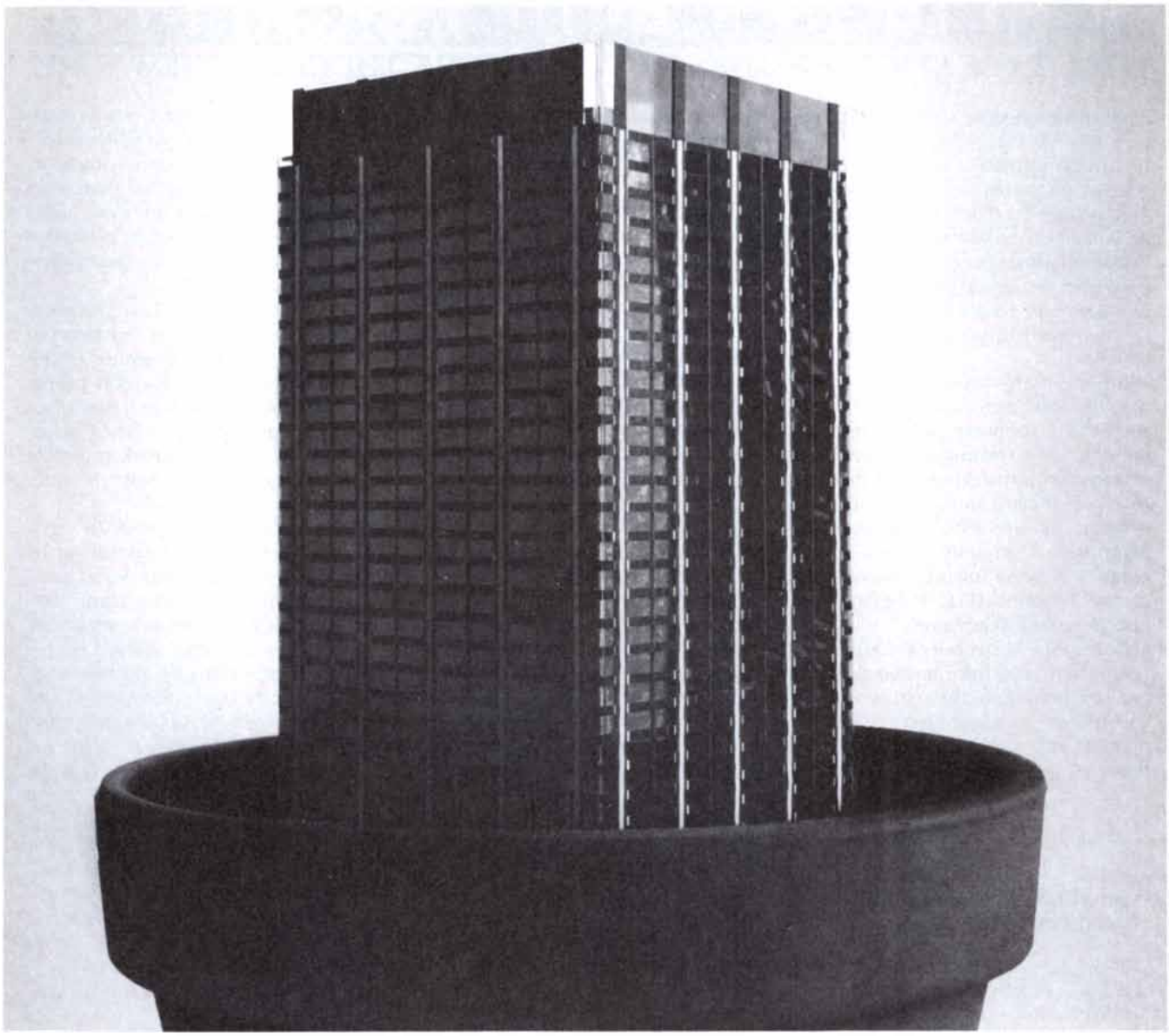
In its broad efforts to improve the business climate, the partnership is creating a tax-expenditure study group to develop policy recommendations and to work closely with city and state officials on reforms.

Labor Force

New York City's labor force of nearly six million represents a wide diversity of skills ranging from computer programmers to garment workers, printers and gem cutters. Wage statistics show pay scales competitive with those of other cities. Manufacturing average wages, for example, are as much as $2.14 per hour less than for comparable work in Cleveland and Los Angeles.

This labor force is the product of one of the nation's most extensive educational systems. New York City has 60 four-year colleges and 29 two-year colleges and technical schools. Among the city's public schools are some that are nationally recognized as outstanding: the Bronx High School of Science, the High School of the Design Industry, the New York High School of Printing and Brooklyn Technical High School.

Two city-based universities have



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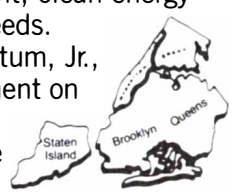

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been designated by the state as Centers for Advanced Technology. Polytechnic Institute of New York is the state's designated Center for Advanced Technology in Telecommunications. As part of its mandate, the center provides assistance to new and small companies in the development of telecommunications technologies and helps them obtain appropriate incubator space.

Among many programs under way at Polytechnic are computerized design methods to improve radio communications, new techniques to enhance image communications and development of efficient intraoffice computer systems for use with small personal computers. Corporate sponsors of the center's projects include Contel Information Systems, GTE, Hazeltine, IBM and New York Telephone.

Columbia University's Center for Computers and Information Systems is a partnership of the school and private industries committed to the development and application of new technologies in those sectors. As part of this program, two new supercomputers are being developed to permit very rapid execution of large-scale tasks.

Building Boom

New York City has been undergoing a construction boom in recent years, from new office and hotel towers in Manhattan to renovation of neighborhoods in all city boroughs. Much of the new building is associated with either the providers or the users of advanced-technology products and services.

Times Square will be revitalized in a multibillion-dollar renewal plan. A new two-million-square-foot merchandise mart is also planned. About 75 percent of the space in the facility will be devoted to products and services related to information processing. Already going up is the major new Jacob K. Javits Convention Center nearby. To open in April, 1986, the center will have the largest single exhibit hall in the nation.

The lower Manhattan financial district, long deserted at night and on weekends, is getting its first major residential projects in many years with a new hotel at the World Trade Center and the huge Battery Park City development. Being built on 92 acres of landfill jutting into the Hudson River at the southern tip of Manhattan, Battery Park City will ultimately contain about 16,000 apartment units, six million square feet of office space and 150,000 square feet of retail space.

Downtown Manhattan, like the midtown area, is undergoing a major building and renovation program. Several historic buildings have been rehabilitated in the process. The former AT&T headquarters building at 195 Broadway, for example, has been completely rebuilt into a fully modern office building while retaining its famed architectural details.

New York City's other boroughs are also getting the attention of real estate developers. Besides the MetroTech industrial park, downtown Brooklyn will be the site of a 600,000-square-foot new office building designed as technical support space for Morgan Stanley & Co. and other tenants.

Another major development is the Atlantic Terminal/Brooklyn Center, a planned office and residential community being developed by Rose Associates. The project will have some 3.1 million square feet of office and retail space and 600 residential units, plus two parks and other amenities.

Pfizer Inc. has made a major commitment to New York. Established in Brooklyn in 1849 as a chemicals firm, Pfizer today is a leading multinational corporation whose health care, agriculture, specialty chemicals, materials science and consumer products divisions span the world.

Pfizer's plant in the East Williamsburg section of Brooklyn continues to be a major economic presence in the area. The plant employs 800 people and is the borough's largest manufacturing employer. The plant's automated process controls make possible high efficiency and greater productivity.

Pfizer is participating with the city's Public Development Corporation in developing a 50-acre industrial park adjoining Pfizer's existing plant. The development will serve as a catalyst to speed up rejuvenation of the area.

In the Bedford-Stuyvesant section of Brooklyn, IBM has successfully operated a component plant, which now has about 400 employees.

Among new developments in Queens is the International Design Center, which provides spacious quarters for interior designers and related firms, and the renovated Astoria Studios, one of the most advanced film and video facilities outside of Hollywood. The studio is helping to bolster the city's position as the major U.S. center of feature film production.

Reducing Energy Costs

Brooklyn Union Gas Company, which serves Brooklyn, Queens and Staten Island, offers special reduced rate plans for selected areas and to businesses moving in. The utility also works closely with businesses to pinpoint financial assistance available to them through private and government sources. "We do whatever possible to attract and keep businesses here," says Michael Teatum, director of area development.

Brooklyn Union is highly active in the community in other ways as well. Through its widely praised Cinderella program, the utility helps to sponsor neighborhood improvements, including financial grants toward renovating housing units.

One of several ways the company works with businesses is its co-generation program, through which a building can recapture excess heat to generate electricity and thermal energy it needs on-site. Helping to make co-

generation more practical are a number of packages on the market that are virtually ready to plug in. In some larger projects, Brooklyn Union is willing to take an equity position in the total cost, and in smaller applications it will act as a broker in putting together the financial package.

"At all times, we are ready to make co-generation happen," says Kenneth Rapp, manager of the Energy Systems Department. "It is part of our commitment to providing total energy services."

Consolidated Edison Company of New York now has a healthy excess generating capacity that ensures reliability and enables the company to maintain stable rates at a time when many other utilities are posting large rate increases. Moreover, Con Edison has expanded its area development program, which provides a 25 percent discount off rates for normal industrial use in sections of the city with underutilized generating capacity.

"The rate reduction program has been immensely successful," says John R. Manak, Con Edison's manager of area development. "Close to 3,200 businesses now have reduced rates and about 15,000 jobs have been created as a direct result."

Natural gas costs are also stabilizing in the city as a result of federal deregulation of the industry, a healthy domestic supply and new gas field discoveries in eastern Canada.

Markets Easily Reached

Businesses located in New York City have the great advantage of being midway between Boston and Washington in the center of the nation's largest market for products and services. The area's superb transportation network provides fast service to customers, enabling factories, warehouses and retail stores to move products rapidly while maintaining minimum inventories.

Subways and buses move about 5.4 million passengers twice each workday, most of them during peak hours. Every workday, commuter trains transport hundreds of thousands of workers into the city from New Jersey, Westchester County, Connecticut and Long Island.

The area's three major airports handle more than 50 million passengers a year. Only 25 minutes from mid-Manhattan, LaGuardia provides frequent flights to other major American cities, including hourly commuter service to Boston and Washington. The two international airports, J. F. Kennedy and Newark, provide direct service to over 400 cities worldwide.

Kennedy, served by some 80 airlines, has the world's largest air-cargo facilities and together with Newark handles about 40 percent of the nation's foreign air-cargo tonnage and more than 50 percent of its total value.

Businesses based in New York City can reach almost one-third of the United States overnight by truck—as far south as Raleigh, west to Cleveland and north to Bangor. The highway network provides fast truck delivery throughout the metropolitan area.

The Port of New York, historically the nation's sea gateway to and from Europe, has 750 miles of waterfront. It is the leading U.S. container port, with 38 container berths in addition to 50 conventional berths. Exports and imports flow through the harbor at a current value of about $50 billion a year.

The first free-trade zone on the East Coast, located in the former Brooklyn Navy Yard, allows foreign manufacturers to ship duty-free components for assembly here and reshipment to foreign destinations.

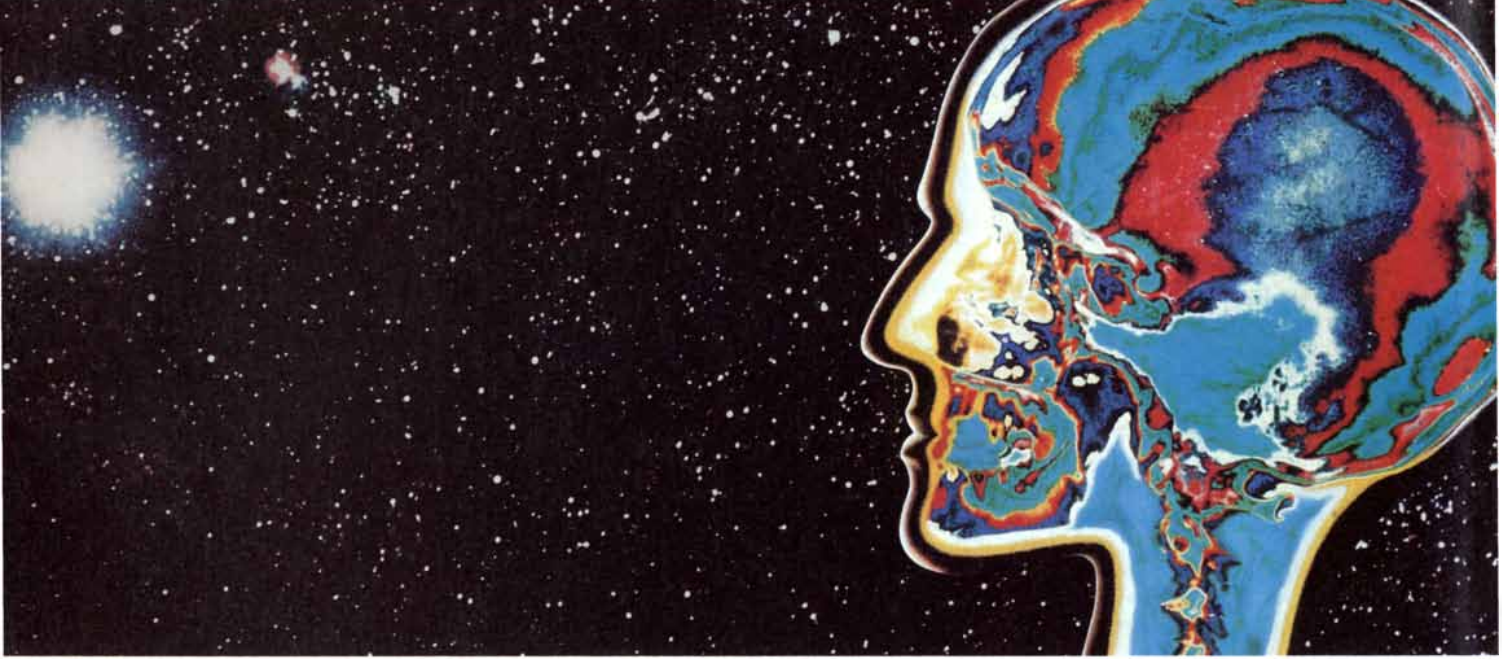
Quality of Life

Innovative advanced-technology industries demand the best in creative managers, scientists and technicians. Such people are attracted to New York in large numbers for many of the same reasons that lured earlier generations. The city is the world's foremost cultural capital, offering a rich feast of the performing arts, museums, art galleries and other attractions.

Always open to change, New York City is building on its many strengths to become a leading center of advanced technology.

"The City of New York" was written by Ronald Burroughs, a New York business journalist. Graphics by Sherin & Matejka, Inc., New York.

Cover: Landsat photograph courtesy of Earth Satellite Corporation (EarthSat), Chevy Chase, Md. The photograph was taken at an altitude of 431 miles. Colors represent variations in the earth's topography; for example, red indicates dense vegetation.



Health Care Futures

The human brain cannot conceive exactly what the world of health care will be like in the year 2000. But we can offer some educated predictions.

There will be more elderly people, 152 million more than there are today. Because of this increase, we will see many more people suffering from heart disease, arthritis, diabetes, and other diseases that afflict the aging.

There will be more known diseases, requiring new forms of medication. And the delivery of health care will be different because of continuing efforts to hold down medical costs.

High expectations

Expectations for high standards of medical care will continue to rise among nations. It will become for many a matter of national priority to provide the best health care available.

At Pfizer, we see the future as a healthy opportunity for us. We've been making the future a reality since 1849. Today, we are one of the most successful companies in the U.S., with $3.85 billion in sales last year.

Research as foundation

We have grown for many reasons, but two of the most important are our research orientation and our marketing skills. Our research has helped us develop some of the major drugs on the market today to treat arthritis, diabetes and heart disease. And we are currently testing their successors.

But we are not focusing on pharmaceutical research alone. Research among other Pfizer units is yielding innovative products for a whole range of hospital and health care applications.

Attuned to the market

Important as research is, we wouldn't be where we are without our marketing capability. We are often seen as the best marketing company in our industry—an advantage as health care delivery becomes more sensitive to market forces.

Our research talent and our marketing expertise—we think they are an unbeatable combination. That's why we're a leader not only in health care, but in agriculture, specialty chemicals, materials science and consumer products.

All of them can play a role in your future. Come invest in ours.

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Bringing science to life.

BOOKS

Sweet power, liquid crystals, anchors aweigh, a bamboo tower, and a Gothick mystery solved

by Philip Morrison

SWEETNESS AND POWER: THE PLACE OF SUGAR IN MODERN HISTORY, by Sidney W. Mintz. Viking Penguin, Inc. ($20). Perhaps three-fourths of the people of the world today still depend for their nutrition on a single starchy staple, a complex plant carbohydrate yielded by potato or rice or maize or millet. Along with it they count on some of a wide variety of sauces, stews and relishes, viewed not quite as food but as food's essential helper. It has been so among sedentary peoples as far back as we have evidence: utensils specialized for cooking rice and its helpers are found in predynastic Chinese graves. One ethnographer cited here, Audrey Richards, evokes the meaning of a true staple. Richards studied the Bemba, whose staple food was a glutinous paste of millet, always taken with a savory and slippery sauce. She would watch people enjoy four or five roasted ears of maize, only to hear them exclaim later: "Alas, we are dying of hunger. We have not had a bite to eat all day."

The modern world no longer adheres to this ancient pattern, even among its poorest classes. We hardly have a staple food. Compared with the norms of history our diet is as exotic as the milk and blood taken by the Masai or the blubber and caribou venison that nourish Inuit hunters. We Americans consume fewer total carbohydrates today than we did in 1910; a sharp increase in fats has made up most of the difference. At present sweeteners supply most of the carbohydrate calories Americans consume. In TR's time flour was virtually a staple, and sugar contributed one-third as much as flour. (A true staple provides the people of a peasant countryside with considerably more than half of their calories, up to 80 or 90 percent.)

This novel work is economic history, as seen and elaborated by an anthropologist of analytic penetration, learning and wit. Sidney W. Mintz is alert to the role of class and implicit power and observes their effect with well-controlled indignation. Now professor at Johns Hopkins, he did his first field work decades ago among the hard-working Puerto Ricans of a cane-field village. He has generalized that experience in this book, not by any field work (yet) but through wide reading in the library.

The domination of working life in the "sugar islands" from Cyprus to Barbados and Fiji by this tropical crop out of India is a phenomenon one clear millennium old. Sugar has long been a plantation crop, initially cultivated by slave labor. Its place in the formative centuries of European imperial power, especially for the British, is plain. "Sugar ... has been one of the massive demographic forces in world history. Because of it, literally millions of enslaved Africans reached the New World, particularly the American South, the Caribbean and its littorals.... It was sugar that sent East Indians to Natal and the Orange Free State, sugar that carried them to Mauritius and Fiji. Sugar brought a dozen different ethnic groups in staggering succession to Hawaii, and sugar still moves people about the Caribbean."

But all that is production: sucrose viewed from the supply side, from below, from overseas. What about the demand up in the metropolis? How is it that a medicine, an exotic spice, a decoration at the feasts of the Elizabethan nobility could come to be a major national source of calories? "A rarity in 1650, a luxury in 1750, sugar had been transformed into a virtual necessity by 1850." First of all had come the bitter stimulant tea, sweetened with white sugar (or its refined syrup, golden treacle), its use spreading group by group from the well-to-do of the city down the social rungs to the rural poor.

Sugar was ubiquitous by 1850, although still at the fringe of the diet—a couple of percent of dietary energy. It added quickly won taste to help out staple bread. With the triumph of industrial capital the planter's claim to special prices and profits withered. The slaves were set free, and sugar from productive mechanized plantations became a dominant Victorian source of cheap calories. By 1900 it supplied nearly one-sixth of all English calories (an eightfold rise in a century), surely more among working-class women and children, who shared unequally in the family's scanty fats and meats.

The focus of inquiry is really that second rise in demand. Tea and two lumps at each meal are enough to make up the first climb to ubiquity. To climb the next power of 10 from flavor fringe to calorie core requires half a cup a day. That hot cuppa won't do it; there must be jam with our daily bread, marmalade, sweet biscuits, custard sauce, sweetened condensed milk, candies and chocolate, and on good evenings a nice treacle pudding. All these appeared, and much more, along with new industries to serve the buoyant demand of consumers who earned an increasing amount of money and found themselves free to choose.

Of course the only choices they could make were among a sharply constrained set of unsolicited new options. Daily life changed; the population grew apace; more working people were ready to work harder to earn more and to consume more; their time became money and their money became goods. The nation turned urban, time-conscious, organized—in short, "modern." Tea and biscuits provisioned each clock-timed work break; more factory laborers ate away from home and returned to an evening meal that in good times ended with a newly conventional course, the sweet (in American English, dessert). Not to be forgotten is the caloric efficiency of tropical cane. Sugar cane yields edible calories per season per acre at a rate four times that of a potato crop. The British worker in the steam-driven mills got more and more tea, tobacco and sugar for less and less work as the decades passed. "No wonder the rich and powerful liked it so much, and no wonder the poor learned to love it."

We still love it, rich and poor, with differences. The family meal with its shared menu is giving way to prepared food individually chosen and to eating out; we witness the decline of mealtime as an everyday ritual for kin groups. (All those trends promote inexpensive, fast-eaten sugar.) The week's round of Friday fish and Sunday chicken has long been broken. The tradition of seasons that once brought "bock beer, shad, fresh dill, and new potatoes, each in its turn, turkey twice a year, and fruit cake with hard sauce at New Year's, survives only on sufferance, finessed by turkey burgers, year-round bock beer, and other modern wonders." One sample among middle-

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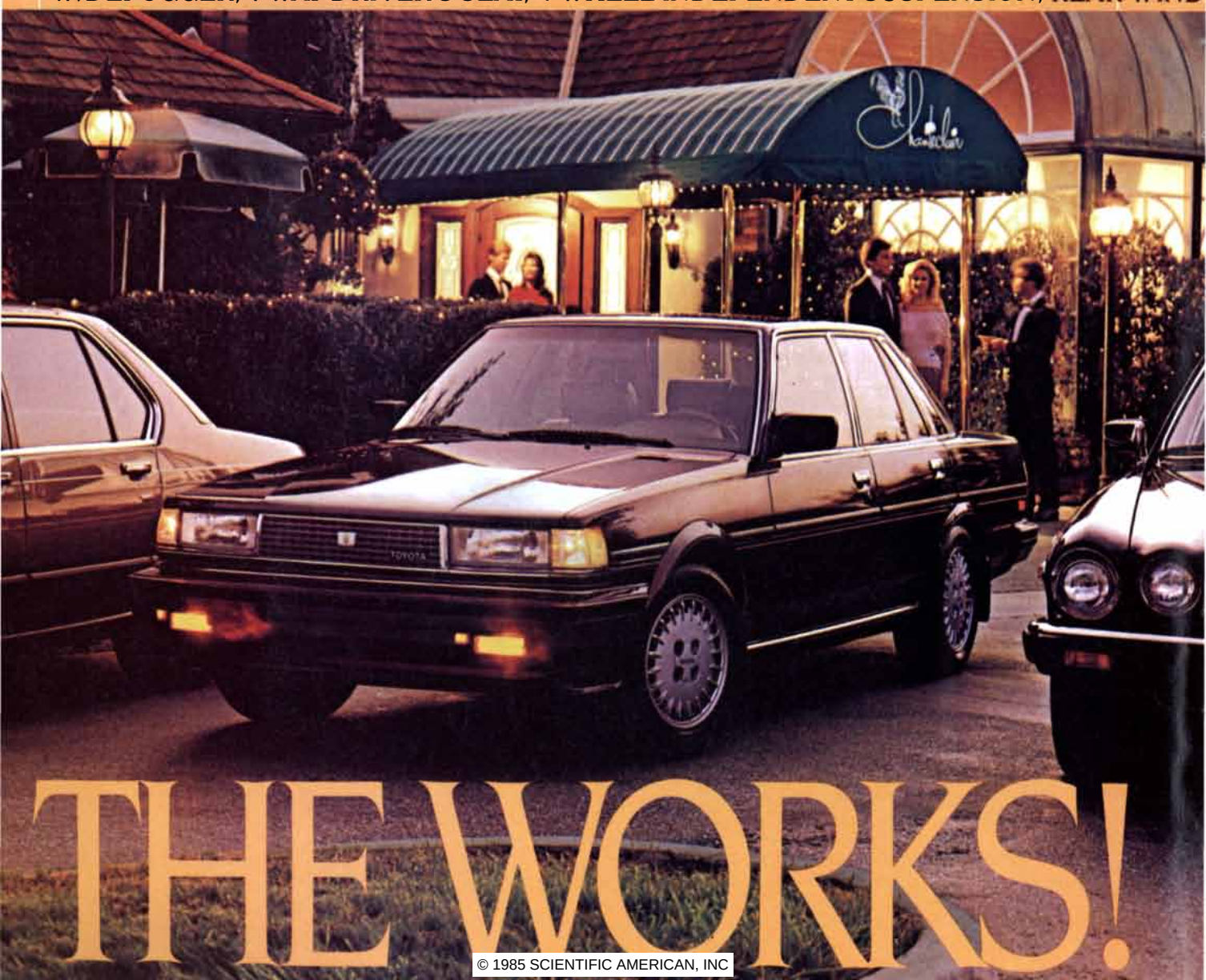


THE WORKS!

class families suggested that an average consumer had 20 "contacts" with food in one day: "gastro-anomie," punned the French sociologist Claude Fischler. The consumer's free choice might now be "between a Big Mac and a Gino's chicken leg in a 30-minute lunch hour." (Both have some sugar, even without recalling the sugared beverage that goes along.) Evidently that free choice itself hardly matters, but the defining constraints are so full of implication that they themselves characterize our society.

The modern chronic shortage is not of food but of time. Our vastly productive new technologies paradoxically ensure that most individuals feel they have "less time, rather than more." Should we be surprised at that, Mintz asks, when "those who run a society so bent on 'discovering' new consumption needs will have little interest in finding time for their satisfaction"? Most of the notable tendencies in eating in America can be found growing thriftily in the other two worlds as well, even to Coca-Cola and its congeners. Plainly a fine book lies in the one closing chapter that attends to the contemporary.

In the nature of so deep-going a critique, its claims are not proved; perhaps they are not now provable. They are fascinating efforts at ordering incomplete information of a diverse kind, an order that in the end illuminates "what being a person means... the history of ourselves." A measure of the book's success is our strong desire to read on; questions crowd the mind.

What about sugar in peasant India, its original home? Or the traditional sucrose staple of the palm-growing people of the Indonesian island Roti? We need more modern comparisons; France is not enough. Why, for instance, does Iceland lead the world in sugar consumption per head? How could it be that many developed lands, once fearful of wartime shortages of sugar, have for a century subsidized an alternate onshore source of sucrose from the sugar beet? Will the enzymatically treated cornstarch sweetener continue its displacement of sucrose in soft drinks and processed foods?

A reader comes away a little puzzled but much wiser. The argument that links sugar uniquely to the economic interests of a decisive class is not quite persuasive. One suspects that the high-gain feedback loops of industrial capitalism could amplify any little tinkle of predilection into a roar of mass consumption, even if there were no cane to be grown. Like the three bittersweet sources of caffeine, like addictive tobacco, sucrose must have some subtle druglike quality, some satisfying rush of glucose, or whatever the physiology may be. It is a versatile foodstuff that is marginally a drug, offering the economic potential of large dosages long tolerated.

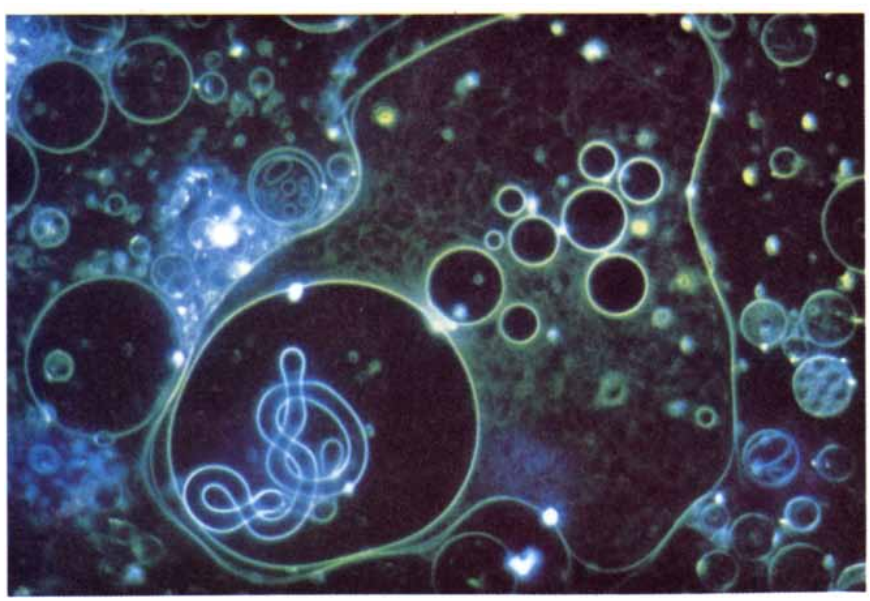
The extensive footnotes are as stimulating as the unexpected illustrations: the frontispiece is William Blake's engraving of three young women, white Europe supported by black Africa and red America. Oddly, the index contains no entry for Coca-Cola, although that important substance is of course discussed in several places.

THE CAMBRIDGE GUIDE TO THE MATERIAL WORLD, by Rodney Cotterill. Cambridge University Press ($34.50). The breaking of some, but not all, of the symmetries inherent in a physical system has come to be seen as a major property of the furniture of the world: "There is no excellent beauty that hath not some strangeness in the proportion," Francis Bacon philosophized long ago. An example is the liquid crystal. For 100 years it has been clear that many long, stiffish molecules, principally organic chains sporting many double bonds or rings, can within a limited range of temperatures stably array themselves parallel in orientation and yet remain disordered in position, like a shoal of fish headed upstream. There are related but more elaborate directional orderings too. The resulting phases, neither solid, liquid nor gas, are liquid crystals, the lattice symmetry broken, whose properties unite the directional optical action of many crystals with some of the mobility of isotropic fluids.

Such substances are today called mesogens. They are by no means rare. Almost 1 percent of all known organic compounds belong to the class at some temperature. The iridescence of a beetle's wings and the transient digits on the face of your wristwatch, obedient to pulses of electric field, are familiar examples. Life has made profound use of the phase, for the wall of every cell has a lipid double layer, the long carbon chains oriented but mobile, that acts both as "a containing bag and a selectively permeable gate." Some dozen color photographs and as many photomicrographs and explanatory diagrams accompany a careful account of these substances, one chapter of 18 in this richly unifying volume.

Sample a few more of the fresh accounts that here unpack the hidden treasure within the old atomists' view of matter as atoms and the void. Today we need to include atomic interactions as well. They are all electromagnetic and happen at several levels of subtlety, from textbook electrostatic attraction and repulsion between ions to the weak induced dipole that forms the hydrogen bond. One chapter treats water, the universal mediator, resting the account on a molecule's-eye view of the shifting, dissociating, equilibrating network of molecules linked by flickering hydrogen bonds. Everyday electrolyte chemistry, with its acids and bases, ions brought into solution and the electrochemical series are made physically clear without algebraic formulas.

A similar chapter discusses minerals, particularly the kingdom of the silicates (more than 90 percent of the mineral species are silicates). Those diverse spatial patterns are all fashioned



Lipid bilayer membranes form spontaneously in solution

of more or less well-linked atomic tetrahedrons, each having four oxygen corner atoms whose bulk hides a little silicon atom within. Usually the tetrahedrons share at least one corner; in quartz every oxygen belongs to two tetrahedrons, so that its formula is not SiO_4 but SiO_2. Into those worlds built of tetrahedrons one finds somewhere regularly inserted the other atoms that fill out the complicated mineral lattice.

A linear chain of such tetrahedrons builds fibrous asbestos; joined in plane layers they form the sheets of mica; amorphous and disordered, but "with only negligible violation of the corner-to-corner rule," the substance is common window glass. So much is classical. Modern ceramics and the now widely generalized glassy stuffs extend these old understandings. Hard, durable and corrosion-resistant, modern ceramics may be composed of any mixture of nonmetal and metal atoms. Metals are bonded by the collective sea of electrons; the near-spherical ions can slip easily because their bonds are nondirectional. In ceramics the bonds hold a fixed direction; the materials are hard. Brittleness arises from the growth of tiny cracks, governed by the scaling relations between the formation of new surface area and the release of elastic energy in the stressed volume. With foresight, interparticle flaws in ceramics can be made to heal rather than grow; the result is ceramic cutting tools, knife blades and springs. Here modern ceramics are skimped in favor of an interesting account of red rust, cement and brick at the atomic level.

There is enthusiasm but no partisanship for the solid state in this remarkably catholic volume. A fine chapter surveys the organic chemistry of the day, full of power derived from its quantum insights. The old roots are not neglected; Friedrich Kekulé's 1862 figure of the benzene ring is reproduced, from a time when the physicists had hardly been persuaded that atoms were real. Nowadays the chemist is as much at home in space as any sculptor, and recent organic molecules take the forms—and the names—of barrels, baskets and propellers. A fine set of pictures shows the luster and directional color changes of an organic superconductor.

The theme of broken symmetry is at its most fruitful and most intricate in the discussion of defects in the crystalline lattice. Point defects such as interstitial and missing atoms are easy to visualize, and surfaces of imperfection such as grain boundaries are not much harder. The line flaw of a dislocation and its relatives are harder to grasp. The geometrical and topological issues are treated by metaphor and homely comparison, backed up by a very useful set of diagrams. The artist Ove Broo Sørensen has here and throughout the text contributed to clarity in major degree with his "breathtaking diagrams" of many arrayed atoms.

Striking photographs made by a variety of microscopic techniques show tangles and layers of multiple lattice imperfections. Interpretation of these images—still not complete—holds the key to an understanding of ductility and brittleness, tempering and fatigue, particularly in metals. This topic, by no means simple, is considered in some detail. Mineral glasses, random close-packed arrays held by covalent bonding, are usually brittle. There are no well-made atomic planes to slip by dislocation. The stress builds up until the sample snaps. But metallic glasses, so far made only in thin ribbons by ultrarapid cooling, show a surprising set of properties, including a kind of local ductility quite unlike that of any ordinary glass.

A clearly drawn, color-keyed version of the complicated phase diagram of iron-carbon at the steely low-carbon end is nicely elucidated in its place; such classical explanations are not forsaken in favor of the novelties. The foundation of modern ideas about the chemical bond, about thermodynamics and its kinetic account of equilibrium, are well laid without any algebra. The beginning chapters amount to a short, careful introduction to physical chemistry.

The last few chapters describe atomic nets, lines, coils and sheets of synthetic and natural polymers, bridging from them to the biochemistry of cell energy and its enzymatic control, to genetics, to chloroplasts, neurons and muscle fibers. These chapters are wisely not comprehensive but instead provide illustrative accounts of topics in molecular biology. One section describes how chloroplasts, able to face subdued sunlight squarely, can turn edgewise to direct rays. Filaments of actin anchored in the cytoplasm move the green structures by means of mechanisms simpler than animal muscle but quite analogous to it.

Rodney Cotterill is professor of materials science at the Technical University of Denmark. He has been educated in Britain and America, and he has carried out research in those two countries and in Japan. The unity at depth between physics and chemistry, between crystal defects and restriction enzymes, has never been served so well in a popular and visually engaging book. Warning: This text is a full and serious exposition lightened by the author's care, his flair for apt figures of speech and the well-planned illustrations. But it is replete with substance (and substances), and it is a reliable first reference resource for a student at any level. Here and there a provocative side remark may start some reader down a false trail. Perpetual motion, for example, is certainly present in superconductors, although Professor Cotterill seems doubtful, just as it is in all atomic ground states (at least until the protons decay!).

ENGINEER'S WITNESS, by Ralph Greenhill. David R. Godine, Publisher, Inc. ($35). Almost every leaf here brings a new photographic evocation of some piece of North American technology celebrated with the sensibilities of the vigorous past century. The Virgin is far off, it may be, but the Dynamo is seen here at its locus classicus, those steam-driven alternators in Machinery Hall at the Columbian Exposition in 1893. A few pages later the Dynamo has ripened from powerful symbol to workaday power source in the world's first major hydroelectric plant. We see a dozen or so men of the Westinghouse installation crew in 1898, clambering over the big coils of their growing 5,000-horsepower alternator at Niagara Falls Power-House No. 1. That generator (10 of which were installed) steadily sent out its two-phase 25-cycle-per-second a.c. to nearby graphite and carborundum furnaces until 1961.

Would you share sights that might have galvanized Mark Twain? In 1868, a few years after his California days in the Mother Lode, two miners are "piping the bank," washing away the gravel hills at one of the richest of hydraulic gold mines, the Malakoff. Water at a pressure of a dozen atmospheres, carried 45 miles across country by canal and piped down into the canyon, fed the six-inch jets. Or look at the riverside somewhere above St. Louis to see four side-wheelers nuzzling the bank, the largest of them the renowned *Grey Eagle,* the steamer that reached St. Paul 10 hours ahead of schedule with the newspapers that carried the scoop of the Queen's first message by means of the Atlantic cable—a trip upriver one summer day in 1858 at a smoking 11 miles per hour.

Another page shows the ocean cable itself being stowed aboard the U.S.S. *Niagara,* the largest ship in the U.S. Navy, by volunteer seamen of its crew. The pioneer cable promptly failed; another photograph shows cable-laying gear on the *Great Eastern,* the outsize ship that laid the lasting submarine link eight years later.

The High Bridge that carried the

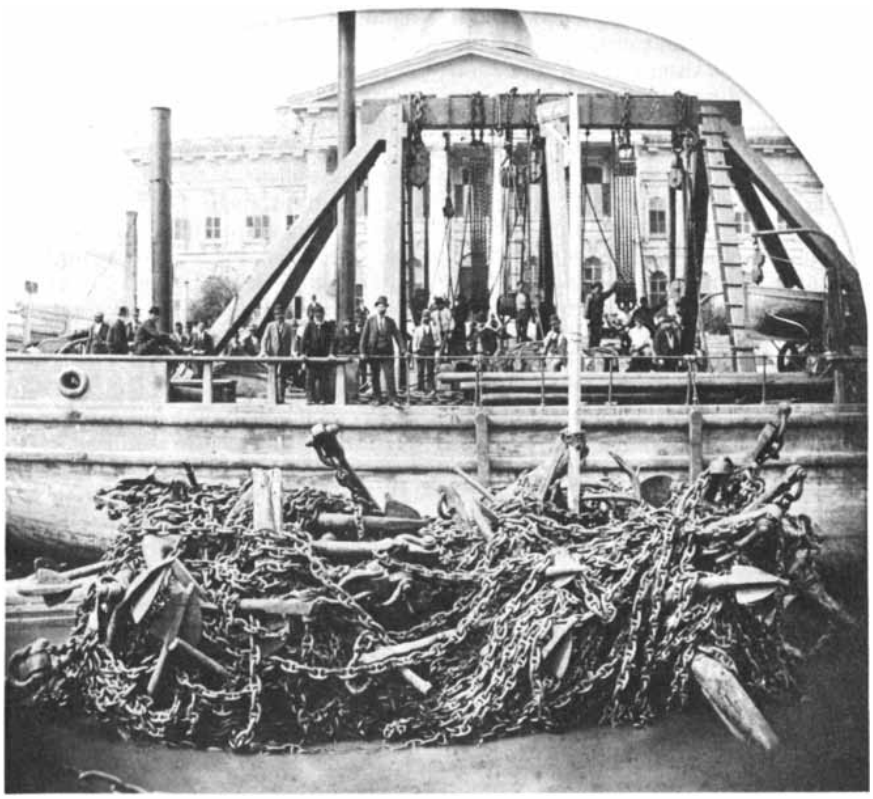
South Side Railroad across the flood plain of the Appomattox near Farmville, Va., was built in 1851. It was a noble viaduct, a timber Howe truss that spanned a kilometer, thanks to wrought-iron verticals and arch ribs; it stood on brick piers that were unusual in wooded America. The photograph shows the bridge just after the Union Construction Corps had installed a temporary trestle to replace the four spans burned by the retreating Army of Virginia, only two days before General Lee's surrender at the courthouse, a day's march upstream. Here, as with the ocean cables, we touch on visions that lay before Walt Whitman.

A remarkable shot catches a few of the iron stacks and stills at the Imperial Refinery near Oil City, Pa., in 1873. In the foreground are railroad tank cars to carry off the lamp-lighting kerosene that was the salable fraction of the product. Much more volatile naphtha, one day to become motor fuel, was of little commercial use before Benz. Storage tanks at the same refinery can be seen burning fiercely in another photograph made a couple of years later, after a lightning strike fired the entire plant. It was an "unsurpassable" blaze whose heat was felt several miles from the spot, according to the account on the back of the original stereograph.

Another harbinger of the 20th century is found at the Washington Navy Yard in 1898. The view looks a long way down the high bay of the gun shop there, in which dozens of enormous lathes are turning cannon. A decade earlier the largest naval gun tubes had to be imported from Great Britain, but this picture testifies to the first maturing of American heavy-ordnance manufacture.

Bridges, steam hammers and blast furnaces, unusual shops and railways, including the vaulting train shed of wrought-iron arches at the old Grand Central Depot, horse cars and steam trains side by side within, fill out this remarkable compilation. You can look on John Roebling and his son, posed among the worthies of his board of engineering consultants on the suspension bridge across foaming Niagara, which the Roeblings built before they undertook to span the East River.

Somehow whimsical is the heavy-duty steam-winch barge of the Quebec Harbor Commission, whose task it was to clear obstructions out of that busy harbor. Ships would cut away a fouled anchor in sacrifice whenever they could not promptly lift it with their capstan. In time a nest of abandoned chain and intertwined anchors grew. We see one such nest brought to shore in 1877, a repellent tangle of 70 iron anchors in heavy chain, the whole mess weighing 240 tons.



A 240-ton nest of anchors and the barge that lifted it from the water

In 1868 the editor of *Scientific American* was a venturer of daring. He had obtained a city charter for the construction of a small underground pneumatic tube to transport packages and mail in downtown Manhattan. He began instead to build, secretly by night, a pneumatic passenger subway eight feet in diameter, using a circular tunnel shield of his own design, the first in America. Two photographs taken in the basement of the clothing store on Warren Street that was to become his terminal show the finished work, the single cylindrical car filling the tube with minimal clearance. The tunnel turned off the street to run south below Broadway for about 300 feet. In 1870 Alfred Ely Beach disclosed his successful coup at an "Under Broadway Reception" for the press and officials. Boss Tweed and his friends had already fixed on an elevated railway system, however. Ahead of its time, Beach's surprise subway was stopped.

These unfamiliar and exciting pictures and the informative text that goes with each one amount to a visual survey of civil and mechanical engineering in 19th-century America—a survey that seems to have no comparably broad counterpart in text. (The bibliography collects many excellent but specialized titles.) An interesting introduction discusses the various photographers of that time who specialized in engineering photographs.

Ralph Greenhill compiled these images, in 12 years of work, from private and museum-held collections in the U.S. and Canada. The wonderful frontispiece catches the spirit of the entire display. It shows a fragile-seeming railroad bridge high across the Kentucky River in the days of light rolling stock, about 1877. On the bank in the foreground a big view camera poised on its tripod waits unattended until there is a chance at some better shot.

PHÄNOMENA, edited by Georg Müller, and THE BOOK OF PHÄNOMENA, a paperbound supplement with selected texts in English translation (45 Swiss francs, both volumes). Zürcher Forum, Gemeindestrasse 48, CH-8032 Zurich. In summer the wooded shores of Zurich's blue lake are cool and inviting. Across a few acres of that lakeshore there blossomed in the season of 1984 a remarkable garden. It is no longer there, but this engaging book documents in German text (the supplement helps readers of English) and many colorful pictures the short life of an "exhibition about phenomena and the riddles of the environment."

The largest flower there was a de-

lightful multistory bamboo tower, 120 tons of the big stalks prepared in Kunming (Zurich's sister city in China) and then erected and artfully lashed into secure place by a Kunming delegation that would not deign to use any nails or screws. (Wood intermediate floors held on steel bedplates marred the purity of design, but they fulfilled local regulations and made the structure as useful as it was eye-catching.)

The spirit of Phänomena is clear enough from the 100 windwheels, resembling clustered white daisies a yard across, that spin in the breeze along every edge of the tower. Stairs and ramps led up, and smooth-lined chutes sloped down. Like this tower, the entire exposition joined playfulness to a varied invocation of the appearances of the world, often accompanied by apt auxiliary examples bringing understanding to the fingertips.

Gravity? A steel tower even higher than the six-story bamboo offering from the People's Republic of China is traversed by a superelevator whose floor consists of an open mesh. There are weights to hold and scales to step on as you brave accelerations of one-fourth of gravity up and down that provide an approach to weightlessness followed a few seconds later by a knee-bending load. (Commonplace high-rise express elevators reach accelerations of one-tenth of gravity.) For a somehow opposite sensation, and an equally valuable exposure to physics, try the thrilling bicycle ride along the high wire, a safety net below. The feat could be managed here without practice and with only a modest amount of daring, since this bicycle carried a heavy counterweight six feet below the wire that assured stability to every novice circus cyclist. Messrs. Coriolis and Foucault and Euler were invoked (mainly anonymously) with spinning chairs and tables that made opportunities for tangible transfers of angular momentum.

Fluid flow? Admire a huge water bell, its 15-foot hemisphere of droplets shimmering above the lake surface, with a number of hand-size versions nearby to help tease out how it works. Add a six-foot water-vortex cone, a spinning wonder held captive in a glass cylinder for steady-state inspection. Smaller and more analytical, a long tank holds at bench height a glycerine solution doped with aluminum powder, in which turbulent flow is slowed and made visible around any barrier you drag along. There is a hydraulic computer, its fluidic oscillators and amplifiers open to view and manipulation. Flettner rotors and airfoil sections sail up a fan-sent breeze, and a one-ton granite sphere spins under the hand within a closely fitted opening lubricated only by the water of a natural spring.

There is a wheeled cart to ride as it jets ahead on rails, the impulse provided by bowling balls that roll backward off the car down a sloping track. A pendulous suspension bridge repays the wary pedestrian with safe but scary motion; a massive pendulum bob hanging beyond reach can be set grandly swinging by many feeble pulls on a slender thread—if the rhythm of repetition is resonant, but not otherwise. There are real, colorful minerals and crystals, including huge points of crystalline quartz, to admire and to gauge by hand; there are mock crystals made by mutually repelling bar magnets, held in tubes that themselves float in air flowing under pressure out of a much-perforated tabletop. Ride a cage hung from a tripod; it avoids the central vertical position because a big magnet in the floor abhors a similar one in the moving cage. (The magnets own up to 800 kilograms of distaste.)

Eye and ear are not forgotten. These displays were mostly sheltered within a few strikingly tensioned tents. Item: A facing pair of sound mirrors offer an open-air whisper circuit, and there is an echo tube one sound-second long. Item: A big geodetic dome is fashioned of mirror facets, so that those who wander within dwell for a while in a multiple kaleidoscope. Item: Heliostat-captured sunbeams are led within one room on a merry chase among mirrors and prisms. In another room 144 tuned tubes, long and short, hang from the ceiling; struck by a rod in the visitor's hand, they utter a spectrum for the ear that is subtle in its selection of overtones.

There were about 250 exhibits more, as small in scale as playful chromatography on filter paper (carried out for the pleasure of seeing the colored drops spread) or as large as a fiberglass parabola, 10 meters in diameter, collecting solar energy. The full book includes them all, and more: mathematics, illusions, mime, an innovative restaurant with Kunming chefs....

Since 1968 the Zürcher Forum has organized hundreds of concerts, readings, exhibitions and days of celebration to win new friends for art and culture among the entire population of the city and the canton. Georg Müller conceived and then, over three years, built up this lively zoo of the phenomena of the world: the very ground of art and science, of our very life. Intended for the wide public, it could not have succeeded without widespread collaboration among engineering firms and skilled craftsmen, university scientists and ingenious designers and inventors, not to mention those construction teams from Yunnan, the masters of bamboo. A page or two on the budget of this enviable and solvent enterprise would have helped us understand it better. Swiss fiscal reticence?

It was bold to plant so fine a museum as one season's flower. Will other cities try it in their own way? The springs of this style are explicitly given; they are the Deutsches Museum of Munich and the Exploratorium of San Francisco. Many of the lakeside exhibits are to be seen now in the Exploratorium in similar form. Quite a few museums of science share in part the approach pioneered by the late Frank Oppenheimer, one that grows out of science itself: genuinely working displays, direct rather than symbolic, participatory rather than didactic, and openly hopeful of widely shared joy and understanding.

THE LOCH NESS MYSTERY SOLVED, by Ronald Binns. Prometheus Books ($18.95; paperbound, $9.95). It is a monster of our own time in a fine Gothick setting. The first accounts appeared in the local papers in 1933. The classical photographs of that long neck, head held high, against no background save the rippling surface of a body of water—can we know which?—were taken on (yes) April 1, 1934, by a London surgeon. The two photographs are reproduced here with an analysis of the whole to-do, from the days of St. Columba (whose claimed "sighting" in the shallow River Ness, not the deep Loch, is usually severely misrepresented) on up to submarines and sonars, by a veteran of Loch Ness searches. It is a model among such studies, but of course the bold title will not in the end be justified.

The author himself closes more persuasively: "The enigma is surely not yet over. There will be more dramatic snapshots, more amazing eye-witness testimony, maybe even a snatch of movie film of something dark and ambiguous.... After 50 years one conclusion can reasonably be drawn. There is no scientific evidence whatsoever of monsters in Loch Ness, and a handful of individuals will go on seeing them there."

Jorge Luis Borges, half-blind but farseeing, knew the real state of affairs: "There is something in the dragon's image that appeals to the human imagination. It is, so to speak, a necessary monster." What is this particular monster in the Loch? It is many things to many witnesses, from patent hoax to otter to boat wake to driftwood to cormorant, but mainly it is the undying will to believe.

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Stopping the Production of Fissile Materials for Weapons

A halt in producing the essential ingredients of nuclear weapons would be easy to verify. It could therefore contribute to tighter control over the amount of weaponry in the superpowers' arsenals

by Frank von Hippel, David H. Albright and Barbara G. Levi

Agreements on nuclear-arms control based, like SALT II, on verifiable counts of missiles and other vehicles for delivering nuclear weapons may soon be impossible to devise. The vulnerability of strategic weapons that has come with precision guidance has stimulated a trend toward small, mobile ballistic missiles, such as the proposed U.S. Midgetman, which may be exceptionally difficult to detect. Cruise missiles and many of the other new weapon systems have been designed to carry either conventional or nuclear explosives, impeding an accurate count of deliverable nuclear warheads.

Clearly a new approach is needed to complement the delivery-vehicle counting rules. We suggest a new look at one of the oldest proposals for restraining the growth of nuclear arsenals: an agreement to cut off any further production of the fissile materials that are necessary for the construction of nuclear weapons.

Every nuclear weapon contains at least a few kilograms of chain-reacting fissile material. Fission of about one kilogram of uranium 235 demolished Hiroshima. Nagasaki was leveled by the fission of one kilogram of plutonium 239 in another weapon. The development of thermonuclear, or "hydrogen," bombs in the early 1950's did not eliminate the need for fissile materials, because such weapons require a fission explosion to ignite the hydrogen fusion reaction.

Since fissile material is an essential ingredient in all nuclear weapons, a cutoff would place an ultimate limit on the number of weapons that could be produced. Proposals for a cutoff of production of fissile materials have therefore been on the international arms-control agenda virtually since the invention of nuclear weapons.

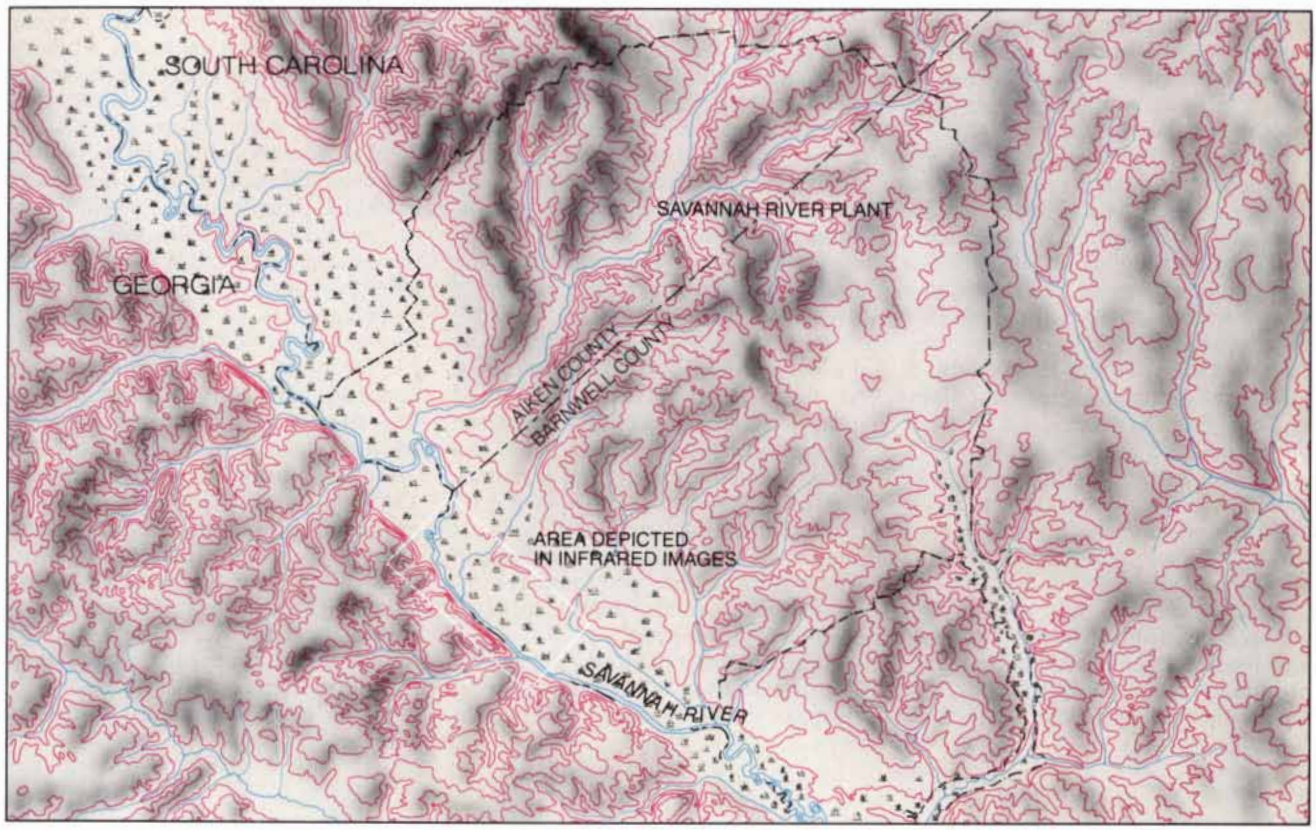
Between 1956 and 1969 a cutoff was repeatedly put forward by the U.S. as a separate arms-control proposal. The Soviet responses were not encouraging, perhaps because at that time the U.S.S.R. had considerably fewer nuclear warheads than the U.S. By the 1980's the two stockpiles were comparable, however, and in 1982 Soviet Foreign Minister Andrei Gromyko suggested that the "cessation of production of fissionable materials for manufacturing nuclear weapons" could be made one of the initial stages of a nuclear disarmament program.

A cutoff would be a natural part of any larger package of mutually reinforcing arms-control and disarmament proposals. For example, to be meaningful any agreement to freeze or reduce the number of warheads would have to contain assurances that new warheads were not being produced.

A cutoff would serve another purpose as well. Continued production of fissile materials for nuclear weapons by the superpowers is severely undermining their efforts to discourage comparable activities by other nations. In the 1950's and 1960's U.S. proposals for a cutoff were often linked to efforts to persuade nonnuclear states to support the Nonproliferation Treaty. That treaty came into force in 1970 and has since been signed by more than 100 states. That the U.S. and the U.S.S.R., the nations that devised the treaty, had not brought their arms race under control resulted in increasingly strong expressions of dissatisfaction with the treaty on the part of the nonnuclear states at the review conferences of 1975 and 1980. The issue can be expected to cause even greater difficulty at the third review conference, which will run from late August through mid-September of this year.

A superpower agreement to cut off the production of fissile materials for nuclear weapons would thus be in the interests of nonproliferation as well as superpower arms control. The purpose of this article is to provide some of the technical background required for a constructive public discussion about the feasibility of a cutoff.

Part of the basis for any such discussion is a description of the nature and availability of the fissile materials themselves. Uranium 235 is the only fissile isotope that exists naturally in more than trace quantities. It is not found in a form that can be used directly in manufacturing nuclear weapons, however. Only .7 percent of a typical sample of natural uranium is U-235. The other 99.3 percent is uranium 238, a heavier isotope that cannot sus-



THERMAL INFRARED IMAGES would help to ensure compliance with a ban on production of fissile materials for weapons. The images shown here reveal discharges of hot water from two U.S. plutonium-production reactors at Savannah River, S.C. In this false-color representation the streams of hot water are red and orange; the cooler background is rendered in blue and gray. The streams are about 100 meters wide until they flow into a swamp, where one spreads out into a delta 1,500 meters wide. These images were made from an airplane flying at an altitude of 1.2 kilometers. Similar images made from satellites could detect hidden reactors.

tain a chain reaction. To make a practical weapon the uranium must be enriched to contain at least 20 percent U-235. U.S. weapon-grade uranium contains more than 90 percent U-235.

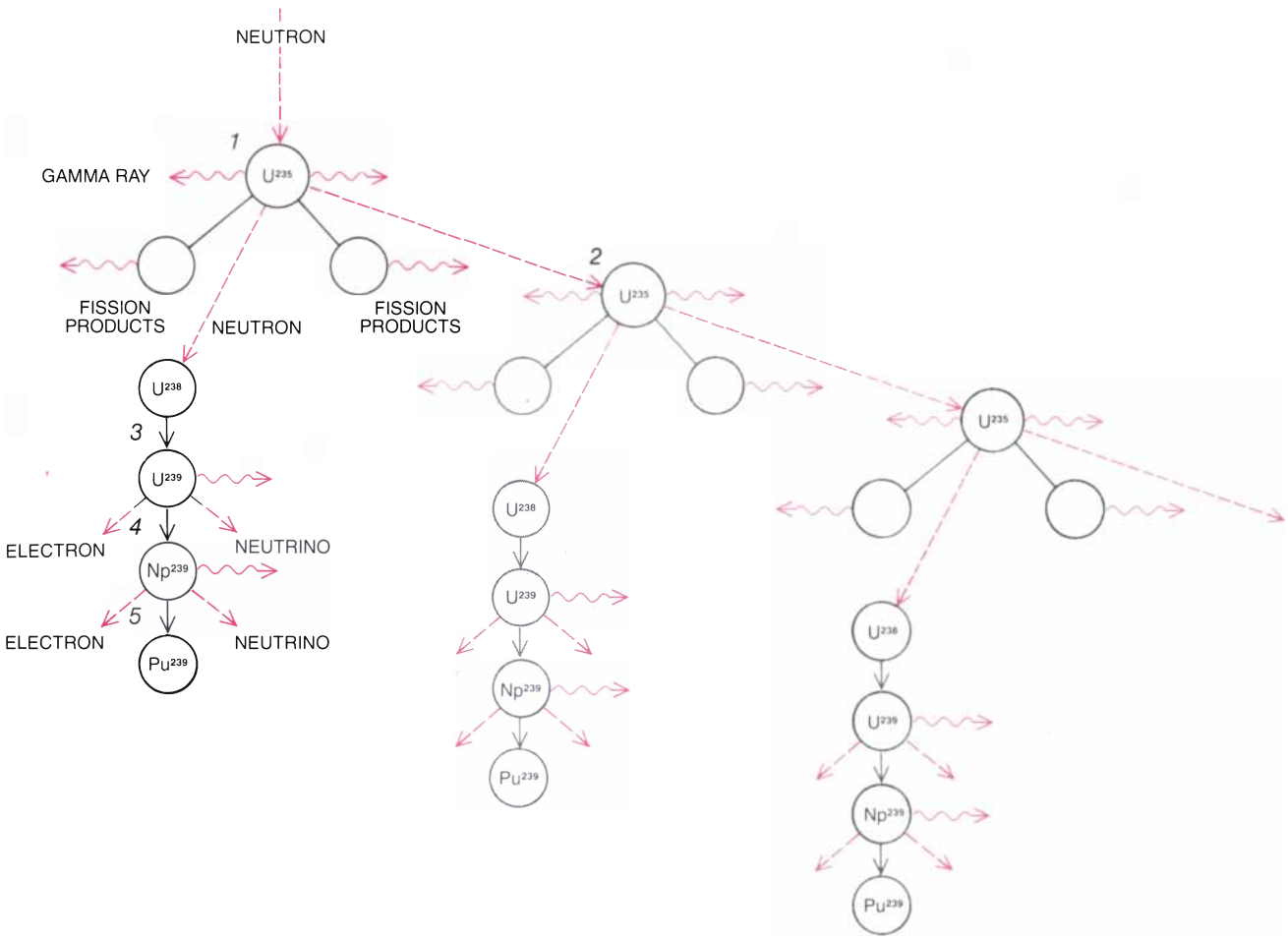
One technology through which this level of enrichment is achieved was developed early in the history of the U.S. nuclear-weapon program. Called gaseous diffusion, it involves diffusing uranium hexafluoride (a gaseous, uranium-carrying compound) through a succession of thousands of porous barriers. In the 1940's and 1950's the U.S. built three diffusion enrichment plants in Tennessee, Kentucky and Ohio. In the early 1960's, at the peak of U.S. production, these facilities produced about 80 tonnes (metric tons) of weapon-grade uranium each year—enough for the production of thousands of nuclear weapons.

By 1964 the U.S. had such a large supply of fissile material that President Lyndon B. Johnson decided to cut back production, explaining that "even in the absence of agreement we must not stockpile arms beyond our needs or seek an excess of military power that could be provocative as well as wasteful." Since then the U.S. uranium-enrichment complex has produced mainly the "low-enriched" uranium that is used as fuel in most nuclear-power reactors. Although highly enriched uranium has been produced for use in naval reactors, research reactors, some plutonium-production reactors and a few power reactors, the U.S. has added no highly enriched uranium to its nuclear-weapon stockpile since 1964. All the weapon-grade uranium used in new warheads has come from the stockpile produced before 1964 or has been recycled from retired weapons. Recently, however, because of the increased demands associated with its nuclear-weapon buildup, the Reagan Administration has proposed resuming the production of highly enriched uranium for weapons.

Another fissile isotope, plutonium 239, is also used in nuclear weapons. To make Pu-239, a sample of U-238 is bombarded with neutrons in a nuclear reactor [*see illustration below*]. Plutonium-production reactors are basically no different from nuclear-power reactors, except that they are operated to yield plutonium containing more than 93 percent of the isotope Pu-239. Such so-called weapon-grade plutonium is not the only grade from which weapons can be made, but it is more desirable than grades that contain higher percentages of heavier plutonium isotopes. Pu-239 is preferred over U-235 for modern, compact nuclear warheads because a much smaller quantity—only a few kilograms—is needed to produce a fission explosion.

During most of the period between 1955 and 1964 the U.S. had 13 reactors producing plutonium. Eight reactors were at the Hanford site, near Richland, Wash., and five were at the Savannah River site, near Aiken, S.C. Together they produced more than six tonnes of plutonium each year, enough for more than 1,000 warheads.

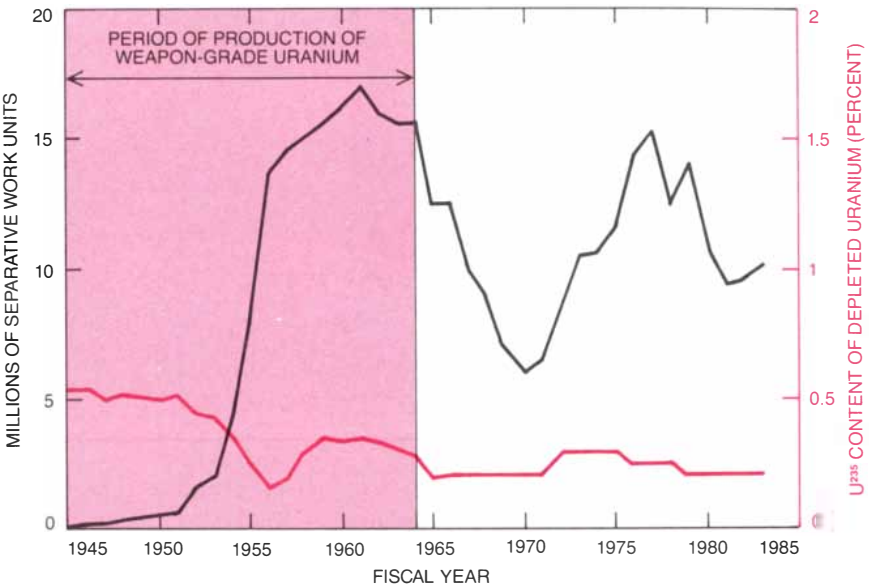
In the eight-year period following



FISSION CHAIN REACTION produces plutonium 239 from uranium 235. When an atom of U-235 is bombarded with a neutron (*1*), it yields intermediate-weight atoms, called fission products, and two or three additional neutrons. One neutron bombards another U-235 atom (*2*), sustaining the reaction. Another is absorbed by an atom of U-238, converting it into U-239 (*3*). The U-239 decays into neptunium 239 by emitting an electron and a neutrino (*4*). Pu-239 is created when the Np-239 emits an electron and a neutrino (*5*).

President Johnson's decision to cut back U.S. production all the Hanford reactors were shut down and two of the five production reactors at Savannah River were mothballed. The other three have remained in operation, along with a newer "dual purpose" reactor, completed in 1964 at Hanford, which generates electric power as well as producing plutonium.

Because of the Administration's plan to produce more than 10,000 new compact nuclear warheads, several projects have been initiated that would increase the rate at which the U.S. stockpile of weapon-grade plutonium grows. These projects include restarting one of the mothballed Savannah River reactors and converting into weapon-grade plutonium some of the 17 tons of fuel-grade and reactor-grade plutonium owned by the Department of Energy.



HISTORY OF U.S. URANIUM ENRICHMENT helps to provide an estimate of the amount of fissile material in the U.S. stockpile. Enrichment activity (*black*) is measured in "separative work units" (SWU's). The number of SWU's is roughly proportional to the amount of energy spent sorting U-235 from U-238. These figures, taken with the percentage of the "depleted uranium" (material left over after sorting out most of the U-235) that was U-235 (*color*), suggest the U.S. could have produced about 750 tonnes (metric tons) of highly enriched uranium before the 1964 cutoff of production. The increase in enrichment activity that began in the early 1970's was due not to production of highly enriched uranium for weapons but to increased production of low-enriched uranium for power plants.

How much fissile material is in the U.S. and U.S.S.R. stockpiles? Enough information is publicly available to allow reasonable estimates of the U.S. stockpile, but public information about the Soviet weapon-production complex is much sparser. It allows only a rough estimate of the size of their plutonium stockpile and yields no clues to the size of their stockpile of weapon-grade uranium.

According to the records of the Department of Energy, the U.S. has since 1944 bought approximately 250,000 tonnes of natural uranium, containing about 1,800 tonnes of U-235. The best way to estimate how much of this U-235 went into weapons is to examine the Government reports that list the annual amounts of "separative work," or enrichment, done in the U.S. uranium-enrichment complex and the associated percentages of U-235 that were left in the "depleted uranium" by-product of the enrichment process. We estimate using these data that the U.S. could have produced up to about 750 tonnes of highly enriched uranium for weapons prior to the 1964 cutoff of production. After estimating the non-weapon-related demands for uranium enrichment through 1964 and subsequent demands for highly enriched uranium, we conclude that there are still at least 500 tonnes of weapon-grade uranium remaining in the U.S. weapon stockpile. Thomas B. Cochran and Milton M. Hoenig of the Natural Resources Defense Council have reached a similar conclusion.

The amount of plutonium in the U.S. weapon stockpile can be estimated from data that have recently been released by the Department of Energy on the heat outputs of its plutonium-production reactors since 1951. Heat output is directly proportional to the amount of U-235 that has been fissioned in these reactors, which in turn is directly proportional to the quantity of plutonium they have produced. (Approximately .9 kilogram of plutonium is produced for each kilogram of U-235 that is fissioned.) On this basis we conclude that the U.S. weapon stockpile contains about 100 tonnes of plutonium. Once again Cochran and Hoenig have made a similar estimate.

Data relating to the amounts of plutonium and highly enriched uranium produced for weapons by the U.S.S.R. have not been made available by that government or by the U.S., but Soviet plutonium production can be gauged from the amount of radioactive krypton 85 that has accumulated in the atmosphere. This isotope, which is produced by fission, is released by facilities that reprocess nuclear fuel. Relatively small amounts are also released by tests of nuclear weapons and by leakage from reactor fuel. Because it is chemically unreactive, Kr-85 accumulates in the atmosphere, where its distribution is nearly uniform because of its long radioactive half-life (approximately 11 years).

Since about 1954 various groups of investigators throughout the world have made periodic measurements of the atmospheric concentration of Kr-85. The most comprehensive and accurate published measurements have been made by Wolfgang Weiss, Albert Sittkus, Helmut Stockburger and Hartmut Sartorius of the Max Plank Institute for Nuclear Physics in Freiberg. By estimating the amount of Kr-85 released in weapon tests worldwide and in fuel reprocessing outside the U.S.S.R. and then subtracting the amount from the total amount of Kr-85 released into the atmosphere, it is possible to estimate how much has been released into the atmosphere by the U.S.S.R. [*see illustration on page 45*]. By this method we estimate that through 1984 the U.S.S.R. had released about as much Kr-85 into the atmosphere as the U.S. If, as in the U.S., most of the Kr-85 was released in reprocessing fuel from reactors that produce plutonium, then the amounts of plutonium in the two countries' stockpiles, like their estimated numbers of nuclear warheads, are roughly comparable. The current rate of plutonium production in the U.S.S.R. appears to be considerably higher than that in the U.S., however.

Suppose the two superpowers agreed to cut off production of fissile materials for weapons. Could one country adequately verify that the other had not violated the agreement? For the purpose of this discussion we shall define adequate verification as the ability to detect within a few years any set of clandestine activities large enough to

increase one of the superpower stockpiles at a rate greater than 1 percent per year. This would be a significant restraint; it represents a rate of production about one-tenth as large as the peak production rates of the past. The strategic significance of smaller violations would be so minor that it is doubtful either superpower would consider the gains to be worth the risks of detection.

For example, taking our estimates of the U.S. stockpiles as a yardstick, a growth rate of 1 percent per year corresponds to production of about five tonnes of weapon-grade uranium or one tonne of plutonium. Undetected violations below this level would still provide the wherewithal to produce hundreds of warheads per year and would therefore be quite significant in absolute terms, but with respect to the existing stockpiles such violations would be insignificant.

The problem of verifying a cutoff can be divided into two subsidiary problems. The first is ensuring that significant quantities of fissile material are not diverted to weapons from legitimate activities; the second is ensuring that there are no significant clandestine production facilities.

The U.S. has always assumed that a cutoff agreement would include a system of on-site inspections of facilities that process fissile materials for purposes other than weapon production, in order to ensure that no significant amounts of material were being diverted. Since about 1965 official U.S. statements have suggested that the inspection could be assigned to the International Atomic Energy Agency (IAEA), which would use techniques similar to those it employs in safeguarding fissile materials in states that have signed the Nonproliferation Treaty and have committed themselves to not building nuclear weapons.

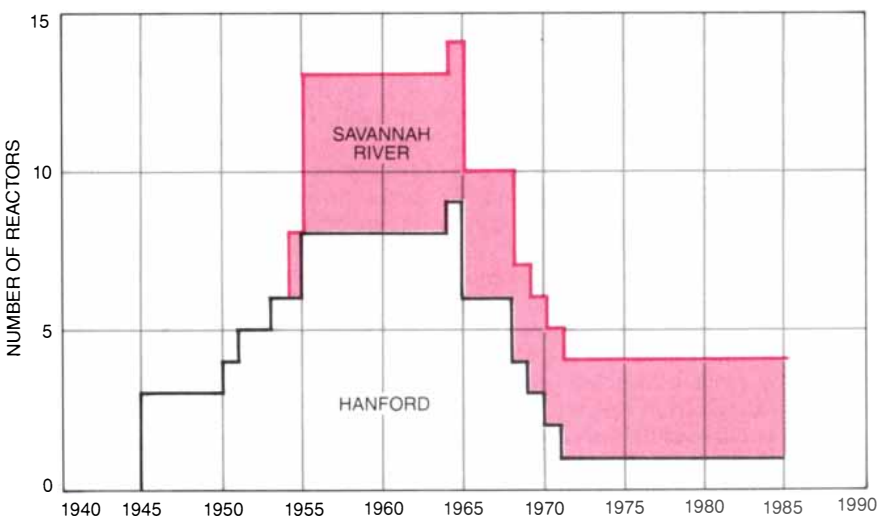
Indeed, as part of its campaign for the Nonproliferation Treaty the U.S. offered to put all its own nuclear facilities except those "with direct national security significance" under IAEA safeguards. An agreement between the U.S. and the IAEA making it possible to implement the offer went into effect in 1980. The Soviet Union made no similar move until 1982, when Gromyko announced that the U.S.S.R. would be willing to place some of its peaceful nuclear installations under the control of the IAEA. A very limited initial agreement was concluded this March, under which the IAEA will be able to safeguard one of the two main classes of Soviet power reactors. Unfortunately, however, the class of reactors that was offered for safeguarding is not the one that could most easily be operated as dual-purpose reactors (like the Hanford reactor that produces both power and weapon-grade plutonium).

The IAEA safeguards are hundreds of times more stringent than those that would be required to verify a superpower cutoff agreement: they are designed to detect within days or months the diversion of enough material to make a single nuclear weapon. The IAEA has specified that the diversion of only eight kilograms of plutonium or 25 kilograms of weapon-grade uranium is significant. Because the nuclear arsenals of the superpowers are already huge, diversions of nuclear material would have to be 1,000 times larger than that to have any potential strategic significance. There is little doubt that the diversion of much less material could be detected. The IAEA safeguards should be able to detect diversions of less than 1 percent of the fissile material flowing through a nation's nuclear-reactor fuel system. In comparison, 5 percent of the flow through the U.S. nuclear-power system or 15 percent of that through the smaller Soviet system would have to be diverted before the diversion amounted to five tonnes of U-235 or one tonne of plutonium per year.

The task of the IAEA safeguards is to confirm, within a specified accuracy, that any fissile material delivered to or produced at a facility is either still there, has been fissioned or has been delivered to another safeguarded location. In this respect the problem of safeguards is similar to the problem of currency safeguards that challenges a bank inspector. Visiting IAEA inspectors periodically check the consistency between actual and reported inventories. Measurements of radiation are used along with other nondestructive measurements on randomly selected nuclear-fuel assemblies to check that there has been no substitution of "counterfeit" fuel.

Where fissile material is in inactive storage the IAEA simplifies its task by applying tamperproof seals to the containers and storage vaults involved so that their contents need not be checked on each visit. Storage areas that cannot be sealed are monitored for suspicious activities by tamperproof cameras. Systems have been developed that make it possible, if necessary, to monitor the pictures being collected by such cameras remotely in real time.

