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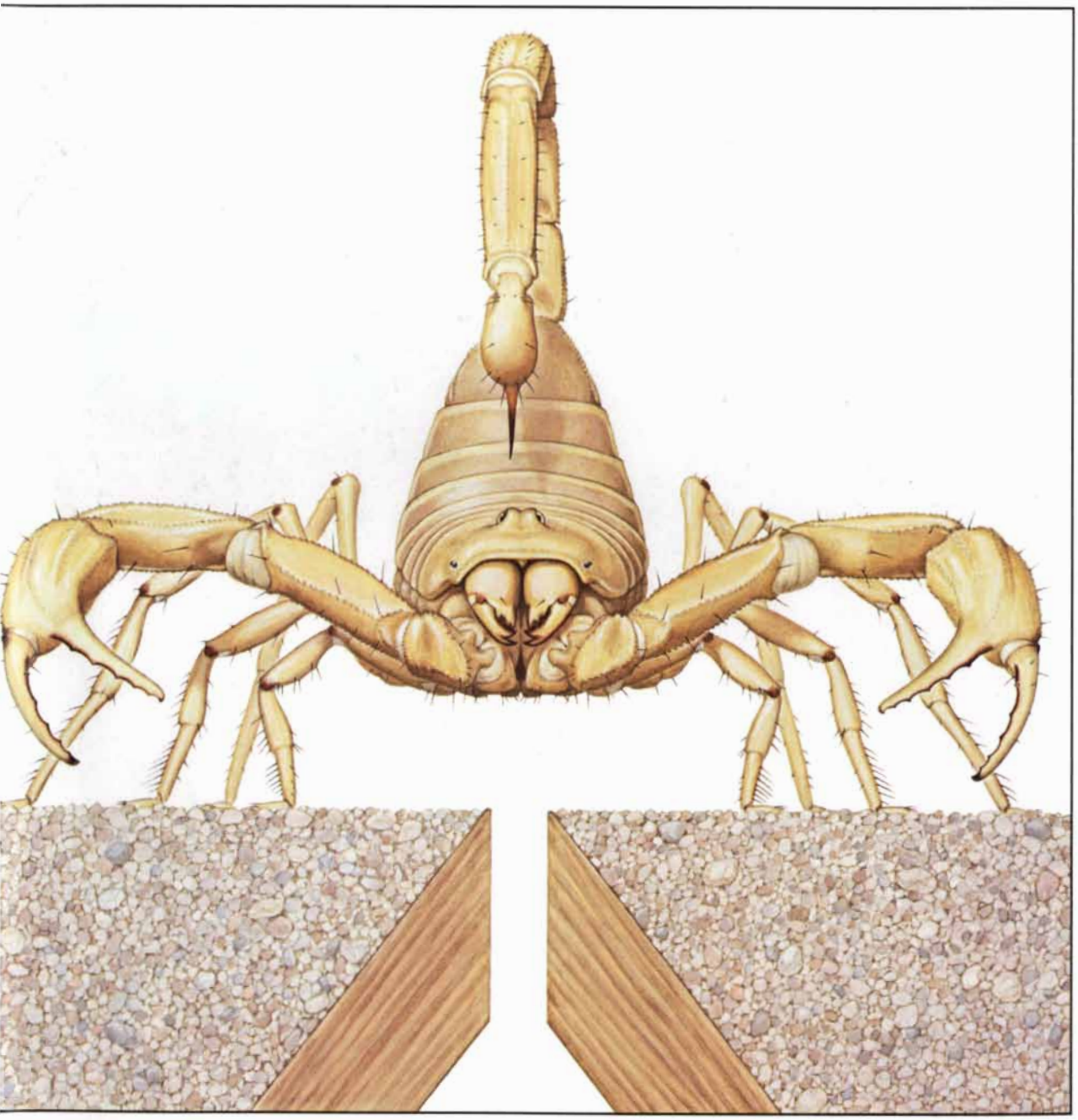

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December 1984

Zeiss

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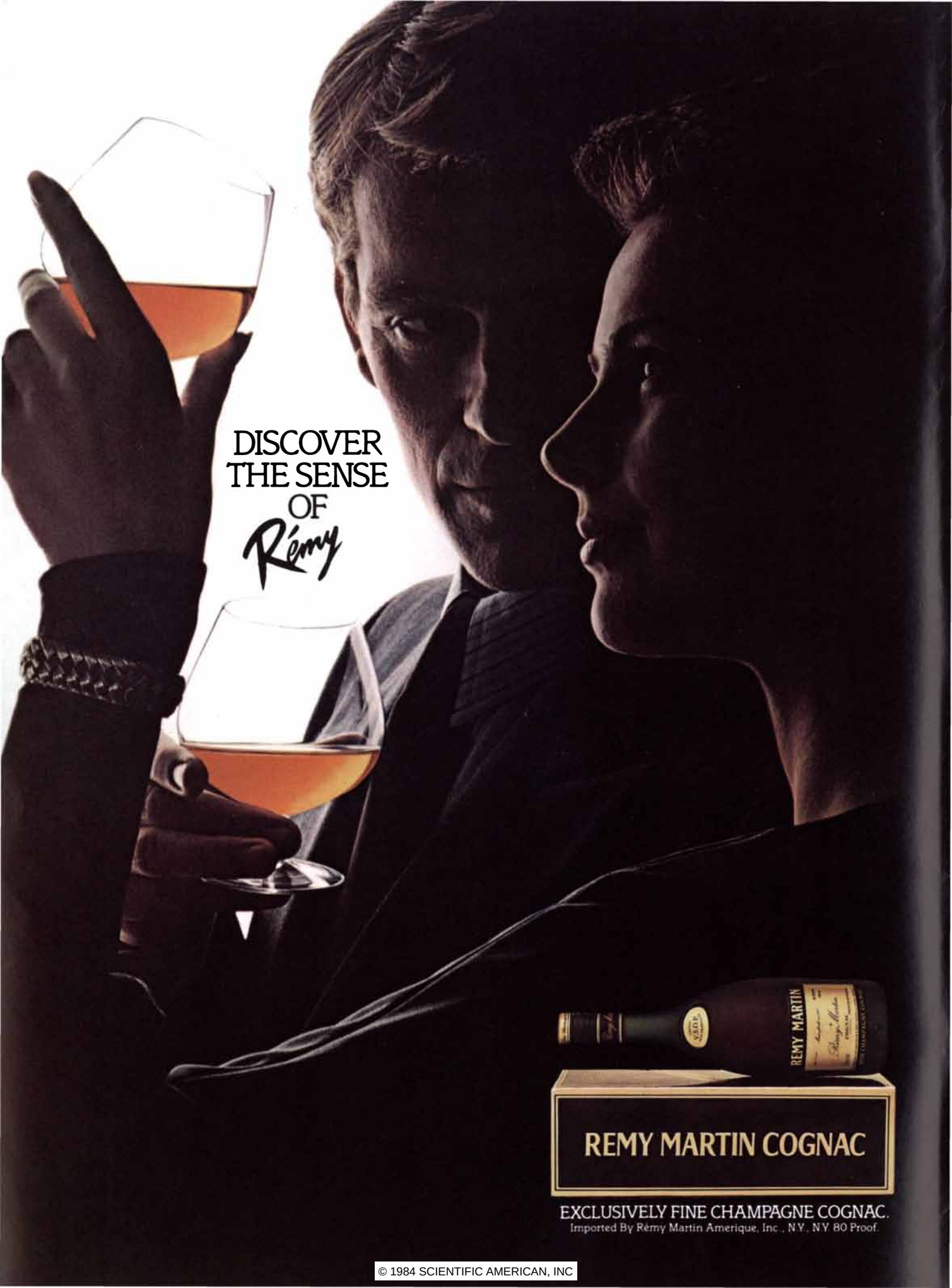

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ARTICLES

DEPARTMENTS

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SCIENTIFIC AMERICAN

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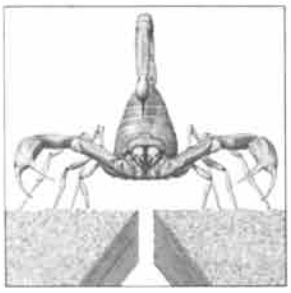

THE COVER

The painting on the cover depicts the sand scorpion *Paruroctonus mesaensis,* a nocturnal inhabitant of the southern Mojave Desert. Here it is shown in a laboratory sandbox, in the context of an experiment that demonstrated its sensitivity to minute vibrations in the substrate (see "Prey Detection by the Sand Scorpion," by Philip H. Brownell, page 86). When harassed, the animal assumes a defensive posture, raising its rear and arching its sting over its head as it faces the direction in which it perceives a threat. The air gap, which blocks the transmission of mechanical waves through the sand but does not interfere with visual or auditory signals, makes it possible to show that the animal turns toward the threatening stimulus only if its legs are touching the stimulated substrate. The scorpion also uses substrate vibrations to locate prey, which it grasps with its large pincers and paralyzes with the neurotoxic sting at the end of its tail.

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Cover painting by Tom Prentiss

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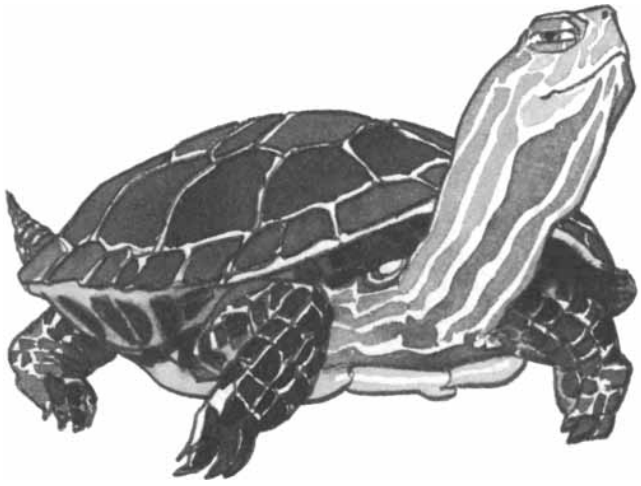

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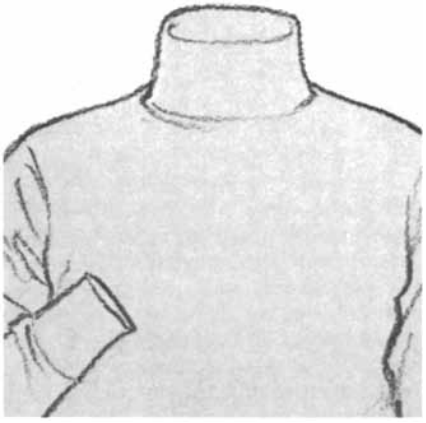

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LETTERS

Sirs:

Stanley B. Prusiner's article ["Prions," SCIENTIFIC AMERICAN, October] was fascinating. Prions seem to be the smallest self-replicating entities known. Their study will surely bring new insights into basic life processes.

The data Professor Prusiner has acquired on prions brought to mind A. G. Cairns-Smith's book *Genetic Takeover and the Mineral Origins of Life*. Cairns-Smith's general theme is that replication by means of DNA or RNA is far too complex to have arisen directly from the necessarily very dilute organic "soup" of the early oceans. There must have been an entire series of earlier, simpler methods of self-replication from which the sophisticated system we see today evolved. The term "genetic takeover" of the title comes from the presumption that genetics is so effective that earlier means of replication could not have survived. Perhaps prions are an exception.

Further study may reveal that DNA or RNA is involved in some subtle way in prion replication. If neither substance is, what are the alternatives? Cairns-Smith has suggested that the very earliest form of self-replication occurred in mineral clays with special crystal structures that replicated by one-dimensional crystal growth and fracture. Characteristics of the crystal structure would be preserved during growth, and each structure would have unique properties that would enhance or retard its chances of further growth (survival). This would provide the basis for evolution.

The characteristics of prions suggest they may consist of a protein with a simple repeating structure that can grow linearly, in either direction, at sites that allow only the specific, fitting amino acid. It would be much like an amino acid polymer and would replicate by fracture and continued growth in a way analogous to Cairns-Smith's crystal replicators. The small and uncertain molecular weight observed for prions, their appearance as rods of differing length, their very slow growth rate and the variations of their terminal amino acid sequence all suggest this possibility.

It would be exciting indeed if the work of Professor Prusiner and his colleagues were to lead to the discovery of an earlier, more basic form of life.

WALTER L. JOHNSON

Southfield, Mich.

Sirs:

Contrary to the biography in your September 1984 issue, I was not the inventor of the "mouse" as a device for rapid user interaction with a computer by pointing. It was in fact developed by Douglas Englebart, William English and others at the Stanford Research Institute in the early 1960's. Nor did I invent the "window," which also goes back to the early 1960's and is associated in my mind with Ivan E. Sutherland. Menus likewise. I shall plead guilty to the overlapping-window idea, which increases the effective area of (always too small) displays. Clearly, though, all these are just stopgap measures until the millennium of "displays without frames" and "commands without restriction" arrives.

ALAN C. KAY

Cambridge, Mass.

Sirs:

The most important implication of Terry S. Reynolds' "Medieval Roots of the Industrial Revolution" [SCIENTIFIC AMERICAN, July] is left to the reader's imagination. His researches seem to indicate that 11th-century Europe was already becoming dependent on mechanical power; that by the 15th century the Europeans had succeeded in using wind and water power to produce a significant and unprecedented increment of added wealth, and that wind and water power were also instrumental in the expanding commerce and wealth of the 15th through the 17th centuries. Since later European exploration, trade and conquest were made possible only by thousands of relatively large ships with metal fittings and cannons, cheap trade goods and so on, it seems very likely that only the protoindustrial use of wind and water made the Age of Exploration possible in the first place.

Because only worldwide trade and colonialism made true industrialism possible, the Industrial Revolution is usually described as the ultimate result of the Age of Exploration. Professor Reynolds' findings indicate that this cause-and-effect analysis should be exactly reversed and that the most important source of Western civilization lies not with explorers in the 15th century but with engineers in the 11th.

MIKE POULTNEY

Orcutt, Calif.

Sirs:

I should like to respond to the letter from J. F. Liu in the November issue concerning my article "Multilingual Word Processing" [SCIENTIFIC AMERICAN, July]. Mr. Liu has raised some points that he sees as shortcomings in Romaji-conversion methods for typing the Japanese and Chinese languages.

His major concern appears to be that if the typist strikes the wrong keys, the wrong word will come out; he gives an example where striking *l* instead of *j* changes the sense of a Chinese word. But this is no different from typing in English, where striking *l* instead of *j* could change the sense from "a jot" to "a lot." Using any typing method whatsoever, if the typist makes a mistake, indeed an error will result.

Mr. Liu then goes on to make three disputable claims. First, he states that *beijing* is "one of the simplest cases in Chinese." In fact, *beijing* has two homophones (words that sound alike but have different meanings), which is average in Chinese. Next, Liu says that an operator might not know which of several intonations of *heji* was meant if that word appeared in a document to be typed, and might thus type the wrong word; however, since the operator would be typing from a text written in Chinese characters, he or she would know precisely which intonation was meant. Finally, Liu asserts that a machine programmed to obey grammatical rules might mistype specialized jargon. This difficulty would not arise because the handling of jargon depends on the contents of the system's dictionary, not on its grammatical rules.

It strikes me as very strange to engage in academic speculation about the potential of a technique that has been fully implemented and sold in commercial products for many years. Romaji-conversion computer typing for Japanese has been an overwhelming success ever since its introduction. In what was originally a Darwinian struggle against a whole zoo of proposed typing systems, it long ago triumphed as the sole survivor. The reason is simply that it is the only easy way to type the Japanese language, and so people buy it.

The Chinese-language marketplace is now just beginning the same elimination of bad typing systems that has already finished in Japan. Romaji conversion of Chinese is now available for the first time in the Xerox "Star" product, and we gladly invite practical comparison or testing against any other method.

JOSEPH D. BECKER

Palo Alto, Calif.

ERRATUM

In the article "How LDL Receptors Influence Cholesterol and Atherosclerosis," by Michael S. Brown and Joseph L. Goldstein (SCIENTIFIC AMERICAN, November) the two drawings on page 65 were inadvertently transposed.

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弟子言年少汝門神
德雖盛然故不如我
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Eighth century sutra—Private Collection, Fogg Art Museum, Harvard University.

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50 AND 100 YEARS AGO

SCIENTIFIC AMERICAN

DECEMBER, 1934: "The Diesel type of engine will become dominant, headlines tell us. A Diesel-powered racing car whirls the 500-mile Indianapolis race at an average speed of 86.14 miles per hour; a giant bus tears from New York to Los Angeles in 91 hours at a total fuel cost of $21.90; the Navy installs a Diesel in its newest submarine, and an airplane so powered covers leagues at a fraction of normal cost. But headlines tell only part of the story. The value of the Diesel as to its future commercial possibilities has to be appraised in less sensational manner. Among engineers there is no unanimity of opinion, hence the potentialities of this engine will have to be gaged from the rate of progress made—internally, in the perfecting of the engine; externally, in its applications. In the stationary power and marine field its place is secure. In railcar and motor-truck transportation definite progress has been made, but it promises to be some years before Diesels will cut any large figure in passenger cars. Here as in aviation much experimental research remains to be done before the Diesel becomes commercially feasible, but to state categorically that it cannot dominate ultimately is to deny the experience of the past."

"During the last 12 months two first class advances in low temperature physics have been made. Professor Peter Kapitza, the director of the Royal Society Mond Laboratory at Cambridge in England, has succeeded in constructing a new type of machine for liquefying helium. His machine makes the preparation of relatively large quantities of liquid helium much easier and cheaper than before. The other advance has been made by Professor W. J. de Haas of the University of Leyden, who has made experiments in which temperatures within one-twentieth of a degree of absolute zero have been reached. The lowest temperature reached by earlier methods was seven-tenths of a degree."

"Was Alaska once a semi-tropical land? Excavations going on near Fairbanks may answer the question definitely in the near future. Sealed in the muck of a few square miles there have been unearthed, among other fossils, mammoths, tiny horses' hoofs, super-bison heads in vast numbers, an enormous elk's antler, extinct bears, the rare mastodon, the largest ivory tusk on record and the skull of a lion. The finds prove that Alaska once teemed with species of wild life now extinct, and that a lush vegetation existed. 'But,' cautions Otto Geist, archeologist of the Agricultural College and School of Mines, 'scientists have not yet determined why some of the finds had long hair.'"

SCIENTIFIC AMERICAN

DECEMBER, 1884: "Middle aged readers can readily recall the time when the empire of Japan and the heart of Africa were equally unknown to the world, and the memory of Perry's notable unsealing of the ports and commerce of Japan must be fresh in their minds. To-day there comes to these shores $14,000,000 worth of goods annually, while the amount and value of these imports augment rapidly. In exchange for the half million dollars' worth of refined petroleum sent to Japan last season, Uncle Sam gets an assortment of invaluable articles. First in value and importance is crude camphor. Japanese vegetable wax is another important product. It is a rival of paraffine wax in many ways. The cuttlefish bone, without which the life of the imprisoned canary would be stale, flat and unprofitable, is still another product of Japanese origin. Then comes Japanese fish oil. Isinglass was imported to the extent of nearly 9,000 piculs, worth $264,500. The metal antimony, of prime necessity in medicine, is yet another valuable product of Japan. The type founder is a large consumer of this peculiar metal also, for it possesses the singular property of retaining its volume when cooling after melting. This endows metal alloyed with antimony with the attribute of retaining a clear cut impression of the mould, so requisite in type making. Among the articles which are found among the Japanese merchants' samples is a silvery powder. This powder glistens from the surface of modern wall paper, imparting a beautiful appearance, and it serves to enhance the charming snow scenes depicted on Prang's Christmas cards. This substance is Japanese mica, ground to powder, and when used as described gives the article it is spread upon all the sparkling beauty worn by the surface of snow under the moon's rays."

"The steadily increasing use of natural gas in western Pennsylvania, West Virginia and Ohio, for manufacturing purposes as well as for lighting, suggests the possibility that its employment may soon have a depressing effect on the anthracite and bituminous coal business over a considerable section of country. In so far as natural gas has been applied to the manufacture of iron, steel and glass, the quality of the products is rather in its favor. For steam raising it is very superior to solid fuel, not merely in the lessening of labor and freedom from ashes, but in that the heat can be more equally distributed lengthwise and around the boilers, to the benefit of the latter in the matter of safety and durability. It is safe to say that the use of gas fuel in this locality now supplants the use of several thousand tons of coal each week, and there is no doubt that the use of gas fuel will largely increase in the near future."

"The modern cargo steamer has now become a wonderfully economical carrier of freight, especially as regards consumption of fuel. A freight train under the most favorable conditions seems wasteful in comparison. The Burgos, a modern steamer specially built to carry cargo cheaply at a slow speed, lately left England for China with a cargo weighing 5,600,000 pounds. During the first part of the voyage, from Plymouth to Alexandria, the consumption of coal was 282,240 pounds, the distance being 3,380 miles. The consumption per mile was therefore only 83.5 pounds, and the consumption per ton of cargo per mile .028 pound. In other words, half an ounce of coal propelled one ton of cargo one mile. The best locomotive performance in this country of which we can find any authentic record gives a consumption of about two ounces of coal per ton of freight hauled one mile at the rate of 13 miles an hour including stoppages."

"One of the greediest mouths which the forests of the United States are required to fill is that of the railway demand for ties, bridge timber, etc. According to Poor's Railway Manual, there were in the United States at the close of 1883, 121,592 miles of railways. The average number of ties needed per mile of track is 2,820, and the duration of a tie averages about six years; hence the annual consumption of ties amounts to the stupendous total of 57,148,240. In view of this enormous draught on the forests of the country, it is evident that the time is approaching when scarcity will cause an advance in price. The not remote prospect of such an advance, as well as the present economy of a proper preservative treatment, has induced several railroads to conduct experiments looking toward some feasible means of timber preservation; and the American Institute of Civil Engineers has been for some time past collecting information regarding the various processes for this purpose, with the object of embodying such information in a report to be shortly given to the public. Of these processes the most effectual, as well as the most practical on account of its low cost, is creosote."

THE AUTHORS

SAMUEL H. PRESTON ("Children and the Elderly in the U.S.") is professor of sociology at the University of Pennsylvania and director of its Population Studies Center. He is a graduate of Amherst College, where he got a B.A. in 1965, and of Princeton University, which granted him a Ph.D. in economics in 1968. He taught demography as assistant professor at the University of California at Berkeley until 1972, then moved to the sociology department of the University of Washington, where he was associate professor and then professor. From 1977 through 1979 he served as acting chief of the Population Trends and Structure Section of the United Nations Population Division. He joined the faculty at the University of Pennsylvania in 1979. Preston, who has written books on patterns of world urbanization, the effects of cigarette smoking on international mortality, and demographic trends in India, is president of the Population Association of America.

RICHARD G. BREWER and ERWIN L. HAHN ("Atomic Memory") are respectively an IBM Fellow at the San Jose Research Laboratory of the International Business Machines Corporation and professor of physics at the University of California at Berkeley. Brewer, who also teaches physics as a consulting professor at Stanford University, studied at the California Institute of Technology and Berkeley, which awarded him a Ph.D. in 1958. He has taught at Harvard University and at the University of California at Los Angeles and is a member of the National Academy of Sciences. His research, for which he won the A. A. Michelson medal of the Franklin Institute in 1979, centers on laser physics and spectroscopy. Outside the laboratory Brewer enjoys growing magnolias, making spaghetti Genovese and swimming. Hahn did his undergraduate work at Juniata College and earned his Ph.D. at the University of Illinois in 1949. In 1952, after postdoctoral work at Illinois and at Stanford, he joined IBM's Thomas J. Watson Research Center as a research physicist. He moved to Berkeley in 1955. He is a member of the National Academy of Sciences and has won a number of awards for his work on transient magnetic-resonance phenomena, spin coupling in matter and laser-induced transient phenomena. Hahn's avocation as a violinist has led him to develop and teach a course on the physics of music for undergraduates.

COREY S. GOODMAN and MICHAEL J. BASTIANI ("How Embryonic Nerve Cells Recognize One Another") are developmental neurobiologists who have worked together since 1981. Goodman is associate professor of biology at Stanford University. He went to Stanford as an undergraduate and received his doctorate from the University of California at Berkeley in 1977. During the next two years he did research on the properties of embryonic neurons as a postdoctoral fellow at the University of California at San Diego. He joined the Stanford faculty in 1979. Bastiani is the senior research associate in Goodman's laboratory. He did his undergraduate work at San Diego and pursued his doctoral studies at the University of California at Davis, which granted him a Ph.D. in 1981. In 1984 the Fondation pour l'Étude du Système Nerveux Central et Périphérique in Switzerland chose him as its first scholar.

JOHN MONFORTE ("The Digital Reproduction of Sound") is a lecturer in the Music Engineering Technology program at the University of Miami, where he is also director of the university's recording services. His bachelor's degree, in electrical engineering, is from the University of Michigan. After his graduation in 1977 he took the position of circuit-design engineer at ADM Technology, Inc., a manufacturer of professional audio equipment. In 1979 he returned to the University of Michigan, where he worked as an electronics technician, maintained the university's recording facility and recorded performances by the school's musical ensembles. Monforte's recording credits include radio and television broadcasts, records and digital compact discs.