The fuel cycle that is currently most common in U.S. and U.S.S.R. power reactors involves the use of low-enriched uranium in fresh fuel and no recovery of plutonium from spent fuel. In such a fuel cycle there is an additional major barrier to the diversion of fissile material to weapons. Even if enough fissile material could be diverted, a major additional clandestine operation would be necessary to convert it into a form usable for nuclear weapons: fresh reactor fuel would need enrichment to higher levels and spent fuel would need reprocessing to separate plutonium from the highly radioactive fission products. These barriers to diversion will exist as long as the superpowers refrain from shifting their nuclear-power systems to fuel cycles involving the use of



NUMBER OF U.S. PLUTONIUM-PRODUCING REACTORS increased steadily until the mid-1960's. Three reactors at Hanford, Wash., produced the plutonium for the bomb dropped on Nagasaki. Two more were under construction there when the U.S.S.R. tested its first nuclear weapon in 1949. Construction of three more reactors at Hanford and five at Savannah River was approved soon afterward. In 1964 a "dual purpose" reactor, which produces both electric power and plutonium, was completed at Hanford. In that year President Johnson decided to cut back U.S. production of fissile materials for nuclear weapons.

plutonium or highly enriched uranium in the fresh fuel.

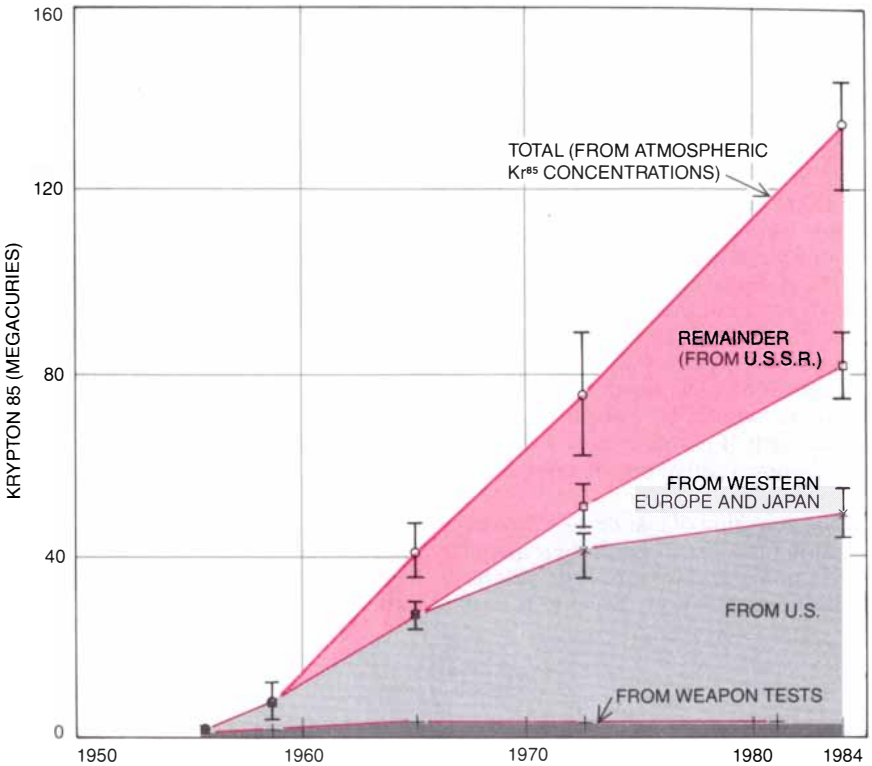
Under a cutoff U-235 would still be used as fuel not only in nuclear-power reactors but also in naval-propulsion reactors. The U.S. and the U.S.S.R. each have more than 100 ships propelled by nuclear reactors. U.S. naval reactors are fueled by weapon-grade uranium and are currently supplied with about five tonnes of U-235 per year. Since the total estimated shaft horsepower of the Soviet nuclear navy is about the same as that of the U.S., and since Soviet ships are at sea a much smaller percentage of the time, it is likely the Soviet navy's demand for U-235 is smaller.

Neither navy is likely to allow international inspectors in its ships or in the facilities that produce fuel for naval reactors. One possible arrangement would be for the superpowers to agree on the amount of U-235 each would be allowed to produce for use in its naval reactors. Under this arrangement the U-235 would be produced entirely at safeguarded plants and an equivalent amount of irradiated enriched uranium would have to be turned in at another safeguarded facility within a certain period of time. These measures would prevent the cumulative diversion of significant quantities of naval U-235 for use in weapons.

The U.S. has about as many research reactors as it has naval power reactors, but their total demand for U-235 is about one-tenth as large. We have no reason to think the corresponding demand in the Soviet Union is much larger. This is a small flow of material (about half a tonne per year) compared with the amount that constitutes a significant violation. In any case, the IAEA has developed thorough safeguards to detect diversions from research reactors.

The final class of reactors whose fuel cycles must be safeguarded are tritium-production reactors. Tritium provides the neutrons that initiate the fission chain reaction and "boost" the fission efficiencies in U.S. nuclear weapons. It is also the source of most of the neutrons produced by the "neutron bomb." Tritium is produced by allowing lithium 6 to absorb neutrons in the same type of reactor that produces plutonium when U-238 is made to absorb neutrons.

Because of its 12-year radioactive half-life, tritium must be replenished even if stockpiles are frozen. This would not call for a very large-scale effort, however. An amount of tritium equal to that in the U.S. stockpile could probably be maintained by a reactor with the capacity of one of the Savannah River reactors. Such a reactor, like any other, could be safeguarded against clandestine production of fissile materials for weapons.



ATMOSPHERIC KRYPTON 85 gives an indication of the size of the U.S.S.R. plutonium stockpile. This isotope is released primarily by nuclear-fuel reprocessing facilities and remains in the atmosphere because it is chemically unreactive. The upper curve, which is based on historical measurements of atmospheric Kr-85 (corrected for radioactive decay), shows the total amount of Kr-85 released to the atmosphere worldwide. The lower curves give the authors' estimates of the contributions to this total originating in weapon tests worldwide and in reprocessing facilities outside the U.S.S.R. The remainder (*color*) represents an estimate of the amount of Kr-85 released by reprocessing facilities inside the U.S.S.R. It is comparable to the amount released by those in the U.S. Most releases from the U.S. and the U.S.S.R. were probably from facilities producing plutonium for weapons, suggesting that the superpowers' stockpiles of weapon plutonium are also comparable.

If legitimate reactors and their fuel cycles can be safeguarded against significant diversion of materials to nuclear weapons, what are the prospects of one side's successfully constructing a clandestine production facility? Under early U.S. proposals for a cutoff of production of fissile materials, each superpower would have deployed roving teams of inspectors to search the other's territory. That approach was unacceptable to the Soviet Union. It was therefore highly significant when, in 1969, the U.S. completely dropped the demand. What brought about such a major change in position?

Part of the answer is that surveillance satellites had given the U.S. Government confidence that it could detect large-scale clandestine production from space. Routine surveillance of the Soviet Union by satellites began in 1961, and by 1969 it had become possible to subject the exterior of every structure on the earth's surface to detailed inspection.

Today indications of the energy intensity of hidden activities can be obtained as well, by telescopes that are sensitive to the infrared radiation emitted by warm surfaces. When the data from such satellite surveillance are analyzed in combination with information culled from internal reports, from intercepted radio and microwave transmission and from interviews with émigrés, the integrated product is stunning. This has been demonstrated convincingly in the Department of Defense's annual publication on Soviet military power.

It is unlikely that either superpower could conceal from such scrutiny the existence of a program large enough to produce one tonne of plutonium or five tonnes of highly enriched uranium per year. There would be many opportunities to discover such a program. For example, the construction of plutonium-producing reactors and their associated fuel-reprocessing fa-

cilities would be the equivalent of multibillion-dollar enterprises. In view of the many thousands of workers who would be involved, it would be extremely difficult to conceal the nature of an effort on this scale.

A great deal of uranium, roughly 1,000 tonnes of natural uranium, would be needed as well. Although this is not a physically large amount of material, it does correspond to a significant fraction of the projected uranium flow in either of the superpowers' nuclear-power systems. It is likely that the diversion of so much newly mined uranium would be difficult to hide, particularly if uranium mills were subject to some level of on-site safeguards.

The detection of clandestine production facilities through their associated mining and milling activities has limitations, however, because a clandestine production program could be supplied for years with uranium from a previously established stockpile. The U.S. has built up a stockpile of hundreds of tonnes of U-235 in depleted, natural and low-enriched uranium. Similar stockpiles probably exist in the U.S.S.R. It is all too easy to imagine that a stockpile of uranium containing up to perhaps 100 tonnes of U-235 could be hidden before a cutoff agreement went into effect.

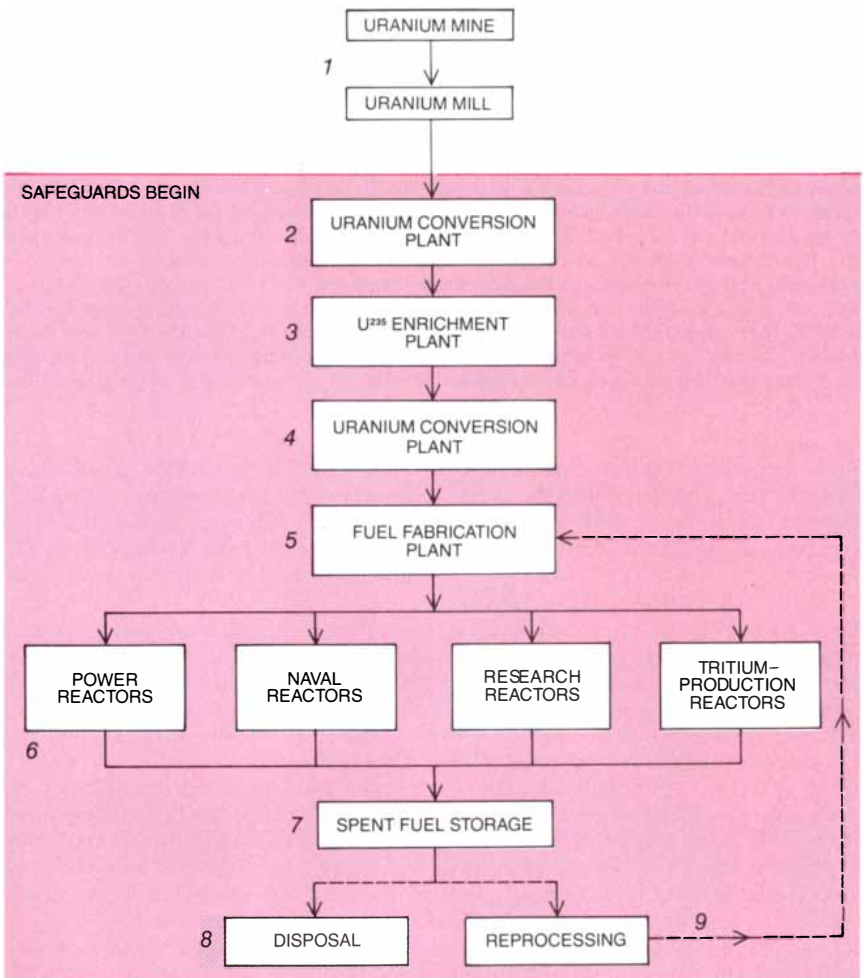
Another way to detect clandestine production plants would be to search for emissions characteristic of their operation. The best example of such an emission is the enormous amount of heat generated by plutonium-production reactors. A set of clandestine reactors capable of producing one tonne of plutonium per year would have an average output of about three million kilowatts of waste heat. Such an amount is about equal to the heat generated by a U.S. city of 300,000 people. It would be hard to dispose of so much heat without detection—sensors exist that can detect from space the presence or absence of ceiling insulation in a single-family house.

The illustration on page 41 shows a thermal infrared image, made from an airplane, of the outflow of hot water from the Savannah River production reactors, each of which has an average heat output of about 1.5 million kilowatts each. Similar images could be obtained at satellite altitudes. Although attempts could be made to reduce the thermal infrared emissions from hot water by, for example, thoroughly mixing it into a large river, the concealment problem would be acute, and the efforts at concealment themselves would provide clues to the nature of the enterprise.

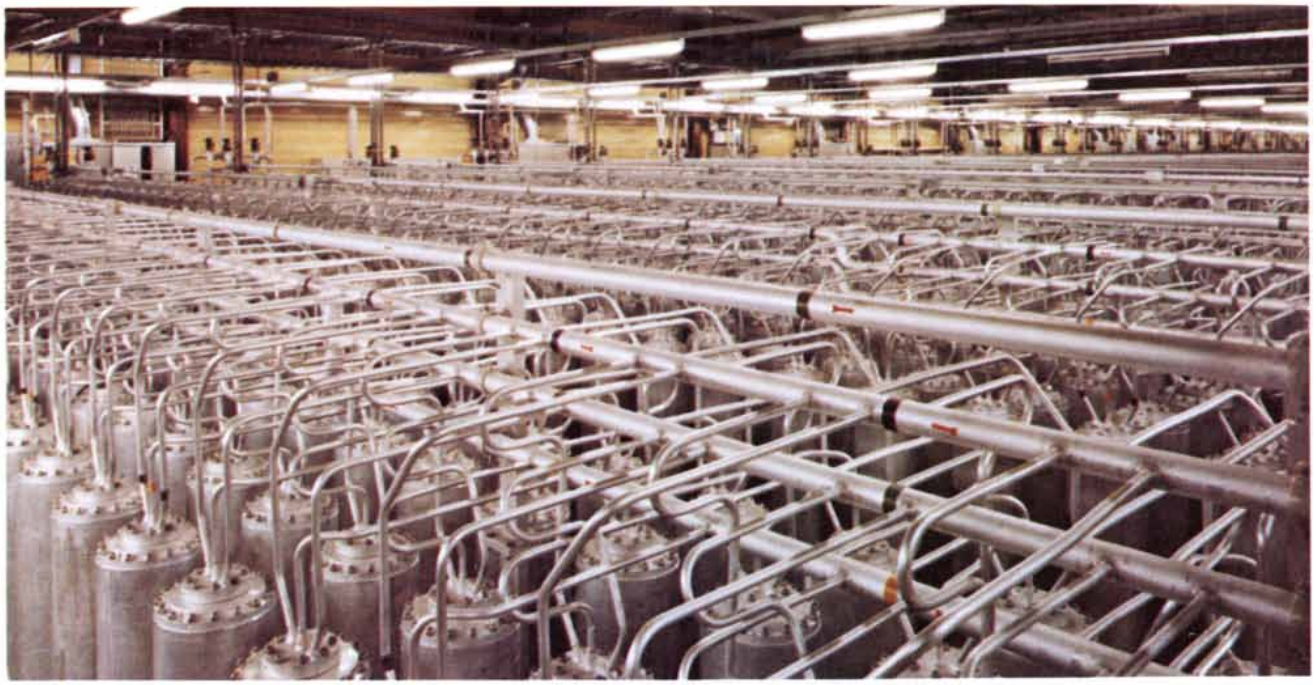
The least conspicuous facilities that are currently able to produce weapon-grade fissile materials are probably the so-called centrifuge enrichment plants. This technology, which is just coming into commercial use, involves spinning cylinders of uranium-carrying gas in centrifuges. Considerably fewer stages are needed in order to reach a given level of enrichment in a centrifuge plant than in a diffusion plant. In addition centrifuge plants are smaller and consume less energy. The appearance of gas-centrifuge plants is much less distinctive than that of diffusion plants, and it might not be possible to identify them from satellite photographs alone. The larger intelligence effort would probably be able to identify them, however, by picking up indications of the enormous effort required to manufacture and install the great number of centrifuges needed to produce five tonnes of highly enriched uranium per year [*see illustration on opposite page*].

The Department of Energy recently announced that its future uranium-enrichment facilities would employ a new technique called laser isotope separation. This technology exploits the fact that the atomic energy levels of U-235 and U-238 electrons are slightly different because of the difference in the masses of the atoms' nuclei. To separate the isotopes a set of lasers are tuned to produce energy that can be absorbed by U-235 atoms (each of which loses an electron in the process) but not by U-238. An electric field then separates the charged U-235 ions from the uncharged U-238 atoms.

An enrichment plant based on laser isotope separation would be smaller than a centrifuge plant; it would therefore be even more difficult to identify



ACTIVITIES TO BE SAFEGUARDED to ensure compliance with a cutoff begin when uranium leaves the mill where uranium oxide is extracted from raw uranium ore (*1*). At a conversion plant (*2*) the uranium oxide is converted into a gas (uranium fluoride) so that it can be enriched (*3*). Then it is converted back into an oxide or a metal (*4*) and fabricated into reactor fuel (*5*). After it has been used (*6*) the spent fuel is stored at the reactor site (*7*). From there it can be shipped to a radioactive-waste depository (*8*) or to a reprocessing plant (*9*), where any fissile uranium and plutonium it contains can be recovered and recycled.



CENTRIFUGE ENRICHMENT PLANT enriches uranium by passing it through a "cascade" of centrifuges. Each of the centrifuges shown (*cylinders*) is roughly the height of a person. This is the least conspicuous type of uranium-enrichment facility now in commercial use. It is smaller and consumes less energy than a diffusion enrichment plant and requires considerably fewer stages of enrichment; it also has a much less distinctive appearance. Nevertheless, construction of a clandestine centrifuge enrichment plant could probably be detected by a thorough intelligence effort. To produce five tonnes of weapon-grade uranium each year (the quantity defined by the authors as representing a significant violation of a cutoff agreement) would require approximately 100,000 centrifuges.

from satellite photographs. Nevertheless, a laser enrichment plant capable of producing five tonnes of weapon-grade uranium per year would still cost the equivalent of hundreds of millions of dollars to construct and would incorporate unusual, high-powered, rapidly pulsed lasers. These features and others would facilitate the detection of such a plant by the larger intelligence effort.

Although each of the means of detection we have discussed could in theory be eluded, the clandestine production of fissile materials would require that the construction and operation of all major facilities involved be concealed successfully for a period of several years. The detection of one suspicious facility by any of the available means of surveillance and intelligence would threaten the entire enterprise.

Ambiguous evidence of clandestine production activities could be brought to a body organized along the lines of the Standing Consultative Commission, which was originally established to discuss questions concerning compliance with the 1972 SALT I treaty. In the absence of satisfactory explanations on-site inspections could be requested, as was agreed by the U.S., the U.S.S.R. and the U.K. in the case of underground nuclear tests, before the suspension of negotiations of a Comprehensive Nuclear Test Ban Treaty in 1980. Systematic obstruction of efforts to obtain answers to legitimate queries would, of course, bring into question the continuation of the cutoff agreement.

The reward for successful concealment of a clandestine production program would hardly be spectacular; it would be a small increase in the size of a stockpile of fissile material that is already unnecessarily large.

If the superpowers are able to reach an agreement banning further production of fissile materials for nuclear weapons, it will be natural to try to extend the ban to include the other states with nuclear-weapon capability and to persuade those states without nuclear-weapon capability who have not signed the Nonproliferation Treaty to do so. A verifiable production cutoff would also lay the basis for verifiable reductions in the quantities of fissile materials already in the arsenals of the nuclear-weapon states.

The obvious way to dispose of fissile materials would be to "burn" them in existing nuclear-power reactors. The weapon-grade uranium would be useless for nuclear weapons after it was diluted with depleted or natural uranium down to the level used in power-reactor fuel. The stockpiles of weapon-grade plutonium would have to be disposed of with greater care, since there is no natural isotopic denaturant for plutonium. One method would be to use the plutonium as fuel in a relatively few heavily safeguarded reactors operated in a "once through" mode (that is, without reprocessing the fuel). Ten large reactors could in this way dispose of all the plutonium currently in U.S. or Soviet weapons in a decade.

Since the superpowers can probably estimate each other's stockpiles of fissile materials reasonably well, there is no obvious reason they could not, on the basis of these estimates, negotiate reductions of 50 percent or so in their weapon stockpiles. When stockpiles had been reduced, small violations would be more important, and so a greater exchange of information and more refined analyses would be necessary in order to lay the basis for further reduction agreements.

There is no reason, however, to delay the actions that could be taken immediately. If the superpowers are willing to accept inspections and other safeguards on their nuclear activities that are not related to weapons, both a cutoff in production of fissile material for nuclear weapons and substantial reductions in the quantities of fissile materials already in the stockpiles could be satisfactorily verified.

Helioseismology

Acoustic waves within the sun are visible as oscillations on the solar surface. Their pattern and period hold clues to structure, composition and dynamics in the sun's interior

by John W. Leibacher, Robert W. Noyes, Juri Toomre and Roger K. Ulrich

Study of the sun, the nearest star, is crucial to an understanding of stellar interiors. Yet the visible surface of the sun, the photosphere, is a layer only a few hundred kilometers thick, occupying less than a thousandth of the solar radius. The photosphere offers only a few indirect clues to the sun's structure and dynamics. The motion of sunspots shows that the sun rotates about once a month but that rotation is faster at the equator than it is at the poles. A ricelike pattern known as granulation changes minute by minute, indicating vigorous turbulence in the gases immediately below; a subtle larger-scale pattern known as supergranulation reveals circulation patterns thought to be tens of thousands of kilometers deep. The surface also displays magnetic fields that vary in a complex way with the 11-year solar activity cycle.

Such phenomena are the surface expressions of processes taking place in the interior regions of the sun: in the core, where thermonuclear fusion generates the sun's energy; in the radiative zone, where energy diffuses slowly outward by means of atomic absorption and emission, and in the convection zone (which is thought to occupy the outer 30 percent of the sun's radius while constituting only about 1 percent of its mass), where rising and falling eddies of gas carry energy out to the photosphere. Yet because these regions cannot be viewed directly, most of what is known about the sun's interior and that of other stars is inference.

Now a new tool, helioseismology, is making it possible to penetrate the opaque brilliance of the solar surface. Continuous wave motions that are somewhat like seismic waves in the earth agitate the interior of the sun. In much the same way as geophysicists study seismic waves to learn about conditions within the earth, solar physicists are exploiting oscillations observed on the sun to probe its interior.

Two kinds of seismic waves penetrate the earth: shear and pressure waves. In shear waves the material is displaced from side to side perpendicular to the direction of travel; shear waves can be sustained only in a solid and so are not seen in the gaseous sun. In acoustic, or pressure, waves the medium is alternately compressed and dilated along the direction of travel; such waves can pass through the solar interior. In a gaseous medium such as the sun or the atmosphere of the earth a third variety, internal gravity waves, can also propagate. So far, however, acoustic waves in the sun have been the major focus of study. The speed and direction of their propagation depend on temperature, composition and motions within the sun. They therefore give a sensitive indication of conditions in the solar interior.

Acoustic waves cannot be traced directly as they follow paths that take them deep into the sun. Their effects at the solar surface are evident, however, in spectrograms of the solar disk and in measurements of surface brightness. On reaching the surface the waves cause the gases there to move up and down, resulting in changes in the wavelengths of spectral lines in the emitted light; the waves also alternately compress and rarefy the surface gases, changing their temperature and therefore their brightness. The sun's seismic activity proceeds at an extremely low level, and so the associated wavelength and brightness fluctuations are small. Nevertheless, a rich spectrum of waves has been detected. Their analysis makes it possible to study the internal structure and dynamics of a star from direct observations.

Until the advent of helioseismology stellar structure theory was the major route to an understanding of the interior of the sun and other stars. The theory gives rise to numerical models of stellar interiors based on equations that describe the physical processes within a star. To arrive at a description of the current state of the sun one begins with a hypothetical zero-age star having a specified chemical composition. The model star is then evolved mathematically to the current age of the sun, 4.8 billion years, in order to recreate the changes in radius and luminosity that take place as thermonuclear reactions convert hydrogen into helium in the stellar core.

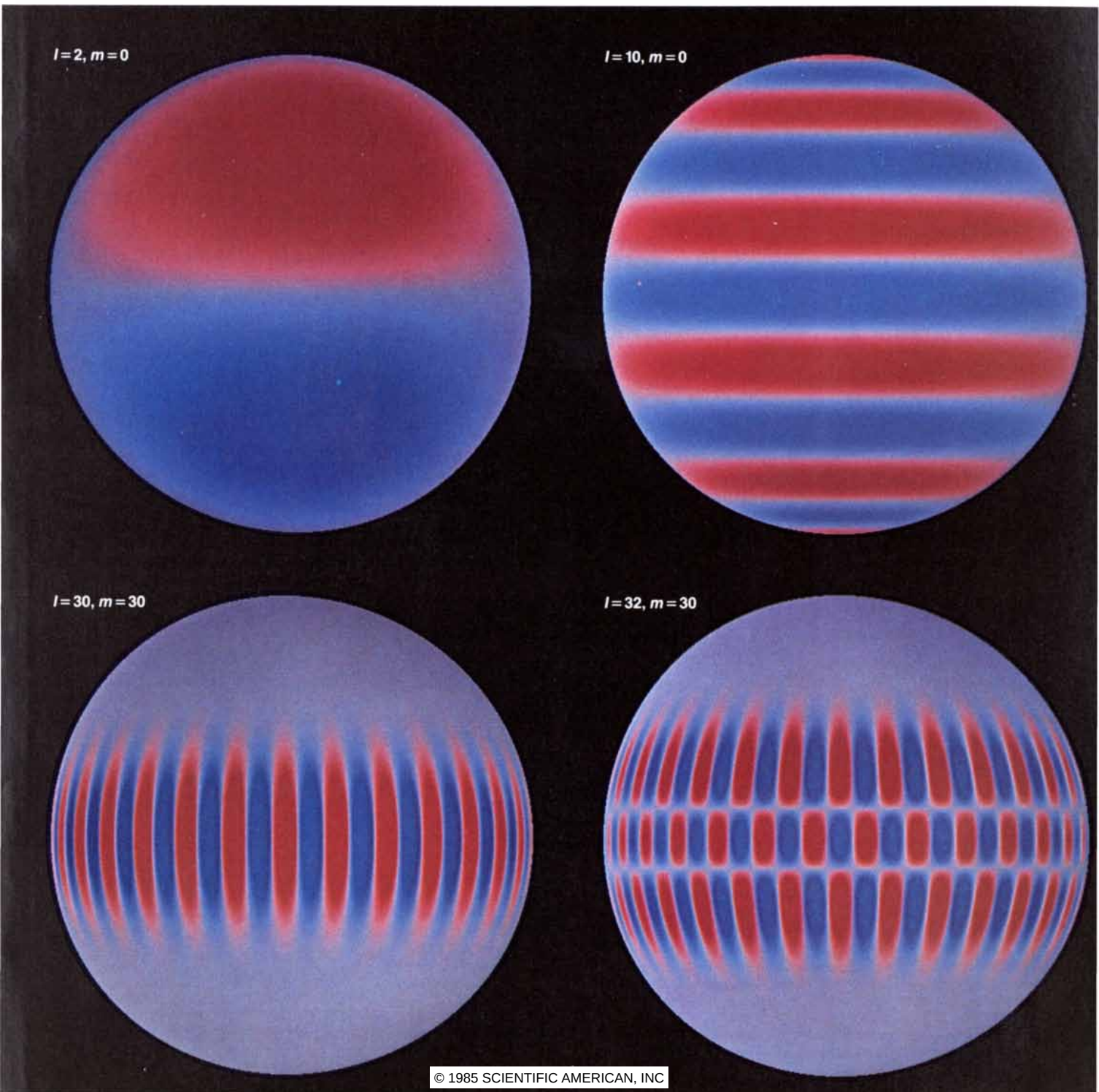
Neither the helium abundance in the newly formed sun nor the efficiency of convective energy transport in its outer layers is well known. Both quantities can therefore be adjusted in order to arrive at a model that agrees with the current luminosity, mass, radius and age of the sun. Such a model, often called a standard solar model, has an initial composition of about 73 percent hydrogen and 25 percent helium by mass—proportions that are in accord with the amount of helium thought

OSCILLATIONS OF THE SUN'S SURFACE are the result of sound waves resonating in its interior; here four of the 10 million resonances that occur in the sun are modeled by computer. Surface regions that are approaching the observer are colored blue; regions that are receding are colored red. In actual observation such surface displacements are evident as Doppler shifts in the wavelengths of light absorbed by the moving gases and as variations in brightness. The spatial pattern and the period of a surface oscillation enable investigators to deduce the three-dimensional structure of the resonance and to infer properties of the solar interior. For each oscillation the degree (l) and the azimuthal order (m) are given. Degree describes the pattern in terms of its total number of nodes (circles along which the surface of the sphere is motionless, seen here as bands of gray between the zones of color); azimuthal order is an indication of the number of nodes that intersect the solar equator.

to have been formed in the big bang. The standard model yields predictions about the pressure, temperature, density and chemical composition at various depths in the solar interior. Helioseismology offers a way to test those predictions by comparing the observed characteristics of solar acoustic waves with those calculated for the model.

By pointing to necessary revisions in the standard solar model, helioseismology may enable solar physicists to surmount a major stumbling block of solar theory: the solar-neutrino problem. It was once thought that the task of modeling an ordinary "main sequence" star such as the sun had been completed, except in some details. For the past 15 years, however, concern has been growing that there may be something wrong in the theory of stellar interiors. The doubts stem from a study by Raymond Davis, Jr., and his colleagues at the Brookhaven National Laboratory of the flux of solar neutrinos: subatomic particles, probably massless and very difficult to detect, that emanate from the thermonuclear reactions in the sun's core. Davis and his co-workers observed the neutrino flux to be only about a third of what is predicted by the standard solar model.

Many modifications of the standard model have been proposed to account for the low flux, but none has decisively solved the problem. Neutrino production decreases drastically as temperature falls, and so a number of workers have proposed ways in which the sun's core temperature could be slightly lower without also lowering the sun's overall rate of energy produc-



tion or changing its radius. If the core contained more hydrogen and less helium, for example, it could generate enough internal pressure at a lower temperature to maintain the observed radius of the sun. Some theorists suggest that the helium abundance in the newly formed sun was less than has been assumed. Others propose that episodes of mixing bring in fresh hydrogen from the outer envelope, diluting the helium built up by nuclear reactions in the core.

Another line of reasoning holds that if the interior of the sun had a very high rotation rate or an extremely strong magnetic field, centrifugal force or magnetic pressure could substitute for high temperature in maintaining the sun's observed radius. A final proposal is that the problem rests not with solar structure theory at all but with particle physics. If, contrary to what is now thought to be likely, neutrinos do have mass, then a solar neutrino of the kind that neutrino experiments are designed to detect could spontaneously change into either of two other kinds before reaching the earth; if the neutrino mass were large enough, the distribution reaching the earth would be divided evenly among the three types and an emitted neutrino would have two chances out of three of going undetected. This solution to the solar-neutrino problem neatly resolves the threefold discrepancy between observation and theory. Helioseismology, by providing a picture of the solar interior that is independent of theoretical models, should make it possible to determine which, if any, of the proposed solutions is correct.

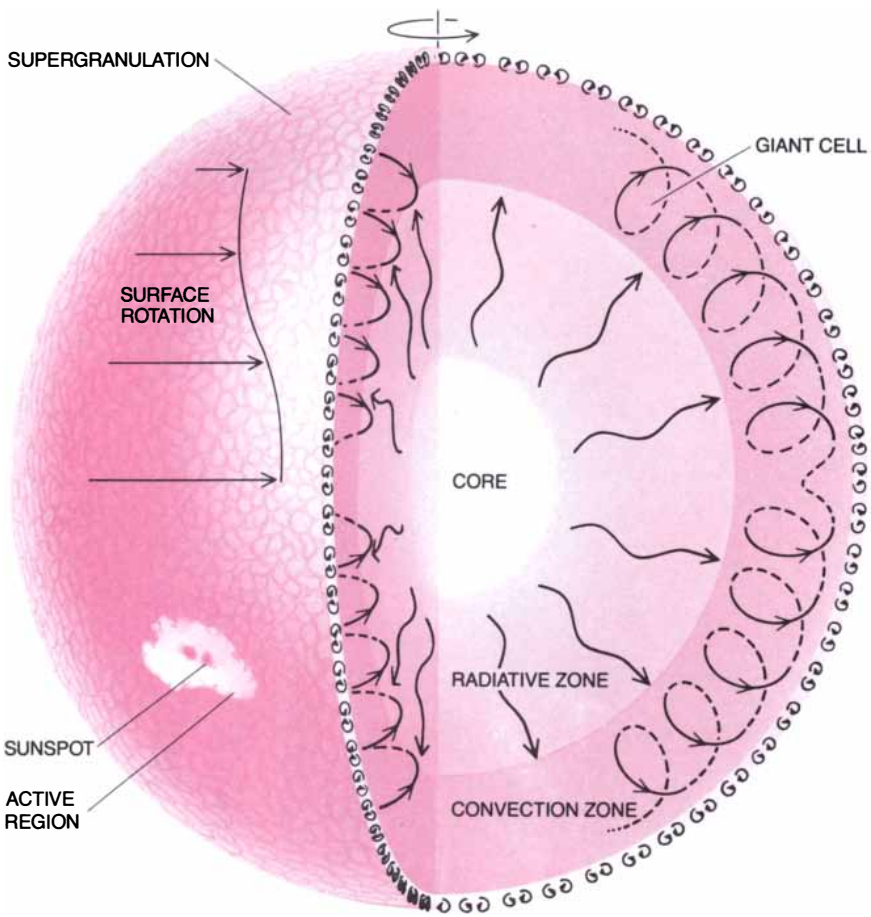
The study of solar oscillations began in 1960 at the California Institute of Technology, when Robert B. Leighton, one of us (Noyes) and George W. Simon set out to study the velocity patterns of gases at the surface of the sun. Their method was to measure Doppler shifts (changes in the wavelength of radiation or sound that occur when the source is moving toward or away from the observer) in solar absorption lines. These are the dark lines in the solar spectrum that occur at the wavelengths at which elements in the outer layer of the sun absorb radiation emitted by the hotter gases below. A decrease, or blue shift, in the wavelength of absorption lines from a particular part of the sun's disk means that region is moving toward the observer; an increase, or red shift, means it is receding.

The workers thought that the velocity pattern derived from the Doppler shifts would be chaotic in character, in keeping with the chaotic changes in brightness of the solar granulation. To their surprise they found the velocities were mainly oscillatory: at a given site the gases rose and sank over a period of about five minutes. The oscillations were not continuous but grew and died away in wave packets lasting for perhaps half an hour.

For a time it was thought the wave packets were a short-lived response of the solar atmosphere to random buffeting by the underlying convection. In 1970, however, the real explanation for the five-minute oscillations began to emerge. Ulrich and, independently, Leibacher and Robert F. Stein, who is now at Michigan State University, deduced from theoretical models of the sun that its interior could act as an acoustic cavity. Sound waves excited in the solar interior, they proposed, could be trapped there.

Ordinary acoustic cavities, such as an organ pipe or a kettledrum, are regions of space bounded by walls that trap acoustic waves by reflecting them repeatedly. The interior of the sun, which lacks physical walls, nonetheless has gradients of density and temperature that can reflect or refract acoustic waves.

The upper reflection point in the solar acoustic cavity lies just below the visible solar surface, where the density decreases sharply with height. A sound wave that is reflected into the interior at this outer barrier reaches a lower limit that is the result of increasing temperature. The temperature gradient causes the speed of sound to increase with depth. Consequently the deeper part of a wave front propagating obliquely into the sun overtakes the shallower part. Gradually the advancing wave front is refracted, or curves, until the wave is once again headed toward the sun's surface; a wave that is trapped thus traces a



INTERIOR OF THE SUN is known largely by conjecture. Energy is generated by thermonuclear fusion in the core and diffuses outward through the radiative zone by atomic emission and absorption. In the convection zone circulation is the main transport mechanism: hot gases rise and cooler gases sink. Such convection is observed at the surface as small-scale granulation (not shown) and supergranulation in the form of cells about 30,000 kilometers across. Below the supergranulation cells the deep convective zone is thought to contain very large convective rolls known as giant cells. The interaction of convection with the sun's rotation causes the rotation rate to vary with latitude at the surface (*arrows*) and with depth. The differential rotation in turn interacts with the motions of the electrically conducting gases to generate the sun's magnetic field, two manifestations of which are sunspots and active regions. Helioseismology promises to refine this picture of the solar interior.

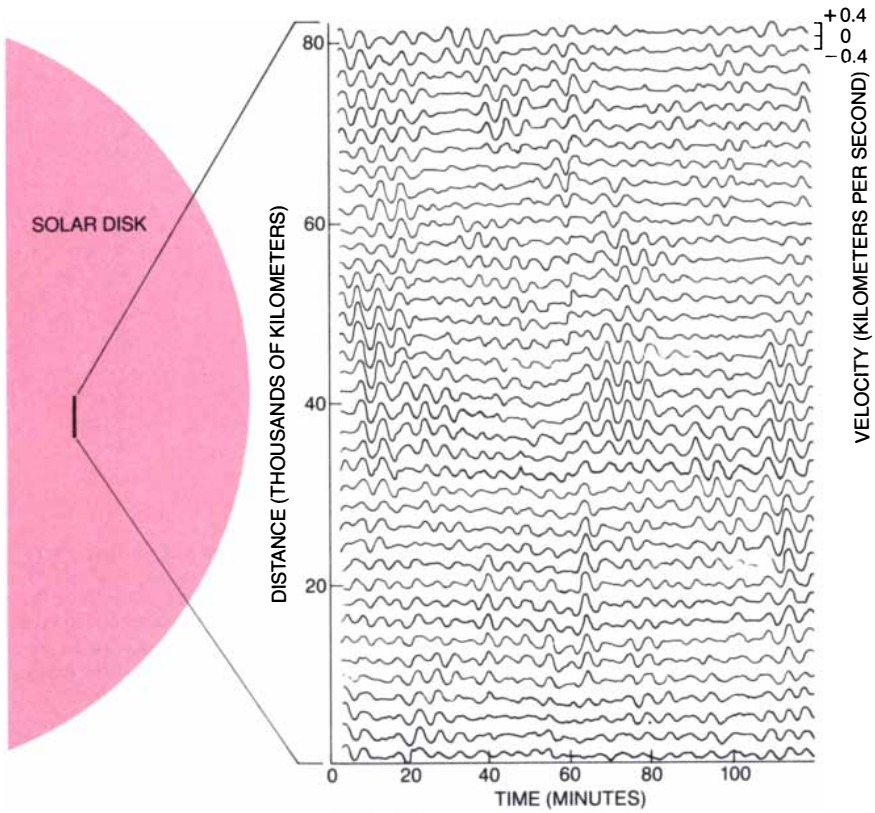
series of arcs below the solar surface.

The bottom of the arcs, where the wave is traveling horizontally, marks the lower boundary of the wave cavity. There the ratio of the wave's horizontal wavelength (the distance between successive wave fronts, measured horizontally) to its period (a quantity known as its horizontal phase speed) will equal the local sound speed. Thus the depth of the cavity differs for waves with different horizontal wavelengths or periods. At the upper boundary of the cavity, just below the solar surface, the waves produce visible oscillations that reveal both their period and their horizontal wavelength. From those quantities the sound speed at the base of the cavity can be inferred.

How might acoustic waves be excited in the sun? It is likely that they result from vigorous turbulence in the convection zone, which could drive and damp them at random. Another possibility is that they are driven by the radiative flow of energy within the sun: alternating compressions and rarefactions of the solar gases could cause the flow of energy to become dammed up in a way that would channel energy into a wave.

The characteristics of acoustic cavities made it possible to confirm that the oscillations detected on the sun's surface represent trapped acoustic waves. When a wave of a particular period is confined in an acoustic cavity, it interferes with itself constructively, setting up a resonance, or standing wave. For every acoustic cavity there is a fundamental resonant period, which is roughly equal to the sound travel time from the upper reflection point to the lower turning point and back again. In the sun this fundamental period defines a wave with a specific horizontal wavelength. Certain shorter-period waves with the same horizontal wavelength, known as overtones, will also resonate within the solar interior, but for them the cavity is deeper because their horizontal phase speed is greater. The depth at which it equals the local sound speed is therefore greater.

An integral number of waves must fit along the arc leading from the solar surface to the bottom of the acoustic cavity and back if a mode is to resonate. For a given horizontal wavelength only certain periods will give a cavity that is the proper depth for resonance. A two-dimensional power spectrum, which displays amplitude as a function of both horizontal wavelength and period, should therefore show the strongest solar oscillations falling in a series of narrow bands, representing the allowed values of period and horizontal wavelength for the resonant modes. In 1975 Franz-Ludwig Deubner, who is now at the University of Würzburg, made the first accurate measurements of both the period and the horizontal wavelength of the "five-minute" oscillations. A power spectrum of his data showed narrow ridges of high amplitude, strikingly confirming the predictions.

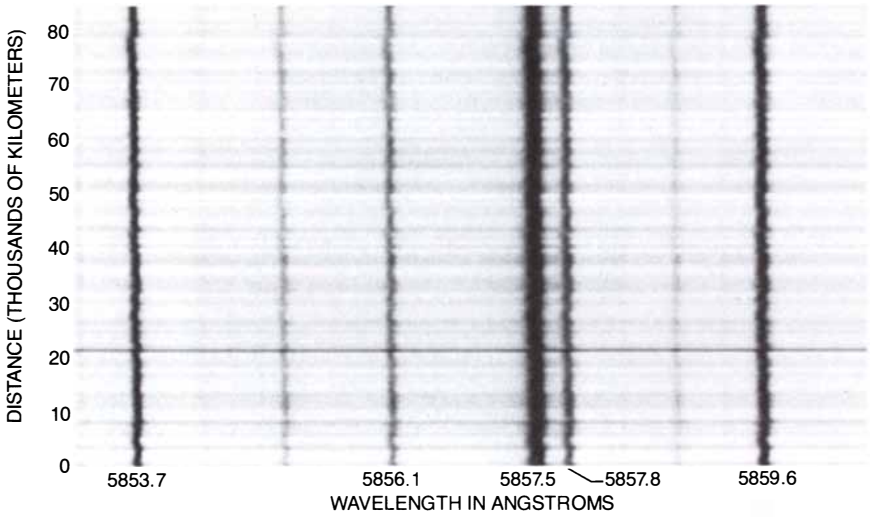


FIVE-MINUTE OSCILLATIONS are evident in plots of radial velocity over time along 80,000 kilometers of the solar surface. At each point the surface gases rise and fall over periods of about five minutes, reaching a maximum radial velocity (at the peaks and troughs of the curves) of about 0.4 kilometer per second. The motions are the surface manifestation of the superposition of the sun's 10 million different acoustic resonances. The modes go in and out of phase with one another, resulting in the growth and decay of the motions and their changing distribution across the sun. Steven A. Musman and David M. Rust of the Sacramento Peak Observatory charted the motions from Doppler shifts observed at each point.

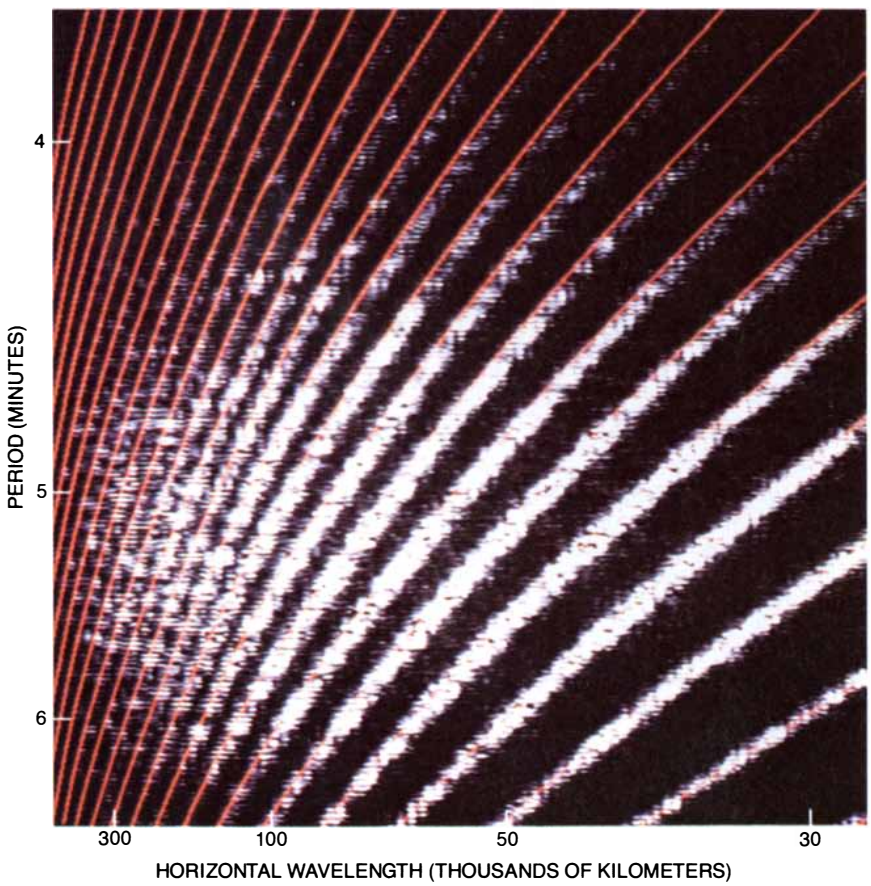
There were small but systematic differences, however, between the combinations of frequency and wavelength Deubner observed and those calculated from the standard solar model by Hiroyasu Ando and Yoji Osaki of the University of Tokyo. The discrepancies hinted that some parameters in the solar model needed to be changed. A likely candidate was the efficiency of the convection processes just below the solar surface. Greater convection efficiency would result in a shallower gradient of temperature and therefore in a slower increase in sound speed with depth. Thus amended, the solar model was expected to predict resonant modes that matched the data better.

Improved observations of the five-minute oscillations made by Edward J. Rhodes, Jr. (now at the University of Southern California), Ulrich and Simon yielded data sufficiently accurate to enable them to assess the efficiency of convection and hence the depth of the convection zone, which is directly related to its efficiency. They, and independently Douglas O. Gough of the University of Cambridge, deduced that the solar convection zone was deeper than had been supposed. A sun with a deeper convection zone would not have the observed radius, however, unless the helium content of its core were higher than it is thought to be. The high neutrino flux expected from a high-helium core would then worsen the neutrino problem.

The power spectrum of the five-minute oscillations confirmed that the observed motions result from the superposition of several million resonant modes with different periods and horizontal wavelengths. The modes with the highest amplitudes have periods of between about three and six minutes; their horizontal wavelengths can be as



SPECTROGRAM of the sun reveals Doppler shifts in the spectral lines of surface gases. The horizontal dimension of the spectrogram corresponds to wavelength; the vertical dimension corresponds to the distance across the solar disk that was spanned by the slit of the spectrograph. The dark vertical lines, which indicate the wavelengths at which the surface gases absorb light emitted deeper in the sun, are displaced from side to side across the observed portion of the sun; the shifts in wavelength result from the radial motion of the gases.



COMPARISON OF THEORETICAL AND OBSERVED OSCILLATIONS, plotted by computer, shows that the oscillations observed on the solar surface result from acoustic resonances in its interior. Only waves with specific combinations of period and horizontal wavelength should resonate within the sun. The colored curves indicate theoretical predictions for resonant modes, based on a "standard" solar model, in which the initial helium abundance of the sun is assumed to have been 25 percent. The bright ridges show the periods and horizontal wavelengths into which six days of observations of solar-surface velocities by Thomas L. Duvall, Jr., and John W. Harvey of the National Solar Observatory were resolved. Overall agreement between observation and theory confirms that the sun acts as an acoustic cavity; slight discrepancies show theoretical models of the sun need to be refined.

short as a few thousand kilometers, the width of individual granules, or as long as the 4.5-million-kilometer circumference of the sun. Individual modes have amplitudes (expressed as the radial velocity of the surface oscillations) of 20 centimeters per second or less. Their random superposition, however, produces the large-amplitude oscillations, with a peak velocity of as much as half a kilometer per second, that were first observed in 1960. These oscillations grow and decay as individual wave modes go in and out of phase.

In spite of the complexity of the oscillations when they are considered together, individual resonant modes can be described rather simply. Because the resonant cavities lie within the spherical sun, a mathematical description of the spatial structure of a resonance must include functions that take into account latitude, longitude and radius. The variables used to describe an oscillation's surface configuration are known as degree and azimuthal order. The degree, denoted l, of an oscillation is the number of surface nodal lines: circles around the surface of the sphere where the velocity due to the wave is zero. The distance between adjacent nodes is about half the horizontal wavelength of the oscillation; thus waves of low l have very large horizontal wavelengths. The azimuthal order, denoted m, is the number of nodal lines that intersect the equator.

The depth structure of an oscillation is determined by its radial order (n), a parameter that is also known as overtone number. It corresponds to the number of vertical wavelengths or alternatively of nodal lines along a radius of the sphere. For each surface configuration, with particular values for l and m, there is a set of values of n, representing the fundamental resonant frequency (with n equal to 1) and its shorter-period overtones. Each mode, characterized by a specific set of values for l, m and n, has a specific oscillation frequency.

Because the depth of the acoustic cavity in the sun increases with increasing horizontal wavelength and with decreasing period, modes for which the ratio of n to l is large penetrate deep into the sun. When l is equal to 0, corresponding to a resonant mode in which the entire sphere expands and contracts in phase, the ratio of n to l is infinite and the pressure wave penetrates to the very center of the sun.

Modes of extremely low degree, whose horizontal wavelengths are comparable to the size of the sun, have attracted much attention because they can readily be separated from the

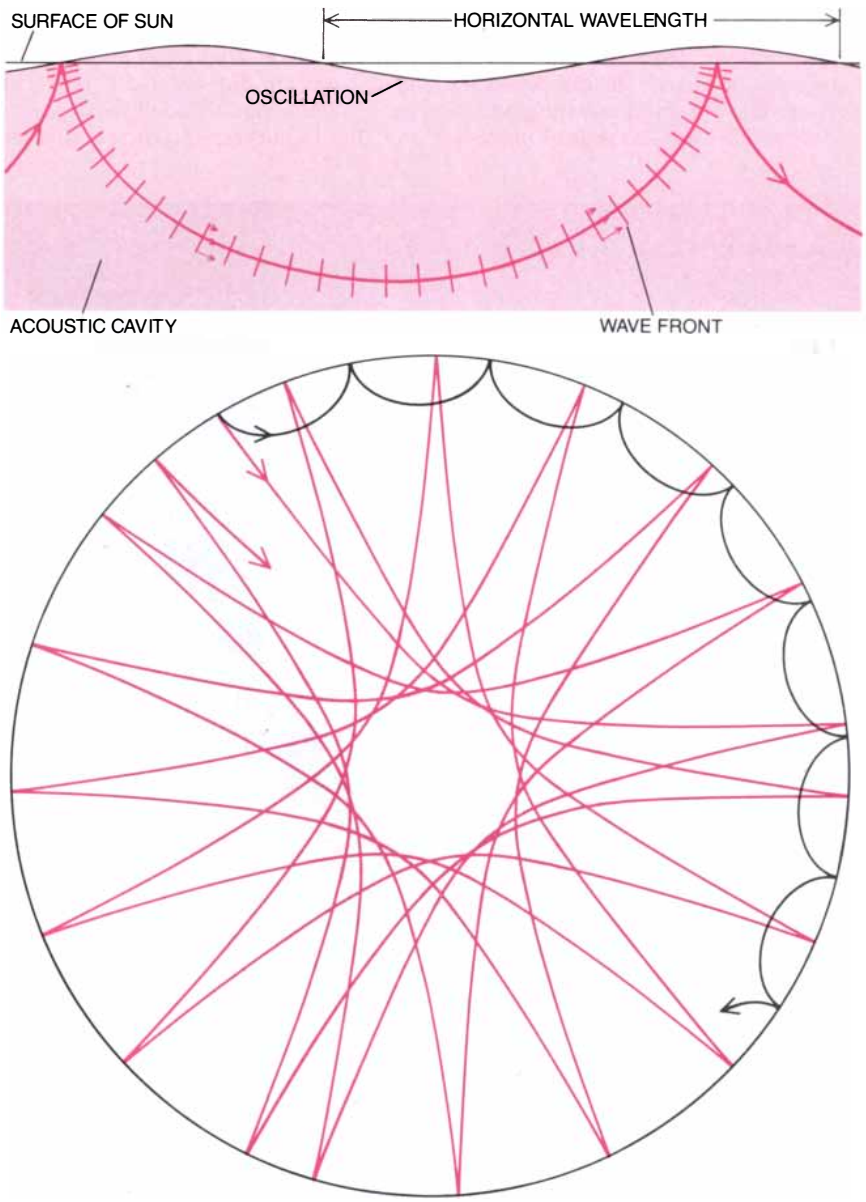
complex spectrum of higher-degree modes that agitate the solar surface. One simply records the Doppler shift of unimaged sunlight, in which light from the entire solar disk is mixed together. In such observations the numerous modes of high degree are nearly invisible; their wavelengths are small compared with the size of the solar disk and the Doppler shifts they produce essentially cancel. Modes with l equal to 0, 1, 2 or 3, in contrast, produce radial motion that is in phase across all or much of the solar disk, yielding a spectral shift that is detectable in unimaged sunlight. The resulting power spectrum is much simpler than the one that emerges from data on high-degree modes, making it possible to study individual modes rather than ridges of unresolved ones.

The velocity of a single mode at the surface is extremely small, however. Detecting the Doppler shift it produces requires a highly precise and stable spectrometer. Gas-cell spectrometers have yielded the most precise results. They compare the absorption lines in the spectrum of gaseous sodium or potassium in a laboratory enclosure with those produced by the moving sodium or potassium atoms on the surface of the sun in order to determine the Doppler shift. Two groups, one led by George R. Isaak and H. B. van der Raay of the University of Birmingham and the other by Eric Fossat and Gérard Grec of the Observatory of Nice, have used gas-cell spectrometers with great success.

The first observations of low-degree solar oscillations showed that the periods, and therefore the frequencies (the reciprocal of the periods), of many of them are very closely grouped. To distinguish among them one needs observations covering enough time to allow modes with frequencies that are only slightly different to go in and out of phase with one another. One 12-hour day of observation does not suffice. When observations are continued over several days, however, nighttime gaps interrupt the data, introducing many spurious frequencies. To avoid such gaps the Nice workers went to the South Pole, where during the austral summer of 1979 they made continuous observations spanning five days. When their data were analyzed to yield a power spectrum, pairs of well-resolved peaks appeared, spaced almost evenly along the spectrum.

By comparing the results with the theoretically predicted frequencies of low-degree oscillations, Jørgen Christensen-Dalsgaard, who is now at the University of Aarhus in Denmark, and Gough showed that each pair represented a pair of modes with increasing overtone number (n) and decreasing degree (l): either 3 and 1 or 2 and 0. Along the spectrum pairs of odd l alternated with pairs of even l. Theory predicts that if modes of higher degree had been recorded, they would have fallen into the same sequences. The workers found that the spacing of the frequencies within each pair was approximately consistent with the spacing predicted by the standard solar model, in which the helium produced by the fusion of hydrogen in the solar core remains concentrated near the very center of the sun rather than being mixed throughout the core.

In order to minimize nighttime gaps and obtain even longer observations than the weather at the South Pole usually allows, the Birmingham group set up a pair of stations, in the Canary and the Hawaiian islands. By combining data from the two sites, which lie at almost opposite longitudes, the work-



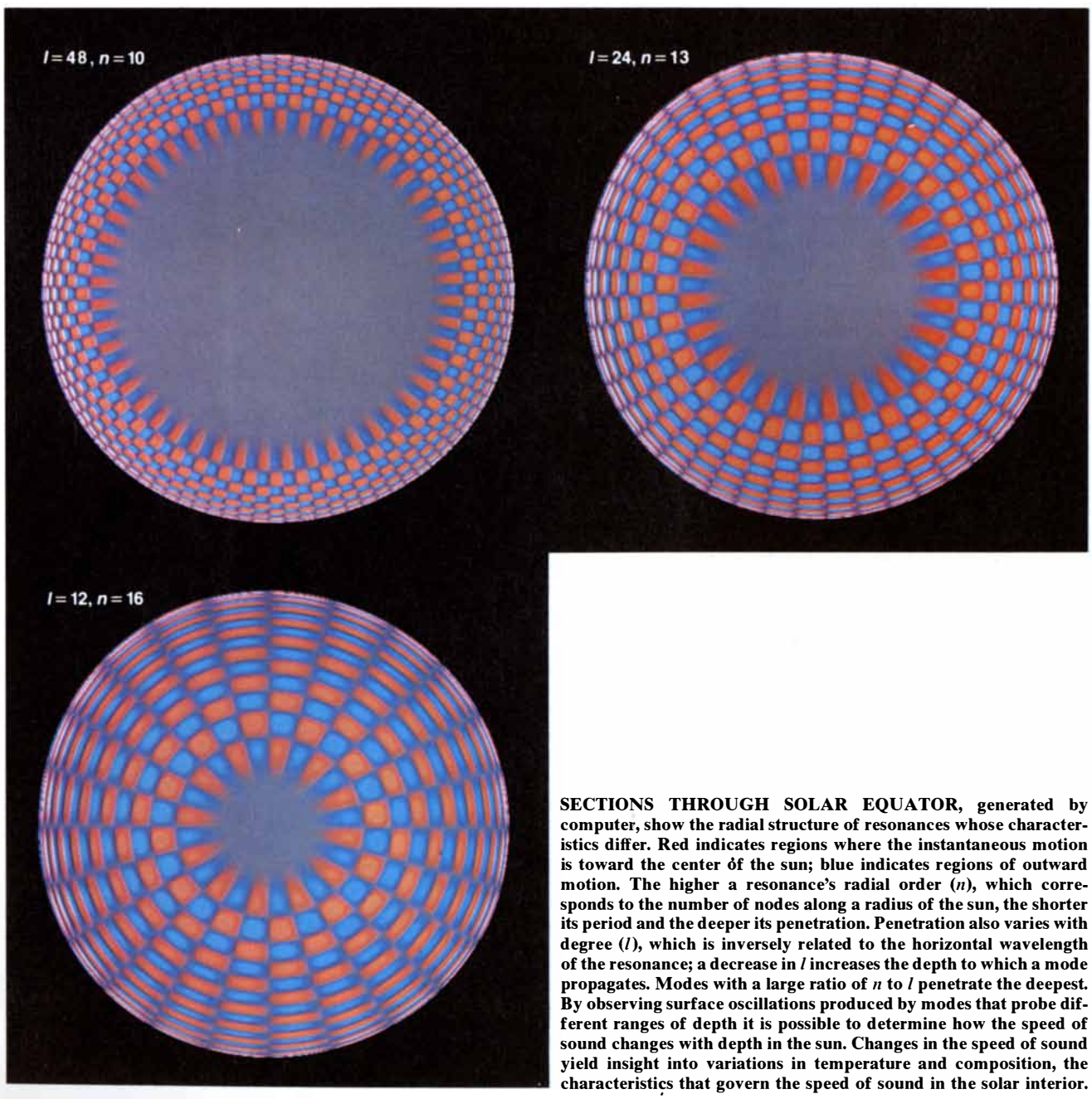
REFLECTION AND REFRACTION below the surface of the sun confine sound waves within acoustic cavities. A sound wave emerging from the solar interior is reflected by the steep decrease in density just below the surface (*top*); as the reflected wave descends it is refracted by the increase in the speed of sound with depth, which in effect rotates the wave fronts until they are again pointing toward the surface. Such trapped waves interfere constructively with themselves as they circle the sun, creating resonances that are detectable as oscillations of the solar surface. The horizontal wavelength and the period of the surface oscillation vary with the period of the wave that sets up the resonance and its depth of penetration. Penetration depth in turn depends on the orientation of the wave when it is reflected. As is shown in the cross section of the sun at the bottom, waves that travel steeply downward are refracted slowly and therefore probe the sun to a great depth; waves that penetrate at a more oblique angle are refracted more quickly and are confined to a shallower cavity.

ers obtained virtually continuous observations; one set of full-disk velocity observations spanned about three months in 1981. Frequency spectra of their data showed the same regular structure that was apparent in the data from the South Pole, but at even higher resolution.

The regularities in the measured frequencies of low-degree modes provide striking confirmation that the theoretical understanding of solar oscillations is basically correct. The actual frequency values deviate slightly from those predicted from the standard solar model, however. The discrepancies between the observed and the predicted frequencies are less than .3 percent, but even this small difference is about 10 times the observational uncertainty for these modes. It is also considerably larger than the uncertainties inherent in the method of predicting frequencies from the standard model. It is clear that significant changes in the model itself are called for.

Hypotheses about the origin or evolution of the sun that depart from the standard view can yield a model that fits the observations better. One such hypothesis is that because of inhomogeneities in the gas cloud out of which the sun condensed, the initial proportions of hydrogen and helium in its interior differed from those in its surface layers. Models incorporating this hypothesis predict a slightly different sound speed in the solar interior than the standard model does, and therefore slightly different resonant frequencies.

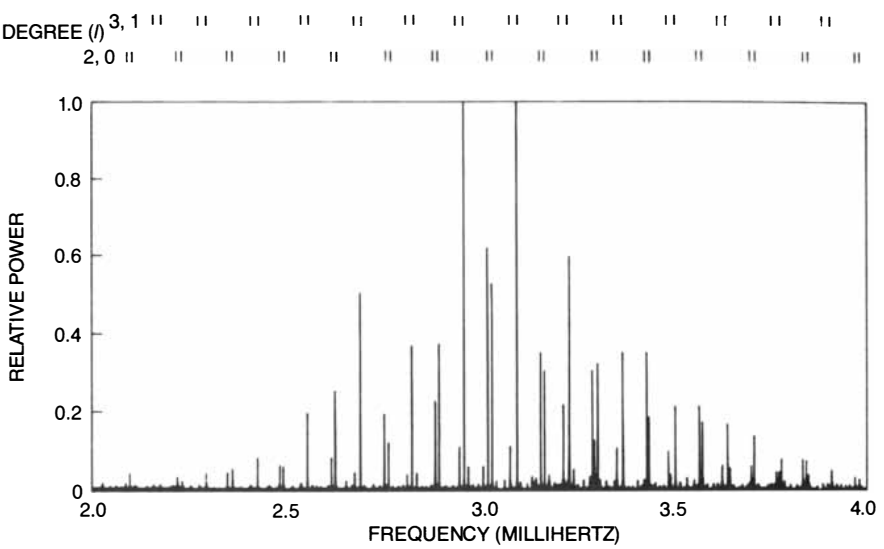
One such model, characterized by a significant overabundance of helium in the core and a somewhat higher core temperature, matches the oscillation data much better than the standard model does. Unfortunately the neutrino flux predicted by this model is even higher—and further from the measured flux—than that predicted by the standard model. Another model, with a lower proportion of helium in the core and a lower core temperature than exists in the standard model, provides a good fit with the observed neutrino flux, but its disagreement with the



SECTIONS THROUGH SOLAR EQUATOR, generated by computer, show the radial structure of resonances whose characteristics differ. Red indicates regions where the instantaneous motion is toward the center of the sun; blue indicates regions of outward motion. The higher a resonance's radial order (n), which corresponds to the number of nodes along a radius of the sun, the shorter its period and the deeper its penetration. Penetration also varies with degree (l), which is inversely related to the horizontal wavelength of the resonance; a decrease in l increases the depth to which a mode propagates. Modes with a large ratio of n to l penetrate the deepest. By observing surface oscillations produced by modes that probe different ranges of depth it is possible to determine how the speed of sound changes with depth in the sun. Changes in the speed of sound yield insight into variations in temperature and composition, the characteristics that govern the speed of sound in the solar interior.

measured oscillations is even larger than that of the standard model.

It appears that plausible nonstandard models assuming an initial chemical composition that changed with depth cannot account for both the observed oscillation frequencies and the measured neutrino flux. One way to reconcile both sets of observations is to assume that the core is momentarily cooler than normal, accounting for the unexpectedly low neutrino flux. If this transient condition were sufficiently short-lived, it would affect the output of light from the visible surface only slightly. Because the acoustic modes are rather insensitive probes of the core itself, an anomalously low core temperature would not yield frequencies differing significantly from the observed ones. Without additional information about the core, however, this idea must remain a speculation.



POWER SPECTRUM of low-degree oscillations, derived from observations of Doppler shifts in unimaged sunlight (light from the entire solar disk), reveals a striking regularity in resonant frequencies. Each of the indicated pairs of peaks represents oscillations with increasing radial order *n* and decreasing degree *l*. Pairs of modes of odd *l* alternate with pairs in which *l* is even. Within the pairs the frequencies of odd-degree modes are spaced slightly farther apart than those of even degree. The close match between the pattern and theoretical predictions made it possible to determine the values of *l*. George R. Isaak and H. B. van der Raay of the University of Birmingham made the observations at Tenerife and Hawaii.

Fortunately there is an entirely different class of resonant oscillations, which reach their greatest amplitude near the core and should therefore be sensitive probes of conditions there. They are internal gravity waves: oscillations of parcels of fluid above and below their equilibrium position. Whereas pressure is the restoring force for sound waves, buoyancy is the restoring force for gravity waves. Gravity waves can travel only in regions of stable stratification and so are largely trapped in the deep interior, below the unstable convection zone.

The period of a resonant gravity wave is determined by its travel time through the region of trapping. The travel time in turn depends on the buoyancy frequency of the medium: the frequency with which a parcel of fluid oscillates after it has been displaced vertically. That frequency is the result of vertical gradients of density and pressure.

Because they are largely confined to the deep interior, gravity waves are difficult to detect at the surface. The only gravity modes that might be evident at the surface as variations in radial velocity and brightness are those of low degree; they undergo the least attenuation in the convection zone. Observing even these modes is not easy, however, because their amplitudes are small and they have periods of an hour or more. Furthermore, theory predicts that gravity modes are numerous and their frequencies are closely spaced. As a result observing times extending over many months or even years will be necessary to determine the frequencies of internal gravity modes with enough precision to use them for the study of solar structure.

Several groups have reported oscillations that may represent internal gravity modes. Andrei Severny, Valeri Kotov and their colleagues at the Crimean Astrophysical Observatory have observed a candidate oscillation that has a period of 160.01 minutes; observations made by Philip H. Scherrer and John M. Wilcox of Stanford University revealed a similar mode. It is somewhat surprising, however, that a single mode rather than the predicted forest of peaks is prominent in the data. Because the observed period is almost exactly one-ninth of a day, it is possible that some subtle effect in the earth's atmosphere creates a spurious oscillation signal.

Frequency spectra of the Stanford observations did reveal other possible gravity modes, however. Theory predicts that the periods of gravity modes should be evenly spaced. Using the prediction as a diagnostic tool, Philippe Delache of the Observatory of Nice and Scherrer tentatively identified a dozen gravity modes with periods of between three and five hours.

The differences among the periods of the candidate gravity modes are somewhat greater than the spacing predicted by the standard solar model, suggesting that the buoyancy frequency of the deep solar interior is unexpectedly low. It may be that the gradients of density and pressure there are less steep than is thought, perhaps because helium is more thoroughly mixed throughout the core than the standard solar model suggests. If it is confirmed, that result would conflict with the evidence for a nonmixed core given by the frequency spacings of low-degree acoustic modes. The study of internal gravity modes is still in its infancy, however, although it holds great promise for helioseismic probing of the very core of the sun.

Most of the questions to which helioseismology has been applied concern the radial structure of the sun: its variation with depth. The technique also provides a powerful tool for studying horizontal motions below the solar surface. Such motions reflect both the rotation of the sun and its large-scale convection. An understanding of the variation in the sun's rotation rate with depth and latitude and a clearer picture of subsurface flows are both essential to the effort to unravel the complicated dynamics of the convection zone. They may also lead to a better understanding of the interaction of rotation and convection that generates the magnetic fields of the sun and other stars.

Acoustic waves are sensitive to the horizontal motions of gases below the solar surface simply because the gas motions tend to carry the waves with them. Waves propagating in the direction of the subsurface motion will move faster than they would in a static medium. Hence their crests will pass a fixed point faster and their measured frequency will be higher. Similarly, waves propagating against the motion will have a lower measured frequency. The frequencies of two otherwise iden-

tical modes propagating in opposite directions through a subsurface flow will therefore be split. The magnitude of the splitting gives the speed of the flow, averaged over the range of depth and latitude within which the modes are confined. Taken together, the frequency splittings of many modes yield a picture of the sun's differential rotation and of its large-scale convective motions.

The largest of the convective patterns, known as giant cells, are thought to be shaped roughly like bananas oriented north and south and lying side by side in the convection zone; their width is comparable to the depth of the convection zone, or 200,000 kilometers. Although giant cells have not been observed directly, supercomputer models of solar convection made by Peter A. Gilman of the National Center for Atmospheric Research in Boulder and Gary A. Glatzmaier of the Los Alamos National Laboratory predict their existence. The large-scale magnetic field patterns of the sun's surface also give hints of giant cells.

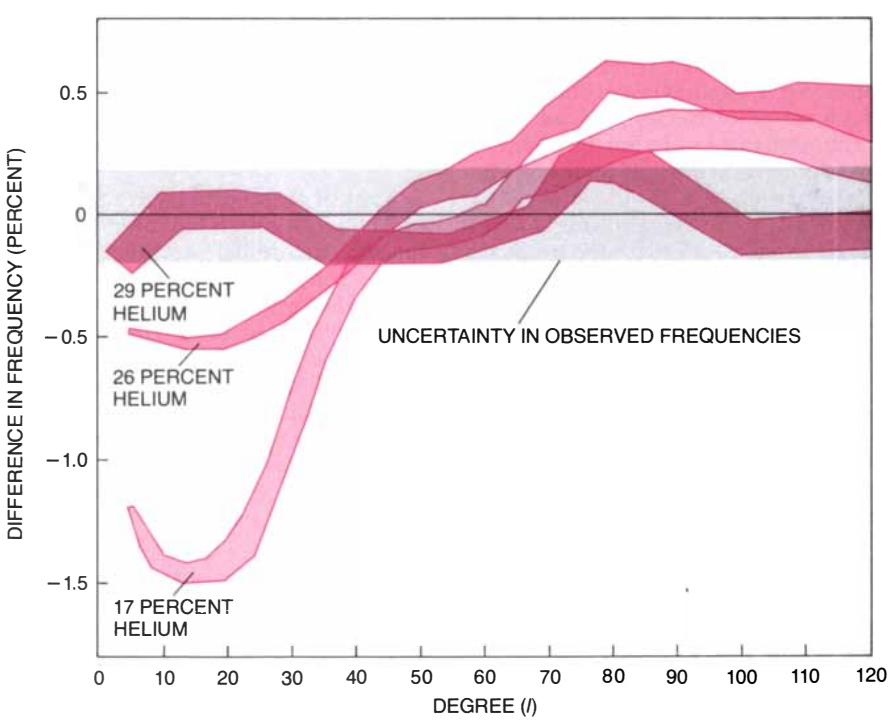
It is thought that the horizontal flows of giant cells are strongest below the sun's visible surface. Giant cells might therefore produce observable shifts in the frequencies of acoustic modes propagating across them; the shifts are likely to be particularly pronounced when the modes have a high degree and therefore a horizontal wavelength that is short compared with the scale of the cells. The amount of frequency splitting would grow and diminish over the course of several days as giant cells rotate into and out of view over the visible disk of the sun. Frank Hill and Laurence J. November of the National Solar Observatory at Sacramento Peak in Sunspot, N.M., working with Gough and Toomre, detected such variations in frequency splitting. The observations suggest that giant-cell circulation reaches horizontal speeds of more than 100 meters per second just below the solar surface.

Helioseismology is also proving its value as a probe of the internal rotation of the sun. It is believed that the sun once rotated much faster than it does today: its present period is about 25 days at the equator and 33 days near the poles. At its surface the sun sheds angular momentum to the wind of escaping gases it generates, but the interior is not subject to the loss of momentum. It seems reasonable to expect that the deep interior, well below the depths to which convective flows can penetrate and redistribute angular momentum, might still be spinning much faster than the surface.

Frequency splittings that result from the sun's rotation were observed recently in acoustic modes by Thomas L. Duvall, Jr., of the National Aeronautics and Space Administration's Goddard Space Flight Center and John W. Harvey of the National Solar Observatory in Tucson. Analysis of their results suggests that the rotation rate actually decreases slowly with depth through much of the sun's interior, although the data hint that the core itself may rotate faster than the rest of the sun. The results with regard to the core are uncertain because acoustic modes are not very sensitive to conditions in the core. The comparatively slow rotation at shallower depths, however, appears to be clearly defined, and it is quite at variance with expectations based on the inferred loss of angular momentum from the surface layers. New observations by Timothy M. Brown at the National Center for Atmospheric Research compound the mystery; they show that just below the surface the rotation rate is nearly constant with latitude, in contrast to what is observed at the surface. Together the results pose a major challenge to dynamical theories of the sun.

One theory that is strengthened by the results from helioseismology is Einstein's theory of gravitation. The perihelion of the orbit of Mercury (the point at which the planet is closest to the sun) is known to precess: it shifts slightly with each revolution. Most but not all of the precession results from the gravitational effects of other planets; one of the triumphs of Einstein's theory was that it could explain the excess precession as a result of the curvature of space and time produced by the gravitational field of the sun.

The explanation assumes that the sun's gravitational field is spherically symmetrical. If the solar interior were distorted by rapid rotation, as Robert H. Dicke of Princeton University has proposed, the oblateness would also contribute to the precession and Einstein's theory would have to be modified. Indeed, Henry A. Hill and his colleagues at the University of Arizona have detected fluctuations in brightness at the edge of the solar disk that they attribute to various acoustic and gravity modes; the data led them to conclude much of the solar interior is rotating so rapidly that alteration of



GAP BETWEEN OBSERVATION AND THEORY varies depending on the assumed abundance of helium in the sun's interior. The graph indicates the differences between observed and theoretical frequencies for solar oscillations that vary in degree (*l*) but share a radial order (*n*) of 13. The curves correspond to the frequencies predicted from models of the sun having the observed surface abundance of helium but an abundance in the deep interior that varies as indicated. The model with 26 percent helium supposes that helium was uniformly distributed in the gas cloud out of which the sun formed; the models with 17 and 29 percent helium assume initial inhomogeneities. The thickness of each curve reflects uncertainties in the theoretical behavior of oscillations at the solar surface; the horizontal band represents observational uncertainties. The high-helium model matches the oscillation data best, but it would yield a much higher flux of solar neutrinos than is observed. The low-helium model, which would resolve the neutrino problem, conflicts with oscillation data. The graphs are based on theoretical work by Ulrich and observations by Duvall and Harvey.

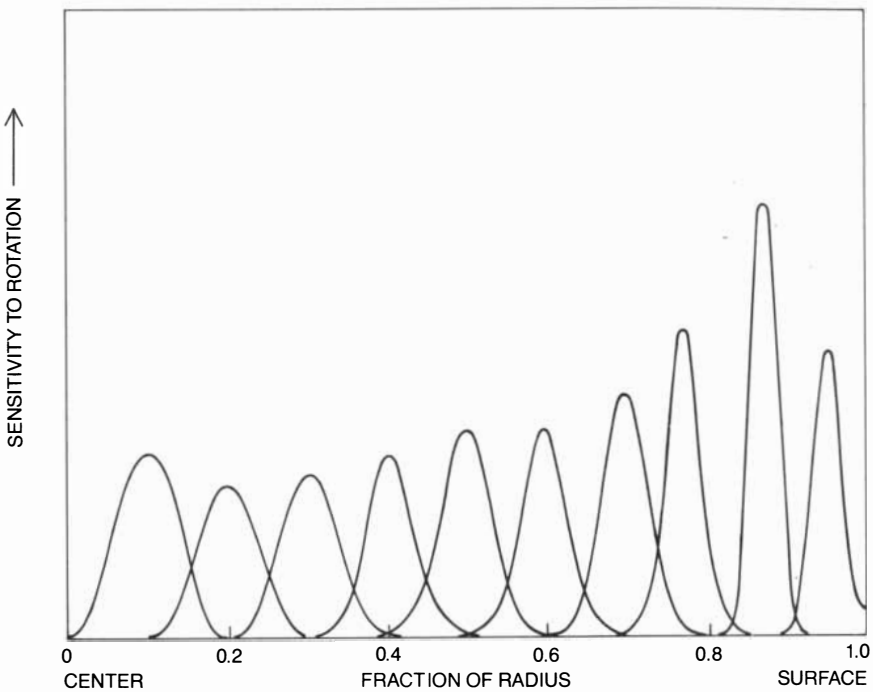
the theory of gravitation is called for.

The acoustic frequency splittings, however, indicafe internal rotation rates that would not result in an interior oblate enough to invalidate Einstein's account of the precession. Even if the very core of the sun is rotating rapidly, the slower rotation of the rest of the solar interior means the net effect of rotation on the sun's gravitational potential is small.

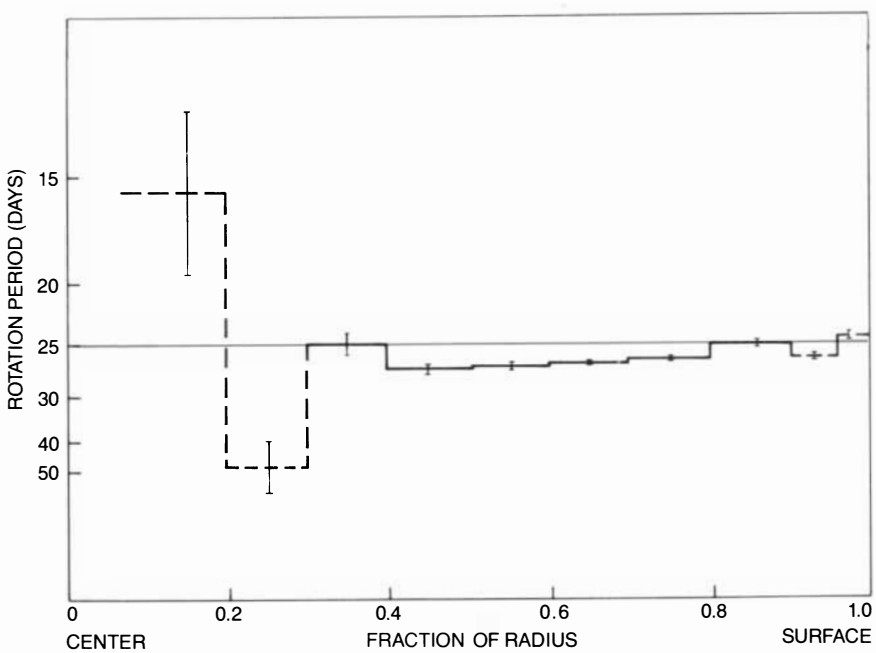
Helioseismology has already yielded significant information about the interior of the sun, but the full power of the technique awaits improved observations. To resolve oscillation modes having closely spaced frequencies one needs continuous data stretching for months or even years. A way to make such observations would be to establish a network of observatories spaced longitudinally around the globe, so that at least one site is always sunlit and untroubled by bad weather. The Birmingham and Nice groups are already developing such networks for observations of unimaged sunlight, while solar scientists at the National Optical Astronomy Observatories are planning a global array of imaging telescopes meant to record modes with a degree of 100 or more.

There is also a need for improved data on oscillations of considerably higher degree, which carry the best information about structure and horizontal flows in the convection zone. Because the displacements produced by such oscillations have a small horizontal scale, their study demands data with high spatial resolution. Such data are best obtained from space, above the atmospheric turbulence that seriously distorts fine detail in the sun as it is seen from the ground. An excellent position for a satellite equipped to measure the small-scale distribution of velocities over the surface of the sun would be an orbit around the inner Lagrangian point, a point of gravitational equilibrium between the earth and the sun. The inner Lagrangian point has a very small radial velocity with respect to the sun, so that a satellite circling it could make solar-velocity observations with unprecedented sensitivity. Such a satellite would also answer the need for uninterrupted observation, since the inner Lagrangian point is continuously sunlit.

A satellite-borne imaging oscillation detector could fly during the 1990's as part of a joint mission of NASA and the European Space Agency. Combined with a network of ground observatories, such an instrument would enable investigators to approach the limits of helioseismology as a tool for exploring the solar interior.



SENSITIVITY of oscillations observed at the solar surface to rotation inside the sun is indicated for various depths. The method by which internal rotation is calculated from surface oscillations is known as inverse theory: one mathematically combines data from a large number of modes, each of them sampling properties over different but partially overlapping intervals of depth. The method, which is also used for other properties of the solar interior, yields results whose resolution in depth improves as more modes are considered; thus the narrowness of each curve indicates the precision with which a calculation of rotation rate can be assigned to a specific depth. Jørgen Christensen-Dalsgaard of the University of Aarhus and Douglas O. Gough of the University of Cambridge did the calculations for the graph.



INTERNAL ROTATION of the sun was calculated from the differences in frequency seen for identical modes propagating in opposite directions. The modes were least sensitive to rotation near the core and near the surface. The broken lines indicate the uncertainty of the analysis there, and the error bars quantify the uncertainties in the observations. The horizontal line indicates the surface rotation period at the equator. The data indicate that throughout much of the solar interior the rotation rate declines slowly with depth rather than increasing rapidly, as had been supposed. The core, however, may be spinning faster than the rest of the sun. Duvall and Harvey made the observations and analyzed them in collaboration with Wojciech Dziembowski of the Copernicus Astronomical Center in Poland, Philip Goode (now at the New Jersey Institute of Technology), Gough and Leibacher.

Oligosaccharins

Fragments of the plant cell wall have been discovered that serve as regulatory molecules. They help to control such functions as growth, development, reproduction and defense against disease

by Peter Albersheim and Alan G. Darvill

Every higher plant is made up of a multitude of cells, all of which have the same complement of genes. How then can different cells have different functions and be shaped differently, so that plants have roots, stems, leaves, flowers and fruits? The answer is that only a small subset of the genes in a particular kind of cell are expressed, or turned on, at a given time. A complex system of chemical messengers activates the genes responsible for forming flowers in some cells, for example, and the genes responsible for root formation in other cells.

The chemical messengers in plants are called hormones or regulatory molecules. Five major hormones have been identified: auxin, abscisic acid, cytokinin, ethylene and gibberellin. In our studies we have identified a new class of regulatory molecules in plants. We call them oligosaccharins. Each of them appears to deliver a message regulating a particular plant function. The functions include defense against disease, growth, and differentiation in the course of development: whether to form roots, stems, leaves or flowers and fruits.

Unlike the oligosaccharins, the five well-known plant hormones are pleiotropic rather than specific, that is, each has more than one effect on the growth and development of plants. Auxin, for instance, stimulates the rate of cell elongation, causes shoots to grow up and roots to grow down and inhibits the growth of lateral shoots. Auxin also causes the plant to produce a second hormone (ethylene), to develop a vascular system and to form lateral roots. The other four well-known plant hormones have a similarly complex array of functions. Indeed, they have so many simultaneous effects, some of them beneficial and others harmful, that they are not of great commercial value in agriculture. For example, the same hormone can have both a beneficial effect such as increased mobilization of food reserves and a harmful effect such as loss of leaves.

The pleiotropy of the five well-studied plant hormones is somewhat analogous to that of certain hormones in animals that stimulate a gland to release many other hormones. For example, hormones from the hypothalamus in the brain stimulate the anterior lobe of the pituitary gland to synthesize and release many different hormones, one of which is corticotropin. Corticotropin in turn stimulates the release of a number of different hormones from the adrenal cortex. The other hormones released from the anterior pituitary also have specific effects on target organs all over the body. One hormone stimulates the thyroid gland, for example, another the ovarian follicle cells and so forth. In other words, there is a hierarchy of hormones.

We think such a hierarchy may also exist in plants. Oligosaccharins are fragments of the cell wall. They are released from the cell wall by enzymes; different enzymes release different oligosaccharins. There are indications that pleiotropic plant hormones such as auxin and gibberellin may actually function by activating the enzymes that release these other, more specific chemical messengers from the cell wall.

Our discovery of oligosaccharins was the direct result of the fact that for many years our laboratory at the University of Colorado at Boulder was simultaneously engaged in two research projects we thought were unrelated. The first project was an effort to elucidate the structure of the plant cell wall. It was the remarkable complexity of the cell-wall components that first suggested their role might be more than a structural one. The second line of research was a study of the molecules involved in a plant's defense against disease. This research pointed directly to the possibility that the cell wall might act as a pseudo-gland: a repository of precursors of a class of regulatory molecules that, on being released, are capable of controlling a number of plant functions.

Plant cells are characterized by a distinctive semirigid envelope, the cell wall. One of the wall's functions is mechanical: it gives the cell, and thus ultimately the plant, strength and form. It lies outside the cell's plasma membrane, which defines the boundary of the cell's cytoplasm chemically. The cell wall is permeable to most molecules; the membrane's permeability is highly selective, enabling it to control the entry of metabolites into the cell and the transport out of the cell of cell-wall components and other molecules synthesized in the cytoplasm. The "primary" wall of a young cell is thin, and it enlarges rapidly. The "secondary" wall of a mature, nongrowing cell is thicker and may assume a shape more distinctive than that of the generally boxlike primary wall.

We study primary walls, which consist almost entirely (about 90 percent) of polysaccharides, large molecules made up of interconnected simple sugars called monosaccharides. (Proteins account for the remaining 10 percent of the wall.) Most cell-wall monosaccharides are either pentoses or hexoses: they have five or six carbon atoms, along with hydrogens and oxygens.

D-glucose is the most abundant sugar in cell walls; indeed, it is the most abundant sugar in nature. (The names of monosaccharides are often prefixed by a D or an L. The prefix identifies the orientation of chemical groups linked to one of the carbon atoms—carbon 5 of a hexose. Most sugars in primary cell walls exist in only one of the two configurations, and so a monosaccharide can generally be referred to without its prefix.) The structure of glucose is typical of the structure of all the monosaccharides found in cell walls.

In aqueous solution glucose can exist as an open chain of six carbon atoms, but far more often it takes the form of a ring in which an oxygen atom connects carbon 1 and carbon 5. In the ring form carbon 1 has a hydrogen atom and a hydroxyl group (OH) attached. There are two versions of the ring because the hydrogen and the hydroxyl can be oriented in either of two ways, designated alpha and beta. In solution the open-chain form and the alpha and beta ring forms interconvert continually.

In polysaccharides and oligosaccharides (small polysaccharides containing from two to perhaps 15 monosaccharides) the monosaccharides are linked to one another by the distinctive glycosidic bond. This covalent bond (a bond in which atoms share pairs of electrons) is formed when carbon 1 of a sugar in the ring configuration is linked to a different carbon atom of another sugar. A molecule of water is extracted from the hydroxyl groups attached to both carbon atoms, leaving a single oxygen atom connecting the two sugar units.

Because the oxygen and hydrogen atoms attached to the carbon 1 of a sugar can have either of two orientations, alpha or beta, there are alpha and beta glycosidic bonds. Although the difference between the two kinds of bond seems small, the same two sugars yield radically different disaccharides depending on whether they are alpha- or beta-linked. For example, two glucose molecules linked by an alpha glycosidic bond from carbon 1 to carbon 4 form the disaccharide maltose; many glucose molecules linked in this way make the polysaccharide starch. Two glucose molecules linked by a beta glycosidic bond at the same positions, however, yield cellobiose; a long chain of glucose molecules thus connected makes the polysaccharide cellulose. Cellulose is identical with starch in chemical composition, but its properties are very different.

Cellulose is the best-known and the best-understood of the polysaccharides of the cell wall. It is a glucan chain (a chain consisting only of glucose units) linked by beta glycosidic bonds between carbon 1 and carbon 4. The chains are linear, and in the primary wall they aggregate to form fibers made up of about 40 chains each. These cellulose fibers are primarily responsible for the strength of the cell. They are embedded, like the steel reinforcing rods in concrete, in a matrix of other molecules, most of which are also polysaccharides.

The matrix of a typical primary cell wall is composed of at least eight polysaccharides. Six of them have been well defined. They are homogalacturonan, rhamnogalacturonan I, rhamnogalacturonan II, xyloglucan, arabinogalactan and glucuronarabinoxylan. Each is named for its chief monosaccharide constituents. For example, the two sugars that are most prevalent in rhamnogalacturonan II are rhamnose and galacturonic acid, although the polysaccharide includes at least eight other sugars.

Until quite recently the matrix polysaccharides were assumed to be more or less like cellulose in structure: chemically simple sets of sugar molecules bonded together in regular, predictable, easily detected patterns. In fact, however, they are vastly more complex. Whereas cellulose is made up of identical sugars, all bonded in the same way, the matrix polysaccharides are instead made up of two or more kinds of sugars connected by several kinds of glycosidic bond. Two molecules of a six-carbon sugar such as glucose can be joined in 64 distinct ways; three different sugar molecules can be joined in more than 1,000 ways! Since a single polysaccharide can incorporate hundreds or even thousands of

FLOWERS grow from a sliver of a tobacco-plant stem maintained in a liquid culture medium. Each flower has an ovary in the center, surrounded by five anthers and a number of poorly developed petals and sepals. The authors and their colleagues induced the tobacco-stem sliver, or "explant," to develop flowers by adding to the medium newly discovered substances called oligosaccharins. These are oligosaccharides (short chains of sugar molecules) that are cleaved from the plant cell wall and act as hormones, or regulatory molecules. Different oligosaccharins have been shown to exert different influences on plant development (*see illustration on page 64*).

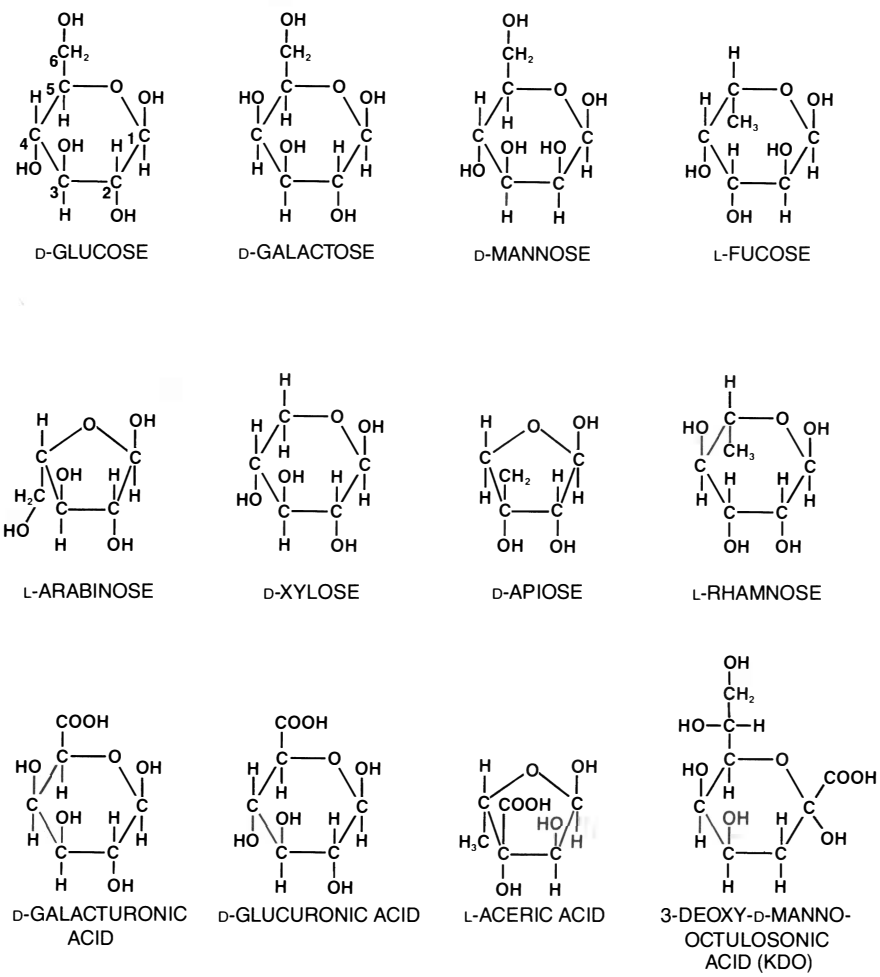
monosaccharides, the number of different potential arrangements is staggering; one cannot guess how many are allowed by the constraints of the real world. The structural complexity of wall polysaccharides is often increased by the presence of nonsugar groups such as methyl ethers and methyl or acetyl esters.

We came to understand the extent and significance of this complexity with the help of new technology. We degraded the cell wall with various enzymes that release specific polysaccharides for analysis and we analyzed the polysaccharides with advanced, computer-assisted chromatographic and spectrometric instrumentation. These techniques have revealed structural features that were previously inaccessible. For example, we have recently uncovered two "new" plant cell-wall sugars: aceric acid and KDO.

Both of them were identified as minor components of rhamnogalacturonan II, whose structure illustrates the extreme complexity of the cell-wall polysaccharides. Rhamnogalacturonan II accounts for approximately 3 percent of the primary cell wall of dicotyledons (broad-leaf plants with a netted pattern of veins); it is present in smaller amounts in both monocotyledons (narrow-leaf plants with parallel veins) and gymnosperms (which include the conifers).

We isolated rhamnogalacturonan II by treating the primary cell wall of cultured sycamore cells with a specific polysaccharide-cleaving enzyme. It makes soluble approximately 15 percent of the cell wall, including all the rhamnogalacturonan II. We purified the rhamnogalacturonan II to homogeneity and found it is composed of 10 different sugars linked in at least 20 different ways—by alpha and beta bonds and through different carbon atoms. We have established that rhamnogalacturonan II is made up of some 65 monosaccharides. So far we have characterized five different oligosaccharides, which together account for most of the 65. We are working to characterize the rest of the components. Then we shall have to learn how they are all fitted together in order to determine the complete structure of this highly complex molecule.

Rhamnogalacturonan II appears to be more complex than any polysaccharide whose structure has been established. Why should it turn out to be a component of every plant cell wall that has been studied? Why do cell-wall matrix polysaccharides in general not have a simple structure, more like that of cellulose? Why do they apparently contain far more chemical information than would be required simply to hold a plant upright?

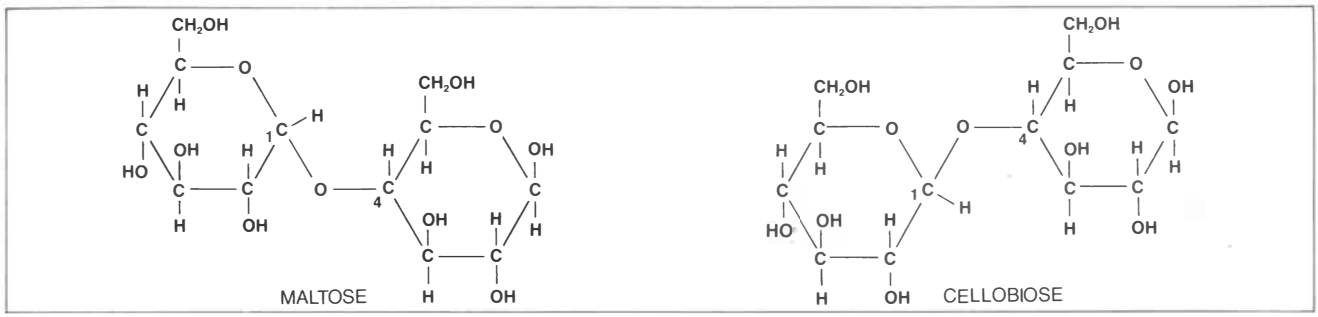


TWELVE SUGARS (monosaccharides) known to be components of the primary cell wall of plants are depicted schematically, with the ring compressed into a single plane. The hexoses (six-carbon molecules) D-glucose, D-galactose and D-mannose are stereoisomers, differing only in the arrangement of the groups attached to their carbon atoms. L-fucose and L-rhamnose lack a hydroxyl (OH) group at carbon 6. The pentoses L-arabinose, D-xylose and D-apiose have only five carbon atoms; 3-deoxy-D-manno-octulosonic acid (KDO) has eight and all the others have six. D-galacturonic acid, D-glucuronic acid, L-aceric acid and KDO carry carboxyl (COOH) groups and hence are acidic sugars. The D- and L- refer to the arrangement of chemical groups linked to carbon 5 of hexoses, carbon 4 of pentoses and carbon 6 of KDO. Only one such configuration (D or L) is found for each sugar in primary cell walls. Studies with new computer-assisted instrumentation and specific enzymes have only recently revealed that KDO and L-aceric acid are present in the primary wall.

Possible answers emerged from our research on the chemical basis of disease resistance in plants. A plant defends itself against fungal or bacterial pathogens by producing antibiotics, called phytoalexins, at the site of infection. Antibiotics are not proteins, and so they are not the direct product of gene expression. What needs to be expressed to make an antibiotic is the set of genes encoding the enzymes that catalyze antibiotic synthesis. Some chemical message has to deliver the signal for expression.

What is that message? We asked: Is there something in the infecting microorganism that signals a plant to make an antibiotic? We chose to work with a fungus that attacks soybeans because James A. Frank and Jack D. Paxton of the University of Illinois at Urbana-Champaign had developed a method for assaying the level of antibiotic synthesis in response to this particular fungal infection.

We learned that what plants recognize is the presence of a fungal oligosaccharide: a fragment released from a polysaccharide that is a structural component of the fungal cell wall. It was quite a surprise. Oligosaccharides, the short chains of sugars we had worked with for years, were not known to be able to carry information and so serve as chemical messages. And yet adding to plant cells a mixture of oligosaccharides (which were released by the random cleavage of a fungal cell wall with acid) could make the plant cells synthesize the enzymes that



GLYCOSIDIC BOND is the characteristic linkage between sugars in polysaccharides. The carbon 1 of a monosaccharide is linked to a carbon atom of a second sugar unit. A molecule of water is extracted from the hydroxyl (OH) groups attached to both carbons, leaving a single oxygen atom connecting the two sugar units. There are two versions of the glycosidic bond, alpha and beta, because the hydrogen atom and the glycosidic oxygen atom attached to carbon 1 can be oriented in two ways. Linking two sugar molecules at the same carbons but with different glycosidic bonds yields very different results. Two glucose molecules linked by an alpha glycosidic bond from the carbon 1 of the first molecule to the carbon 4 of a second one (*left*) form the disaccharide maltose; many glucose molecules linked in this way form starch. A beta glycosidic bond linking two glucose molecules from carbon 1 to carbon 4 produces the disaccharide cellobiose (*right*) instead of maltose. A chain of glucose molecules linked by such beta glycosidic bonds constitutes cellulose.

catalyze antibiotic synthesis. The oligosaccharides could clearly be considered regulatory molecules.

We set out to determine the structure of the smallest piece of the fungal cell wall that would cause plant cells to synthesize antibiotics. At first the problem did not seem too difficult because the cell-wall polysaccharide we were working with consisted only of a chain of glucose. This glucan chain turned out to be an intricately branched one, however, and so the project proved to be far more challenging than we had expected.

Cleavage of the polysaccharide had yielded a complex mixture of glucose-containing oligosaccharides of different sizes. We separated the oligosaccharides according to the number of glucose units in each and determined that the smallest fragment capable of stimulating the synthesis of antibiotics in plants was a hepta-beta-glucoside: an oligosaccharide made up of seven glucose units interconnected by beta-glycosidic bonds. That finding did not exactly settle the matter, however, because there were more than 300 differently arranged hepta-beta-glucosides in the fragments of the glucan! Separating the one active form from the more than 300 inactive forms proved to be an enormously difficult task because they were chemically so similar.

It was in 1974 that we initiated the effort to purify the active oligoglucoside and almost 10 years later that we succeeded—and then only because there had been tremendous advances in analytical instrumentation. The task of isolating one pure, active heptaglucoside and five pure, inactive heptaglucosides was successfully completed in 1983 by Janice K. Sharp, a graduate student in our laboratory. She ended up with only a minute amount of each heptaglucoside. In 1974 we had expected to need a full gram of pure heptaglucoside to decipher a structure. By 1983 the technology was so improved that the 50 micrograms (50 millionths of a gram) of each heptaglucoside Sharp isolated was enough to enable us to determine their structure.

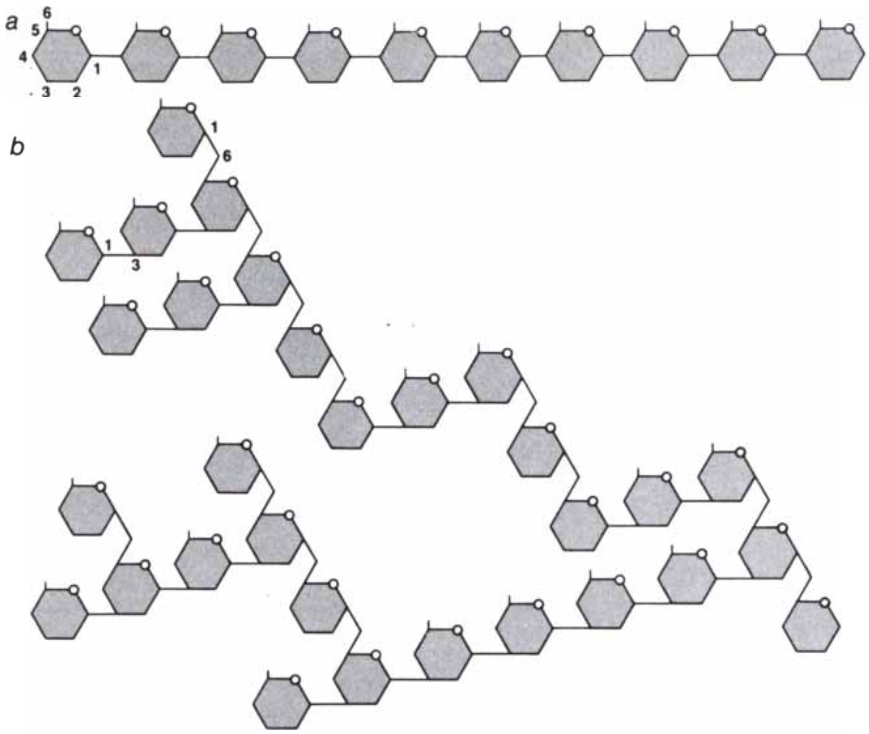
The results established that a plant recognizes and responds to a remarkably specific oligosaccharide structure. The active form—the oligosaccharin—and the inactive forms of the heptaglucoside are very similar. They differ only in the positions at which the two side chains (each a single glucose unit) attach to the backbone (a chain of five glucose units linked by beta-glycosidic bonds). The side-chain positions determine which of the heptaglucosides is active [*see bottom illustration on next page*]. The presence of only a billionth (10^{-9}) of a gram of the active heptaglucoside is enough to activate the synthesis of messenger-RNA molecules from the DNA of the enzyme genes, and so to initiate antibiotic production. The antibiotic functions to stop the growth of the fungus from which the heptaglucoside originated.

The next obvious step was to rephrase the question we had asked about fungi and ask: What is it in bacteria that causes plants to make antibiotics at the site of infection? Michael G. Hahn, another graduate student, studied the effect of several bacterial species on soybeans and got a striking answer. He found that in the case of bacterial infection the message is not in the pathogen's cell wall but in the wall of the plant cells. The presence of the bacteria somehow brought about the release of an oligosaccharide from one of the plant's own cell-wall polysaccharides. The released oligosaccharide caused nearby plant cells to make antibiotics. The active oligosaccharide turned out to be part of a pectic polysaccharide of the plant cell wall. ("Pectic" means rich in galacturonic acid, another of the simple sugars.) Eugene A. Nothnagel, a postdoctoral research associate, found the active oligosaccharide was an oligogalacturonide: a simple linear array of galacturonic acid units.

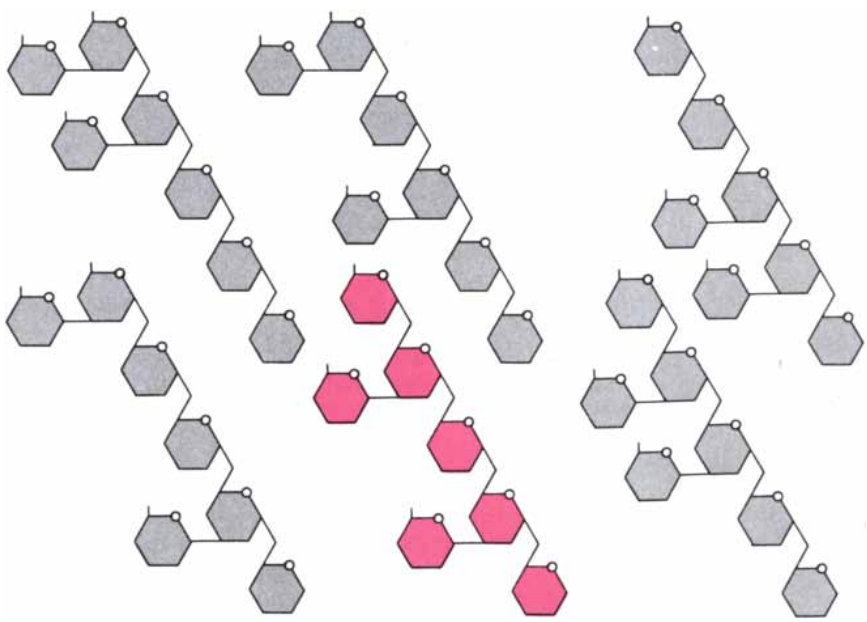
Charles A. West and his co-workers at the University of California at Los Angeles confirmed that an oligogalacturonide from the plant cell wall can stimulate plant cells to make antibiotics. They went on to describe one mechanism for the release of this oligosaccharin. In the case of a fungus that attacks castor-bean plants, an enzyme secreted by the fungus releases the oligogalacturonide from the cell walls of the plant. The oligogalacturonide—an oligosaccharin—stimulates the plant cells to make antibiotics. Keith R. Davis, another graduate student, discovered a related mechanism when he purified an enzyme from a bacterial plant pathogen, *Erwinia carotovora*. Davis found the bacterial enzyme releases an oligogalacturonide from the plant cell wall, in soybeans and in the other plant species examined, that stimulates soybeans to make antibiotics.

Still another variation was discovered by Gary D. Lyon, a visiting scientist. He learned that when certain plant cells are damaged, the cells themselves produce an enzyme that releases oligosaccharides (presumably oligogalacturonides) from nearby cell walls, and that these oligosaccharides stimulate plant tissue to synthesize antibiotics. In other words, whether a bacterium, a fungus or a virus attacks and damages the cells of a plant, the plant can respond and make antibiotics; it need not "see" an enzyme supplied by the microbe.

Several different mechanisms, then, appear to effect the same result: the



GLUCOSE UNITS can be linked in many ways. The structures of parts of two beta glucans (molecules made up solely of glucose units linked by beta glycosidic bonds) are illustrated. All the glucose units (*hexagons*) are in the six-atom pyranose ring form and all are glycosidically linked from carbon 1 of the first glucose to carbon 3, 4 or 6 of the next glucose unit. When a beta glucan is arranged in a linear manner, with carbon 1 linked to carbon 4 of the next unit, cellulose is formed (*top*). A very different kind of polysaccharide is formed when carbon 1 of the first glucose is linked to carbon 3 or 6 of the next one (*bottom*). The branched arrangement and varying glycosidic linkages make this beta glucan far more complex than cellulose. The complexity is typical of polysaccharides cleaved to make oligosaccharins.



FIRST OLIGOSACCHARIN identified by the authors and their colleagues was a heptaglucoside, or seven-glucose chain (*color*), isolated from the cell wall of a fungus that attacks soybeans. It differs from a number of inactive cell-wall heptaglucosides only in the positions at which the two side chains (each a single glucose unit) are linked to the backbone (a chain of five beta-glycosidically linked glucose units). The active heptaglucoside—the oligosaccharin—is released from the fungal cell wall by an enzyme present in the host plant. Applied to soybean cells, minute quantities of the heptaglucoside oligosaccharin can activate the genes responsible for the synthesis of antibiotics that can inhibit the growth of the fungus. The inactive heptaglucosides, in any amount, never turn on the genes responsible for antibiotic synthesis, and they do not interfere with the ability of the oligosaccharin to do so.

release of an oligosaccharide from its cell-wall polysaccharide to serve as an oligosaccharin that stimulates the production of antibiotics. In our original experiments with fungi (we eventually learned) it was an enzyme from the host plant that released the heptaglucoside oligosaccharin from the fungal cell wall. In other cases it is an enzyme secreted by the disease agent, whether fungal or bacterial, that releases an oligogalacturonide oligosaccharin from the host plant's cell wall. And when a plant cell is injured, the plant cell itself secretes an enzyme that releases the oligosaccharin from the plant's own cell walls.

Davis and Brian Hodgson, who was a visiting scientist in our laboratory, have shown that two of these mechanisms may act together. When the heptaglucoside (released from the fungal cell wall by an enzyme in the plant) and the oligogalacturonide (released from the plant cell wall by an enzyme in either the pathogen or the plant) are both present, there is a synergistic effect: it takes much less of each substance working together to activate the synthesis of the antibiotic than would be required if one of the oligosaccharins were acting alone.

Having established that a fungal heptaglucoside and a plant oligogalacturonide can regulate gene expression in plant cells to generate antibiotic production, we searched for other fragments that might defend plants against insect pests. Clarence A. Ryan, Jr., of Washington State University and his colleagues had shown how plants defend themselves against certain insect enzymes (proteinases) that digest plant proteins. The plant cells synthesize inhibitors of the proteinases when the cells are triggered to do so by a chemical message Ryan called the proteinase-inhibitor inducing factor (PIIF). We collaborated with Ryan's group to establish that PIIF indeed is an oligosaccharin cleaved from a polysaccharide of the plant cell wall. Ryan and his colleagues then showed that an oligogalacturonide that stimulates synthesis of the proteinase inhibitor is similar to one shown earlier to stimulate antibiotic synthesis. It appears that oligogalacturonides can act differently, depending on what plant cells they interact with, to turn on the appropriate defense response.

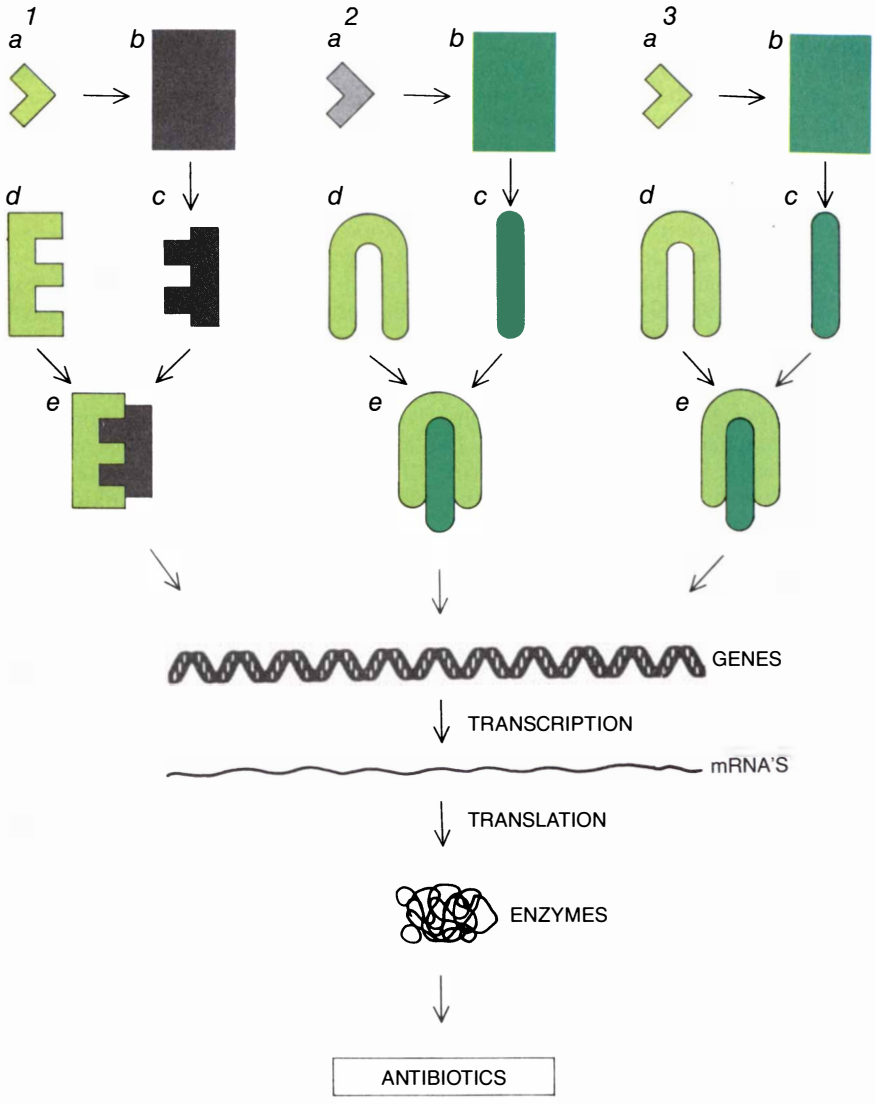
A particularly important and widely observed defense response of plants is the self-sacrifice of the first few cells of a plant that come in contact with an invading microbe. This "hypersensitive resistance response" is thought to somehow impede invading microbes long enough for other defense mecha-

nisms (such as the accumulation of antibiotics) to take effect.

We speculated that an invading microorganism might bring about the release of an oligosaccharin, from cell walls in the neighborhood of the infection, that is recognized by plant cells as a signal to undergo hypersensitive death. In support of our hypothesis Noboru Yamazaki, a visiting scientist, and we were able to isolate from the walls of sycamore cells an oligosaccharin that kills sycamore cells. Steven H. Doares, a graduate student, found that the sycamore oligosaccharins can kill not only sycamore cells but also maize cells, and that oligosaccharins from maize cell walls kill sycamore cells as well as maize cells. These results and others indicate that the cellular suicide may well be triggered by the cell's recognition of oligosaccharins released from neighboring cell walls in response to an invading microbe. The oligosaccharin that induces cell death is not an oligogalacturonide but some other fragment having a more specific function.

Having identified oligosaccharins able to activate defense responses in plants, we considered the possibility that similar molecules help to regulate other functions of plants, such as growth, development and reproduction. Was it possible that (at least in some cases) classical plant-growth regulators such as auxin and gibberellin work indirectly, by activating specific enzymes that release oligosaccharins—which in turn directly regulate many of the normal physiological processes of plants?

The ability of auxin (and synthetic auxins such as 2,4-D) to stimulate the growth of pea-seedling stem segments has been studied for many years. William S. York and we studied the ability of oligosaccharides from the sycamore cell wall to modulate auxin's effect on the rate of growth of pea-stem segments. We found that mixtures of oligosaccharides extracted from sycamore cell-wall polysaccharides could inhibit auxin-stimulated growth in pea-stem segments maintained in a culture dish. It took about three years to isolate a highly purified, active oligosaccharin fraction from xyloglucan, a polysaccharide present in the primary walls of plant cells. The fraction strongly inhibits auxin-stimulated growth of pea stems. We believe the active oligosaccharin is either a nonasaccharide (a nine-sugar fragment) or another fragment very closely related to the nonasaccharide. The concentration of the oligosaccharin required to inhibit auxin-induced growth is about 100 times lower than the concentration of auxin required to stimulate growth.



SYNTHESIS OF ANTIBIOTICS by plants is triggered by oligosaccharins. Three mechanisms are known by which an oligosaccharin can be released from a cell wall. In some fungal infections (*1*) an enzyme from the infected plant (*a*) cleaves from the fungal cell wall (*b*) a heptaglucoside fragment (*c*). The fungal heptaglucoside is an oligosaccharin. In other cases (*2*) the fungal or bacterial pathogen supplies an enzyme that cleaves the infected plant's cell walls, releasing an oligogalacturonide oligosaccharin (*c*). Finally, in some cases a plant that is damaged in any of several ways (*3*) itself supplies an enzyme that cleaves the oligogalacturonide from its own cell walls. In all three cases the oligosaccharin presumably combines with a receptor in the plant (*d*) to form an activated signal molecule (*e*). The signal causes a number of plant genes to be transcribed into messenger RNA's, which in turn are translated into enzymes. The enzymes then catalyze the synthesis of various antibiotics.

This work dovetailed neatly with findings reported about 10 years ago by Gordon A. Maclachlan of McGill University and his colleagues. They demonstrated that treating pea stems with auxin not only stimulates growth but also increases about fiftyfold the activity of a particular enzyme in the wall of the pea-stem cells. They later found that the enzyme cleaves xyloglucan into its oligosaccharide components, which are predominantly nona- and heptasaccharide fragments. We have now found that the nonasaccharide fragment of xyloglucan (or a closely related oligosaccharide) released by the cleavage enzyme inhibits auxin-induced growth. In other words, auxin (which in general stimulates pea stems to grow) also activates the enzyme that releases a cell-wall oligosaccharin acting to inhibit the auxin-induced growth. Such "feedback" modulators of hormonal activity are well known in animal systems but had not been shown to operate in plants.

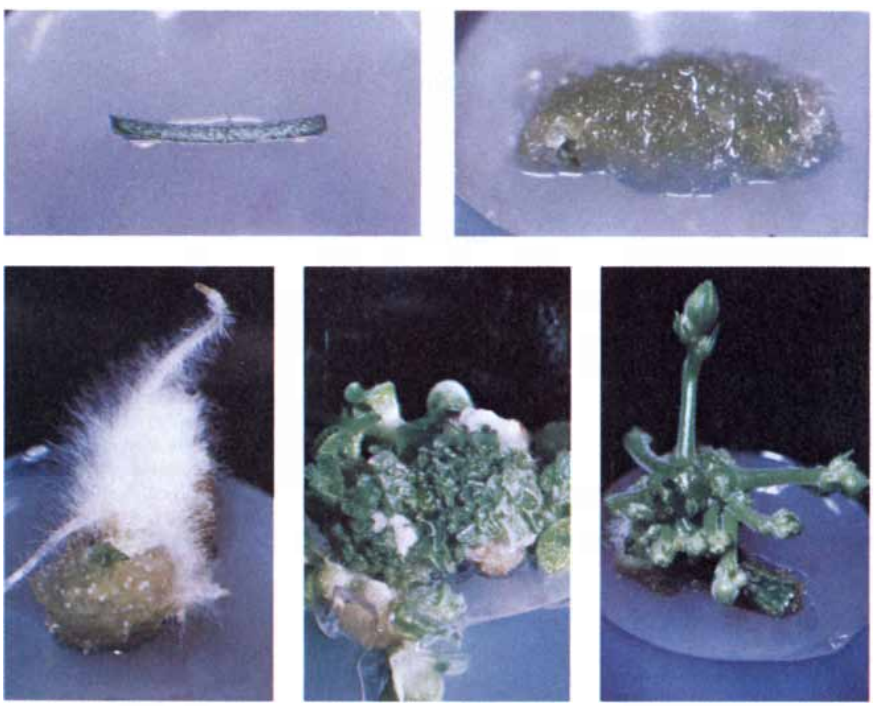
We assume that auxin increases the activity of the polysaccharide-cleaving enzyme by making more of it—by activating the genes encoding it. We think

that when auxin thus increases the amount of the oligosaccharin inhibiting auxin-induced growth, the oligosaccharin may be transported down the plant stem to inhibit the growth of lateral buds. It is well known that cutting off the apical bud at the tip of a plant makes the plant bushier. It has been thought that removing the bud removes the source of auxin, which has been assumed to be directly responsible for apical dominance, or the inhibition of lateral growth. We propose instead that removing the source of auxin actually decreases the amount of the enzyme that releases the inhibiting oligosaccharin from xyloglucan. If we are right, it is the oligosaccharin (which, we have shown, inhibits the growth of stem segments) that directly inhibits lateral bud growth. Experiments are now under way to find out whether the oligosaccharin makes a plant grow tall and thin by inhibiting the growth of lateral buds.

Might oligosaccharins have roles not only in defense responses and the control of growth and shape but also in regulating organ development (morphogenesis) and reproduction? To determine their role in morphogenesis and reproduction we wanted to test their ability to induce plant tissue growing in a culture medium to form particular organs. Kiem Tran Thanh Van and her colleagues at the Laboratoire du Phytotron at Gif-sur-Yvette in France have developed an elegant tissue-culture system for testing the effect of factors in a culture medium on the growth of thin strips of tobacco-plant flower stems. They floated thin tobacco "explants" on liquid culture mediums containing salts and glucose (as a source of energy). They added precisely predetermined amounts of auxin and cytokinin and adjusted the acidity of the culture medium. In a series of experiments they found that the ratio of auxin to cytokinin and the acidity of the culture medium determined whether the explants grew to form undifferentiated callus or differentiated to form either flowers, vegetative buds or roots.

We hypothesized that the actual effect of the auxin, cytokinin and level of acidity is to influence the release and modification of an array of chemical messages, each of which regulates the biochemical reactions responsible for a particular developmental program. Tran Thanh Van, Patrick Toubart and Alain Cousson at Gif-sur-Yvette collaborated with David J. Gollin, Paulanne Chelf and us to test this possibility.

We added mixtures of oligosaccharides isolated from sycamore cells to the tobacco-explant culture medium to see whether the mixtures included oligosaccharins able to influence organ development. There were several different mixtures of oligosaccharides, including one we had earlier shown to inhibit flowering and promote vegetative (nonreproductive) growth in duckweed. The same mixture that inhibited flowering in duckweed was found to both inhibit flowering and stimulate prolific vegetative budding in the tobacco explants. The oligosaccharins were effective in impressively low amounts, from 100 to 1,000 times less than the amounts of auxin and cytokinin present in the media. In the presence of a different mixture explants that formed vegetative buds in the absence of added oligosaccharides formed flowers. Still another oligosaccharide mixture caused explants that would ordinarily have formed vegetative buds or callus to form prolific roots instead.



EFFECT OF OLIGOSACCHARINS on morphogenesis was tested with tobacco explants by Kiem Tran Thanh Van and her colleagues. The stem of a flower of a tobacco plant is cut off and strips composed of the epidermis (one cell layer), subepidermis (one cell layer) and parenchyma (from one cell layer to three layers) are removed. The strips are one or two millimeters wide and 10 millimeters long (*top left*). Some 20 such explants are floated in a liquid medium containing glucose (as an energy source) and salts in a petri dish. The plant hormones auxin and cytokinin are added, along with various mixtures of oligosaccharins supplied by the authors. The ratio of auxin to cytokinin, the acidity of the culture medium and the particular mix of oligosaccharins determine the developmental response. As is shown by these photographs (which are of single explants grown on solid agar), an explant may, under the influence of various oligosaccharins, form an undifferentiated callus (*top right*), roots (*bottom left*), vegetative shoots and leaves (*bottom middle*) or floral shoots (*bottom right*).

The ability of oligosaccharins to regulate organ development in tobacco explants is compelling evidence for the possibility that these cell-wall fragments act as regulators of morphogenesis and reproduction in plants. The results of the experiments we have described, together with our original findings on the complexity of cell-wall polysaccharides, support our theory that plant cell walls are the repository of a large number of specific oligosaccharins. The oligosaccharins may represent another tier in a hierarchical hormone system. They appear to regulate not only the activation of defense mechanisms but also aspects of plant growth, morphogenesis and reproduction. One day it may be possible to spray specific oligosaccharins (or analogues of oligosaccharins) on plants (or to manipulate the genes controlling the release and metabolism of oligosaccharins) to tell plants to flower or to form seeds and fruits or tubers, to become resistant to a disease or an insect, to drop their fruit, to grow faster or to become bushier. Oligosaccharins should eventually have a significant impact on agricultural yields.

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Manage

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SCIENCE AND THE CITIZEN

Falling Star?

The notion that extraterrestrial forces have regularly and catastrophically intruded into the history of life gained wide currency a little more than a year ago. In the scenario that has received the most attention in the scientific and popular press, a dim, distant companion star of the sun is held to send periodic showers of comets into the inner solar system, where some of the comets strike the earth, causing a mass extinction of species. Called the Nemesis hypothesis after the name of the putative star, the proposal has been the subject of newspaper articles, two editorials in the *New York Times* and a cover story in *Time* magazine. A reassessment of the fossil evidence now suggests the regular extinctions said to be the handiwork of Nemesis may never have taken place.

Nemesis and similar theories grew out of an earlier and more modest claim. In 1979 Luis W. Alvarez, Walter Alvarez, Frank Asaro and Helen V. Michel of the University of California at Berkeley reported that a layer of clay deposited at the end of the Cretaceous period (about 65 million years ago) in Italy, Denmark and New Zealand contains anomalously high levels of iridium. Iridium is rare in the earth's crust, but it is abundant in meteorites. Widespread extinctions, including the demise of the dinosaurs, marked the end of the Cretaceous. The workers proposed that the extinctions and the iridium layer had a common cause: the impact of an extraterrestrial object, probably an asteroid about 10 kilometers in diameter. Since then the finding that an iridium anomaly exists at many other sites around the world and that the iridium-rich clay also contains minerals apparently altered by heat and shock have bolstered the case for a Cretaceous impact.

The impetus to extend the isolated event proposed by the Berkeley workers into a cycle of catastrophes came in late 1983 in the form of an analysis of stratigraphic data on fossil marine animals, done by David M. Raup and J. John Sepkoski, Jr., of the University of Chicago. For each stratigraphic stage into which the fossil record of the past 250 million years is divided they determined the rate of extinction (defined as the number of families that became extinct in the stage divided by the number of families existing during the stage). The rate peaked regularly, at intervals of about 26 million years. (Statistical tests also indicated a weaker periodicity of 30 million years.) Raup and Sepkoski suggested that the periodicity reflects a recurrent event, probably of astronomical origin, in the physical environment.

Astronomers and astrophysicists were quick to supply possible mechanisms. In several scenarios the regular oscillation of the solar system above and below the plane of the galaxy drives the periodic mass extinctions. Michael R. Rampino and Richard B. Stothers of the National Aeronautics and Space Administration's Goddard Institute for Space Studies proposed, for example, that during passages through the galactic plane, which occur at intervals of about 33 million years, encounters with clouds of gas and dust disturb the solar system's family of comets, setting one or more on a collision course with the earth.

Daniel P. Whitmire of the University of Southwestern Louisiana and Albert A. Jackson IV of the Computer Sciences Corporation, and simultaneously Marc Davis of Berkeley, Piet Hut of the Institute for Advanced Study in Princeton, N.J., and Richard A. Muller of Berkeley, proposed models in which the extinction periodicity reflects the orbital period of a companion star of the sun. The companion would currently lie at a distance of several light-years, but its orbit would be eccentric. Every 26 million years, at its closest approach to the sun, the star would pass through the dense inner region of the Oort cloud, a region of comets that is thought to envelop the solar system. The gravitational influence of Nemesis would precipitate a comet shower. (The star got its name when an editor at *Nature* selected it from a list of possibilities Muller and his colleagues were considering.)

Support for the notion of periodic impacts has come from the finding of a regularity in the ages of large impact craters that matches the extinction cycle; other geologic events, including reversals in the earth's magnetic field and episodes of tectonic activity, also seem to have occurred on a similar timetable. The proposed mechanisms have been criticized, however, on astronomical grounds. It appears, for example, that clouds of gas and dust are not clustered densely enough near the galactic plane to produce a sharp perturbation of the solar system's flock of comets as the sun crosses the plane. As for the Nemesis model, some workers now argue that a companion star at the great distance that is required would

Manicouagan Crater in Quebec, 70 kilometers wide: possible trace of a comet shower?

have little chance of staying bound to the sun long enough to have triggered the regular extinctions.

Now the focus of the criticism has shifted from the models themselves to the finding that elicited them: the apparent periodicity in the fossil record. In a recent paper in *Nature* Antoni Hoffman of Columbia University contends that uncertainties in fossil dating and biases in Raup and Sepkoski's methodology cast doubt on their results.

Hoffman points out that Raup and Sepkoski pared the 3,500 families in their original data down to 567 by removing families whose origin and extinction cannot be resolved to single stages and families with currently surviving species. The culling of the data reduced noise and the uncertainty resulting from the fact that many recent fossils are classified as members of extant groups although they may represent morphologically similar but extinct groups. But it also meant that small fluctuations in extinction rate during recent stages would be magnified by the reduced number of families under consideration. When Hoffman restored the omitted families to the data, many of the sharpest extinction peaks disappeared.

The original finding of periodicity also turned out to be highly sensitive to the geologic time scale used to establish absolute dates for the stages. Equally plausible time scales for the past 250 million years or so can differ by 10 million years or more on the dates of stratigraphic boundaries. Given a time scale different from the one Raup and Sepkoski adopted, the 26-million-year periodicity weakened.

In another line of argument, presented in a paper in *Geological Magazine,* Hoffman and Joe Ghiold of Louisiana State University suggest that Raup and Sepkoski's criterion for identifying a mass extinction is biased toward periodicity. The criterion is not quantitative. Instead an episode of mass extinction is simply any local peak in extinction rate: any stage in which the rate is higher than in the preceding and following stages. To analyze the effects of that definition Hoffman and Ghiold apply it to a hypothetical model in which the rate at which families become extinct varies at random from stage to stage. For each stage the probability that the extinction rate is higher than in the stage preceding it is one-half; the likelihood of its being higher than in the following stage is also one-half. The probability that the stage represents a peak in extinction rate is therefore one in four.

Even if extinction rate varies randomly, an average of one stage in four will count as a mass extinction. In the time scale Raup and Sepkoski adopted, the geologic stages in the period they consider have average durations of 6.2 million years. Hence, Hoffman argues, Raup and Sepkoski's definition of mass extinction, together with their time scale, makes a rough periodicity of about 26 million years inevitable. There may indeed have been a periodicity in the extinction rate, but the regularity could also be an artifact. If it is, the case for Nemesis and its companion theories weakens.

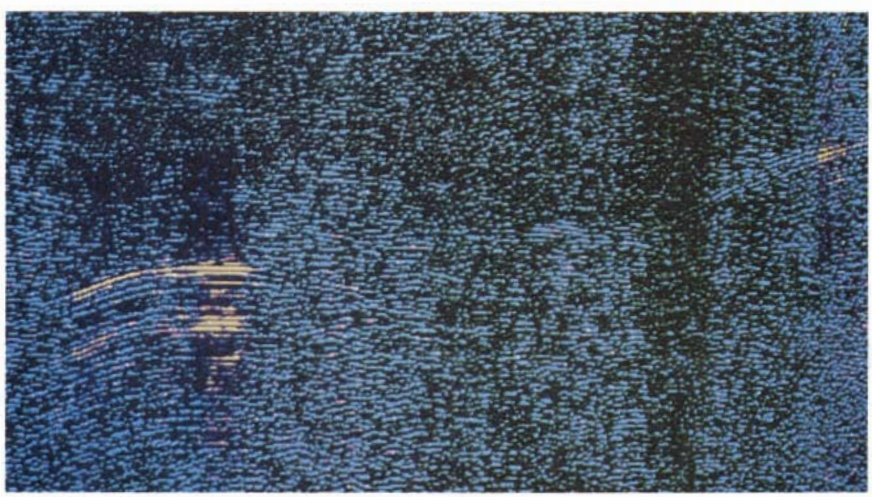
Raup and Sepkoski stand by their finding. In their original work they tested their result by randomizing (shuffling) the data and analyzing it for periodicity. The 26-million-year cycle was not evident, which suggests that it is inherent in the real data and is not an artifact of the investigators' method. Since then they have done an analysis of the complete 3,500-family data set; the 26-million-year periodicity reappeared. Sepkoski has also found the regularity in extinctions analyzed at the level of the genus, a finer taxonomic division than the family. Reports of both new analyses are in press.

Hoffman's arguments do not rule out the possibility that extraterrestrial influences have shaped the history of life, even if they make it unnecessary to suppose the celestial intrusions have been regular. In applying various statistical criteria to Raup and Sepkoski's data Hoffman found that the final stage of the Cretaceous consistently qualified as a mass extinction. The unmatched disruption of the biosphere that occurred then and the coincident iridium layer continue to make a powerful case for an isolated impact's having ended the reign of the dinosaurs.

Hidden Graft

Some 300 million years ago North America collided with Africa, raising the Appalachian mountains and closing the ancient ocean known to geologists as Iapetus. Some 110 million years later the continents came apart again when a new ocean, the Atlantic, opened between them. The continents rifted along much the same line as the one on which they had joined. In at least one place, however, the rifting was disordered: a part of Africa transferred itself to North America. The part is known today as Florida. The suture between North America and this fragment of Africa's crust has now been found. It lies deep under southern Georgia.

The finding—the first direct detection of a deep suture zone—was made by the Consortium for Continental Reflection Profiling (COCORP), based at Cornell University. The southern-Georgia work was led by K. Douglas Nelson of Cornell. The consortium employs Vibroseis, a technique de-



Strong reflections* (yellow) *occupy the suture zone in a seismic profile from southeastern Georgia

vised by the Continental Oil Company to aid petroleum exploration. It requires five vibrators, each mounted on a truck; roughly 2,000 small seismometers buried along a baseline about ten kilometers long, and a further truck that orchestrates the shaking and carries recording equipment. Twenty seconds of synchronous shaking produces seismic signals. The result is a pattern of reflections caused by discontinuities deep in the earth.

The geologic provenance of Florida had first been surmised from totally different data. In 1966 J. Tuzo Wilson of the University of Toronto examined samples of rock recovered from drill holes made in the coastal plain of northern Florida. The rock came from a subsurface feature known to field geologists as the Suwannee basin. Fossils in the rock were similar to fossils from rock of identical age (as old as 500 million years) in western Africa but different from the fossils in Appalachian rock of that age. The COCORP profiles show the Suwannee basin; it lies under the flat, strong reflections from the sediments the Atlantic has deposited in relatively recent geologic times to create the coastal plain. The profiles from southern Georgia show a further subsurface feature: a sequence of sediments and volcanic rocks suggesting a failed basin—a site where the crust stretched and weakened but nonetheless resisted the upwelling of volcanic rock that initiates formation of an ocean floor. Field geologists, who know the feature from well samples, call it the South Georgia basin.

The suture between North America and Africa appears to be just northwest of the basin. It shows up in the COCORP profiles as a broad, complex zone of dipping reflections. Several lines of evidence combine to suggest that the zone in fact is the suture. For one thing, the zone intervenes between what has been identified as African basement rock (underlying the Suwannee basin) and as North American basement rock (in western central Georgia). The rock is metamorphic, and it predates both the Atlantic and Iapetus; it was part of the great African/North American landmass that broke apart, rejoined and broke apart again. Radiometric techniques applied to samples recovered from wells give it an age of about 1.1 billion years.

Then too, the zone coincides with a prominent anomaly in the pattern of magnetism detected in the crust by aerial surveys. In particular it coincides with the Brunswick anomaly, a band extending eastward across Alabama and Georgia. The band has long been taken to mark a crustal disruption of some kind. Offshore the Brunswick anomaly comes into alignment with the boundary between the continental crust of North America and the oceanic crust of the Atlantic. From that point northward, the COCORP group concludes, the Atlantic broke open precisely along the line on which Iapetus had closed.

Most recently the COCORP group has been making profiles across the Brunswick anomaly in southeastern Georgia. There the group finds some remarkably strong reflections from within the suture zone at depths as great as 18 kilometers. The strength and the lenslike shape of the reflections lead the group to speculate that the reflections may be the first detection of a gas-liquid interface deep in the crust. The fluids were trapped, it seems, in a structure created during the suturing. Although the actions of fluids trapped in the crust are poorly understood, they are likely to be crucial in determining how the crust deforms.

Ringing False

After ringing true for three or four centuries the bells in many of the steeples and carillons of Holland have, in the past 25 years, gone out of tune.

Acid rain is the cause of the problem. It corrodes the wall of a bell, thinning the metal and lowering the bell's pitch. The corrosion affects small bells faster than large ones. Consequently the pitch of different bells is lowered disproportionately and the sound of the carillon becomes increasingly dissonant. The remedy is to lower the tone of the larger bells by carefully scraping the inside in order to adjust the frequency.

High-sulfur coal that was burned in the Netherlands until the 1960's is responsible for the problem. Sulfur dioxide from coal smoke mixed with moisture in the atmosphere to form sulfuric acid, which (as a constituent of rainwater) attacked the bells. Andre Lehr of Royal Eijsbouts, a major bell foundry in the Netherlands, believes all the 15,000 or so bells in the country may have been damaged. Because of the extent of the problem, the environment ministry of the Netherlands has commissioned a study of the relation between air pollution and bell tone.

Sick System

Could the Federal Government's hospital payment plan, based on diagnosis-related groups (DRG's), be intensifying one problem as it tries to solve another?

Two years ago, in an effort to control rapidly increasing expenditures for hospital treatment under its Medicare program, the Health Care Financing Administration (HCFA) of the Department of Health and Human Services began to phase in a new system of payment based on DRG's. A DRG is a cluster of related illnesses. Under the new payment system every illness is assigned to such a group. Each DRG in turn is associated with a fee—an average cost of treatment that a hospital can claim from the Government. The system also takes account of the fact that the cost of treating the same disease by the same procedure can vary from hospital to hospital. For example, the cost of patient care in university teaching hospitals, which typically receive the most seriously ill patients through referrals, is usually higher than it is in community hospitals. The HCFA tries to compensate such institutions by adjusting the fixed DRG reimbursement rates according to the ratio (which is relatively high in teaching hospitals) of medical residents to hospital beds.

A study by a team at Johns Hopkins University, published in the *New England Journal of Medicine,* indicates that for many hospitals the system does not successfully relate compensation to costs. The Hopkins investigators were Susan D. Horn, Gregory Bulkley, Phoebe D. Sharkey, Angela F. Chambers, Roger A. Horn and Carl J. Schramm. They based their conclusion on an analysis of the medical records of more than 57,000 inpatients from six hospitals: three university teaching hospitals, two community teaching hospitals and one community nonteaching hospital. The records were assigned to their respective DRG's and scored in terms of a "severity-of-illness index."

The investigators found that about a third of all DRG's examined showed a wide variation in severity. For example, a diseased gall bladder may necessitate an operation, which in one patient's case may entail five days in the hospital and a bill of less than $5,000; another patient who undergoes the surgery might spend three weeks in the intensive-care unit and incur a charge of more than $20,000.

Such variation is not a problem as long as a hospital gets roughly equal numbers of complicated and uncomplicated cases, in which case its costs would average out at about the level of compensation set by the DRG scale. The Hopkins investigators found that some hospitals consistently handle the more complicated cases, however: the cases that generate the highest costs.

The HCFA's resident-to-bed supplement does not effectively offset the additional expense, the investigators conclude. A ranking of the hospitals

according to how much money they would be entitled to under the HCFA's DRG-based system differed markedly from a ranking of the same hospitals according to an aggregate measure of the severity of the cases they treat.

The investigators believe some reliable measure of an illness's severity is needed as an integral part of any equitable system of hospital payment. The current DRG system—particularly if it comes to be widely accepted by other government and private health-care programs—may, in the name of controlling inflation, put disproportionate financial pressure on the very hospitals that, in a sense, do the most good: those that treat the sickest patients.

Letting Go

Metastasis begins when a cancerous cell frees itself from the tissue in which it has grown, changes shape (usually by becoming round) and migrates to another site, where it multiplies to form a tumor. How does a cell escape from its original site? A team from two medical schools has found an important part of the answer.

In normal tissue, cells are linked and held in place by a variety of glycoproteins (proteins with sugar chains attached), including one called fibronectin. Fibronectin consists of rather intricate and heavy molecules extruded by individual cells. The molecules form a meshwork that connects the cells to other components of the extracellular matrix. Instead of simply adhering to the cell surface the fibronectin molecule attaches at a specific site to a complex protein embedded in the cell membrane. The protein extends through the membrane to the cell's interior. There it joins the proteins of the cytoskeleton, which gives form to the cell somewhat as tent poles give shape and stability to a tent.

For metastasis to take place the connection between a cancerous cell and the fibronectin must be broken. When that happens, the cell is free to drift away through the bloodstream or the lymphatic system. It is the breakdown of such a connection that Wen-Tien Chen and Jinq-May Chen of the Georgetown University School of Medicine and Dentistry and Sarah J. Parsons and J. Thomas Parsons of the University of Virginia School of Medicine have observed.

The investigators deciphered the process by studying in culture chick embryo fibroblasts and the associated fibronectin. They began by infecting the cells with a temperature-dependent strain of Rous sarcoma virus (RSV), a retrovirus that causes a cancer of connective tissue in chickens. At 41 degrees Celsius, a temperature at which RSV cannot replicate, no change was observable in the cells or the culture. At 37 degrees C., the temperature at which RSV multiplies, the cells became round and black spots appeared in the fluorescent medium, indicating that fibronectin was disintegrating.

To confirm that this was happening the workers did the experiment with radioactively labeled fibronectin. They were able to detect radioactive fibronectin fragments in the medium. When they compared the positions of the black spots with the locations of rosettelike contact points (marked by fluorescent antibodies), they made an exciting observation: the regions of degraded fibronectin coincided neatly with the contact-point rosettes. Outside the transformed cell, at locations corresponding to the sites of the contact points, an enzyme that degrades fibronectin was clearly at work.

What events or factors within the transformed fibroblasts might be related to the presence of the enzyme? The workers turned their attention to another enzyme: pp60*src,* the protein product of RSV's oncogene, or cancer-causing gene. They ran the experiment again, using an immunofluorescence technique involving monoclonal antibody to pp60*src*. The workers found that at 37 degrees C. the enzyme migrated strongly to the contact-point rosettes (as well as to other areas called focal adhesions). Once again the cells became round and the positions of the contact points and the areas of degraded fibronectin coincided precisely. In a control experiment in which uninfected cells were subjected to the same treatment no change in shape was observed, there was no viral pp60*src* and the fibronectin remained intact. The Chens and the Parsons conclude that without the viral enzyme the fibronectin-degrading enzyme could not do its work and the cancerous fibroblasts would not be able to drift away from the fibronectin mesh.

Quantum Leaps

One of the central concepts to emerge from recent studies of molecular evolution is that of the molecular clock. The idea is that random mutations seem to alter the genetic material, DNA, at a rather steady rate over long periods. One can therefore establish a clocklike relation between the number of replacements of nucleotide bases (the subunits of DNA) and elapsed time and so track the divergence of species. After reanalyzing existing genetic data, however, John H. Gillespie of the University of California at Davis has proposed a hotly disputed theory. He argues that molecular change may instead occur in sporadic bursts and that an "episodic clock" is therefore a better model of the process.

Gillespie writes in *Proceedings of the National Academy of Sciences* that he has developed a new mathematical technique for describing the complex dynamics of molecular change. Working with records from the National Biomedical Research Foundation (NBRF) in Washington, D.C., he applied his technique to data for the amino acid sequences of several proteins, such as hemoglobin and cytochrome *c,* from a wide variety of mammals including humans, rodents, rabbits, cows and whales. Since the sequence of amino acids in a protein is specified by the sequence of bases in the gene encoding the protein, Gillespie in effect could examine the rates at which genes change. He concluded that what appears to be a steady rate of DNA mutation is an artifact: it results from a gross averaging of fluctuations over enormous periods.

Gillespie thinks the bursts of activity characterizing his episodic model may reflect environmental changes. The apparent steadiness of the molecular clock, on the other hand, has fostered the view that molecular change is dominated by the accumulation of neutral mutations: mutations that are neither advantageous nor disadvantageous for an organism. Some molecular biologists have therefore argued that, although natural selection operates at the organismal level, it is not felt at the molecular level. The episodic model suggests that natural selection may have an effect at the molecular level by exerting pressure at the organismal level.

Universal Time

A pulsar is thought to be a spinning neutron star that emits a narrow beam of electromagnetic radiation. As the beam sweeps through the sky like the light from a lighthouse it intermittently points toward the earth, where it is observed as a series of pulses. In the case of some pulsars the interval between pulses is so regular that the stars are in effect celestial clocks. One of these has now been shown to be amazingly accurate. Called PSR1937 + 21, it is by far the fastest of all pulsars, rotating 642 times per second, or once every 1.56 milliseconds. According to astronomers who have been observing it since its discovery in late 1982, it has been marking time as precisely and reliably as the best atomic clocks.

The observations are reported in

Nature by Michael M. Davis of the Arecibo Observatory, Joseph H. Taylor and Joel M. Weisberg of Princeton University and Donald C. Backer of the University of California at Berkeley. Microwave pulses emanating from PSR1937 + 21 are detected with the 305-meter telescope at Arecibo, and the arrival times are measured with a rubidium clock. They are then checked against a master clock at the U.S. Naval Observatory in Washington—actually a bank of cesium clocks whose measurements are averaged to produce the best-possible time standard.

The regularity of the pulsar is not immediately apparent. Like other pulsars PSR1937 + 21 is slowing down as it radiates energy, but the deceleration rate is remarkably constant and therefore easily taken into account. The signal is delayed in an inconstant way, however, by passage through the interplanetary and interstellar medium and through the sun's gravitational field. Changes in the earth's velocity as it moves in its orbit also affect the pulse arrival times.

All these effects of earthbound observation must be calculated and corrected for by means of a mathematical model that converts the arrival times into "barycentric dynamical time": the time at the center of mass of the solar system. In that frame of reference the pulsar signal turns out to be extremely regular. Over the course of a year the signal drifts only about a microsecond out of synchrony with the Naval Observatory standard, a performance comparable to that of any individual cesium clock.

Because of its precision the pulsar clock may place a useful constraint on cosmological theories. Some of those theories hold that chaotic processes in the fraction of a second after the big bang generated a cosmic background of gravitational radiation. (According to general relativity, an accelerated mass emits energy in the form of gravitational waves, but such waves, assuming they exist, are so feeble that they have never been detected directly.) The dilation and contraction of spacetime caused by a passing gravitational wave would be expected to produce variations in the pulse arrival times; the more intense the gravitational wave, the greater its effect on the pulsar signal.

The constancy of the signal from PSR1937 + 21 to within a microsecond per year sets an upper limit on the amplitude of the hypothesized gravitational background. So far the limit does not contradict theoretical predictions, because it is higher than any of them. Technical improvements and continued observations over the next decade, however, should enable Backer and his colleagues to lower the limit by two or three orders of magnitude, thereby testing the theories.

This optimistic forecast assumes that the pulsar itself will remain stable. Many other pulsars have been subject to "glitches": a rapid speeding up of the pulse rate followed by a longer period during which the star settles down again to its normal behavior. Moreover, an upper limit on the intensity of the gravitational background radiation is not confirmation that the background exists. Such confirmation cannot come from observations of a single pulsar, because any perturbation in the signal could be attributable to an unknown type of disturbance of the star itself. To demonstrate the presence of a gravitational background astronomers will need to find more millisecond pulsars and show that disturbances in their signals are correlated. A new pulsar, to be of any help, would have to be as accurate and reliable a clock as PSR1937 + 21.

Astronomical Ophthalmology

An "adaptive mirror" that makes the view from a ground-based telescope as sharp as the view from a telescope in space has passed a series of tests at the National Solar Observatory

at Sacramento Peak in New Mexico. The "mirror" is actually a complex arrangement of optical and electronic elements that adjusts the light reaching a conventional telescope mirror to correct for distortions of the image normally caused by turbulence in the earth's atmosphere.

The adaptive mirror tested in New Mexico is the product of three years of work by Robert C. Smithson and his colleagues in the Solar and Optical Physics Department of the Lockheed Palo Alto Research Laboratory. The system breaks the shimmering image received by the Vacuum Tower Telescope at Sacramento Peak into 19 smaller images. Operating separately on each small image, it senses the extent to which the atmosphere has bent the incoming wave front of light and electronically restores the correct orientation. Then it combines the 19 corrected images at a common focus on the single mirror of the telescope.

In the recent tests the Sacramento Peak telescope was aimed at an active region of the sun. The observers reported that the resulting images of the solar surface were five times sharper than uncorrected images obtained simultaneously.

This adaptive mirror and others under development are not thought of as replacements for telescopes carried by space vehicles. Instead the assumption is that telescopes in space will soon be recording new phenomena, which will then require more extensive study from the ground.

At present the adaptive mirror requires a bright source of light. Eventually the investigators hope to perfect adaptive mirrors that will serve for observations of stars. In theory the light source will have to be at least of the 12th magnitude, which is quite bright. The recent tests revealed, however, that the instrument corrects seeing over a larger area than had been predicted. Hence it may be possible to find a 12th-magnitude star close enough to a dim object of interest so that the corrected image will show that object sharply too.

Audiogram

A hologram is a three-dimensional image, or interference pattern, made with laser beams. Normally a hologram is captured in a photographic transparency and viewed with laser light or ordinary white light. Investigators working at the Massachusetts Institute of Technology have developed holographic devices that interact with sound waves as well.

Daniel E. Oates, Paul G. Gottschalk and Peter V. Wright explain in *Applied Physics Letters* how the devices work. The storage medium is a small block of iron-doped lithium niobate one centimeter long, one centimeter wide and about a millimeter thick. By directing two argon-laser beams at the block, the workers create a holographic grating within it. Such a grating consists of a three-dimensional series of parallel planes of light (regions where the wave fronts from the lasers constructively interfere) sandwiched between parallel planes of dark (regions where the wave fronts destructively interfere). Iron atoms lying in the planes of light (high-energy zones) absorb energy and emit electrons. The electrons subsequently drift to the planes of dark (low-energy zones), where they remain trapped even after the lasers are turned off. The flow of electrons causes properties of the block to change in a regular way; for example, the density of regions corresponding to light planes is less than the density of regions corresponding to dark planes.

Such variation in density affects the speed of sound waves. A sound wave directed into the lithium niobate hologram can even be reflected if the frequency of the wave lies within a narrow range determined by the distance between the grating spaces. If the incident wave is made up of a number of different frequencies, only those that

lie within the band will be reflected. The holographic device can therefore serve as a filter that eliminates these frequencies.

Filters are important components of satellite and communications systems. Oates says the holographic device is ideally suited for such applications because it is simple and compact and can be mass-produced.

Piping Hot

Workers at the Los Alamos National Laboratory have developed a heat pipe that can transmit as much as 150,000 watts per square inch—more power per unit of area than passes through the surface of the sun and 20 percent more than any other heat pipe has been able to transmit.

The heat pipe, designed by Michael A. Merrigan, Edward S. Keddy, J. Tom Sena and Steven P. Limback, has three main components: an outer casing, a wick and a working fluid. The outer casing is a molybdenum cylinder four meters long and three-quarters of an inch in diameter, with a wall .03 inch thick. The cylinder is closed at both ends. The wick, a hollow cylinder made of a fine mesh screen of molybdenum-rhenium wires, rests just inside the casing, separated from the casing's inner wall by a distance of about .02 inch. The space between the wick and the casing is filled with molten lithium, the heat pipe's working fluid. Surface tension keeps lithium from passing through the mesh screen into the volume enclosed by the wick.

In operation one end of the pipe is placed near a source of heat. Lithium molecules near that end of the pipe vaporize, separating from the liquid's surface, and enter the hollow space inside the wick. The density of lithium gas inside the wick is small enough so that the molecules of lithium vapor travel from the "evaporator" end of the pipe to the "condenser" end at nearly the speed of sound, relatively unhampered by collisions with other molecules. At the condenser end lithium-vapor molecules pass through the mesh screen again to rejoin the liquid lithium, giving up some of their heat energy in the process. Capillary action pulls liquid lithium back along the wick toward the evaporator end, where the cycle starts over. Approximately two grams of lithium travel from one end of the pipe to the other each second. The heat pipe operates at a temperature of about 1,500 degrees Kelvin (degrees Celsius above absolute zero), and the difference in temperature between the two ends is approximately 10 degrees.

Heat pipes could be particularly useful in space, where low weight and mechanical simplicity are critical. Several pipes could cool an orbiting nuclear reactor and distribute energy to other devices. If one pipe failed, the others could still function.