PHILIP H. BROWNELL ("Prey Detection by the Sand Scorpion") teaches in the zoology department at Oregon State University at Corvallis as assistant professor. He studied at the University of California at Berkeley, where he received an A.B. degree in 1970, and at the University of California at Riverside, where he got his doctorate in 1975. In postdoctoral research at the University of California at San Francisco he investigated the nervous systems of mollusks and the cellular mechanisms responsible for their long-term behaviors, work that he continues at Oregon State. Brownell's research interests also include arthropod sensory systems and behaviors, and he has a love for deserts. In combination these predilections led him to study the sand scorpion.

YE. A. KOZLOVSKY ("The World's Deepest Well") is Minister of Geology of the U.S.S.R. He also holds the titles of Professor and Doctor of Technical Sciences, has taught economic geology and has explored major ore deposits in the Soviet Union and elsewhere. In 1965 he became chief of the technical department of the Soviet ministry of geology; later he was made director of the All-Union Research Institute of Mineral Resources and Geological Exploration. In 1975 he rose to his present position. Kozlovsky is editor-in-chief of the Soviet Union's monumental *Mining Encyclopedia* and director of his country's research program of superdeep drilling.

LYNN A. COOPER and ROGER N. SHEPARD ("Turning Something Over in the Mind") are experimental psychologists who have collaborated extensively on the study of mental images. Cooper is associate professor of psychology at the University of Pittsburgh and senior scientist at its Learning Research and Development Center and its Center for the Philosophy of Science. She went to the University of Michigan as an undergraduate and got her Ph.D. from Stanford University in 1973. Cooper has won the American Psychological Association's Distinguished Scientific Award for an Early Career Contribution to Psychology. Shepard is professor of psychology at Stanford. He earned his undergraduate degree at Stanford in 1951 and his Ph.D. from Yale University in 1955. In 1968 he returned to Stanford as a member of the faculty. He has received a number of awards and fellowships, including the Distinguished Scientific Contribution Award of the American Psychological Association, and is a member of the National Academy of Sciences. Shepard and Cooper first worked together when she was a graduate student at Stanford; the book *Mental Images and Their Transformations* (The MIT Press/Bradford Books, 1982), of which they are coauthors, surveys their ensuing research.

JOHN D. HARBRON ("The Spanish Ship of the Line") is a foreign affairs analyst for the Thomson Newspaper Group in Canada with a long-standing interest in ships and the sea. He is a graduate of the University of Toronto; after postgraduate work at the University of Havana he entered the Royal Canadian Navy. As an officer he taught naval history at the Canadian Naval College at Royal Roads in British Columbia. Following his retirement from the navy he wrote for a number of American, Canadian and British publications before joining the Thomson Group. Harbron holds various distinctions, including the title of commander of the Order of Isabel la Católica of Spain. For help in his research for the present article he is indebted to the Museo Naval of the Spanish Navy in Madrid and in particular to its director, Capitán de Navío José María Zumalacárregui.

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COMPUTER RECREATIONS

Sharks and fish wage an ecological war on the toroidal planet Wa-Tor

by A. K. Dewdney

Somewhere, in a direction that can only be called recreational at a distance limited only by one's programming prowess, the planet Wa-Tor swims among the stars. It is shaped like a torus, or doughnut, and is entirely covered with water. The two dominant denizens of Wa-Tor are sharks and fish, so called because these are the terrestrial creatures they most closely resemble. The sharks of Wa-Tor eat the fish and the fish of Wa-Tor seem always to be in plentiful supply.

This simpleminded ecology might appear stable, almost soporific, were it not for the fact that the shark and fish populations undergo violent oscillations. Many times in the past the fish population has been all but devoured, whereas at other times the sharks have starved almost to extinction (even when there were plenty of fish). Yet both sharks and fish survive. To discover why, I designed a program to simulate their feeding and breeding activities.

Before I had ever witnessed these ecological rhythms on a display screen, however [*see illustration on page 19*], I mused for a long time about the rules and the details of the WATOR program. Over lunch one day I found myself musing across the table from David Wiseman, who is my department's resident systems wizard at the University of Western Ontario. After describing the project to him I noticed that Magi (for such is Wiseman called) was smiling enigmatically. The next morning he proudly ushered me into his office to display a working program.

"Watch," he said and pressed a key. An initially random assortment of fish and sharks flickered slowly from point to point in what seemed to be a chaotic manner. Some sharks failed to eat and disappeared. Other sharks had offspring just as voracious as themselves. A few fish, lucky enough to occupy a region where there were currently no sharks, multiplied into a large school. Presently a number of sharks discovered the school, congregated at its edges and gulped their way a short distance into it. A few minutes later the summary of current statistics displayed on Magi's screen told the story: there were now 578 fish and just 68 sharks.

Someone walked into Magi's office and ran out again. Before five minutes had elapsed the room was crowded with people cheering on the sharks. Slowly a wall of sharks closed in on the hapless fish. Elsewhere on the screen a small school of fish slowly multiplied unnoticed. Groans went up when the large school of fish finally disappeared and sharks, dying one by one, milled about looking for prey. I thought of changing the rules to allow sharks to eat one another, but I realized that a feeding frenzy would not significantly prolong their existence and might put the early history of that other small school in jeopardy. When two roaming sharks finally stumbled onto it, the cycle began anew.

The program for Wa-Tor is neither very long nor difficult to write. Readers who have personal computers, even those with little programming experience, will find it a rewarding project when the code is finally written, debugged and running. Parameters such as breeding times, starvation periods and initial population sizes can be set before a run. It is then just a matter of sitting back and watching as an initially disorganized mélange of fish and sharks slowly forms ecological patterns.

The WATOR program embodies a number of simple rules that govern both shark and fish behavior. The creatures swim in a rectangular ocean grid whose opposite sides are identified in pairs. This means simply that if a fish or shark occupies any rightmost grid point and decides to swim east (to the right), it will reappear at the corresponding leftmost grid point. The same relation holds between the vertical extremes. The resulting two-dimensional wraparound space is really just a torus, the actual surface of Wa-Tor [*see illustration on page 20*]. Anyone writing his or her own WATOR program may select any convenient size for the ocean grid. For example, Magi, whose program runs on a VAX computer, has set up an ocean that is 80 points wide and 23 points high. My own version of WATOR, written for an IBM PC, uses a humbler, 32-by-14 ocean.

Time passes in discrete jumps, which I shall call chronons. During each chronon a fish or shark may move north, east, south or west to an adjacent point, provided the point is not already occupied by a member of its own species. A random-number generator makes the actual choice. For a fish the choice is simple: select one unoccupied adjacent point at random and move there. If all four adjacent points are occupied, the fish does not move. Since hunting for fish takes priority over mere movement, the rules for a shark are more complicated: from the adjacent points occupied by fish, select one at random, move there and devour the fish. If no fish are in the neighborhood, the shark moves just as a fish does, avoiding its fellow sharks.

The creator of WATOR selects five parameters in order to set up a given simulation. The parameters *nfish* and *nsharks* represent the numbers of fish and sharks at the beginning of a run. The program distributes the specified numbers of fish and sharks randomly and more or less uniformly across the planet's surface. The parameters *fbreed* and *sbreed* designate the number of chronons a fish and a shark respectively must exist before each has a single offspring. (Both species are apparently parthenogenic.) Finally, *starve* specifies the number of chronons a shark has in which to find food. If it swims about any longer than this without eating, it dies and sinks out of sight. During each chronon WATOR moves each fish and each shark once and displays the results on the screen. With rules no more complicated than these, one can watch the ecology of Wa-Tor lurching from crisis to crisis.

Magi and I have witnessed a number of five-parameter scenarios in which Wa-Tor's ocean became overpopulated with fish only to have the sharks eventually multiply to a point where all the fish were eaten and the sharks died. On other occasions we have seen all the fish in one large school being eaten. The sharks that had gorged themselves finally starved, never discovering a very small cluster of fish nearby. On a few occasions we have seen the prey-predator relation sustain itself through two or even three population cycles before the ultimate crash in shark population. Nothing in the parameters selected for those scenarios, however, gave any hint of the characteristics that would ensure an eternal ecology. How had the denizens of Wa-Tor survived?

It has been said that biology is destiny. Magi and I are tempted to declare that ecology is geometry, at least as far as the planet Wa-Tor is concerned. The ultimate fate of a given scenario does not

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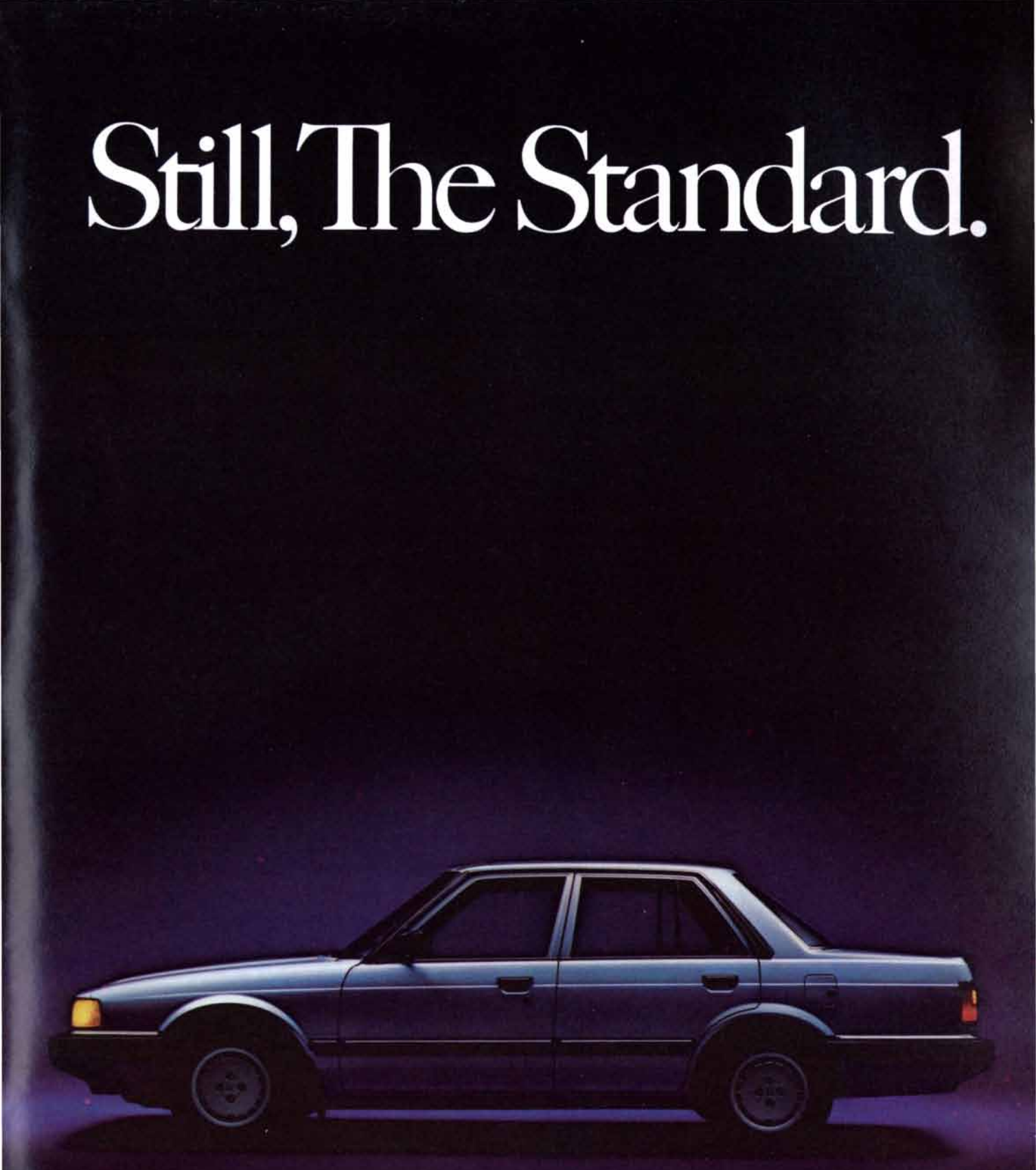

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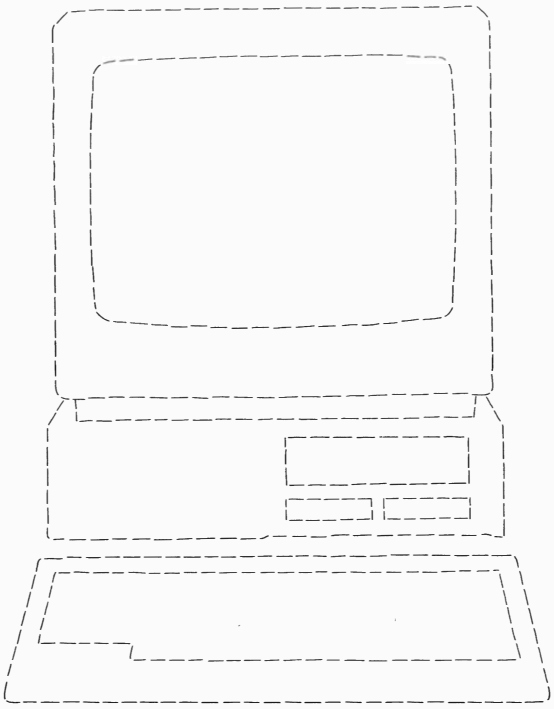

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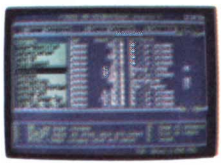

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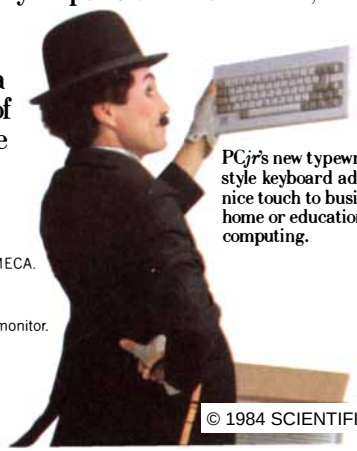

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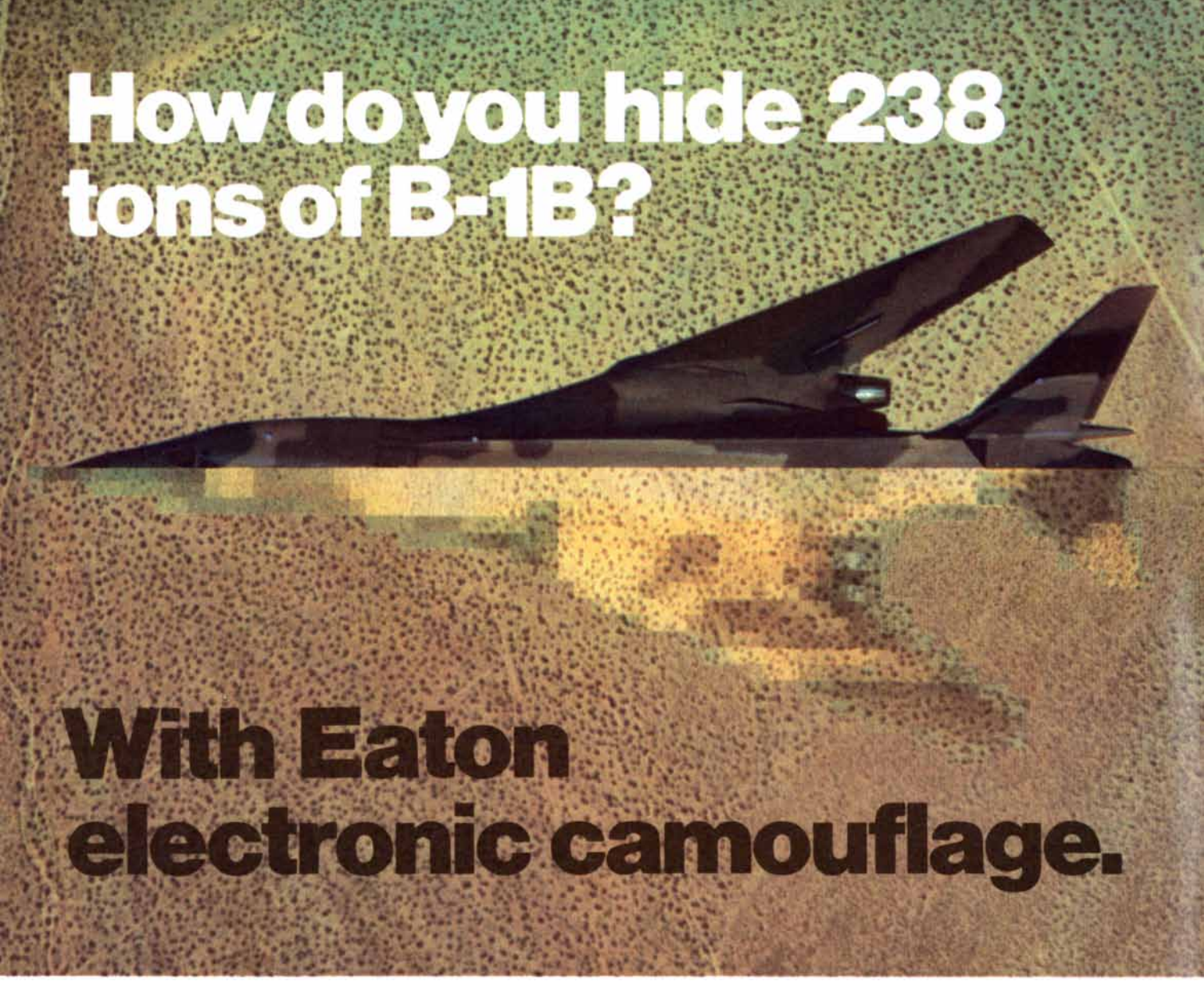

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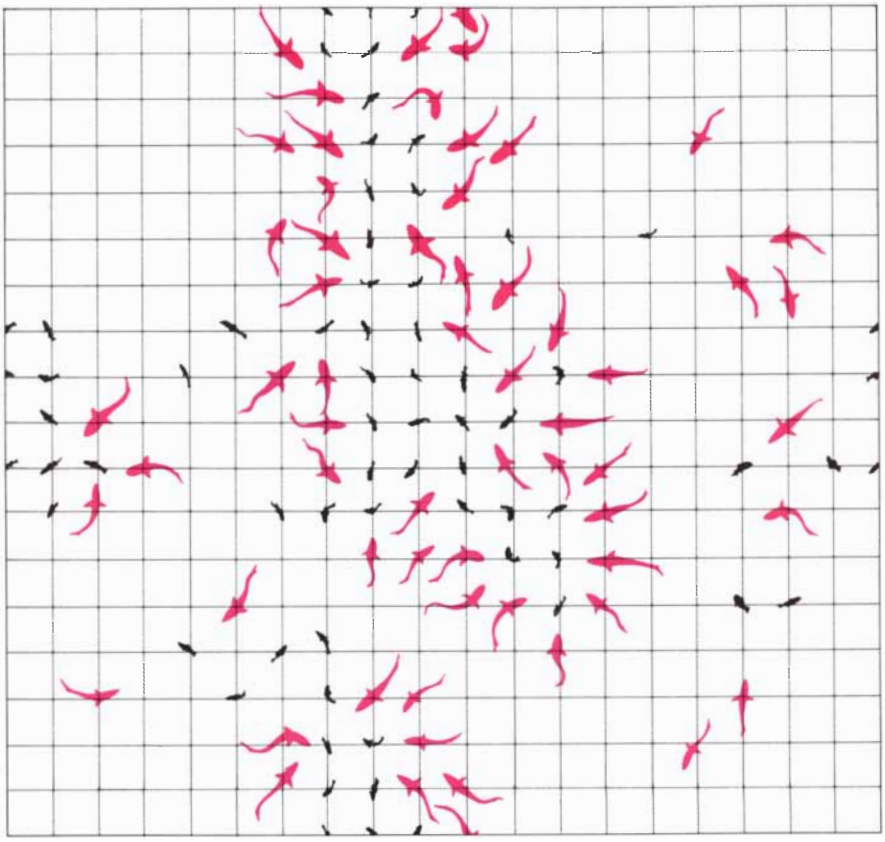
seem to depend on the initial random distribution of a specified number of sharks and fish. Nor does it seem to depend in an accidental way on the actual random movement of sharks and fish. Instead the likelihood of a population crash appears to follow closely the fish-shark geometry that manifests itself on our screens: the more highly organized and localized either population becomes, the likelier it is that the ecology is doomed. Meditating on this theme, we were led to wonder how we might choose the five parameters in a way tending to break up the geometry. Then came a flash of insight: if sharks had congregated at the edges of a school of fish, one way to break up the resulting geometry would be to have the sharks breed less often. The congregation itself, after all, was less the result of motion than it was of breeding.

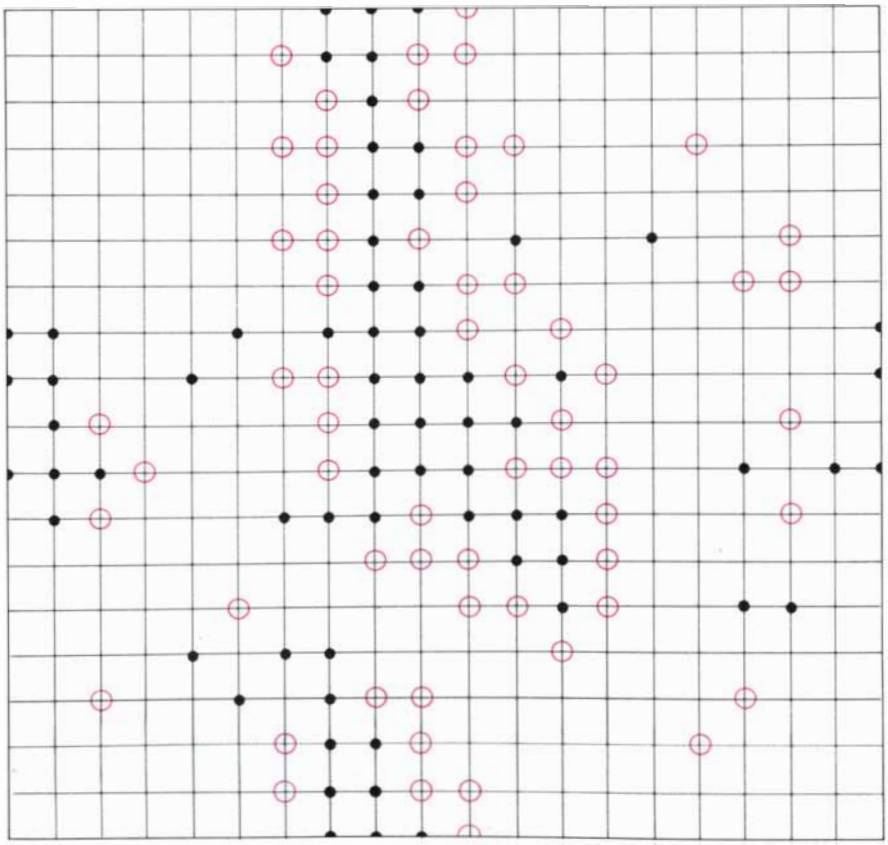
Before forming this hypothesis we had chosen roughly equal breeding times for sharks and fish. Balanced reproduction rates, we thought, would result in balanced populations. This kind of vague thinking probably accounts for many woes in today's technological world. In any event, I put 200 fish and 20 sharks in my 32-by-14 ocean and set the fish to breed every three chronons but barred any shark from reproducing before 10 chronons had elapsed. Shark starvation time was set more or less arbitrarily at three chronons. We were rewarded, after watching my rather slow program for 15 minutes, by seeing a full recovery from the initial population decline. Moreover, the geometry, although it was still present, was more suggestive than definite. Schools were shapeless conglomerations with ragged edges, and at some places on the screen sharks and fish milled about at random.

I let the program run all afternoon, glancing up occasionally from more important matters on my desk. The program ran all night, and when I visited my office after my morning lecture, I found fish and sharks still pursuing a cyclic existence. Here was Wa-Tor!

There are many ways to implement a WATOR program but perhaps the simplest involves a number of two-dimensional arrays. I use five arrays called FISH, SHARKS, FISHMOVE, SHARKMOVE and STARVE. These arrays, all 32 by 14, keep track of the positions and ages of sharks and fish. Specifically, FISH(I,J) represents the presence or absence of a fish at the point with coordinates (I,J). If a fish is absent, the position has the value -1. Otherwise it contains a record of the age in chronons of the fish that is present. The same scheme is used for the array SHARKS to keep track of the positions and ages of the sharks. The array FISHMOVE holds a record at each position of whether a fish has been moved there during the current computational cycle.



A realistic view of sharks eating fish



A more easily programmed view, in which circles represent sharks and dots represent fish

Such a record enables the program to avoid moving a fish twice during the same chronon. SHARKMOVE fulfills the same function for sharks. The array called STARVE registers the time at which a shark last ate. If there is no shark at a position, the entry is -1.

The simplest display of the action on Wa-Tor is a line of characters on the screen for each row in the arrays; a blank at a position means it is unoccupied. A period (.) represents a fish and a zero (0) represents a shark. Although this display might seem to be limited, it is surprisingly informative and enjoyable to watch.

In WATOR's initial phase the required numbers of fish and sharks are scattered uniformly over the toroidal ocean. The program then cycles through the three segments or subprograms described below; each program cycle occurs during one chronon of time.