Organic Transistors

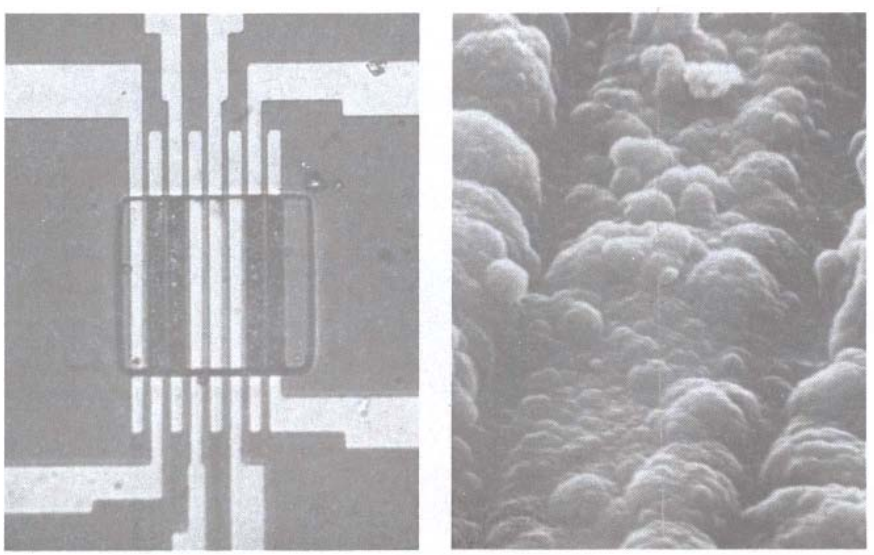
Certain organic polymers are good electrical conductors in their oxidized state (that is, when they have given up electrons) but are insulators in their reduced state (when they have acquired electrons). Mark S. Wrighton and his collaborators at the Massachusetts Institute of Technology have taken advantage of this property to manufacture transistors based on polymers rather than on such semiconductors as silicon.

A conventional transistor consists of three metal electrodes, called the source, gate and drain electrodes, attached to a silicon crystal containing regions that have differing electronic properties. A voltage applied to the gate opens or closes an electronic "channel" in the silicon substrate, through which current flows between the source and the drain. In a sense a transistor is an amplifier or a switch: a small electrical signal applied to the gate can make it possible for a much larger signal to pass between source and drain.

In Wrighton's device two strips of gold serve as source and drain electrodes. The gold wires are covered by a single thin sheet of a polymer such as polypyrrole or polyaniline; the entire assembly sits in an electrolytic solution (a solution in which electrochemical reactions can occur). There is no gate electrode; the electrolytic solution performs the function of the gate and the polymer performs that of the electronic channel between source and drain. If the electrolytic solution oxidizes the polymer sheet, current can flow through the polymer from one gold wire to the other. If the solution contains mainly reductants, the polymer acts as an insulator and no current flows. It seems paradoxical that a material should be a better conductor when it is oxidized and so has fewer electrons; in the case of polypyrrole, however, it is not electrons but "holes" (regions of positive charge resulting when sites are vacant that would normally be occupied by electrons) that transmit current by moving through the material.

Transistors made with polymers could function effectively in instruments designed to detect the presence of specific chemicals. If a polymer could be manufactured that is oxidized only by a certain set of chemicals, it could be the basis for a device in which current flows whenever those oxidants are present. A detector that incorporates a polymer-based transistor could be built on a silicon-based microprocessor chip and integrated directly into its electronics.

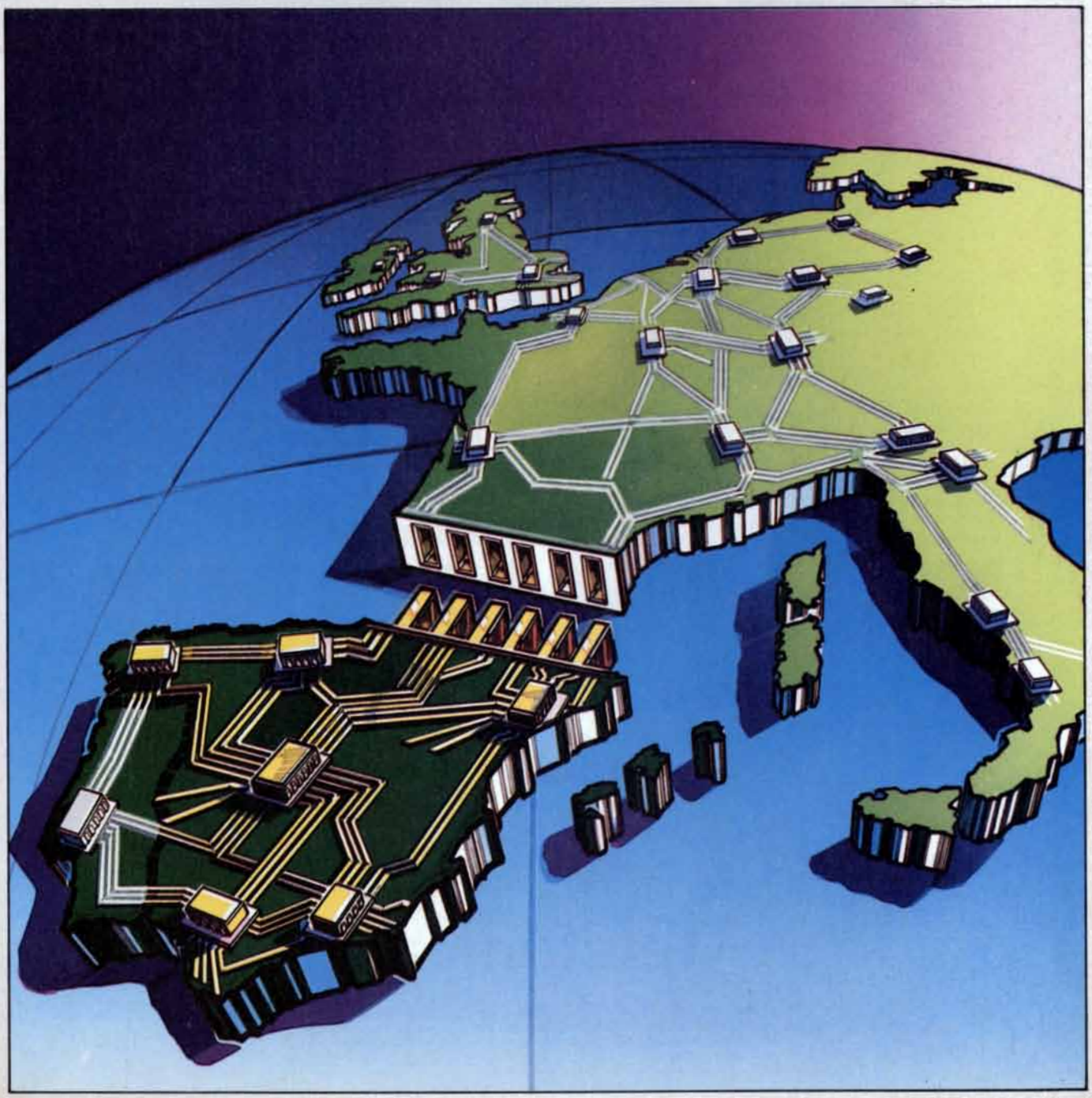
Some of the polymers studied by Wrighton's group have a property that would make them particularly effective in such detectors. Like polypyrrole, these polymers become conductors when their reduced form is oxidized; unlike polypyrrole, however, if the slightly oxidized form is oxidized further, the polymer becomes an insulator again. By manipulating the size and location of the "window" of oxidation in which these polymers are conductive, it may be possible to build devices that detect specific chemicals while ignoring stronger oxidants.



Two organic transistors **(dark gray, left)** *made by coating gold wires with a polymer* **(right)**

SPAIN

INDUSTRY AND TECHNOLOGY



SPAIN, AN ENTIRE COUNTRY BEHIND THE TELEPHONE

In Spain, TELEFONICA has for sixty years been making the telephone something more than just a communication instrument. Recently TELEFONICA and its group of companies* have made an enormous effort in research and technological developments. This has paid handsome dividends. Today every business sector in Spain benefits from TELEFONICA's advances in telecommunications.

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SPAIN

INDUSTRY AND TECHNOLOGY

After centuries of isolation Spain is preparing to join the European Economic Community. The entry evokes enormous enthusiasm from Spain's industrialists, entrepreneurs and politicians, as well as the general public. This special report by Michael Knipe and Harry Debelius examines the country's industrial and technological readiness.

"This country has the . . . capability to be the California of Western Europe," says Santiago Bergareche, a leading venture capital financing specialist in Madrid; his optimism is typical of businessmen throughout Spain.

Of course, an initial period of painful adjustment is anticipated. Spanish industry has grown in a greenhouse of protectionism. Even allowing for a seven-year transition, economists estimate that the Common Market's tariffs and other fiscal practices will cut the overall protection of Spanish industry in half.

"Some of us will cry out in pain," says Juan Llorens Corrio, vice-president for corporate development at ENASA, the national truck company that uses the *Pegaso* trademark. "But in the long run the benefits will outweigh the disadvantages."

Jesus Laforgue, projects director of Spain's capital goods manufacturers' association, estimates that at the beginning companies will suffer a 10 percent loss and export competitiveness will be cut by three or four points. "People are concerned, but we cannot go back," he says. "Even if we could stay out of the common market, we would still have to carry out our industrial modernization policies."

Prime Minister Filipe Gonzalez recently detailed an ambitious and comprehensive industrial restructuring program to prepare for Common Market entry, saying Spain had to free its resources for reinvestment in new high-technology industries. Spain, he warned, could not afford to miss out on the technological revolution as it had the industrial one.

At the heart of the government's policy is a pledge to double state spending on research and development (R&D). The need is great. Throughout the Franco years and before, research and development were ignored, *"Que inventen ellos,"* "Let the others invent," was a common expression.

This left a grim legacy. Only one in every five hundred Spaniards is a scientist, compared to one in about eighty-three people in the United States. But with roughly the same number of university graduates as elsewhere in Europe, Spain has the potential. So the government has increased the budget for scientific research in the universities from 0.5 percent to 0.8 percent — still a modest amount but an indication of intentions. After a decade of no increase in the number employed in university research, more places are being created and there is greater emphasis on applied research.

Coordinating research

Furthermore, a law to promote and coordinate scientific and technical research is expected to be passed by parliament in the fall.

By cutting the number of departments which currently oversee research programs, the legislation would simplify bureaucratic procedures and establish more effective coordination of research activities. As a spokesman for the Higher Council of Scientific Research in Madrid puts it, "It establishes a legal framework but not a corset."

The proposed law also takes into account Spain's new decentralized political structure. Supervision and organization of specific projects would become the responsibility of the regional governments, with Madrid's role often limited to stimulating and coordinating the work. The Madrid government would still define priority objectives in applied research and thus program the country's investigative resources.

Linking the eighteen self-governing regions with one another and with Madrid would be a general council composed of a representative from each region and one from an interministerial commission.

The Higher Council of Scientific Research would assume the role for which it was created in 1939, and which, for various reasons, it has not been able to achieve — that of a command post and clearinghouse for research projects all over the country. Similar though more restricted functions would be assumed by the Nuclear Energy Commission and the Geological and Mining Institute.

But the main part of the law calls for a National Plan for Scientific Research and Technological Development to set guidelines. The plan, which would be revised periodically, is intended to specify priorities and furnish estimates of project budgets (including personnel and training costs). The interministerial commission would oversee its execution.

An advisory council, incorporating representatives of labor unions, management associations, universities, and the interministerial commission, would propose objectives to be included in the National Plan and judge the final draft of each revision of the plan before it is submitted to the government for approval.

New approach to research and development

"R & D units used to be considered a luxury here," says Florencio Ornia, the director general of industrial and technological innovation at Spain's Ministry of Industry and Energy. "But fortunately, the general situation is changing and companies are beginning to realize that the way out of the recession is through the development of technology."

Ornia, 47, was appointed two years ago. Since that time he has reorganized his department, enlarged its budget for the stimulation of research, streamlined the procedure for authorizing loans for new technology, and made surveys of the technological assets and needs of different companies. He has sent scores of advisors into the field to detect their problems and help solve them.

"The important thing is to develop more concern for technological innovation," he explains, pointing out with pride efforts of the regional governments, as well as the administration in Madrid.

"I'm optimistic," he says, "because there are indications of a change . . . . If we can keep on favoring that change, and if entry into the EEC takes care of the

rest, then my optimism will have been justified."

Ornia adds that this emphasis on native technology does not bar new operations in Spain by multinationals. But the technology multinationals bring should be of a type which is otherwise unavailable to Spanish industry.

In 1983, Spanish business paid out Pts88 billion ($515 million)* in fees for patents, licenses and technical assistance, while exporting merely Pts18 billion ($105 million) worth of industrial ideas. Yet Ornia is not worried. "A country that wants to reach the take-off point in industrial and technological terms has to buy technology, just as the purchase of manufacturing equipment... propitiates the resurgency of industry." he remarks.

His real concern is not how much is spent but whether the imported technology is the kind the country needs. About 80 percent of the bill for imported technology is for technical assistance. Ornia feels that if more were for advanced technology instead, Spain's own technological development would benefit and its exports would become more competitive.

Another worry is the dominance of foreign technology. According to Ornia, 85 percent of the patents registered in Spain comes from foreign individuals or firms. In Common Market countries an average of 55 percent of patents are foreign. "We have to face up to the need to have patents of our own if we don't want to find ourselves swamped when we enter the EEC," Ornia says. He has high hopes for the proposed legislation to promote and coordinate scientific research.

R & D by royal decree

At Ornia's right hand in the drive to promote Spanish innovation is Jaime Vallori, director general of the Center for the Development of Industrial Technology (CDTI, in Spanish). He is the man who made Japanese mushrooms sprout in Galicia and Catalonian software sell in America.

"CDTI was formed in 1980, but it didn't work," he says frankly. "There was just too much bureaucracy. So we changed it. By means of a royal decree at the end of 1983, CDTI was transformed into an Entity of Public Law, a sort of private company owned by the state. That freed us from complicated paperwork and cumbersome legal restraints and long delays, and made our operation more flexible."

CDTI clearly works now. It stretches its Pts1.5 billion (less than $10 million) budget a long way to catalyze the development of new technology. Its activities can be divided into two categories: project financing and technological assistance.

CDTI finances any project its experts are convinced has good possibilities. It offers loans, repayable at moderate interest rates in two to six years, of up to 70 percent of the investment necessary to get the project rolling; occasionally it offers grants. In addition to putting up its own money, the center helps find additional funding. Its financial cooperation usually takes one of three forms:

- risk and venture capital, with CDTI sharing both the risks and the profits, if any, with the company in question;
- risk capital only, in which CDTI helps finance the project but does not share in the profits; or
- joint venture, with CDTI as a partner.

It also offers advice; for instance, it suggests matches between companies (foreign and Spanish, or Spanish and Spanish) which might find benefit in the mutual development of a certain technology.

Sr. Vallori works in a spartanly furnished office on Madrid's smart Cestellana Avenue with a staff of forty, twenty-eight of whom hold degrees in various disciplines. He himself is an aeronautical engineer from Mallorca.

He is hopeful about Spain's chances of multiplying its still sparse technological assets, but believes some businesses will not be able to stand the strain of competition that will come with entry into the Common Market. "Some entrepreneurs have turned rancid," he smiles, referring to those who are incapable of changing the mentality they acquired in Spain's protective past. "But we have some alert young-minded businessmen who are aware of the importance of technology," he adds. " Technology is just beginning to see the light of day in Spain."

Thanks to CDTI, Mr. Kazuta Kimura is raising Japanese *shiitake* mushrooms in Spain's northwestern region of Galicia, using a new method which actually makes them bigger, juicier and cheaper than in Japan. His company, Nihon ODD Iberica, exports 100 percent of its crop to the Orient. Other companies that got a helping hand from Sr. Vallori and his team include several software companies; a firm which is breeding California worms for bait in Spain; a company developing a venereal disease testing kit with the cooperation of researchers at three Spanish universities and the Massachusetts Institute of Technology, Spain's pioneer *estero* (salt pond) fish farm; and a laser manufacturer in Barcelona who believes he can undersell similar American products.

Venture capital incentives

Reiterates Florencio Ornia, the director general for innovation at the Ministry of Industry and Technology: "The central basis of our policies for the future is ... to create the right environment for new technologies to grow."

The determination to encourage innovation is clear from CDTI. "We invested more money in new innovative projects last year than we had in the past seven years put together," says Sr. Vallori, the director general of CDTI. "And this year we hope to double that figure."

A similar attempt to encourage innovative industry has been mounted by the Banco de Vizcaya, one of the country's leading banks. In the past two years, through its *Sociedad Bancaya de Promocion Empresarial (SBPE)*. It has invested up to Pts100 million ($584 million) in thirty-five small and medium-sized firms involved in innovative projects from solar energy generation to laser beam applications.

"It is important to realize," says Santiago Bergareche, SBPE's managing director, "that Spain is not yet a country ready for real high-technology development. We are an industrial country but not at the level of Italy, the Netherlands or Sweden. We should forget for the moment about robotics and electronic breakthroughs. But there are plenty of other areas where we can build upon our resources, (such as) our coastline, our climate and our large consumer market among others. What we need to cultivate urgently is entrepreneurial talent."

Opportunities for growth

While the rest of Western Europe has all but reached a saturation point in material development, Spain still has a long way to go. Its gross national product is less than half that of West Germany, for example. This means Spain has a large and relatively untapped market for development; moreover, its central geographic location near not only the rest of Europe but North Africa, together with its relatively skillful yet inexpensive labor force make it a prime prospect for

* *$ = 171 pesetas*

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foreign investment.

Foreign investments have already begun moving into Spain in force. The Japanese, for instance, have enthusiastically invested around Pts33 million in the past few years. Their concerns in Spain now employ more than twelve thousand, five hundred people and Tokyo and Madrid have signed more than two hundred and fifty agreements on technical cooperation.

There is little about Spain that is not huge and imposing. Its mountains, arid plains and extremes of climate create a brooding grandeur. Its history, too, has bred a proud and majestic nation which stands out as one of the most individualistic in Europe.

The Spanish are fully aware of their past industrial shortcomings, but they have a strong sense of destiny. It is no exaggeration to say they have not forgotten their brief sixteenth century reign as the most powerful nation on earth — free of Moorish subjugation, Spain became the center of the Holy Roman Empire, which ruled South America, Central America and much of the known world. Today the Spanish are uncomfortable with their second class image but are emboldened by a strong determination to change things. The ramifications of their entry into the Common Market will be profound and the big three of the community — West Germany, Britain and France — have cause to heed the arrival of their large, haughty and potentially powerful neighbor.

Workforce flexibility

Last year the government negotiated a wage agreement with labor unions which allowed for a band of wage rises this year of between 5.5 and 7.5 percent followed by increases in 1986 of between 90 and 107 percent of the expected inflation rate.

Measures were also taken to provide employers with greater flexibility in maintaining their workforces. A decree was issued permitting managers to hire workers with a contract that states the worker can be dismissed with only twelve days compensation for each year worked. The contract can be renewed every six months for up to three years.

Another important measure has been the reform of part-time contracts. Part-time work for women, which used to be prohibited, is now allowed and social security contributions have been adjusted to take account of the time an employee works.

The aim is to increase the number of part-time contracts from a low of 0.5 percent to nearer the European norm of 20 to 25 percent.

SPAIN MEETS THE TECHNOLOGICAL CHALLENGE

Spain, like other nations in the world today, is in the middle of a major technological revolution whose real challenge lies in the restructuring of the relationship between culture and science. Insofar as the essence of the current process of technological change lies in the production, processing, and transmission of information, ideas and machines proceed to join together in a single system that transforms cultural capacity into a source of productive knowledge. Therefore, countries like Spain, with medium-level natural resources and poor energy sources but with a very rich historical civilization encouraging intellectual creativity, could increase their contribution to economic development and social progress by means of the current scientific revolution.

These historical roots have on occasions, represented an obstacle to technological development by transforming cultural traditions into ideological obscurantism and ancient institutions into bureaucratic inflexibility. Maybe this was the cause of the technological gap between Spain and some other European countries, in spite of our ability to produce scientists such as Ramón y Cajal or technological innovators such as Juan de la Cierva. Because of historical circumstances, Spain came late to the first two technological revolutions of the industrial era. This will not happen this time as the developed world enters the third technological revolution. This time, the Spanish Government is not taking refuge in the traditional resigned attitude, summed up by the phrase "Let them invent", meaning foreign researchers, it is accepting the new technological challenge.

The capacity of a country to master the necessary knowledge to meet social claims in an ever more interdependent world, is what defines and determines its potential for taking advantage of the Technological Revolution or entering a process of dependence and relative backwardness.

Spain is at present undergoing a process of institutional and scientific renovation that very soon will come to fruition.

In recent years a great number of researchers, technicians and scientists have undertaken post-graduate training in the best foreign universities. Some of our young managers have been trained in advanced management techniques. These are the promising groups who will lead the technological change in the years to come in the new, modern Spain.

Spain is changing rapidly and our country's membership in the Common Market will allow us to make progress in the renovation of our economic and social structures, widening the horizon in such a way that the concept of Nation will be integrated into higher levels of meaning, forming units of a magnitude similar to that of the U.S.A. or Japan. In this context, Spain will play an essential role in the Common Market, while still being an international platform between Europe and other areas of the world.

This process will require a considerable effort on the part of the whole of Spanish society, an effort that my government is ready to lead. Therefore, the necessary steps are being taken to gain full advantage of this historical opportunity. These steps aim at modernizing our industries and improving our educational system, through measures designed to encourage foreign investment in Spain, to bring the scientific world closer to business, to step up our technological and industrial participation in international programs, to increase the possibilities of technological exchange with other countries, to eliminate redundant bureaucracy in administration and, essentially, to upgrade the education of skilled personnel so that they can contribute the fullest expression of their potential to the business world, to the universities, and to the whole of society.

The new path that we have taken is already showing results.

In this task, we rely on the positive cooperation of many countries which are establishing joint ventures with us to reach the goals of new development. I invite all of them to extend and intensify our relations, being certain that they will find in Spain a favorable climate. Together, we will be able to respond to the exciting challenge of this third Technologial Revolution for the well-being of our society.

Felipe González
Prime Minister of Spain

Aquaculture

The man-made salt pans bordering on the Bay of Cadiz in southwestern Spain have provided inhabitants with salt for some five thousand years. By allowing sea water to flood the rectangular shallow ponds and then evaporate in the sun, the natives "manufacture" salt.

But now, a Spanish biologist named Lazaro Rosa has found a new use for the salt pans — or rather, he has industrialized an ancient fringe benefit: He is fish-farming. The salt pans are an ideal artificial environment for certain species of sealife, at least as far as taste and ease of harvesting go. They produce what Spaniards know as *estero* seafood. (Estero literally means "puddle"). In these small ponds the fish are deliberately trapped. The high salt concentration gives the fish a sweeter flavor which is preferred by many seafood lovers.

Estero fish used to be caught one at a time. Now, Rosa heads a group doing business under the name of *Cultivas Piscicolas Marinos*, or Seafood Cultivation, to mass-produce the estero seafood. The enterprise employs eight biologists, a veterinarian, a chemist and three agricultural engineers, as well as less-skilled workers. With the largest hatchery in Europe for fingerlings of the dorada, a type of bass, Rosa leaves nothing to chance. The fish are hatched, raised, and harvested with a combination of modern methods and ancient wisdom. Some of the harvesting techniques were developed by the fish-farm's founders. Most fish, for example, first are siphoned into a large tank. There, the water is drained off and they are netted.

Production is not limited to fish. Oysters, clams and prawns are also "planted" in the shallow earth-bottomed pans to grow fat and tasty. Of the nineteen square kilometers of salt pans available to seafood cultivation, less than one has been used since the project began three years ago; but from now on Rosa expects to add at least one square kilometer to his fish farm annually. Production now totals 125 tons per year, and by 1990 the group anticipates it will produce at least 1,000 tons per year.

Backed by both the government and private capital, the group struggled through its first years when profits seemed as elusive as flipping fish. There is every indication, however, that the profits will come, and they will be as savory as the estero fish. Fish from the salt pans has always been highly prized. These specially cultivated fish, sold not surprisingly under the trade name of *El Estero*, command a higher price than the same species fished from the sea.

Fish-farming is no newcomer to Europe, or to Spain for that matter. But Sr. Rosa believes he and his team are pioneers in the mass production of estero seafood.

Solar energy

In the foothills of the Guadarrama Mountains just north of Madrid, an experimental solar power station is being installed. Its projected capacity of 100 kilowatts is not impressive unless you consider that it will be one of the largest of its type in Europe.

The estimated cost per kilowatt will be about ten times that of the average commercially generated kilowatt, but the station's function is not to save money, not immediately anyway. Located at San Agustin de Guadalix, it will test various types of photovoltaic panels and auxilliary equipment designed for the storage and conversion of sunlight-produced electricity.

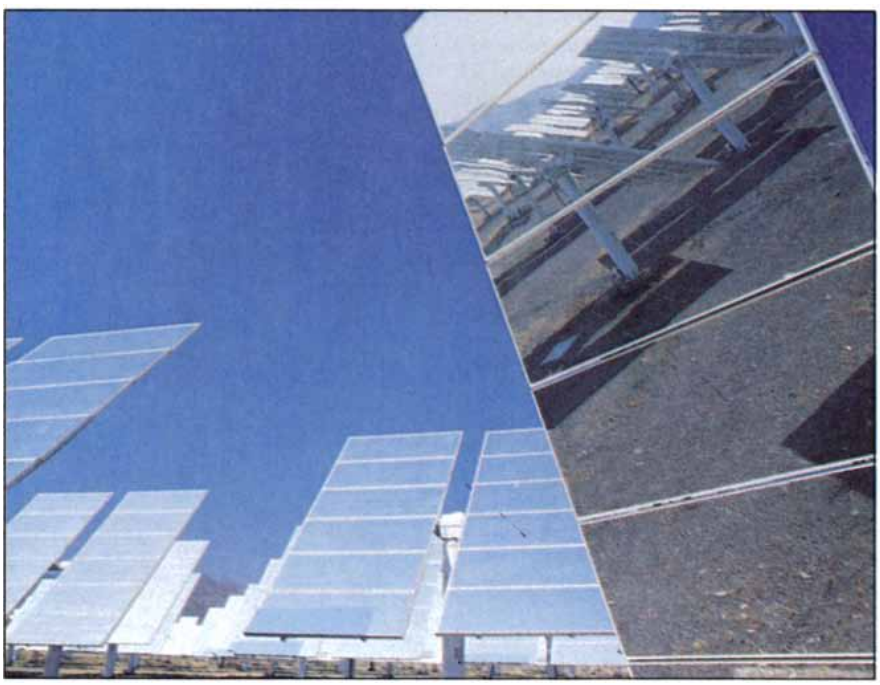
Forty percent of the panels there will be a new type developed and currently marketed by Spaniards, with Spanish technology. The panel is the brainchild of physicist Xavier Eguren. It is unique mainly because it is active on both sides, so that when properly mounted on white-painted or otherwise reflective surfaces, it produces up to twice the energy of a standard panel of the same size.

The panel was the subject of Sr. Eguren's thesis when he studied at the Madrid Polytechnic University. It is now the basic product of the Malaga-based company he directs, Isofoton, which has a workforce of twenty-five. Production is still small: The monthly panel production is enough to create only fourteeen kilowatts. But the rate of production is increasing and new products are being added to the line. The solar panel is now being offered as part of a package, that includes all the elements of an integrated solar energy converter system, complete with a regulator and other devices needed for quick and simple installation.

The exclusive Spanish design is attracting attention from foreign experts in the fast-developing world of new energy systems. Exports account for 20 percent of production, even though the invention is still in the stage of evaluation and refinement.

Further experimentation and research have revealed other products which the company is considering, such as photo-optic sensory devices.

Spain, blessed with more sunshine than most of the rest of Europe, has other experimental solar power centers, including two in the southeastern province of Almeria. But both of those utilize the sun's energy merely as heat to make steam to turn turbines.



The Image Bank: Luis Castañeda.

Solar panels in the southeastern province of Almeria.

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  In addition, the 15 percent of intagibles on R&D can be deducted from the taxes.

OTHER ADVANTAGES AND INCENTIVES

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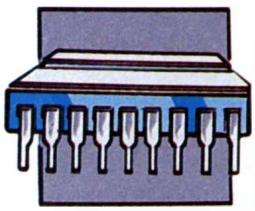
Electronics policy



"Only exports can provide definitive and tangible evidence that competitiveness has been achieved," says Minister of Industry and Energy Juan Majo. Exports, he points out, can result not only from the efforts of Spanish companies in international markets; they can be achieved also through arrangements between multinational firms and their Spanish affiliates, whereby a given share of the affiliate's output is marketed outside Spain through the parent company.

Over the last two years Spain's exports of electronics and computers have increased by a remarkable 226 percent. Meanwhile, more than two dozen major investment projects have been set up involving leading international and national companies. These should increase internal production, exports and technical development still further.

But three years ago the Spanish electronics and computer industry was in a grim state. Purchases of electronic products accounted for only 1.9 percent of the gross national product while they were 3.1 percent of Italy's, 3.2 percent of France's, 3.8 percent of Japan's and 4.5 percent of the U.S.'s. Even more disturbing was the fact that domestic production accounted for only 42 percent of domestic demand while imports accounted for 58 percent. In the previous year domestic output had grown by 18 percent while imports had increased by 24 percent. With only a few exceptions, Spanish electronics showed no sign of being able to achieve international competitiveness. "The Spanish electronics industry had been very unsuccessful," says Majo. "Almost every company was losing ground in the face of competition from the multinationals." Until his appointment as Minister in July, Majo was director general of electronics and data processing at the Ministry.

He argues that the electronics industry's economic gains are only a small part of its potential significance. The development of technology will boost other areas of economic activity. It has to be regarded therefore as a prerequisite of continuing industrialization.

Accordingly, an ambitious plan is being implemented to increase substantially the demand and supply of electronics and computer products.

The target is to get net domestic consumption from the 1982 level of Pts439 billion ($2.567 billion) up to Pts728 billion ($4.257 billion) in 1987 (at 1982 prices). This would mean a cumulative annual increase of 10.6 percent. Spanish output of equipment and systems which amounted to Pts227 billion ($1.327 billion) in 1982 is intended to rise to Pts545 billion ($3.187 billion), representing a cumulative annual increase of 19.1 percent. Export volume should increase from the 1982 figure of Pts55 billion ($321 million) to Pts229 billion ($1.340 billion), a cumulative annual increase of 33.1 percent.

These quantitive objectives assume an overall economic growth of three percent per year over four years and, thus, that the growth of net domestic consumption of electronic/data processing goods will outstrip the growth of the GNP by about seven percentage points.

The objective, from a strategic point of view, is to achieve medium-term stability of the industry's structures and increased penetration into international markets. Government support is being granted to both Spanish companies and the Spanish operations of foreign firms on the strength of their projection of competitiveness in export markets.

Microelectronics

In microelectronics, the speed of technological development, the high costs of technology and the amortization of such expenditure are such that they present a formidable obstacle to new domestic incentives. The Ministry of Industry therefore decided that rather than attempt to promote the installation of facilities for domestically originated technology, it would encourage the installation of plant for the manufacture of integrated circuits by major multinational companies.

The government's view is that optimum dimensions mean production levels above those required by the domestic market, thus permitting significant quantities for export. However, in the field of semi-custom and custom type integrated circuits, the fundamental aim is to meet the Spanish industrial demand and to control design and manufacture so that they may be within the reach of Spanish companies which are capable of designing them. Says Majo: "It is not always necessary to be working in the vanguard of technology, but maintaining control of design technology is vital. This enterprise must spring from the modest base now existing in Spain, together with a technologically advanced partner who can ensure the provision of whatever technology is required for start up."

Another key aspect of the program is the establishment of a microelectronics research, and development center with the participation of university laboratories, the higher council for scientific research and various state-owned companies operating in the sector.

A network of service centers will be established and endowed with sufficient terminals and peripherals to enable firms to design microelectronic circuits. Companies will be encouraged to use this network to make their own design and semi-custom design microelectronic circuits. This is important, says Majo, because many companies will find it necessary in the future to design products with a greater electronics content, and the electronics will have to be individually designed for each client. The availability of such original electronics, for companies which develop new products in general and companies designing and manufacturing integrated circuits will be crucial to the technological growth of other sectors as well.

Alongside the other measures being taken, university post graduate courses are being offered at polytechnical universities and schools of engineering to train technicians in integrated circuit design.

Government incentives

With the aim of stimulating investment in productive activities, preferential official credits are being granted for industrial investment in the electronics and computer field if it is undertaken in accordance with the government plan.

Regulations for the granting of loans have been modified to allow up to 75 percent financing of imported industrial assets which are not domestically available.

There is a deduction in company tax rates equivalent to 95 percent of the capital increases obtained from risk capital.

Research and development costs borne by companies can now be set off against their taxes for that year at the rate of 15 percent for intangibles and 30 percent of the purchase price of fixed assets for R & D. And the government is now actively seeking agreements with foreign companies to set up development activities in Spain, preferably through association with Spanish research centers or companies.

In 1984, investments in R & D projects involving government agencies equaled 87 percent of those in the previous eight years, showing the new attention and effort devoted to this field, says Carlos Solchaga, Spain's Minister of Economy. Below, he answers questions:

How important do you consider foreign investment in Spain to be and what initiatives is the government taking to attract it?

Foreign investment is primarily an addition to national investment which raises the production potential of our economy. Moreover, it facilitates exporting our goods to international markets and promotes the transfer and input of new technologies. On the other hand, the ability to attract foreign capital is always clear proof that business opportunities in our country are comparatively better than in other countries. For these and other reasons, the Government has recently made important changes which remove virtually all barriers to foreign investment.

Can you provide the latest statistics of the amount of foreign investment Spain has attracted?

After some years of relative stagnation, between 1975 and 1980, foreign investment has made a strong recovery. Thus, direct investments rose from Pts85,415 billion in 1980 to Pts182,842 billion in 1982, and this recovery was continued in the two succeeding years so that by 1984 the figure was Pts213,523 billion ($1.25 million).

The industrial sector as a whole absorbed 54 percent of all foreign investments in 1984, the main beneficiaries being the steel-using industries, including in particular the motor industry, as well as the chemicals sector and the agro-food industry. A breakdown according to principal investing countries shows that, in 1984, 40.4 percent came from the EEC (mainly Germany, the United Kingdom, the Netherlands and France), 14.7 percent from the United States (although a significant portion of U.S. investments was channeled through the Netherlands), 9.5 percent from Switzerland, and 9.1 percent from Japan. Investment from petroleum-exporting countries was also significant and accounted for 8.6 percent of the total.

And what, in your view, are the benefits Spain has to offer foreign investors?

The trend in foreign investments, according to the figures I have quoted, shows that Spain continues to exert a strong attraction in this respect. To some extent, this reflects recognition of those factors which make investing in our country an interesting proposition:

the existence of an internal market with high growth potential; the likelihood that, on joining the EEC, Spain will become an attractive staging area for exports to the European markets; the existence of a suitably diversified industrial infrastructure, including numerous highly-industrialized areas which provide wide opportunities for foreign trade; and the availability of an abundant supply of labor which has now achieved a high standard of qualification. These are, inter alia, some of the factors which account for this power of attraction.

The major liberalization of foreign investment already mentioned, coupled with wide facilities for the repatriation of profits, are other significant factors which should be borne in mind — plus a comprehensive and generous system of Government aid from which foreign investors can benefit in exactly the same way as Spanish investors and companies.

What impact do you anticipate Spain's entry into the EEC will have on the country's industrial development in the short, medium and long term?

Obviously the short-term impact of joining the EEC will vary in different sectors and industries, according to how sensitive they are to outside competition, and ultimately according to their competitiveness on the world market. However, from a dynamic viewpoint, the effect of EEC entry on our industrial development is going to depend on the ability of the various sectors, and particularly of individual companies, to press forward in the face of increasing competition towards specialization in technologically advanced and internationally competitive products. In this respect, the industrial reorganization and redevelopment policy being pursued by the present Government is aimed, inter alia, at furthering and supporting this necessary process of adjustment, while at the same time ensuring that the short-term impact on a number of sectors likely to be more severely affected by membership, does not jeopardize their chances of survival and subsequent expansion. To sum up, our overall view as regards the medium- and long-term impact of EEC entry on our industrial development is an optimistic one. Otherwise we would never have applied for membership.

There has been a reluctance on the part of Spain's private sector to invest. To what do you attribute this? Is it continuing and if so how do you plan to overcome it?

Low investment from the private sector is not exclusive to Spain. Unfortunately, the problem is fairly widespread throughout the world. However, one cannot conceal the difficulties arising from this situation and its negative effects on any attempt at economic recovery and reduction of the present high levels of unemployment. Many reasons account for this reluctance on the part of investors, but generally speaking, they all stem from the same factors which emerged around a decade ago and basically since 1978, have had a negative influence on the rate of investment in virtually all the developed countries. With regard to Spain, the position has been further aggravated by a very late start in adapting our production and institutional structures to the new conditions. The fall in demand at home and abroad, consistently high rates of inflation, the reduction of industrial surpluses, and other factors dealt a severe blow to the hopes of investors. The process of adaptation has, in fact, commenced only recently, while achievements in the fight against inflation and in providing a climate aimed at restoring confidence among investors are also recent and are still being consolidated. On the other hand, an event of major significance is

the signing of the treaty of accession to the EEC, which has removed many uncertainties and defined the competitive area in which Spanish companies will be operating in the future.

In any case, the healthy recovery of industrial surpluses over the past two years is an encouraging sign since it is a necessary condition, although insufficient in itself, for a strategy of economic recovery in which private enterprise is expected to play a leading role. The continuation of existing policies aimed at consolidating the gains made in the struggle against inflation, completing the industrial restructuring process now under way, controling the deficit in the public sector; and reducing even further the present institutional and labor-market constraints are still essential requirements in creating a climate favorable to investment recovery. Obviously, and more importantly for a medium-sized economy such as Spain's, the beginning of a sustained world economic recovery — particularly in those countries which, because of their size, perform a major revitalizing role — is another highly significant factor.

Since the government came to power, inflation has been reduced from 16 percent to around 10 percent. However, it is still 2.5 percent higher than your principle trading partner, France. How seriously do you regard this problem and what are you doing about it?

Indeed, the fact that inflation fell from 16 percent in 1981 to 9 percent in 1984 can be regarded as a clear and tangible result of the consistent efforts made by the present Government to reduce the strong inflationary trend which had been persisting in the Spanish economy. It is true that inflation here is still higher than in some OECD countries, among them France. However, despite the minor effect on inflation which may come about next year with Spain's entry into the EEC and the introduction of Value Added Tax, the fact that a reversal of inflationary trends has been achieved makes us hopeful that in the medium term we will be able to do away with this small difference in our rate of inflation.

Would you care to detail the measures that have been taken to restructure the steel, fishing and shipbuilding industries? Have these measures been completed? What more can be done to modernize these industries?

The restructuring of these sectors was another area in which delays occurred, mainly because of indecision by previous Governments. In fact, the restructuring process was commenced by the present Government in 1983 and the bulk of the work was completed throughout 1984.

The measures taken were similar to those adopted by other EEC countries and were based on a twofold aim. Firstly, to facilitate adaptation to demand (in terms of a reduction in surplus capacity) and place business concerns on a sound financial footing. Secondly, to promote greater competitiveness, both by providing financial backing for rationalization and modernization projects, and through efforts aimed at improving management and marketing structures.

As is the case with most countries, the extent of the changes needed made it necessary for the Administration to provide guidance throughout the initial stage of the restructuring process and to support it by using public resources and funds on an exceptional basis. However, such assistance cannot and should not be provided indefinitely; once the immediate objectives have been attained, it will be the responsibility of each individual company to achieve economic viability in the medium and long term without relying on Government support.

What is your policy on nationalization of industries and the privatization of industries?

The policy we are currently pursuing in this respect is very clear. On the one hand, we are taking firm steps to do away with a practice which had become almost epidemic in Spain, i.e. the nationalization of industries which no longer proved attractive to the private sector. Although in some cases this was done in the public interest, in other cases it was based on interests which could not be justified from a public standpoint, or on a misguided view of the role and aims of the public sector in industry. Moreover, because of the heavy losses incurred by these industries, it had the effect of seriously jeopardizing the financial position of the nationalized industries as a whole.

On the other hand, we are determined to de-nationalize those industries which, because of the nature of their operations, should not properly be included in the public sector. We have already taken action in this respect by privatizing certain industries in the services sector, and others. Similarly, we are anxious to increase or facilitate the participation of private capital in other industries which, while ideally retaining a measure of State participation, could be profitably run on a mixed-economy basis.

What do you consider to be the greatest problem you face?

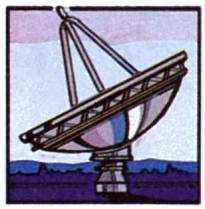
Firstly, to reduce the current level of unemployment which, because of the predominantly industrial nature of the present economic crisis, has a particularly severe effect on industry.

Secondly, and closely linked with the problem of unemployment as a major factor which will affect its outcome, the need for Spanish industry to be placed on a competitive footing so that it can become fully integrated into the EEC. Membership of the Common Market poses a major challenge to the Spanish economy, and specifically to Spanish industry. This challenge will necessitate an enormous effort in terms of adaptation and new initiatives, both by private business and by the Government.

What do you regard as your Ministry's greatest achievements?

From the point of view of industrial policy, I regard as the greatest achievements: having firmly established a coherent policy to bring about industrial restructuring at the lowest possible social cost; the systematic implementation of a plan aimed at adapting the energy sector to present-day requirements; the stepping up of technological research and development in order to ensure the expansion of Spanish industry within the new framework of international competition; and increasing support for small and medium-sized firms which in Spain represent a very significant part of the industrial fabric.

Telecommunications



For the first time, the *Compania Telefonica Nacional de España* (CTNE), the telephone company, is looking for business beyond Spain's borders; in preparation, it is rapidily acquiring subsidiary companies in the field of electronics.

"We have the capability of playing the role of a little multinational," claims the president of Telefonica, Luis Solana. Sr. Solana, a political appointee with a banking background, considers himself more of an entrepreneur than a politician — for the duration of the socialist administration at least. He believes that the Spanish telephone company should "accept the role that most of the world's companies have accepted, that of being a driving force for the development of the electronics and telecommunications industries.

"The enormous purchasing power which a firm like the telephone company has in periods of diminishing investment should be used to the full. It can bring forth new enterprises, . . . attract new technologies and help this country cross the threshold of the twenty-first century in the vanguard of technology, because these are industries that are going to generate employment in the future.

"Consequently, this has led to the creation of a group of companies related to Telefonica. (There are now about fifteen companies in the group.) Some of them, four or five, are absolutely new. Others are traditional. We bought some existing companies which were in very bad shape. We relaunched or helped relaunch others, such as in the case of the reconversion of Standard *Electrica* — as far as I'm concerned the most important one.

"At this time, Telefonica is lending considerable support to reindustrialization and modernization in Spain."

Evidence of such support is the contract signed recently by TNE (which has both public and private capital) and AT&T for the design and manufacture of integrated circuits, a deal which is expected to result in eventual sales of about $300 million. A company jointly owned by the Spanish telephone company and AT&T will soon start building its new factory and production is scheduled to begin in 1987. By 1991, the factory is expected to be in full operation, producing 26million circuits per year, with a staff of about seven hundred. Of that work force, one hundred and fifty will have been given valuable, advanced training in the United States in the design and manufacture of integrated circuits. This elite cadre is considered a fringe benefit for Spain, a human nucleus for further technological expansion.

The new company is expected to attract other high-tech firms and stimulate the development of other market segments in such areas as telecommunications, information systems, automation, consumer electronics, industrial electronics and defense.

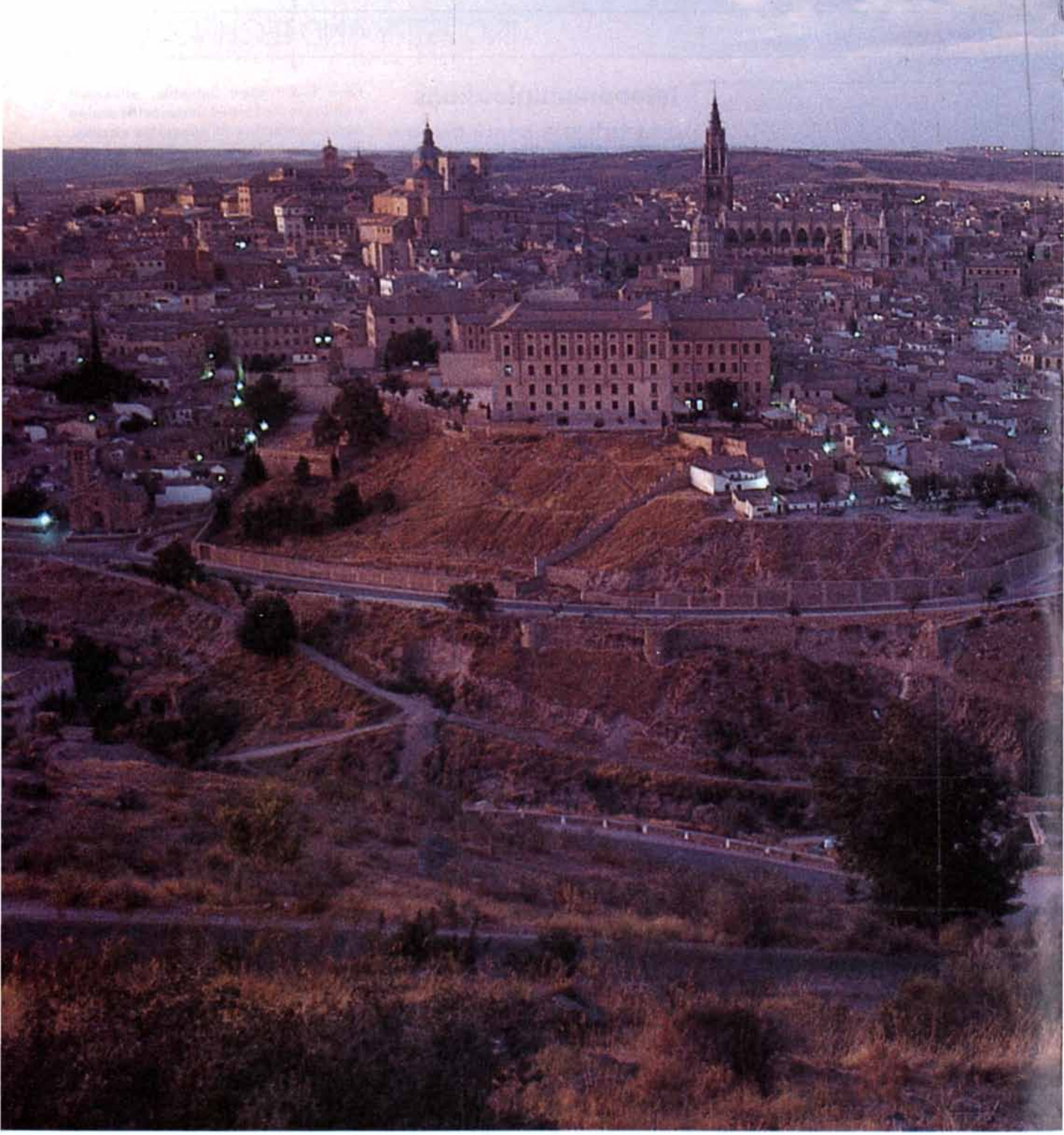
One of Telefonica's most significant acquisitions is *Secoinsa*, a firm dedicated to communications and information systems, with a factory in Malaga, research centers in Madrid and Malaga, and offices in most major Spanish cities. Says Solana: "We were shareholders in Secoinsa with INI *(Institutu Nacional de Industria*, the state-owned industrial cartel) and *Fujitsu*, and INI agreed to sell us its shares.

". . . Now, in a parallel action, we are speeding up negotiations with Fujitsu, to bring Fujitsu in as a big Secoinsa shareholder, so it can use Secoinsa as a key element in its general, industrial and research strategies.

The telephone company president added, "The most important thing for me at this time is the presence of Telefonica in Latin America. We want Latin American countries to see for themselves that the medium-level technology that Telefonica and its group have is easier to absorb than the advanced technology the big multinationals can offer . . . It lets the development of their industry keep abreast of that of their services. At the moment we are studying two industrial projects, one in Puerto Rico and the other in Argentina, which I expect will possibly lead to very important decisions in the coming months, since these projects involve the manufacture of items by the Telefonica group, in its own name, with Spanish patents in Spanish-speaking countries.

"These first steps are not terribly profitable because the projects are not so big; they are prudent projects. At Telefonica, we are looking out on the world cautiously. There is no tradition of a presence abroad, because we did not have patents for use abroad before. We did not have national patents and we did not have the capability of going outside the country. Now we are beginning to have the capability.

"Now the group is coordinated and there is a will to be represented in a series of countries as the Telefonica group. We have things that are going to interest them."



TANDEM OOB

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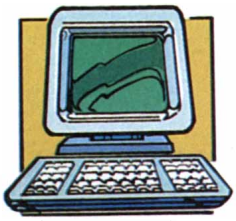
Computers



Secoinsa, which is the leading Spanish manufacturer of mini and personal computers, terminals and peripherals, has the distinction of being one of the few complete-cycle companies in the country with operations ranging from its own research and development to direct sales to the user.

Unlike its main competitors, who either manufacture or import, Secoinsa undertakes its own market studies, draws up specifications for product development, then produces, manufactures and markets through twenty retail outlets, providing software and maintenance backup. The company increased its turnover by 56 percent last year to Pts1.8 billion ($10.5 million) and is making a determined bid to increase its market share further still.

Secoinsa has been active for ten years and, says technical and marketing manager Joan Ribera, in that time it has learned the value of concentrating its resources on products that need medium capital and technology, such as home computers, office computers, CRT printers, and switching systems.

Says Ribera: "When we find there is an opportunity, we try to satisfy the customer quickly." First, they try to find the right product; then, if that fails, they try for a viable substitute.

"We recognize," says Ribera, "that even if our products are well conceived, well adapted and cost competitive, Secoinsa, as a systems integrator and seller to end users, needs a complete range of products. And that means we need overseas technology."

So the company has an arrangement with Fujitsu that gives the Japanese company a 7 percent share of Secoinsa while enabling the Spanish company to take advantage of Fujitsu's complete range of products from mainframe machines to home computers. The remaining 93 percent of Secoinsa's shares are in the hands of Telefonica.

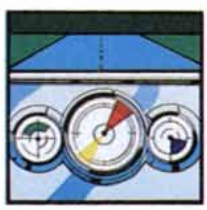
"Our R & D is not devoted to 'bright star' projects," says Ribera. "It is geared to pragmatic research into products that we can develop quickly, market and sell fast. . . . Our R & D needs to be devoted exclusively to quality, functionality, and cost effectiveness."

Out of a budget of Pts1 billion ($5.85 million) Secoinsa invests Pts600 million ($3.51 million) in specific items spread over its range of eight main products: office computers, personal computers and automatic workstations, local networks and gateways, packet switching systems, modems, CRT's, printers, and operating systems.

At present, exports account for only 8 percent of the company's business, and this consists mostly of switching systems in the U.S. and business computers in Britain, France, and South America. "We are not yet well positioned in Europe," Ribera concedes. "Up to now our priority has been our home market. There is a lot of competence in that area, (the European Market) and I'm not sure we can increase our sales very easily. But we intend to make a determined effort."

Secoinsa's small business computer, the 20 Series, is priced at Pts3.5 million ($20,500) — between 20 and 30 percent cheaper than its nearest multinational rival — and 1,000 units have been sold. The Series 400 mini computer costs Pts50 million ($293,000) and 120 units have been sold. A home computer, which is just being launched, costs Pts150,000 ($877.20) and the company expects to sell 5,000 units. Another new product is a gateway which will sell at Pts800,000 ($4,700), and sales are anticipated to be around 2,000.

From proximity fuses to avionics



The rapid but always orderly growth of *Equipos Electronicos S.A.* (EESA) converted a company that was originally established in 1971 by the French Thomson CSF Group solely as a sales organization, into one of Spain's most promising designers and manufacturers of electronic products. Its sales have almost quintupled in the past five years and are expected to rise by another 39 percent this year.

The company policy of dedicating about 10 percent of total sales revenue to research appears to be paying off. It's part of a successful diversification program that brought the firm a long way from its rather shaky launch into the defense industry in 1977.

In 1978, the French owners abandoned ship. So Spain's state-owned industrial cartel INI bought out Thomson's stock as well as the minority of shares held by a Basque industrial group. Once INI got control of 100 percent of EESA, the company started to take off.

The number of employees grew from three hundred and four in 1979 to about five hundred at present, and the sales-per-employee ratio nearly quadrupled, from Pts2 million ($11,561) to an estimated Pts7.7 million ($44,509). Yet the balance sheet is expected to reflect a net profit only by the end of the present year. Losses for 1983 amounted to about Pts150 million ($867,052), and last year the company almost broke even.

A Spanish navy contract for proximity fuses gave EESA its real start in manufacturing. Still the only Spanish company capable of turning out this product, EESA had a production capacity of 30,000 units per year — a lot more than the Spanish navy, initially its only client, could absorb. By 1979 it became absolutely clear to the management that it was a question of diversify or die.

Then, EESA signed a contract with Racal of Britain to make radio-telephones. Within one year, the Spanish army put in an order. Benefits were measurable in more than a mere increase in sales. The company's venture into the manufacture of radio-telephones combined with its own research and innovation program and created a whole new design. A prototype of the EESA radiotelephone is currently being tested by the Spanish army, and the company expects it to be a good export item.

Says EESA'S President Eduardo Moreno Cerezo: "In these past seven years the firm has experienced growth in every aspect, accompanied by strong diversification. The diversification was excessive in some ways but . . . nevertheless had its positive side . . . We went through an intense process of accumulating technology, from which we expect to reap a good harvest in the future."

Another promising field which diversification led EESA into is avionics. It now produces passive radar protection devices for the Mirage F-1 fighter-bomber. It has a $2 million contract for components of the new A-320 European Airbus and a Pts4 billion ($23 million) contract to build testing equipment to be used in the maintenance of a fleet of McDonnell-Douglas F-18 fighter-bombers ordered by the Spanish air force.

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DCN: Shipbuilding Technology

The Shipbuilding Division (DCN) of Spain's National Institute for Industry (INI) is in a unique position among shipbuilders. Its long experience in the construction and design of ships, combined with a steady flow of ideas to improve design and increase the efficiency of the ships it builds, puts it in a good competitive position. Its numerous yards and factories gives it the capability of producing an extensive variety of ships, each of them practically tailor-made to fit the buyers' needs – and not merely the usual types of vessels.

The DCN group is made up of four large companies: Astilleros Espanoles S.A. (AESA). Astilleros y Talleres del Noroeste S.A. (Astano), H. J. Barreras S.A. and Astilleros Canarios S.A. (Astican). AESA has five factories of its own, Fuerto Real, Cadiz, Seville, Sestao, Manises and Olaveaga, and three affiliates, S.A. Juliana Constructora Gijonesa, Astilleros y Talleres Celaya S.A. and Astilleros de Santander S.A. (Astander).

Constructions ranging from offshore drilling platforms, incorporating the latest technology developed in Spain and abroad, through luxurious yachts and tall-masted sailing ships, like those built in Spanish yards for cadet- training programs of the Mexican and Venezuelan navies, round out DCN's range of products.

Because each of its plants is equipped for a certain kind of work, the division can build, convert or repair all kinds of vessels, from the biggest to the smallest.

Each of its installations complements the others. The huge modern shipyards at Puerto Real, on the Bay of Cadiz, are ideally suited for building ships in excess of 40,000 GT. Container ships, Ro-Ro cargo ships, tankers and bulk carriers constitute the typical line of products at Puerto Real. Not far from there, the Cadiz factory handles repairs and extensive remodeling.

The yards at Seville, on the Guadalquivier River, are ideal for the construction of ships of less than 20,000 GT of various types: refrigerator ships, all-purpose cargo ships, gas tankers and bulk carriers.

The installations at Sestao in Bilbao are suited for turning out ships from 15,000 to 45,000 GT such as special tankers for the transport of chemical products and bulk carriers. Major repairs and overhauls are handled at nearby Olaveaga. Marine engines are made at Manises near Valencia.

Celaya specializes in sailing ships, ferries and naval patrol vessels. Astander handles repairs and new construction, particularly of tugboats, cable-laying ships and refrigerator ships. Container ships, refrigerator ships and freighters up to 20,000 DWT are built by Juliana at Gijon in the north.

Astican, in Las Palmas in the Canary Islands, is perfectly located on Atlantic trading routes for its mission: repairs and extensive overhauls. Barreras, in the northwestern Spanish port of Vigo, is dedicated to the construction of ferries up to 14,000 GTC, multipurpose vessels up to 10,000 DWT and large tuna fishing vessels.

Astano's works at El Ferrol, near Corunna, are dedicated to marine engineering projects such as the construction of off-shore equipment and to repair and extensive remodeling.

Special design features and the incorporation of new technology for more efficiency, offer proof of these companies' efforts to make ships that will do their jobs better at less cost. Long patient studies, including exhaustive hydrodynamics tests, resulted in a number of patented devices,

such as AESA's Tip-Vortex-Free (TVF) propeller. It is similar to a conventional propeller in appearance, except that the outside edge of each blade is squared off and bent sternwards at a right angle. The TVF design provides a fuel saving of 10 to 15 percent, depending on the ship on which it is installed. This development is already on the market. So far it has been installed in a 27,000 DWT bulk carrier and has been refitted to overhauled 260,000 and 300,000 DWT supertankers. The TVF design permits the transmission of thrust to the very edge of the blades, without blade-tip drag and cavitation.

Eliminating noise and vibrations is one of the major concerns of DCN's researchers, and they have achieved results which put this Spanish group at least on a par with the world's other leading shipbuilders.

Noise researchers are in a position to predict beforehand the level of noise and vibrations that might exist in any given structural design. This makes it possible to redesign certain parts or take other remedial action before the ship gets off the drawing boards. DCN has been combatting the noise problem a long time, contrasting theoretical with real performance.

Such feedback helps perfect anti-noise and anti-vibration measures.

Another DCN idea is the development, for the world market, of a family of ships with economical and strategic characteristics to meet the foreseeable demand of the 1990's. For example, future versions of a conbulker, grain carrier, container ship and open combination. All of them offer brilliant operational characteristics, adapted to the peculiarities of each type of traffic.

To accomplish this, a number of solutions had to be found, some of them unconventional. Among them are a low length-beam ratio, a double stern, superstructure situated in the bow area, wide-opening hatches and a high degree of automation.

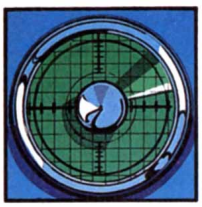
In the field of engine dynamics, the group's researchers have acquired sufficient know-how to tackle sophisticated multiple-engine power-unit projects involving power take-off from various points, and they are able to anticipate and overcome any problems such a project might entail, before it gets to the construction stage.

The group has worked out details of designs for integrated power units for certain types of ships, to furnish propulsion power, electricity, heat and other necessities with increased fuel economy.

DCN's own system of Computer Aided Design/Computer Aided Manufacture (CAD/CAM) is under development. It will help rationalize hull work, piping, electrical installations and the distribution of internal space – in addition to offering advantages for the builder, such a control of inventory, procurements, etc.

Studies have produced prototypes with features which reduce operational costs and increase profits for ship-owners and operators, such as more economical propulsion, reduction of the crew through automation and simplification, and speed and ease in loading and unloading.

Radar systems



In the tough business of selling air traffic control systems around the world, the private Spanish company, *Ceselsa*, has about a dozen competitors.

"It is not easy," says Enrique Gutierrez Bueno, director of external relations. "We're not yet competitive as far as image is concerned. We're new to the game; we're new kids in town. That's the problem. But we make it up in price. For instance, with a system we're attempting to sell in Uraguay, we're 20 percent lower than the next bidder and 50 percent lower than the highest bidder. So the bottom line is price. We've streamlined our technology, eliminating some of the functions that make traffic control systems complicated and expensive, and our labor rate is less expensive than most other countries'. These things add up to real advantages.

"Another plus factor for us is the fact that we are a small enough company to be flexible. We can adapt to the customer's requirements more readily than a large contractor can."

Ceselsa's first project in 1974 was the installation of an American-produced radar system throughout Spain. It soon became evident to the company executives that there was no reason why Ceselsa should not develop its own radar technology. This remains the company's forte. Its most recently developed secondary surveillance radar system, the IRS-10, is a monopulse system which transmits and receives challenge and response information. After processing, different pieces of input, the IRS-10 makes digital reports on, for example, an approaching plane's range, azimuth, identification codes and altitude. Because the system uses a modular concept, different formats of messages are possible depending on the external display and data processing systems.

The radar is built around general purpose microprocessors for control and formulation tasks. Two intelligent switching devices control the IRS-10 operation; a remote unit with failure indicators makes the system highly reliable with minimum maintenance support.

Developed by Ceselsa, the antenna for the IRS-10 is an open array device with a configuration that provides good coverage at low altitude. It has a low cut-off angle and elevation pattern, which means that it does not suffer from ground returns or false target close-ins.

Industrial modernization

Steel

For political reasons, Spain's reconversion program was late getting started, compared to those of other European countries, but it was, and is, no less painful. In spite of the reductions that have already been made, steel production is double the domestic demand. Last year, 8.9 million tons were exported, but fierce international competition and the universal slump in steel consumption make reconversion and modernization all the more necessary.

Investments for reconversion in the three leading companies are to be in the neighborhood of Pts110 billion ($643 million).

In the subsector of special steels, only 62 percent of the companies will be affected by reconversion, since the remainder are in sound shape. In non-integral common steels, the government is refraining from taking the initiative, although some companies are carrying out reconversion plans on their own.

Agriculture

In a sector as unpredictable as agriculture, where profits depend not only on good planning but on good weather as well, any comprehensive reconversion plan, particularly with a view to Spain's eventual entry into the Common Market, was bound to have its critics.

Fortunately for the authorities, the medium-term Plan for Agricultural Reconversion went into effect at the end of 1983, just as a prolonged drought was ending and one of the best crop years in a long time was beginning. There were some sectors in agriculture which did not fare too well, but the general improvement in the farm panorama muted the voices of dissent. One hundred thousand hectares (247,000, acres) of olive groves were uprooted and the land was converted for other crops.

The uprooting of excess vineyards went slowly, but the low price guarantee set by the administration (with obligatory conversion of surpluses into alcohol) helped discourage production.

A five-year plan for cotton, inaugurated last year, calls for the eventual production of 100,000 tons on one hundred thousand hectares, with 70 percent of the land to be farmed by machine.

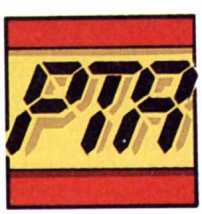
Fishing

The reconversion of the Spanish fishing fleet is a painful process, but one that would have been necessary even without the difficulties posed by Spain's upcoming association with the Common Market.

Traditionally, Spain has more fishing vessels than any other country in Europe (although the average tonnage is low) and is the biggest market for seafood in Europe (although per capita consumption is higher in the smaller countries of Norway and Portugal). To Spain's disadvantage, its people prefer species which for the most part do not abide in nearby waters.

Since the start, in 1979, of formal negotiations for Spanish membership in the Common Market, annual and progressive cuts in the total catch allowed for Spanish vessels fishing in Common Market waters, and cuts in the number of ships licensed to fish there, have made Spain pay more attention to the renewal of its aging fleet and to the need to find other places to fish. 50 new vessels have been built.

Liquid crystals



Angel Iglesias is a self-made electronics engineer who displays the type of entrepreneurial initiative and business acumen that the government is trying to encourage.

His San Sebastion-based company, *Ikusi*, is an electronics manufacturer at the forefront of liquid-crystal paneling. Recognizing the commercial potential of newly emerging liquid-crystal technology, Iglesias and his staff worked hard and fast to develop methods of using it. Ikusi has just completed a Pts150-million ($877,000) contract to equip the Las Palmas Airport in the Canary Islands with a complete system of computerized liquid-crystal flight indicators and monitors.

"This is a very new concept," says Iglesias. "The Las Palmas Airport is the first in Europe to be equipped in this way and it will be a perfect exhibition model, which should help us sell the system elsewhere."

Some of the advantages of liquid-crystal panels, says Iglesias, are: they have a clearer display definition, do not use energy, and do not get hot. The technology has considerable potential for applications in train and bus term-

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inals, in supermarkets, and in sports stadiums.

Another new project developed by the company is a sophisticated crane-control mechanism based on electro-optical rather than mechanical engineering, which provides thirty-two different directional commands. After twelve months development work, it went into commercial production in June. Export orders have already been received from France, and Iglesias is optimistic about its sales potential in the U.S.

Iglesias left school at the age of twelve, studied electrical engineering at night, formed his own company in 1960, producing and installing television aerials, and moved into the electronics field in the 1970's. Ikusi's activities are divided now into four divisions — radio-control instruments, closed-circuit television equipment, fire security systems, and indicator panels. The company has a labor force of two hundred of whom sixteen work in R & D and four in quality control. Sales increased by 26 percent last year. About 17 percent are exported and the export target is 35 percent.

Faster trains

With the TALGO Pendular Train, Spanish railway technologists answered a question that had long challenged the industry: How could long-distance trains be made to go faster, economically, and without loss of passenger comfort.

The pendular version of the TALGO achieves this because it can operate on existing track, which saves considerable expense. It was first put into service in 1980 and began operating between Madrid and Paris a year later, completing the 780-mile journey in 11 hours 55 minutes, an average speed of 60 mph. The TALGO train is made to "snake" around bends in the old track without vertical or transversal displacement between the cars. The car-heads are suspended over a pair of independent wheels guided by a simple mechanism which ensures that they run parallel to the track, however sharp the curve. This allows a considerable lightening of the train's deadweight and a low center of gravity.

Tilting a train while it goes around the bends is what enables it to attain greater speeds. If safety traditionally imposes one limit on velocity, comfort restricts it even further, due to the disagreeable effect of an excessive lateral force on the passenger. Tilting trains overcome this limitation without overstepping the safety threshold. The force of acceleration on a passenger depends on the tilt of the car and is significantly reduced if the car is tilted inward, toward the curve. Thus, a tilting train can substantially increases its speed while maintaining an acceleration on the passenger equal to that produced by a conventional train. The tilt may be obtained by means of curve detectors which trigger hydraulic or pneumatic mechanisms which in turn rotate each car laterally. The TALGO system of natural pendulation, however, is based on simply raising the suspension well above the center of gravity.

The suspension of the Pendular TALGO cars is provided principally by a diaphragm-type pneumatic springs which by means of leveling valves regulate the height on straight track. On curves, the valves automatically stop working and the springs behave as purely elastic elements. They adapt their position as a result of the centrifugal force, until the moment of this force is balanced with the consequent tilting of the car; there is no chance of error and no consumption of energy.

Says Lucas Oriol Lopez Montenegro, TALGO's director, and son of the company's founder: "We knew that the pendular system was within the reach of our technology. Backed up by a lot of hard work and the millions of miles of railtime in our experience, we came up with the answer."

Plastics innovation

Plastic crayons that are better for children than wax crayons, and aromatic plastic for packaging, are among the innovative products that have been developed by IQAP S.A., one of Spain's leading plastics concentrate manufacturers.

Located at Manlleu, north of Barcelona. IQAP's primarily produces additive concentrates and specially formulated compounds for the plastic industry. 80 percent of its work is in this field. Two years ago, however, it went into crayons as well. The company had been considering how it could best diversify. Then IQAP's general manager, Francesco Xavier Rovira i Vilaro, was sitting at his desk idly playing with a ball of the company's concentrate masterbatch when he noticed that the ball was drawing on some papers on his desk. This was not one of the properties required of the masterbatch. But Rovira recognized it as something he could develop in a child's crayon.

IQAP's plastic crayons are less messy than wax ones, completely non-toxic, capable of being sharpened for clearly defined writing or drawing, and erasable. Last year 20 million were sold, mostly in Spain but with 20 percent exported to Portugal and Holland. This year sales have been running at an additional 20 percent, exports have spread to Switzerland and Scandinavia. IQAP is confident of doubling the figures next year.

"This year has been a year of transition," says Joan Rovira i Vilaro, IQAP's commercial director and the general manager's brother. " . . . We are negotiating with distributors in the U.S." Among the derivatives of the crayons being marketed are modeling clay and finger paints.

In the process of developing the plastic crayons, IQAP's R&D team devised a method for giving the plastic the smell of wax; they quickly recognized the importance of a product's smell in marketing it. So they are developing an aromatic cromofix that can make packets of detergent smell like flowers, trash cans smell like pine trees, synthetic shoes and handbags smell like leather, and coffee bags smell like coffee.

Another innovative product they have developed is a carbon-black conductive plastic which prevents static electricity and has wide-ranging possibilities as a protective covering.

IQAP's industrial concentrates production is divided into five main lines: color concentrates for polyvinyl chloride (PVC) which is used mainly in electric wiring, certain kinds of boots, soles of shoes, and hoses, as well as in some rigid forms; special PVC compounds for use in products that serve more highly specialized needs; color concentrates for polyolefins which are used specially for film manufacturing and in making monofilaments and artificial raffia; color concentrates for engineering polymers, that leave the polymers' physical properties unchanged; and various additives and other concentrates, such as softeners, flame retardants, ones that are ultraviolet resistant, and others that can be tailor-made to customers' requirements. The total number of products exceeds 450.

Last year IQAP's sales totaled $3 million, twice as much as in the previous year. This year a 25 percent increase is anticipated and the projection for 1988 is $8 million. At present, exports account for 30 percent of sales and are expected to go to 40 percent.

ENDESA

A company profile

In a move aimed at ensuring the effective coordination of manpower and financial and technical resources, Spain's publicly owned electric utility companies were restructured two years ago, being grouped around ENDESA, which ranks as the top producer of domestic coal and electricity with 21.2 percent of the total and 50 percent of all coal-fired power, obtaining a saving of 5.7 million tons of fuel oil.

As a result, ENDESA – the Empresa Nacional de Electricidad, S.A. – purchased the shares of the other public electric utilities (ENHER, GESA and UNELCO) and one mining company (ENCASUR). The new ENDESA GROUP is now responsible for the production of 16 million tons of coal – 41 percent of Spain's domestic production. It has installed electrical capacity of 7,856 megawatts – 20.2 percent of the Spanish total – and produces annually 35,586 GWh 29.6 percent of the national total.

The National Energy Plan maximizes the utilization of domestic energy resources. It will limit Spain's dependence on oil by encouraging the use of coal and of hydroelectric and nuclear energy. Where the country's dependence on foreign resources amounted to 67 percent in 1982 it will be down to 45 percent by 1990. At the same time the overall use of oil will come down from 61.5 percent to 45.2 percent of gross domestic energy consumption.

In 1983 hydroelectricity accounted for 39.5 percent of installed capacity, fuel oil for 28.2 percent, coal for 21.3 percent and nuclear for 11 percent. By 1992 the importance of fuel oil will drop substantially in percentage terms while all the other sources will go up. Hydroelectric power will represent 41.3 percent, coal 24 percent, nuclear 15.9 percent and fuel oil only 18.8 percent.

According to the "Plan Energetico Nacional", ENDESA GROUP is present in the coal, nuclear power and hydrogeneration fields.

In terms of coal production ENDESA GROUP is the country's largest producer and its output, 16.7m metric tons, is equivalent to 4.1m metric tons of fuel oil. About 13m metric tons of coal are extracted annually from the open pit mine at Puentes de Garcia Rodriguez (La Coruña), about 1.8m metric tons from the mines at Andorra (Teruel) and 1.5m metric tons from Peñarroya (Cordoba) and Puertollano (Ciudad Real). This production accounts for 75 percent of the Spanish total output of brown lignite and 25 percent of black lignite.

Spain's coal reserves are considerable but sulphur content is high and combustion quality is poor. ENDESA GROUP, therefore, gives priority attention to research into fluidized bed combustion, coal cleaning and gasification.

Says ENDESA GROUP's executive president, Feliciano Fuster Jaume: "Our efforts are dedicated to finding the best way of using our coal without damaging the environment and incurring the least penalty in efficiency."

●

Mining research studies, more than 30,000 km^2, are being pursued with the twofold purpose of finding new seams and upgrading knowledge about deposits already being worked in Galicia, (Ginzo de Limia, Paderne de Allariz), Aragon (Alloza, Crivillen,...), Andalusia (Villanueva del Rio y Minas, Padul,...) and Puertollano at Ciudad Real. Findings show that substantial reserves exist, but their feasibility and profitability are under consideration.

To optimise overall production of all electricity generating facilities in northwestern Spain, ENDESA has implemented an integrated power control system with a regional control center at Montearenas near Ponferrada, which is equipped with computers, remote stations and data gathering facilities and a related communications network.

In the field of the electric power output, ENDESA GROUP has invested Ptas. 23,500 million pesetas ($137.5 million) in the construction of a fifth 350 MW fossil-fuel unit at Compostilla. At present, the Compostilla plant, which burns anthracite and brown coal form the El Bierzo coalfield, has a capacity of 1,312 MW.

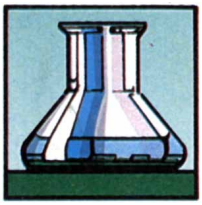
Another project completed in 1984 is a 550 MW coastal plant at Almeria, costing 37.000 million pesetas ($216 million). This plant burns imported coal and port facilities to service coal carrying vessels of up to 70,000 tons have also be constructed. The port can be expanded to handle vessels of up to 120,000 tons and will have a service dock for vessels of up to 10,000 tons.

Environmental protection activities are primarily focused on the development and improvement of the coal combustion by installing a pilot plant and a fluidized bed combustion equiped with telecontrol systems.

ENDESA has a 13,872 strong labor force. The companies of the group pride themselves on the fact that by using domestic resources for electricity generation they have enabled savings of some million tons of fuel oil which would otherwise have had to be imported.

ENDESA's new coal-fired power station at Carboneras.

Pharmaceuticals



Only four or five companies around the world produce lactic acid, an organic acid much in demand as a food preservative or a means of regulating the growth of micro-organisms. One of these companies is the Barcelona-based *Luis Ayuso S.A.*, which has captured 23 percent of the worldwide market. Its lactic acid is made from only natural sources and is therefore free of hydrocarbons, petrochemical by-products and nitrated compounds. This pure lactic acid is widely used in the pharmaceutical and food industries, and is especially useful in babyfood.

Organically, lactic acid plays an important part in the metabolism of the intestines. Its fermentation shifts putrefaction, creating correct assimilation and preventing the production of toxins in the intestinal tract. It has a similar effect when used as a preservative in foodstuffs, but it neither masks nor overpowers aromas or flavors weaker than itself.

Nearly forty years ago, Luis Ayuso Utiel, a distinguished Spanish chemist experimenting with different processes for the tanning industry, recognized the effectiveness of lactic acid as a means of improving the treatment of hides in the deliming process, and formed his own company to produce the acid commercially. When the market for synthetic lactic acid began to develop, the company exhaustively analyzed the various methods of production available. It decided that petrolium derivatives were inappropriate in the food industry, which was a major part of its market. Today, the company's production of lactic acid by fermentation of natural products enables it to provide a whole range of qualities required in the industrial, technical and pharmaceutical sectors, as well as in the food industry. And 60 percent of its production is exported, with Japan the main foreign market.

In 1964 Luis Ayuso saw a need in the footwear and leather markets for chemical coatings and adhesives; so he formed a second company, *Merquinsa*, which investigates, manufactures and sells synthetic macromolecules — polymers or resins.

Says Jose Luis Ayuso, director general of *Merquinsa* and the founder's son: "Our exports increase in quantative terms by around 15 to 20 percent a year." Does he expect this to continue? "Absolutely. This is one of the main factors in our success. We are a very export-oriented company and we will continue to be so. Our technology is good enough for us to sell in very sophisticated markets like Germany and Japan and our prices are competitive. A few years ago, it might have been difficult to imagine a Spanish company selling polyurethane emulsions in Germany — rather like Britain selling oranges in Spain. But that is what we are doing.

"We decided ten years ago to invest in both people and equipment. So we recruited young chemists with good chemical backgrounds and we trained them here and at universities abroad."

Merquinsa invests up to six percent of its sales in R&D annually and devotes additional funds to particular projects. It has recently embarked, with 50 percent backing from the Ministry of Industry, on a two-year, Pts250 billion ($1.4 million) special project to research and develop ways of using naturally derived products for the synthesis of polymeric materials, which has been done academically but not commercially.

Siliconas Hispania, S.A., a company founded in 1955 with the sole purpose of specializing in silicone products, four years ago developed new techniques for vulcanizing at room temperature.

The company's silicex elastomer RTV 863, which is used in the manufacture of molds for mass production of polyurethane, polyester or plaster pieces, is a two-component silicone elastomer whose cross-linking takes place at room temperature. The cross-linking starts as soon as the catalyst CR 05 is added to the elastomer RTV 863, and it presents high flexibility and mechanical properties, particularly in tensile and tear strength.

Another major product is silicex emulsion 217, an elastomeric emulsion based on modified polysiloxanes. Designed for fabric finishing, it is applied by padding to impart softness and crease-free elasticity.

The company produces methyl, modified and phenyl fluids; fluid, reactive and special emulsions; antifoams, pastes and greases, and both heat and room-temperature vulcanizing elastomers. Its markets include the aeronautic, automobile, construction, cosmetics, electronics, food, paint, petroleum, pharmaceutical, rubber and textile industries.

As the only active silicone company in Spain, *Siliconas Hispania S.A.* has captured 36 percent of the domestic market.

Ecology

Reaching 357 meters into the sky (higher than the Eiffel Tower), what is claimed to be the tallest chimney in Europe stands at Puentes, near Corunna, in Spain's northwestern region of Galicia.

The towering smokestack at the Puentes coal-fueled electric power station symbolizes the emphasis which ENDESA, the state-owned group of power companies, places on the conservation of the environment. This chimney, like those at other ENDESA power plants, is equipped with a ninety-nine-percent-effective electrostatic filter. That, combined with its height, makes it significantly less polluting.

ENDESA came by its concern for the ecology naturally. Its first venture was to install a power plant at Ponferrada, near Leon, to utilize anthracite from nearby mines. Since that time, the company concentrated on coal-fired generator stations, while many competitors stressed other solutions, such as hydraulic, oil-burning or nuclear plants. The generally high sulphur and ash content of Spanish coal made an environmental conscience a must for ENDESA.

Today ENDESA is a full-cycle energy services group; its activities range from coalmining and gas production (to fuel its own power stations), to distribution of electric power for domestic and industrial uses, to the manufacture of solar panels and heat pumps. It also produces energy at hydraulic, nuclear, geothermal, solar and wind-powered installations.

Environmental concern is evident in other activities of this company, such as the operation of eighty-six pollution-monitoring stations — largely automated — and experimental efforts to take advantage of residual heat from power plants. Fish hatcheries and various types of agricultural installations, warmed by such recycled heat, are at Ponferrada and on the Mediterranean island of Mallorca.

ENDESA is also keenly interested in the more efficient use of energy. Inaugurated early this year, the power plant at Moralets, in the northeastern region of Catalonia, is the biggest hydraulic station in the country to utilize the "re-pumping" technique: pumping water from a lower level to refill a higher reservoir during hours when the energy demand is low, in order to generate more electricity in hours of peak demand (and higher rates).

Tourism

The "invisible export", tourism, brings in enough foreign currency to pay for four-fifths of Spain's petroleum imports bill. And considering that there are more tourist hotel bedrooms on the Spanish island of Mallorca alone than in all of Greece, Yugoslavia and the Portuguese Algarve combined, it is not surprising that the Spanish Institute of Tourism uses the most advanced computerized calculations to fine-tune its operations. Manuel Figuerola Polomo, the Institute's chief of economic and business studies, says that such tools make it possible to foresee temporary or regional slumps in tourism and prepare for them or try to head them off. They make it possible, too, to improve the message transmitted to potential foreign visitors. In short, they make marketing more of a science than an art.

They also help to put the competition in perspective. Constant analyses of what other countries are offering helps to keep the Spanish businessmen competitive and to show them where improvements in cost-cutting are indicated.

Input-output tables, developed at the institute, take into account the vast combination of factors relating to tourism which bears on the economy; thus, they furnish a fairly accurate picture of what tourism means to the economy. The development of a fictitious currency unit, the UCT, gave researchers a stable index for studying the economic structure of tourism.

The lessons Spanish officials learned on the ground were sometimes hard ones. For example, when the tourist boom began in this country, no authority seemed to be aware of the danger of saltwaters seeping into the groundwater reserves in certain island and coastal areas, as a result of excessive well-drilling and pumping of fresh water to satisfy the needs of burgeoning tourist complexes. That lack of foresight made scarce water supplies scarcer and seriously threatened the survival of agriculture and livestock in areas adjacent to tourist zones; as the water became saltier, it not only became unfit for humans, it also became less useful for irrigation and unfit for animals.

The progressive salinization of wells has been halted now, but reversing the process is a much more difficult task. Nevertheless, even that situation offers technological benefits for the future.

Necessity was the mother of invention in Mallorca, where water recycling experiments conducted by a branch of the Agriculture Ministry and private industry are showing promising results. A cheap, reliable, safe system for processing waste-water and recycling it through the irrigation of certain crops is nearly ready for commercialization. On a large enough scale, it could guarantee the future of farming near tourist zones and actually improve the quality of drinking water pumped from wells, to the benefit of both men and livestock.

National airline

With more than 12 million passengers in the 1983 – 84 season, *Iberia, Líneas Aéreas de Espana S.A.*, is Europe's third busiest airline, and the seventh busiest in the world.

Data processing is a highly important element in its operations. Ever since 1962, when Iberia installed its first computer, the 423-person data processing division has been one of the most sophisticated information-processing centers in Spain. More than four thousand terminals are connected, via a complex communications network in real-time, to Iberia's computers, which have the capacity to process over 15 million instructions per second. Applications including ticket reservation, hotel booking, fare calculation, teleticketing, check-in, etc., offer high-quality service to passengers.

The team of data-processing technicians keeps the existing applications up to date and is constantly at work developing new ones. At the moment, the implantation of new software packages to allow optimum short-term average income (per passenger-mile) is under study. These management techniques, known as "Yield Management", constitute an important tool for an airline, which must adjust its supply and demand in real-time to maximize income.

In addition, programs have been worked out to solve various problems in real-time, in such operations as flight planning, aircraft tracking, and balanced loading.

The heart of Iberia is its materiel division near Madrid's Barajas Airport, which includes five large hangars on a floor space of 205,000 square meters. A work force of 5,225 is employed in such tasks as the fabrication and repair of bonded metallic structures and the repair of structures made with composite materiels. At present, repairs on secondary structures made with first-generation composite materiels are under way, and the installations are being modified to allow for work with advanced composite materiels. Equipment includes a particles analyzer and counter (for metallic and other particles), for use in fluids normally used in aviation (hydraulic liquids, oils, fuel); this is capable of detecting particles ranging from 0.6 of a micron to 800 microns.

The engines sector at Iberia.

The materiel division also carries out all the check-ups and repairs of electronic components of A-300 Airbuses used by the multinational Atlas Group, which comprises Iberia, Lufthansa, Sabena, Alitalia, and Air France. The check-ups of the cells of the group's B-747 Jumbos are also carried out there, in conjunction with Air France. Altogether, maintenance is performed on twenty of Iberia's own wide-body planes (B-747s, DC-10s, and A-300s) as well as one hundred other planes belonging to Iberia (B-727s and DC-9s) and the other airlines, which fly a total of 280,000 hours per year.

The engines sector of the Materiel Directorate has advanced test banks, shops, and assembly buildings. JT8D, JT9D, and JT3D engines are overhauled there, and for many years, complete engine overhauls of the Air France Concordes (Olympus) were carried out also. Obviously the activities of the engines sector are not limited to catering to the needs of Iberia's fleet. The sector works for the European companies of the Atlas Group; for other air transport companies such as Aerolíneas of Argentina, Aero Postal of Venezuela, Aero Perú, and Air Cameroon; and also for the Spanish armed forces. For example, Iberia maintains the Harrier (Pegasus) engines as well as the GE T58 turbines of Spanish navy helicopters. Over two hundred engine overhauls per year are carried out at Iberia's installations.

Tasks of maintenance and overhaul not only require teams of skilled technicians and the proper means; they also call for very advanced computerized information support. A package of programs known as MATS I is used for materiels management. Now Iberia, with SAS and Sperry, is developing MATS II, a more advanced version.

Flight crews are trained at two study centers at the Barajas Airport, which are equipped with the latest technology such as automatic training devices with programs developed by Iberia.

The company has trained two hundred pilots for other international airlines in its flight simulators for the A-300 Airbus, Boeing B-727, and McDonnell-Douglas DC-9.

Casa

Many aircraft manufacturing companies have attempted to produce a versatile light transport aircraft with low maintenance costs, capable of operating under all types of adverse conditions in the manner of the renowned DC-3. One of the few to succeed, commercially, has been the Spanish company *Casa*, which has sold more than four hundred of its C-212-300 planes.

Designed principally for regional transport lines, the C-212 is a high-wing twin-turboprop metal-structure aircraft of semi-monocoque design with fixed landing gear, capable of operating from short, unprepared airfields and carrying twenty-four passengers.

Commissioned in 1969, initially for the Spanish airforce, the C-212 is now flying in thirty countries in both military and civilian capacities.

Casa has built on the success of the C-212 by introducing the CN-235, one of the new generation of regional airliners which will accommodate up to forty-four passengers. Developed jointly by Casa and Nurtanio of Indonesia, the CN-235 is a pressurized twin-turboprop high-wing aircraft with a tough, retractable tricycle landing gear. It offers a more modest level of cabin pressurization than its principal competitors and differs from other "super commuters" in having a ventral ramp-type rear door.

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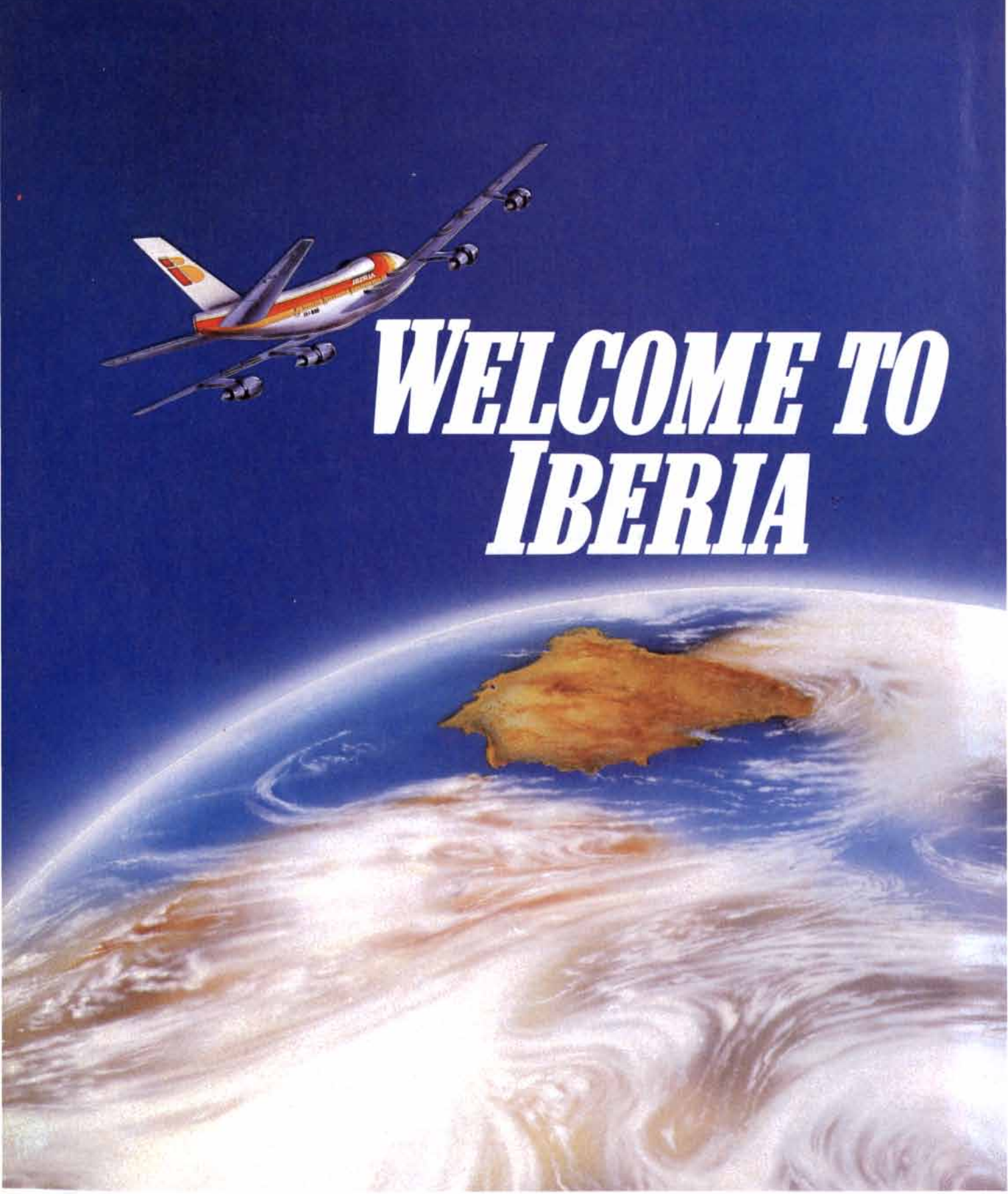

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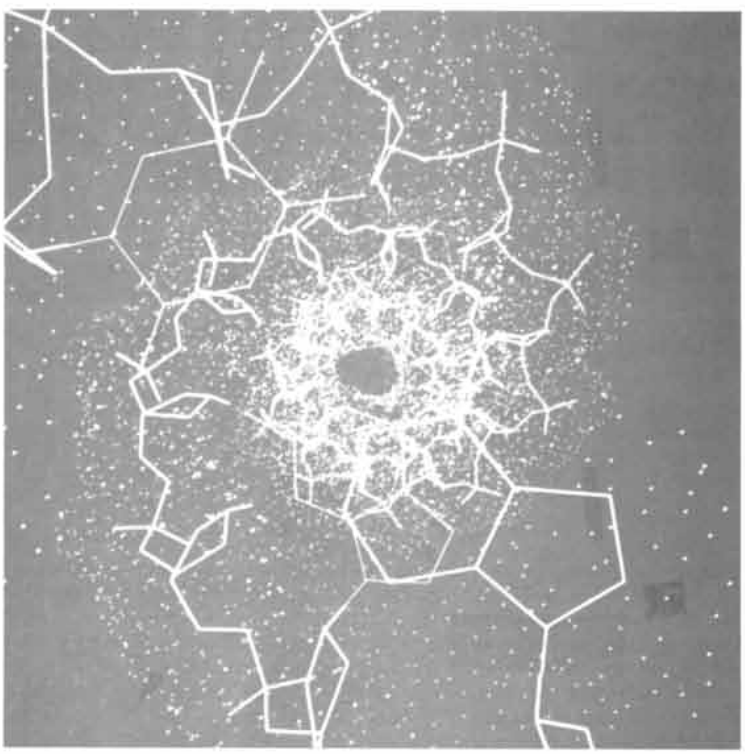

THE MOLECULES OF LIFE

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October 1985

The Compartmental Organization of the Golgi Apparatus

This cellular organelle modifies proteins, sorts them and packages them for delivery. Recent work shows the Golgi is divided into three compartments, each specialized for a different type of modification

by James E. Rothman

Although the cell is the fundamental structural unit of all organisms, the cell itself is by no means indivisible. On the contrary, each cell is divided into as many as a dozen compartments, or organelles, that are specialized to carry out different sets of functions. For example, the nucleus carries the genetic information; the secretory granules store substances that are eventually released from the cell; the outer membrane, or plasma membrane, determines what passes into and out of the cell. Each compartment fulfills its function by means of a group of linked chemical reactions, and every one of those reactions is catalyzed by a protein serving as an enzyme. Compartmental organization is crucial to the functioning of the cell because without it thousands of enzymes would be randomly mixed, resulting in a chaotic splay of biochemical activity.

To prevent the random mingling of biochemical activities thousands of newly made proteins must be modified, sorted and delivered with great precision to the correct compartment. In the past two decades it has become clear that the director of most of this traffic in macromolecules is the Golgi apparatus. Found in all eukaryotic cells (those with nucleii), the Golgi apparatus consists of tiny membrane-enclosed sacs that are flattened and stacked like dinner plates. Into one end of the stack go newly made proteins. Most of these proteins bear long chains of sugar molecules and are therefore called glycoproteins. As they pass through the stack they are chemically modified in specific ways that often depend on their ultimate destinations. As they leave the other end of the stack the proteins are divided according to their destinations and sent on their way.

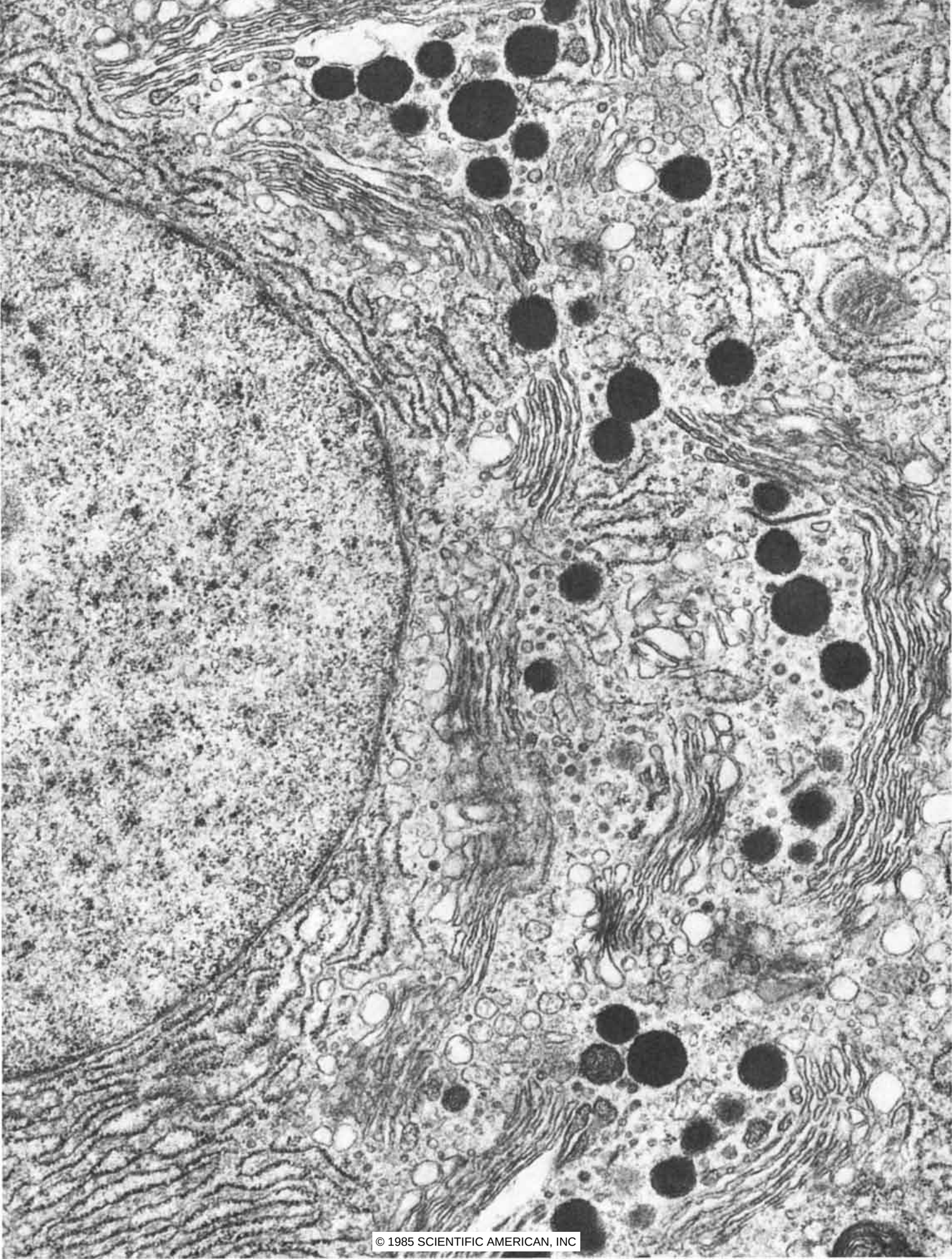
Until recently little was known about how the Golgi apparatus is organized to carry out the complex processing and sorting operation. Since 1980 work in my laboratory and in others has shown that the Golgi stack has a precise internal structure: it is divided into at least three compartments consisting of one or more saccules apiece. Each compartment contains the enzymes needed to perform particular steps in the sequence of protein modifications; the compartments thus resemble processing stations in a factory. In order to be modified correctly a protein must pass through all the stations in sequence. Now that the relations between structure and function in the stack have begun to emerge, interest has shifted to finding out how the proteins move through the stack, how they are sorted according to destination and how they are packaged for delivery.

The Golgi Stack

Each membrane-enclosed saccule in the Golgi stack is called a cisterna. The average number of cisternae in a stack varies considerably from cell to cell. In a typical mammalian cell there might be, say, five or six cisternae in each stack; in the cells of plants and lower organisms there are often 20 or more. The cisternae are generally about a micrometer (one thousandth of a millimeter) in diameter. Like the other membranes of the cell, the membrane that encloses the cisterna consists of a lipid "bilayer" that includes two layers of apposed lipid molecules. A variety of proteins are inserted among the tightly packed lipids. The mechanisms that cause the tiny, membranous sacs to assume their flattened shape and remain in close proximity to one another are not yet understood.

In any event, as long as the cell is not dividing, the saccules remain in the characteristic stacked arrangement. The stack is not symmetric. At one end are cisternae specialized for receiving newly made glycoproteins. That region of the stack is called the *cis* end, and the surface at that end of the stack is called the *cis* face. The glycoproteins arriving at the *cis* face have been assembled on ribosomes bound to the outer surface of the endoplasmic reticulum. The endoplasmic reticulum consists of an extensive, continuous membrane with a complex shape. As the proteins are assembled they are either injected into the lumen (interior space) of the endoplasmic reticulum or in-

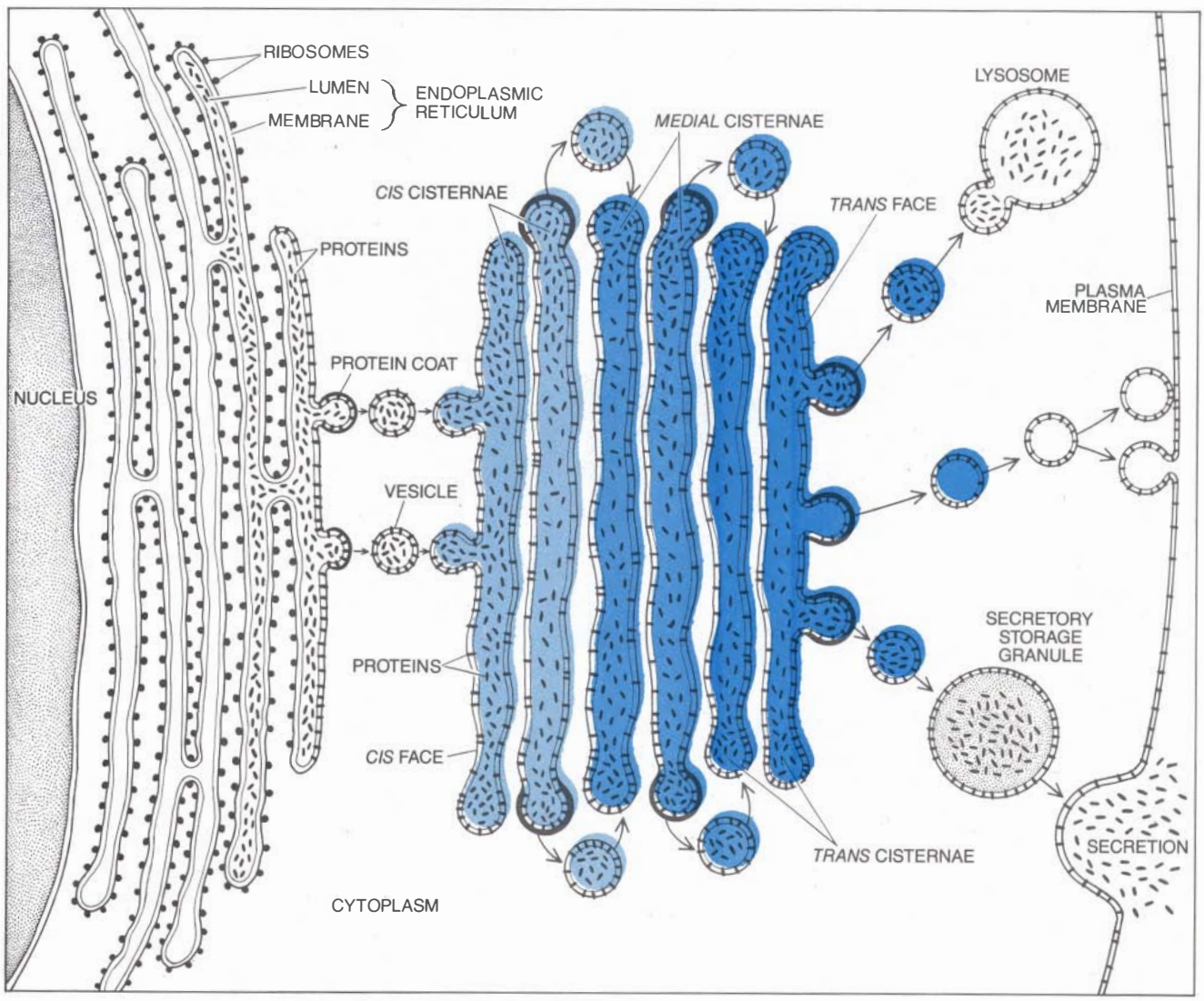
GOLGI STACKS are extensively distributed throughout a cell of Brunner's duodenal gland, which actively secretes proteins. The large circular area at the left is the cell nucleus. The irregular forms dotted with dark specks that fringe the nucleus and appear in other parts of the cell are sections of the organelle called the endoplasmic reticulum; the dark specks are ribosomes. Proteins destined for secretion, among other types, are assembled on the ribosomes of the endoplasmic reticulum and are then transported to the Golgi stacks: the groups of wavy parallel lines scattered through the cell. Each wavy line is actually the cross section of a flattened, membranous sac called a cisterna. In the Golgi stack the proteins are chemically modified and sorted; near some cisternae the small transport vesicles that carry secretory products from one cisterna to another are visible. The secretory proteins are then packaged in secretory storage granules: the circular black forms. The storage granules, which carry the proteins out of the cell, were darkened by a stain. The electron micrograph was made by Daniel S. Friend of the University of California at San Francisco Medical Center.



serted into its membrane, depending on the particular type of protein. The newly made proteins are then encapsulated in a vesicle made of a piece of the membrane of the endoplasmic reticulum. When the transport vesicle reaches the *cis* face of the Golgi stack, it fuses with the cisternal membrane. The contents of the vesicle are thereby introduced into the cisterna at the *cis* end of the stack, which forms the starting point of their transit toward the other, or *trans,* end of the stack.

The newly achieved understanding of what goes on as the glycoproteins move from the *cis* face to the *trans* face of the Golgi stack is founded on a series of investigations that began at the end of the 19th century. Almost from its discovery in 1898 by the Italian histologist Camillo Golgi the organelle that bears his name was suspected of having a role in the passage of secretory proteins to the outside of the cell. In the 1960's George E. Palade of the Rockefeller Institute for Medical Research and his colleagues established that secretory proteins pass through the Golgi apparatus. Using a combination of radioactive labeling, staining and electron microscopy, Palade followed proteins in pancreatic cells from the ribosomes through the Golgi apparatus and then into secretory storage granules, the vehicles of their ultimate release by the cell. Charles P. Leblond of McGill University and his colleagues found that as the secretory proteins pass through the Golgi stack, sugar molecules are generally added to them. Leblond's discovery was crucial, because it demonstrated for the first time that proteins undergo an essential processing operation as they move through the Golgi stack.

The work done from about 1970 to 1980 yielded both a broader grasp of the main purpose of the Golgi apparatus and a firmer one. A landmark in that process was reached in about 1970 when the Golgi apparatus was isolat-



THREE COMPARTMENTS, each containing a unique set of enzymes, have been identified in the Golgi stack. The ribosomes that assemble the proteins to be processed in the Golgi stack are bound to the membrane of the endoplasmic reticulum. As the proteins are completed they are either inserted into the membrane of the reticulum or injected into its lumen (interior space). The proteins are encapsulated in vesicles made up of a piece of the reticular membrane. The vesicles are covered by a protein coat that is needed to enable them to bud from the membrane; after a vesicle buds off, the coat is shed. The vesicle moves toward the Golgi apparatus and fuses with specialized cisternae at one end of the stack, which make up the *cis* compartment. The proteins are then transported by other vesicles to the cisternae of the *medial* and the *trans* compartments. As the various proteins pass through the stack, each one is modified according to its final destination. In the *trans* compartment the proteins are sorted and packaged for delivery. Some proteins go to the secretory storage granules, others to lysosomes (large vesicles that contain degradative enzymes) and still others to the cell's plasma membrane.

ed in a highly purified form in the laboratories of Sidney Fleischer of Vanderbilt University, Saul Roseman of Johns Hopkins University and Palade. Their achievement made it possible to analyze the biochemical components of the Golgi stack and test for the presence of various enzymes in its membranes. The ensuing work revealed that the stack houses a diverse array of enzymes that carry out a great variety of chemical modifications. The enzymes not only add and remove sugar molecules but also can add phosphate groups, sulfate groups and even fatty acids to the protein molecules. The exact purpose of the modifications remains unknown, but they have provided biochemists with excellent tools for probing the organization of the Golgi apparatus.

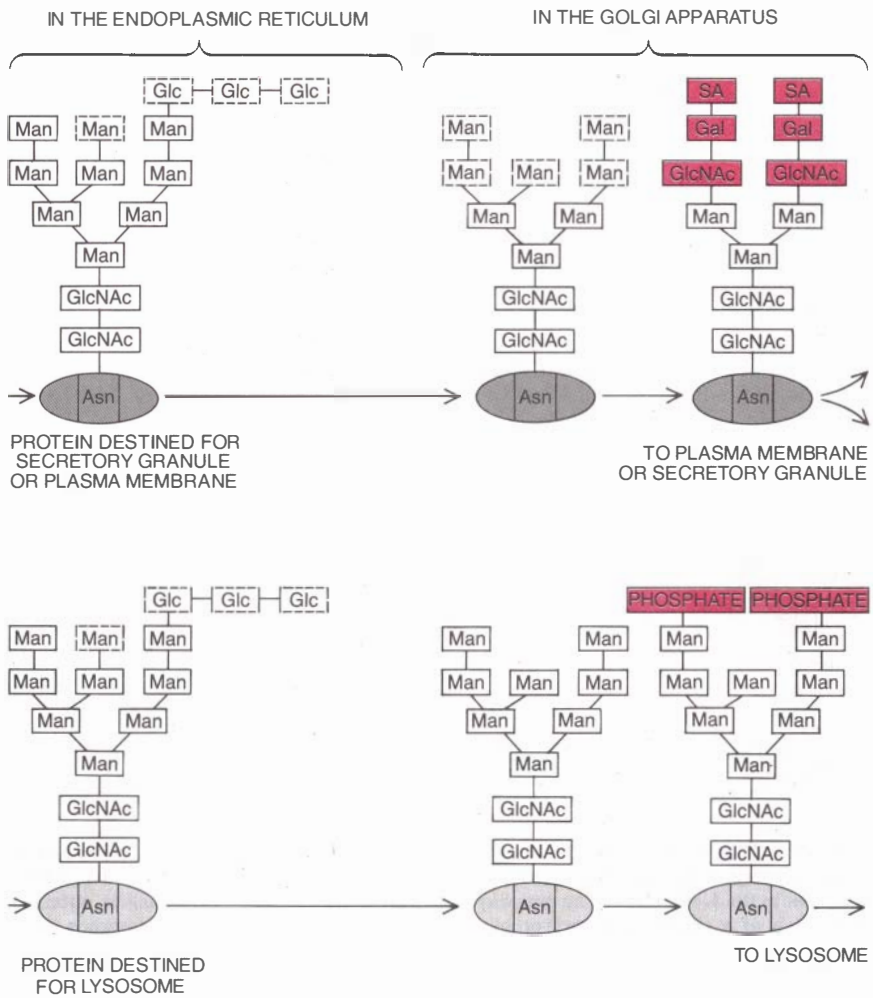
Furthermore, it was discovered that the types of sugar molecules that are added to proteins passing through the Golgi stack are found in many cellular compartments other than the secretory granules. Among those compartments are the lysosomes (large vesicles containing degradative enzymes that break down macromolecules not needed in the cell) and the plasma membrane. It became clear that secretory proteins are not the only proteins to traverse the Golgi apparatus: proteins addressed to many of the compartments in the cytoplasm also undergo that passage before being sent on their separate ways. These findings implied that in addition to modifying the proteins the Golgi apparatus also sorts them into groups corresponding to their various destinations.

The Glycosylation Pathway

How is the Golgi stack organized to carry out the processing and sorting? The first hint that the saccules might constitute compartments specialized for different processing steps had actually come in the 1950's and 1960's, long before the chemistry of the apparatus was understood. Cytologists who employed histochemical dyes and precipitates to stain the Golgi stack observed that certain substances stained some saccules within the stack but not others. The differential staining, however, could not yield precise information about how the stack is organized in functional terms because the exact biochemical significance of the staining was (and still is) obscure in most cases. Moreover, the sequence of processing steps in the saccules had not been worked out, hence no link could be made between the staining reactions and the processing steps.

By the end of the 1970's the complete sequence of steps by which the oligosaccharides, the long sugar chains of glycoproteins, are built up in the Golgi stack had been almost fully deciphered. The unraveling of the pathway was a major advance in biochemistry that required contributions from several laboratories. The most notable contribution came from the laboratory of Stuart A. Kornfeld of the Washington University School of Medicine; his efforts were complemented by those of Harry Schachter of the University of Toronto, Robert L. Hill of the Duke University Medical Center, Phillips W. Robbins of the Massachusetts Institute of Technology and Kurt von Figura of the University of Munich. First the glycosyltransferases (the enzymes that catalyze the attachment of new sugars to the oligosaccharide chain) were discovered and arranged in their correct order. The processing pathway was filled in by the discovery of other enzymes that catalyze unanticipated intervening steps in which key sugars are removed from the chain.

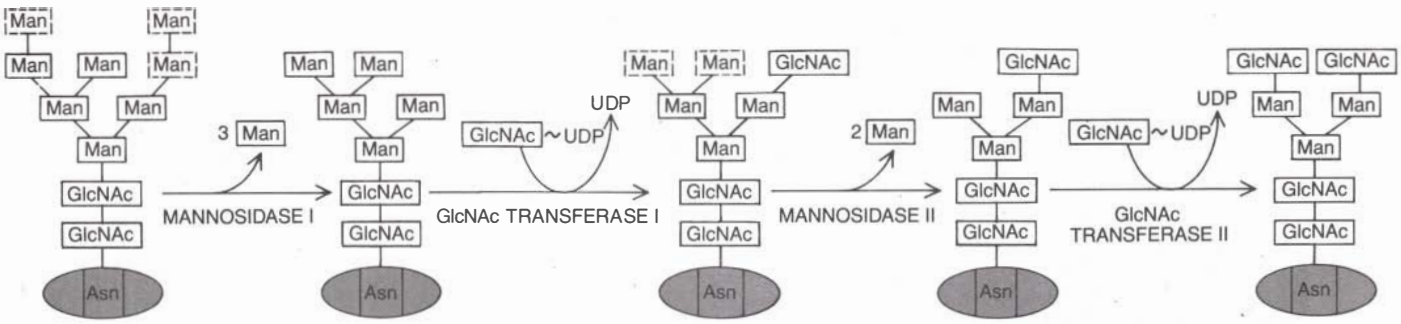
The processing pathway begins in the lumen of the endoplasmic reticulum, where the same oligosaccharide molecule is added to every nascent glycoprotein. The oligosaccharide includes 14 sugar molecules. There are two molecules of *N*-acetylglucosa-



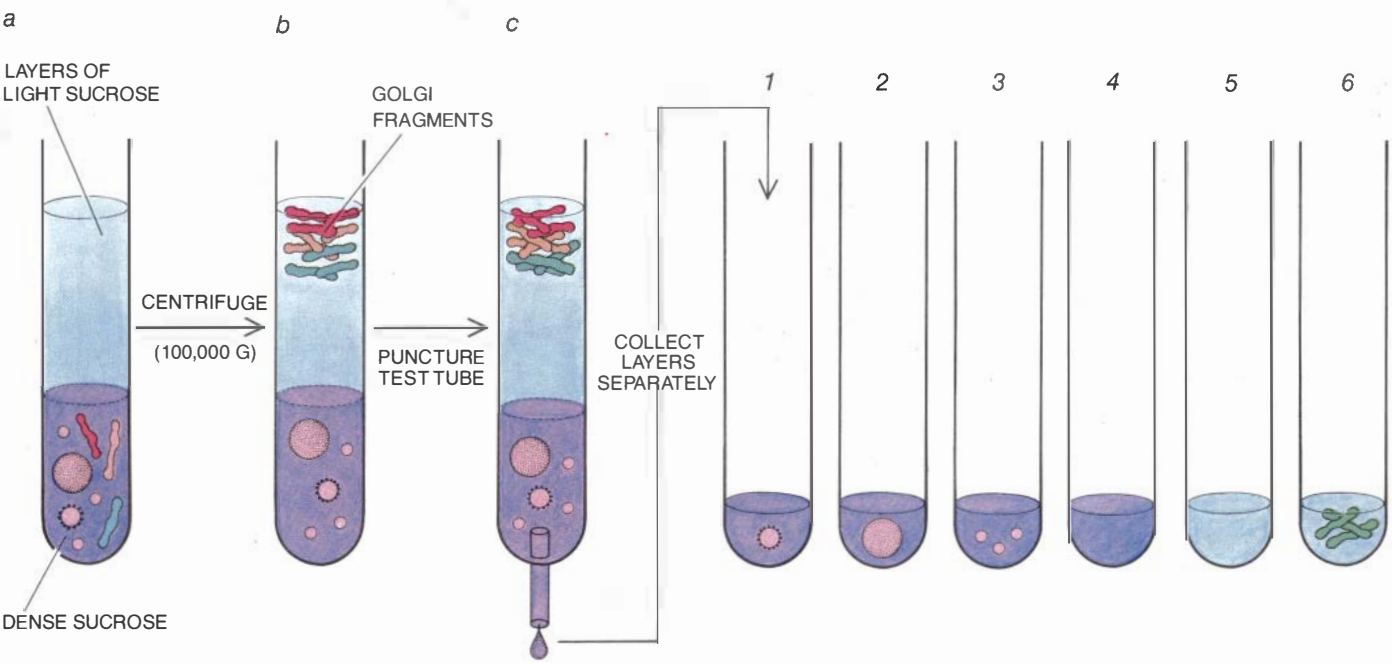
OLIGOSACCHARIDE CHAIN is added to almost all proteins destined for the Golgi stack while they are still in the endoplasmic reticulum. The oligosaccharide chain (*left*) consists of 14 sugar units, all either six-carbon sugars or derivatives of six-carbon sugars. A protein with attached sugars is called a glycoprotein. The same oligosaccharide chain is added to all glycoproteins in the endoplasmic reticulum; it is always attached to the amino acid asparagine. Enzymes in the endoplasmic reticulum quickly remove all the glucose units and one of the mannose units from the chain. What happens to the glycoproteins after they enter the Golgi stack depends on their destination in the cell. Secretory proteins and plasma-membrane proteins generally lose most of their mannose units and gain sialic acid, galactose and *N*-acetylglucosamine units (*upper right*). Lysosomal proteins have phosphate units added to them in the Golgi stack but undergo little additional processing there (*lower right*).

mine (GlcNAc), nine molecules of mannose and three molecules of glucose. (These sugars, and the ones subsequently added to the oligosaccharide chain in the Golgi stack, are either six-carbon sugars or chemical derivatives of six-carbon sugars.) While the protein is still in the endoplasmic reticulum, all three glucose units and one of the mannose units are quickly removed and the proteins are transferred in vesicles to the Golgi apparatus.

As a result of processing in the endoplasmic reticulum the many different types of glycoproteins arriving at the *cis* face of the Golgi stack all have identical oligosaccharide chains. Once inside the stack, however, different proteins are treated quite differently. For example, proteins that will end up in the lysosomes are recognized as such, and each lysosomal protein receives phosphate groups on its sugar chain but undergoes little further modification. Secretory proteins and plasma-membrane proteins, on the other hand, typically undergo much more extensive processing that includes the removal of most of their mannose units. The mannose sugars are removed in two steps. First an enzyme called mannosidase I removes three specific mannose units; immediately an enzyme called GlcNAc transferase I attaches one molecule of GlcNAc to one of the remaining mannose units. Mannosidase II then removes two more mannose units and GlcNAc transferase II adds another molecule of GlcNAc. After the mannose units have been removed and the GlcNAc units added, other enzymes add ga-



GLYCOSYLATION PATHWAY consists of the sequence of enzymatic steps by which the oligosaccharide chain of a glycoprotein is modified in the Golgi stack. The pathway shown here depicts the modification of a typical secretory or plasma-membrane protein. First an enzyme called mannosidase I removes three mannose units from the chain. Immediately thereafter an enzyme called *N*-acetylglucosamine transferase I adds one unit of *N*-acetylglucosamine (GlcNAc). The addition of sugar units requires considerable energy, which is obtained by splitting a high-energy bond previously formed between the sugar and a phosphate group that is part of an accessory molecule. The accessory is a nucleotide: either uridine diphosphate (UDP) or cytidine monophosphate (CMP). After the



DENSITY-GRADIENT EXPERIMENTS provided the initial evidence that each group of processing enzymes in the Golgi apparatus is found in a different part of the stack. Cells were broken down into fragments and put into a dense sucrose solution at the bottom of a test tube (*a*). Layers of sucrose of decreasing density were added above the solution containing the cell fragments. The tube was spun in a centrifuge at 100,000 times the force of gravity (*b*). Density-gradient centrifugation caused each type of cell fragment, including bits of the Golgi cisternae, to rise until it reached a sucrose layer whose density equaled its own. The centrifuge tube was then drained drop by drop into a series of tubes, each holding membranes of the same density (*c*). Fragments of the Golgi cisternae were found in three tubes, implying the existence of three types of fragments having different densities. Chemical analysis showed that each type

lactose and sialic acid to the oligosaccharide chains of these proteins.

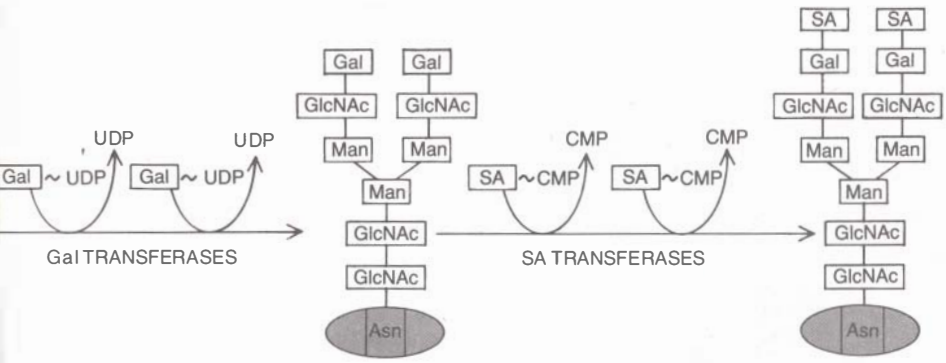
Three Compartments

The new understanding of the glycosylation pathway provided the molecular tools for examining the internal organization of the Golgi apparatus. In 1981 William G. Dunphy and Erik Fries (who were then respectively a graduate student and a postdoctoral fellow in my laboratory) and I discovered that mannosidase I is in a different part of the Golgi apparatus from the enzymes that add galactose and sialic acid. The experiments on which our finding was based relied on the differential density of the Golgi compartments. Test tubes were prepared containing a dense sucrose solution at the bottom. Cells were broken open, which freed their organelles; the cell fragments were then put in the tubes. Sucrose solutions of decreasing density were layered on the dense solution at the bottom of the tube. If such a tube is spun in a centrifuge, the solid particles within the tube rise until they reach the layer whose density equals their own.

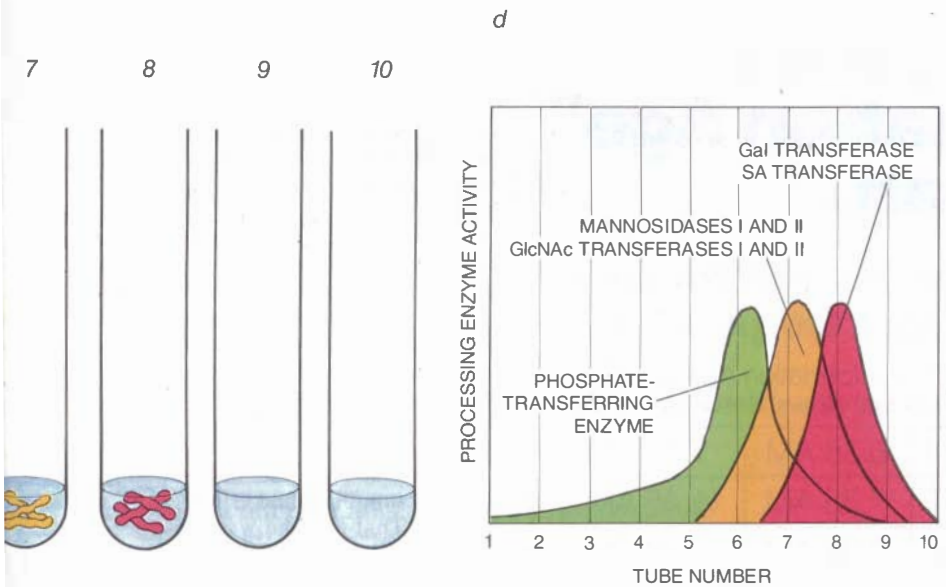
When the cells are broken up before being centrifuged, the cisternae (or the remaining fragments of them) are generally torn apart. If the cisternal remnants from different parts of the stack have different densities, they will be separated in the sucrose gradient during centrifugation. The contents of each layer of the tube can be determined by draining the tube drop by drop and then subjecting each portion to biochemical analysis. Dunphy, Fries and I found that the cisternal bits and pieces had indeed separated into two regions. The denser set of fragments contained most of the mannosidase I; the lighter set contained the galactose transferases and the sialic acid transferases. We concluded that the mannose units must be removed in one part of the stack before the galactose and sialic acid units are added in another part. This was the first evidence that the Golgi stack contains compartments that are biochemically specialized.

That evidence was confirmed by experiments in living cells that had been infected with the virus that causes a disease called vesicular stomatitis; the cells had been taken from the ovaries of Chinese hamsters. On entering a cell, such a virus usurps the cell's protein-synthesizing machinery to make its own proteins. The vesicular-stomatitis virus contains only one type of glycoprotein, called the *G* protein. Thus the Golgi apparatus, which in an uninfected cell contains hundreds of types of glycoproteins, is in the infected cell occupied almost completely by a single type of glycoprotein: the *G* protein. As a result the course of the *G* protein through the stack is relatively easy to follow. *G* proteins whose first mannose units had just been removed were detected in the denser membrane fractions containing mannosidase I. *G* proteins that were receiving galactose sugars, however, were detected in the lighter fractions containing the galactose transferases.

By 1983 we and others (notably Kornfeld and Carlos B. Hirschberg of the St. Louis University School of Medicine) had shown that almost all the enzymes in the glycosylation pathway are associated with particular fractions of the Golgi apparatus. Mannosidase II was observed along with the GlcNAc transferases in the dense fraction where mannosidase I had been found. That layer was separate from the one where the galactose and sialic acid transferases had been found. Those findings were significant but not as startling as a discovery made



first GlcNAc has been added mannosidase II removes two more mannose units and GlcNAc transferase II adds another unit of GlcNAc. The final steps in the pathway are the addition of galactose and sialic acid by enzymes specific to those sugars. The precise sequence of the successive enzymatic steps involved in the processing of glycoproteins in the Golgi apparatus was worked out during the 1970's. Once the steps were known, work was undertaken to locate the various enzymes of the glycosylation pathway within the Golgi stack.



of fragment is associated with one set of processing enzymes (*d*). The densest fragments contain the enzymes that catalyze the addition of phosphate groups to proteins destined for the lysosomes. The medium fragments contain the enzymes that remove mannose and add GlcNAc to secretory proteins and to plasma-membrane proteins. The least dense fragments contain the enzymes that add galactose and sialic acid. The density-gradient findings suggested there are at least three types of Golgi cisternae, and that each type of cisterna is biochemically specialized for carrying out certain steps in the glycosylation pathway.

by Kornfeld and his colleagues. They found the enzymes that add phosphates to lysosomal proteins in yet a third fraction, denser even than the one containing the mannosidases. It had become clear that the Golgi apparatus includes at least three biochemically specialized compartments. The next problem was to locate each compartment in the stack.

Mapping the Compartments

Because the cisternae must be torn apart for the fractions to separate in the sucrose gradient, density-gradient methods are not suitable for locating the biochemically defined compartments in the intact Golgi apparatus. Therefore to draw the structural map we turned to electron microscopy of intact cells. The density-gradient work had shown that the enzymes responsible for transferring phosphates to lysosomal proteins, the GlcNAc-transferring enzymes and the galactose-transferring enzymes should be found in different cisternae. To find the compartment holding a particular enzyme, we decided to employ the transferases as markers: each enzyme would selectively stain its compartment in the Golgi stack of an intact cell. The stained compartment could then be identified by electron microscopy.

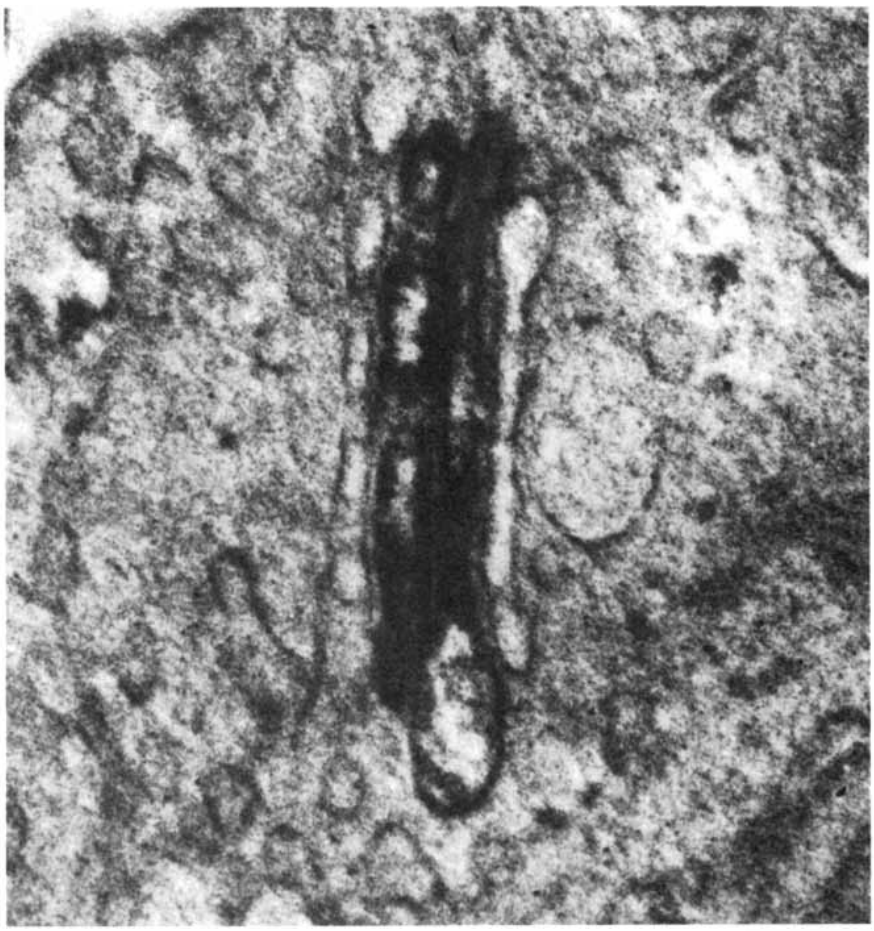
Although the procedure is easy to describe in principle, it is not simple to carry out. First each enzyme must be obtained in an almost completely pure form, which is in itself a major task. The purified enzyme is then injected into laboratory mice, which develop antibodies to the foreign substance. The antibodies then form the material for a complex procedure that ultimately yields monoclonal antibodies to the transferase: antibodies reacting exclusively to that enzyme. When the monoclonal antibodies are put in a cell, they bind only to the Golgi cisternae containing the transferase. Those cisternae are rendered visible in the electron microscope by coupling the monoclonal antibodies to a peroxidase, an enzyme whose product makes a black stain.

We decided to use the antibody-based technique to find GlcNAc transferase I. That enzyme was chosen because it acts in the middle of the glycosylation pathway. If the physical boundaries of the middle compartment could be determined, the boundaries of the initial and final compartments would be found simultaneously. Moreover, GlcNAc transferase I had already been purified for other purposes by Hill. Dunphy prepared GlcNAc transferase I by Hill's procedure, generated a monoclonal antibody to the

enzyme and used it with the peroxidase. Rabbit liver cells, whose Golgi stacks tend to have four or five cisternae, were incubated with the labeled antibody; the liver cells had already been opened so that the antibody could penetrate their outer membrane and reach the cytoplasm. To our delight we found that GlcNAc transferase I was confined to two or three cisternae at the center of the stack, which were designated *medial*.

Independent of the density-gradient work, the location of the GlcNAc-adding enzyme by the staining method immediately confirmed the principle of the three compartments, since GlcNAc is added in the *medial* cisternae but not in the *cis* cisterna or the *trans* cisterna on each side. The desired map correlating structure with function was beginning to emerge. Earlier findings from other laboratories helped to fill in the map. In 1982 (two years before we located the *medial* cisternae) Jürgen Roth of the University of Geneva and Eric Berger of the University of Bern had determined by methods similar to ours that the galactose-adding enzymes are present only in the *trans* cisternae. Their results combined with ours showed that glycoproteins receive GlcNAc in the *medial* cisternae before moving to the *trans* cisternae, where they receive galactose and probably sialic acid. Because the enzymes that attach phosphates to the sugar chains of the lysosomal enzymes on entry to the Golgi apparatus have not yet been purified, they have not been added to the map. Yet it seems almost certain they will be found in the only cisternae that have not been spoken for: those of the *cis* compartment.

The simple tripartite map that has been drawn so far does not necessarily exhaust the compartmental organization of the Golgi apparatus. Indeed, it seems probable that there are still finer subdivisions. For example, the *medial* compartment, which often consists of several cisternae, may be divided into specialized subcompartments. Further work could well increase the number of functional units on the map. There is reason to think, however, that the number will not grow much. It is reasonable to assume the compartmental divisions of the Golgi apparatus are so fundamental to cellular functioning that they are uniform in all cell types. The smallest Golgi stacks have four cisternae. If the basic functional divisions are conserved in all cells, stacks with four cisternae must include all the functional divisions. Hence it is likely there are no more than four basic compartments. Stacks with more than four cisternae may have multiple copies of one type or another, but presumably no additional functional divisions.



MEDIAL COMPARTMENT of the Golgi apparatus was identified in the author's laboratory as the part of the stack that houses the GlcNAc transferases; the identification was made by means of electron microscopy and a staining procedure. The electron micrograph shows a Golgi stack consisting of four cisternae. The central pair have been darkened by a stain that indicates the presence of one of the enzymes that adds GlcNAc to glycoproteins in the Golgi stack. The stain was formulated by preparing monoclonal antibodies to the enzyme, which bind only to that protein. The antibody was indirectly coupled to horseradish peroxidase, an enzyme whose product makes a dark stain. When the antibody was put into rabbit liver cells, it bound to the GlcNAc-adding enzyme, and so the peroxidase stained the cisternae where that enzyme is found. Locating the GlcNAc-adding enzyme in the *medial* compartment was a significant step in mapping the Golgi stack: one could immediately deduce that the phosphate-adding enzymes must be in the *cis,* or first, compartment and that the enzymes adding galactose and sialic acid must be in the *trans,* or third, compartment.

Why Compartments?

Although the compartmental organization of the Golgi apparatus is by now incontrovertible, the fundamental purpose served by that form is not yet understood. Compartmental organization does offer certain strategic advantages in the processing of the oligosaccharide chain. For example, during processing the lysosomal proteins retain all their mannose units in spite of being exposed to the mannose-removing enzymes in the *medial* cisternae. Presumably the mannose units can be retained only because the proteins destined for the lysosomes receive their phosphate units in the *cis* compartment; the phosphates somehow protect the mannose sugars from cleavage in the *medial* compartment. Since the mannose units have not been trimmed, GlcNAc cannot be added in the *medial* compartment, nor can galactose or sialic acid be added in the *trans* compartment.

Compartmentalization may also contribute to the sorting of proteins for delivery. A striking feature of the internal operation of the Golgi stack is that the proteins are generally not physically separated according to destination until they reach the *trans* compartment. The evidence for this conclusion includes the fact that many glycoproteins destined for the secretory granules, the plasma membrane and even the lysosomes contain galactose

...10...9...8...

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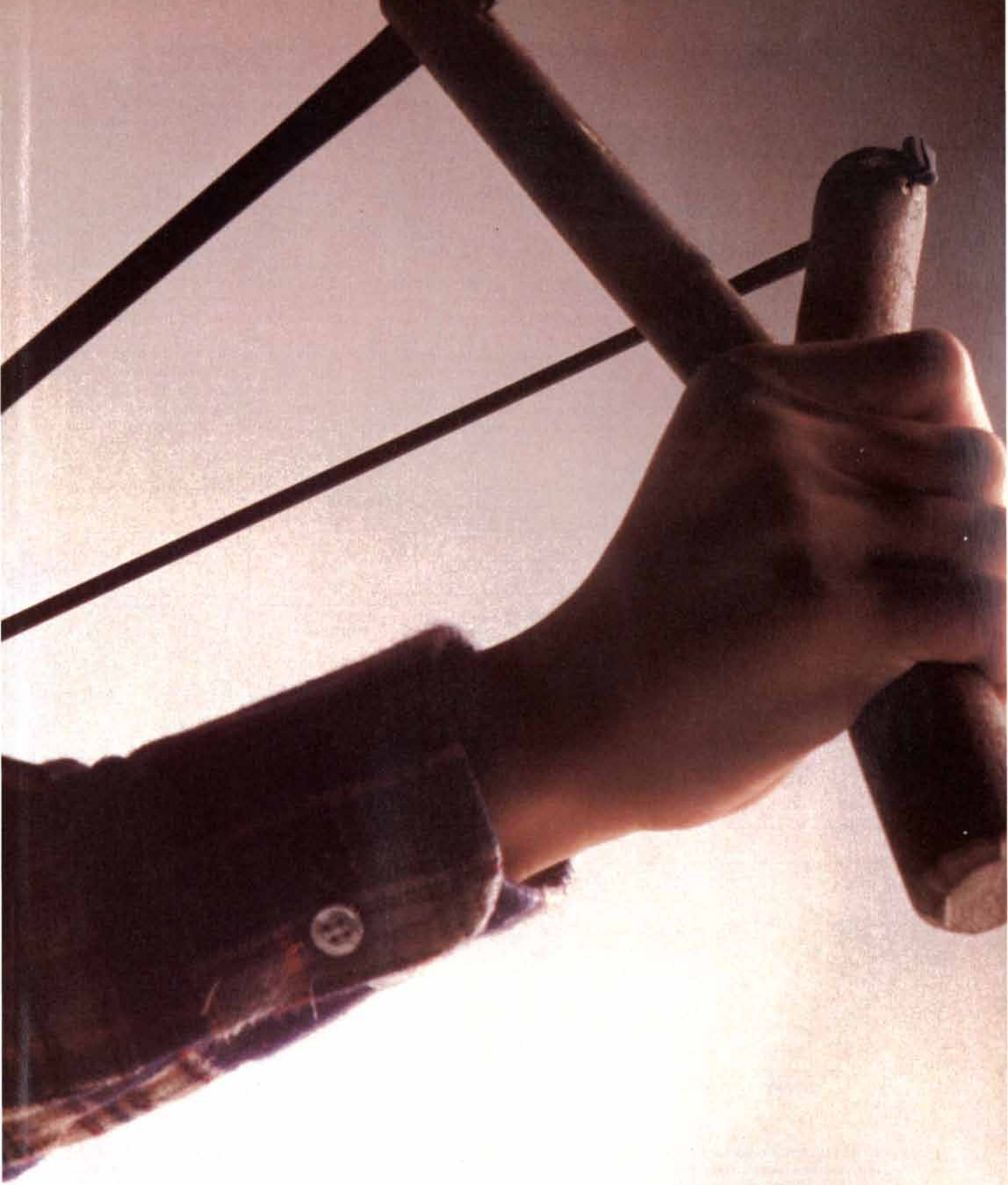


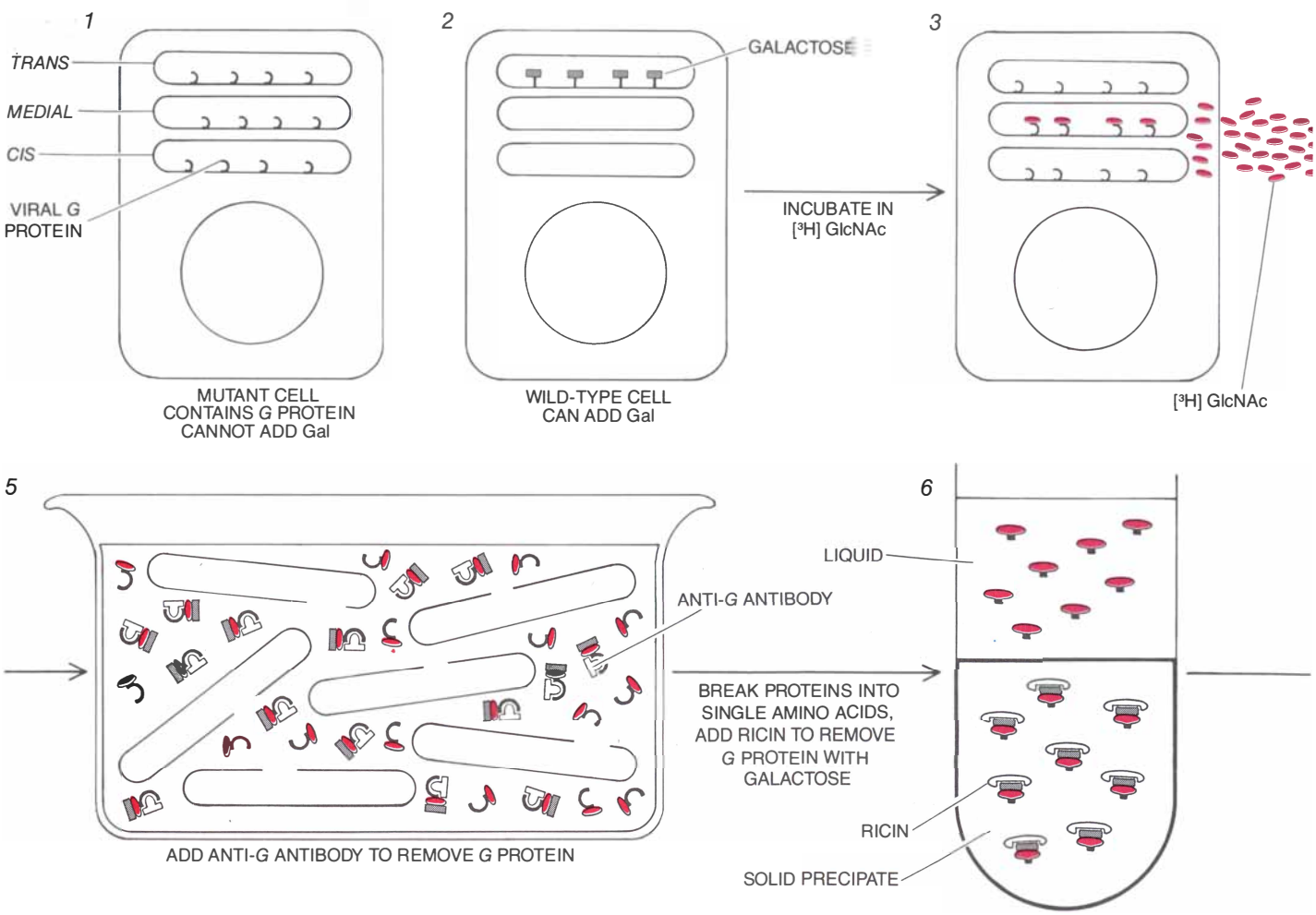
and sialic acid units, which are added only in the *trans* compartment.

Nevertheless, each type of protein may be recognized and "tagged" for delivery to a particular address much earlier. Kornfeld and his colleagues discovered that the lysosomal proteins are distributed in just such a two-stage process. The first stage is the addition of phosphates in the *cis* compartment, which serves to tag the proteins for future sorting. The phosphate-transferring enzyme recognizes some as yet unknown structural feature unique to lysosomal proteins. It does not recognize the sugar chain common to all glycoproteins and will not transfer phosphate to glycoproteins destined for compartments other than the lysosome. The tagged proteins are later captured by a receptor system specific to phosphates and packed into vesicles that go on to fuse with the lysosomes. Whether analogous mechanisms underlie the sorting of other types of proteins is not yet known. If such sequential distribution mechanisms are common, the Golgi stack may be partitioned largely to facilitate the orderly sequential recognition, sorting and "addressing" of proteins as they traverse the stack.

Getting from *cis* to *trans*

Whatever the overall purpose of compartmentalization is found to be, one thing is clear: in order for the compartmental system to operate the glycoproteins must pass through all the compartments in the correct sequence. Two main models have been proposed to explain how the proteins get from *cis* to *trans*. In one model, which might be called cisternal progression, new cisternae form continuously as vesicles derived from the endoplasmic reticulum coalesce at the *cis* face of the stack. Each newly formed cisterna then moves through the stack; the processing operations taking place within the saccule change as it progresses toward the *trans* face. On reaching the *trans* face the cisterna breaks up into transport vesicles that carry the proteins to their ultimate destinations. In such a scheme no material is transferred between cisternae. Instead the cisternae change their biochemical character as they move.

Until rather recently the cisternal-progression model was the most widely accepted hypothesis. Indeed, it was so widely accepted that the *cis* face of the stack was once known as the forming face and the *trans* face as the ma-

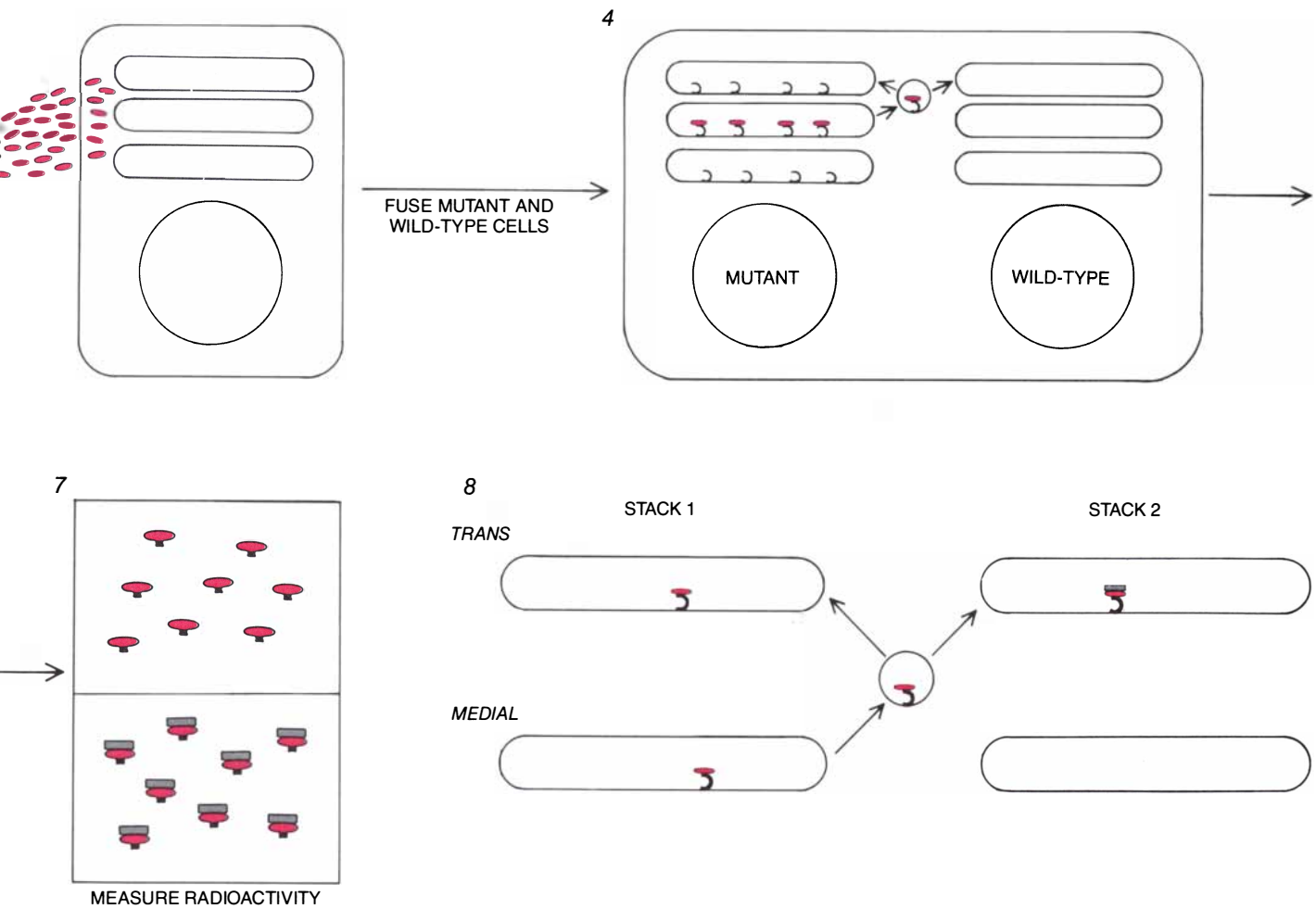


HOPPING BETWEEN COMPARTMENTS of the Golgi stack was demonstrated in a complex experiment done in the author's laboratory in 1983. The experiment involved two types of Chinese-hamster ovarian cell. One type was a mutant that could not add galactose to glycoproteins in its *trans* compartment. The mutant cells were infected with a virus; their Golgi stacks contained almost exclusively one viral protein, the *G* protein (*1*). The other cells were wild-type, or normal, and could add galactose (*2*). Both types of cell were put briefly in a medium that included a precursor of GlcNAc containing tritium (^{3}H), a radioactive isotope of hydrogen (*3*). In the *medial* compartments of the mutant cells' Golgi stacks, processing enzymes added the tritium-containing GlcNAc to *G* proteins. The two cell types were then fused (*4*). After brief incubation the fused cells were dissolved in a soap solution. Antibodies to the *G* protein were utilized to purify that protein from the solution (*5*). The *G* protein was broken into amino acids and a specialized plant

ture face. The recent work on compartmentalization has changed the picture. Since each group of cisternae is now known to have unique biochemical contents, it is difficult to imagine one compartment changing into another. The alternative hypothesis has therefore become more attractive: that the cisternae remain fixed while the maturing glycoproteins are carried forward by vesicles that bud from the membrane of a cisterna in one compartment and fuse with the membrane of a cisterna in the next compartment. Several bits of circumstantial evidence suggested this hypothesis might be correct. The Golgi stack is surrounded by a swarm of small vesicles known to contain the transported proteins. Transport vesicles are known to be selective enough to remove the maturing glycoproteins from a cisterna and leave the processing enzymes behind. Furthermore, vesicles provide the usual means of transport between the other compartments of the cell.

One way of deciding which model is correct is to find out whether proteins can "hop" from one Golgi stack to another. If a glycoprotein can begin its transit in one stack and end it in another stack, it follows that the proteins are carried from cisterna to cisterna. Cisternal progression makes no allowance for such hopping between different Golgi stacks. Unfortunately hopping cannot be detected in a single cell. Each cell contains many copies of identical Golgi stacks, all functioning simultaneously. If a particular glycoprotein molecule is found in the *trans* compartment of one stack, there is no way to tell whether the protein came from the *medial* compartment of the same stack or from that of a different stack.

To test for hopping I therefore devised an experimental system that included two types of cells whose Golgi stacks functioned differently. Like the cells employed in some of the mapping work, both were Chinese-hamster ovary cells. One was the wild-type (normal) cell, which could, of course, add galactose to its glycoproteins. The other was a mutant cell that had been isolated by Kornfeld and his colleagues in the mid-1970's. The mutant had a genetic defect that rendered it incapable of adding galactose to glycoproteins in the *trans* compartment of its Golgi stacks. To facilitate the experiment the mutant cell was infected with the vesicular-stomatitis virus. As described above, in cells infected by the virus the Golgi apparatus is almost completely



protein called ricin (which is of the type termed a lectin) was added to the solution containing the *G* protein. Ricin binds to galactose, forming a precipitate that can be separated from the liquid part of the solution (*6*). The *G* proteins with galactose chains were thus separated from those without galactose. Since both types were radioactive, their relative quantities could be measured by a device called a scintillation counter, which detects radioactivity. There were approximately equal amounts of *G* protein with and without galactose (*7*). The only source of radioactive *G* protein was the *medial* compartment of the mutant cells, but the *G* protein could have acquired galactose only in the *trans* compartment of the wild-type cells. Therefore any *G* protein containing galactose must have "hopped" from a mutant *medial* cisterna to a wild-type *trans* cisterna when the cells were fused (*8*). The presence of galactose in half of the *G* protein implies that when the protein leaves a mutant *medial* cisterna, the probability of its going to a different stack is at least 50 percent.

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taken up by a single transiting glycoprotein, the *G* protein, which is coded for by the virus's genetic material. Since the wild-type cells were not infected, they contained no *G* protein.

The difference between the Golgi stacks of the mutant and the wild-type cells was exploited to find out whether the *G* protein would hop from one type of Golgi stack to the other when the mutant cells were fused to the normal ones. First the cells were incubated in a medium containing a precursor of GlcNAc that includes tritium, a radioactive isotope of hydrogen. The mutants took up the radioactive sugar into the *medial* compartment of their Golgi stacks, where it was added to the *G* proteins. (The wild-type cells also take up the sugar but have no *G* protein to which to add it.) Immediately the wild-type and mutant cells were rapidly fused with each other to form a common cytoplasm containing both wild-type Golgi stacks and mutant stacks.