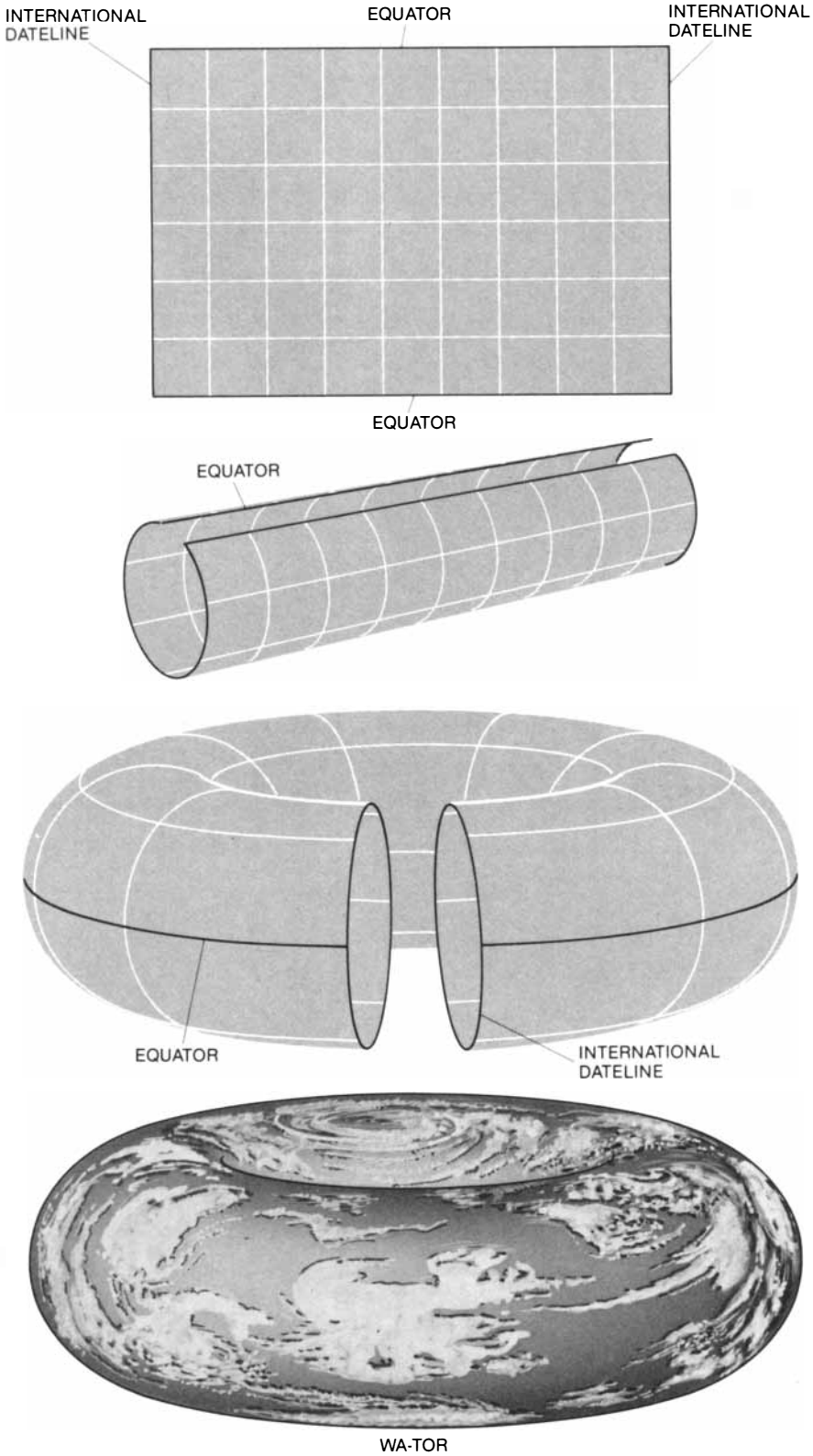
FISH SWIM AND BREED:
For each fish in the FISH array, the program makes a list of adjacent unoccupied positions and moves the fish to one of these at random. This means FISH must be set to -1 at the old position and set to the fish's current age at the new position. The array FISHMOVE is updated in the manner described above. If the fish's age equals *fbreed,* the program puts a new fish at the old position and gives age 0 to both fish. Again FISHMOVE records the new fish. If all adjacent positions are occupied, the fish does not move or breed.

SHARKS HUNT AND BREED:
For each shark in the SHARK array, the program makes a list of adjacent fish positions (if any). The shark chooses one of these at random, moves there and eats the fish. This means not only that the program must modify SHARKS and SHARKMOVE as it modified FISH and FISHMOVE, but also that it must set the corresponding position in the FISH array to -1. Also, STARVE at that position is set to 0. If there are no adjacent fish, the shark moves just as a fish does. If the shark's age equals *sbreed,* a new shark is produced in exactly the same way as a new fish is.

DISPLAY:
The program scans both the FISH array and the SHARKS array. It displays a period for each fish and a 0 for each shark. The display can be done all at once in this way or broken into two parts: one executed after the fish have moved, the other executed after the sharks have moved.

To populate the initial ocean, the programmer constructs a loop that generates two random numbers *nfish* times. The numbers are scaled to the horizontal and vertical dimensions of the ocean he or she intends to have. At each of the random positions thus selected, the program places a fish in the FISH array and assigns it a random age between 0 and *fbreed*. Sharks are distributed similarly. In both cases the position is checked to see if it is already occupied. The effect of giving both sharks and fish random ages is that they then breed at random times in a natural way. Without this precaution one would witness the sharks and fish suddenly doubling in numbers, a disconcerting and unnatural sight.

There may be novice programmers



The toroidal planet Wa-Tor and its representation on a flat map (or a flat computer screen)

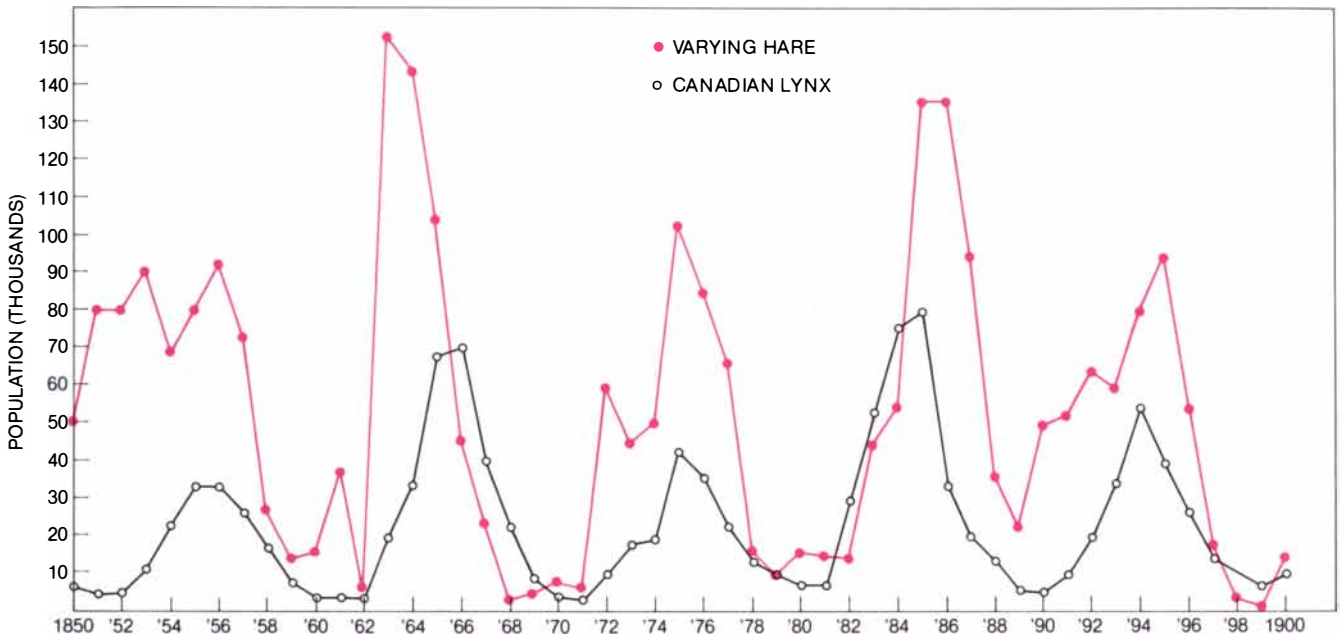
who find the foregoing description a bit too general to form any clear idea of how to write a WATOR program. Those programmers can begin by writing what is known as a staggering-drunk program. Such a program might consist of a single loop (say a while-loop) that has seven instructions. These are written in nonprejudicial algorithmic language. Assignments are indicated by left arrows and the variables X and Y are the coordinates of a staggering drunk. They are altered according to the random integer assigned to a variable *direction*. Depending on whether this integer equals 0, 1, 2 or 3, the drunk (a point on the screen) moves north, east, south or west.

```
direction ← integer part
   of (random × 4)
if direction = 0 then X ← X + 1
if direction = 1 then X ← X − 1
if direction = 2 then Y ← Y + 1
if direction = 3 then Y ← Y − 1
display (X, Y)
```

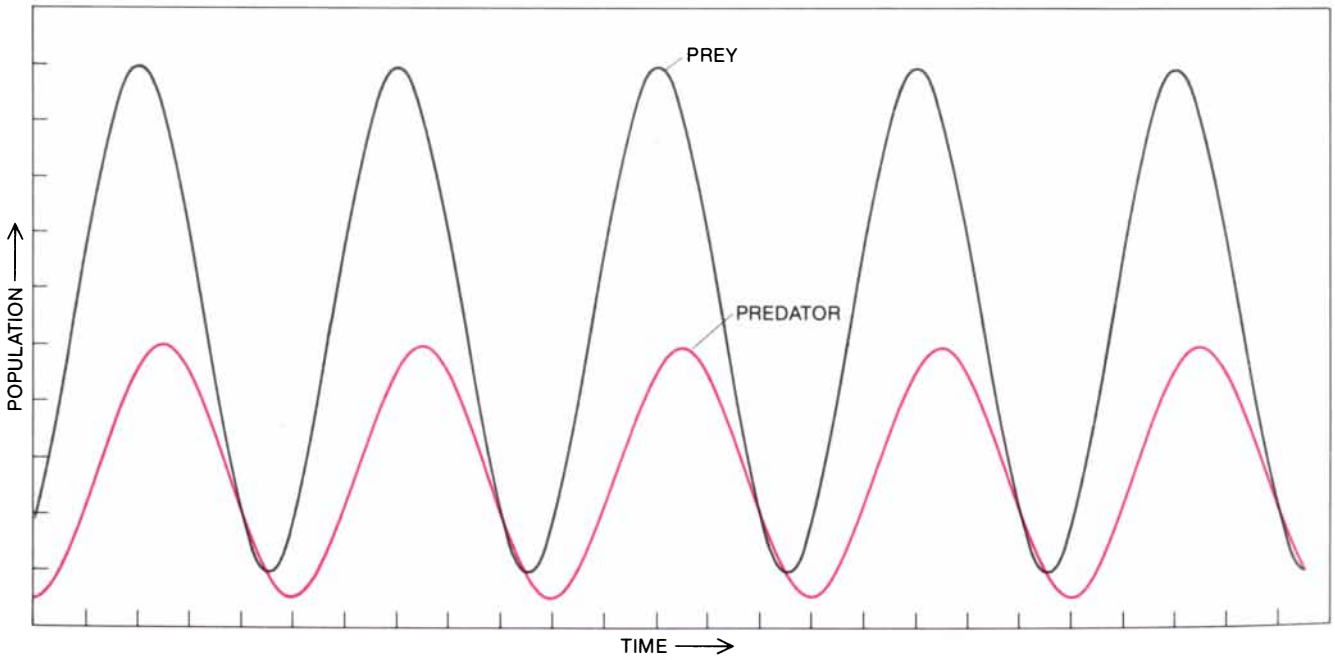
If your particular random-number generator produces a decimal number *random* between 0 and 1, this algorithm will scale it to a decimal number the value of which lies between 0 and .3999. The integer part of the resulting number must be 0, 1, 2 or 3.

I cannot claim that watching a point of light wandering minutely on your screen matches the ecological drama of the sharks and fish, but writing this program does give some insight into how parts of WATOR might be constructed.

Expert programmers reading this column will have thought of other approaches to writing the WATOR program. The amount of processing can be greatly reduced by using linked lists to



Numbers of lynxes and hares (in units of 1,000) trapped for the Hudson's Bay Company from 1850 to 1900



A theoretical predator-prey relation: a solution to the Lotke-Volterra equations

keep track of sharks and fish. With such a data structure the time required for one computational cycle is proportional to the number of sharks and fish present and not to the size of the ocean.

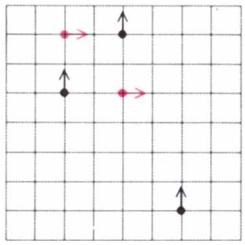
WATOR may yield some insights into animal populations here on earth. We know that small populations face a high probability of extinction and, even if neither predators nor prey die off, they are almost certain to undergo cyclic changes in number. In simple predator-prey ecosystems the predator and prey populations sometimes follow two overlapping cycles of population maxima and minima. The sizes of the populations of the varying hare and the Canadian lynx recorded by the Hudson's Bay Company from 1847 to 1903 in the Canadian subarctic follow this pattern [*see illustration on preceding page*]. The figures give the number of each species trapped from one year to the next. Presumably these numbers are proportional to the actual population sizes present during this period. If they are, the cycles are easily explained as the result of lynxes eating their way into an ever increasing hare population that begins to decline as the number of lynxes increases. Soon there is less food for the lynxes and they begin to starve, breed less or both. When the lynxes are reduced in numbers, the hares begin once again to multiply.

Contrasted with this chart is a smooth set of curves representing a solution to the Lotke-Volterra equations. These equations were first formulated in 1931 by V. Volterra, an Italian mathematician. They assume what might be called a continuous predator continuously in search of a continuous prey. The solutions to these equations exhibit a cyclic variation that, at first glance, appears to reflect the lynx-hare empirical data. Biologists are not in agreement, however, that the lynx-hare numbers are explicable by such simple reasoning. For one thing, at least two other predators of hares are involved: microbes and man.

It makes perfectly good sense, however, to compile statistics on the sharks and fish of Wa-Tor, and Magi and I have done so. Our recent graphs of the shark and fish populations tend to look more like the lynx-hare charts than the Lotke-Volterra solutions do. Still, we continue to be puzzled by the long-term instability shown by certain parameter combinations. Perhaps some reader, working with his or her own WATOR program, will provide further insight. Is there some kind of general rule we might use to predict, for a given combination of parameters, whether the resulting ecology will be stable? To what extent do the cyclic fluctuations follow the Lotke-Volterra equations?

The ocean of Wa-Tor is toroidal for a very simple reason: it is much easier to write a program for an ocean that has no boundary or shore. If the ocean is to be, say, 32 units wide, it is a simple matter to use numbers modulo 32 as the X coordinates of fish and sharks. If they have X coordinate 31 and appear on the right-hand side of the screen during one chronon, they may well have X coordinate $32 = 0$ and appear on the left side during the next chronon. The same system is used vertically.

The toroidal ocean of Wa-Tor gives rise to some very strange effects, as exemplified by the following puzzles. The first of these effects involves a bug in an early version of my WATOR program. This bug caused each fish to swim one unit north and each shark to swim one unit east during each chronon of time. Thus a shark got to eat a fish only if it found itself occupying the same location as its prey. In the ocean below, how many fish were never eaten by sharks?



Another puzzle involves intelligent sharks and fish. Suppose each shark and each fish takes turns moving to any of its four neighborhood points. It turns out that a single fish, if it is intelligent enough, can always evade a single shark, no matter how intelligent the predator. In the toroidal ocean of Wa-Tor, two sharks hunting a lone fish may produce a different ending. If you endow each creature with all the intelligence you like, even allowing the sharks to hunt cooperatively, can you discover a way out for the fish? The result does not depend on the dimensions of the ocean.

The subject of perceptrons ["Computer Recreations," September] reminded some readers of applications and spurred others to investigate the subject on their own. Ed Manning of Stratford, Conn., built a "perceptron of sorts" 10 years ago designed to convert real images into the digitized squares of a perceptron's retina. Manning was one of a few people who noticed a mistake in the multiple-rectangle window perceptron shown at the top of page 34 of the September issue: the last four demon patterns should each be half blue and half white. Manning wondered whether the mistake was "intentional to plumb readership." I am tempted to say that it was.

Gary D. Stormo, an investigator in the Department of Molecular, Cellular and Developmental Biology at the University of Colorado at Boulder, has used the perceptron concept in automated pattern recognition. Specifically, he has constructed a perceptron-weighting function to recognize binding sites in messenger-RNA nucleotide sequences. He uses the perceptron convergence theorem to guide the performance of his perceptron toward an optimal level. The results have been very encouraging: the perceptron recognizes binding sites with "substantial success."

Any window perceptron that includes either an all-white or an all-black window pattern in its list is a good perceptron. Lowell Hill of Venice, Calif., noted this and wondered whether an all-white or an all-black retina constitutes a legitimate picture. The answer depends on the pattern. It seems reasonable, in the case of the multiple-rectangle perceptron, to regard an all-black retina simply as one large rectangle.

In the course of a most successful foray into the mini research project I suggested, Constantine Roussos of the Lynchburg College Computer Center in Lynchburg, Va., decided to exclude window perceptrons with all-white or all-black window patterns. Among his achievements is a characterization of good perceptrons (those that recognize at least one pattern). The characterization uses translational relations between the window patterns on the perceptron's list. If one shifts a window pattern by a single unit in any of the four principal directions, one must obtain another window pattern on the list. Roussos then concentrated on minimal window perceptrons, those with a list that cannot be further reduced without destroying the goodness of the perceptron. Such perceptrons are building blocks for the set of all good perceptrons. Roussos wrote a computer program that discovered all minimal window perceptrons having list sizes of orders 2 through 5. No minimal window perceptron of order 6 exists. Roussos raises a challenge by turning around the task I had set: I proposed that readers find a pattern recognized by a given perceptron; Roussos suggests discovering a perceptron that recognizes a given pattern.

John M. Evans of Hartford, Conn., blames perceptron failings on the restriction inherent in a two-level hierarchy of local demons reporting to a single head demon. By introducing a kind of demonic middle management, Evans overcomes the connectivity limitations for ordinary perceptrons discovered by Minsky and Papert. The low-level demons themselves constitute a kind of retina whose blacks and whites correspond to whether particular demons report or not. A second layer of demons watches the pattern created by the low-level demons; it reports the presence of subpatterns to the head demon. A three-layer device can distinguish which of the four test patterns are connected and which are not.

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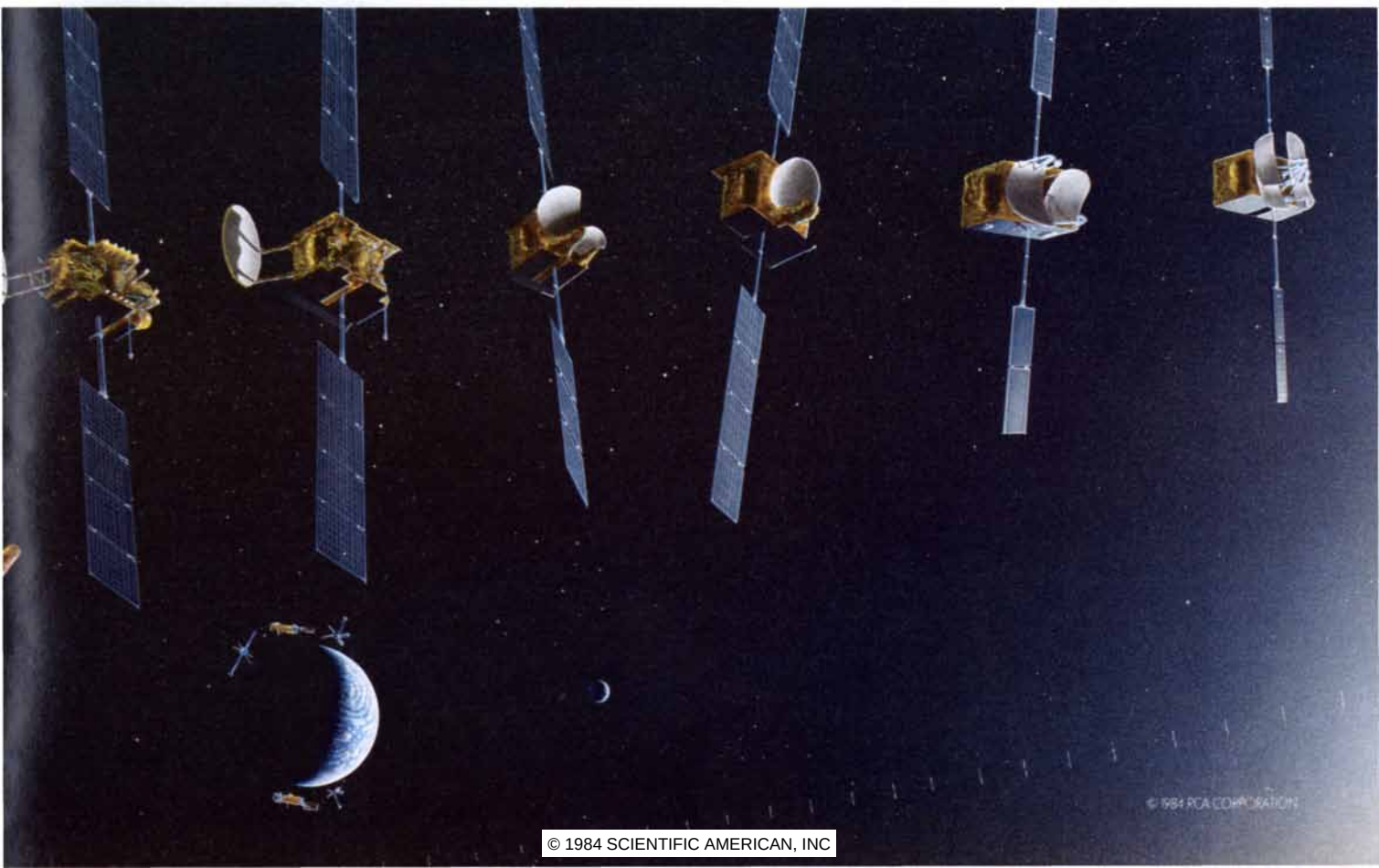

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BOOKS

A holiday celebration of books concerning science, for children and other explorers

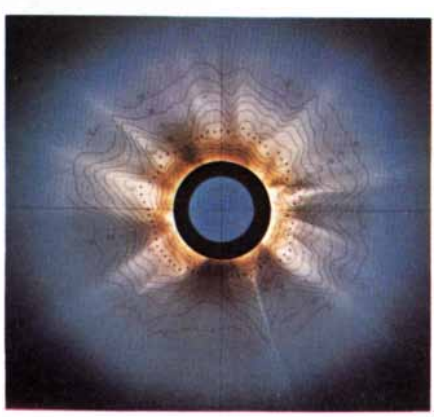
by Philip and Phylis Morrison

These reviews present only a small fraction of the worthwhile new books. This year we saw high quality in every category. It is disappointing, however, to encounter so few books about the laboratory sciences.

Time, Scale and Motion

BEYOND VISION, by Jon Darius. Oxford University Press ($29.95). The Science Museum in London has given birth to a new national museum, devoted to photography, film and television. This substantial volume brings to any reader the inaugural exhibition held there: a set of 100 photographs of historic scientific interest made between 1842 and 1982 and presented in chronological order. Quite a few are in color, which is often an indispensable part of their significance. Most of the photographs are displayed on a large full page; some are accompanied by smaller auxiliary images. They are evidence of the variety of visual data on which our view of the world has been founded. "The sensitive photographic film is the true retina of the scientist," said P. J. C. Janssen in 1888. (He took marvelous photographs of the solar surface, none of which are here.) The net is cast widely and includes many contemporary video techniques.

Most images depend on or imply a theory, without which meaning is meager indeed. A few are so direct that the most innocent viewer grasps their importance at once: the unlikely gape of the last Tasmanian tiger needs no interpretation. The shadowy bones of the imaged hand of Wilhelm Konrad Röntgen, signet ring on his finger, at once recall the sense of wonder that circled the world as 1896 opened, marked by the beginning of 20th-century physics, with its new visualizations of an unseen microcosm. We can admire in almost the same easy style views of submarine hot springs or the Voyager photographs of the strange volcanic moons of Jupiter. The camera has moved the viewer nearer to the object through 700 million miles of space or a couple of miles of seawater; otherwise the image is quite familiar. The sea-floor geyser shown is more or less just what the *Alvin*'s brave pilot saw down there with his own eyes.



A solar eclipse

A few motifs repeat, in a spiral of our visualizing power: cells, viruses, atoms, particle tracks, the corona of the eclipsed sun. The earliest time-stopping photograph shows a mortar shell caught by the first snapshot shutter in 1858; Thomas Skaife maintained that his "optical brake" worked in a 50th of a second. The latest optical brake stops a pip of laser light in a matter of picoseconds. Bullets, trotting horses and a somersaulting cat lie in between.

Spectra are here too. From the very first they are more abstract. Here is the daguerreotype of the sun's spectrum, made by J. W. Draper in Virginia in 1842 and sent for publication to Sir John Herschel. It is hard to make out the dark lines. The final pages show a tiny image-tube spectrum made in 1982 by Ann Savage and Bruce Peterson using an objective prism on the U.K. Schmidt telescope in Australia. Their measurements of red shift established one insignificant dot among thousands on the plate, already singled out as a radio source, as the most distant discrete object known. A quasar of remarkable luminosity, it lies some 10 billion light-years away.