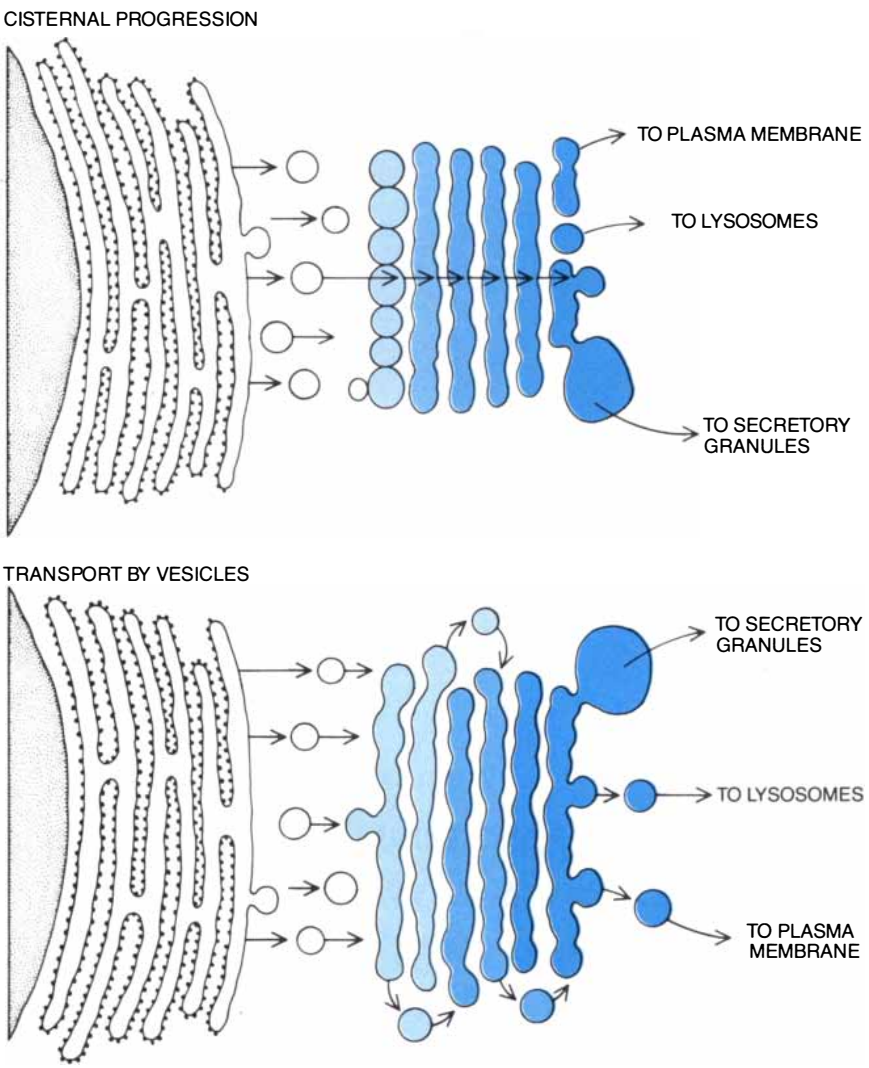
Evidence for Hopping

Initially all the radioactive *G* protein was in the mutant Golgi stacks. Would *G* proteins hop over to the stacks from the wild-type cells? I had to employ an elaborate analytical procedure to find out. After a short wait to allow the postulated hopping to occur, the fused cells were dissolved in a soap solution. Then antibodies to the *G* protein were used to purify all the *G* protein from the crude extract. A specialized plant protein that binds only to sugar chains that include galactose was utilized to separate the sugar chains of the *G* proteins with galactose from those without galactose. Because both types of *G* proteins contained radioactive GlcNAc, the relative quantities of the two groups could then be determined by a machine called a scintillation counter, which measures radioactivity.

What information could this elaborate procedure be expected to yield? The only source of the radioactive *G* protein was the *medial* compartment of the Golgi stack in the mutant cells (the compartment where the radioactive GlcNAc was added). On the other hand, galactose could be added only in the *trans* compartment of the stacks that had originated in the wild-type cells. Therefore if any radioactive *G* protein contained galactose, it must have hopped from a mutant *medial* cisterna to a wild-type *trans* cisterna. If a *G* protein molecule did not contain galactose, it could be assumed to have continued on to the *trans* compartment of the mutant Golgi stack. (In spite of their inability to add galactose, the mutant cells were known to transport proteins through the cisternae normally.) Thus the procedure can indicate the presence of hopping. Moreover, the relative proportions of the two fractions of *G* protein (with and without galactose) can show how common hopping is.

To my amazement I found that not only does hopping occur but also it is as much the rule as the exception. About half of the *G* protein had acquired galactose. This result implies that when a *G* protein left the *medial* compartment of the mutant stack, it made an essentially random choice between the two types of Golgi stacks. Such random hopping is clearly inconsistent with cisternal progression. The transported glycoproteins do not necessarily move systematically through one stack. Instead they are transported from one compartment to the next by vesicles that can leave the stack at every transfer. If the proteins are to traverse the compartments in order, the vesicle must have the intrinsic capacity to find a cisterna corresponding to the next compartment in the sequence. Since the Golgi stacks can be spread throughout the cell, the identification must be made without clues from physical proximity or from the overall organization of the cytoplasm.

Further work has begun to reveal the outlines of the vesicular transport



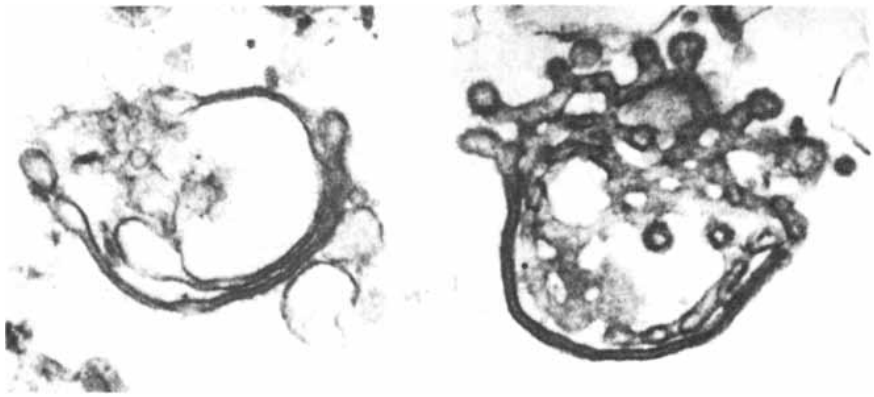
TWO MODELS have been proposed for how glycoproteins pass through the Golgi stack. In cisternal progression (*upper panel*) a new cisterna is formed by the fusion of vesicles at the *cis* face of the stack. As cisternae continue to form behind it, the cisterna moves through the stack. The processing operations carried out within the cisterna somehow change as it traverses the three compartments. At the *trans* face of the stack the cisterna breaks up into vesicles that deliver the glycoproteins to their destinations. In vesicular transport (*lower panel*) the cisternae do not move. Instead the glycoproteins are transported from compartment to compartment by vesicles formed from the membrane at the rim of the cisternae. Until fairly recently cisternal progression was the most widely accepted hypothesis. The hopping of proteins from one Golgi stack to another, however, is clearly inconsistent with cisternal progression; glycoproteins are probably transported through the stack by vesicles.

system. By methods analogous to the ones used for following the *G* protein from *medial* to *trans* we showed the protein also hops from *cis* to *medial.* When the *G* protein hops into the *medial* compartment, GlcNAc is added to it. The fact that a protein can hop into and subsequently out of a site where GlcNAc is added establishes independently that the Golgi stack houses three functionally distinct compartments and that diffusible vesicles provide transport through the sequence of compartments. The functional map established by the hopping experiments thus meshes precisely with the biochemical map provided by density-gradient experiments and the structural map derived from electron microscopy. We also found that vesicular transport is a one-way affair. For example, a protein that reaches the *trans* compartment cannot find its way back to the *medial* compartment.

Since glycoproteins can be transported so efficiently from the *medial* compartment of one stack to the *trans* compartment of another stack in a distant part of the cytoplasm, one might well wonder why the compartments are bound together at all. Although the question has not been answered, I suspect that the stacked form is necessary because in some cells the vesicles cannot escape from the stack, which is necessary if they are to hop to another stack. It is reasonable to assume that when the vesicle buds from the cisternal membrane, it becomes separate from the stack in one sense. This dissociation, however, does not automatically lead to hopping. In order to hop the vesicles not only must separate from the stack but also must be able to escape from the stack and travel to another one.

Dissociation v. Escape

In certain types of cells the cytoplasm is organized by a meshwork of fibers. In such cells the vesicles may dissociate from the stack but not be able to escape from it completely. Under those conditions (which may prevail in the majority of cells) transport between widely separated compartments would be extremely slow if it were possible at all; the compartments of the stack would have to be in close proximity to allow the rapid vesicular transport known to take place between them. In cells without a high degree of cytoplasmic organization, on the other hand, diffusion would be rapid and the vesicles would automatically escape from the stack once they had separated from the cisternal membrane; the result would be hopping. Whether the vesicle can ultimately escape from the stack or not, the capacity to dissociate from the stack and select the correct target membrane is central to the vesicular-transport model.



VESICLES BUD FROM CISTERNAE in a cell-free test-tube system devised by the author and his colleagues. When the Golgi stack is disrupted and spun in a centrifuge, the cloud of vesicles surrounding the cisternae is stripped away (*left*). If a crude mixture of cytoplasmic enzymes and the cellular energy carrier ATP is added to the naked cisternae, however, the cloud of vesicles is regenerated (*right*). Efforts are now under way to identify the specific enzymes needed to generate the vesicles; such findings should show how the transport system for glycoproteins operates in the intact Golgi stack and elsewhere in the cell.

Understanding the details of how the transport system works will undoubtedly have implications for other parts of the cell. In addition to transporting newly made glycoproteins from the endoplasmic reticulum to their ultimate destinations by way of the Golgi stack, vesicles have a central role in endocytosis, the process of transport from the cell surface to lysosomes by way of intermediate compartments known as endosomes [see "How an Animal Virus Gets into and out of Its Host Cell," by Kai Simons, Henrik Garoff and Ari Helenius; SCIENTIFIC AMERICAN, February, 1982]. In each of these transport steps the same questions arise: What causes a vesicle to bud from its source membrane? How does each type of vesicle identify its correct target? What causes the vesicle to fuse with the correct membrane of that target, thereby delivering its cargo?

Answers to some of these questions can be expected soon because my colleagues and I have developed a test-tube system in which proteins are transported between cisternae of Golgi stacks isolated from cells. This is the first time any of the vesicular transport systems has been reconstituted outside a living cell, a crucial step in elucidating the molecular mechanisms of transport. Cell-free transport in the test tube was first achieved by Fries and me in 1980. Recently William E. Balch and William A. Braell (former postdoctoral fellows in my laboratory) along with Benjamin S. Glick (a graduate student) and I have utilized the test-tube system to begin to determine the chemical preconditions for vesicle formation.

When we isolated Golgi stacks in a sucrose gradient, the transport vesicles that normally form a cloud around the cisternae had been stripped away. The isolated Golgi stacks were then incubated in such a way as to enable them to resume transport between cisternae. This was done by putting the stacks in a medium containing a crude mixture of cytoplasmic enzymes along with the energy-rich substance ATP. The result was the generation of a population of fresh transport vesicles. The regenerated vesicles proceeded to transport proteins correctly to the next compartment. As our investigation continues we shall cull from the cytoplasmic mixture the enzymes needed for budding, for targeting and for fusion with the target membrane. It should then be possible to tell what role each enzyme plays in the transport process.

In the past five years great progress has been made in understanding the structure and functioning of the Golgi apparatus. Building on the groundbreaking work of the 1960's and 1970's, it has been firmly established that the Golgi apparatus has three functional compartments and that vesicles with great powers of discrimination transport glycoproteins through the compartments in sequence. Attention has now turned to the transport vesicles themselves; in the next few years cell biologists will certainly come to know much more about these discerning carriers. Since transport by vesicles is of great significance in many cellular contexts, fundamental insights into cell growth and division could come from the work that is in prospect on the compartmental organization of the Golgi apparatus.

Bimetallic Catalysts

Chemical reaction rates are controlled by varying the composition of miniscule clusters of metal atoms. Such clusters are now employed in petroleum refining and may have a number of other applications

by John H. Sinfelt

In 1817 the English chemist Sir Humphrey Davy discovered a remarkable property of platinum. He found that in the presence of that metal oxygen reacts readily, often explosively, with other gases such as hydrogen, carbon monoxide and various volatile hydrocarbons. Such reactions can occur in spite of the fact that the initial temperature of the gases and of the platinum may be far lower than that required for ignition in the absence of platinum. The platinum-induced combustion reactions, which yield water and carbon dioxide as products, do not consume the platinum. The work of Davy provided an example of the phenomenon of catalysis, a term (meaning "loosening" in Greek) introduced by the Swedish chemist Jöns Jakob Berzelius in 1836. Although Berzelius recognized the importance of catalytic phenomena in chemistry, a lack of understanding of the basic principles involved hindered progress for many years. A major advance took place in about 1900 when the German chemist Wilhelm Ostwald proposed that a catalyst can influence only the rate of a chemical reaction; a chemical change occurring in the presence of a catalyst must also be capable of occurring in the absence of a catalyst, although at a much lower rate.

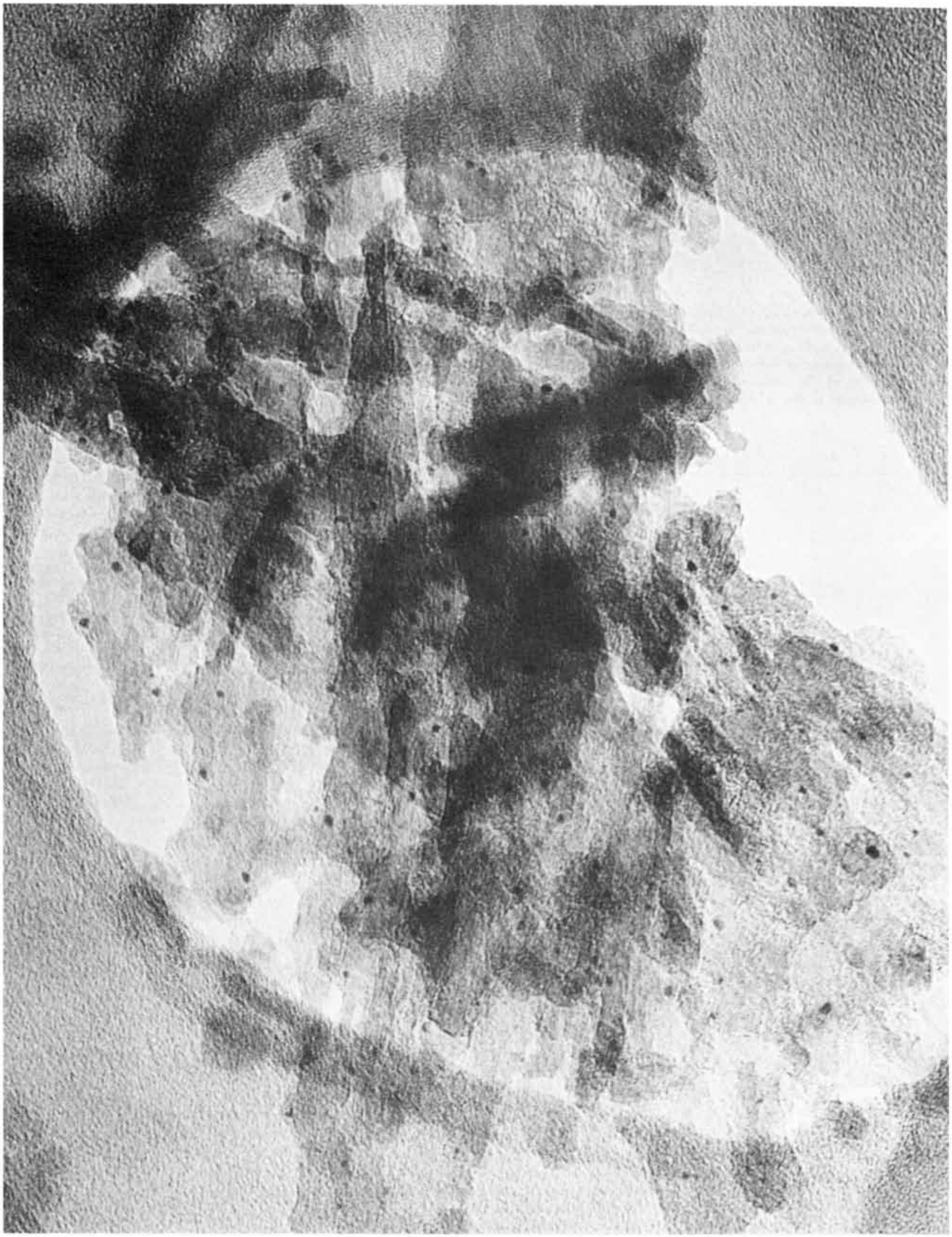
Ostwald's insight paved the way for the widespread investigation and application of catalytic phenomena. Catalytic processes now provide the basic technology for the manufacture of a host of vitally important materials, ranging from fertilizers to synthetic fibers and petroleum products such as gasoline and heating oil. Work done by my colleagues and me over the past two decades at the Exxon Research Laboratories has contributed to these applications and to an understanding of catalysts. We have focused our efforts on bimetallic catalysts (catalysts composed of two metals). We found that in situations where a molecule can undergo several different reactions bimetallic catalysts often eliminate undesirable reactions and maximize the desired one. We also found that two metallic elements can form an effective bimetallic catalyst even if they do not mix with each other to form an alloy. Finally, we discovered a new class of catalysts containing bimetallic clusters. The clusters are often 10 to 50 angstrom units in size (an angstrom unit is a ten-billionth of a meter).

Bimetallic clusters have already had a major impact on petroleum refining. We found that a catalyst containing platinum-iridium clusters leads to a higher rate of formation of high-octane-number gasoline components (aromatic hydrocarbons such as toluene and xylenes) than do earlier catalysts containing pure platinum clusters. The higher the octane number of a gasoline, the greater the resistance to "knock" in an internal-combustion engine. Knock is a detonation that interferes with the smooth combustion of the fuel; the result is a decrease in the power output of the engine. Augmenting the amount of aromatic hydrocarbons in gasoline provides an alternative to the use of tetraethyl lead for obtaining high octane numbers. Our bimetallic catalyst, both by itself and in combination with other catalysts, has consequently been a key factor in making "low lead" and "lead-free" gasolines feasible.

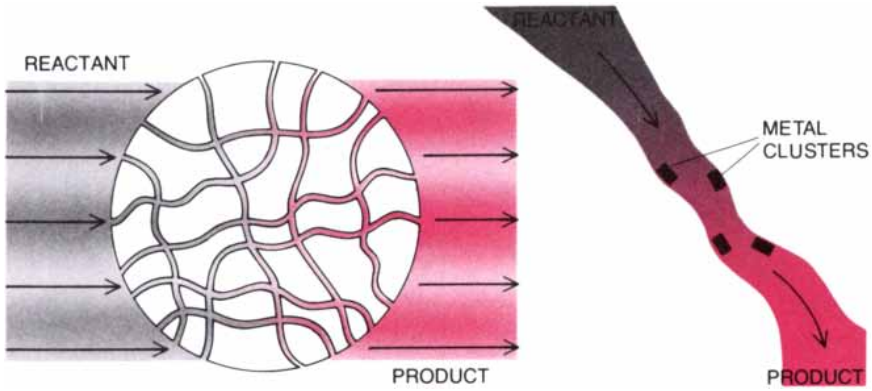
Throughout the course of our work we have employed a form of catalysis known as heterogeneous catalysis, in which the reacting molecules are present in a phase separate from that of the catalyst. (In homogeneous catalysis, in contrast, the catalyst and the reacting molecules are present in the same phase, commonly in a liquid solution.) In a typical situation in heterogeneous catalysis a fluid phase (often a gas) flows through a bed of catalyst particles. One widely employed type of catalyst consists of particles of a porous material, known as a carrier, in which submicroscopic metal clusters are embedded. Depending on the application, the particles could range in size from a couple of tenths of a millimeter to several millimeters. The material constituting the bulk of the particles is often an oxide such as alumina (Al_2O_3) or silica (SiO_2) containing a network of pores. The pores have an average diameter of about 100 angstroms. The metal clusters reside on the walls of the pores and therefore must be smaller than the pores.

As the gas flows through the catalyst bed, reactant molecules diffuse into the pores of the particles and are adsorbed onto the surfaces of the metal clusters. In the chemisorption, or chemical adsorption, of a reactant molecule on a metal cluster, a chemical bond forms between the molecule and a surface site. A site may consist of a single atom or an array of atoms. Where an array of atoms is involved the atoms may be of a single element, as they are in a pure-metal cluster. Alternatively the array could consist of more than one type of atom, as in the case of a bimetallic cluster, for example. The chemisorption process forms a surface compound.

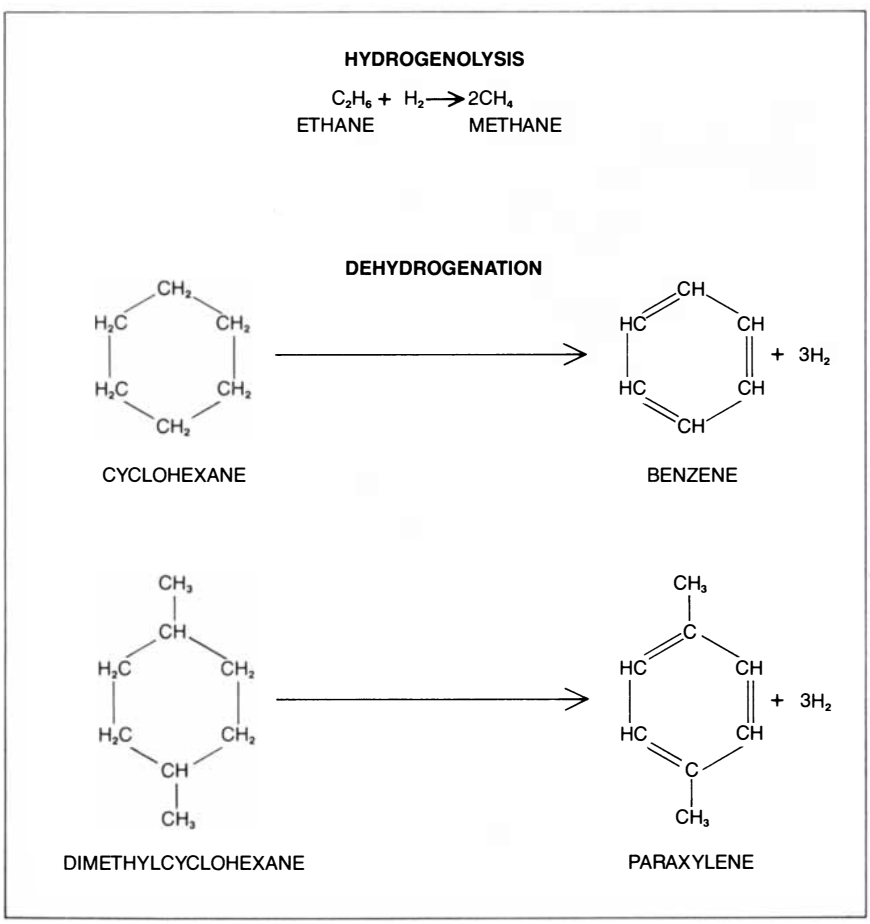
The surface compound then undergoes chemical transformations on the clusters to yield molecules of a different chemical species, which are subsequently desorbed (the process of adsorption in reverse). The product molecules then diffuse out through the network of pores into the gas stream flowing through the empty space between the particles. The desorption of a product molecule from the metal cluster releases a site for further participation in the reaction. The active catalyst sites are used repeatedly in the reaction. The composition of the gas



PLATINUM-IRIDIUM CLUSTERS appear as black dots in an electron micrograph of a catalyst in which the clusters are dispersed throughout granules of a highly porous aluminum oxide. The clusters are employed in the production from petrochemicals of aromatic hydrocarbons (ring-shaped molecules) that inhibit knock in internal-combustion engines. Each cluster is a bimetallic catalyst, an agent composed of two metals that facilitates chemical reactions. The clusters measure about 10 angstrom units (an angstrom unit is a ten-billionth of a meter). The light egg-shaped region in the center of the image is a hole in the mount on which the sample rested.



PERMEABLE GRANULE (*left*) contains a network of pores represented by intersecting lines. Metal clusters reside on the walls of the pores (*right*). Molecules diffuse through the pores, where they adhere to the surface of the clusters. The adsorbed molecules then undergo chemical transformations on the clusters to yield molecules of different chemical species. Molecules of the chemical product diffuse out through the pores. Since the clusters are not consumed in the process, they can be utilized for many chemical transformations.



HYDROCARBON REACTIONS are important both in the characterization of metallic and bimetallic catalysts and in the production of petroleum products. One such chemical transformation is the hydrogenolysis of hydrocarbons (*top*). In this class of reactions carbon-carbon bonds in hydrocarbons are ruptured and hydrogen is incorporated to form new hydrocarbons. An example is the reaction between ethane and hydrogen that produces methane. Another important class of reactions is the dehydrogenation of hydrocarbons (*bottom*), which consists in rupturing carbon-hydrogen bonds and removing hydrogen. The dehydrogenation of cyclohexane to benzene and hydrogen is an example of this kind of reaction. The reaction rates for both the hydrogenolysis of ethane and the dehydrogenation of cyclohexane depend on the composition of the catalyst employed. The two reactions therefore serve as useful chemical probes. Dehydrogenation is also employed in the production of aromatic hydrocarbons (such as paraxylene) that have excellent antiknock properties.

stream changes in its passage through the catalyst bed as the gas is depleted of molecules of reactant and enriched in molecules of product. The performance of a catalyst in facilitating this chemical change has been customarily referred to as its activity.

In developing an understanding of the general factors that influence catalytic activities of metals, one can gain insight by studying a given reaction over a series of metals. A good example is found in comparing the catalytic activities of metals for the hydrogenolysis of hydrocarbons. That reaction consists in rupturing the carbon-carbon bonds of hydrocarbons and adding hydrogen to form new hydrocarbons. The simplest example is the reaction between one molecule of ethane (C_2H_6) and one molecule of hydrogen (H_2) to form two molecules of methane (CH_4). Sir Hugh Taylor and his colleagues at Princeton University originally investigated this reaction on nickel, cobalt and iron catalysts. At the Exxon laboratories we extended the work to a number of other metals and observed dramatic variations in the levels of their activity.

Our investigation of the hydrogenolysis activities of metal catalysts affords a good background for selectivity studies of bimetallic catalysts. The periodic table of elements provided a framework for our studies. The elements in the periodic table are arranged in vertical columns called groups and in horizontal rows called periods. Elements in a given group tend to show similar chemical behavior whereas those in a given period exhibit a systematic variation of properties across the period. It is instructive to consider how hydrogenolysis activity varies from one metal to another within such a period.

We measured the activities of metals in three periods that include the first, second and third transition series, focusing our attention on the metals in group VIIA through group VIII to group IB. Since group VIII has three subgroups, designated $VIII_1$, $VIII_2$ and $VIII_3$, each of the transition series contains three metals within this group. We obtained the most complete set of data on hydrogenolytic activities for metals of the third transition series. In this series osmium, a member of subgroup $VIII_1$, has the highest activity. The activity of platinum, a member of subgroup $VIII_3$, is eight orders of magnitude lower than the activity of osmium, and the activity of iridium, a member of subgroup $VIII_2$, falls between the extremes. Precise data on the activity of gold, the group IB metal immediately following platinum in this series,

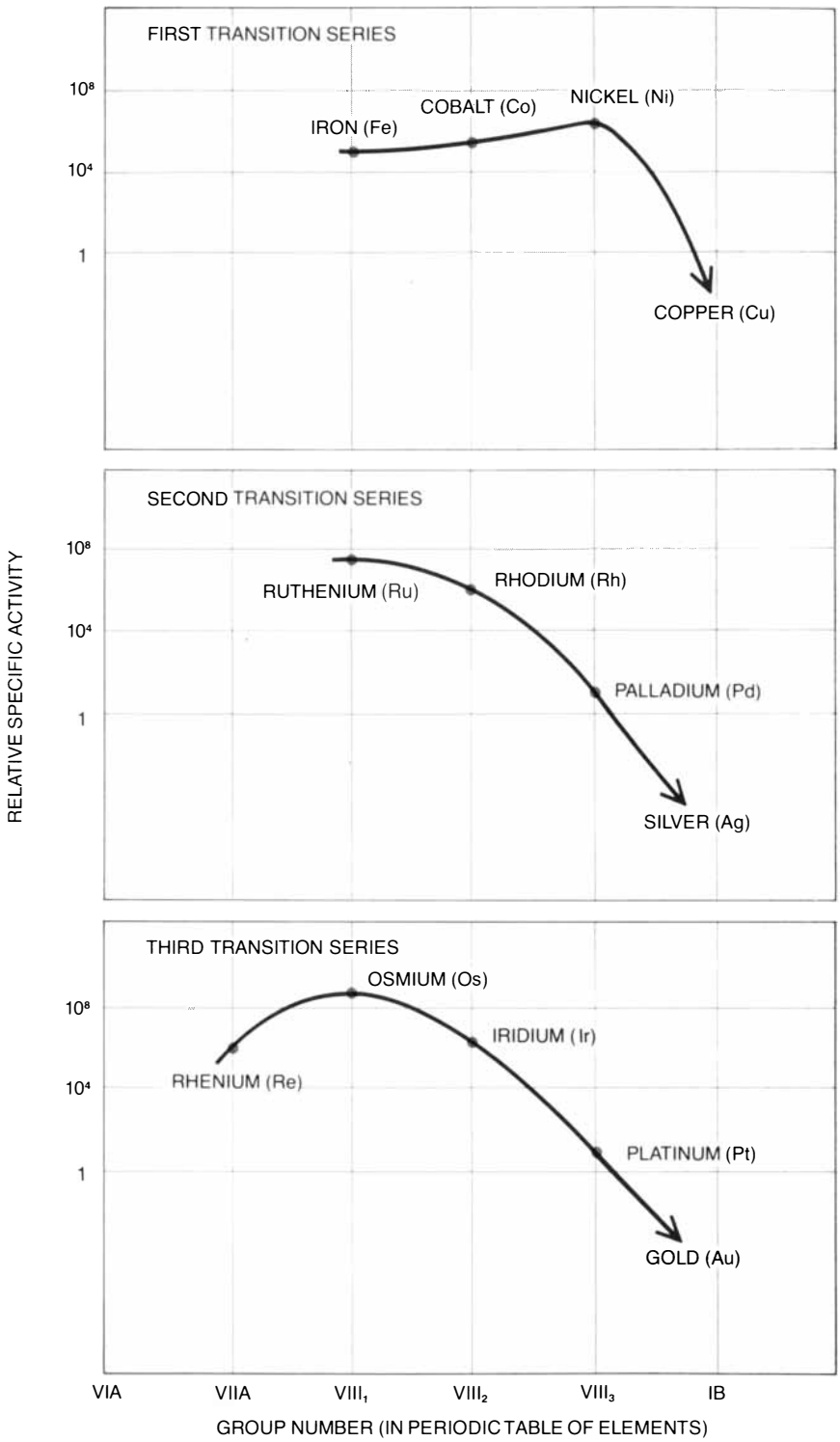
are not available. It is known, however, that gold is much less active than platinum for hydrocarbon hydrogenolysis reactions in general.

In the second transition series we found a similar variation in activity ranging from ruthenium through palladium (group VIII members) to silver (a group IB member). The pattern of variation in the first transition series, however, differs from the pattern of the second and third series. We observed that the activity of nickel, a member of subgroup $VIII_3$, is higher than that of iron, a member of subgroup $VIII_1$. The activity of copper (the group IB metal following nickel), however, is much lower than that of nickel. This result is in agreement with the pattern of the other two series.

A qualitative understanding of the pattern of variation follows from a principle that relates catalytic activity to both the ease with which a molecule of reactant binds to a catalyst (chemisorption) and the strength of the chemisorption bond. The catalytic activity reaches a maximum when a reactant molecule is rapidly adsorbed but its bond with the catalyst is only moderately strong. If the chemisorption bond is too strong, the adsorbed molecule will not undergo a reaction. Even if a reaction occurs, the product will not readily desorb from the surface. Metals exhibiting these qualities include most of the members of groups VIA and VIIA (such as manganese, chromium and tungsten), which immediately precede the group VIII metals in the periodic table.

A bond that is too weak can also frustrate catalysis. Metals often exhibiting this quality include all the members of group IB (copper, silver and gold). Chemisorption may also take place too slowly. Since the metals in group VIII rapidly adsorb molecules and allow reaction to occur, they are particularly important in catalysis.

After completing our investigation of ethane hydrogenolysis on metals, we began examining the selectivity of bimetallic catalysts. We studied the hydrogenolytic activities of bimetallic catalysts consisting of a highly active group VIII metal in combination with an inactive group IB metal. To determine whether the effect of a group IB metal on the catalytic activity of a group VIII metal depends on the type of reaction, we included a second reaction in the investigation, the dehydrogenation of hydrocarbons. In contrast to hydrogenolysis, this reaction consists in rupturing the carbon-hydrogen bonds of hydrocarbons and removing hydrogen, a process that leads to the formation of other hydrocarbons. Spe-



VIIA	VIII			IB
FIRST TRANSITION SERIES				
Mn	Fe	Co	Ni	Cu
SECOND TRANSITION SERIES				
Tc	Ru	Rh	Pd	Ag
THIRD TRANSITION SERIES				
Re	Os	Ir	Pt	Au

CATALYTIC SPECIFICITY is strikingly illustrated by the wide range in the ability of metal catalysts to enhance the hydrogenolysis of ethane to methane. Each graph corresponds to one of the three transition series of the periodic table of elements (*left*). The horizontal axes of the graphs indicate the relative positions of the elements in the transition series. The vertical axes denote the specific activity of each element with respect to the others. The data show that the activities of the group IB metals (copper and silver) are many orders of magnitude lower than those of such group VIII metals as nickel, ruthenium, rhodium, iridium and osmium.

cifically we considered the dehydrogenation of cyclohexane (C_6H_{12}), which yields one molecule of benzene (C_6H_6) and three molecules of hydrogen per cyclohexane molecule.

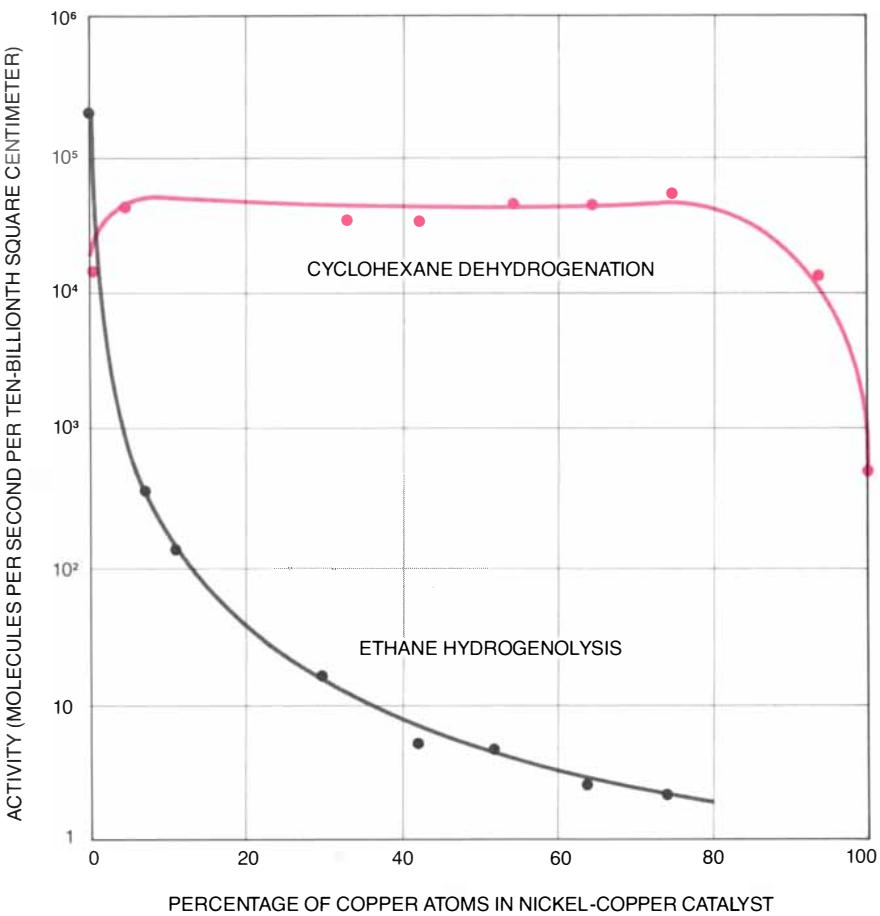
The first bimetallic system we investigated was nickel-copper. Nickel and copper mix with each other to form alloys. We investigated the catalytic activities at 316 degrees Celsius of a series of nickel-copper alloys of varying composition. These alloys, unlike clusters, were not high-surface-area materials. Rather they were in the form of metal powders in which approximately one atom in a thousand was a surface atom.

Before considering the activities of nickel-copper alloys for hydrogenolysis and dehydrogenation reactions, it is important to realize that the surface composition of a nickel-copper alloy differs in general from the bulk composition. Copper tends to concentrate markedly in the surface of nickel-copper alloys. Even a nickel-copper alloy containing only a small amount of copper still has a surface dominated by an abundance of copper atoms.

The effect of copper on the activity of nickel for ethane hydrogenolysis differs greatly from its effect on the activity for cyclohexane dehydrogenation. The hydrogenolytic activity of catalysts in which copper atoms account for only 5 percent of the total number of atoms is a thousandfold less than the activity of pure nickel. As we increased the copper content, the hydrogenolytic activity decreased continuously. In contrast, the activity of nickel for dehydrogenation of cyclohexane is affected very little over a wide range of composition, and it actually increased as we added the first increments of copper to nickel. Only when the composition of the catalyst approached pure copper did we observe a marked decline in dehydrogenation activity.

We found another example of a selectivity effect with ruthenium-copper catalysts. On pure ruthenium, cyclohexane dehydrogenates to form benzene, but it also undergoes extensive hydrogenolysis to yield small alkane molecules such as methane. The incorporation of copper with ruthenium inhibits the hydrogenolysis reaction while allowing the dehydrogenation reaction. The selectivity of the conversion of cyclohexane into benzene therefore improves markedly. The ruthenium-copper catalyst is particularly interesting because the copper atoms do not intermix in the bulk with the ruthenium atoms. Instead the copper atoms sit on top of the ruthenium surface layer, and ruthenium-copper bonds are present at the interface.

The presence of copper can therefore influence the selectivity of a group VIII metal whether or not the copper mixes with the metal. My colleagues and I also observed selective inhibition of the hydrogenolysis activity of group VIII metals when we substituted gold or silver for copper. In general we have found that a group IB metal suppresses the hydrogenolysis activity of a group VIII metal and improves its selectivity for catalyzing such reactions as the dehydrogenation and isomerization of hydrocarbons. Findings reported by a group of workers in the Netherlands led by W. M. H. Sachtler and V. Ponec corroborate our work.



BIMETALLIC CATALYSTS composed of nickel (a group VIII metal) and copper (a group IB metal) in varying ratios have different effects on the rates of dehydrogenation and hydrogenolysis. (Compared with nickel, copper is an ineffective catalyst for either reaction.) The horizontal axis indicates the percentage of copper atoms in the nickel-copper catalysts. The vertical axis indicates the activity of the catalysts. The dehydrogenation of cyclohexane (*colored curve*) is affected only slightly by the addition of copper to nickel until 80 percent of the catalyst consists of copper. The hydrogenolysis of ethane (*black curve*), in contrast, decreases sharply as the amount of copper in the cluster increases. A group IB metal such as copper will generally suppress the hydrogenolytic activity of a group VIII metal; its influence on dehydrogenation activity is much smaller. Consequently the selectivity for dehydrogenation can be enhanced at the expense of competing hydrogenolytic reactions.

My colleagues and I also obtained significant results in the aspect of our research concerned with the preparation and characterization of bimetallic clusters. In approaching this problem we explored the possibility of preparing very small alloy crystallites. Since pairs of metallic elements that do not intermix can exhibit significant interactions for catalysis, however, it did not seem appropriate to use the term alloy catalysts when referring to bimetallic catalysts in general. A term such as bimetallic aggregates seemed preferable to alloys. After working for some time on the technique of dispersing bimetallic aggregates on carriers, I introduced the term bimetallic cluster. Clusters typically range in size from 10 to 50 angstroms. Sometimes they are so small that virtually every atom in a cluster is a surface atom.

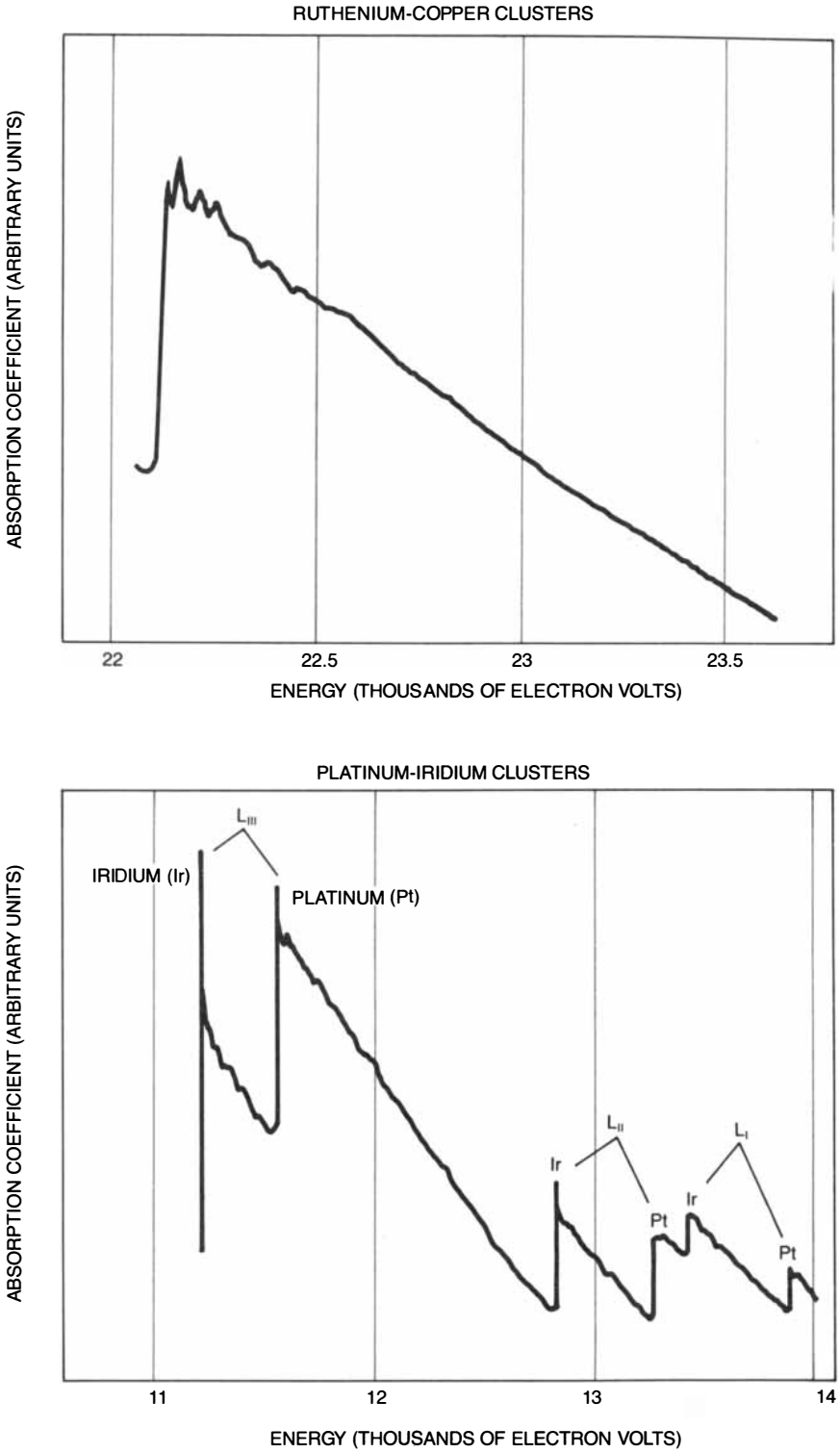
We first prepared ruthenium-copper clusters. We wetted silica with an aqueous solution of ruthenium and

copper salts. By drying the resulting material and treating it with hydrogen at elevated temperatures (400 to 600 degrees C.) we produced ruthenium-copper clusters on the silica.

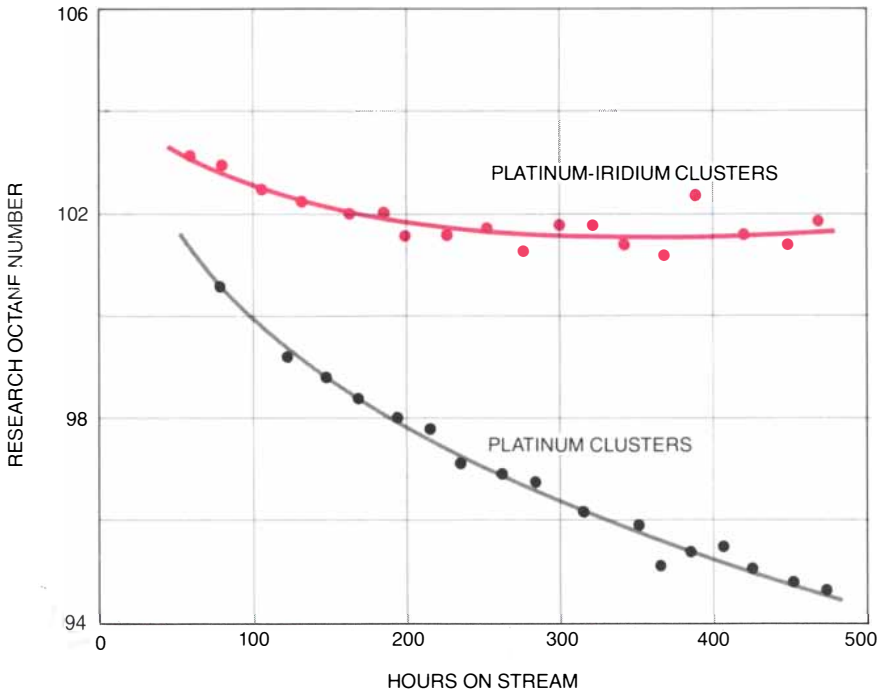
When we began our work in the early 1960's, we wanted evidence that we were producing actual bimetallic clusters instead of monometallic clusters of pure ruthenium and copper. At that time the ability of physical methods to obtain structural information on such systems limited direct experimental verification of the presence of bimetallic clusters. To obtain evidence for interaction between the two metallic components we exploited our earlier work on bimetallic catalysts prepared without a carrier. The hydrogenolysis of ethane to methane proved an ideal chemical probe of clusters because the addition of a group IB metal to a group VIII metal suppresses the hydrogenolytic activity of the group VIII metal. The absence of such suppression would have suggested that the two metallic elements had not formed bimetallic clusters. We found significant evidence for interaction not only between ruthenium and copper but also between other group VIII and group IB metals.

In recent years advances in X-ray-absorption spectroscopy have provided workers with a valuable physical probe for obtaining information on the structures of bimetallic clusters; the knowledge gained supplements what has been learned by means of chemical probes. When one exposes a sample of material to a beam of X rays, the extent of absorption of the X rays depends on the thickness of the sample and the X-ray energy. Absorption occurs when an X ray excites an electron of an absorbing atom from a low energy state to a high energy state. If the X-ray energy is high enough, it will eject the electron (known as a photoelectron) from the atom. At such an X-ray energy the absorption increases sharply, producing an absorption edge. When the X-ray energy exceeds the energy required to detach electrons in a given state from an atom, the photoelectrons retain the excess energy as kinetic energy.

As one increases the X-ray energy beyond the threshold required to produce photoelectrons, the kinetic energy of the photoelectrons increases and absorption of the X rays decreases. The decline in absorption persists until the energy of the X rays becomes high enough to excite electrons out of the next-lower energy state characteristic of atoms in the sample material. At such an X-ray energy one observes another absorption edge. As the X-ray



X-RAY-ABSORPTION SPECTROSCOPY is useful in the characterization of clusters. A beam of X rays is directed at the catalyst being probed. When the energy of the X-ray beam is great enough to separate an electron from an atom, an abrupt increase in X-ray absorption occurs. Such an energy level (called an absorption edge) characterizes an element. Ruthenium-copper clusters (*top illustration*) exhibit an absorption edge at an energy slightly greater than 22,000 electron volts. Generally elements have a series of absorption edges. The graph for platinum-iridium clusters (*bottom illustration*) displays six absorption edges, which lie between 11,000 and 14,000 electron volts. For X-ray energies greater than those corresponding to the absorption edges, the absorption coefficient fluctuates. Analysis of the fluctuations characteristic of ruthenium-copper clusters indicates that actual bimetallic clusters are formed, as opposed to monometallic clusters of the individual elements. In the case of platinum-iridium the fluctuations following a so-called L absorption edge (such as L_{III}) indicate that the clusters are not uniform mixtures of platinum and iridium atoms.



PLATINUM-IRIDIUM CLUSTERS are more efficient than platinum clusters in the production of gasoline components having a high octane number. After several hundred hours of use (hours on stream) the platinum-iridium clusters (*colored curve*) yield a product of significantly higher octane number than that obtained with a platinum catalyst (*black curve*). The performance of the platinum clusters declines as time passes. The comparison shown was conducted at a temperature of 487 degrees Celsius and a pressure of 14.6 atmospheres.

energy increases beyond a value that corresponds to the absorption edge the absorption decreases again.

Absorption in the region following an absorption edge does not decrease smoothly as X-ray energy increases: photoelectron scattering effects give rise to fluctuations. Analysis of this extended X-ray-absorption fine structure provides a measure of both the distances between the constituent atoms and the number of neighboring atoms of a particular kind that surround an absorber atom.

Because X-ray-absorption studies appeared to offer a promising way to investigate bimetallic catalysts, I collaborated in the mid-1970's in a series of such studies with Grayson H. Via and Farrel W. Lytle. Working at the Stanford Synchrotron Radiation Laboratory, we obtained strong supporting evidence for the presence of ruthenium-copper and osmium-copper bimetallic clusters in silica-supported catalysts containing low concentrations of these elements. In the analysis of the fine structure associated with absorption edges of copper, ruthenium and osmium, we found that copper atoms bind extensively to ruthenium or osmium atoms as well as to other copper atoms. Ruthenium and osmium atoms, on the other hand, have very few neighboring copper atoms as opposed to atoms of their own kind. The results agree with those obtained from experiments with chemical probes: a cluster apparently consists of a core of ruthenium or osmium atoms surrounded by a surface layer of copper atoms.

X-ray-absorption spectroscopy also proved useful in our investigation of platinum-iridium clusters. We worked with these clusters because we were interested in substituting them for the platinum clusters originally employed in the production of high-octane gasoline components.

Analysis of extended X-ray-absorption fine structure reveals inhomogeneity among platinum-iridium clusters. It can be concluded either that the ratio of platinum to iridium varies from cluster to cluster or that platinum- and iridium-rich regions may exist within a given metal cluster. Surface-energy considerations support the latter interpretation. Since platinum should have a lower surface energy than iridium, my colleagues and I suggest that a platinum-rich region should exist on the surface. An iridium-rich region would then constitute the central core of the cluster, so that a composition gradient would exist from the inside to the outside of the cluster.

In view of the theory that platinum concentrates on the surface of platinum-iridium clusters, one would expect that platinum and iridium would increasingly segregate from each other as the clusters become smaller and the ratio of surface atoms to total metal atoms increases. When the ratio equals one-half for clusters containing 50 percent each of platinum and iridium, for instance, one might even find all the platinum on the surface and all the iridium in the interior. When the ratio approaches unity, complete segregation cannot be achieved if the clusters are spheres. Such segregation is possible, however, if the clusters have a two-dimensional "raftlike" shape. The perimeter of a central iridium or iridium-rich raft would then be studded with platinum atoms.

Platinum-iridium clusters have a higher performance in petroleum reforming than platinum clusters. Reforming is a process in which certain hydrocarbons are converted into high-octane-number hydrocarbons. The performance of platinum decreases substantially during use because carbonaceous residues, which are characteristic by-products of high-temperature petroleum processes, foul the surfaces of the clusters. The accumulation of the residues on platinum-iridium clusters is less than the accumulation on platinum. One reason is that iridium is much more active than platinum for the hydrogenolysis of the residues or the precursors of the residues, and it therefore limits their buildup.

Increased hydrogenolysis, however, can also lead to increased rates of conversion of hydrocarbons into light gaseous products. A catalyst containing iridium alone increases the yield of these low-value substances. In the case of platinum-iridium catalysts, however, the interaction of platinum and iridium moderates the hydrogenolytic activity of iridium. At the conditions employed in reforming (temperatures near 500 degrees C. and pressures of 15 to 30 atmospheres), the inclusion of iridium with platinum increases the production of valuable gasoline components to about the same extent as it increases the production of light gaseous products. One consequently obtains a satisfactory distribution of reaction products at a high rate.

In the years since its first commercial application in 1971, the platinum-iridium catalyst has been employed in many Exxon reforming units throughout the world. In the early stages of the work I received a great deal of help from two very able co-workers, James L. Carter and Allen E. Barnett. At a later stage many individuals from vari-

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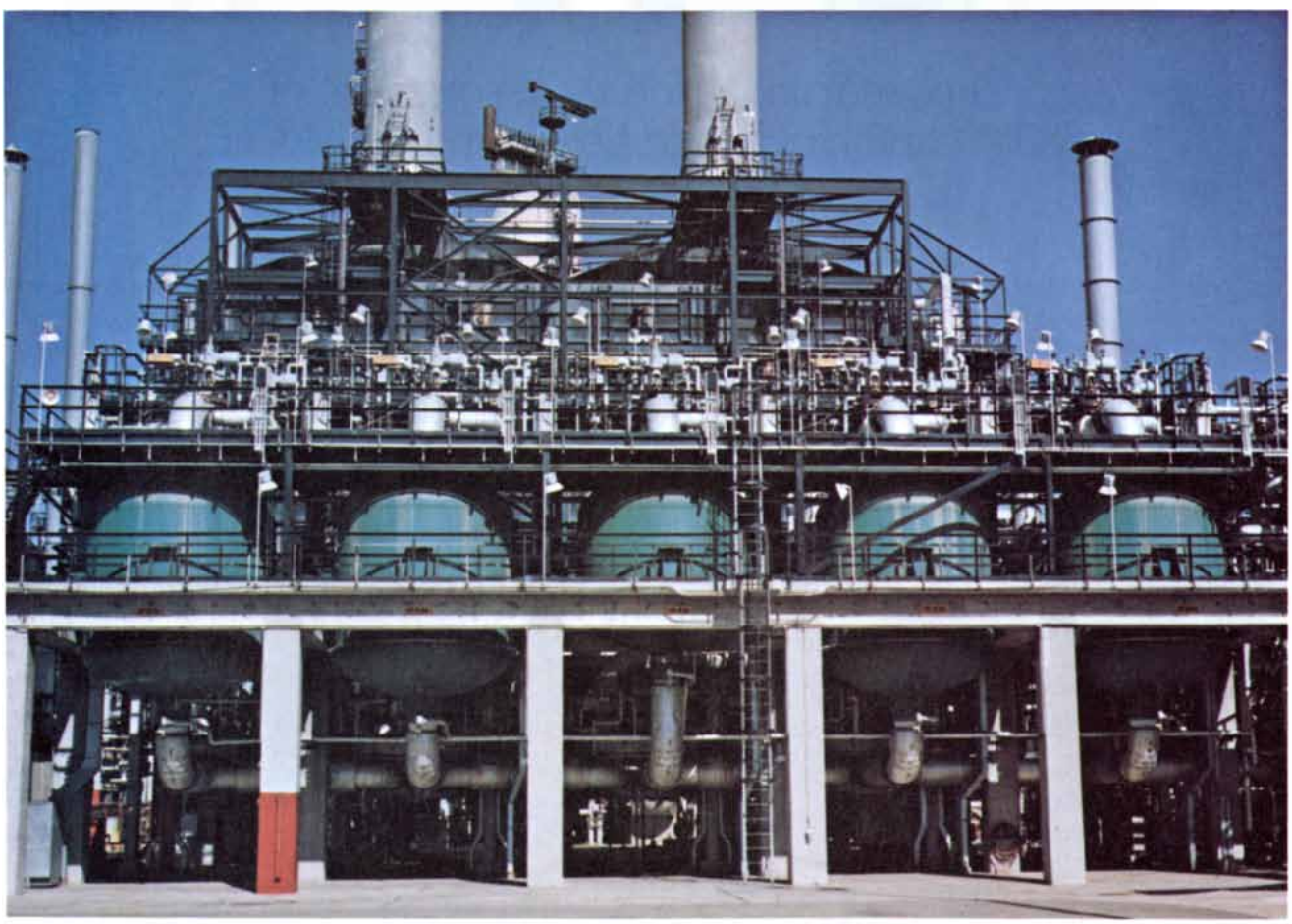
ous parts of Exxon made contributions to the commercialization of the catalyst, which has also been employed by some other companies under license from Exxon.

My colleagues and I have combined our catalyst with another reforming catalyst consisting of platinum and rhenium supported on alumina. The Chevron Corporation developed this catalyst. The platinum-rhenium combination differs from the types of bimetallic catalysts discussed above in that rhenium is a metallic element from group VIIA of the periodic table. Platinum-rhenium catalysts are particularly effective for the selective conversion of cycloalkanes (saturated hydrocarbon rings) into aromatic hydrocarbons (unsaturated hydrocarbon rings), whereas platinum-iridium catalysts are highly active for the conversion of noncyclic alkanes into aromatics. An unsaturated hydrocarbon ring contains less hydrogen than a saturated hydrocarbon ring.

Since the aromatization, or formation, of cycloalkanes occurs much more readily than the aromatization of noncyclic alkanes, a reforming system conveniently divides into two separate regions. The aromatization of cycloalkanes occurs primarily in the first region, whereas the aromatization of noncyclic alkanes occurs predominantly in the second. Consequently one can employ a platinum-rhenium catalyst in the first region and a platinum-iridium catalyst in the second. In practice a reformer consists of a number of reactors in series. The initial reactors can be filled with a platinum-rhenium catalyst and the tail reactors with a platinum-iridium catalyst.

Petroleum refineries employing a combined catalyst system obtain the advantages of both types of catalyst in a single operation. A number of commercial reforming units use combined catalyst systems of the type described here. Several factors, including the activity of the catalyst system and the yields of the various products obtained with it, affect the choice of a catalyst system. The relative importance of the different factors and hence the economic analysis depend on the particular application.

The application of bimetallic catalysts in the petroleum industry has been widespread. The catalysts currently in use have exhibited outstanding performance in refineries throughout the world. Research on bimetallic catalysts continues. Although the work in this area has already had a major impact on the reforming process, it is very likely that improvements of existing systems will emerge as a result of further work. Moreover, the outlook for applications of bimetallic clusters in reaction systems other than reforming would appear to be excellent in view of the many possible combinations of metallic elements. The extension to polymetallic clusters (clusters containing more than two metallic elements) offers the possibility of even greater flexibility in the design of catalytic systems.



FIVE CATALYTIC REACTORS at the Imperial Oil, Ltd., refinery in Strathcona, Canada, produce high-octane gasoline components. The reactors (*green*) are filled with granules containing platinum-iridium clusters. A vaporized petroleum fraction is admitted into the first reactor. The effluent from that reactor is subsequently reheated and passed into the second reactor, and so on down the line. The final product is rich in high-octane gasoline components. The smokestacks project from furnaces used in heating the oil vapors.

A new technique may expand the use of lasers in commercial and military applications. The approach, called optical phase conjugation, is considered a major advance in optics because it offers a solution to distortion problems that have limited the use of lasers. When a laser beam passes through a turbulent atmosphere or a severely strained optical component, the beam is distorted and the information it carries is degraded. The Hughes Aircraft Company technique, however, forces the laser to retrace its path through the distorting medium so the beam emerges free of distortion. The method eliminates the need for complex electro-optical and mechanical components to correct the distortions.

Pilots of future aircraft may rely on artificial intelligence systems to help them assess combat situations and take appropriate offensive or defensive actions. Hughes engineers are conducting studies for the U.S. Air Force on potential uses of artificial intelligence for fire control and battle management. One focus is how to identify targets automatically and present this information for a pilot's use. Another aspect involves tactical analysis, including decision-making that advises a pilot whether to attack, flee, apply electronic countermeasures, or fly low-altitude routes. New automation techniques may be necessary for pilots to cope with the fire control systems that now are being designed for the next generation of military aircraft.

The first attempt to sample the atmosphere of an outer planet, NASA's Project Galileo will journey 750 million miles to Jupiter this decade. The mission will consist of two spacecraft, an orbiter and a Hughes-built probe. Six instruments inside the probe's descent module will assess the structure and composition of the atmosphere, determine the location and structure of clouds, calibrate a precise ratio of hydrogen and helium, and measure lightning, radio emission, and energy absorption. The probe will transmit data to the orbiter for relay to Earth. Project Galileo will be the first interplanetary vehicle launched from the space shuttle. The launch is set for May 1986 and arrival for August 1988. Four Hughes-built probes explored the atmosphere of Venus in 1978.

High-energy laser pointing and tracking systems are among the advanced electro-optical systems supported by the Albuquerque Engineering Center in New Mexico. The center's scientific disciplines include physics, optics, mathematics, lasers, image processing, electro-optical control systems, and computer science. Programs involve electro-optical sensors for strategic military applications, including work performed at the U.S. Air Force Weapons Laboratory at Kirtland Air Force Base and the White Sands Missile Range. The Hughes center is expected to expand from its current staff of 42 highly trained professionals to greater than 100 over the next three years.

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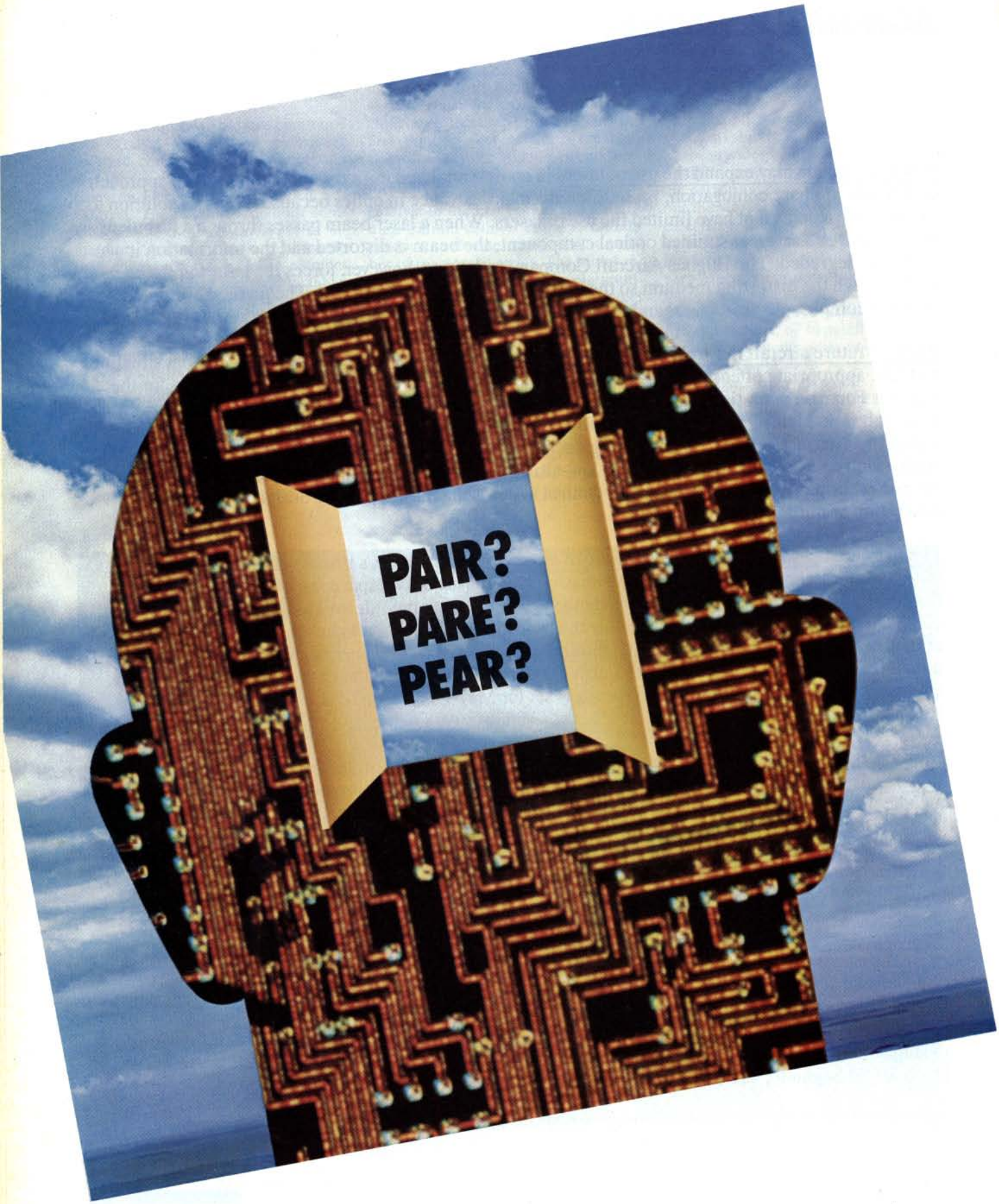


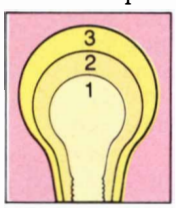
Would you like to know how computers can tell the difference between a pair in a poker game and a pear on a plate?

How they can understand a variety of speakers with a diverse variety of accents—and reply in pear-shaped tones, using normally connected speech?

Then read on to learn more about computers that recognize words, comprehend meaning from context, even synthesize human speech from a mere shadow of itself.

It's All In The Algorithms

Utilizing three levels of speech-processing algorithms, AT&T is giving the computer a more 'robust' understanding—the capacity to comprehend connected speech from different speakers.



Three levels to understanding

Acoustic pattern matching (1) identifies the spoken words.

Grammatical processing (2) figures out how the words are put together.

And semantic processing (3) extracts meaning from the context. With each successive step, the computer moves closer to accurate understanding.

Acoustic pattern matching determines how much latitude the waveform (pronunciation) of a word can have before it becomes unintelligible to the computer.

By isolating the specific characteristics the waveform of a word contains—independent of the accent of a speaker—we increase the probability that it will be correctly matched to a pattern stored in a computer's memory. But, correct recognition of words is only the beginning of computer understanding.

Computer Grammar 101

Grammatical processing further increases the probability of recognizing words. It analyzes them within the constraints imposed by language—the allowable sequences of syllables in a word or words in a sentence.

For a specific vocabulary and situation, it is possible to define every sequence the computer can recognize. Based on probabilities assigned to each word it recognizes—and where that word falls—the computer determines which of its possible sequences is the most likely. This process gains two advantages: It allows words that might not otherwise be recognized to be correctly accepted; and it speeds up processing time by using sequence position to limit the number of words it looks at for a pattern match.

A Meaningful Relationship

Semantic processing is the point where the computer crosses the line between recognition and understanding—the point where words are given meaning within a specific context. This endows a system with one of its most human qualities: knowing when a request isn't understood, and asking for appropriate clarification.

Talk Isn't Cheap

Making a computer listen intelligently is one thing; making it respond intelligibly, however, is another.

Enabling a computer to talk, reproducing the subtleties of human speech, has required large amounts of memory—a high cost item. Therefore, an 85 percent reduction in the amount of information needed to store and generate high-quality speech can mean significant cost reductions.

That's just what a new AT&T speech synthesis technique, called multi-pulse linear predictive coding (MP-LPC), provides. It reduces the 64 thousand bits per second previously needed to 96 hundred.

Speech signals mimic the human vocal tract—they have redundancies built in. MP-LPC codes speech to remove these redundancies, then tells the computer how to reconstitute the original speech from the mini-version in its memory. This coding eliminates unnecessary bits from being stored and transmitted.

Getting Down To Business

At AT&T, our goal is to make computers listen and understand as fast as people speak—and speak to and understand as many people as possible. Speech-processing algorithms, developed by AT&T Bell Laboratories, have moved us several steps closer to that ideal.

For example, most speech recognition systems make the speaker pause between words. But AT&T, using advanced recognition algorithms, has developed a Stock Quotation System, now in field trial, that allows callers to enter and retrieve current market information in natural, normally-connected speech. Users simply speak the number codes for any of over 6,000 stocks, and the service provides current quotes—delivered in computer-generated speech.

Numbers are nice, but make for limited conversation. Closer to our goal of a conversational computer is the Flight Information System. It uses the Official Airline Guide as its data base. In its limited environment, this laboratory system converses with the user in natural speech in response to normal flight information queries.

One Of Our First Callings

AT&T has been deeply involved in speech technology since the genesis of the telephone. From the beginning, our goal was to make mechanical communications fast, foolproof and economical.

Today, with the advent of the computer, we're moving toward the ultimate ideal: creating machines that serve our needs and save our energy in the most natural manner—by voice command.

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The right choice.

A Web-building Jumping Spider

Unlike most other jumping spiders, the Australian species Portia fimbriata builds webs. With acute vision and deceptive predatory tactics, it hunts other spiders both in webs and on the open ground

by Robert R. Jackson

In the tropical rain forests of Queensland, Australia, lives *Portia fimbriata,* a most unusual spider. On the basis of their behavior nearly all other spiders fall into one of two broad groups: the sedentary web builders and the cursorial (running) hunters. Web builders have poor vision; they detect their prey, primarily insects that blunder onto the web, by the vibrations the insects trigger in the silk. In contrast, cursorial spiders do not build webs; they pursue their prey on vegetation and on open ground. Among this group the salticids, or jumping spiders, are particularly noteworthy not only for the leaping ability that gives them their name but also for their highly developed vision. *Portia fimbriata* has large, ghoulish eyes that clearly mark it as a member of the salticid family. And yet, unlike typical salticids, it builds webs.

Indeed, my attention was first drawn to *Portia* when I was casually looking for spiders in debris-cluttered webs attached to trees and boulders in a Queensland rain forest. At the time, in 1979, the species was not unknown, but its behavior had not been studied. With my finger I pushed aside what I thought was a tattered, moldy leaf; I soon realized my mistake when the "leaf" waved its palps (the two limbs extending from a spider's mouthparts), lifted its cephalothorax (the head) and stared at me with its large eyes. I readily identified the spider, which was roughly a centimeter long, as *Portia*. Thus began a line of research I have been pursuing ever since. Of the several hundred *Portia* I have studied in the field and in the laboratory, almost all have occupied webs.

The spider also turns out to be extraordinary in another way: it is a highly versatile predator. Typical salticids specialize in the pursuit of moving insects. A salticid's six small, lateral eyes can detect movement in a field of view encompassing as much as 360 degrees; once the spider has turned to face the moving object, the two principal eyes enable it to determine whether the object is a mate, a rival or potential prey. When a salticid spots an insect, it stalks, chases and eventually leaps on its prey, sinking its venomous fangs into the animal's body and often holding on until the toxin takes effect.

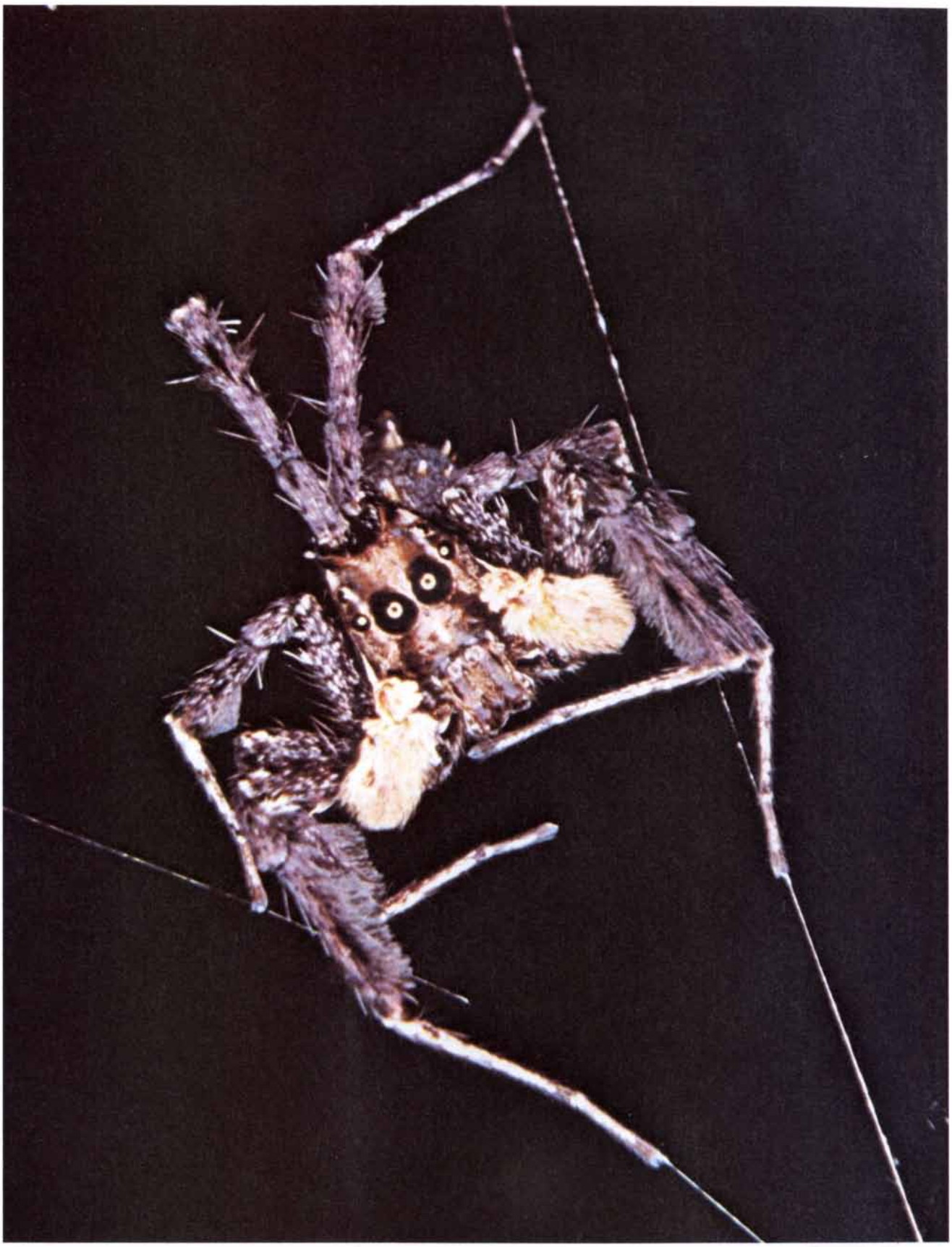
Portia sees at least as well as any other jumping spider, but it is not a specialized predator of insects. Its chief victims are other spiders, both web builders and salticids. This diet alone distinguishes *Portia* from most jumping spiders, and the range of its predatory behavior is even more remarkable. *Portia* does not employ a single, general strategy, as one would expect of a predator that feeds on many species. (Among animals too the jack-of-all-trades is usually the master of none.) Instead it draws on a variety of tactics, each tailored precisely to a specific type of prey. The ease with which it hunts in webs is particularly surprising for a jumping spider.

The first question that concerned me was whether *Portia* occupies the webs of other species or builds ones of its own. By individually labeling 59 *Portia* with spots of paint I was able to observe their behavior in the rain forest and determine that they do both. It was astonishing to watch a salticid spinning a web, walking steadily and with apparent ease across the growing silken edifice, pivoting its abdomen periodically to extrude new lines and with a rear leg holding them free from entanglement as it fastened them to old lines or to rocks and vegetation. Even the rotary motions *Portia* used to catch hold of the silk strands with its legs were characteristic of typical web builders.

Female *Portia* and juvenile males spin webs; adult males, whose chief activity is mating, do not. Like web-building species from other families but unlike other salticids, the labeled *Portia* were notably sedentary. Some of them remained in the same web for as long as 48 days, molting several times and eventually mating and laying eggs. An adult or a juvenile male sometimes lived in the same web with an immature female, with the pair mating after both partners had matured.

The webs built by *Portia* generally consist of three inclined sheets converging at the bottom and opening at the top. Dead leaves are usually suspended in the three-dimensional tangle of threads that traverse the concavity. Females hoist leaves into their webs by repeatedly attaching and tightening new lines of silk to a leaf while breaking old ones. Choosing a leaf with a slightly concave shape, they place their eggs in the cavity and cover them with silk. They then spend much of their time standing over the eggs with their legs flexed under the body and their palps retracted next to the chelicerae (the jaws). In this "cryptic rest posture" the outlines of the appendages are concealed, and the spider looks even more like a leaf than it otherwise does. Presumably the resemblance helps to conceal it from visually hunting predators such as birds and lizards.