Dr. Darius is a museum curator of wide research experience, as both astronomer and physicist. He has provided an impressively detailed page of support for each photograph and an excellent list of primary references. Amidst all this technical variety there are few noticeable slips. The awesome mushroom cloud of the first thermonuclear explosion of 1952 shown here in color is accompanied by a full but confused description of the secret device.

Any good reader can profit from this splendid gallery of the sights of science; science students at the higher levels will find the annotated pictures wonderful challenges for closer study and full discussion.

NEWTON AT THE BAT: THE SCIENCE IN SPORTS, edited by Eric W. Schrier and William F. Allman. Charles Scribner's Sons ($14.95). Everyone is now aware that science and technology (at a level well beyond the common-sense distillation of experience that served the Greeks) play an ever increasing role in the winner's circle of every sport. Look at the aerodynamics of the dancing knuckleball, still poorly understood; the clever cams (recalling the Nautilus exercise machine) in the bicyclist's new crank set, with which American over-the-road cyclists began to make veteran French wheelmen take notice; the famous tale of the bulbed Australian yacht keel; the pub dart with a tungsten-alloy barrel up front; the pasta dinner—spaghetti, not spinach—meant to load up the marathoner's muscles with a fine store of glycogen.

The short pieces in this anthology of magazine columns treat those examples and some three dozen more, from Frisbee design (not yet rationalized) to astroturf. Nontechnical and journalistic, they gain authenticity because they flow largely from interviews with expert participants in all these novelties: athletes, designers, physicians, coaches and manufacturers. It is easy reading for kids, all the more so once they have grasped the idea that it is okay to hop the line in order to pick and choose dishes from this cafeteria menu of sporting science. It is disagreeable that a book bearing the aegis of the A.A.A.S. lacks dates (even by the year) for the highly topical selections comprising the volume.

Earth, Sky and Sea

THE SECRET LANGUAGE OF SNOW, by Terry Tempest Williams and Ted Major. Illustrations by Jennifer Dewey. Pantheon Books ($10.95). Ten chapters of this engagingly original book have titles that are words from the language of an Inuit group that lives along the Kobuk River in Alaska. In this region where the Arctic Circle touches the sea there is a taiga of scrawny fir and birch; alder thickets mark the banks of streams and soft moss is underfoot. We meet the people a little and hear a few of their stories. But this book is not about them or their speech. It is about snow and how it works, a piece of Arctic ecology that uses their science.

Snow is snow to people who flee it by rushing inside. But to the Kobuk, who for all their electric light and snowmobiles still hold snow as a way of life, it is perforce more varied and real than that. Their language has categories for kinds of snow that English lacks, pieces of scientific description distilled from long observation. Consider noisy unstable *pukak,* which can slide in avalanche; *siqoqtoaq,* mature sun crust, its surface glassy at night, or *qamaniq,* the hollow bowl in the snow where the evergreens shadow the ground. The hollow protects the seeds from which the landscape of spring will grow as surely as the first dogtooth violets blossom there, while all around the open meadows are still quilted in snow.

The physical origins of each snow are explained here simply. There is the regrowth of crystals as colder new snow layers overlie the earlier, warmer falls; there is the rime growing on cold vertical surfaces that stop the warmer wind, and a variety of other forms. These conditions are decisive to hunter, vole and all the other living forms neatly adapted to the Arctic life.

If you would probe the geology of a snow cover, simply dig a big hole at some place where the snow lies fairly deep. The layers will show up, particularly if you examine them through a hand lens. Their texture and mechanics can be tested with a finger; then you might "imagine yourself a tiny meadow vole" living within the *pukak.*

The authors and the artist know their snow, from books, from the laboratory and in the field from skis; Ted Major is a naturalist and teacher and now the manager of cross-country ski operations at Yellowstone. He and his collaborators do not neglect the deep feelings that go with the searching snowy way of life: each chapter opens with a poetic page. Any good reader close enough to snow and skis to sometimes dream of them will find this work a fine introduction, attractive for the proverbial age span, from eight to 80.

THE RISING OF THE WIND: ADVENTURES ALONG THE BEAUFORT SCALE, text by Jacques Yvart, illustrations by Claire Forgeot. The Green Tiger Press ($15.95). Consummate artistry makes this remarkable book a harmonious mosaic, half poetic fantasy, half striking visual rendering of the quantitative scale of wind strength that we owe to Captain Sir Francis Beaufort. For each of the 13 steps of the echelle Beaufort a large right-hand page shows a colorful painting, posterlike in its unity with the words it bears. At Force 10 there blows a whole gale. We read the wave height. The wind speed is expressed in four different units. Boxes display Beaufort's careful texts, suited for observers on land, near shore and on the

Force 5 on the Beaufort scale

open sea. A whole gale described for landsmen reads "seldom experienced inland; trees uprooted; considerable structural damage occurs." We see vividly the uprooted trees and the sea with high foam-whitened waves. At Force 0, a calm; the smoke rises vertically from the fisherman's peaceful pipe, and wave height in the blue sea is nil.

So much for one of the worlds here joined; the other is the running text, itself illustrated by a large number of strong and simple woodcuts mainly in color. It tells a magical story of two island children, in a time so long ago that children still remembered how to swim with the fish and fly with the birds. With their friend the blind Poet they enjoy and endure all the winds along the scale including the terror of the hurricane, celebrating each with a verse. The tale closes on a day of calm, perhaps a happy end, perhaps only a memory of the gentle beginning.

Both Beaufort and the blind Poet wrote the same last line: "The sea is like a mirror." At Force 2 near the shore, notes the captain, ships "with light canvas and topsails full and bye make 2 knots." A delightful glossary of such sailor's terms adorns the margins.

TO KNOW THE STARS: A SIMPLE GUIDE TO THE NIGHT SKY, by Guy Ottewell. Astronomical Calendar Publications, c/o Department of Physics, Furman University, Greenville, S.C. 29613 (paperbound, $5). EXPLORING THE NIGHT SKY WITH BINOCULARS, by David Chandler. Paintings by Don Davis. David Chandler Co., P.O. Box 309, La Verne, Calif. 91750 (paperbound, $5.95 postpaid). These books complement each other; each is a guide to the night sky, visually of immediate and lasting help, pedagogically no less than gifted.

Mr. Ottewell is himself astronomer and artist. His book offers a dozen simplified maps of the night sky, each corresponding to a month and accompanied by a text page that presents the myths of the constellations, along with some comment on the reality overhead. Stronger still is the text of the thin book, some 16 pages of explanation. It begins with straightforward directions for viewing the night sky, suitable for grade school readers. At once a succession of imagined circumstances leads the young sky watcher to recognize the reality we know behind appearance. First of all, let sun and earth vanish; then the picture is simple, "just you, space, and the stars." It is sun and earth, night and day, horizon and yearly round that make it difficult to know the stars. A few pages with sketches give as good an account as can be found of the changing night sky. The scale of space is made graphic and the muster of the brightest stars and nearby stars is given. Meteors and their showers are nicely announced, open for viewing around the year. The maps are drawn for the north Temperate Zone, where most viewers dwell. This logically simplified compilation for children and their untrained friends is more or less timeless; no program is given for the intricate dance of moon and planets. But there is no more straightforward guide to the stars of the sky.

If you know your way a little with unaided eye about the night sky, the next step is the use of a good pair of binoculars. A steady hand makes a powerful aid to astronomical exploration out of the same instrument someone uses by day for watching football or seeking birds. The Galilean wonders appear: the moon's craters, Jupiter's four moons, the phases of Venus, swarms of stars in open clusters such as the Pleiades. All the best (northern) sights are nicely mapped and described here, with the season for each, and the paintings quite accurately evoke just what you will see. A dark sky is the most difficult requirement for the marvelous sight of several external galaxies. During and after the final weeks of 1985 the show will include a faint but exciting glimpse of Halley's comet, swinging near on its once-in-a-lifetime visit. It is a good year to learn to use binoculars.

Young people old enough to have some access to the night sky, winter or summer, and to search patiently for a considerable time are the likeliest to gain from Chandler's practical guide. Binoculars allow good tracing of the constellations even though you live under lighted city skies.

Technology

ANNO'S FLEA MARKET, by Mitsumasa Anno. Philomel Books ($10.95). Once again this artist who is so crazy about drawing takes his readers on a

wordless journey through riches. This time the trip is all in one place on one day, within the square of a walled city. There one Saturday from dawn to dusk the citizens hold a magnificent flea market. The voyage is for and about small artifacts, everything people might make or grow and then cart for sale to the kids, the men and the women who wander through and fondly examine these wonderful old goods.

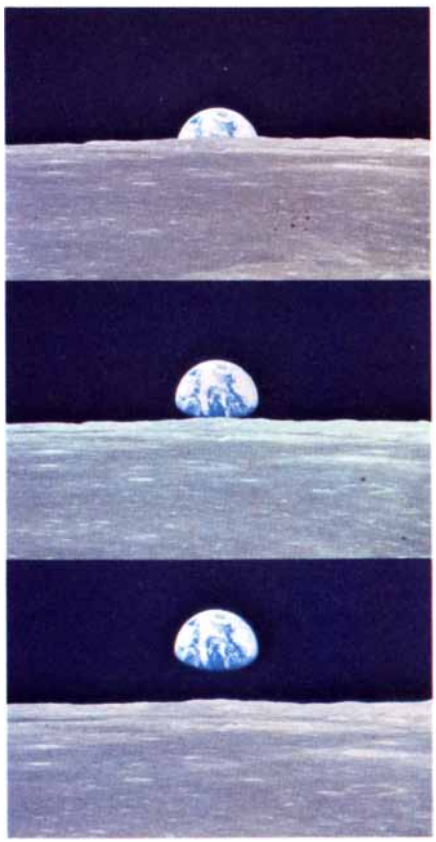
Page by page the objects are spread before you on tables, pushcarts and cobblestones. Examine one spread. You find large crabs, bushels of shellfish, flower bulbs, half a dozen varied plows, some 50 other farm implements, plenty of smith's tongs with an anvil and bellows, a rack of violins, mandolins, cellos and contrabass viols, daunting false teeth and dental tools, churns, grindstone, simple threshing machines, a big lawn roller, some handmade pinwheels and a cartload of fresh fish. There are about 15 such double spreads. Need one list more? A small galleon and two steam locomotives, one so old and small that it had no cowcatcher, exceed the rule for size. The date is even more sharply limited; nothing here seems to have been made since the 1930's. A baker is loading his wonderful brick oven; a telescope, a microscope, an orrery, an astrolabe and a pair of mounted human skeletons in seeming conversation are for sale to the scientific. There is a tabletop arrayed with varied antique telephones, and another one of fine old cameras, but no electronic devices, not even a tube radio. A queue of women wait patiently to try on slippers, one perhaps of glass; a young woman is enduring being laced into a gown that is far too tight for her. Mr. Toad appears to be there with an old car, but not the red one. This is a display of wonderful junk from East and West among people of every dress and age, all drawn with admiration, knowledge and humor. The blond mermaid is stuffed, but the performing bear and monkey are quite real.

WOOD WORKS: EXPERIMENTS WITH COMMON WOOD AND TOOLS, by William F. Brown. Illustrated by M. G. Brown. Atheneum Publishers ($11.95). "This is a book about things that work. Children *everywhere* have *always* made things that work." It is a happy fact that this book works too. Fifty informal yet careful pages outline 14 projects for grade school carpenters; among them are a pinball machine (a theme for many variations), a very tall flagpole and Savonius' rotor. There is a fine little introduction to millwork, by way of belts of elastic cord with pulleys improvised out of half a dozen likely beginnings, such as broomsticks and spools. There is a context also: dates and people and little sketches of famous forerunners in the machine arts.

Even better perhaps are the first 50 pages. In the same candid and helpful tone the authors introduce young and active readers to the right use of simple tools: a hammer, a saw, goggles, clamps, a square and a ruler. For less than $20 a pair of partners can set up. How to use tools, nails, glue, lumber and sheet lumber, paint and odds and ends of wood and metal is the central topic of the work.

The social environment of builders is no less important than the physical kit. "Do it yourself does not mean do it alone. Learn to use help.... Too much help isn't helpful." Here is how to start, how to find work space, how to locate wood: "Everyone wants to build. Everyone wants scrap sometimes. Everyone enjoys a polite request." Recycled wood saves for everyone, and the pages tell just where to look for it, in the neighborhood, the Yellow Pages and shops helpful to small customers. Surprisingly complete yet never patronizing, this book glows with the light of long and thoughtful experience in working beside children. Older tyros could do a great deal worse than to follow its wise leads; they might add an electric drill to the kit.

ENTERING SPACE: AN ASTRONAUT'S ODYSSEY, by Joseph P. Allen with Russell Martin. Two hundred color photographs. Stewart, Tabori & Chang, Inc. Distributed by Workman Publishing ($25). In the shuttle life in space is no longer Spartan: you wear sport shirts and slacks, eat barbecued beef and sleep in a bunk of your own, although with feet on the floor and head halfway to the ceiling. A photograph shows the author enjoying weightless life by pursuing an escaped orange-juice sphere with ready soda straw.



Moonscape with earthrise

The odyssey here is only a week's trip or so in orbit, between the flaming thrust of launch and the dead-stick landing in the desert. Dr. Allen, a trained physicist, is a man ambitious to teach well, and he does that here with his writer-colleague. This account of what it is like to round the earth 17 times a day is direct and clear, full of nontechnical detail.

The 10 airplanelike windows supply the best few pages of this day-by-day story. It is the earth the crew sees through them, the earth from 200 miles up, in endless change on the silent voyage. Sudden spellbinding sunsets follow each other every 45 minutes. Each staccato night is marked by untwinkling stars in velvet blackness like that of a desert sky. The earth too is black at night, black as the void of space, save for the faint clusters of glowing light that mark the great cities of the surface, the orange-red pulsing of great forest and grass fires, and the fireworks of thunderstorms. (How can one say the earth lies below? It as often seems to be above, according to the perceptions of the traveler.)

By day there is more to see, and we who read can share it. The clarity of the text here is matched by the brilliance of the photographs, which document what an ordinary camera sees from the shuttle. Of course, the photographs here show more than the shuttle itself, inside and out, for some look back into the past glories of NASA and some seek to evoke the future as well, beyond earth orbit. Here are not one but three shots in sequence of the earth setting on the airless moon. Here is a remarkable view of the shuttle orbiter, sunlit against night black space, caught by a satellite it had just released. The final image shows an untethered astronaut against the blackness, a human satellite in orbit, the blue curve of earthsphere to the side.

It is altogether a strikingly beautiful book (printed in Japan) and a timely one, but only in the few pages of preface did Allen allow a personal tone to sound over that of the careful, reflective observer he is. When he was a boy, he writes, he hoped for adventure, perhaps as explorer, cowboy or race-car driver. It was not to be. Now, he reports, his children, David and Elizabeth, "bored by astronauts, want to become explorers, cowboys, and race-car drivers, and to do a host of truly exciting things when

they grow up." Other kids who read this book may dream of headlong adventures in space.

FUN FLYING! A TOTAL GUIDE TO ULTRALIGHTS, by Gareth J. Kimberley. TAB BOOKS Inc., Blue Ridge Summit, Pa. 17214 (paperbound, $10.25). Personal yet wide in outlook, this brief book tells the story of the "giant step backwards." That backward leap, of course, was the recent development of powered aircraft meant entirely for fun, whose general performance, speed, range and weight were all below that of the Wright Flyer of 1903. Mr. Kimberley flies for Qantas out of Sydney; he recounts from direct experience the international narrative of the ultralight airplane with the good judgment you would expect.

Otto Lilienthal pioneered the hang glider well before Kitty Hawk; he crashed tragically after a stall at 50 feet in 1896. The renaissance in hang gliders came in about 1963, when a water skier of Sydney, John Dickenson, adapted the NASA Rogallo parawing as a tow kite for his sport. In 1969 Australian ski kiters came to San Francisco, and soon the Rogallos and a few other designs were operating as hang gliders down seaward slopes around San Francisco Bay. By 1976, on both sides of the Pacific, powered craft had appeared, flown by then not merely to begin a glide but for their own aerial virtues. That step was clearer in Australia, where regulations defined minimal aircraft soon after Ron Wheeler's Scout first flew. (That 130-pound plane, now Mark III, is on the market in Sydney; you can even get floats for it!)

An exceptionally interesting chapter tells of the choices the author made in the design of his own ultralight a few years back. The piece is not meant to teach aircraft design but is an introduction to that wonderful art by a man who succeeded. He is not a professional designer or engineer but a pilot of 9,000 hours experience: "I must have learned *something,*" he engagingly says.

He did: his Sky-Rider flies neatly at 40 miles per hour. Besides the excellent history and the design chapter, he provides more conventional chapters on theory, weather, airmanship and learning to fly. In an ultralight the first flight is a solo. A final chapter supplies photographs and specifications for about three dozen ultralight designs from several countries. No single small book could be a total guide to this risky and demanding sport, but this is a first-rate introduction, as good for the firmly earthbound as for the hopeful flier.

By now the mushroom growth threatens a curious reversal; within the past two years U.S. ultralights have tended to increase in performance. Engines were 20 horsepower; now they are 50. Speed was 35 m.p.h.; now it is 65. Fast flight motivates enclosed cockpits; complete little airplanes come to replace minimal fliers. The leap is being reversed, and the very nature of ultralights is called in question.

Biology

SUCH AGREEABLE FRIENDS: LIFE WITH A REMARKABLE GROUP OF URBAN SQUIRRELS, by Grace Marmor Spruch. Drawings by Nurit Karlin. William Morrow and Company, Inc. ($9.95). That's the Village for you. Even the squirrels there are out of the ordinary, athletic, hungry, brash, discerning diners. They interact with that species found in such density around them, the one that casually holds so rich a supply of delicious hard-shelled nuts. (Peanuts, like the staple acorns of the wild world, are food for squirrel body but not for soul.) This delightful book, as clear-eyed as it is loving, is an artful chronicle worked up out of a diary of a decade and more of intimacy with these graceful, clean and little-understood city rodents, written by a most literate physicist.

Her husband, a humorous and patient man, another (N.Y.U.) physicist, calls the author "One-Parameter Gracie." Her theorizing here is founded on enthusiasm, to be sure, but it is no less penetrating for that and throws light on urban squirrels and urban humans alike. It is of course individual Eastern gray squirrels she has spoiled, watched closely, tested out and now and then lost her heart to—for a while. The relation began in 1970, when one hardy squirrel made its way through the window ajar at the top of the fire escape into the fifth-floor walk-up the Spruchs lease on Eighth Street. A variety of characters populate the book. There is many a squirrel (no two are the same once you learn to discriminate) seen from immature youth to old age and disappearance. There is also the watching couple, and a variety of consultants and confidants in the human world. These range from eminent behavioral psychologists to the periodontist who offered to make a bridge for an ailing squirrel. (A proper veterinarian in fact filed down the dangerously unmatched lower teeth.)

Grand leaps and powerful nut cracking are convincingly explained. The animals regularly leaped upward three feet even though missing the railing at the top might cost a five-floor fall. They never missed. But the move down the same three feet was usually made by a vertical climb: the kinematics of a bouncing ball gives the insight.

Village squirrels are not only imagined as special. The Spruchs lived for a time on the suburban fringe of Cambridge, Mass. There wary, skittish squirrels live the sweet life, among plenty of trees, well-fed dogs and few cars; they "would have nothing to do with us." City people love squirrels, freely give them handouts, even nurse the ill; the animals are viewed as entertainers, a valued last link with nature. In the suburbs squirrels are the enemy, suspected defilers of attics and manifestly robbers of costly birdseed.

The story continues, although the squirrels are only beginning to come back to Eighth Street after a few years of low population. This is an amateur's model experience; it ought to be enjoyed and emulated one way or another by many city kids. The valuable, lightheartened but serious book, albeit small, deserved an index.

SHELLS: FORMS AND DESIGNS OF THE SEA, by Andreas Feininger. One hundred and fifty-two photographs by the author, a few in color. Dover Publications, Inc. ($8.95). SONGS OF THE GARDEN, by Utamaro. Annotation by Yasuko Betchaku and Joan B. Mirviss. Facsimile in color of a woodblock book. Metropolitan Museum of Art and The Viking Press ($19.95). Visual representation of the real world is an important task of the natural scientist, but it lies at the core of the work of the artist. These two books of images are works of art within the broad domain of realism; they do not attempt even to classify or to catalogue, but they represent what is beautiful within a carefully limited segment of the natural order. The works are as accessible to the youngest readers as they are prized by the most sophisticated. Libraries will find long-lasting use for both books.

The photographer Andreas Feininger has seen shells not as specimens but as objects of wonder and beauty, placed into compositions, viewed close up or lighted with shadow and contrast. The pigmented growth markings of the Royal Purple Olive, to choose only one of these large images, seem to recede to the horizon like a range of crystalline peaks. The volume is a bargain selection from an expensive book of a decade ago.

Utamaro Kitagawa painted 15 designs of crickets, horseflies, bagworms and a mantis to illustrate a cycle of humorous love poems. Published in 1788, the cycle consists of a series of woodblocks under a Japanese title simply rendered as "The Book of Insects." The creatures appear in their familiar places, on garden plants, which are themselves mostly recognizable from the painting. "Since childhood, Utamaro has enjoyed observing minute details," his old painting master wrote in a postscript to the unorthodox book. The gifted engraver preserved the artist's detail by carving his cherry-wood blocks "as if untangling a spider's web." The editors' gloss identifies insects and plants and translates

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A HERITAGE OF

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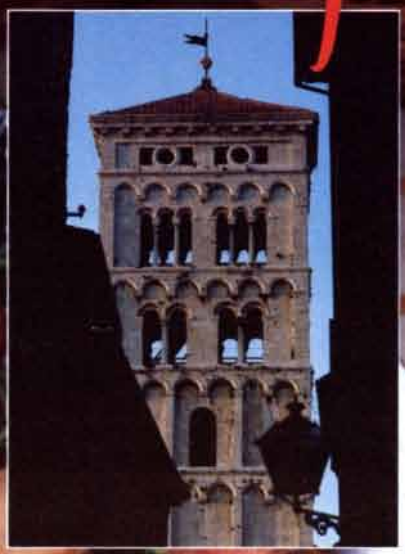
My wife Vicki and I recently discovered the great beauty of Lucca's art and architecture, and while exploring the dozens of markets and restaurants we rediscovered the absolute naturalness with which wine and food should be enjoyed together. Though this ancient city has renewed itself over the years, it has done so without destruction of the past, preserving the history and culture of the town.

It is this same continuity of heritage that is the heart of our family winery. Since my grandfather founded Sebastiani Vineyards in 1904, wine styles have changed with changing tastes. But as we have grown and come to produce wines of even greater elegance and complexity, our original vision



Sam and Vicki Sebastiani shopping and sharing the holidays with friends in the ancient Italian city of Lucca.

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From my family to your family . . . Buon Natale!

Sam J. Sebastiani

remains intact, "Wine and food and family and friends are the classic ingredients of a gracious dinner table."

the brief poems, perhaps too elegant for our place and time. The entire work is a delight for sharp young eyes able to see beauty in the small world of the lowly.

LADYBUGS, by Sylvia A. Johnson. Photographs in color by Yuko Sato. Lerner Publications Company ($8.95). Half of the first page of this small, easy-to-read book shows a ladybug on a twig. Orange with black polka dots, the image of the little beetle is the size of your hand. The text—adapted from the Japanese—opens with the safe observation that no insect can match the favorable press enjoyed by these small predators. Fritz Müller's designer genes?

Excellent macrophotography all in color takes the reader through the life cycle of the beetles: mating, eggs, hungry larvae molting, pupae and the handsome adults. Those spots are variable and do not allow sure identification of a species; the common seven-spotted bright red species is not so variable.

It is on the aphid myriads that most ladybugs prey. Their strong jaws are suited for that hunt, but against tough ants the ladybug plays turtle. Ladybugs hunt on the ground; flight is for special trips, say when there is report of a fire at home. The two pairs of wings, the stiff showy covers and the transparent back wings that beat, are nicely contrasted in a number of photographs. Color is defense, in a way, for it warns of the bad taste any bird that rashly seizes a ladybug will find. In such an emergency some bitter orange blood actually oozes from the leg joints of the beetle.

The supply of beetles in quantity for garden and farm defense, a genuine trade, rests on collection of hibernating ladybugs that group in red-and-black bushelfuls in favorite sheltered spots. Refrigerated over the winter, they are sold and released in the spring to go back to work in hungry defense of human crops. The book is a natural for a close look into a life cycle attractive to grade school readers; it makes a useful introduction to anyone who wants to know about ladybugs.

CHARLES DARWIN AND T. H. HUXLEY: AUTOBIOGRAPHIES, edited with an introduction by Gavin de Beer. Oxford University Press (paperbound, $5.95). In the summer of his 68th year Charles Darwin wrote a warm autobiography, fascinating, earnest and candid, to provide a sketch of his mind for his grandchildren to read—and for many another. Only in about 1960 was the manuscript published in unexpurgated form; the version publicly known for almost a century had been decisively sanitized by his family on theological grounds.

Thomas Henry Huxley was of course "Darwin's bulldog," a productive scientist, a writer of lucid and supple prose, a leader of what he called "the New Reformation" around evolution and its implications. His sketch of his own life, written at 64 under at least a claim of protest—"autobiographies are essentially works of fiction," he said—is characteristically sharp and witty, if too brief to satisfy in full.