Portia's web does not function only as a nest. In the rain forest the spider often fastens its web to that of another species, sometimes even surrounding the alien web and creating a single, compound structure. In that respect it is no different from many web builders. Its motive, however, is different: to invade the alien web and prey on the host spider. On entering a web *Portia* vibrates the silk with specialized movements of its palps and legs. The host spider is deceived and responds to the vibratory stimuli as if they were generated by a conspecific or by a po-



AUSTRALIAN SPIDER *Portia fimbriata* **builds webs, yet its large eyes identify it as a visual hunter belonging to the salticid family. Typical web builders have poor vision; typical salticids, or jumping spiders, do not build webs.** *Portia* **spins its webs in dark spaces between trees and under rock ledges in the Queensland rain forest. This photograph was made in the laboratory by Densey Clyne; the bright rings on the eyes are not pupils but reflections of the photographer's flash. The spider is approximately a centimeter long.**

tential prey item (an insect) rather than by a predator.

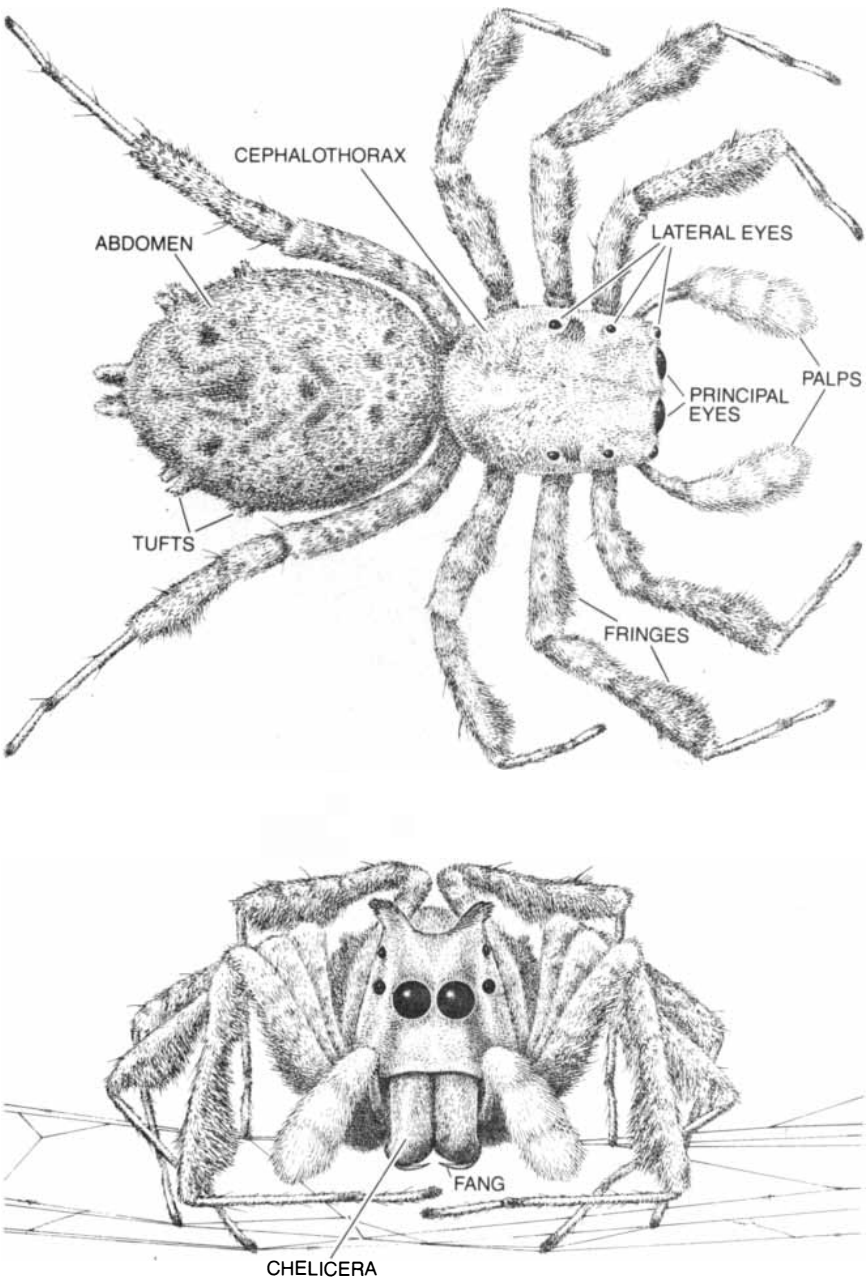
By analyzing videotapes of *Portia* in action I have determined that it engages in three distinct types of vibratory behavior, which I call fluttering, striking and plucking. Soon after it enters an alien web it tends to extend its palps or its front four legs forward and flutter them against the silk in a short series of rapid vertical oscillations. Early in the encounter *Portia* may also strike the web with its two palps simultaneously or with one or more of the front four legs; in this behavior the limbs are raised slowly up and back and then brought down sharply on the silk.

Plucking predominates later in the encounter. The spider catches a silk line with the tarsus (the terminal segment) of a palp or a leg and snaps the line up or down. Plucking is a highly variable behavior: the spider may pluck once or several times in rapid succession, while stationary or while walking; it can use virtually any combination of its eight legs. A plucking leg may move a distance of from one to seven millimeters. *Portia* often varies its plucking considerably while facing the host spider, as if it were looking for the right combination of stimuli to attract its prey. If the prey starts to approach, *Portia* continues to pluck with the same set of appendages, moving them with a roughly constant velocity and amplitude. If the prey spider halts its approach, however, *Portia* again vibrates the web in a more variable fashion.

Sometimes the web builder is lured all the way to its doom; in other cases *Portia* stalks slowly across the web. When the prey is about five millimeters away (half of *Portia*'s body length), *Portia* raises its front four legs up and back and extends the fangs at the tip of the chelicerae. It may hold this position for seconds or even minutes. Finally it lunges forward, grasping the spider with its chelicerae or simply stabbing the spider with its fangs. In the latter case the punctured spider runs away as the predator looks on. After about 15 seconds the venom injected through the fangs takes effect and the prey spider is convulsed and paralyzed. *Portia* then walks across the web and retrieves its prey.

Two of the web-building species on which *Portia* feeds are social spiders that live in complexes of between 10 and 100 webs. On occasion I have observed a *Portia* roaming in such a complex for days, evidently harvesting the rich supply of food. In the laboratory I saw *Portia* feeding not only on the social spiders but also on insects snared in the sticky silk; sometimes the invaders took insects right out of the chelicerae of the host spiders. *Portia* may also feed on a host spider's eggs, making a hole in the silken egg case by biting it and salivating on it. Given that eggs do not move, the ease with which *Portia* finds them is evidence of the acuity of its vision.

Other species of spider invade alien webs and employ individual predatory tactics similar to those of *Portia*. For example, Mary Whitehouse of the University of Canterbury in New Zealand and I have been studying two species of mimetid spider that also capture web builders by mimicking the vibrations triggered by a snared insect. Various species of the genus *Argyrodes* specialize, as Whitehouse and Fritz Vollrath of the University of Oxford have shown, in stealing insects from the webs of other species. And Simon Pollard of Canterbury has studied a hunting spider, *Clubiona cambridgei*,



CRYPTIC REST POSTURE (*bottom*) enables *Portia* to hide itself from predators. The spider masks the outline of its legs and palps by flexing them and holding them close to the body. When it pursues other jumping spiders, it retracts the palps next to the chelicerae (jaws) in the same way; during ordinary locomotion the palps are held forward. The unusual hair fringes on the legs and the tufts on the abdomen help to make *Portia* look like a leaf. It seizes prey with the chelicerae or stabs them with the fangs, which contain venom ducts.

that feeds voraciously on spider eggs. *Portia* appears to be unique, however, in that it uses all these hunting methods. Moreover, this is true not only of the species as a whole but also of individual members.

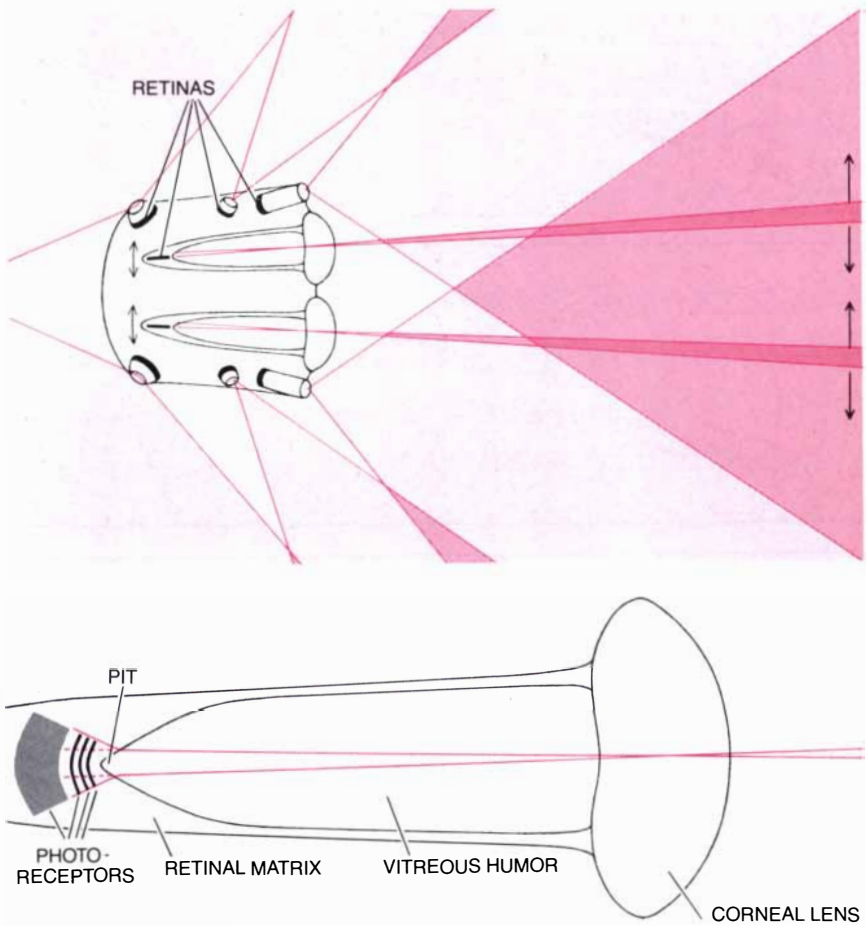
The webs built by *Portia* are not effective snares for insects. Flies and other insects occasionally adhere to the silk, but usually for only a few seconds, and the spider generally ignores them. By fastening its web to a web complex of another species, however, *Portia* seems able to use the insects in another way: as bait. The struggling insects send vibrations into the neighboring complex, whose residents respond by attempting to raid *Portia*'s web, only to be hunted down themselves. Without leaving home *Portia* may harvest a bounty of unsuspecting invaders, since the vacated parts of a web complex are soon filled by other spiders.

When *Portia* does leave its web to hunt, it rarely hunts insects; indeed, in the wild it has never been observed to do so. In the laboratory it will occasionally pursue an insect by trying to get within a few millimeters of the animal before lunging at it. The tactic almost always fails, and *Portia* rarely continues the pursuit. In sharp contrast to typical salticids, which feed almost exclusively on insects, it seems to prey on insects only incidentally, when it can get them easily. The agile chasing and leaping that other salticids engage in so effectively is absent from *Portia*'s predatory behavior. Even when they are not stalking prey, most jumping spiders dash about, but *Portia* usually moves slowly and ponderously.

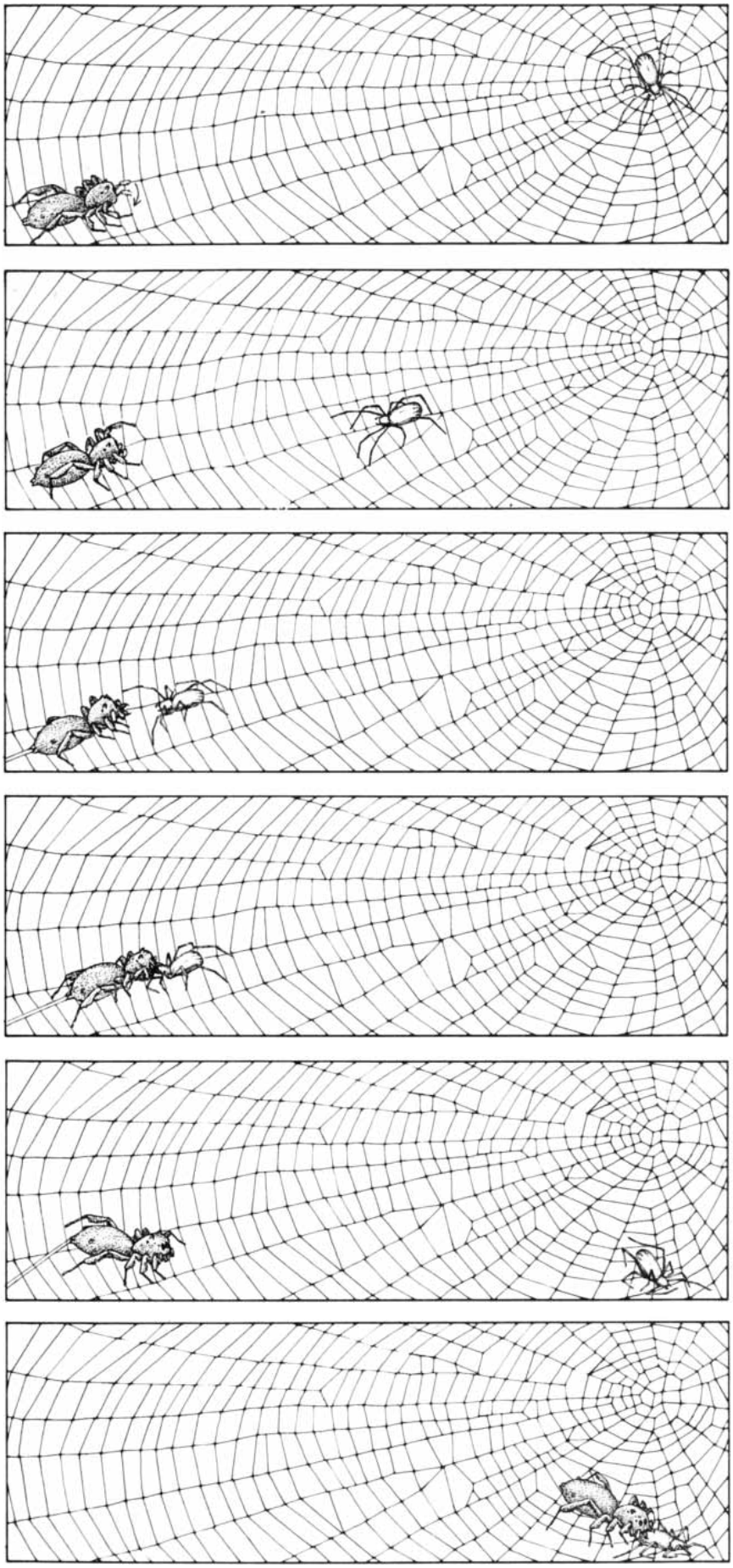
Although slow stalking is ineffective for hunting insects, it is well suited to the prey that form the second major component of *Portia*'s diet: other species of jumping spider. No other spider is known to have special tactics for preying on salticids; salticids are protected by their speed and vision, which are much more developed than those of other spiders. Yet typical jumping spiders seem to have as much trouble recognizing *Portia* as I first did. The adaptations that conceal it from predators apparently conceal it from prey as well.

This "crypticity" has a lot to do with the way *Portia* moves. When it stalks salticids, it steps very slowly; one step may take several seconds and advance the spider only a few millimeters. Between steps it often pauses and waves its palps and legs. Both during and between steps the movements of the palps and legs look choppy or mechanical. Almost any combination of legs

EYES of *Portia* stand out on a scanning electron micrograph of its cephalothorax. The middle pair of lateral eyes are large and functional, whereas in other species of jumping spider they are degenerate and vestigial. This indicates *Portia* is a relatively primitive species.



WIDE FIELD OF VIEW encompassed by the six lateral eyes is shown in a schematic horizontal cross section of *Portia*'s cephalothorax (*top*); the large, mobile principal eyes provide acute vision. When the lateral eyes detect a moving object, the spider turns its principal eyes toward the object. The vertical cross section of a principal eye (*bottom*) shows its telephoto lens system: the corneal lens is converging, and the deep pit in the retinal tissue matrix acts as a diverging lens, enlarging the image of the object on the retina. Without the pit the image would cover fewer photoreceptors and would therefore be poorly resolved (*broken colored lines*). With the telephoto system *Portia* can identify prey at 30 centimeters.



may move at a given moment in a variable and unsynchronized way, jerking up and down several times before returning to the substrate, each leg following a different sequence that does not repeat itself in any obvious way. The motion of the legs, in turn, bears no relation to that of the palps, whose outlines are concealed by being pulled back next to the chelicerae, as they are in the cryptic rest posture. (When *Portia* is walking normally or when it is stalking web builders, the palps are held forward.) The random movements give *Portia* an appearance unlike that of a spider or even an animal—and rather like a dead leaf being struck by light flickering through the forest canopy.

Portia approaches the prey spider only when the latter is turned away. When the salticid faces it, *Portia* stops, although it often continues to wave its palps and legs. The salticid shows no sign of recognizing the imminent danger. Sometimes it grooms, rubbing dust from its eyes with a palp. Sometimes it walks directly toward and even under the waiting predator, but usually *Portia* continues its slow, relentless approach until it is standing over the smaller salticid, which faces away, still oblivious. *Portia* then seizes or stabs its victim in the region of the pedicel, the narrow waist between the cephalothorax and the abdomen. Finally it carries its prey from the rock or tree trunk where the hunt has taken place back to its web to feed.

Portia displays remarkable persistence in stalking both jumping spiders and web builders. In Queensland I found a labeled *Portia* in the same web on three successive days, plucking on the first two and eating the host spider on the third. A pursuit and capture of a salticid observed from beginning to

INVADING A WEB and hunting the host spider is one of *Portia*'s main predatory tactics. Through special movements of its palps and legs *Portia* sets off vibrations that attract the web builder, which reacts as if they came from an ensnared insect or a member of its own species. Soon after entering the web *Portia* often flutters its palps or its front four legs against the web (*1*); later it switches to plucking silk strands with varying combinations of all its limbs (*2*). When the web builder has approached to within about five millimeters (*3*), *Portia* raises its front four legs, extends its fangs and fastens a dragline to stabilize it during the attack. It may maintain this position for minutes before lunging and stabbing the spider with its fangs (*4*). As the stabbed spider attempts to flee, *Portia* watches, waiting for the venom to take effect and convulse the spider (*5*). It then crosses the web to retrieve its prey (*6*).

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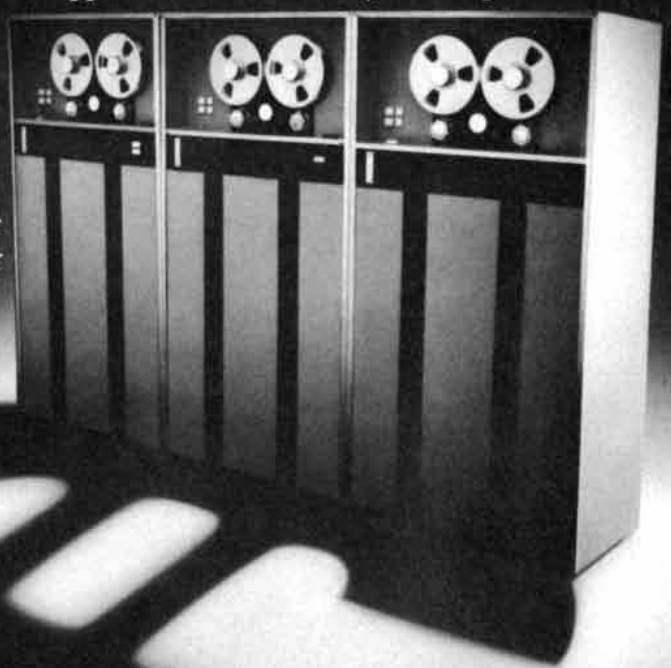

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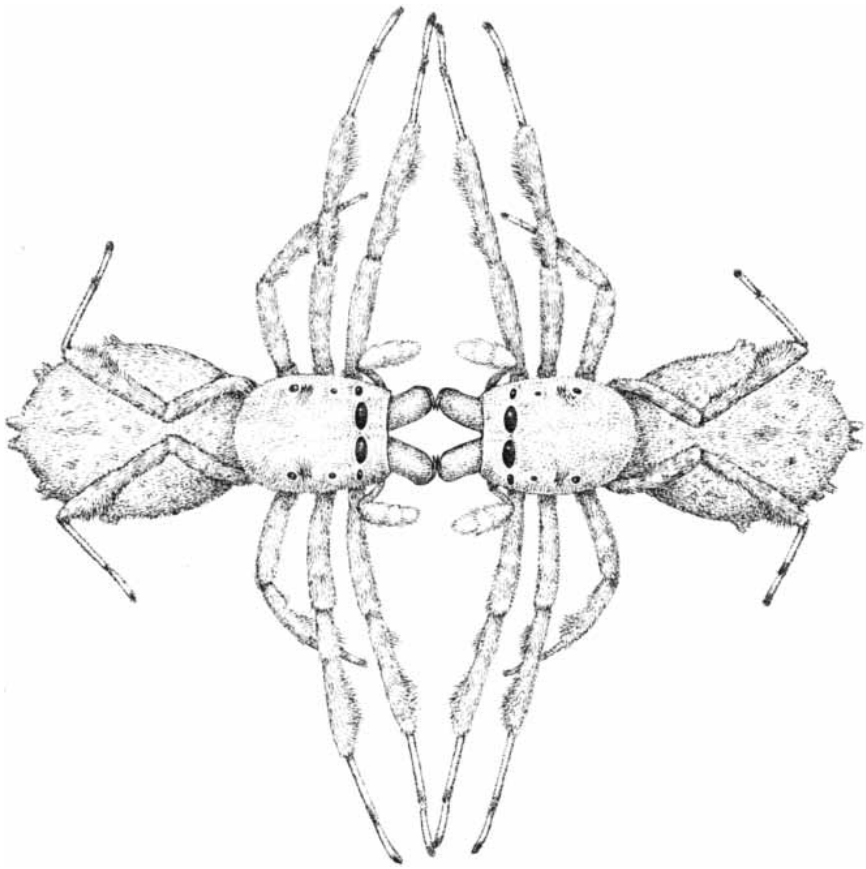
end lasted for about 90 minutes. In my laboratory I have often watched *Portia* stalk a salticid or vibrate on a web continuously for more than an hour. Ultimately it almost never failed to capture its prey.

The extraordinary predatory behavior displayed by *Portia* depends heavily on visual acuity. Vibratory stimuli provide it with reliable information on the presence but not the location of prey; when an electronic vibrator is coupled to a web occupied only by *Portia,* the spider plucks the silk but does not consistently turn to face the probe. On the other hand, it does turn toward prey spiders on an adjacent web separated from its own by glass, which blocks the transmission of vibrations. It also discriminates between salticids and flies behind glass, and between flies behind glass and its own image in a mirror. It ignores the flies, stalks the salticids and directs a threat display at its reflection, which it presumably takes to be a rival. *Portia* can make these discriminations from as much as 30 centimeters away, a visual range as great as or greater than that of many other species of jumping spider studied by my colleague Aynsley Macnab.

The visual structures of *Portia* and of typical salticids are essentially similar. Much of what is known about salticid eyes, including details of their field of view [*see bottom illustration on page 105*], is attributable to the work of Michael Land of the University of Sussex. By covering different combinations of eyes with opaque paint, it was easy to verify that in *Portia* the small lateral eyes control the spider's orientation, whereas the large principal eyes are responsible for acute visual discriminations. To achieve the necessary resolution a large image must be projected onto the retinas of the principal eyes, one that touches as many photoreceptors as possible. In *Portia* and in other salticids the image size is maximized in two ways.

First, the retinas of the principal eyes are positioned far from the corneal lenses, at the rear of elongated tubes that extend deep into the cephalothorax. This increases the focal length and therefore the size of the image. *Portia*'s cephalothorax is only about four millimeters long, however, and so the degree of magnification attainable by elongated eye tubes alone is limited.

David S. Williams and Peter McIntyre of the Australian National University in Canberra have found a second anatomical feature in *Portia* that improves visual resolution. The retina of each principal eye is embedded in a tissue matrix shaped like a cone that opens toward the front of the eye. Because the refractive index of the matrix is greater than that of the clear fluid in the middle of the eye tube, the conical pit just in front of the retina acts as a diverging lens. The pit and the converging corneal lens together function as a telephoto lens system that increases the size of the retinal image and therefore the eye's resolving power by about half. The principal eyes of *Portia* (and, as A. David Blest of Canberra has shown, of other salticids as well) are in effect miniature Galilean telescopes. Similar diverging lens systems have been found in hawks and falcons by Allan W. Snyder of Canberra and William H. Miller of the Yale University School of Medicine. Like salticids, such birds must accommodate powerful eyes in small heads.

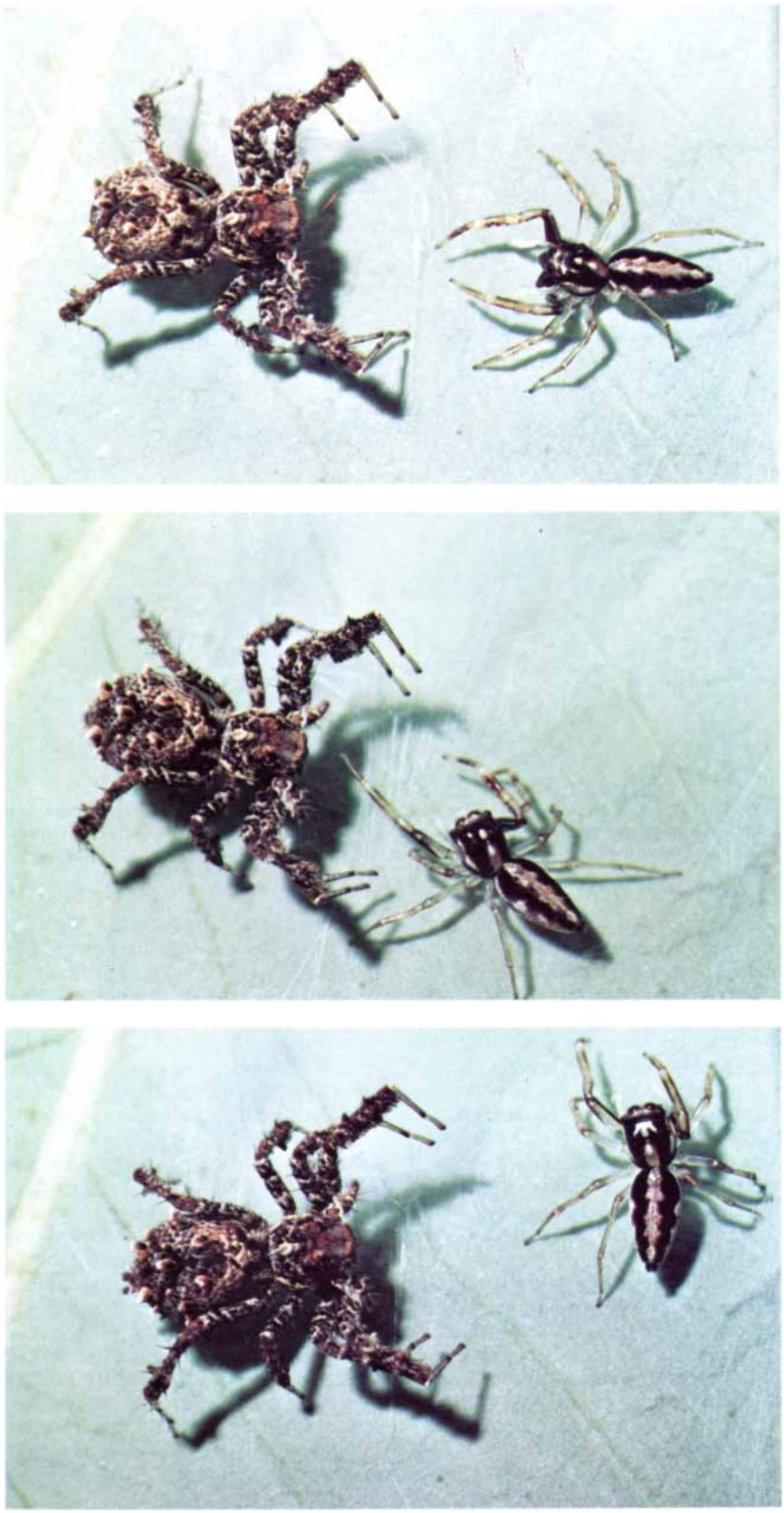


FEMALE *PORTIA* do battle, often for control of a web, by pressing their chelicerae and front legs together and pushing. Each spider tries to reach its legs over those of its rival; sometimes legs are torn off. When one *Portia* chases another from a web, it eats its rival's eggs.

Visual acuity is important to *Portia* for more than just its predatory behavior; its interactions with members of its own species are to a large extent visually mediated as well. Between spiders of the same sex the most conspicuous types of display behavior are "hunched legs" displays, in which the first three pairs of legs are held highly flexed and near the body. The first two pairs usually wave up and down. Often the two spiders sway slowly from side to side or circle each other repeatedly at close range. Other salticids display similar behavior, but *Portia*'s performance looks particularly menacing.

Interactions between females tend to escalate. With their faces pressed together, their fangs open and their legs extended on each side, the two spiders push each other back and forth. When one manages to reach over the other with one or more legs, a grappling match ensues during which one of the rivals may lose some limbs. Eventually one spider decamps. Sometimes the encounter pits an intruder against another *Portia* defending her web; if the resident is evicted, the intruder immediately eats the resident's eggs and may then deposit her own eggs in their place.

In pursuing prey and in avoiding predators *Portia* tries to be inconspicuous by moving slowly and mechanically, but in communicating with members of its own species, when the point is not only to see but also to be



STALKING SALTICIDS away from webs is another of *Portia*'s predatory behaviors. In this sequence *Portia* has slowly approached a prey spider on a leaf. As long as the prey is facing it *Portia* remains motionless, palps retracted (*top*). Apparently oblivious, the salticid walks toward *Portia* (*middle*). When the salticid turns away, still unaware of the danger (otherwise it would flee), *Portia* resumes its approach; it attacks only when it has positioned itself over its prey. The pursuit may last for more than an hour and is usually successful.

seen, such movements are inappropriate. Particularly during courtship *Portia* evinces speed and agility that are a startling contrast to its predatory behavior. Females often charge across their webs toward courting males, occasionally culminating the attack by leaping directly onto the male from several centimeters away. Such behavior does not necessarily imply a lack of receptivity on the part of a female; after fleeing, the male generally renews his courtship displays, and sometimes he eventually mates with the aggressive female.

The male's visual displays consist of specialized postures and movements of the legs; they are similar to those employed by typical salticids. While he is still distant from the female, the male raises his front two legs stiffly, angles them forward and waves them up and down out of phase. When he has moved closer, he switches to a different display, moving the raised forelegs rapidly sideways, bringing them toward each other and then separating them. Finally he walks onto the female and begins copulating. Typical female salticids keep all their legs on the substrate while mating, but *Portia* is unusual: the female often lowers herself from a leaf, with the male on her back, by a line of silk.

The male performs his visual displays both on and away from webs. On webs, however, his courtship behavior has an added component: vibratory communication. In this respect *Portia* resembles the typical web builders, which because of their poor vision rely mainly on specialized vibratory behavior to communicate with other members of their species. During courtship, for example, a male web builder may pluck the silk with his forelegs or drum it with his palps in a characteristic way to attract the female's attention.

Portia's vibratory courtship consists of a special gait adopted by the male only when a female is present on the web. Ordinarily this "jerky walking" is concurrent with the visual displays, but experiments have shown that the visual displays are not essential and that the stimulus transmitted by jerky walking is indeed vibratory: a pair of blinded *Portia* can court and mate. Apparently the characteristic vibrations set off by jerky walking enable the female to locate her mate. The male's behavior in turn is triggered by olfactory stimuli (pheromones) released by the female. Such communication by odor is highly unusual for a salticid, but it too is a common feature of courtship among members of typical web-building species.

Thus when it is on webs, and particularly when it is denied the use of its eyes, *Portia*'s courtship behavior parallels that of a web builder; away from webs, it courts as other salticids do, by means of visual displays. These observations suggest that *Portia* has evolutionary significance and is not merely a bizarre zoological curiosity. Indeed, Fred Wanless of the British Museum of Natural History has argued that *Portia* is one of the most primitive of extant salticids. The argument is based on morphological evidence, in particular on the fact that the middle pair of lateral eyes, which are degenerate and hence vestigial in most jumping spiders, are functional in *Portia*. The aberrant behavior of this peculiar spider may offer a clue to the origin of the salticids and their complex eyes.

Blest and I have suggested the following hypothesis about salticid evolution. The common ancestor of *Portia* and of the typical salticids was a web builder with poor vision. The ancestral species lived in a habitat like the Queensland rain forest in which the webs of other species were numerous and often contiguous with its own. Neighboring webs proved to be a rich source of food, and so the salticid ancestor developed the habit of invading them. In doing so it initially relied on vibratory stimuli to locate its prey, as modern web builders do. Vibratory signals are not entirely reliable in such situations, however, because they depend on web characteristics that vary from species to species. An evolutionary advantage would therefore have been conferred on members of the ancestral species that could detect prey on all types of webs by using a sense that is independent of web dynamics: vision.

Once the ancestral spider became specialized at web invasion, it would have had to leave its web on occasion to foray across open ground in search of new webs to invade. In this context the ability to run and to leap across barriers might have evolved. At the same time the ancestor's now-developed vision would have enabled it to prey on moving insects. The advantages of specializing on insect prey might then have led it to abandon the tactic of invading webs; insects are generally more plentiful than other spiders, and they can be captured more rapidly, without prolonged stalking. Once the spider stopped invading webs and started living off insects it chased on the ground, it would have had no need to build webs of its own. From that point on the numerous salticid species would have evolved through

His family gathered around him on that chilly November day to bid him final farewell. Papa put up a brave facade.

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SUCCESSFUL PURSUIT of a salticid ends with *Portia* seizing the prey spider in its chelicerae. Generally *Portia* then returns to its web, dragging the salticid. Since it can only consume liquids, it injects the spider with enzymes from its mouthparts that digest and liquefy the internal tissue. It then sucks out the liquid and pushes the dried carcass off the web.

adaptation to different environments.

That would also have been the point at which *Portia* diverged from the typical salticids, retaining the habits of web building and web invasion. Perhaps *Portia* kept these behaviors because of special environmental circumstances: it continued to occupy a habitat in which neighboring webs were abundant. Another likely reason is that the unusual safety from predators enjoyed by *Portia* as a result of its cryptic, leaflike appearance would have been lost if it had engaged in high-speed pursuit of insects. Slow approaches, on the other hand, would not have compromised its cryptic advantage, and such approaches were appropriate to the stalking of web builders, which would be alerted by rapid movement. When other salticids became abundant in the Queensland rain forest, *Portia*'s cryptic appearance and its customary slow movements could be adapted to the exploitation of the rich new food source.

Typical jumping spiders may betray signs of their web-building roots. Although they do not spin webs, they do build tubular silken nests, usually under a rock or in some other dark, secluded spot; females lay their eggs in the nest and generally remain there while inactive. More significant, when a male salticid encounters a female inside a dark nest, he does not attempt to attract her with the usual visual displays. Instead he engages in vibratory courtship behavior; for example, he pushes and pulls the silk with his legs or fangs in a characteristic way. (*Portia* sometimes succeeds in luring a salticid from its nest by plucking the silk in a similar manner.) When this behavior was discovered about a decade ago, it came as a surprise, because most workers accepted the traditional view that all salticid communication is visually mediated. The most logical explanation is that the typical salticids have retained some of the behavior of their web-building ancestors, and that *Portia,* a kind of evolutionary intermediate, has retained such behavior to a greater degree.

Although the hypothesis may never be proved, it does make testable predictions. For example, a spider like *Portia* evolving in a habitat where salticids are much less abundant than they are in Queensland would not be expected to prey on them. Although I have been using the name *Portia* as a shorthand for *Portia fimbriata,* the name actually belongs to a genus that includes about a dozen known species occupying a wide variety of environments. My colleagues and I are currently studying the behavior of some of these species and of other primitive salticids. By comparing the observations of a number of different species, we hope to further unravel the evolutionary history of this unique family of spiders.

Slips of the Tongue

They offer glimpses of the process underlying one of the most complex of all behaviors: speech. The study of slips is facilitated by several research techniques that induce slips in the laboratory

by Michael T. Motley

Several years ago, in the course of being interviewed for a job, I was introduced to a competitor for the position. Extending my hand and meaning to say, "Pleased to meet you," I accidentally said, "Pleased to beat you." Although both of us laugh about it now (neither of us got the job), the slip made for considerable embarrassment at the time.

What caused the slip? Almost a century ago Sigmund Freud asserted that hidden meanings could be read into all verbal slips. More particularly, he held that all slips of the tongue reveal the speaker's hidden anxieties and motives. Among those who study the cognitive processes responsible for language and speech production, that hypothesis has long been unpopular. The "Freudian slip" is difficult to examine in the laboratory, and it was neglected in favor of hypotheses that were easier to test. Moreover, theorists tended to view the production of speech as a more or less autonomous process—one with no room for involuntary influences by motives, anxieties or other factors irrelevant to the speaker's intended message.

Further still, the categorical nature of Freud's claim that all slips have hidden meanings makes it rather unattractive. It is difficult to imagine, for example, that my six-year-old daughter's mealtime request to "help cut up my meef" was the result of repressed anxieties or anything of that kind. It seems more likely that she simply merged "meat" and "beef" into "meef." Similarly, about the only meaning one can easily read into someone's saying "roon mock" instead of "moon rock" is that the *m* and the *r* got switched. Even so, how does it happen that words can merge or sounds can be switched in the course of speech production? And in the case of my "pleased to beat you" error, might Freud have been right?

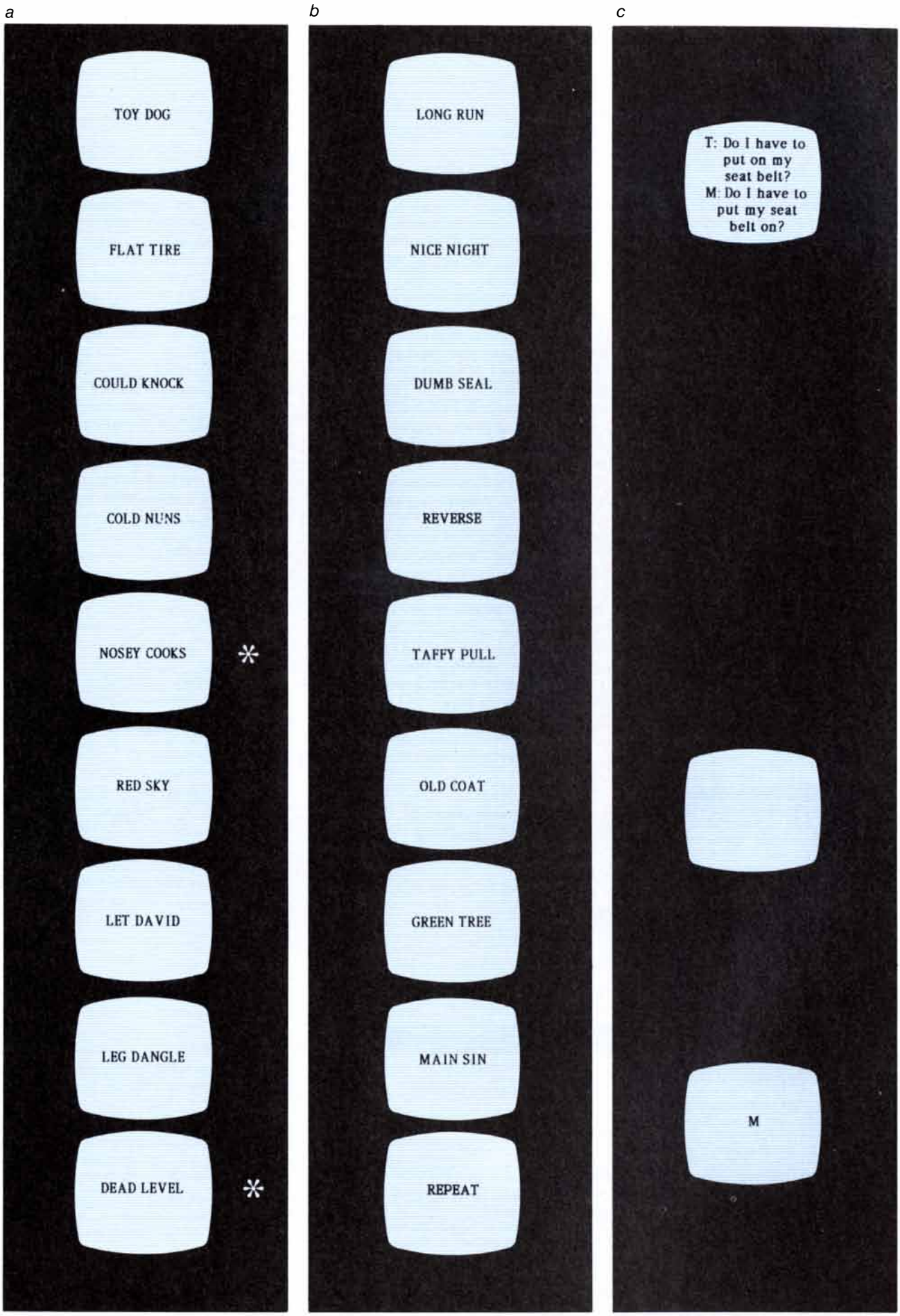
Serious attention to these questions and related ones has been renewed in the past decade. Paradoxically, however, the modern interest in verbal slips derives from an interest in error-free speech production. Spoken language is among the most complex and mysterious behaviors in the human repertory. It is one of the dwindling number of behaviors that continue to resist computer simulation. The fact that speech production is usually error-free makes the process even more remarkable. At the very least a speaker wanting to express a thought must choose words that fit the intended meaning, must select a grammatically legitimate organization of the words and must supply the appropriate motor commands to the larynx, the tongue and the lips. All these decisions and formulations of signals can occur in an instant, and so it is unlikely that they are under conscious governance. On the other hand, what people say is so often original—as a sequence of words if not as a thought—that speech is unlikely to be the result of mere reflexes.

The complexity and efficiency of speech production make it difficult to study: its constituent decisions and operations follow one another too quickly to be easily isolated and examined. It is therefore a good thing (at least for students of human speech) that people make verbal slips. In effect, a slip of the tongue offers a freeze-frame observation of the speech-production process. When someone says "magician" instead of "musician" the mistake affords a glimpse into the speaker's word-selection process. When phonemes are transposed ("tea and flick spray" instead of "flea and tick spray") or substituted ("brouse" instead of "blouse"), other windows are briefly opened.

Most of the credit for the modern interest in slips of the tongue belongs to Victoria A. Fromkin of the University of California at Los Angeles, who in the 1960's began to document the verbal slips she witnessed in everyday speech. Over the years Fromkin and her colleagues have collected several thousand examples of verbal slips, and other investigators have begun their own collections. The work reveals that in many ways verbal slips follow identifiable patterns.

When slips involve switched words, for example, the transposed words are almost always of the same syntactic, or grammatical, category. Nouns tend to switch places with other nouns (as in "He threw the window through the clock"), verbs tend to switch places with verbs ("Please wash the table and clear the dishes"), and so on. The pat-

THREE METHODS that elicit verbal slips in the laboratory all require that subjects respond to words on a screen. In phonological biasing (*a*) the subject is induced to make spoonerisms (that is, to transpose phonemes, or individual speech sounds, between two words by accident). The subject reads word pairs silently; then the sound of a buzzer (*asterisks*) instructs the subject to say the current pair aloud. Unknown to the subject the preceding pairs are contrived so that their initial phonemes duplicate the expected error; this biases the subject toward the utterance of a spoonerism. The predicted slips are "cozy nooks" (for "nosy cooks") and "led devil" (for "dead level"). In sequencing conflict (*b*) the instruction "reverse," appearing on the screen, requires the subject to say the preceding word pair in reverse order; the instruction "repeat" requires the subject to say the preceding pair aloud. The predicted slips are "deal some" or "some deal" (for "seal dumb," the reversal of "dumb seal") and "sane men" (for "main sin"). In phrase-option competition (*c*) two sentences are viewed for 10 seconds; each sentence is preceded by a letter (here *T* or *M*). The screen is blank for some five seconds; then the appearance of a letter (here *M*) instructs the subject to say one of the sentences. The predicted slip is "Do I have to put on my seatbelt on?"



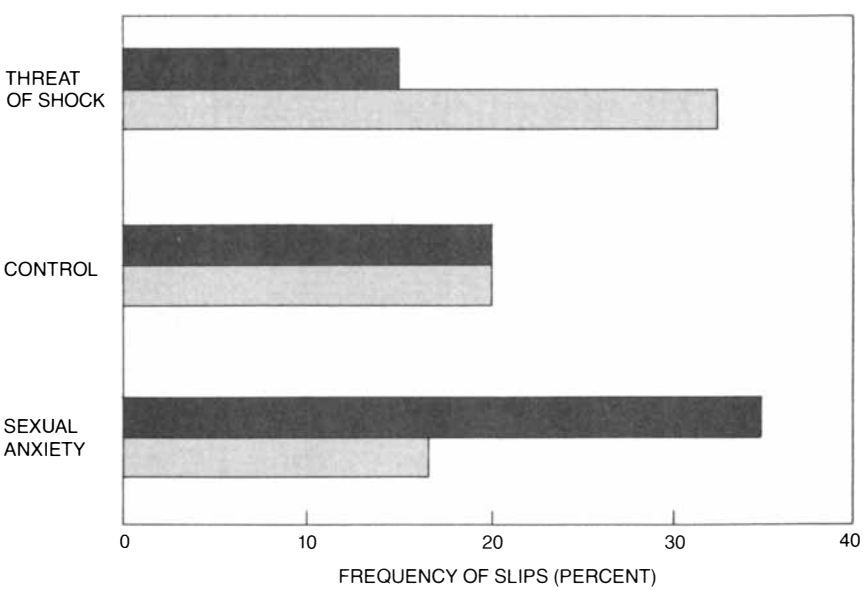
tern suggests that a speaker's lexicon, or mental dictionary, organizes words according to their grammatical categories. A further type of error—"It's right where you puted it" or "Listen to the honking geeses"—implies that the ingredients for fine-tuning within grammatical categories (ingredients such as tense indicators for verbs and plural endings for nouns) are not stored as parts of words but instead are added in the course of speech production. (The assumption here is that the lexicon would not include nonexistent words such as "puted" and "geeses.")

The analysis of natural slips of the tongue therefore reveals a good deal about the mental organization of linguistic components. On the other hand, it reveals little about how the components are processed in the mind of the speaker. One way to begin examining such processing is to elicit verbal slips in a laboratory environment. That is the strategy I have employed for the past 10 years or so. Most of the work has been a team effort with my colleagues, Bernard J. Baars of the University of California at San Francisco and Carl T. Camden of Cleveland State University.

Several techniques have been devised to elicit verbal slips that are accidental on the part of the speaker but predictable on the part of the experimenter. One of the most reliable methods induces the type of slip known as a spoonerism, that is, a transposition of phonemes between adjacent or nearly adjacent words. "Flute fry" for "fruit fly" and "shred hinker" for "head shrinker" are two examples from natural speech. To elicit spoonerisms in the laboratory, target word pairs (the ones the speaker intends to say, such as "fruit fly" and "head shrinker") are embedded in a list of word pairs. Each pair on the list is flashed briefly on a screen. These days the screen is usually a computer-terminal screen, and the word pairs are flashed at intervals of about a second.

The subject is instructed to read the pairs silently unless a cue is presented (usually the sound of a buzzer), and in that case to say the word pair aloud. The cued pairs of course are the targets, but unknown to the subject the targets are preceded on the list by two or three word pairs contrived so that the phonemes expected to be transposed in the spoonerism are already in their transposed positions. For example, "fruit fly" might be preceded by "flat frog" and "flying froth." This creates enough of a bias toward error so that for an average subject one in every three targets elicits a spoonerism.

In all important respects the verbal slips elicited by this technique are indistinguishable from natural slips of the tongue. Varying certain features of the technique makes it possible to test hypotheses about speech production. A prominent example is Freud's assertion about verbal slips. What one needs to test that hypothesis is a way of inducing subjects to make slips at a time when one can be fairly certain what anxieties or motivations the subjects are experiencing.



"FREUDIAN SLIPS" were induced by the author and his colleagues. The subjects (undergraduate males) all saw the same sequence of word pairs displayed on a screen. In one experiment ("Threat of shock") the subjects were warned they would receive an electric shock from electrodes attached to the body. No shocks were given; nevertheless, the subjects' anxiety preferentially elicited spoonerisms related to electricity (*gray bars*). "Cursed wattage" for "worst cottage" is an example. In another experiment ("Sexual anxiety") the presence of a woman monitoring the experiment preferentially elicited spoonerisms with sexual content (*black bars*). "Fast passion" for "past fashion" is an example. The results support the hypothesis that (in these experiments at least) slips of the tongue reveal hidden anxieties.

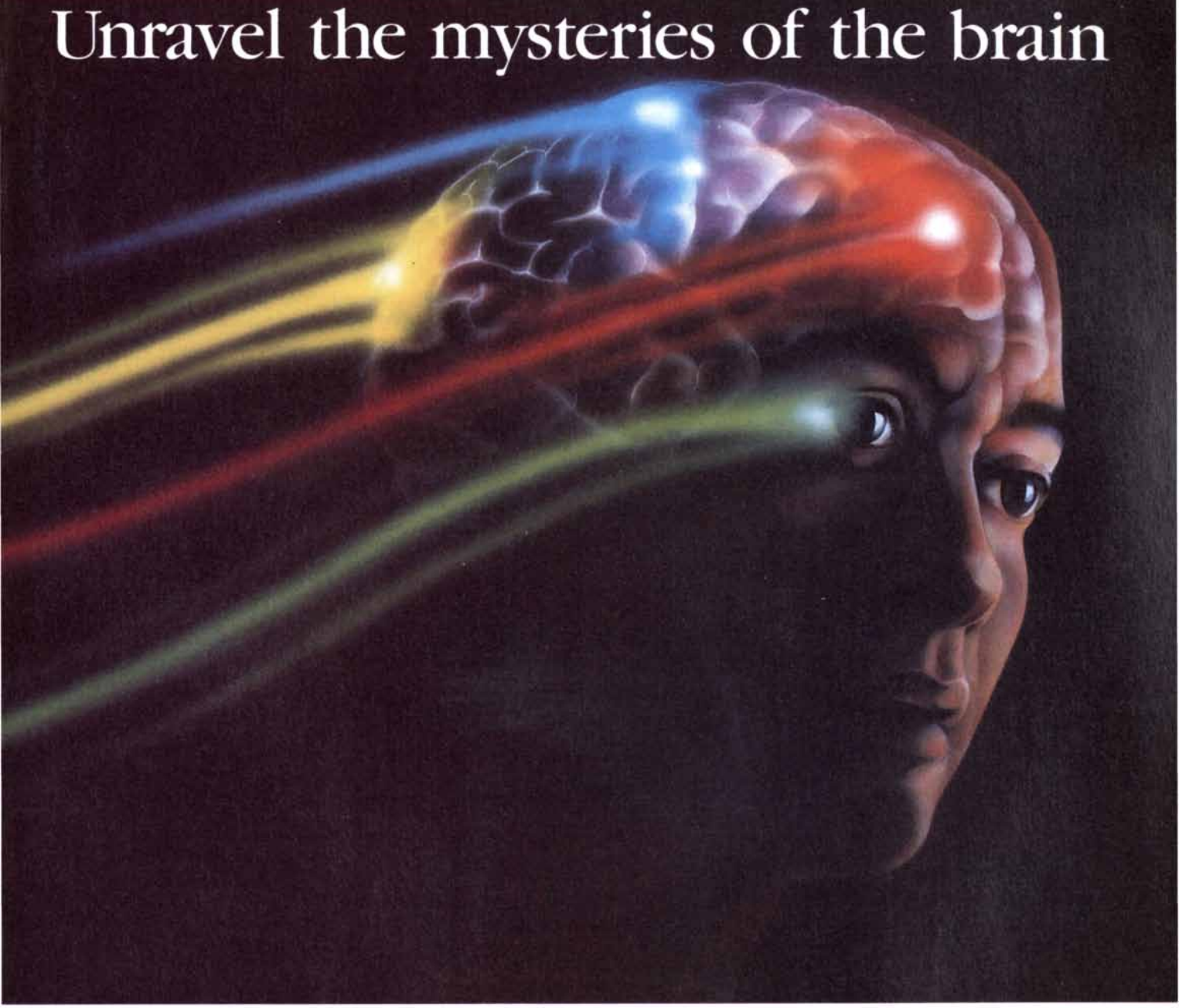
In our first tests of Freudian slips we had two ways of manipulating anxiety on the part of college-age male subjects. In one set of manipulations we attached bogus electrodes to each subject and told him that at some randomly chosen moment in the experiment he would receive a painful electric shock. No shocks were actually administered; the point was simply to ensure some anxiety. In the second set of manipulations an attractive and provocatively dressed woman posed as the experimenter. In a third set of manipulations conditions were neutral. The word-pair list for eliciting spoonerisms was the same in all three cases. It included targets that could result in verbal slips related to electric shock and an equal number that could result in slips related to sexual attraction.

The outcome was what Freud might well have predicted: subjects tested under the conditions of anxiety made far more anxiety-related slips than unrelated ones. Under threat of electric shock the subjects would tend accidentally to say "damn shock" when they meant to say "sham dock," "carried volts" when they meant to say "varied colts" and "cursed wattage" when they meant to say "worst cottage." Under the influence of the provocatively dressed "experimenter" the more frequent errors included "fast passion" for "past fashion," "happy sex" for "sappy hex" and "bare shoulders" for "share boulders."

In a related study the subjects who were guided through the sequence of word pairs by the attractive "experimenter" were first given a standard paper-and-pencil test of sexual anxiety. (The test, which asks the subject to agree or disagree with a sequence of statements, is known as the Mosher Sex Guilt Inventory.) The subjects whose scores on the written test were most indicative of an anxious personality proved also to be the ones who uttered the greatest number of sex-related spoonerisms. This is entirely consistent with Freud's hypothesis that verbal slips are indicative of anxieties one would prefer to keep hidden from others. One would expect sexually anxious males to be the last to express their state voluntarily, but apparently they are the ones most likely to do so unconsciously, by way of verbal slips.

The experiments support the idea that information having nothing to do with the message one intends to

Unravel the mysteries of the brain



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0204

TYPE	TARGET	VERBAL SLIP
PHONEME LEVEL		
Anticipation	"flapped and trilled"	"trapped and trilled"
Perseveration	"mad dash"	"mad mash"
Reversal (spoonerism)	"Those shoes are cute."	"Those cues are shoot."
Substitution	"blouse"	"brouse"
Addition	"oily"	"groily"
WORD LEVEL		
Reversal	"Come to the dinner table."	"Come to the table dinner."
Blend	"blending and merging"	"blerging"

TYPES OF VERBAL SLIP include ones that affect the phonemes in an utterance and others that transpose words or collapse them into single nonsense words. In general the slips tend to preserve linguistic validity, so that erroneous sequences of phonemes are nonetheless sequences encountered in spoken English. "Ropj," for example, is not a typical slip.

transmit may nonetheless interfere with the production of the message. How might such interference come about? A digression to unintentional double entendres may be helpful. A double entendre is a kind of unintended pun in which an utterance signals two meanings. One meaning is related to the intended message; the other meaning is related to another thought on the part of the speaker—a thought that was not meant to be communicated. A colleague reading a book-length collection of graffiti once remarked to me, for example, that "some of these graffiti are really off the wall." The intent was a comment on their sensibility, not on their medium. A neighbor once chose the expression "Pipe down!" to quiet a child who was hammering on some water pipes.

Unlike Freudian slips, double entendres do not represent a mismatch between what was said and what was intended. There is no error in the utterance. Nevertheless, one suspects that the particulars of the utterance were influenced by thoughts not intended to be part of the message transmitted by the speaker. Embarrassing double entendres emphasize the point. Consider the unintended implication of the congratulations offered to an overweight colleague on the occasion of a promotion: "You're finally in Fat City!" Again the question is whether extraneous thoughts or emotions can influence lexical selection. In the case of double entendres laboratory experiments demonstrate that the answer is yes. Asked, for example, to complete the sentence "Tabloid news magazines tend to print stories that are ——," subjects are as likely to say "sensational" or "inaccurate" or "irresponsible" as they are to say "shocking"—unless they have been threatened with the possibility of electric shock, in which case "shocking" is by far the commonest response.

The most promising explanation of how Freudian slips and unintentional double entendres occur is found in theories that originated in cognitive psychology and are now being explored in the field of artificial intelligence. The theories posit "spreading activation" in the lexicon. The lexicon is taken to be organized so that each stored word is linked to associated words. Presumably the semantic requirements (the meanings) within a message being readied for utterance serve to activate the associations. Presumably too the activation spreads in chain-reaction fashion. It is assumed that the strength of the activation diffuses and fades as it spreads. (There is preliminary evidence that the activation is strongest for semantic associations, weaker for phonological associations and weakest for syntactic associations. That is, it is strongest for meanings, weaker for sounds and weakest for grammatical associations.) Moreover, it is assumed that since lexical items can be interrelated, an activation can return to an item activated earlier in a sequence. In this way the item can accumulate a level of activation exceeding the level of its original activation. One implication of such a model is that words can be selected for utterance in an unconscious fashion. That is, the lexical item with the highest eventual activation can be selected automatically.

If the spreading-activation model is modified so that lexical activation can arise not only from the thoughts instigating an utterance but also from extraneous thoughts, it becomes possible for the model to encompass unconscious double entendres and Freudian slips. That is, a lexical item accumulating activation in the normal course of message processing can acquire a further increment of activation through its association with an extraneous thought and thus get a boost toward being the lexical item selected. I once heard someone remark, for example, that "the Checkers speech dogged Richard Nixon throughout his career." The unintended pun arose because the speech is well known for its strategic reference to Checkers, the Nixon family's dog. Presumably a number of lexical items had been activated as potential verbs for the remark, but secondary thoughts about the Checkers speech had given extra activation to "dog," so that it was selected more or less automatically.

Many verbal slips can be explained in much the same way. During a recent conversation I had about bourbon whiskeys, one of the participants mentioned "Black Daniels," meaning to say "Jack Daniels." The Jack Daniels bottle has a black label. Presumably the lexical item "black" was activated, and for any number of reasons, including its phonological similarities to "Jack" and perhaps also to the word "bourbon," which heavily emphasizes the phoneme *b,* it had the greatest eventual activation and so was selected automatically from the lexicon. The same type of explanation can be offered for my wife's spoonerism "scratch and stiff snickers" for "scratch-and-sniff stickers." The stickers were chocolate-scented, and Snickers is the name of a well-known candy. Similar slips have emerged in our work with the experimental induction of spoonerisms when we preceded targets with word pairs semantically related to the expected error. We have found, for example, that the target "bad mug" is much more likely to elicit the error "mad bug" if it is preceded by something conceptually similar (such as "irate wasp") than if it is preceded by something conceptually irrelevant (such as "Irene's watch").

So far I have emphasized verbal errors in which the interference with the production of an intended message comes from lexical items that, although activated, presumably were not among the items considered for the message. There are several types of verbal slips in which the interference comes from items competing to be in the message. Plainly that is the case for slips in which two synonyms merge into a single word, perhaps a nonsense word, as in "Help cut up my meef." A straightforward explanation for such slips is that the speech-production system begins with one word but switches to another. Why then does the slip not consist of the first part of the replaced word and all of the replacement, for example "mbeef"? Perhaps the reason is that phonemes are displaced from slips in obedience to the English language, which disallows certain phoneme combinations at the beginning of

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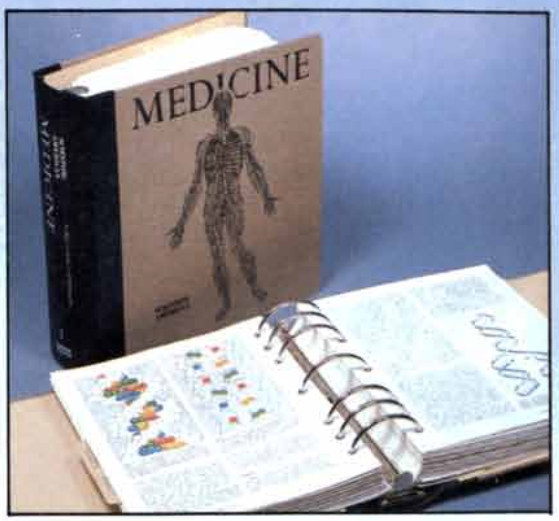

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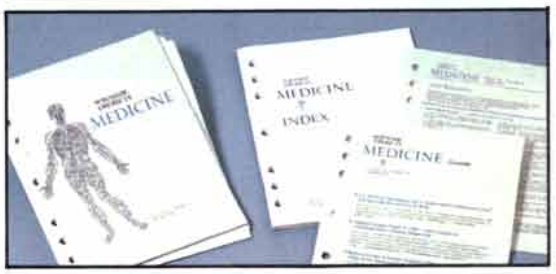

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a word. When lexical indecision is induced in the laboratory, the resulting verbal slips depend entirely on the phonological viability of the slips. The competition between "taunt" and "mock" yields "tock," for example, but never "tmock." On the other hand, the competition between "sob" and "weep" yields "sweep" as often as "seep."

Just as some slips result from indecision over a particular word selection, others are the result of indecision over the eventual sequence of the words in a message. One of my favorite examples enlivened a political oration I heard in Columbus, Ohio, in 1979: the candidate was proclaimed to be "as American as mother pie and applehood." It is a safe bet that the speaker, consciously or not, considered both "motherhood and apple pie" and "apple pie and motherhood." The conflict between the options contributed to the slip.

The same type of conflict is most likely responsible for spoonerisms such as "foon and spork," which presumably arises from a conflict between "fork and spoon" and "spoon and fork," or "lunder and thightning," which arises from a conflict between "lightning and thunder" and "thunder and lightning." Evidence supporting this explanation derives from a study in which we varied the technique for eliciting spoonerisms. Instead of giving a single cue (the sound of a buzzer) to elicit an attempt at a target, we presented one of two alternative cues. One cue told the subject the target words were to be spoken in the order in which they were presented, whereas the other signaled that the words were to be spoken in reverse order. Subjects experiencing conflict over whether to say "green lime" or "lime green," for example, would often say "lean grime."

There are many variations on the general scheme of conflicts giving rise to slips of the tongue. Still, the commonest conflict seems to be modifier conflict, or indecision over whether or not to include an adjective in an utterance. "You didn't hear a thingle sing I said" might arise from a conflict between "a thing" and "a single thing." "Soodle noup" might emerge from "soup" v. "noodle soup." "Wed rig" might emerge from "wig" v. "red wig." Thus many verbal slips that appear to be no more than errors in phonological processing are more likely the result of conflicts at the lexical level of speech production, that is, the level of word selection. Indeed, it seems to be a general principle that verbal slips at one level of linguistic organization are instigated by conflict between units at a higher level. Experiments have shown, for example, that phrase-order conflict, such as indecision between "She wore her robe while she washed her hair" and "She washed her hair while she wore her robe" can be the cause of word-switch errors: "She wore her hair while she washed her robe."

Rare verbal slips such as "Why did this be done?" or "What could have I done with the check?" or "Did he knew who you were" are also instructive. They are exceptional because the error is apparently syntactic rather than lexical or phonological. One explanation for such slips is that syntactic rules have failed. Contemporary linguistic theory posits, for example, a

	TARGET	VERBAL SLIP	SOURCE OF CONFLICT
a	"Do you think we need a *blue* book for the exam?"	"Do you think we need a *black* book for the exam?"	Spoken by a white student to a black classmate following a history lecture on the civil-rights movement
	"It needs *organic* unity."	"It needs *orgasmic* unity."	Spoken by a professor to an attractive student
b	"This new *combination* will challenge John Deere."	"This new *combine* will challenge John Deere."	The subject was the merger of two firms known, like John Deere, for manufacturing combines.
	"Surely."	"Shirley."	Spoken in response to a question about dolls. The speaker had a new Shirley Temple doll.
c	"chilly"	"frilly"	"chilly" v. "frigid"
	"runt"	"shrunt"	"runt" v. "shrimp"
d	"moon rock"	"roon mock"	"moon rock" v. "rock"
	"weights"	"lates"	"weights" v. "lead weights"
e	"French and Spanish"	"spench and franish"	"French and Spanish" v. "Spanish and French"
	"done and said"	"sun and dead"	"done and said" v. "said and done"
f	"Brush your teeth and make your bed"	"Brush your bed . . ."	"Brush your teeth and make your bed" v. "Make your bed and brush your teeth."
	"Have a good trip, and be careful."	"Have a good careful . . ."	"Have a good trip, and be careful." v. "Be careful, and have a good trip."
g	"Listen to the honking geese."	"Listen to the honking *geeses.*"	"Listen to the honking geese." v. "Listen to the geese's honking."
	"Let's scramble those eggs."	"Let's get scrambled those eggs."	"Let's scramble those eggs." v. "Let's get those eggs scrambled."

CONFLICTS IN SPEECH PRODUCTION may be responsible for a great proportion of all verbal slips. In some slips (*a*) the conflict is between the message being prepared for utterance and a thought extraneous to the message. In other slips (*b*) the thought is related to the message but was not intended for utterance. In still other slips the conflict involves two words contending for utterance (*c*), or the decision whether or not to modify a noun with an adjective (*d*), or two orderings for words (*e*) or two orderings for phrases (*f*). Yet another type of slip may arise from a conflict between two equally legitimate ways in which to put a message in words (*g*).

series of rules by which "Did he know who you were?" is derived from the more basic utterance "He knows who you are." The rules establish tense by changing "are" to "were" and "knows" to "did know"; they establish the interrogative by inverting "He did know," producing "Did he know." A neural misapplication of the rules governing tense could change "knows" to "did knew," and that would account for the slip.

A much simpler explanation is also available. It posits that for slips such as "Did he knew who you were?" two legitimate constructions were competing to be spoken, just as in other types of verbal slip. In this case the competing constructions would be "Did he know who you were?" and "He knew who you were?" In a similar way "Why did this be done?" could result from conflict between "Why did this happen?" and "Why has this been done?" Moreover, I feel confident that when I once asked, "Has the dog been eaten," the question emerged from a conflict between "Has the dog eaten?" and "Has the dog been fed?" My colleagues and I have elicited syntactic slips exactly like these examples by inducing competition between two syntactically valid options displayed on a computer-terminal screen.

A remarkable thing about verbal slips of all types is that the error always tends to be an utterance linguistically legitimate in its own right. For example, slips that form real words are much commoner than slips that form nonsense words. ("Barn door" for "darn bore" is much more likely than "bart doard" for "dart board.") By the same token, slips that are syntactically legitimate predominate over slips that are syntactically anomalous. ("Did con" for "kid Don" is much more likely than "did cared" for "kid dared.") Further still, phonological anomalies ("mbeef" or "ropj") almost never occur. Why should the speech-production system tend always to produce legitimate utterances? The meaning of an error is bound to be a distortion of the intended message; why then should it matter whether the error is linguistically valid? The implication is that the speech-production system contains a built-in mechanism protecting automatically against most anomalous constructions.

Investigators are divided on the question of precisely how the protection mechanism operates. One view holds that the spreading-activation lexicon in itself provides automatic protection against anomalous utterances. Since the lexicon contains only valid items, the activation within it is

unlikely to create new and anomalous ones. To the extent that verbal slips arise before items are chosen from the lexicon, the view is viable. The other view holds that a review process occurs well after items are selected from the lexicon but before articulation. In other words, an impending utterance is "edited" for linguistic integrity. This view too is viable, particularly to the extent that verbal slips arise after items are chosen from the lexicon.

Which view best explains how the system of speech production accomplishes its general avoidance of anomalous utterances? The question is not settled, but many proponents of one view or the other are moving toward middle positions. In any case, it is clear from the experimental work with slips of the tongue that the speech-production system concerns itself with more than whether a given utterance expresses the speaker's intended meaning. It somehow acts to ensure more generally that utterances are linguistically valid.

Another unsettled question is whether all natural verbal slips are the result of message-option conflicts. Our experimental work induces such conflict and yields abundant verbal slips, but it does not rule out the possibility of other types of slip. Indeed, a few natural slips are hard to explain in terms of message-option conflicts. It is difficult to imagine what conflicts could have led to slips such as "coregaty" (for "category"), "daygo plaints" (for "dayglo paints") and "checking cashes" (for "cashing checks"). Perhaps an explanation would emerge if one knew more about the context of each such slip; perhaps not. Obviously, however, the possibility that unrecognized sources of cognitive interference underlie some verbal slips is worth pursuing.

One thing that distinguishes human language from other forms of biological communication is that language virtually always offers a wide variety of alternatives for the expression of a message. The speaker need not deliberate over the choices; a choice can be made rather automatically and uttered flawlessly, all within an instant. Students of speech are far from understanding the process. To learn more one can take advantage of what appears to be a fairly general principle: Cognitive indecision over alternative forms for a message sometimes results in a slip of the tongue. By instilling cognitive indecision, eliciting verbal slips and examining the conditions that precede and facilitate the slips, we hope to learn more about the unique qualities of human speech.

Yellow Rain

A yellow substance found on rocks and leaves in Southeast Asia is alleged to be an agent of chemical war. The material is indistinguishable from the feces of indigenous honeybees

by Thomas D. Seeley, Joan W. Nowicke, Matthew Meselson, Jeanne Guillemin and Pongthep Akratanakul

Since the late 1970's reports of chemical warfare have emerged from Laos and Kampuchea. The allegations have come from refugees and soldiers opposed to the Laotian and Kampuchean governments that are supported by Vietnam, and they soon prompted investigations by the U.S. Government. In June, 1979, two officials of the Department of State conducted 22 interviews in Thailand with refugees from Laos, using a medical questionnaire prepared by U.S. Army experts in chemical warfare. The records of the interviews tell of bombs and rockets delivered by aircraft, which were said to have caused a variety of medical symptoms and many deaths.

The State Department investigators were given samples of the alleged chemical agent—pieces of vegetation spotted with a yellow substance—which were sent to the Army's Chemical Research and Development Center (CRDC) in Aberdeen, Md., for chemical analysis. Four months later Army physicians held further interviews with refugees who said they had witnessed chemical warfare in Laos, and they too received samples, which were subsequently transmitted to the CRDC. Again the samples were yellow spots a few millimeters in diameter, said to have been sprayed by an aircraft. In these early interviews and in subsequent interviews with refugees from Laos the deposits of the presumed chemical-warfare agent are almost always described as yellow; they have come to be known as yellow rain.

The diversity of the reported medical symptoms led the Army interviewers to conclude that several chemical agents had probably been employed: a nerve gas, a riot-control agent and a chemical that causes internal bleeding. Nevertheless, the Army's chemical analysis of pieces of vegetation with and without yellow spots, of yellow materials scraped from rocks and vegetation and of water—more than 50 samples in all—turned up nothing. No known chemical-warfare agent could be detected by even the most sensitive techniques.

On September 13, 1981, the scientific impasse seemed to be broken. Secretary of State Alexander M. Haig went before the Berlin Press Conference with a dramatic announcement: "For some time now, the international community has been alarmed by continuing reports that the Soviet Union and its allies have been using lethal chemical weapons in Laos, Kampuchea and Afghanistan. We now have physical evidence from Southeast Asia which has been analyzed and found to contain abnormally high levels of three potent mycotoxins—poisonous substances not indigenous to the region and which are highly toxic to man and animals."

The physical evidence to which Secretary Haig referred was a sample of vegetation from Kampuchea, reported to be contaminated with minute quantities of three fungal toxins called trichothecenes. The toxins were reported not by the Army but by a laboratory at the University of Minnesota to which the Government had sent the sample. Trichothecene toxins, which are produced by species of the fungal genus *Fusarium,* sometimes contaminate cereal grains, and in animals they are reported to cause skin lesions, vomiting, diarrhea and gastrointestinal bleeding. The detection of the toxins was the smoking gun the State Department relied on to charge the U.S.S.R. with waging or abetting chemical warfare.

Such actions would constitute violations of two international arms-control treaties: the 1925 Geneva Protocol, which bans the use but not the possession of chemical and biological weapons, and the 1972 Biological Weapons Convention, which bans even the possession of biological weapons, including toxin weapons. Although Laos and Kampuchea are not parties to the Geneva Protocol, the U.S., the U.S.S.R. and Vietnam have ratified the agreement. All the relevant countries, including Kampuchea, Laos, the U.S., the U.S.S.R. and Vietnam, are parties to the Biological Weapons Convention.

In this context the U.S. accusation is an extremely serious charge. The Government's evidence for the charge, however, is ambiguous. In particular, analyses by the Army have never detected trichothecene toxins—or any other chemical-warfare agents—in any samples from sites of alleged chemical attack in Kampuchea or in Laos, which puts the earlier reports of their presence in serious doubt. Moreover, our own investigations lead to an alternative explanation for yellow rain. We have good physical and biological evidence that yellow rain is the feces of Southeast Asian honeybees.

The evidence cited by the U.S. Government in support of its conclusions can be arranged in three main categories: the interviews with alleged witnesses of chemical warfare, the reports of trichothecene toxins in samples and the numerous descriptions and samples of the yellow material itself, collected from the alleged attack sites. A fourth category of evidence, secret intelligence reports, is not available for independent evaluation.

The accounts of chemical warfare come primarily from interviews with Hmong refugees from Laos. The Hmong are a highland people some of whom constituted a secret army maintained by the U.S. Central Intelligence Agency in Laos during the Vietnam war. Beginning with the collapse of U.S. support in 1975, many of the Hmong fled Laos for Thailand; thou-

sands of them have subsequently settled in the U.S., where they have been accepted as political refugees. Some of the Hmong who remained in Laos continued to resist the Laotian communist government and the occupying Vietnamese forces. Since 1978 Hmong refugees from Laos have reported numerous chemical attacks, which allegedly began in 1977 or before and continued at least until early last year.

Various investigators, including representatives of the State Department, the Army, the Canadian government and the United Nations as well as American volunteers, have conducted more than 200 interviews with alleged witnesses, most of whom were Hmong refugees who described suspected chemical attacks in Southeast Asia. Secretary of State George P. Shultz summarized the information collected between 1979 and mid-1982 in a report to Congress: "Usually the Hmong state that aircraft or helicopters spray a yellow rain-like material on their villages and crops." In an earlier report to Congress, Secretary Haig refers to a "reported symptomology of victims which commonly included skin irritation, dizziness, nausea, bloody vomiting and diarrhea and internal hemorrhaging." According to Secretary Haig's report, it was this constellation of symptoms that led in 1981 to the tests for trichothecenes toxins.

One of us (Guillemin) has examined the records of 217 such interviews, including 193 that were conducted with Hmong refugees, all done between January, 1979, and August, 1983. The descriptions of the color of the alleged chemical deposits remain consistent throughout the interviews, but the accounts of the nature of the alleged attacks and the medical symptoms following them vary widely.

More than 85 percent of the people interviewed who specify the color of the deposits of the alleged agent say it was yellow. As for the method of attack, about 40 percent of the respondents cite a specific type of aircraft: various propeller-driven airplanes, jets and helicopters are all mentioned. Only about a third of the respondents note any particular kind of system for disseminating the alleged chemical agent, and again the accounts vary: the reports cite rockets, bombs, sacks, air-

YELLOW SPOTS on vegetation in the forest of the Khao Yai National Park in Thailand closely match the samples and the descriptions of an alleged chemical-warfare agent known as yellow rain. According to reports published by the U.S. Department of State that summarize interviews with alleged witnesses to chemical warfare, yellow rain has been sprayed by aircraft, rockets and bombs in attacks against insurgents and civilians in Laos and Kampuchea, causing sickness and death. The authors present evidence that yellow rain has the same natural origin as the spots on the vegetation in the photograph have: they are the feces of Southeast Asian honeybees. The bees build as many as 100 nests in a tree and make massive cleansing flights that leave a swath of yellow, fecal spots.