The two appear together in this bargain paperbound version of a volume a decade old. Very interesting photographs of people and places, and helpful supporting matter compiled or written by the editor, provide additional perspective. Among all the published lives of scientists there are yet few that rival the interest of this Victorian book.

ANIMALS OF COURSE! FEET, by Jill Bailey. G. P. Putnam's Sons ($3.95). A book of 12 pages, each five inches square and as thick as cardboard, these colorful photographs are aimed at the youngest members of the read-to set. Each one shows a strange but significant appendage, with the question "Who has these feet?" The next page gives the answer through a picture, except that the last page ends with "We do of course." Similar amusing views and tiny puzzles make up three other books in this international series.

Language and Mathematics

THE SECRET GUIDE TO COMPUTERS: VOLUME 1, by Russ Walter. Birkhäuser Boston, Inc. (paperbound, $14.95). Borne on a flood of frustrating books written by half-articulate authors and false pedagogues, this introduction to microcomputers and their culture is a Dayglow lifebuoy.

Content: In four chapters the reader is irresistibly led to the keyboard in a way that is like the learning of language by children. From the outset every instruction leads to a useful result. Step by step the student gains productive control of a programming language, until a creditable fluency is reached that encompasses branches, loops, random numbers, adequate mathematics and even the beginnings of structured programming style. The medium of instruction is BASIC. The structure is so firm that even if another language were the aim, following the book would be pure gain, although much carefully summarized detail would not be relevant. The rest of the chapters introduce the rich culture of computers, everything from a page about Ramón Lull to the hyperbolic history of A.I. There is a simple account of chips, disks, printers, games and monochrome art. It is here that Walter's candor shines; he makes clear, usually in uppercase, the faults and foibles others ignore or cast in vague hints. The effect is that of a private conversation with a well-informed and talkative friend who knows the inside story.

Style: The text reads like the patter of

a midnight disc jockey of bubbling talent; it is flip, self-deprecatory, randy and invariably good-humored, packaged in a bundle of corny poses. The teen-age reader is sure to enjoy it all; the strongly sexual humor (even a page or so of computer-formed soft pseudoporn) makes the book unacceptable for use by grade school kids in many schools. A version free of raunchiness is on the way.

Meanwhile Russy-poo is unique in the computer self-instruction world, both for the useful frank content and for the coherence of his style. The detailed account of the workings of the false psychotherapist Eliza, a wonderful old program that simulates by incredibly simple means a session of Rogerian psychotherapy, is all by itself worth the cost of the volume. First-rate advice on what and how to buy are part of the rich mix; no room that holds a small computer and anyone more than 16 years old who is learning to use the device is well equipped without "the only major book whose author's stupid enough to print his home phone number"—and then to answer it around the clock.

TRAIN TALK: AN ILLUSTRATED GUIDE TO LIGHTS, HAND SIGNALS, WHISTLES, AND OTHER LANGUAGES OF RAILROADING, by Roger Yepsen. Pantheon Books ($9.95). "The railroad is a country that stretches from Atlantic to Pacific, from . . . jungle to . . . tundra. Chances are, its weedy borders reach right into . . . your own town." A scruffy place, little changed in this century, it has languages of its own, languages that grew among the people who had to work effectively together as the trains sped along the skeins of track.

First of all there is the language of trackside signals. You might see some old semaphore arms; surely you will find high arrays of lights rather like traffic lights. On Conrail the signals are all one color, yellow, good for penetrating fog. The pattern lighted gives the word: proceed when three lights show in a vertical column, stop at once if the lighted row is horizontal. In the Baltimore & Ohio dialect they use color too, the same three colors as traffic lights, and a strange bluish tint called lunar white, meant perhaps for the fogs of the Chesapeake. Dwarf signals next to the rails go with the high ones; they look as though they were meant for "foot-high engineers" rolling by, but in fact they are watched by the crews of slow-moving trains around the yards. Sometimes they show purple instead of red so as not to distract the red-alert eye of a worried engineer on the main line.

On board there is a language in use among the crew that also includes warnings for the standstill world. Running lights and flags, swinging lanterns, the short and long blasts of steam whistles and diesel air horns, all encode mean-

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ings. Four longs signal that the train is coming to a grade crossing or station: look out! Then there is the highball, given by knowledgeable friends along the track whenever the train speeds by in good order. You can do it too, by pulling an imaginary whistle cord overhead up and down several times. The engineer might toot in cheerful return.

Boxcars too carry messages. They are unraveled here briefly. The book ends with a neat account of a little railroad archaeology, reading the old rails and the right of way for the marks of trains long gone by. Any grade school reader who lives near a railroad, busy main line or a quiet siding, will find a story here and an invitation to explore.

IS IT ROUGH? IS IT SMOOTH? IS IT SHINY? by Tana Hoban. Greenwillow Books ($10.25). IF YOU LOOK AROUND YOU, by Fulvio Testa. Dial Books, E. P. Dutton, Inc. ($10.95). HOLES, by Joan Elma Rahn. Houghton Mifflin Company ($9.95). These three small books center not on words but on pictures. They form a graded set of introductions to a meaningful look at the real world; if you like, they are the roots of observation and its conceptual maps. The first book, by the gifted photographer Tana Hoban, presents 30 color photographs, shiny pennies in the hand, fuzzy cotton in the boll, a crinkled elephant, a wonderfully fibrous pile of hay and a young girl draped in a shining costume of metallized plastic. Color and sharp detail present the engaging spectrum of texture in a setting of reality that is the first fruit of this wordless book. The photographs also hold a great deal more, to be amplified by any imaginative prereader and an older friend.

The second book has a few words, one sentence to a page. For each text page there is a page with a whimsical scene painted in color. Kids or their pets are present in a wide range of settings out to a rocket ship with a good view, boy and girl bound for the moon. The words are geometric: point, line, circle, cone, sphere. Our world is a sphere, like a ball. Far enough away, even the big round earth looks like a point among the stars. The concepts are deep; the pictures carry them lightly.

Joan Rahn's pictures are clear black-and-white photographs of the real. The text now employs a few sentences for each picture; this is genuine early reading for meaning. We encounter physical as well as geometric concepts: a hole can be a straw or the space under a bridge. It can allow passage, like a door and an underpass, or it can bar it, like a screen. A hole can hold fluid, like a sponge or the tip of a pen, or it can retain a button. Recorder, stencil, string bag, fan and the lips of a girl saying "cheese" and "chose" display other meaningful examples of the empty form, by no means a nothing! The book is a small field guide to holes, serious but pleasant beginning reading. The author has provided a witty boost to common sense.

People and Their Tales

TEAM WORK: A PICTURE ESSAY ABOUT CREWS AND TEAMS AT WORK, by George Ancona. Thomas Y. Crowell ($10.95). "Two people tied to each other with a rope and harness—that's the only safe way to climb a mountain." Up they go, these two partners. She leads first, inching up the rock face, wedging a metal chock into some crack and snapping her rope onto it: protection. Far below he holds the rope end fast around a rock. Once on the first ledge, she in turn belays the rope from above, to hold her partner safe as he climbs. They reach the wide view at the top only after many leapfrogging steps. Careful climbers, they leave nothing, removing their chocks and snaps as they climb. What a team!

Six larger and more diverse teams fill out the book. Each team is shown at work clearly, with its tools and its blended, interdependent skills. First come the hefty roughnecks who drill gas fields. They work in crews of four, under a tool pusher who supervises all three shifts at a well. Those steel tubes are heavy, but length by length they are threaded together to enter the long hole as it is bored around the clock. The tall derrick and its power assists make it possible for the crew to manhandle by chains and main force the forgings that grasp and turn the long drilling string.

A hospital nursing team of a dozen women and men, a small film crew, the pit team of a stock-car-racing entry, a fashion-design team of designer, patternmaker, cutter and two experts to sew the samples, and four men who crew for a 24-foot racing sloop fill out these teams. Every team member's name is listed in the book. Of course each team is embedded in a much larger social context, here more or less ignored: even the mountaineers are not alone on the summit. They need their steel fittings, strong rope, maps, training, food, the days off. The problem of an economic society built of cooperating strangers by the millions is the problem of the modern world, beyond the team. This is a warmly appealing start toward appreciation of face-to-face groups organized around a shared task.

THE STORY VINE: A SOURCE BOOK OF UNUSUAL AND EASY-TO-TELL STORIES FROM AROUND THE WORLD, by Anne Pellowski. Illustrated by Lynn Sweat. Macmillan Publishing Company ($14.95; paperbound, $7.95). CAT'S CRADLE, OWL'S EYES: A BOOK OF STRING GAMES, by Camilla Gryski. Illustrated by Tom Sankey. William Morrow and Company (paperbound, $6.95). In Zaire and Angola and other places too the itinerant storytellers may bring out a vine to which are tied a number of objects that mark stories current in the repertoire. Anyone can point to an object and thereby order up a story.

Anne Pellowski is an experienced storyteller and teacher of the art. Her imaginary vine is loaded with folkloristic objects that help her to tell each of her stories. They include string figures, pictures made with markers or drawn in sand, dolls (particularly the nested *matrioska*), finger play, the setting of riddles and musical accompaniment on the *sanza,* the African thumb piano. For each mode she furnishes a few chosen tales, careful details for what to do and a page or so of references to books with more stories.

Pellowski's inventory is worldwide: she tells two stories along with ancient sequences of string figures, including a cat's cradle. One is a story made up afresh by three girls she met in Baldwin, Wis.; the other was shaped in Tonga a few years ago out of an old tale about a yam farmer. She intends her book more as a resource for storytellers and their teachers than simply for reading; certainly it works well in both roles, particularly if a number of young friends pool their energy and talents in one of the directions mapped.

Camilla Gryski is also a cheerfully learned friend of these time-honored active entertainments. Her book offers a full guide to string figures, the ones described in the first book and a dozen more, along with a nice elaboration on their distribution and techniques. There are no stories to go with them, but there are intriguing captions to the named figures, telling how to make the green parrot fly or how to summon the magic that reveals the Apache door. She writes: "Anthropologists used to be described as people with their pockets full of string." Her pocket is thus; she lives and works in Toronto, and she carries string for nimble fingers all across Canada.

NOAH'S ARK, by Michael Harrison and Christopher Stuart-Clark. Oxford University Press, distributed by Merrimack Publisher's Circle, 47 Pelham Road, Salem, N.H. 03079 ($14.95). The book is a kind of crowded literary Ark: poems, songs, riddles, paintings, plays are gathered here, more than two by two. The first theme is the tale of the Flood, recounted in versions from Gilgamesh to the Miracle Play of Chester. Next, the pages walk through a bestiary in verse, each page from Albatross to The Zebras displaying a drawing or a painting. Some of the poets cited bear celebrated names: Gerard Manley Hopkins, Roy Campbell, Ted Hughes.... But there are many others, old and new. John Mbiti offers a snake's fierce song: "Neither bows nor guns have I/But I

Noah's ark

flash fast with my tongue/And I have/ Venom, venom, venom!"

The cargo of words includes the animals never seen after the Flood, the dragon and the unicorn, and other beasts corrupted by their imaginary state of being. The episode of the dove, the replenishment of the land, is enlarged on, along with modern warnings of a second flood, against which the rainbow was an early talisman. The postscript is a song of the Pygmies of the rain forest, a song like a distant echo far from the floodlands of Genesis. It declares their fright at the "Mighty bow of the hunter on high,/ Of the hunter who chases the herd of clouds,/Like a herd of frightened elephants,/Rainbow, tell him our thanks./Tell him: 'Do not be angry!'/ ... Rainbow, tell it to him."

This is a fine anthology, spanning folklore, poetry and visual image, mainly contemporary, those made for the young and for us all. A sense of the unity of culture arises out of the particularity of each work of art.

There is one fault with this tasteful and devoted book: the sources are often hard to learn. They are mentioned solely as acknowledgments, good for authors but frustrating for readers, who seek not recognition but more light. If the source of the Gabon Pygmy song is given at all, it was missed in a long search of tightly printed lines of copyright holders. That same fault mars many an artfully made collection.

WHY CORN IS GOLDEN: STORIES ABOUT PLANTS, illustrated by Susana Martínez-Ostos, text adapted by Vivien Blackmore. MY SONG IS A PIECE OF JADE: POEMS OF ANCIENT MEXICO IN ENGLISH AND SPANISH, illustrated by William Stark, text adapted by Toni de Gerez. Little, Brown and Company ($12.95 each). These two thin books—the entire series numbers four—are apt for reading to the youngest children while they watch the brightly painted large pages. The first book tells seven old tales of the people of Mexico long before Columbus, stories of the golden corn and the dark aromatic chocolate, of sunflower and aloe. The opening story tells of a time long ago. The flowers

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ON EARTH—NASA SPACE STATION.

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were already beautiful but confused. "If anyone said, 'Flower,' they all turned their heads, ... for they had no names of their own."

The second matching book presents a dozen poems about golden fish and turquoise birds and cotton that grew in balls of every color, and even of true storytellers who use words of joy. These metrical short lines are translations from the Nahuatl, the language of the Toltec who long ago lived north of the Valley of Mexico, in modern Tula. They were transcribed from the old manuscripts after the conquest, and they are given here side by side in English and Spanish versions. Both books were made by scholars and artists in Mexico and printed there; they bring a freshness many young readers need and value.

Field Guides

THE NEW YORK CITY WILDLIFE GUIDE: WILD CREATURES OF NEW YORK CITY AND WHERE TO FIND THEM, by Edward R. Ricciuti. Illustrations by Suzanne Connah Ames. Nick Lyons Books/Schocken Books (paperbound, $9.95). A FIELD GUIDE TO AIRPLANES OF NORTH AMERICA, by M. R. Montgomery and Gerald L. Foster. Illustrations by Gerald L. Foster. Houghton Mifflin Company ($11.95). "There are serpents in Manhattan, muskrats in Staten Island, foxes in the Bronx, sandpipers in Brooklyn, and pheasants in Queens." These serpents are not a metaphor for citizens who prey on the gullible herds that throng Broadway; they are snakes proper, mainly the northern brown, or DeKay's, snake, slim-bodied, less than a foot long, marked with two rows of dark spots. The species has adapted to urban life, finding shelter and plenty of insects and worms in debris-strewn vacant lots, say in Greenwich Village. "It is actually more abundant in the city than in adjacent areas."

Overall the city is warmer than the environs, its drainage is far sharper, both air and water are fouled. It abounds in manmade cliffs where a host of pigeons nest, along with a few fierce peregrines to hunt them. It provides foodstuffs everywhere, transiently as garbage and for the long term in a few large dumps. These provisions are relished by the most successful of the larger urban wild species, our commensal raccoons, possums, crows, squirrels and Norway rats. They live as appealing beggars, cunning scavengers, or gnawers and nibblers in hidden places. The next link in the food chain joins on naturally: as long as rats and squirrels abound, there is food for big red-tailed hawks. Aloft above the dumps and landfills they wheel, or perch high on some tall cabled pole near Central Park or Prospect Park. The long grassy strips that divide and border highways go tangled and unmowed these summers, in an era when the troubled city economizes on its appearance. Insects and mice flourish there, and above them patrol keen-eyed kestrels, to whom an expressway can be as open country. Look up for those colorful little falcons whenever you sit in a traffic jam by day, save in winter.

So the small book goes, listing and discussing about 120 species of animal, from the pink Arctic jellyfish often swarming off city beaches to the little brown bat and the great blue heron. There are many drawings of these city creatures, and lists of times and places to seek them, in particular some two dozen parks in all the boroughs where wildlife watching is good.

Observation of fliers that are the handiwork of our own wingless species provides another form of birding. This airplane book, the first American guide of its kind, cogently and delightfully supports participants in this pastime. About 300 species of aircraft are depicted and described by two expert watchers, who live not far from the extension of a busy runway at a big military and civil airport just west of Boston. Here you will see the sparrows of the class, such as the Piper Super Cub, a high-wing single-engine fabric plane "common as crabgrass." There are the predators, such as the widely seen F-16, a combat fighter by General Dynamics, described as "a bundle of graphite-epoxy wrapped around an afterburning turbofan jet." Ten families of planes are grouped by configuration, from biplanes and crop dusters to business and airline jets and military aircraft. The emphasis is on visual description, using the idea of field marks pioneered by Roger Tory Peterson for feathered birds: easily seen features that allow discrimination among species. The choice of models is meant to include native or naturalized types, but not the exotics or the home-built. Every plane you can buy a ticket for is here; you can tell the two three-jet widebodies apart by noting that the DC10 rear engine extends straight through the tail fin, whereas the Lockheed L1011 tail engine exhausts through the end of the fuselage.

One inference is explicit in these factual paragraphs: evolutionary convergence is strong in aircraft design today. The Airbus A300, product of a European collaboration, and the all-American Boeing 767 look and perform alike. Two business jets, one designed in Canada, the other in Japan, differ only subtly, indicating "the limits to the imagination imposed by the science of aeronautics."

What is a field guide? Plainly we do not view the category as limited to natural history. Above all, it is a book presenting an observable set of examples that can be regarded as evidence related to one theme; the emphasis is usually but not always visual. A good field guide is more than a reasoned catalogue; it should raise by precept and by example the beginnings of theoretical unity within the factual diversity displayed. It offers at least the promise of an inductive growth in understanding, even where that cannot be complete.

This year there are many good field guides in the sense outlined; interest will determine selection.

THE WHALE WATCHERS' GUIDE, by Robert Gardner, illustrated by Don Sineti. Julian Messner (paperbound, $5.95). The compact book presents drawings of a couple of dozen of these wonderful beasts, both the usual full view, as though seen close up in some magically vast aquarium, and three more little sketches showing each species as it really appears to a lucky watcher approaching the living animal at sea. About half of the book provides an agreeable general background. Will there be whale ranches one day in the lagoons of the atolls and no more hunting of the wild whales?

MACMILLAN ILLUSTRATED ANIMAL ENCYCLOPEDIA, edited by Dr. Philip Whitfield. Macmillan Publishing Company ($35). The first drawing of all shows a spiny anteater, the last the extraordinary ocean sunfish. In between a dozen species of rabbits are drawn, occupying two pages in beautiful color and texture. They take their place in a global company of 2,000 other beasts grouped with their kin in fur, feathers, fins or scales, all succinctly described; size and habitat are made clear.

THE DINOSAUR ENCYCLOPEDIA, by Dr. Michael Benton. Simon & Schuster, Inc. (paperbound, $5.95). This small, colorful book lists and categorizes some 130 dinosaurs, form by painted, reconstructed form, from Acanthopholis to Zephyrosaurus.

FIREWOOD: A WOODCUTTER'S FIELD-GUIDE TO TREES IN SUMMER AND WINTER, by M. Michaelson. And Books, 702 South Michigan, South Bend, Ind. 46618 (paperbound, $7.95). Range maps and photographs of form, bark, leaf and fruit guide you to a warm winter evening; more than 50 species of trees are included. (Cutting the trees is of course not obligatory.)

BASEBALL ACCESS, edited by Richard Saul Wurman. Access Press Ltd., Los Angeles, Calif. (paperbound, $4.95). The most appealing of a series of guides in bright modern color, this slender book treats the teams, the parks, the history, the equipment, the physics and the stratagems of our national sport brilliantly. It is most informative for field use facing the television screen.

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Children and the Elderly in the U.S.

Since 1960 the elderly have fared far better than children at the hands of society. The reasons are related to shifts in the relative sizes of the two groups and to changes in the American family

by Samuel H. Preston

In the 1960's and 1970's two developments that had not been expected by demographers changed the age structure of the U.S. population in a dramatic way. The first was a decrease in the number of children. From 1960 to 1982 the number of children younger than 15 fell by 7 percent. The decline was mainly due to the drop in the birth rate that followed the "baby boom."

The second development was a rapid increase in the number of elderly people. Between 1960 and 1980 the number of people 65 or older grew by 54 percent. The increase was caused mainly by a sharp reduction in the death rate among older people, acting on a population that already was large because of the large number of babies born between 1890 and 1915. As a result, during the 1970's the elderly population of the U.S. increased at a higher rate than the total population of India.

One might expect such a change in age structure to help the young and hurt the old. Fewer children should mean less competition for resources in the home and greater per capita availability of social services such as public schools. More old people, on the other hand, should put great pressure on resources such as hospitals, nursing homes and social security funds. I believe, however, that exactly the opposite has happened. Since the early 1960's the well-being of the elderly has improved greatly whereas that of the young has deteriorated. Demographic trends underlie these changes: in the family, in politics and in industry the growing number of older people and the declining number of children have worked to the advantage of the group that is increasing in size.

In order to account for what has happened to children and older people in the U.S. it is first necessary to document the changes in living conditions among the two groups. The measures that are commonly used by social scientists to measure the well-being of large groups include levels of income, health, educational achievement and reports of satisfaction with life.

One of the most straightforward ways to compare children with the elderly is to measure the fraction of the two groups that live in poverty. Since children generally do not have independent incomes, one cannot directly compare personal income. One can, however, measure the incomes of the families in which the children live and compare the incomes to a minimum standard of need. The Bureau of the Census uses an Economy Food Plan drawn up by the Department of Agriculture as the basis of such a standard. Families that have an income equal to an amount less than three times the cost of the food plan are said to be living in poverty.

By this standard there have been remarkable changes in the proportion of children who live in poverty compared with the corresponding proportion of the elderly. In 1970, 16 percent of those under 14 lived in poverty compared with 24 percent of those older than 65. By 1982 the situation had been reversed: 23 percent of children lived in poverty compared with 15 percent of the elderly [*see illustration on opposite page*].

Monetary income is not the only measure of material well-being. Noncash transfer payments such as food stamps and Medicare have a strong influence on the condition of society's dependents. The Census Bureau estimated that in 1982 the market value of noncash transfers was $98 billion, much of it in medical payments to the elderly. If this sum is taken into account, the disparity in poverty status between children and the elderly is increased further. The fraction of the elderly living in poverty in 1982 falls from 15 to 4 percent. The corresponding reduction for children is only from 24 to 17 percent.

An examination of public outlays as a whole reinforces the idea that the elderly have done better than children at society's hands in recent years. Mary Jo Bane of Harvard University concluded that in 1960 the average government expenditure (including Federal, state and local funds) on each elderly person was about three times the expenditure on each child. Both types of spending increased rapidly in the succeeding decades; hence the ratio remained about the same through 1979. Because the expenditure on the elderly started from a higher level, however, the absolute gain for each elderly person was much larger than the gain for each child.

Since 1979 there has been a sharp break in the pattern of government expenditure that kept the ratio of per capita outlays for the two groups roughly constant. Many public programs for children have been cut back while those for older people have been expanded. For example, the Aid to Families with Dependent Children (AFDC) program has been substantially reduced. In 1979,

out of every 100 children in poverty 72 were enrolled in AFDC. By 1982 only 52 out of 100 were in the program. In comparison, Medicare outlays rose from $3.4 billion in 1967 to $57.4 billion in 1983, and it has been estimated that they will rise to $112 billion by 1988.

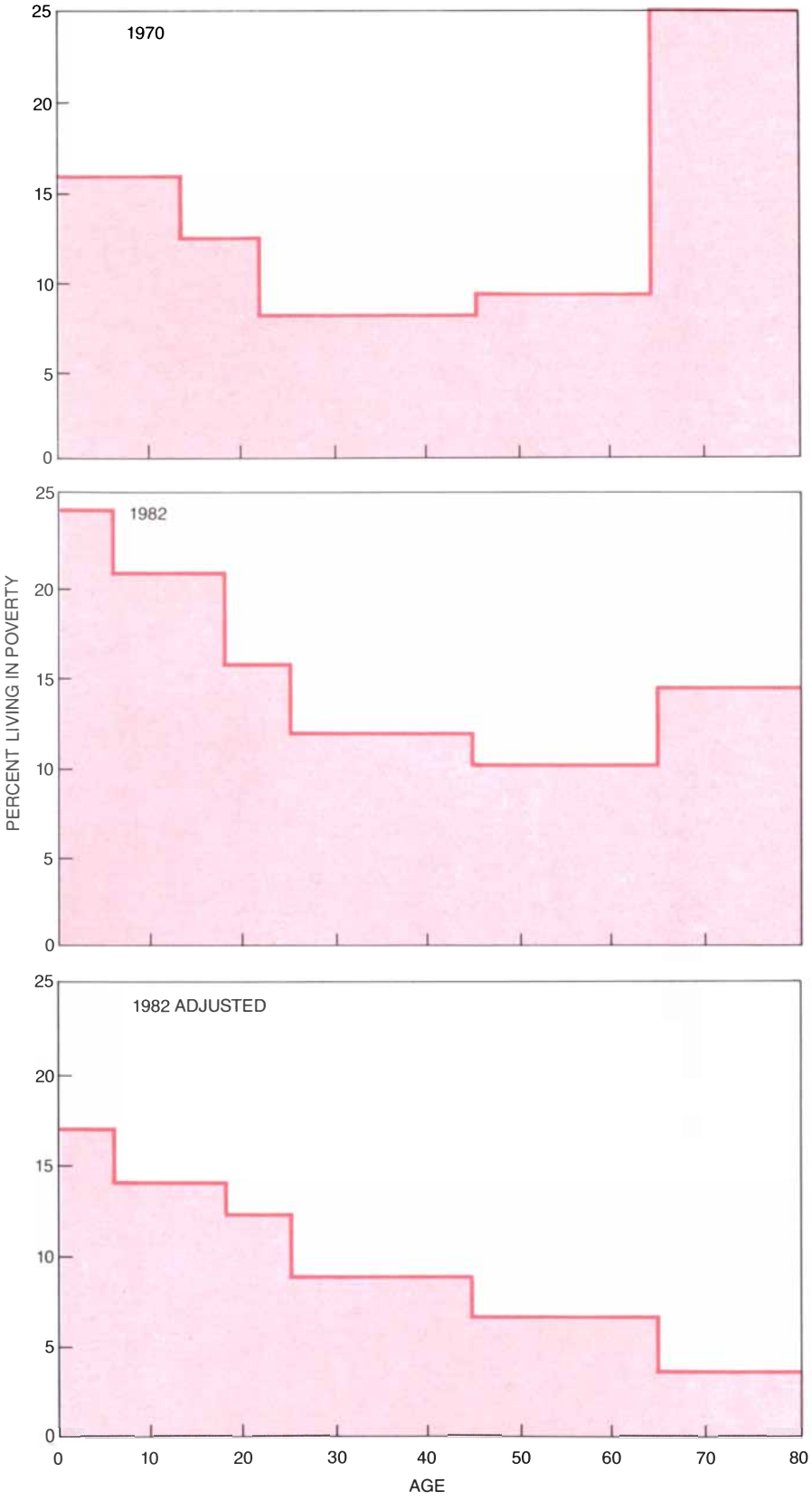
The Federal Office of Management and Budget has recently begun estimating the fraction of all Federal benefits that are directed to those who are 65 or older. Older people got $44 billion in Federal funds in 1971 and $217 billion in 1983. The 1983 figure is equivalent to about $7,700 per person who is older than 65 and is a sum larger than the total spent on national defense in that year.

Federal expenditures on children are harder to calculate, but I have attempted to do so from budget documents. The total Federal outlay on the major child-oriented programs (AFDC, Head Start, food stamps, child health, child nutrition and aid to education) is about $36 billion for 1984; this is about a sixth of the total spending on the elderly. Because there are more children than old people, the expenditure per child through these programs is less than a tenth the expenditure per older person. These figures are not strictly comparable to the data collected by Bane, but they do give a sense of the increasing disparity between public outlays on the young and those on the old.

The gulf in well-being that separates the old and the young has been widened still further by the fact that public spending on the young has become less effective. The largest portion of public money spent on the young goes to public schools. Many indicators suggest the quality of public schooling has declined drastically in the past two decades.

The sum of the scores on the verbal and mathematics sections of the Scholastic Aptitude Test (S.A.T.) declined by 90 points from 1963 through 1980. The Wirtz Commission, which was the most authoritative group to investigate this trend, concluded that about half of the decline was due to the fact that a wider range of students now take the test than took it in the 1960's. About half of the decline, however, represents an actual decline among students with qualifications similar to those taking the test earlier. Most of the real decline took place in the early 1970's. In addition there has been a decrease in the proportion of U.S. teen-agers who finish high school. In 1965 the fraction was 76.3 percent; by 1980 it had fallen to 73.6 percent.

Education is the principal public service for the young; health care is the principal service for the old. Some 69 percent of the medical bills of people 65 or older are paid for with public funds. The Congressional Budget Office estimates that in 1984 the Federal Government will spend an average of $2,948 on



INCIDENCE OF POVERTY among the old and the young has changed dramatically since 1970; the changes have been beneficial to the elderly and harmful to the young. Each panel shows the proportion of each age group in the U.S. population living in poverty. The measure of poverty employed is based on an Economy Food Plan formulated by the Department of Agriculture. Those with family incomes less than three times the cost of the plan are considered to be poor. In 1970 (*top*) a larger proportion of old people than of children were living in poverty. By 1982 (*middle*) the situation had been reversed: a much higher proportion of children lived in poverty. If the 1982 data are adjusted by taking account of noncash transfers such as Medicare payments (*bottom*), the relative advantage of the elderly becomes even clearer.

health care for each person 65 or older.

A good index of the effectiveness of public spending on health care is the mortality rate. Between 1968 and 1980 mortality rates improved in all age groups in the U.S. The improvements, however, were not equally distributed between the young and the old. Demographers employ statistical standards called "model life tables" to compare the relations of death rates in different age groups with the relations that would be expected from international and historical experience. If model life tables are used to analyze the recent changes in mortality in the U.S., it can be shown that the greatest improvements in the death rate have occurred in the older age groups. By normal standards of progress, children and young adults gained the least [*see upper illustration on opposite page*].

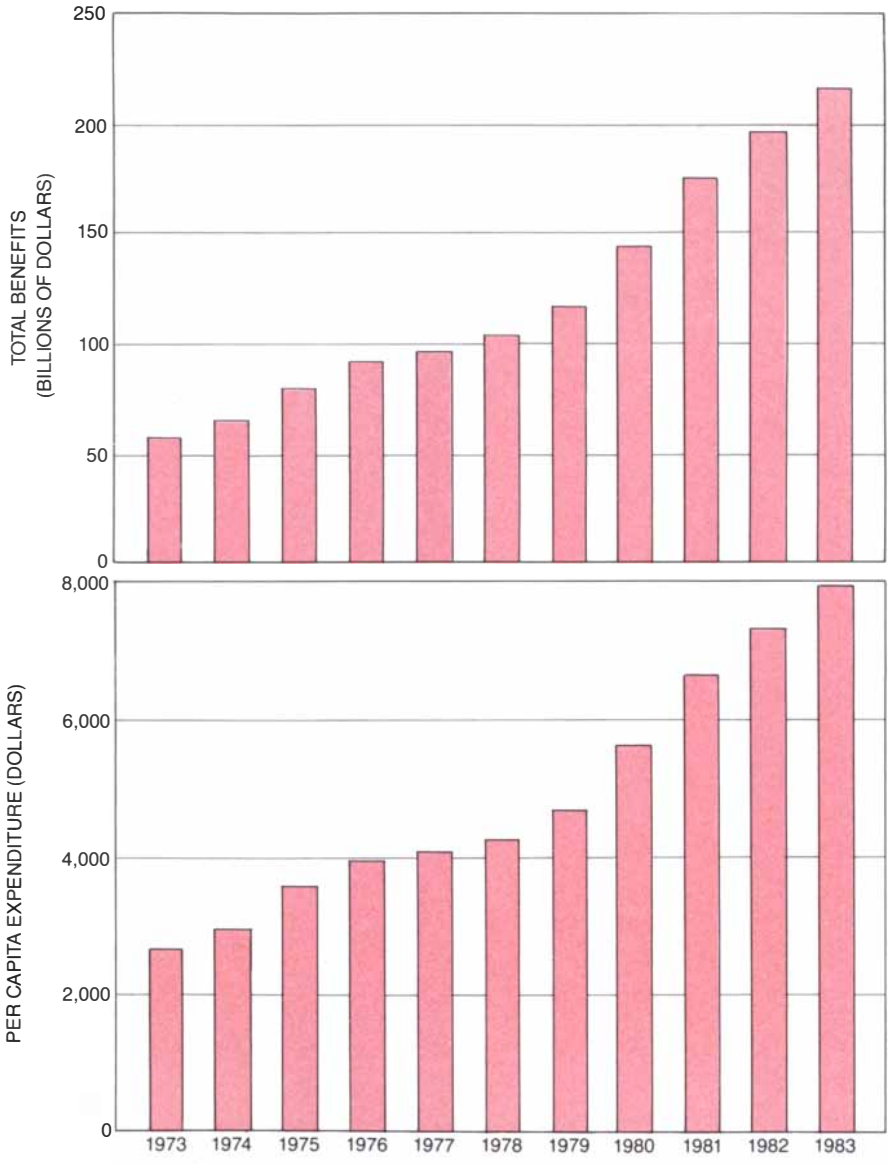
Thus according to several measures, including health, educational achievement and poverty status, the elderly appear to be doing better than the young. The elderly are not oblivious to the improvement in their welfare. A Gallup poll made in 1982 found that 71 percent of those 65 or older reported they were highly satisfied with their standard of living, by far the greatest level of satisfaction in any age group. The proportion of the elderly who scored "Very high" on a psychological scale of anxiety fell from 22 to 15 percent between 1957 and 1976, while the corresponding proportion of younger adults rose sharply. Furthermore, since 1960 there have been reductions in the suicide rate among the elderly, which also seems to suggest increased well-being.

Although suicide is rare among children, the trend appears to be upward. Other indicators also suggest that a deterioration has occurred in the mental health of children. The U.S. Health Examination Survey asked parents whether "anything had ever happened to seriously upset or disturb your child?" The fraction of parents who answered in the affirmative rose from 27 percent in 1963–65 to 37 percent in 1976.

The major reason for the increased emotional disturbance among children, as reported by parents, seems to be the intensification of marital discord. Indeed, changes in the structure of the family appear to be closely connected to what has happened to both children and the elderly in recent years.

One reason that changes in family structure can have such a strong effect on the status of dependent groups is that the family is an important vehicle for the transfer of society's resources. James N. Morgan of the University of Michigan estimated that roughly a third of the U.S. gross national product takes the form of transfers from income earners to nonearners within family groups that live together.

As a result, any change in the family's capacity to care for its dependents has powerful consequences for those who are being taken care of. These consequences are more significant for children than they are for the elderly because the family has relinquished to the state an increasing share of responsibility for elderly dependents. Hence older people are to some extent protected against changes in family structure.



FEDERAL EXPENDITURES ON THE ELDERLY have increased sharply since the early 1970's. The upper panel shows the total amount spent each year on those 65 or older since 1973. The lower panel shows the per capita expenditure. Federal expenditures on children are not listed separately in budget documents, and so trends are hard to measure. It appears, however, that expenditures on children have not increased nearly as fast as those on older people.

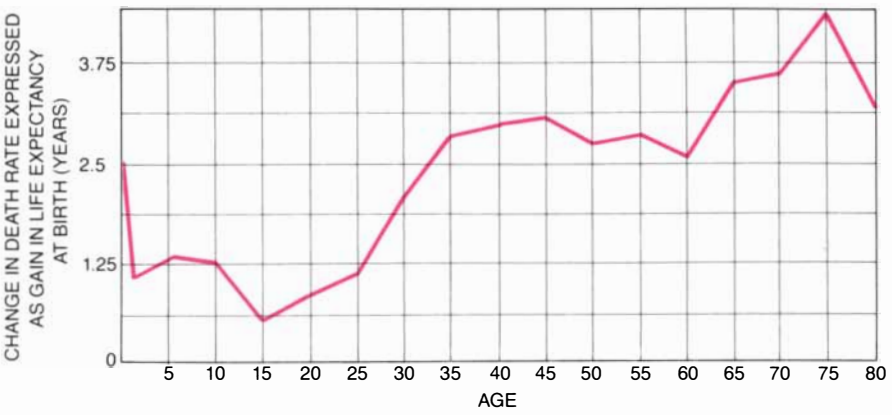
The situation is very different for children. The government assumes a much smaller share of support for the young than it does for the elderly. The conjugal family is the chief source of support for children. In recent years it has begun to divest itself of its responsibility for the young, just as earlier it abandoned much of its responsibility for the elderly. Absent fathers are the main factor in this divestiture. In 1960 only 5.3 percent of births were out of wedlock. By 1980 the figure had risen to 18.4 percent. The rate of illegitimacy has a strong influence on resources available for children because in most out-of-wedlock births the father takes no lasting responsibility for his child.

Even for children born in wedlock, the situation has deteriorated. According to Larry Bumpass of the University of Wisconsin at Madison, persistence of the divorce rates that prevailed at the end of the 1970's will mean that 43 percent of the children born in wedlock will experience parental separation before they are 16. If the rate of increase in

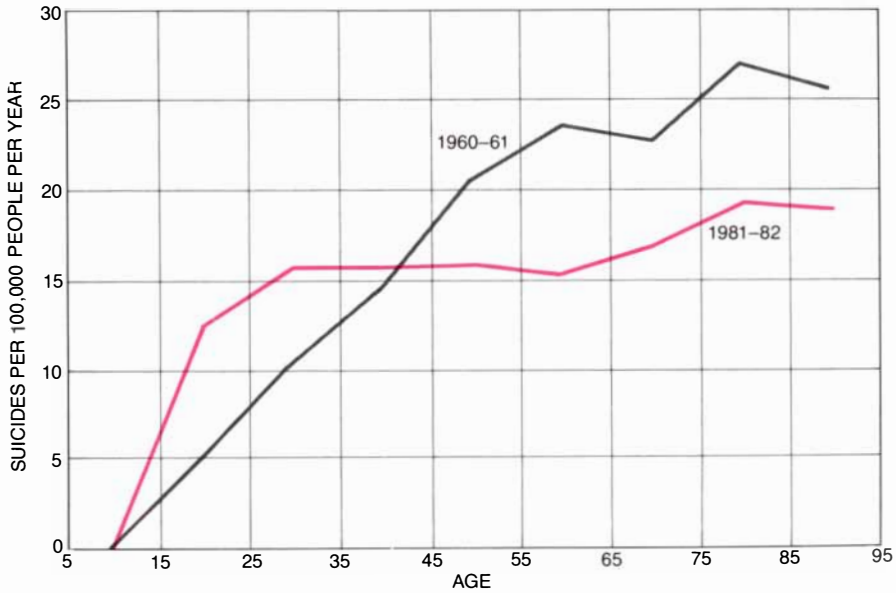
divorce of the past decade continues, the proportion could reach two-thirds. Furthermore, fathers contribute little on the average to the support of children from previous marriages. A recent study by the Census Bureau found that fewer than half of all children living with their mother after a divorce were supported by payments from their father. The immediate consequence is that the economic condition of mothers and children deteriorates after a divorce. Morgan and his colleague Greg J. Duncan conclude that in divorces occurring from 1972 through 1978, 72 percent of the affected children experienced a reduction in their family's income in relation to the minimum standard of need.

It is obvious that the economic consequences of marital disruption have much to do with the increase in the number of children who live in poverty. Census Bureau data show that 69 percent of the increase in the number of children living in poverty from 1970 through 1982 occurred in households headed by women. Evidence suggests that the instability of the nuclear family is also responsible for some of the decline in educational achievement.

The main vehicle other than the family for transferring resources to dependents is the state. In a pluralistic democracy such as that of the U.S. the formation of public policy is strongly influenced by the relative power of interest groups. In recent decades the old have become a far more powerful interest group, while the constituency for children has declined in power.



REDUCTIONS IN MORTALITY from 1968 through 1980 have been concentrated among older people. Changes in death rates at various ages can be compared by computing the change in life expectancy at birth that generally is associated with each change in mortality. Such relations are estimated from data on a wide range of populations. For example, the change in death rates for people aged 75 through 79 that occurred from 1968 through 1980 is normally associated with a four-year gain in life expectancy. At age 15, however, the corresponding gain was less than a year. The data suggest the health of the elderly has improved far more than that of the young. The curve for females is shown; the shape of the curve for males is similar.



SUICIDE RATE has increased among the young and decreased among the old in the past two decades, probably reflecting changes in psychological well-being. In 1960–61 the suicide rate increased steadily with age, reaching a peak at about age 80. By 1981–82 there had been sharp increases in the suicide rate among people in their teens. The curve for 1981–82 is fairly flat after age 35, however, suggesting that living conditions no longer deteriorate with increasing age.

In exerting their political influence the elderly draw on support from three overlapping but substantial groups. The first group consists of the elderly themselves. The second consists of members of the under-65 population acting on behalf of elderly family members who are currently or potentially in need of financial assistance. The third consists of the entire under-65 population acting on behalf of themselves in their own (future) old age. The elderly, unlike some other special interests, make up a group we all expect, or at least hope, to join eventually. Most government programs for those more than 65 years old are to some extent perceived as a social contract enabling middle-aged adults to transfer resources to themselves later in life.

Children have only one of these three sources of political influence. Young people cannot vote. Furthermore, adults cannot agitate to improve conditions in their own childhood, since that is the past. Children's only remaining source of political influence is parents acting on behalf of their progeny.

Because of the imbalance between the sources of political support available to older people and the sources available to children, the change in age structure can have a "multiplier" effect on public policy. The sharp mortality decline in the older age groups has led not only to an increase in the number of voters older than 65 but also to an increase in the number of middle-aged adults who have living parents and an increase in the number of years beyond 65 that the average adult can expect to live.

The most significant of these changes is probably the increase in the number of elderly. In the past decade the increase has been combined with a high level of political participation. In the 1982 congressional elections 65 percent of those aged 65 through 74 voted. This was the highest percentage of any age group and more than twice the rate among people aged 20 through 29. Once again the trend reverses earlier patterns: in the congressional elections of 1966 the voting rate for those older than 65 was lower than it was for any age group between 35 and 64.

The elderly probably have also come to exercise a stronger claim on the polit-

ical allegiance of those younger than 65. I estimate that in 1980 the average 40-year-old couple had 2.59 living parents and 2.72 living children. If present fertility and mortality rates persist, however, the average 40-year-old couple would eventually have 2.88 living parents and 1.78 living children. It would not be until age 52 that the average couple would have as many living children as they would have living parents.

When parents are 52, of course, most children have left home. It turns out that under current fertility and mortality rates there is no stage in the life cycle when the average married couple will have more children under the age of 20 than they will have surviving parents. The dependency concerns of the middle-aged are thus shifting toward the elderly, at least in numerical terms.

None of this would matter if people of different ages and in different domestic circumstances saw public issues in the same light. But they do not. For example, the 1983 Gallup Poll of Public Attitudes toward the Public Schools asked whether people would vote to raise taxes for schools if asked to do so by the local school board. Those younger than 50 were evenly split; those older than 50 were opposed by 62 to 28 percent.

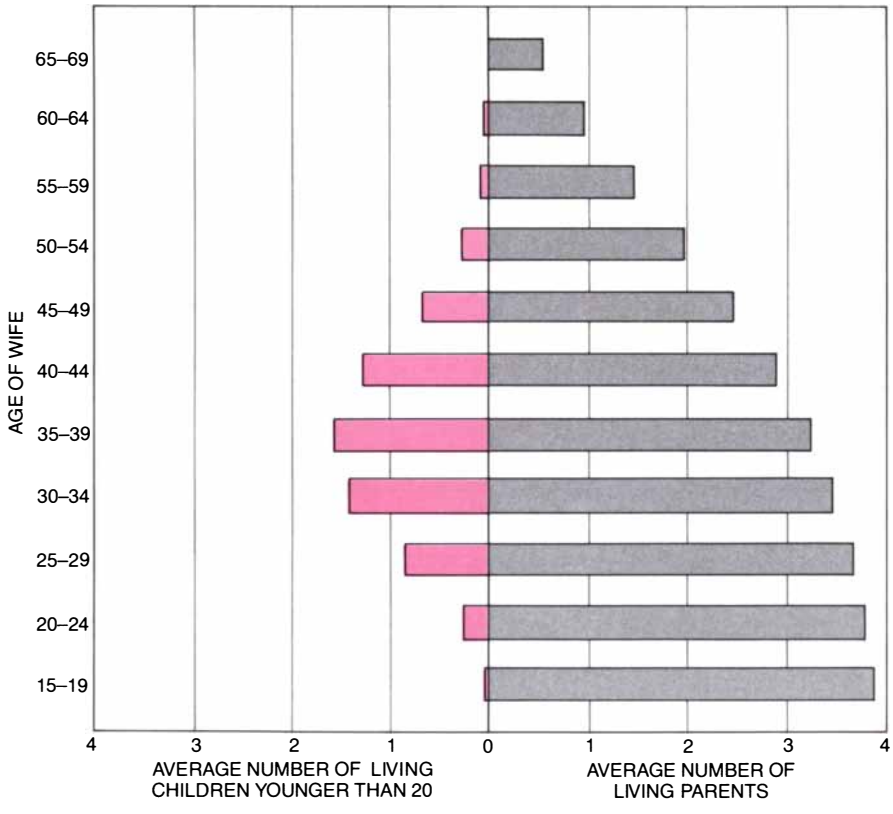
The foregoing discussion of politics deals only with the part of political behavior that is motivated by self-interest. What about altruism? Altruism is not a negligible motive in human affairs, particularly altruism directed toward people with whom an individual shares some corporate identity. I suspect, however, that W. Norton Grubb and Marvin Lazerson, then at the University of California at Berkeley, were at least partially correct in proposing that we have drifted toward a form of society and government based mainly on self-interest and adversarial relations between groups. Grubb and Lazerson argue that in U.S. society there has never been a strong sense of collective responsibility for other people's children. Furthermore, the wide availability of effective contraception could well have exaggerated this split between private and collective concerns. Reliable contraceptives give a married couple a high degree of control over whether they have children. Since children are now the result of a private decision rather than of chance, many people today think the parents should bear the cost of child rearing. On the other hand, we do not choose to have parents and so there is no equivalent motive for insisting that parents be privately supported.

A second factor that probably helps to suppress altruism toward other people's children is the fact that these children are increasingly from minority groups with whom the majority have trouble identifying: 24 percent of those younger than 15 are black or Hispanic, compared with only 11 percent of those older than 65.

Both in the family and in politics demographic mechanisms have improved the situation of older people in relation to that of the young. A third, quite subtle, mechanism operates to the same effect in the industries that provide services to the two dependent groups.

For the young, the most important service is education. The most significant recent trend in education has been the decline in enrollment. Between the early 1970's and the early 1980's public elementary school enrollment fell 11 percent and secondary school enrollment fell 18 percent. I think a persuasive argument can be made that the decrease in enrollment is one reason for the apparent decline in the quality of U.S. schools. On a casual examination the evidence seems to be to the contrary. Between the early 1970's and the early 1980's the total expenditure per pupil in constant dollars increased by 22.5 percent. The student-teacher ratio fell from 22 to 18. The average amount of professional experience of teachers rose, as did the fraction of teachers who had master's degrees. The problem is that none of these variables has been shown to be related to students' academic performance. Eric A. Hanushek of the University of Rochester recently reviewed 130 studies of factors affecting achievement in school. Hanushek concludes that the only reasonably consistent finding in the studies is that students' academic achievement increases with the intelligence of the teacher.

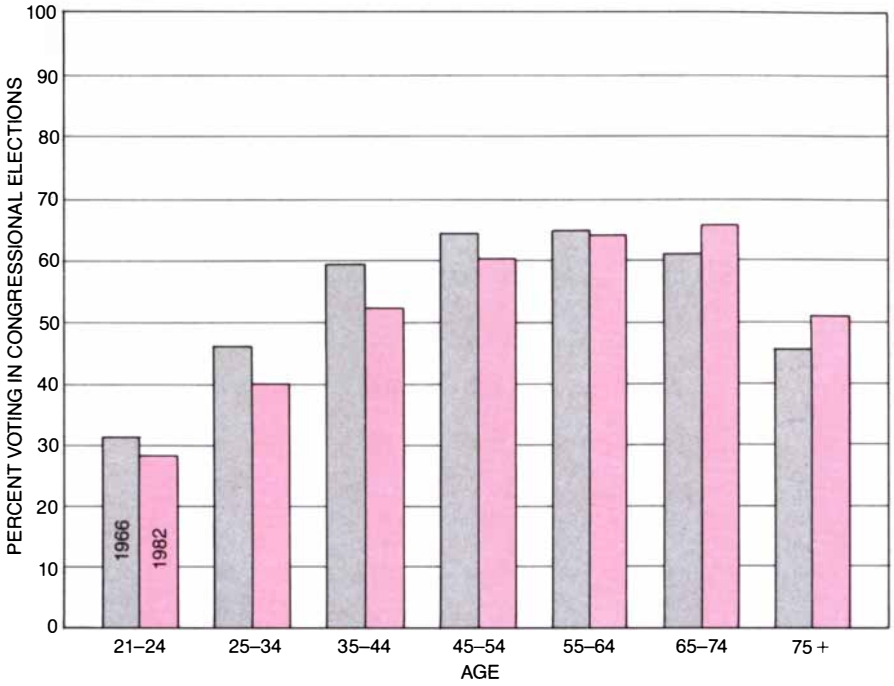
Since the quality of teachers is such an important variable and since better salaries would be expected to attract better teachers, the work of Hanushek and others focuses attention on working conditions for teachers. Hence it is surprising to note that teachers have not shared in the increased expenditures on schools. From 1973 through 1983 teachers' real incomes declined by 12.2 percent. Moreover, reductions in teachers' incomes are correlated with decreases in school enrollment. I used state enrollment and salary data to compare changes in teachers' salaries with changes in enrollment over the period from 1972 through 1982. The correlation suggests that in the 1970's for each decline of 10 percent in school enrollment teachers' salaries decreased about 1.2 percent.



BALANCE OF DEPENDENTS has shifted toward the elderly because of decreases in both birth and death rates. The chart shows the number of living parents and children under age 20 that the average working-age couple will have at each stage in life. Husbands and wives are assumed to be the same age. The data are based on the assumption that the fertility and mortality rates of the early 1980's will persist. Under this assumption there is no point when the couple will have more children than they will have living parents. Such trends have probably caused increasing concern among working-age couples about supporting dependent elderly parents.

The outcome of a reduction in average salary is predictable: the brightest workers, who can readily get other jobs, leave a field or do not enter it in the first place. This is what has happened in teaching. The decline in S.A.T. scores among all high school students is quite sharp, but the decline in S.A.T. scores among those intending to major in education has been even more acute. In 1973 future education majors scored 59 points lower than the national average on the combined S.A.T.; by 1982 they scored 82 points lower. The negative selection of those going into teaching has been aggravated by negative selection among those already in the field. The 1972 National Longitudinal Survey of high school seniors shows that the mean S.A.T. score for those who enter the field of teaching and then leave it is 42 points higher than the score of those who enter and stay. Those who remain permanently in the profession have a combined S.A.T. score 118 points lower than the score of those who have never taught.