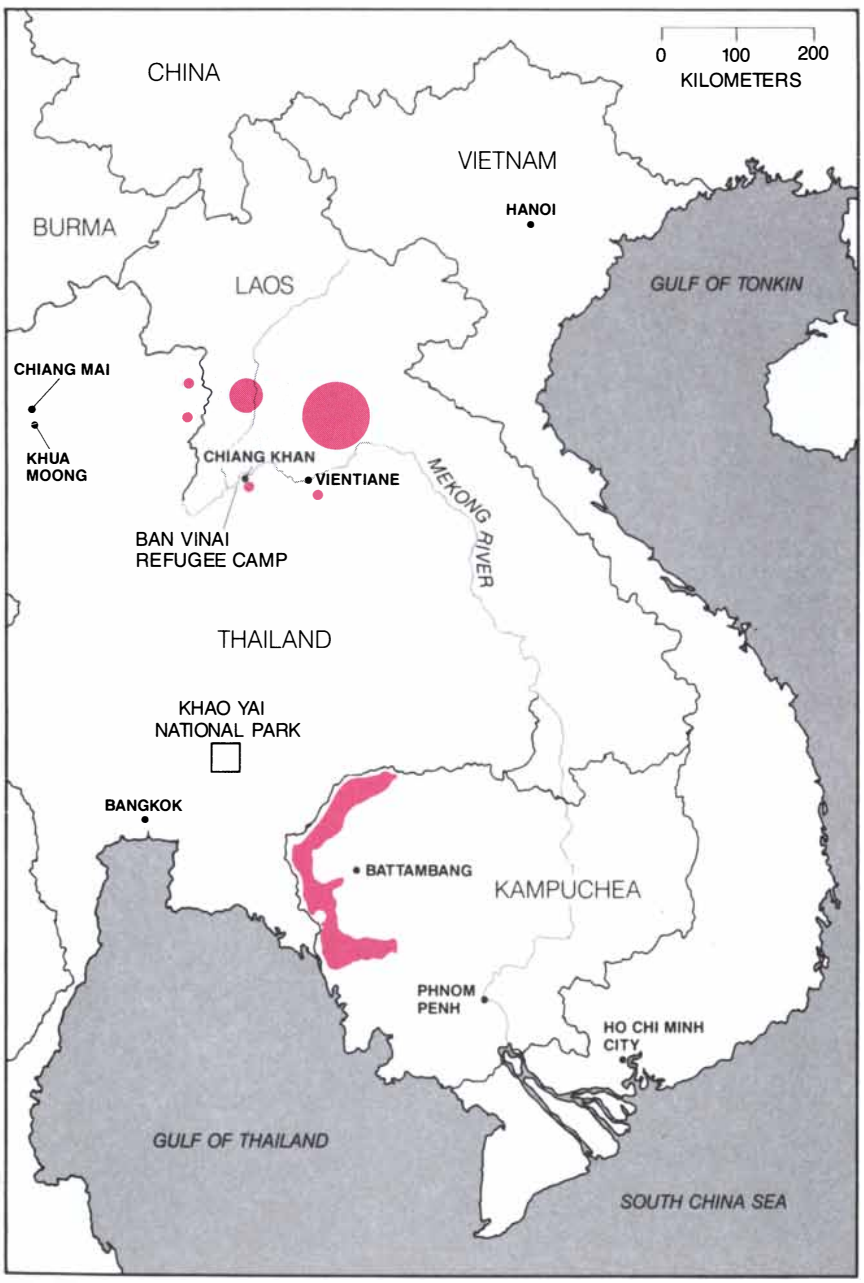
craft sprays and artillery fire. Notwithstanding the many samples of yellow rain that have come out of Laos and Kampuchea, no chemical munition or fragment has ever been obtained.

Sixty percent of the respondents report deaths. Nevertheless, the set of symptoms described as common in the Haig report is rarely seen. For example, only 8 percent of the respondents report having bloody vomiting, 10 percent report having bloody diarrhea and 21 percent report having rashes or blisters. If all the interviews are counted in which a symptom is cited, whether in the respondent or in others, the frequency of each symptom is still less than 25 percent. Only eight of the 217 people interviewed reported the three symptoms in combination, either in themselves or in other alleged victims. Remarkably, the frequency of reported illness is as high among respondents who describe arriving at a site after an attack as it is among respondents who were allegedly exposed directly.

One cannot dismiss the accounts of sickness and death, but one must be aware of the ambiguities in the interviews before interpreting them as evidence for chemical warfare. One main weakness in accepting the reports in the interviews at face value is the difficulty of distinguishing phenomena that are merely associated with one another by the respondents from phenomena that are causally interrelated. According to the interview reports, aircraft, yellow deposits, sickness and death were all observed on many occasions. Whether some of these phenomena caused the others, however, must be open to doubt. Indeed, as we shall discuss below, there is strong evidence that aircraft had nothing to do with the appearance of the yellow deposits and that the yellow material is not harmful to people.

There are other reasons to be skeptical about the interview reports. Almost all the interviews were done with refugees in camps who were selected in advance because they said they had been victims or witnesses of chemical attacks. Randomly chosen refugees from the same villages, who might have provided cross-checks, were not sought out. Both the respondents and their interpreters were aware that the purpose of the interviews was to gather information about chemical warfare, and no controls were employed to make sure they did not try to accommodate their responses to the categories and expectations of the Western investigators. Even the interviewers themselves were not free of unintentional bias. Their questioning often presumed the existence of chemical warfare, and they did not probe for alternative explanations. Solid conclusions about the occurrence of chemical warfare cannot be drawn from the evidence in the interviews.

There are several earlier cases in which sickness and death in Southeast Asia may have mistakenly been attributed to unusual materials from the sky. One example is reported in a 1972 study of the effects of herbicides in Vietnam, which was conducted for the Department of Defense by the National Academy of Sciences (NAS). According to this study, Vietnamese Montagnards interviewed in refugee camps attributed diarrhea, vomiting, skin rash, fever, dizziness, the coughing of blood and many deaths to the spraying of herbicides on or near their villages. Exposure to each of three different herbicides was reported to cause sickness and death, although none of these herbicides would be expected to have such severe effects. Moreover, a simultaneous study by the NAS showed that lowland Vietnamese exposed to the same herbicides rarely claimed such serious effects. It is likely that the reports of sickness and death among



REGIONS OF ALLEGED CHEMICAL ATTACKS are shown on the map in color. Most of the allegations have come from Hmong refugees in the Ban Vinai refugee camp in Thailand. In the forest of the Khao Yai National Park three of the authors (Akratanakul, Meselson and Seeley) found swaths of honeybee feces that closely resemble samples and descriptions of yellow rain. The three were caught in a fecal shower in the village of Khua Mọong.

DATE OF ATTACK	DISSEMINATION SYSTEM	CHEMICAL AGENT	VOMITING	DIARRHEA	CHEST PAIN	RASHES OR BLISTERS	BLEEDING	DEATHS
OCTOBER 1977	ROCKET	YELLOW-GREY CHEMICAL	(+)					25
1978	BOMB	YELLOW CLOUD						SOME
FEBRUARY 1978	UNSPECIFIED	YELLOW RESIDUE			(+)	(+)	(+)	500
FEBRUARY 1978	BOMB	YELLOW RESIDUE					(+)	7
MARCH 1978	UNSPECIFIED	YELLOW DROPS			+			5
SPRING 1978	UNSPECIFIED	YELLOW SPLOTCHES	+	+	+	+	(+)	0–2
MAY 1978	4 BOMBS	YELLOW DUST						18
MID–1978	6 ROCKETS	RED GAS						SOME
JUNE 1978	ROCKET	YELLOW-RED RESIDUE	(+)		(+)	(+)		10–30
JUNE 1978	UNSPECIFIED	YELLOW GAS	(+)	(+)				90
OCTOBER 1978	8 ROCKETS	YELLOW-GREY FOG						ABOUT 150
OCTOBER 1978	4 ROCKETS	YELLOW CLOUD						8,000
OCTOBER 1978	ROCKET	RED GAS						0
NOVEMBER 1978	UNSPECIFIED	YELLOW AND BLUE GAS		+	+			80
NOVEMBER 1978	ROCKET	YELLOW GAS						29
NOVEMBER 1978	BOMB	YELLOW RAIN						2
1978 AND 1979	UNSPECIFIED	YELLOW RAIN	(+)					40
APRIL 1979	SACKS	RED-BROWN RESIDUE			+			4
APRIL 1979	UNSPECIFIED	YELLOW RAIN						20–30
APRIL 1979	UNSPECIFIED	YELLOW-BROWN RAIN	+	+	+	+		3
APRIL 1979	UNSPECIFIED	YELLOW SPOTS	(+)	(+)		(+)		2
MAY 1979	UNSPECIFIED	YELLOW RESIDUE	+	+	+	+		SOME

EARLY INTERVIEWS with Hmong refugees who said they had witnessed chemical warfare in Laos are summarized in the table. The interviews were done in June, 1979, by officials of the State Department. Symptoms reported by the refugees are designated by a plus sign; if the symptom was reported only in people other than the respondent, the plus sign is in parentheses. The summaries are arranged chronologically according to the date of the alleged attack. The interviewers were given samples of the alleged chemical agent from two of the attacks, namely the fourth and the last entries in the table. These samples were yellow spots on pieces of vegetation.

Montagnard refugees can be traced in part to endemic diseases and in part to hearsay and exaggeration. Medical symptoms and deaths attributed to yellow rain may have a similar genesis.

In principle, chemical analysis of samples collected from the sites of alleged attacks could lead to firm conclusions about the occurrence of chemical warfare. In support of its conclusions the State Department has often cited reports of trichothecenes in environmental and biomedical samples. The U.S. Army and two university laboratories have tested a combined total of about 100 environmental samples from alleged attack sites in Laos and Kampuchea for trichothecenes. Trace amounts of trichothecenes have been reported in six of these samples, all collected in 1981 and 1982. Furthermore, the trichothecene *T*-2 or its metabolite *HT*-2 have been reported in the blood, urine or tissues of 20 people, all said to have been exposed to chemical attack in 1981, 1982 or 1983. The Army has not examined any of the biomedical samples, and so it can provide no confirmation for the positive test reports. There is a serious conflict, however, between the Army's results for the environmental samples and the ones cited by State.

All the positive reports for trichothecenes have come from the two university laboratories. Chester J. Mirocha of the University of Minnesota tested six environmental samples from alleged attack sites, sent to him from the CRDC by way of the Armed Services Medical Intelligence Center at Fort Detrick, Md. Mirocha reported that five of the six samples were positive for trichothecenes; they include a sample of vegetation, a water sample and three samples of material scraped from rocks and vegetation. Mirocha's analyses were the earliest ones done for trichothecenes, and they included the analysis on which Secretary Haig based his charge. Joseph D. Rosen of Rutgers University analyzed one sample, a yellow material obtained by the television-news organization of the American Broadcasting Company (ABC Television News), and he reported that the sample was positive.

On the other hand, since late in 1982 more than 80 environmental samples from alleged attack sites in Laos and Kampuchea have been analyzed for trichothecenes by the Army laboratory, and not one of them has been found to contain the toxins. There is little doubt about the Army's ability to detect trichothecenes: control samples intentionally contaminated with trichothecenes have consistently yielded positive test results. Moreover, like the six environmental samples reported as being positive for trichothecenes by the university laboratories, most of the samples analyzed by the Army were vegetation, water or yellow materials scraped from rocks and leaves. About 50 of the Army's samples were collected in 1981 and the rest later.

One of the environmental samples that Mirocha reported as being positive has also been tested by the CRDC. The sample is a yellow material scraped from rocks in Laos in 1981, and according to Mirocha's results, it carried the highest concentration of a trichothecene toxin reported for any of the samples: 143 parts per million of the toxin *T*-2. About a year after Mirocha's analysis the CRDC tested part of the same yellow material from which Mirocha's sample had been taken. The Army found no trace of *T*-2.

Such gross divergence in the test results for trichothecenes—six out of seven positive, 80 out of 80 negative—cannot plausibly be explained by statistical errors in sampling. Instead it raises a number of serious and still unanswered questions: How long would the toxins be stable and detectable in the relevant samples? Could the positive test results somehow be caused by experimental artifacts? Can one be assured of the authenticity and the integrity of the samples? Without answers to these questions the analyses of the samples cannot be accepted as evidence that chemical warfare was waged with trichothecene toxins.

The third category of evidence cited in support of the chemical-warfare theory consists of the frequent descriptions and many samples of the yellow

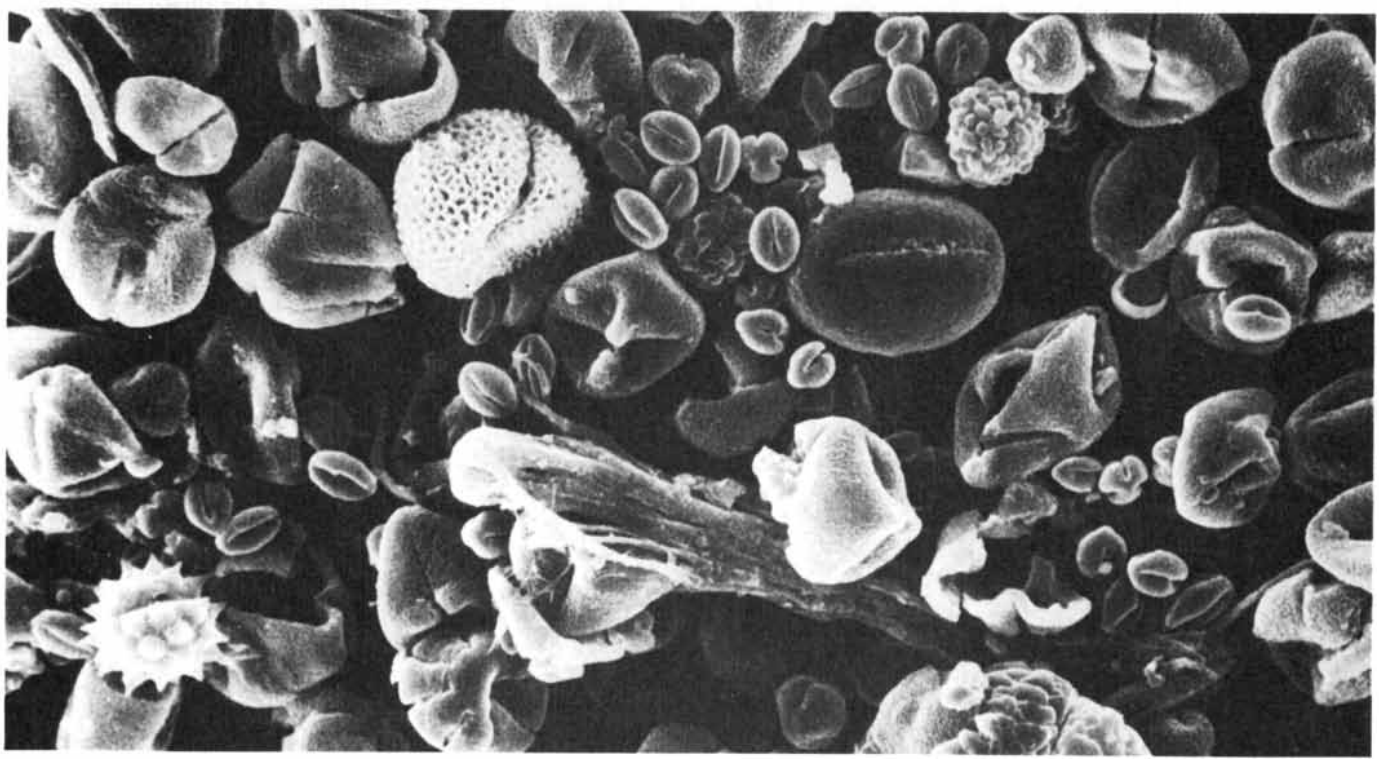
substance said by the refugees and presumed by the Government to be a chemical-warfare agent. According to various Government reports, including the reports to Congress by secretaries Haig and Shultz, the substance is a "yellow rain-like material" that falls to form "sticky yellow spots" that soon dry to a powder. Since 1979 dozens of samples have been given to American, British, Canadian and other officials.

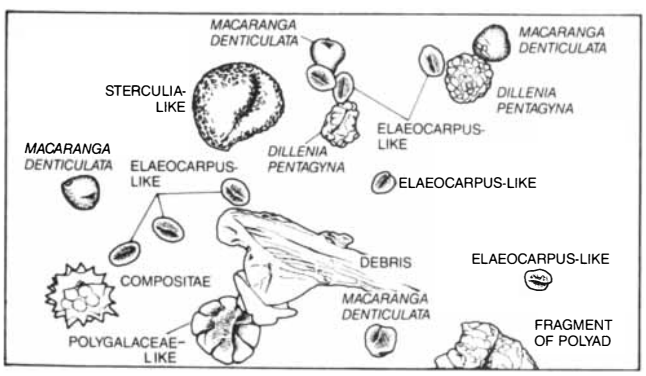
In January, 1982, investigators at the British Chemical Defense Establishment in Salisbury, England, found that samples of yellow rain contain large amounts of pollen. Soon afterward the same discovery was made independently by workers at Mahidol University in Bangkok and at Agriculture Canada in Ottawa. The findings have been confirmed for samples from at least 30 alleged attacks in Laos and Kampuchea, including samples given to the U.S. investigators in 1979. According to Emory W. Sarver of the CRDC, "most of the samples that are of yellow rain are fairly dry and they have a high level of pollen grains in them." To the best of our knowledge all the samples of the yellow material examined under the microscope have, without exception, been found to consist primarily of pollen.

The reasons for adding pollen to a chemical-warfare agent are obscure, and they have not been adequately explained by the proponents of the chemical-warfare theory. In a briefing held in November, 1982, and distributed by the U.S. Information Agency, Gary Crocker of the State Department notes that the particles of pollen are not windborne but rather are "the type of thing a honeybee would take from flowers." The physical introduction of pollen into the alleged chemical agent would then presumably require that pollen gathered by honeybees be harvested, mixed with fungal toxins and dispersed from weapons. Neither the logistics of the enormous harvesting operation required to account for the quantities of pollen that would be needed nor the significance of the kinds of pollen found in the samples is addressed by that hypothesis. We shall have more to say on this point.

In the same 1982 briefing Sharon A. Watson of the U.S. Armed Forces Medical Intelligence Center suggested a role for the pollen in the chemical agent: "The agent, as it comes down, is wet, and at this time the primary exposure appears to be through the skin.... But as the agent dries, a secondary aerosol effect can be caused by kicking up this pollen-like dust that is of a particle size that will be retained in the bronchi of the lung." Watson's explanation is faulty on two counts. First, a relatively large amount of energy is needed to form an aerosol from a congealed deposit. Second, the samples of yellow rain examined in the laboratory show no tendency to disperse.

The abundance of pollen and the lack of a plausible military explana-





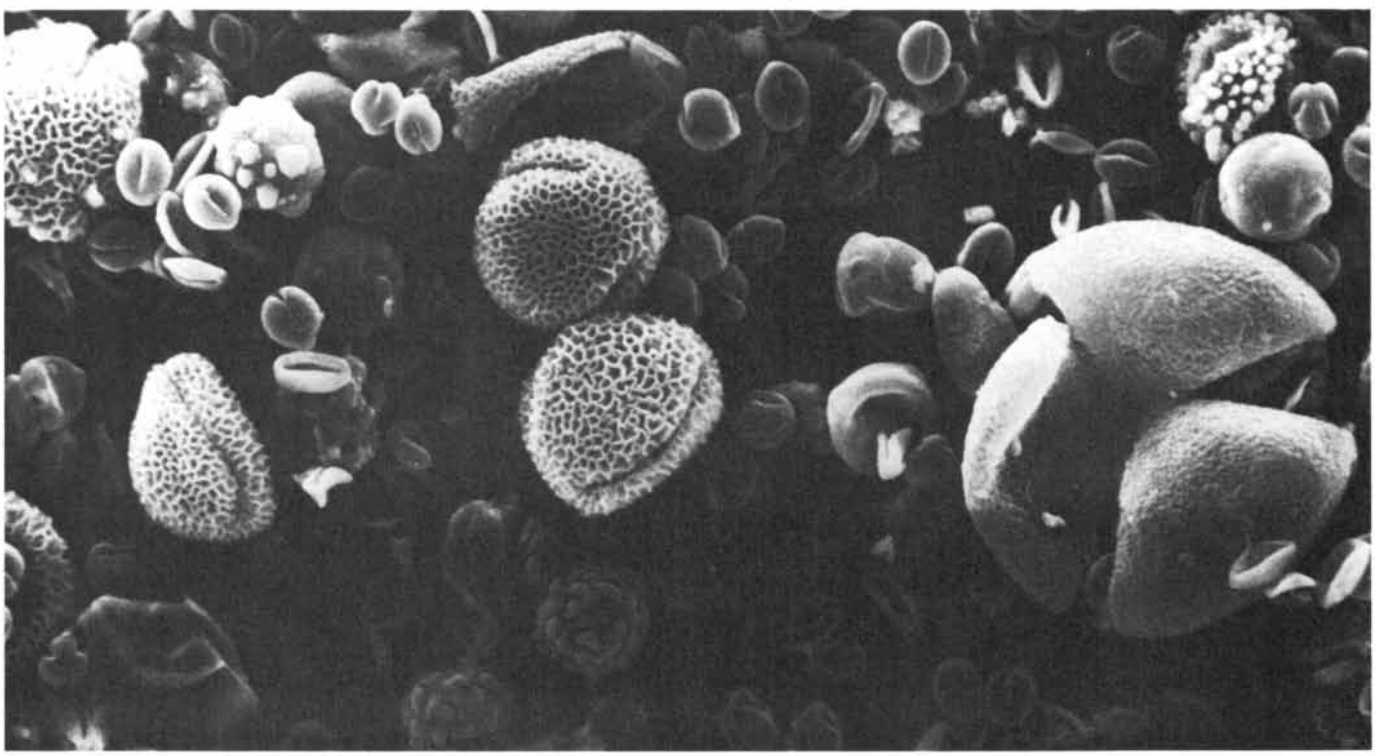
POLLEN GRAINS make up the bulk of the material both in yellow rain deposits and in honeybee feces. The scanning electron micrograph on this page shows pollen in the sample of yellow rain from Laos, obtained by ABC Television News; the scanning electron micrograph on the opposite page shows pollen from the feces of the honeybee *Apis dorsata*. Identifications and classifications of the pollen are given in the key maps. There are three types of pollen

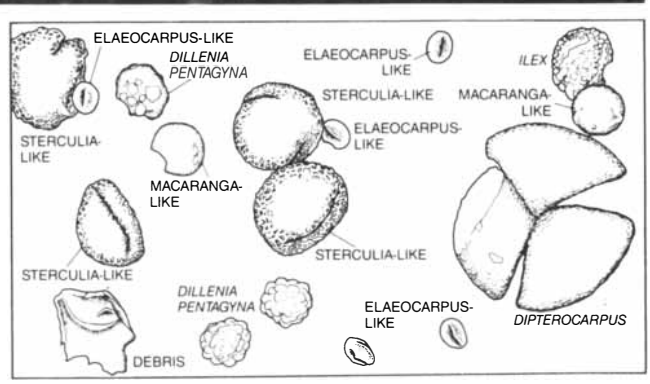
tion for its presence suggested that yellow rain has a natural origin and led us to obtain samples of yellow rain for independent examination. The samples, which were made available to us by the Canadian government, include leaves and pebbles, each spotted with one or more yellow deposits. They were given to Canadian diplomatic personnel in Thailand by Hmong refugees, who said they had gathered the samples in late March or early April, 1982, at the sites of two chemical attacks in Laos. We have also examined a sample of yellow material obtained by ABC News and said to have been scraped from vegetation by Hmong soldiers at a site of an alleged chemical attack in Laos in March, 1981. The ABC News sample is the same one that was analyzed by Rosen, who reported it to contain 48 parts per million of *T*-2, in addition to other trichothecenes.

In April, 1983, Carl Kaysen of the Massachusetts Institute of Technology, Stewart Schwartzstein of the Institute for Foreign Policy Analysis and one of us (Meselson) assembled a conference in Cambridge, Mass., to discuss the evidence for chemical warfare in Southeast Asia, with particular emphasis on the source and composition of yellow rain. The conference participants included experts in anthropology, botany, chemical warfare, chemistry, medicine and mycology as well as officials from the U.S. Army and the State Department. Peter M. S. Ashton of Harvard University made a crucial observation at the meeting. Preliminary analysis published by the Australian Department of Defense in Canberra showed that the plant families represented in the yellow rain pollen could be identified with certain families strongly represented in Southeast Asia. Ashton pointed out that the flowers of these plant families are frequently visited by bees.

If yellow rain has a natural origin, Ashton's observation raised an important question: How could the pollen come to be highly concentrated in rain-like spots on rocks and leaves? The puzzle led Ashton to approach one of us (Seeley), who is an expert on the behavior and ecology of honeybees. Seeley noted that the Government's description of yellow rain is an accurate description of the fecal droppings of honeybees. Like yellow rain, the feces take the form of small, yellow, pollen-filled spots that dry to a powder.

To test the hypothesis that yellow rain is the feces of Asian honeybees we began a series of comparisons between yellow rain and bee feces. Fred Dyer, then a graduate student at Princeton University, was in India at the time studying Asian honeybees. Dyer sent us fecal deposits of *Apis cerana* and *Apis dorsata,* two of the three Asian species of honeybees. Yellow rain is of course most often described as yellow, but according to witnesses, its color also varies from pale yellow through shades of yellowish brown





visible in the electron micrograph of yellow rain that match grains seen in the micrograph of bee feces: the Elaeocarpus-like grains, which are the smallest grains and the most numerous; the Sterculia-like grains, which have a reticulate surface, and the grains of *Dillenia pentagyna,* which have a clumpy, irregular surface. The scanning electron micrographs were made by one of the authors (Nowicke); the magnification of each micrograph is 950 diameters.

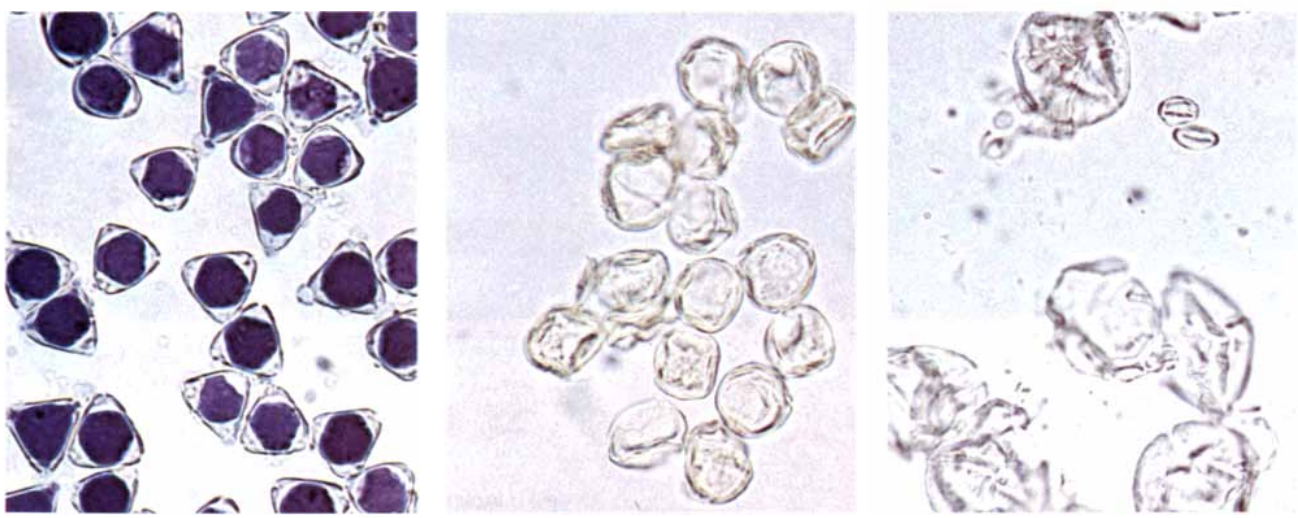
POLLEN TYPE	SAMPLES OF YELLOW RAIN								FECES OF HONEYBEE *APIS DORSATA*		HONEY FROM CHIANG KHAN, THAILAND
	ABC NEWS	LEAF 3, SPOT A	LEAF 3, SPOT B	LEAF 4, SPOT A	LEAF 4, SPOT B	LEAF 5, SPOT A	LEAF 5, SPOT B	ROCK	CHIANG MAI, THAILAND	KHAO YAI NATIONAL PARK	
AQUIFOLIACEAE *ILEX*		⦿		○	○	○	○		○	○	
COMPOSITAE	○								○		
DILLENIACEAE *DILLENIA HOOKERI* *DILLENIA PENTAGYNA*	○ ○									○ ○	○ ○
DIPTEROCARPACEAE *DIPTEROCARPUS*										○	
ELAEOCARPACEAE ELAEOCARPUS-LIKE	⦿									⦿	⦿
EUPHORBIACEAE *MACARANGA DENTICULATA* MACARANGA-LIKE	⦿	⦿		●	⦿	⦿	⦿			⦿	
FAGACEAE-LIKE			●					⦿	○		○
GRAMINEAE									●		
ICACINACEAE *APODYTES*	○	⦿		○	●	⦿	○				
MELASTOMATACEAE	○	⦿		⦿	⦿	○	⦿				○
STERCULIACEAE STERCULIA-LIKE	○									⦿	

○ MINOR COMPONENT, LESS THAN 5 PERCENT OF POLLEN GRAINS IN SAMPLE

⦿ 5–50 PERCENT OF POLLEN GRAINS IN SAMPLE

● MORE THAN 50 PERCENT OF POLLEN GRAINS IN SAMPLE

POLLEN TYPES in samples of yellow rain from Laos and in samples of honey and honeybee feces from Thailand are listed in the table. Pollen types not identified in the samples are not included in the table. The ABC News sample of yellow rain is one of six environmental samples reported to contain trichothecenes, which are toxic substances produced by certain fungi. It was collected by a Hmong soldier at the site of an alleged chemical attack in 1981. The leaf and rock samples were collected by a group of Hmong at two sites of alleged attack in 1982. The six leaf samples represent two spots on each of three leaves. Spot *B* on leaf 3 is made up almost entirely of Fagaceae-like pollen, a type that is absent from spot *A* on the same leaf. The remaining leaf spots include similar pollen types but in quite different proportions. Such diversity of pollen from spot to spot would not be expected from a manmade spray. The rock sample was obtained from rocks with yellow spots. The samples of bee feces were made by pooling several spots scraped from leaves by the authors. All the pollen types identified in yellow rain are from plant families common in Southeast Asia. The table shows these types are also present in honey and in the feces of *Apis dorsata,* which demonstrates that the pollen types in yellow rain are gathered by indigenous honeybees.



PRESENCE OF PROTEIN in pollen grains is indicated by the dye Coomassie Brilliant Blue. Protein is digested out of the grains by enzymes in the intestinal tract of the bee, and so pollen grains that have passed through a bee do not stain in the presence of the dye. The pollen grains in the photomicrograph at the left were gathered and stored (but not eaten) by the honeybee *A. dorsata;* they stain a deep blue. In the photomicrograph in the middle are pollen grains from the feces of *A. dorsata* that were also treated with the dye; they do not stain. In the photomicrograph at the right are pollen grains in the ABC News sample of yellow rain. None of the grains in the right photomicrograph are stained by the dye, just as one would expect if the yellow rain sample is made up of bee feces. The photomicrographs were made by Phillip M. Rury of Harvard University; the magnification in all three photomicrographs is 520 diameters.

and reddish brown. Our own samples of yellow rain confirm this distribution of colors, and the distribution matches that of the Asian honeybee feces we received from India.

As we noted above, the average diameter of the spots of yellow rain that are reported to fall on alleged attack sites is about three millimeters, and they range from two to six millimeters across. The average diameter of the spots of yellow rain made available to us by the Canadian government is 3.2 millimeters, and the standard deviation of the distribution is one millimeter. The measurement is indistinguishable from the average diameters we measured for the fecal deposits of the two honeybee species we received from India.

Both honeybee feces and samples of yellow rain include high concentrations of pollen: approximately a million pollen grains per milligram. The pollen makes up about half of the volume of the material, and it is held in a coherent mass by an amorphous matrix that is only partially soluble in water. Bee hairs and bits of fungi are minor components both in samples of yellow rain and in bee feces.

We also tested the pollen grains in yellow rain for the presence of protein. It is known that when pollen passes through the digestive system of the bee, the contents of the pollen, including the protein, are digested out of it. On the other hand, pollen that does not pass through the bee retains its protein intact, and such pollen stains a deep blue in the presence of the dye Coomassie Brilliant Blue. We found that freshly gathered pollen, pollen taken from stores in the nests of bees and pollen from honey all stain deeply, which indicates a high protein content. In contrast, most of the pollen grains in bee feces are not stained by the dye. What is significant, the pollen found in our samples of yellow rain was not stained either, just as if it had been digested by bees. It would seem that in order to accept the chemical-warfare theory of yellow rain in the face of this evidence one would have to imagine an enemy so devious that its chemical weapon is prepared by gathering pollen predigested by honeybees.

The most detailed evidence for the origin of yellow rain is derived by analyzing scanning electron micrographs of the pollen it contains. Pollen grains carry the male genetic material for all plants that reproduce from seed. Almost all such grains have apertures, or thin, preformed areas in the grain wall, which allow the sperm nuclei to be released. The size of the grain, its surface sculpture and the shape and number of apertures on its surface can be highly specific for the taxon, or plant group, from which it comes. In combination such features can make it possible to distinguish pollen from different genera within the same plant family and, in some cases, to distinguish pollen from different species within the same genus. Since botanists recognize more than 200,000 species of flowering plants, pollen analysis can sometimes give specific information about the source of the materials that contain the pollen.

What happens to the distinctive appearance of the pollen grains when honeybees eat them? Typically the pollen is first gathered by older bees and stored in the nest. The young adult bees then eat it, whereupon most of the interior of the grain, including fats and protein, is digested by the bee. The exine, however, which is the outer shell of the grain, is indigestible and passes into the feces. The morphological characteristics relied on to identify pollen are largely unaffected by the bee's digestive system.

One of us (Nowicke), assisted by Janice Bittner, also of the Smithsonian Institution, has analyzed the pollen in the Canadian samples and in the ABC News sample of yellow rain. The work yields three important conclusions. First, all plant taxa that have been identified from the pollen in yellow rain are common in Southeast Asia, and their habitat is compatible with ecological conditions near the sites of the alleged chemical attacks. Second, many of the pollen types found in samples of yellow rain match the types found in honeybees, in honeybee feces collected in Thailand and in samples of honey collected in the mountains of northern Thailand and along the Thai-Laotian border. The presence of yellow rain pollen types in bees and bee feces validates the implication of our protein-stain experiment: the pollen was indeed gathered by Southeast Asian honeybees.

Third, no two spots of yellow rain that have been examined, not even adjacent spots on the same leaf, have the same mixture of pollen types. Instead there are wide variations from one spot to another. Such diversity in the composition of the pollen from spot to spot is characteristic of honeybee feces, but it would not be expected from a manmade mixture. Thus laboratory examination of the yellow rain samples, including the ABC News sample that reportedly contains trichothecene toxins, has provided detailed evidence that yellow rain is honeybee feces.

At this stage in our investigation it still remained an open question whether honeybee defecation could account for one of the central claims made by the refugees, namely that the alleged chemical-warfare agent falls in light showers like rain. We knew that honeybees do not normally defecate in their nests; instead they do so in flight. Indeed, beekeepers in temperate climates are familiar with the massive defecation flights of the European honeybee *Apis mellifera* on the first warm days of spring. The behavior is attributed to the bees' need to defecate after the long period of enforced confinement during cold winter weather. In the Tropics, however, such synchronized cleansing flights were not necessarily expected, and none had been reported in the scientific literature.

After proposing that yellow rain is the feces of Asian honeybees, we learned of a report published in China that described massive showers of bee feces in northern Jiangsu Province in September, 1976. The local population could not determine the cause of the phenomenon, and so it was brought to the attention of the geology department at Nanjing University. According to the report by Zhang Zhongying and his colleagues, the showers must have been extraordinary: they generally lasted for several minutes, and they deposited yellow spots rich in pollen over areas of from .2 hectare to six hectares. The spots ranged in diameter from two to six millimeters.

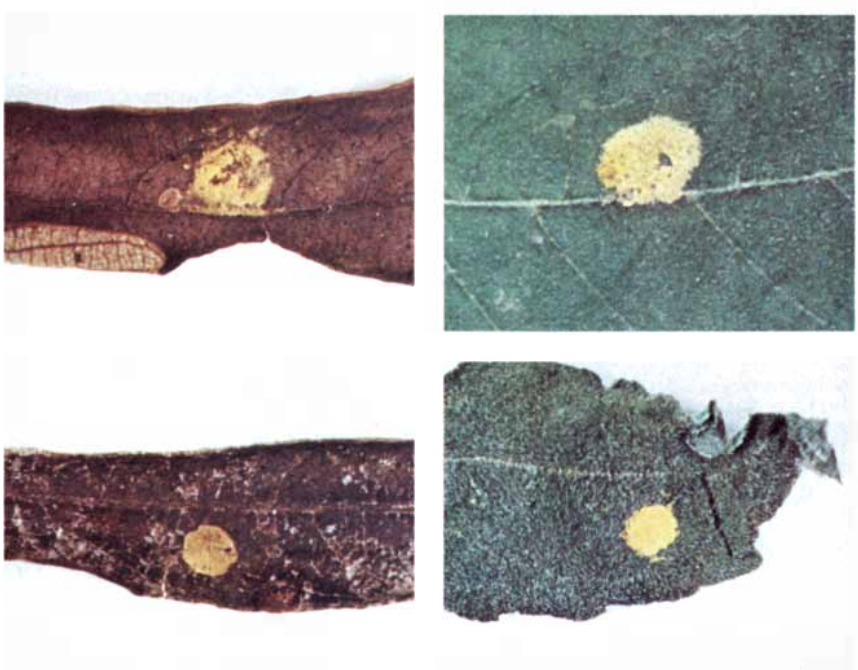
It is significant that no one who witnessed the showers reported seeing any bees overhead. The deposits were only later identified as honeybee feces through examination in the laboratory. The bee species was not identified, but the bees may not have been native: *A. mellifera* had been introduced into the region for the commercial production of honey some time before the cleansing flights were noticed. Nevertheless, the occurrence of massive cleansing flights in September showed that they need not take place only after a long period of cold weather.

To determine whether honeybees indigenous to the Tropics of Southeast Asia also make such massive cleansing flights, three of us (Akratanakul, Meselson and Seeley) undertook a field study in Thailand in March, 1984. The bees we observed were mainly *A. dorsata,* one of the species of Asian honeybees and one of the two species whose fecal deposits we had already studied in the laboratory. The worker bees of *A. dorsata* are the largest workers among the Asian honeybees, and they usually build nests that hang from the limbs of tall trees in forests and villages. Typically the population of a nest is between 30,000 and 50,000 bees, and there is often more than one

nest in a single bee tree. Exceptional trees have as many as 100 nests.

We examined 10 nesting sites of *A. dorsata:* nine were in trees and one was under the eaves of a building. We found leaves, rocks or both spotted with honeybee feces at all the nesting sites. On horizontal surfaces the spots were circular; their average diameter was 3.2 ± .9 millimeters. The color of the spots on young leaves ranged from white through yellow to shades of brown and brownish red, although yellow was strongly predominant. The texture of the spots varied from waxy to powdery. At two nesting sites the air was particularly hot and dry, and there were no spots on the younger leaves of the vegetation. The absence of spots showed that the defecation flights had stopped at least several weeks earlier, even though at one site the bees were still foraging. We found recently fallen feces, including moist, sticky deposits, at all the other eight nesting sites.

***APIS DORSATA*, the giant Asian honeybee, is seen on the surface of a nest. Between 30,000 and 50,000 bees inhabit a typical nest, and often more than one nest is found in a tree.**



YELLOW RAIN and honeybee feces leave deposits that are indistinguishable to the eye. The spots on the leaves in the photographs at the left are the deposits made by yellow rain; the leaves were turned over to Canadian government officials in Thailand in April, 1982, by Hmong refugees. The refugees said they had collected the leaves at the site of a chemical attack in Laos the month before. The spots on the leaves in the photographs at the right are the fecal deposits of the Southeast Asian honeybees *Apis cerana* (*upper right*) and *A. dorsata* (*lower right*). The spots vary on the average from three to five millimeters in diameter.

We devoted our closest study to a site about 800 meters above sea level in the forest of Khao Yai National Park, where two of us (Akratanakul and Seeley) had investigated the behavior of honeybees in 1979 and 1980. The park includes 2,200 square kilometers of largely undisturbed evergreen forest in the mountains 120 kilometers northeast of Bangkok. The nesting site was a dead dipterocarp tree; hanging from a limb of the tree were three large nests of *A. dorsata* about 20 meters above the ground. A swath of yellow-spotted vegetation about 40 meters wide extended from near the base of the tree out to a distance of about 160 meters. The long axis of the swath followed a partial opening in the forest canopy, which ran downhill toward a valley about five kilometers away where the bees were probably foraging. Directly under the nests and out to about 20 meters from the tree the density of the spots in the swath was low, but it then increased sharply to a density of about 100 spots per square meter. The density remained at roughly this level out to about 120 meters from the tree before it finally began to decline. Our counts represented only two days' accumulation of spots because they were done following an unseasonably heavy rainstorm that had washed away most of the older deposits.

The mere observation of a fecal swath does not determine whether the deposition takes place as a distinct shower or as an intermittent spattering that occurs over a relatively long time. A shower would of course be compatible with the refugees' description of yellow rain. To resolve the question we placed six large sheets of white paper in various exposed places between 40 and 140 meters from the nesting site, near the center axis of the swath. We examined the sheets of paper periodically one morning between 7:00 A.M. and 12:30 P.M. Sometime between 9:00 and 9:35 A.M. there was a fecal shower. All six sheets registered the shower, and the average density of spots was 29 per square meter. If our samples were typical of the entire swath, the fecal shower must have covered at

least 6,000 square meters and deposited more than 100,000 spots.

We found that each spot on the sampling sheets included copious quantities of pollen. There were from 100,000 to a million pollen grains in a typical spot, just as there are in spots of yellow rain. We made scanning electron micrographs of the pollen in 10 of the spots and found there were different and sometimes widely varying mixtures of pollen in each spot. Two of the pollen types, which for convenience we call Elaeocarpus-like and Sterculia-like, match grains we had already seen in samples of yellow rain, including the ABC News sample. Indeed, most of the pollen types we identified in yellow rain are also found in samples of honey and feces of *A. dorsata* from Thailand.

During the shower recorded in Khao Yai National Park we were outside the swath, and so we could only conclude that the shower had lasted for no more than 35 minutes. Later we were actually caught in a fecal shower. We were visiting a region known for bee trees in which an unusually large number of nests are suspended. In the village of Khua Moong, about 20 kilometers south of Chiang Mai in Thailand, we examined the area around two such trees, one bearing about 30 nests and the other more than 80, hanging from 20 to 50 meters above the ground. As we observed the second tree through binoculars from a clearing about 150 meters away, we saw a lightening in the color of several nests. Hundreds of thousands of bees were suddenly leaving their nests. Moments later drops of bee feces began falling on and around the three members of our party. About a dozen spots fell on each of us. We could neither see nor hear the bees flying high above us.

The shower began at 5:17 P.M. and lasted for approximately five minutes. The density of the spots on the hood and roof of our parked Land Rover was 209 per square meter. The fresh deposits were sticky, and they varied in size and color much like the spots we collected at Khao Yai National Park. Our observations showed that showers of honeybee feces do indeed occur in the Tropics of Southeast Asia; moreover, the showers and spots closely resemble the showers and spots said to be caused by yellow rain.

We next sought to learn whether the Hmong refugees might mistake bee feces for an agent of chemical warfare. To investigate the question we went to the Ban Vinai refugee camp, where most of the interviews with witnesses of the alleged chemical attacks have been conducted. One of us (Akratanakul) speaks Lao and so we were able to question 16 groups of people we encountered at random in the camp.

We showed leaves spotted with the feces of *A. dorsata* to each group and asked them to identify the spots. Thirteen of the groups concluded they did not know what the spots were, although some people said they had seen such spots before. One group of nine people and one group of six told us the spots were *kemi*, their term for the alleged poison. The remaining group included three men, one of whom identified the spots as insect feces. No one else we encountered came as close as this man to a correct identification. After some discussion among themselves, however, the three men agreed the spots were *kemi*.

Our interviews with Hmong refugees from Laos indicate the Hmong do not generally recognize honeybee feces for what they are. Moreover, some of the Hmong identify bee feces as the alleged agent of chemical warfare.

We conclude that yellow rain is the feces of honeybees, not an agent of chemical warfare. This conclusion has emerged from many independent sources: from detailed laboratory comparisons of samples of yellow rain and bee feces, from field observations of the behavior of bees and from interviews with Hmong refugees. Bee fecal deposits account for all the consistently reported features of the deposits left by yellow rain, including their color, size and texture, their deposition in showers and their high pollen content. They also account for the results of our detailed pollen analysis and other laboratory tests.

A single clear discrepancy between yellow rain and bee feces, such as a mismatch between the average diameters of the two classes of spots, would naturally have forced us to reconsider our hypothesis. No such discrepancy has been found. In contrast, to support the hypothesis that yellow rain is a chemical-warfare agent one must invoke an entire series of unsupported suppositions. The chemical-warfare theory even fails to explain such striking properties of yellow rain as the presence and the variety of pollen in the samples.

It cannot be proved that some kind of chemical warfare has not taken place. The evidence for it, however, from interviews with alleged witnesses as well as from the chemical analysis of samples, is ambiguous and conflicting. We are reasonably confident about the origin of the alleged chemical agent itself, the yellow rain: it is a phenomenon of nature, not of man.

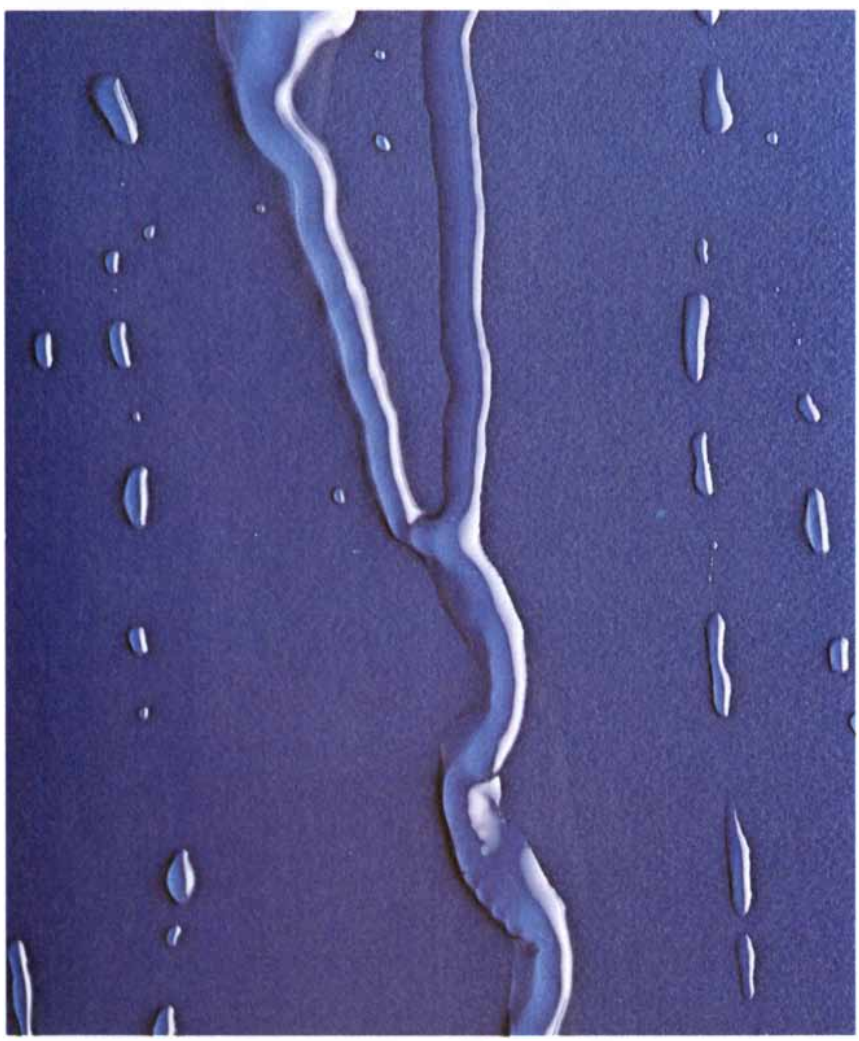
THE AMATEUR SCIENTIST

What forces shape the behavior of water as a drop meanders down a windowpane?

by Jearl Walker

A windowpane speckled with rain offers two subtle puzzles in the physics of fluids. How do the drops cling to the glass? When water runs down the glass in a stream, why does it often meander instead of going straight?

The clinging of drops is often attributed to the surface tension of water, yet under a common definition of surface tension the drops should not cling. Meandering is often attributed to contamination on the glass, yet contamination seems unlikely to account for the normally regular pattern of a meandering stream.



Drops of water and a meander on a sheet of Plexiglas

Imagine a small drop of water on a solid horizontal surface such as a piece of glass. If the drop does not spread over the surface as a film, it forms a roughly hemispherical, slightly flattened bead. The shape is determined in part by the mutual attraction of the water molecules; that force acts to minimize the surface area. The surface is effectively a stretched, elastic membrane.

Usually the tendency to minimize the surface area is described in terms of tension on the surface of the drop. Imagine a line running across that surface. The surface tension is represented by forces that pull perpendicularly to the line, causing it to be in a state of tension. The surface tension of the water is defined as the ratio of the force pulling on one side of the line to the length of the line.

The perimeter of the contact area between the drop and the solid surface is called the triple-phase line because of the conjunction of water, air and solid. The angle at which the water touches the solid at the triple-phase line is called the contact angle. It is measured between the solid and a tangent to the water surface. If the contact angle is less than 90 degrees, the water tends to spread over the solid and is said to wet it. If the angle is more than 90 degrees, the water pulls itself into a bead and does not wet the solid.

In the early part of the 19th century Thomas Young, who is remembered for his pioneering work on optical interference, stated that the size of the contact angle is set by the tendency toward equilibrium of three tensions pulling on the triple-phase line. The tension of solid and water pulls in one direction along the interface between the solid and the water in what is properly called an interfacial tension. The tension of solid and air pulls in the opposite direction. The surface tension of the water pulls along a tangent to the surface of the water.

The horizontal component of the pull from the water's surface tension is, say, rightward and its size depends on the cosine of the contact angle. According to Young's argument, if the triple-phase line is in equilibrium, so that the drop is neither spreading nor contracting, the net horizontal force on the line must vanish. A specific value of the contact angle results in a balance of the horizontal forces on the line.

Young's argument is simple, but no one has verified it experimentally. Moreover, measurements of the contact angle of water on a solid surface

differ among investigators. Hence Young's theory is open to question. Indeed, the common observation that water drops often cling to a windowpane is ample evidence that the theory is wrong.

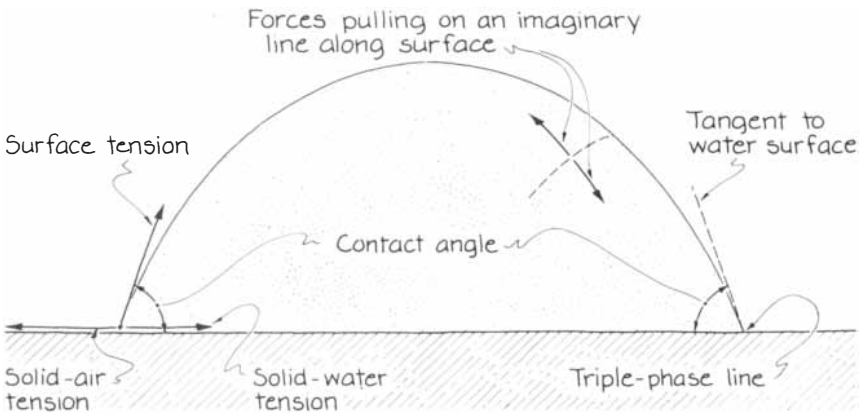
One flaw in the theory is that no one has yet demonstrated how the surface of a solid can be in a state of tension of the kind required by Young. The concepts of the tension of solid and water and of solid and air are therefore in doubt, and so is the existence of a three-phase line. A better model might embody a three-dimensional zone in which the shape of the water surface within a few molecular widths of the solid surface may be quite different from what can be inferred with simple measurements.

You can readily demonstrate that Young's theory is in error by depositing a small drop of water on a horizontal plate of clean glass. According to the theory, the drop is in equilibrium and the contact angle must have a certain value. If you carefully add a small amount of water from a syringe, however, you can increase the size of the drop without making the triple-phase line move outward over the glass. The contact angle must then be larger than it was before, contrary to Young's theory. Similarly, you can remove a small amount of water from the drop to decrease the contact angle. Again the triple-phase line stays in place, contrary to the theory.

Obviously the drop is in equilibrium over a range of contact angles rather than at a single value. It spreads over the glass only when the contact angle exceeds some upper limit. It contracts only when the contact angle drops below some lower limit. After either event the contact angle is again within the range of values that make for stability. The upper limit to the contact angle is called the advancing limit, the lower one the receding limit. The ability of a drop to be in equilibrium at different values of the contact angle is referred to as the hysteresis of the contact angle. (Hysteresis describes a situation in which the forces acting on a body change but the resulting effect is delayed.)

It is hysteresis that enables a drop to cling to an inclined surface, including a vertical windowpane. Tilt the glass on which you have placed a drop. (Keep the tilt short of the amount that makes the entire drop slide.) The upper end of the drop remains in place while the lower end slides a short way down the slope. The contact angle is then small at the upper end of the drop and large at the lower end. If equilibrium resulted from only a single value of the contact angle, the drop would immediately slide down the glass.

The shape of a resting drop



Forces that act on a drop of water

Why a drop displays hysteresis is a subject of current research. One factor is the roughness of the surface holding the drop. Even glass is rough on a microscopic scale. The triple-phase line is thought by some workers to nestle in the hills and valleys of the surface. Perhaps the contact angle does have a specific value, but the microscopic tilting of the surface changes the apparent contact angle to some other value.

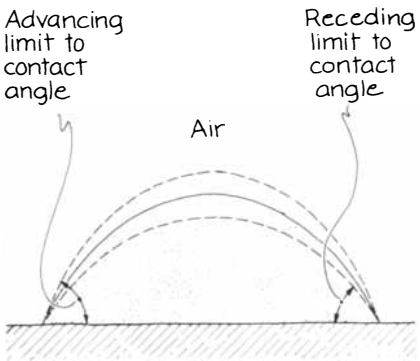
The variation in the contact angle may also be due to microscopic variations in the composition of the solid surface. Adsorbed films and other contamination would also contribute to variations in the contact angle. In some cases the triple-phase line might in fact move, but so slowly as not to be noticed.

If you tilt the glass plane enough, the drop may begin to slide downward. Much research is directed at predicting the conditions that give rise to this kind of movement. In applications such as the spraying of plant leaves one wants the drops to remain on the inclined surface even if it is appreciably tilted. In other applications one wants the drops to run off, leaving the solid surface dry.

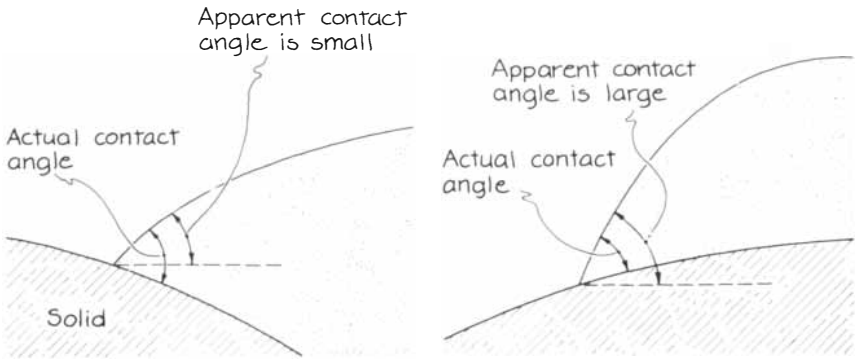
For a given size of drop what is the largest angle of tilt at which the drop will stay in place? For a given angle of tilt what is the largest drop that will cling to the substrate?

Suppose the glass is tilted enough to put the drop on the verge of sliding. The force tending to dislodge the drop is the component of the drop's weight that is directed along the glass. The force working against the slide is due to the surface tension on the drop. In the simplest model the force resisting the slide is equal to the product of the water's surface tension and the horizontal width of the drop. When you tilt the glass more, the weight component increases until it overwhelms the force due to surface tension; the drop then slides down the glass.

In another simple model the sliding begins when the weight component



Patterns of the contact angle



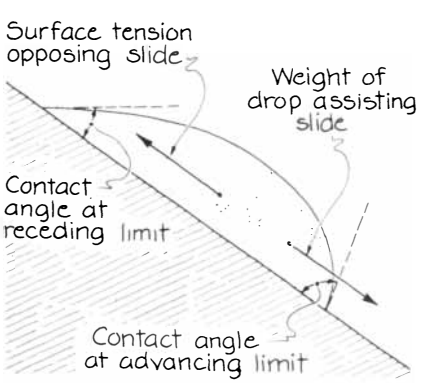
Apparent contact angles on a microscopically rough surface

causes the contact angle on the lower edge to grow beyond its advancing limit. Even more sophisticated models for resistance to sliding have been constructed by incorporating the contact angles on both the lower and the upper edges of the drop.

I investigated the behavior of a water drop on a plate of Plexiglas. Since the water was from a tap, both the drops and the Plexiglas were undoubtedly contaminated. When the plate was horizontal, the drop was a bead. As I tilted the plate the bottom of the drop slid slightly, narrowing the width of the drop. As the tilt increased, the drop began to slide down the Plexiglas, leaving a thin trail.

By tilting the plate so that some drops traveled slowly enough for me to follow them with a magnifying glass I found that the sliding consisted of a series of swift, short advances. Sometimes I spotted narrow fingers that darted ahead. I could not see what caused them. When I made a drop advance on a visible speck of contamination or even on a hair, no fingers appeared. Perhaps both the fingers and the sudden advance of an entire drop result from microscopic contamination or tiny variations in the topography of the Plexiglas.

My second puzzle concerns meandering. Since water on a tilted surface is pulled downward by gravity, the path of the stream should be straight down. Yet in many experiments the stream meanders, thus developing bends that connect relatively straight stretches slanting to one side or the other. A meander may remain stable for hours or may be so unstable that the stream thrashes over the surface like a snake. What forces give rise to meandering?



A drop in equilibrium

Much of the puzzle seems to have been solved recently by Takeo Nakagawa of Kanazawa University in Japan and John C. Scott, who was then at the University of Essex. They made a stream of water flow along a smooth plate of Plexiglas one meter long and .6 meter wide. A grid was attached to the bottom face of the plate. The slope of the plate could be varied between five and 85 degrees in five-degree increments. The water flowed from a reservoir down onto the plate through a vinyl tube whose inside diameter was one centimeter.

After the total stream length was measured from a tracing of the stream, Nakagawa and Scott computed the sinuosity, which is the ratio of the total stream length to the nonmeandering length. The depth of the stream was measured with a needle at intervals of five millimeters down the slope of the plate and one millimeter across the width of the stream. From these data the shape of the stream's cross section was constructed.

The stream, seemingly free of turbulence, emerged from the tube 20 centimeters from the top edge of the plate. To reveal the flow within a stream a hypodermic needle was used to inject a small amount of methylene-blue solution into the stream. The discharge rate of the water was kept steady by maintaining a constant head of water in the reservoir. The rate was measured by collecting the water for a certain period of time at the lower end of the plate and then weighing the water. After each experiment the Plexiglas was cleaned with soft tissues and dried for 30 minutes.

To repeat some of these experiments I built a similar apparatus. I bought a sheet of Plexiglas from a hardware store and taped it to a sturdy wood shelf so that it could not flex. The upper end of the shelf was supported by two laboratory jacks with which I could change the tilt of the Plexiglas. I measured the tilt with a protractor, attaching to it a small weight on a string so that I could keep track of the true vertical.

In a few trials I added a short length of roof gutter at the bottom edge of the Plexiglas. The water ran into the gutter and out through an opening that normally would be connected to a downspout. By timing the collection of water in a graduated beaker under the opening I computed the volume flow rate (the volume of water flowing past a checkpoint each second).

Above the Plexiglas I put a large beaker, which was continuously filled with water from a garden hose. A plastic tube ran from a side arm on the beaker to the Plexiglas, where it was taped in position with its opening facing down the slope. I kept the beaker overflowing to maintain a constant flow of water onto the Plexiglas. (I did my experiments outdoors, but a room with a floor drain would have served.) The beaker was taped to a laboratory jack so that I could vary the flow rate by altering the height of the beaker and thus the head of water.

Nakagawa and Scott discovered that when they tilted their Plexiglas more than 30 degrees, the stream formed a stable meander if the volume flow rate was between an upper and a lower limit. If the flow exceeded the upper limit, the meander was unstable and changed constantly. If the flow dropped below the lower limit, the stream broke up into drops that slid separately down the Plexiglas. Between the limits the stream always meandered.

As the tilt was increased beyond 30

degrees the value of the upper limit decreased, narrowing the range of flow rates within which the meander was stable. At a tilt of less than about 30 degrees the lower limit disappeared; consequently the meander was stable at any small flow rate. The sinuosity of the meander increased whenever either the slope of the plate or the flow rate increased.

Nakagawa and Scott measured the cross-sectional area of a stream in order to monitor the speed of the water. One can determine speed in this way because the volume flow rate through a cross section equals the product of the cross-sectional area and the average speed of the water through the cross section. Since a constant flow of water requires that the volume flow rate be the same everywhere along the stream, the cross-sectional area varies inversely with any change in speed. For example, if a stream were to flow directly down a Plexiglas slope while being accelerated by gravity, it should become narrower as the length of travel increases. (In the course of about 10 centimeters, however, the viscous drag from the Plexiglas overcomes the acceleration; the cross-sectional area is then constant.)

Nakagawa and Scott presented data on the area and shape of the cross sections along a stream displaying a stable meander. From the discharge tube the stream went almost straight down the slope for about seven centimeters, becoming narrower and maintaining a symmetrical cross section with the highest point at the center. Beyond seven centimeters the stream meandered several times. The bends connected relatively straight sections slanted to one side or the other of the plate. Within the meander the cross-sectional area varied, being large just before a bend and smaller within the bend. Hence the flow was slow just before a bend and faster in the bend.

The cross sections within the meander were asymmetrical because the highest point was off-center. I call the deeper side of the cross section a ridge. In straight, diagonal stretches the ridge was on the lower side of the stream. Near the upper end of a bend the ridge crossed the stream, so that it ran down along the outside of the bend and then along the lower side of the next diagonal stretch.

Nakagawa and Scott maintain that the ridge causes the meanders. In a stream with a symmetrical cross section the forces from the surface tension along the opposite sides cancel. If the cross section is asymmetrical, the force on the ridge side is larger than the one on the shallow side. This imbalance yields a net force toward the shallow side.

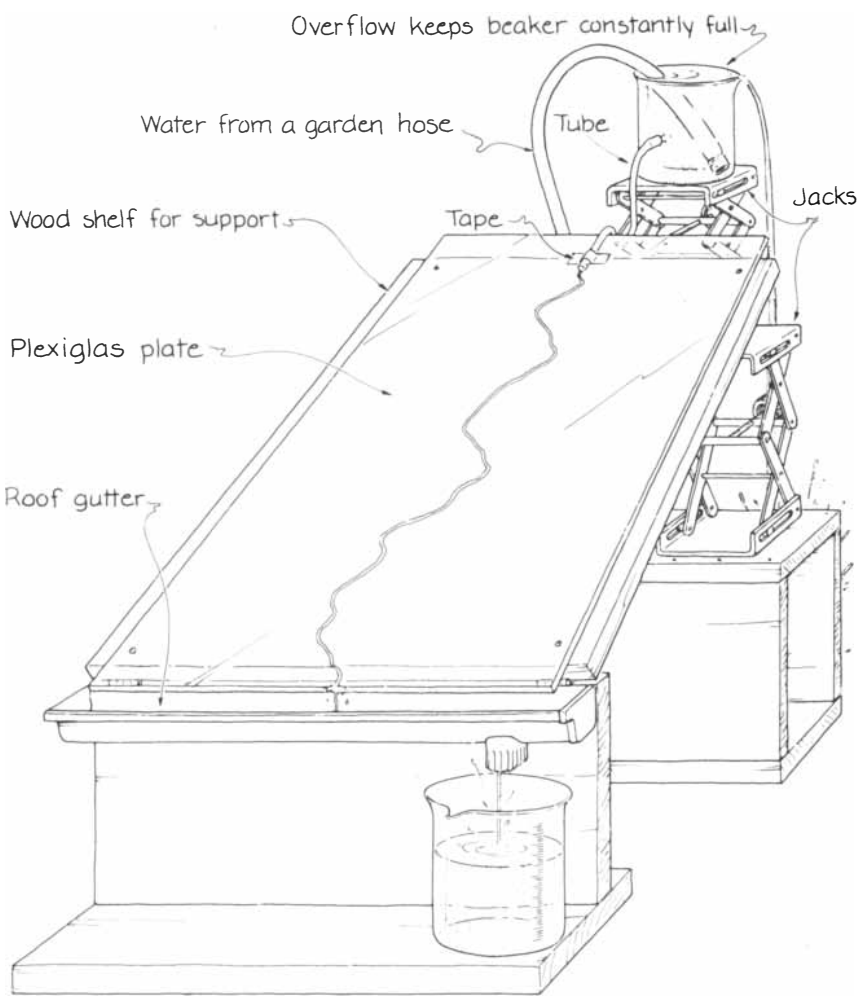
The ridge first appears at the point where the stream flows approximately straight down from the discharge tube. Presumably it is created by contamination or microscopic roughness of the plate or by undetected turbulence in the stream. The net force arising from the ridge deflects the stream, sending it into the first diagonal stretch of a meander.

The diagonal stretch can be stable against the pull of gravity because the ridge is then on the lower side and the force from it is upward. This arrangement is similar to that of a drop clinging to an inclined surface, held in place by the net force due to surface tension. As in the case of a drop, the contact angle is large on the lower side and small on the upper side.

As the water flows along the diagonal stretch, however, it is no longer accelerated as much by gravity as it was when it ran straight down. Viscous drag from the plate slows the water, increasing the cross-sectional area and also the contact angle on the lower side. Just before a bend the contact angle on the lower side exceeds the advancing limit and the water begins to run straight down the plate.

The stream would continue in the same direction except for the continued presence of the ridge. At the beginning of the fall the ridge shifts across the stream. The force due to the ridge then deflects the stream into another straight, diagonal section. The turn is the bend in the meander.

In doing my experiments I observed several more characteristics of the flow of water down a slope. Usually a drop slid down, meandering slightly or not at all. Similarly, streams with low volume flow rates often did little meandering. Strong meanders had prominent loops at the top of the plate but indistinct ones lower down. Occasionally I had a stream that meandered strongly at the top of the plate and weakly near the bottom, with a virtually straight run between the me-



A homemade apparatus for studying meanders

anders. How does one explain these phenomena?

I believe that when a sliding drop forms an asymmetrical cross section, the force due to the asymmetry quickly restores the symmetry. The drop is momentarily deflected to one side but does not travel far along this slanted path. Since it has less mass than a stream, it may also be affected more by contamination and irregularities along the surface. The result is a wiggly path.

The pattern developed by a stream with a low volume flow rate seems to depend greatly on the initial straight run. I created such a stream and blocked it briefly by holding a cloth near the discharge tube. Each time I released the water the stream formed a different pattern: sometimes a strong meander, at other times little or no meandering. The pattern seemed to depend on how the pool of water just above the cloth first broke free. Apparently if no significant ridge developed in the initial straight run, the stream meandered weakly, whereas a significant ridge or strong turbulence caused a definite meander. The path of the initial descent persisted, indicating that the first wetted section of the plate determined the direction of flow.

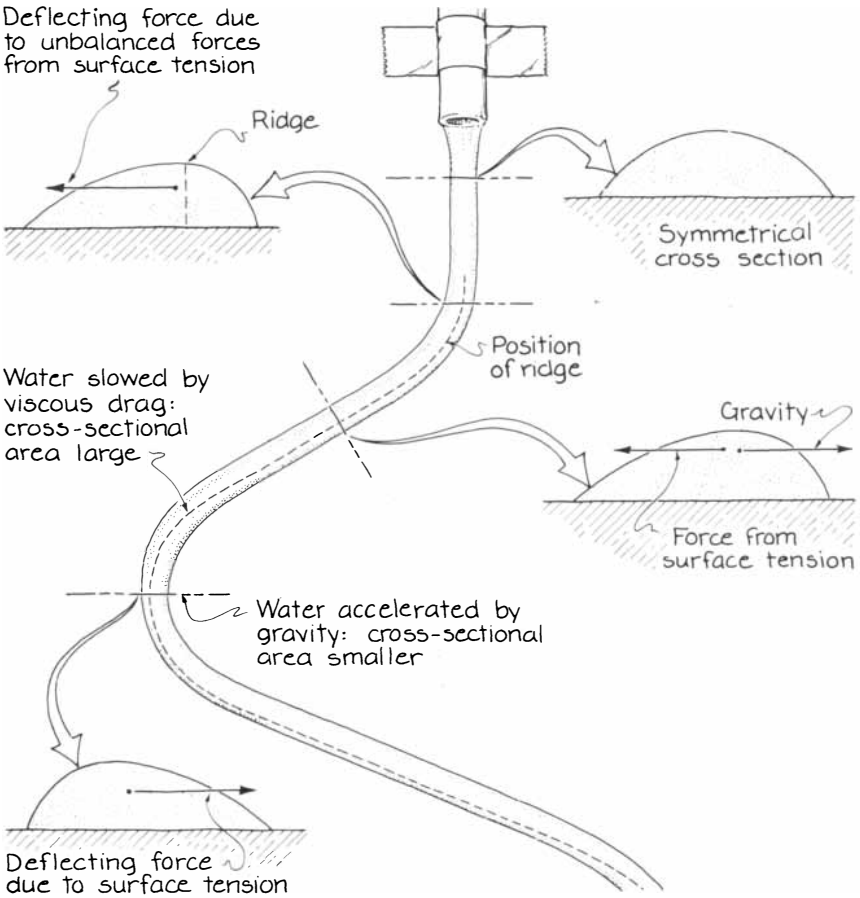
In many trials I began with a low volume flow rate and a slight meander. As I increased the flow rate the first meander shifted down the slope, presumably because the force due to a ridge required more time to deflect the stream. The stream also began to reshape itself into stronger meanders with longer diagonals and greater distances along the slope between bends. This pattern seems to be due to the flow of water within the ridge on the diagonal stretches. Water approaching a bend overshot the bend before it began to fall along the plate. As overshoot persisted the bend migrated down the plate and to one side, and the diagonals lengthened.

After a while the diagonal stretch leading to a bend began to slide down the plate, apparently because the viscous drag in the stretch slowed the flow, thereby increasing the cross-sectional area and also the lower contact angle. Once that angle exceeded the advancing limit the diagonal stretch began to slide. If it slid faster than the bend, it collapsed, breaking off from the bend and forming a new bend nearer the middle of the plate. When an old bend broke up, the water in it quickly ran down the plate.

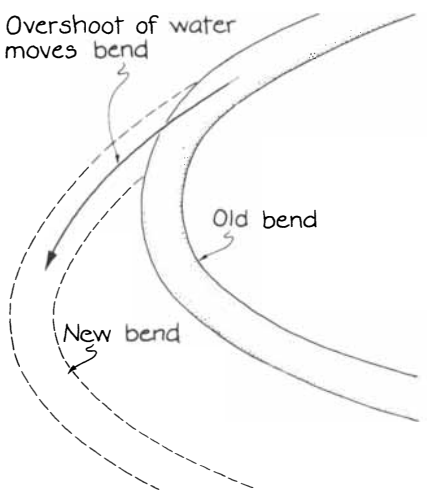
When I further increased the volume flow rate, the stream began to collapse, often in the diagonal stretches; sometimes it released not only an old bend but also several parts of a diagonal. The intact portion of the stream rapidly developed a new bend, which might curve in the same direction as the old one or in the opposite direction. The rapid collapse and release of isolated stretches of the stream gave the illusion that the main part was thrashing about over the plate, propelling water into a fan of angles toward the bottom.

In one set of trials involving a stable meander I used a syringe to inject food coloring into the stream. Without color the stability of the meander gives the impression that the flow is sluggish. The coloring shows how rapidly the water is flowing.

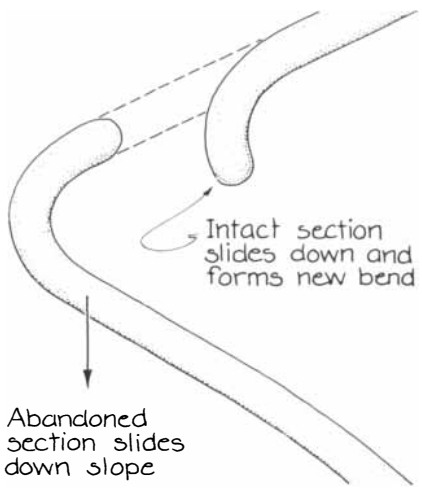
Not long after I put in the color the stream cleared except in the upper



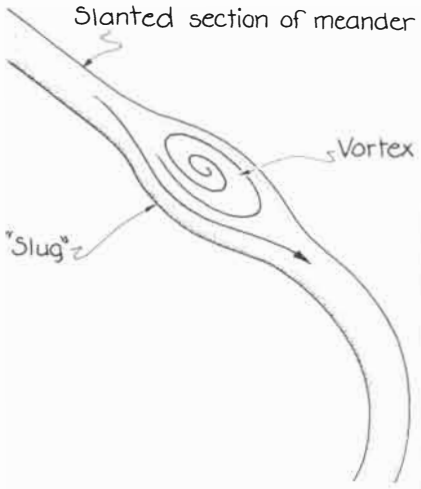
A meander and its cross sections



The migration of a bend



The collapse of a diagonal



The flow within a "slug"

sides of the diagonals of meanders. These stretches kept the color several seconds longer, suggesting that the flow is slower in them than it is through the ridges along the lower sides.

Next I put in a smaller amount of coloring at a steady rate. Where the flow was fast the color was too weak to see, but in the regions where the flow seemed to be sluggish small amounts of color were visible.

During these trials I noticed another peculiar feature of a stable meander. At times the stream developed wide sections I call slugs. A slug would remain stationary for a while and then creep along the stream, often causing a meander to collapse.

With a magnifying glass I examined the flow of color through a slug. I discovered that in the upper side the water flow formed a vortex: colored threads looped around, flowing both upstream and down. I then understood how a slug could make a meander collapse. The formation of the vortex at the upper side of the slug forces the water to flow faster and with more turbulence along the lower side. The contact angle on the lower side could then increase beyond its advancing limit, leading to a collapse. Alternatively, the vortex could suddenly increase in size, disrupting the flow through the slanted section and deflecting the flow downward.

Much can be learned from further analysis of clinging drops and meandering streams. You might investigate how putting alcohol in the water alters the results I have described. (Alcohol lowers the surface tension of the water.) Do viscous fluids such as cold syrup meander? Does the meandering of streams increase or decrease if the roughness of the slanted surface is increased?

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But these are just a few of the problems Transet 1000 can solve for you. For more information, see your authorized Hayes dealer. Soon.

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