The most plausible interpretation of these very unsettling data is that the demand for teachers was reduced by the decrease in the number of school-age children. The reduction in demand led to a lower average wage for teachers. Therefore a disproportionate number of the brightest teachers (who get the best results) left the field and many potentially good teachers avoided the field altogether. This result is clearly incompatible with the hypothesis that school districts would use funds liberated by falling enrollments to raise salaries and find better teachers. Quite the opposite has apparently taken place.



VOTER PARTICIPATION is one of several factors that have made the elderly an increasingly influential group in U.S. politics. The chart shows the proportion of each age group who voted in the congressional elections of 1966 (*gray*) and 1982 (*color*). Between the two elections voting became more common among the old and less common among the young. Hence in 1982 the highest voter-participation rate was among those from 65 through 74 years old.

Medical care is a service as crucial to the elderly as teaching is crucial to the young. The medical profession, however, requires less discussion because it is manifestly robust. Whereas the number of teachers has remained constant and their salaries and quality have declined, in medicine the opposite has been true. Applicants to U.S. medical schools are so outstanding that the system for choosing among them has been described as a lottery.

It is also notable that large amounts of capital have flowed into the health-care industry in the past decade. These investments have been converted into advances in equipment and improvements in the training of medical personnel. Capital has been attracted to the industry by a sharp increase in the demand for health-care services. The growth of demand is due in turn to an increase in the number of elderly and the expansion of entitlement programs that enable older people to afford more and better medical treatment. Thus the elderly, whose number has grown quickly, have been far better served by their specialized industry than the young, whose number has declined.

Some readers may be disturbed by the fact that in demonstrating the existence of the demographic mechanisms affecting the elderly and the young, age has been emphasized to the exclusion of other traditional demographic variables, including race. In discussing the changing status of children and the elderly in the U.S., however, I see no reason to analyze the races separately. For those who think the current problems of children are confined to racial minorities it should be pointed out that there is not one trend described above that does not apply to both blacks and whites. On the contrary, in the case of some of the most significant trends, including rising illegitimacy rates and declining school achievement, the changes have been much greater among whites than they have among blacks.

In summarizing the lessons to be learned from recent demographic trends I do not want to paint the elderly as the villains of the piece. I am primarily concerned about the fate of children and in that context the elderly serve largely for comparison. Nevertheless, it is unrealistic simply to wish away the possibility that there is direct competition between the young and the old for society's resources.

Even if the young and the old are to some extent competitors, however, the elderly alone do not decide where society's resources are to be expended. That is a collective, political decision that society makes. It is certainly reasonable to ask whether such decisions in recent decades have taken us along a useful course. There is surely something to be said for a system in which conditions improve as we pass through life.

On the other hand, the failure to devote resources to children cannot be defended so easily. Whereas expenditure on the elderly can be thought of mainly as consumption, expenditure on the young is a combination of consumption and investment. The quality of education and the psychological well-being of children are crucial to the future productive capacity of the U.S.

If we care about our collective future rather than simply about our futures as individuals we are faced with the question of how best to safeguard the human and material resources represented by children. These resources have not been carefully guarded in the past two decades. Rather than assuming collective responsibility, as has been done in the case of the elderly, U.S. society has chosen to place almost exclusive responsibility for the care of children on the nuclear family. Marital instability, however, has much reduced the capacity of the family to care for its own children. Hence insisting that families alone care for the young would seem to be an evasion of collective responsibility rather than a conscious decision about the best way to provide for the future.

Atomic Memory

Atomic systems that have decayed from some ordered states can be induced to recover their initial order. The degree to which order is restored allows investigation of interactions difficult to observe

by Richard G. Brewer and Erwin L. Hahn

In 1872 Ludwig Boltzmann, a founder of modern thermodynamics, gave a lecture in which he said that the entropy, or disorder, of isolated systems increases irreversibly as time passes. On hearing this the physicist Joseph Loschmidt rose in protest. He argued that the laws governing the motions of all particles are symmetric with respect to time. Thus any system that had decayed from order to chaos could be made orderly once again simply by reversing the momentum of each particle, without affecting the total kinetic energy of the system. In defiance Boltzmann pointed his finger at Loschmidt and said, "*You* reverse the momenta."

This scholarly conflict illustrates the paradoxical nature of the second law of thermodynamics, which states that systems tend toward maximum entropy. Yet Loschmidt's argument remains cogent. If one were able to film the motions of any small group of particles and show the film to a physicist, he or she would have no way of telling in principle whether the projector was running forward or backward. Consequently, according to Loschmidt's criticism (which has come to be called the Loschmidt paradox), any law that governs the behavior of large collections of particles should be symmetric with respect to time. While the meaning and implications of the second law are still active topics of research and disagreement [see "The Arrow of Time," by David Layzer; SCIENTIFIC AMERICAN, December, 1975], there now exist several methods by which Loschmidt's time reversal can be realized. In other words, a system of particles that has apparently decayed from a highly ordered state can be returned to that state by reversing the motions (or some other degree of freedom) of its constituent particles. In effect an assembly of atoms is able to exhibit a kind of memory of its earlier condition.

If a system is to display this kind of atomic memory, it must be prepared so that it has some kind of order, often hidden, in its apparently disordered state. In the atomic systems we shall discuss, this hidden order is provided by exposing samples (which may be solid, liquid or gaseous) to coherent electromagnetic radiation of various types, including radio waves, microwaves and laser beams. Sound waves can also play this role. The reemergence of an ordered state in such systems becomes evident when the sample emits its own coherent electromagnetic pulse, an echo of the earlier radiation. Apart from their inherent interest, these echo pulses and related forms of coherent emission provide novel ways to study the fundamental behavior of atomic interactions.

The concept of hidden order can be demonstrated by an analogy. Imagine a group of runners poised at the starting line of a circular racetrack [*see illustration on page 52*]. The starter fires a gun, the race begins and the runners spread out along the course, each running at a different fixed speed. Once they have circled the track several times, some runners will have lapped others and there will be no obvious visible correlation between the runners' relative positions and their various speeds. Someone who had not seen the start of the race might assume that there was no particular order in the disposition of the runners, that they represented a disordered system.

Now suppose the runners have contrived to turn around and retrace their paths at some prearranged signal (perhaps a second firing of the starter's gun) that is given t minutes into the race. If all the runners maintain their speeds, albeit in the opposite direction, they will come together and cross the starting line in unison exactly $2t$ minutes after the beginning of the race. They will have recovered their initial order. (This order will, of course, disappear once again after the runners cross the line.)

The even simpler case of all runners traveling together at the same radial speed is not to be ignored either. Here the initial order is preserved and there is no need to reverse the runners' direction. This example has an electromagnetic analogue, called the "free induction decay" effect, that has found wide use in both radio- and optical-frequency regions.

A more concrete example of a memory effect can actually be demonstrated by mechanical means. A viscous fluid is placed in the ring-shaped space between two concentric plastic cylinders. Whereas the outer cylinder is stationary, the inner one is free to rotate about its axis. A streak of colored dye, representing an initial alignment of particles, is injected into the fluid. When the inner cylinder is turned, the dye disperses throughout the liquid. If one were to show the volume between the cylinders to a thermodynamicist, he or she would say that the dye is completely disordered (that the entropy is at a maximum) and that the mixing process is complete and irreversible. Actually the liquid is in a state of hidden order (or constant entropy): reversal of the rotation of the inner cylinder reverses the mixing process; after an equal number of reverse rotations the dye streak reappears.

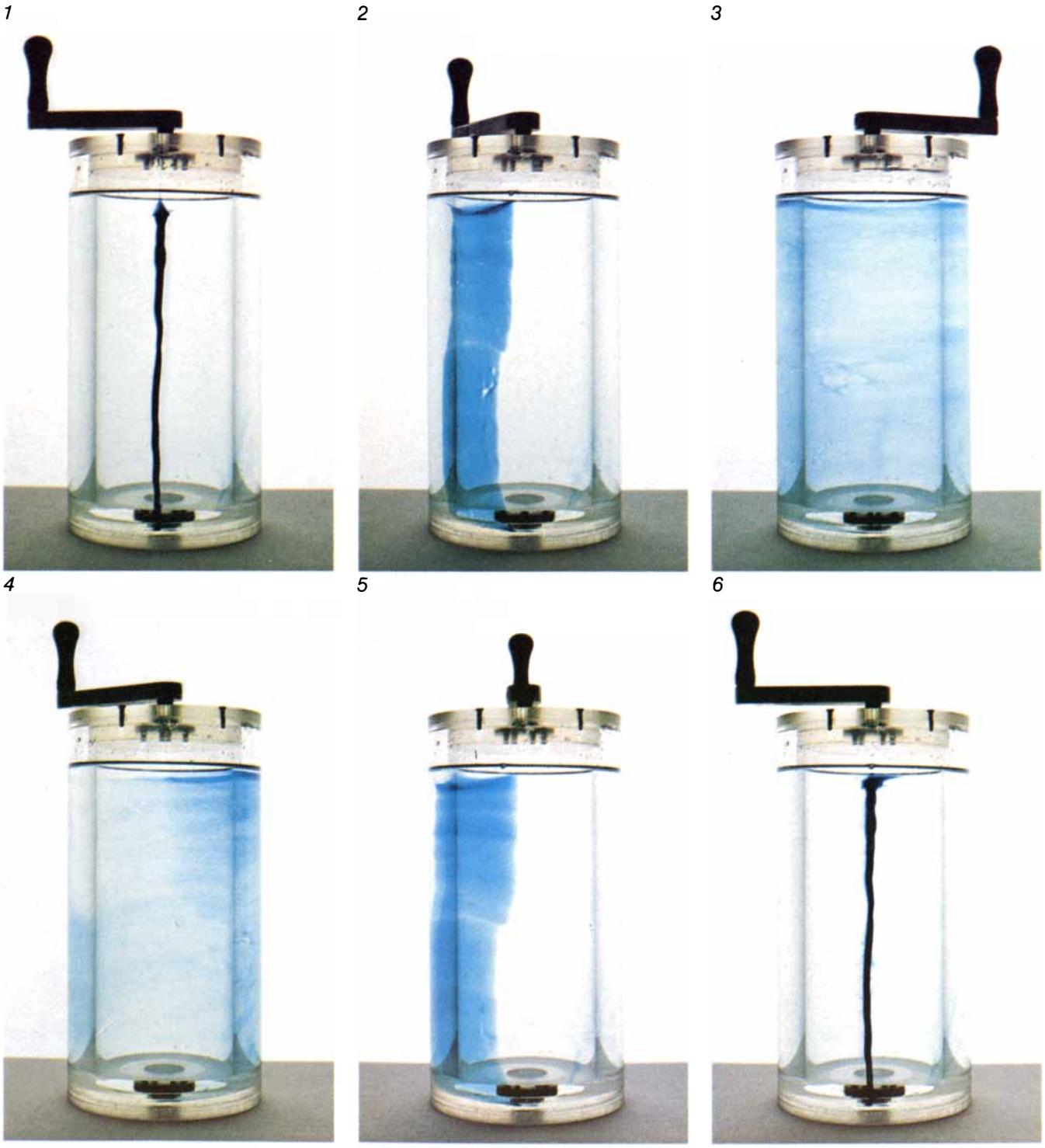
In 1950 one of us (Hahn), then at the University of Illinois, discovered a memory effect that is similar in principle to the cases of the runners and the dye but that operates on the atomic scale. A sample of glycerin was placed in a magnetic field and exposed to two short bursts of electromagnetic radio-frequency (rf) radiation, separated by an interval t of a few hundredths of a second. The sample retained a memory of the pulse sequence, and at time $2t$ seconds after the first rf pulse the sample itself emitted a third pulse, an echo. This phenomenon is known as the nuclear-spin echo.

The nuclear-spin echo is a consequence of the gyromagnetic properties of atomic nuclei, such as the proton that constitutes the nucleus of most hydrogen atoms. Because the proton spins and is electrically charged, it has a magnetic moment, which is similar in some ways to the angular momentum of a gyroscope. The spin axis of a proton that is out of alignment with a constant mag-

netic field, like the axis of a tilted gyroscope in a constant gravitational field, precesses: it traces a circle about a line parallel to the force field [*see illustration on page 54*]. The precession frequency, the rate at which the proton's axis goes around its circle, depends in part on the strength of the external magnetic field. This tendency of the proton's spin axis to precess about an applied constant field is the basis of the spin-echo effect.

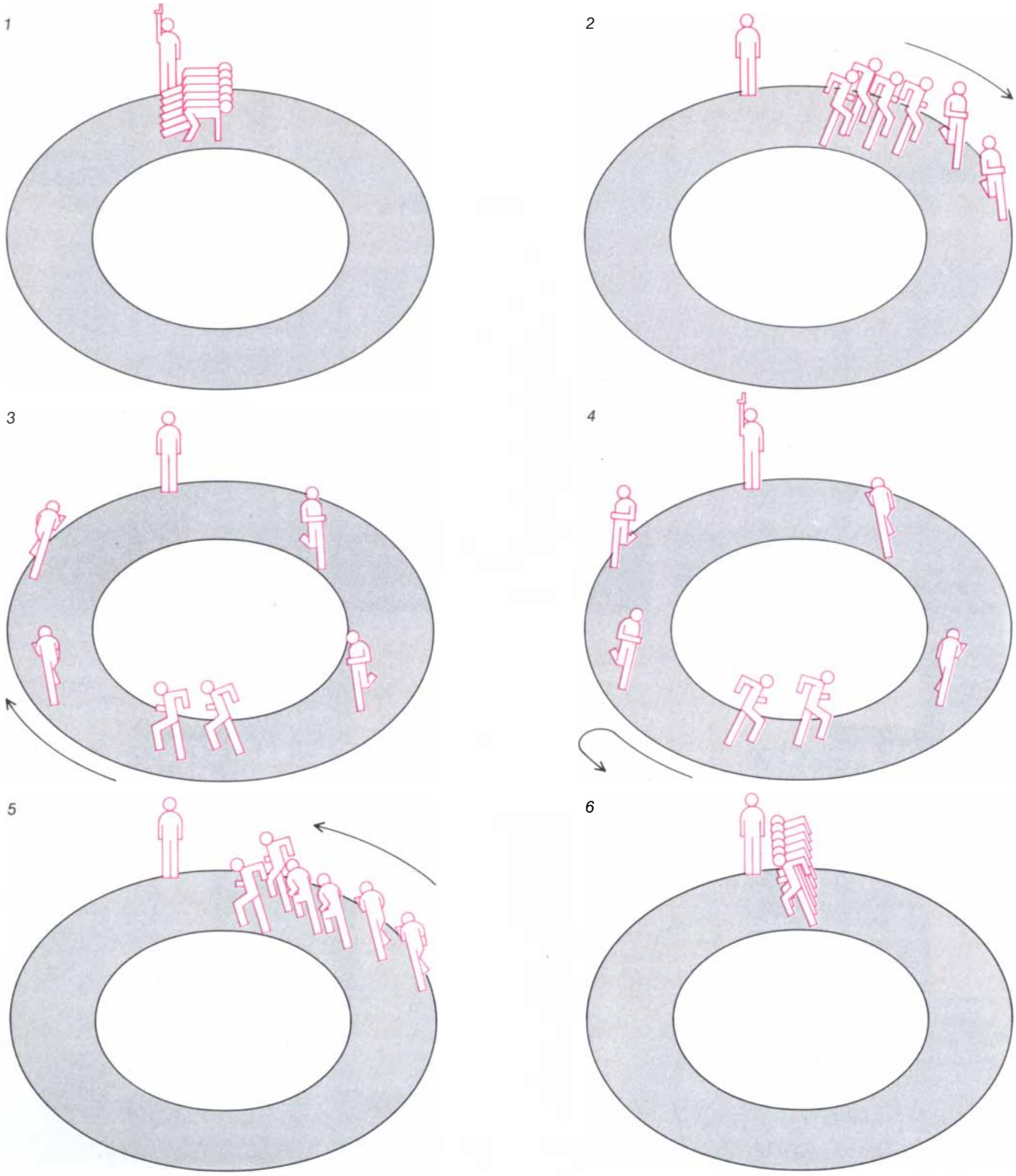
In a spin-echo experiment the constant components of the spin axes of the protons in the sample are initially aligned parallel to a constant external magnetic field. Since they are exactly parallel to the field, they do not precess (as a perfectly vertical gyroscope would not precess). The first radio-frequency pulse is then applied. This rf pulse contains a circularly polarized component—a small rotating magnetic field—that rotates at the rate at which the protons' spin axes would precess if they were out of alignment with the constant field and if it were the only field present.

The rf pulse causes the ensemble of protons to execute a complicated motion, best described as a combination of two less complex precessional motions



HIDDEN ORDER is demonstrated by a device consisting of two clear plastic cylinders that share a common axis. The volume between the cylinders is filled with a clear, viscous fluid. A streak of dye, consisting of an initial orderly alignment of particles, is injected into the fluid (*1*). While the outer cylinder is held still, the inner one is turned (*2*) until the dye appears to be completely mixed with the fluid (*3*). Apparently the initial alignment has been lost, but when the inner cylinder is reversed (*4, 5*), the particles realign and the streak reappears (*6*).

[*see illustration on page 55*]. The simpler of these two motions is a precession about the static external field: the rf pulse tilts the spin axes out of alignment with the constant field (although they remain essentially in alignment with each other during the short pulse time) and they begin to precess about the static field lines at their normal rate of precession. Since the magnetic field contained in the pulse also rotates at this rate, the angle between the rotating rf field and any proton spin axis remains constant as the proton spins precess. From the vantage of the protons the pulse field seems constant in direction. Consequently the proton spins precess about both the pulse field and the constant field. The combination of these two precessions is a downward spiral, traced by the spin axis of each proton.



ELECTROMAGNETIC ECHO PHENOMENA find an analogy in the patterns formed by runners on a track. At the start (*1*) they are in a highly ordered state: in line. When the starter fires his gun and the race begins, they spread out (*2*) until the relation of one to another appears disordered (*3*). (The relation seems most disordered if some runners have lapped others.) The starter fires his gun again (*4*), and the runners reverse direction, so that the former leaders are now at the rear. In *6* they have caught up and the original order is restored.

The angle through which the protons tip is determined by the strength and duration of the rf pulse. In a typical spin-echo experiment this first pulse might be timed so that it tilts the proton spins exactly 90 degrees from the vertical; in other words, they come to lie on the plane that is perpendicular to their original orientation.

If the constant magnetic field is left on, the proton spins will precess in unison in this new plane; in a sense they will resemble one giant spinning magnet. Like such a spinning magnet, the protons emit an oscillating electromagnetic pulse, the free induction decay signal, so named because the synchronized free precession of spins induces a decaying electromagnetic signal. This signal corresponds to the start of the race; the spin axes are now in a state of dynamic order.

In time this order decays. One reason for the decay of the free induction signal may be that the static magnetic field does not have exactly the same strength throughout the sample. Since the protons' precession frequency depends on the strength of the external field, a proton in a region where the magnetic field is stronger will precess more rapidly than the others, just as some runners are faster than others. The spin axes come to point in different directions. They gradually fan out, like the runners on the track; the spin axes of those protons that precess rapidly will point ahead of the axes of the slower-precessing protons [*see illustration on page 56*]. The angle formed between any two spin axes that come to point in different directions is called the phase angle; the magnitude of the phase angle is a measure of how much the two spin axes are out of synchronization. As the protons desynchronize they no longer emit the oscillating electromagnetic field, the free induction decay. The sample is now in a state of apparent chaos.

After the protons' free induction decay the sample is excited with the second rf pulse, which is like the second firing of the starter's gun. This pulse is at the same frequency as the first one, but in a typical experiment it lasts twice as long; consequently the plane in which the proton spin axes lie is flipped through a full 180 degrees, ending once again in an orientation perpendicular to the constant field. It is as though the plane in which the spin axes lie has been turned upside down or reflected in a mirror.

Following the first rf pulse, the phase angles between faster- and slower-precessing spins had gradually grown larger. Just after the second pulse, which flips the plane in which the axes lie, the phase angles between the various axes are the same as before but the relative positions of the faster- and slower-precessing axes are reversed. In other words, prior to the second pulse the faster-precessing axes had gradually come to point slightly ahead of the direction in which the slower-precessing ones pointed; after the second pulse the plane in which the axes lie has been turned upside down (or mirror-reflected) and the slower-precessing axes point slightly ahead of the faster-precessing ones.

The faster-precessing proton spins are now behind the slower ones, just as the faster runners were behind the slower runners after the starter's second signal. As in the race, rapidly precessing spin axes will eventually catch up with the slower ones, and so the axes will realign. At this moment the atoms will emit another burst of radiation, the echo pulse, showing that the seemingly lost order has now been recovered.

In the spin-echo effect the applied rf bursts are said to be in resonance with the proton spins because the frequency of the bursts exactly matches the protons' natural frequency of precession. This spin-flipping property of resonant radiation is the cornerstone of the nuclear-magnetic-resonance (NMR) techniques discovered independently in 1946 by Edward M. Purcell of Harvard University and by the late Felix Bloch, then at Stanford University. In NMR spectroscopy the investigator excites a sample in order to determine which frequencies of radiation will induce spin flipping; each resonant frequency corresponds to a unique nuclear spin in a particular nuclear environment. For example, the strength of the local magnetic field can vary in different parts of a molecule because an electron cloud partially shields its nucleus from an external field. Once an NMR technician knows the spin-flipping frequencies, he or she can determine the chemical makeup of the sample. Spin echoes are among the most useful of NMR imaging techniques. The externally applied fields can be controlled to determine the occurrence of a given precession frequency over a large sample, even one as large as a human body.

There is another way that spin-echo effects can be used to study properties of various substances. In our racetrack analogy the runners will not all finish simultaneously if some of them have tired and have reduced their speeds during the race; in a sense any change of speed introduces a disorder within the hidden order. A corresponding disorder in an atomic sample could involve collisions between the atoms, magnetic interactions between neighboring atoms or movement of an atom from a region where the external magnetic field is high to one where it is lower, thereby changing its rate of precession. If the delay between the two rf pulses is lengthened, the random disorder introduced between pulses will increase and the echo signal will be weaker. A physicist or chemist can thus use the strength of the echo, or its decay time, as a measure of such random processes in matter as thermal agitation, internal motion and the fluctuation of local fields.

With the development of coherent laser light the echo concept was extended in 1964 to optical frequencies by Norman A. Kurnit, Isaac D. Abella and Sven R. Hartmann of Columbia University [see "Photon Echoes," by Sven R. Hartmann; SCIENTIFIC AMERICAN, April, 1968]. The physical principles underlying the spin and photon echoes are the same: both are examples of hidden order produced and revealed by coherent radiation. The spin echo, however, involves atomic nuclei whereas the photon echo usually involves atomic electrons. As Richard P. Feynman, Frank L. Vernon, Jr., and Robert W. Hellwarth, then at the California Institute of Technology, were able to show, both situations can be described by the same mathematical formalism, which is a generalization of Bloch's original gyroscopic equations.

The above experiments show that the hidden order within seemingly disordered systems can sometimes be revealed. It has also been shown that certain phenomena, such as molecular collisions, can introduce elements of disorder into the hidden order, causing the echo strength to decay. Can echo experiments be devised that will negate even such randomly occurring, seemingly irreversible effects?

The suggestion seems to contradict one's intuition that the large-scale consequences of such random events as collisions between molecules are in principle irreversible. In this instance intuition is misleading, because it is sometimes possible to eliminate even the disordering effects of elastic molecular collisions. This result is achieved by applying a large number of incident pulses spaced close together. These multipulse experiments were first done in NMR by Herman Y. Carr, now at Rutgers University, and Purcell. Jan Schmidt of the State University of Leiden, Paul R. Berman of New York University and one of us (Brewer) later extended the multipulse work into the optical region. We shall describe such a case, a photon-echo experiment on a gaseous sample.

The photon-echo effect is in principle very similar to the nuclear-spin echo. In the spin echo an incident rf pulse resonates with proton axes to align them in a state of dynamic order; this order seems to decay but is recalled by a second resonant rf pulse, which reverses the relative phase angles of the protons, causing them to realign and produce an echo. The photon echo is analogous, except the incident radiation is provided by a laser (that is, in the optical region), and

it resonates with oscillations of the electron cloud surrounding each gaseous atom to produce an echo pulse.

The gaseous atoms of a typical photon-echo experiment are in a state of chaotic thermal motion; they behave like billiard balls, undergoing elastic collisions, which change their velocities but not their internal states. If the atoms are elastically scattered after being excited by the first laser pulse, they experience slightly altered trajectories and velocities. Because of the Doppler effect, each affected atom's emission frequency (which is analogous to the precession rate of a proton axis) is changed. The ensemble of atoms is no longer in a state of hidden order. In the racetrack analogy it is as though collisions between the runners had changed each runner's velocity. In the NMR case the same kind of decay occurs because some molecules of the liquid sample diffuse randomly to regions of differing magnetic field strength.

Returning to the racetrack analogy, imagine that the starter fires the gun many times in rapid succession, each time causing the runners to reverse their paths. Even if a runner's speed has changed slightly (because of a collision) between gunshots, he will still be in approximate alignment with the other runners as they cross the starting line, because he will not have deviated very far from his "ordered" position in the short time between shots.

This multiple-reversal sequence has an even more dramatic effect. Suppose a certain runner's speed has been slightly increased by a collision. He will thus run a greater distance per unit of time than he would have if no runner had collided with another. Since he repeatedly reverses his direction, however, he deviates from his ordered position, first in one direction and then in the other, by equal amounts. The distance by which he deviates from his ordered position will therefore average out to zero. He will stay roughly in alignment with the other runners. In a sense it is as though the collision never happened.

In the same way, if a gaseous sample was excited with many closely spaced pulses, then the Doppler shifts caused by elastic collisions would be averaged out to zero. An atom that has changed its velocity will indeed have an emission frequency different from that of the average atom. Since, however, each of the multiple pulses will reverse that atom's phase (as each gunshot will reverse a runner's direction), the atom's emission frequency will alternate between being higher and lower than the mean. On the average the atoms will be excited in unison. Since the atoms remain synchronized, the effect of elastic collisions is minimized.

After each of the many pulses the atoms will come back into alignment, as the runners do between the multiple gunshots, and each time the atoms realign they emit another echo pulse. The chain of many pulses thus produces a chain of many echoes, one echo between each pair of pulses.

The Carr-Purcell multipulse experiment is really a way of enhancing the ordinary echo effect; the experimenter applies many incident pulses in order to produce many echoes, prolonging the sample's state of order.

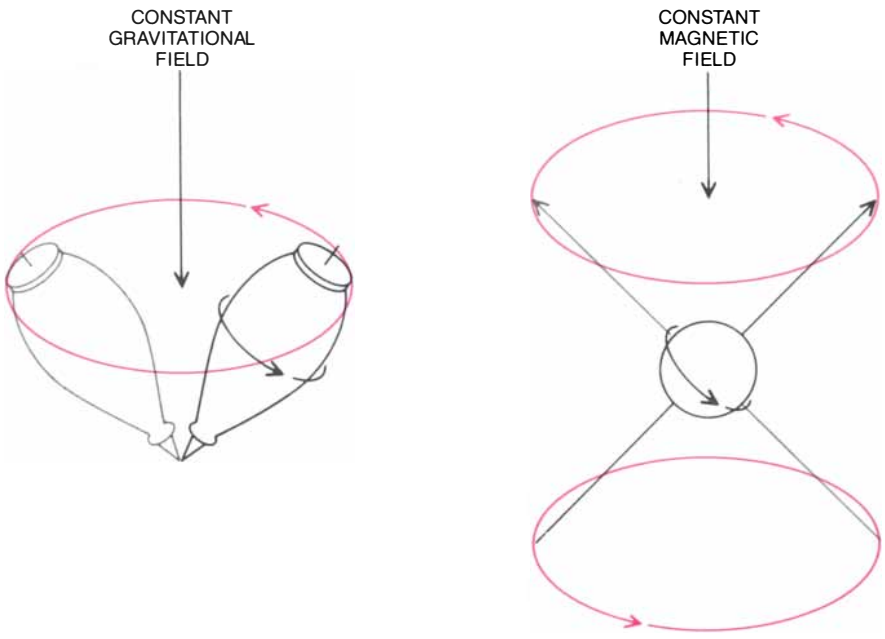
There is another type of multiple-pulse experiment which is even more striking. Called the "magic-sandwich echo" effect, it was first demonstrated by John S. Waugh, along with Won-Kyu Rhim and Alex Pines, who were then students of his at the Massachusetts Institute of Technology. The effect involves subjecting a sample to a long series of specially processed pulses in order to produce a single echo. What is special about the magic-sandwich echo effect is that it can be demonstrated in a sample that would ordinarily not produce any echo at all. Without the application of this unusual train of pulses, the sample's earlier state of order could never be recovered.

In a typical magic-sandwich experiment a calcium fluoride crystal is placed in a constant magnetic field. As in the spin-echo experiment, an rf pulse that tips the spin axes of the fluorine nuclei by 90 degrees is applied to the sample. The crystal then emits a free induction decay signal, like that emitted by the liquid sample in a spin-echo experiment. After the signal has died out another 90-degree pulse is applied, followed immediately by a long series of 180-degree pulses in rapid succession and then by another 90-degree pulse. This is the sandwich: the two 90-degree pulses represent the bread and the series of 180-degree pulses is the filling.

There is still no simple pictorial model for describing what happens during the magic-sandwich effect. It can only be said (according to the currently accepted mathematical description) that the magic sandwich actually changes the sign of the equation of motion for the fluorine nuclei; that is, it achieves precisely the momentum reversal that Loschmidt described to Boltzmann.

Even in an experiment involving multiple pulses there is still some decay of the echo signal; succeeding echoes grow weaker. This decay, in the case of a gas, is due primarily to inelastic collisions, which are collisions violent enough to produce irreversible quantum changes in the energy levels of the atoms involved. The echo decay in a multipulse experiment is therefore a measure of the rate of inelastic collisions and diffusion in a sample. This means that a multipulse experiment can be used to select specific types of atomic interactions for study without the complication of competing dynamic processes.

There is yet another way to produce atomic memory, one in which time reversal is not required. The basic idea appears in the racetrack analogy. It is possible to have all the runners travel at



GYROSCOPIC PRECESSION in a gravitational field models the precession of a proton in a magnetic field. The axis of a spinning, tilted gyroscope (*left*) moves in a horizontal circle, a motion called precession about a constant force (in this case the force of gravity). In the same way a proton (*right*), a charged particle with intrinsic spin, precesses about a constant magnetic field.

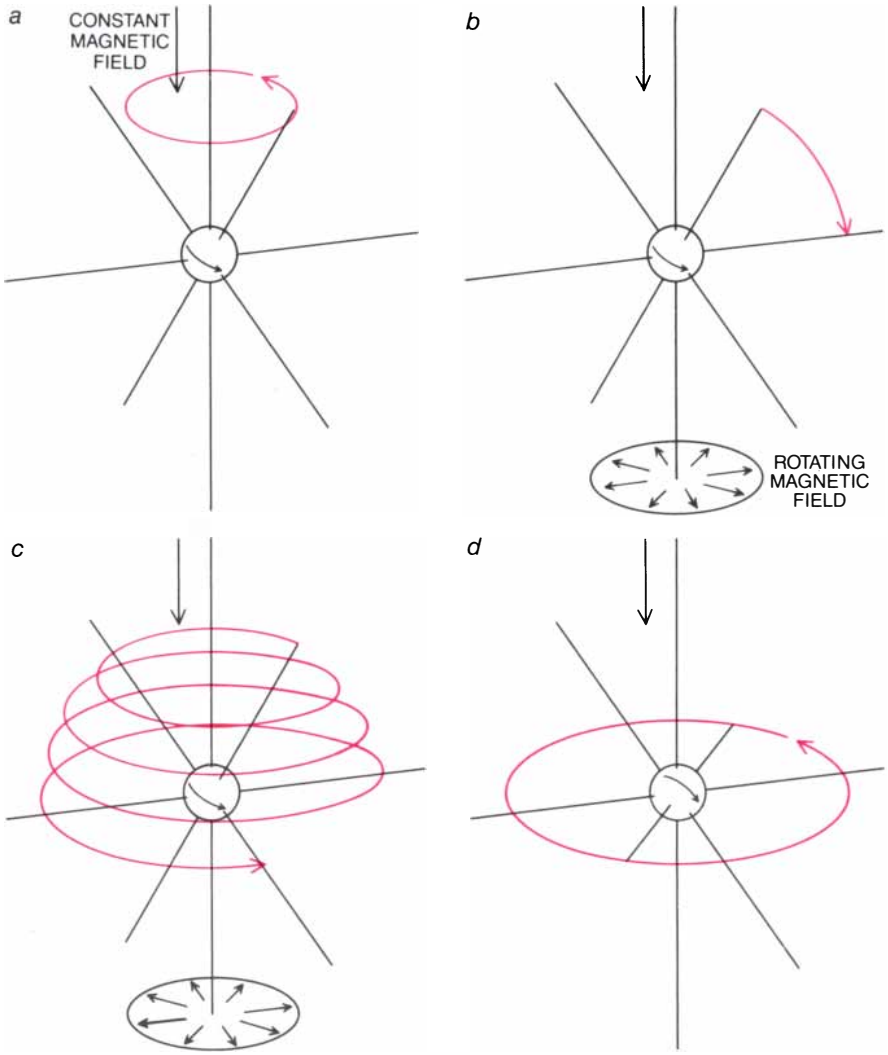
the same radial speed, preserving their initial alignment. This is the simplest case of all, but how can it be achieved?

In a gaseous sample it is possible to select all the atoms that have one specific velocity by exciting the sample with a nearly monochromatic (single frequency) continuous wave (cw) laser beam of the appropriate resonant frequency. Because of the Doppler effect, identical atoms moving at different velocities will absorb light at slightly different frequencies. If the laser frequency is spectrally pure, that is, if it is essentially a single frequency, then only the atoms with one particular velocity will be selected and prepared coherently. To return to the racetrack analogy, it is as if runners of only one particular speed were allowed to start the race.

The alignment of these coherently prepared atoms is demonstrated in a laser-frequency-switching apparatus: after a long excitation period the frequency of the laser beam is suddenly switched to a new value so that it is no longer in resonance with the prepared group of atoms. This switching ends the excitation. The coherently prepared atoms, however, now act like a set of identical tuning forks that have been struck simultaneously: since they all have the same resonant frequency, they reinforce one another and radiate in unison an intense, coherent beam of light in the forward direction. The beam has all the properties of laser light (coherence, directionality and a single frequency) because the atoms retain a memory of their ordered state. This is the optical analogue of the free induction decay associated with magnetic resonance.

The free induction decay effect was first discovered in NMR in the radio-frequency region by one of us (Hahn) and in the optical region by the other of us and Richard L. Shoemaker, now at the University of Arizona. Like the echo effect, free induction decay enables the physicist or chemist to measure, in materials of many types, properties that are ordinarily difficult to observe. By studying the decay of various emission frequencies under different conditions, one can achieve a better understanding of the interactions within and among the molecules of a sample.

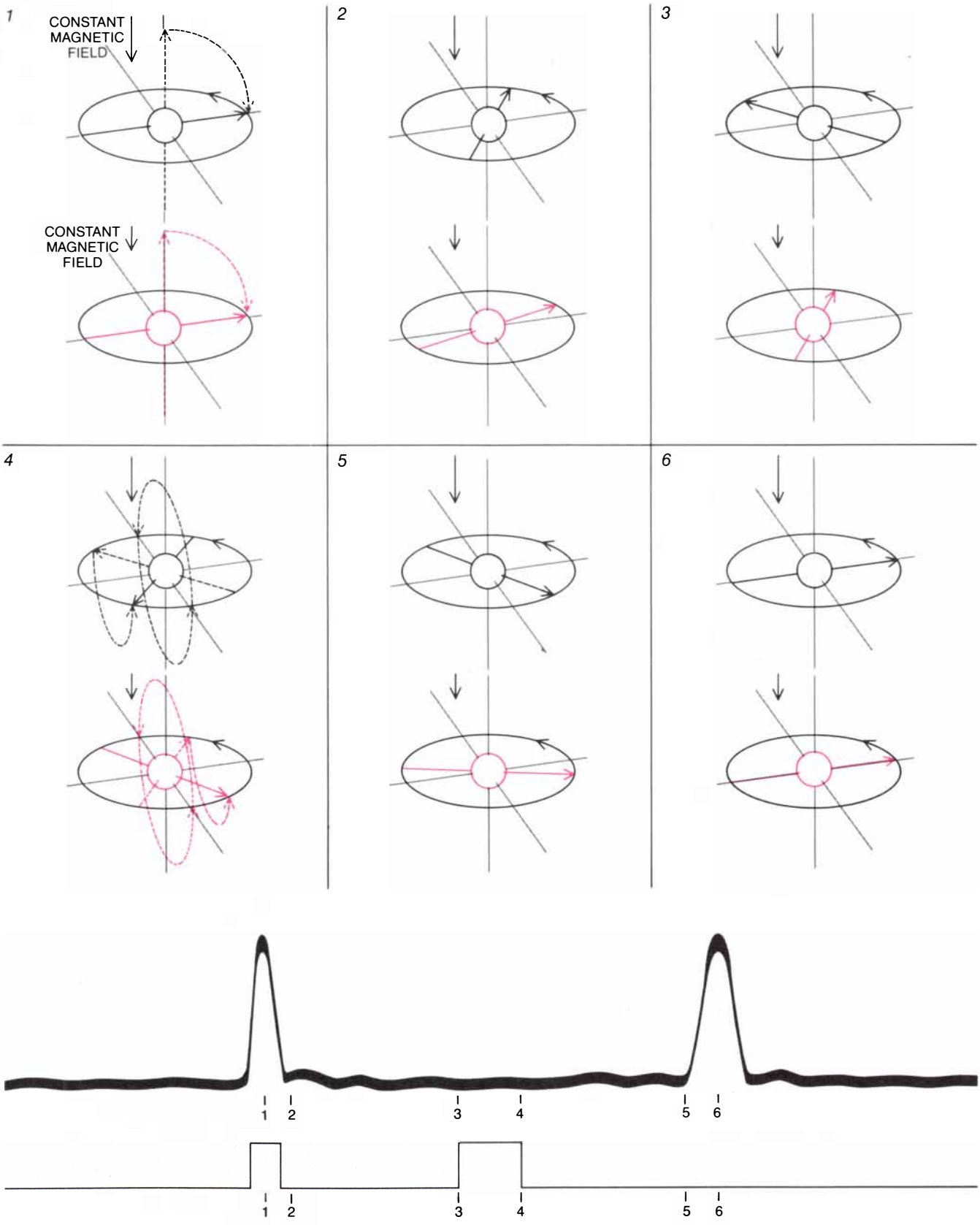
Laser frequency switching was introduced at the International Business Machines Corporation's San Jose Research Laboratory by one of us (Brewer) in collaboration with Azriel Z. Genack. It has been used to observe not only free induction decay but also an entire class of atomic memory phenomena. The process of tuning the laser into and out of resonance with an atomic sample is equivalent in a sense to applying pulses of laser light; thus switching a laser into resonance with a sample for two short periods of time is essentially equivalent to applying two short laser bursts and will produce the same echo phenomenon. The frequency-switching technique has the advantage that switching processes can be more precisely timed and controlled by electro-optic devices. In addition interference between the sample's emission and the laser light (at its new frequency) produces a strong (heterodyne) beat signal that can be used to distinguish the sample's emission from any background noise.



PRECESSION OF A SPINNING PROTON subjected simultaneously to a constant magnetic field and a rotating (circularly polarized) magnetic field is the combination of two simpler precessions. The first is a precession about the constant magnetic field (a, *color*). If the second, rotating field rotates at precisely the rate at which the proton's spin axis precesses, the angle between the two remains constant; from the vantage of the precessing proton the rotating field seems to be a constant one, and the axis precesses downward about this horizontal field (b, *color*). The combination of these two motions, as seen by an outside observer, is a downward spiral (c, *color*). The rotating field is turned off once the spin axis lies in the plane perpendicular to the constant field, and the axis continues to precess about the constant field (d, *color*), staying in this plane.

One of us (Brewer), with Ralph G. DeVoe of IBM, has recently used the laser-frequency-switching technique to examine the fundamental gyroscopic equations used by Bloch in his first description of NMR. According to Bloch's equations, the nuclear-memory decay time should not depend on the strength of the applied fields. In 1955 Alfred G. Redfield showed, using thermodynamic arguments, that these equations required modification. He observed the nuclear magnetic resonance of a pure metal and found that an intense radio-frequency field can actually lengthen the memory lifetime (that is, reduce the rate of decay) through a time-averaging effect that is similar in some ways to a time reversal.

DeVoe and Brewer have extended Redfield's argument into the optical region. To do so they used one of the stablest tunable lasers in existence (the laser's emission frequency can be adjusted and, when it is set, is stable to five parts in 10 million million). With this laser DeVoe and Brewer performed a



SPIN-ECHO EFFECT is induced by two radio-frequency (rf) pulses, which tip the spin axes of the protons in a liquid sample in a constant magnetic field. Two representative protons are shown; the magnetic field in the region of the black proton is stronger than the field in the region of the colored one. In *1* the first pulse tips the axes until they lie in a plane perpendicular to the constant field, where they continue to precess. Since the constant field differs from region to region within the sample, some axes will precess faster than others and will come to point in different directions (*2, 3*). A second rf pulse, twice as long as the first, then flips the plane in which the spin axes precess until they lie in the same plane as before but with the relative positions of faster- and slower-precessing axes reversed (*4*). The faster-precessing axes are now behind the slower ones (*5*). Like the faster runners, they will eventually catch up (*6*). The two oscilloscope traces represent the sequence of rf pulses (*top*) and the signals given off by the sample when the protons align (*bottom*), including the echo pulse (*6*).

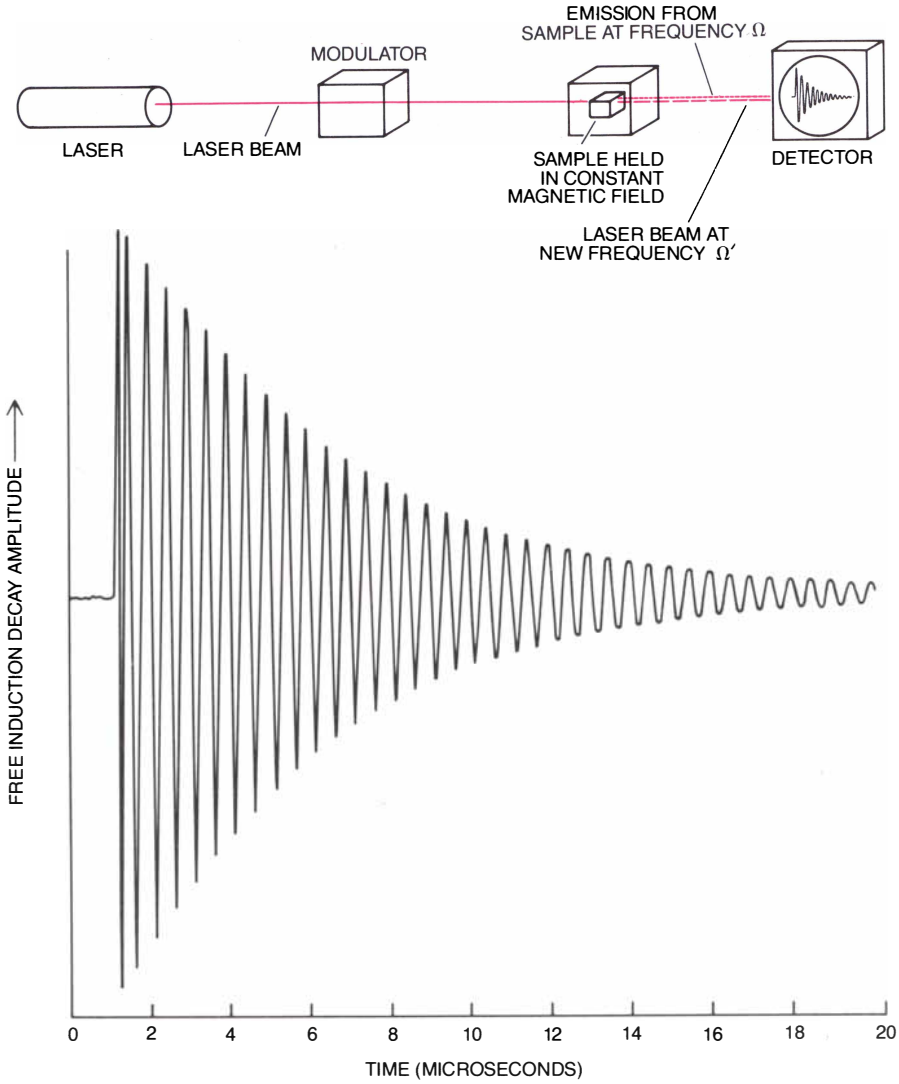
free induction decay experiment. The sample examined was a crystal of lanthanum trifluoride containing praseodymium impurity ions. A nuclear magnetic interaction between the praseodymium and the neighboring fluorine nuclei caused the memory decay.

Like a proton, a fluorine nucleus behaves as a spinning charge, creating its own magnetic field. The fields of fluorine nuclei are strong enough to flip neighboring fluorine nuclei in the same way as an rf pulse can flip a proton. When a fluorine nucleus flips, the resulting change in the local magnetic field is sometimes strong enough to flip yet another neighboring fluorine nucleus. Such random sequences of spin flipping are common in the lanthanum trifluoride crystal.

When a lanthanum trifluoride crystal is exposed to coherent laser radiation of the correct resonant frequency, the praseodymium ions become synchronized and emit their own coherent radiation, a free induction decay signal. Fluorine nuclei that undergo random spin flipping can desynchronize the neighboring praseodymium ions, causing the coherent optical emission to die out.

DeVoe and Brewer measured this decay time using the laser-frequency-switching technique described above. They excited a sample of lanthanum trifluoride with a tunable dye laser and then switched the frequency of the laser so that it no longer resonated with the praseodymium impurity ions. This required an extraordinarily frequency-stable laser in order to excite a very small range of frequencies: the linewidth of praseodymium is only 10 kilohertz, roughly 10 million times narrower than earlier optical measurements in solids. Once the laser frequency had been switched, the praseodymium emitted the free induction signal, which decayed in about 17 microseconds.

It is possible to quench the magnetic interaction between fluorine and praseodymium by increasing the intensity of the laser used to excite the crystal. An increase in laser intensity drives the praseodymium ions more rapidly between higher and lower quantum states as they absorb and reemit photons. Each time the praseodymium ion goes through an absorption-emission cycle, the nuclear magnetic interaction between it and the neighboring fluorine nuclei changes sign; in other words, the interaction that had been present between a praseodymium ion and a fluorine nucleus will act in the opposite direction after the praseodymium ion has absorbed and reemitted a photon. Thus a fluorine nucleus that had been causing a praseodymium ion to desynchronize from the others will effectively reverse its effect on that ion and force it back into synchronization. This is similar to the reversal of phase order produced by the laser in a multipulse Carr-Purcell experiment. If the time between reversals of phase order is shorter than the time between the desynchronizing events (in this case random fluorine flips), then the disturbances caused by the fluorine nuclei are compensated because their interactions with the praseodymium are reversed. With Axel Schenzle of the University of Essen in West Germany and Masaharu Mitsunaga of IBM, DeVoe and Brewer have developed a general microscopic quantum theory of this phenomenon that extends Redfield's thermodynamic argument into the optical part of the spectrum for the first time.



LASER-FREQUENCY-SWITCHING APPARATUS was used by one of the authors (Brewer) and Ralph G. DeVoe to observe another class of atomic memory effects. A laser beam of frequency Ω is used to excite a crystal sample, which is held in a constant magnetic field (*center*). Then the laser frequency is switched to a new value, Ω′, by a modulator (*left*). The sample itself, resonating from the first laser beam, gives off coherent radiation, the optical free induction decay, at the original frequency Ω. Emission from the sample combines with the laser beam to produce an interference signal at a detector (*right*). The duration of this signal tells the experimenter how long the atoms of the sample retain a memory of the initial laser beam.

The techniques of pulsed radio-frequency radiation, the principles of which have been known for nearly 40 years, are important tools in science and medicine, primarily in NMR body imaging and the structural analysis of chemical compounds and the solid state. With the development of extremely precise and stable lasers, these methods are just now being made possible in the optical region.

These atomic-memory phenomena would have delighted Loschmidt because they show that some types of decay, even decay caused by random collisions, can be reversed. Beyond their philosophical charm, however, atomic-memory phenomena can be very useful. By eliminating the decay effects of some processes, they enable physicists to study other processes in greater detail, giving us a clearer view into the structure and interactions of materials on the atomic level.

How Embryonic Nerve Cells Recognize One Another

Developing neurons seek one another out and interconnect with high specificity. In the insect embryo they appear to do so by following pathways whose surface is labeled by specific recognition molecules

by Corey S. Goodman and Michael J. Bastiani

The human brain is composed of hundreds of billions of nerve cells, each of which projects numerous long fibers that intertwine and interconnect with remarkable specificity. One of the major mysteries of biology continues to be how the nervous system is wired during embryonic development. How do individual neurons, or nerve cells, find and recognize one another and make the appropriate connections?

The structures that serve as pilots for the outgrowth of embryonic nerve fibers were identified at the end of the 19th century by the pioneering Spanish neuroanatomist Santiago Ramón y Cajal. They are club-shaped amoebalike extensions at the end of the nerve fibers; Ramón y Cajal named them growth cones. He, and after him Ross G. Harrison of Yale University, saw that the outgrowth of a nerve fiber is not random: a particular growth cone always extends along a particular pathway to find and recognize its correct target. They hypothesized that growth cones must be endowed with some exquisite chemical sensitivity and that their targets must be specified chemically. The idea was elaborated in the early 1960's when Roger W. Sperry of the California Institute of Technology proposed his chemoaffinity hypothesis. He concluded that "the final course laid down by any given fiber reflects the history of a continuous series of decisions based on differential affinities between the various advance filaments that probe the surroundings ahead and the diverse elements that each encounters."

In the past decade much has been learned about the structure of growth cones and the mechanism of their movement from studies of dissociated neurons in tissue culture, notably those done by Dennis Bray of King's College in London, Paul C. Letourneau of the University of Minnesota and Norman K. Wessells of Stanford University. Growth cones put out numerous hairlike extensions called filopodia (Sperry's "advance filaments") that reach in many directions and explore their environment. Filopodia are dynamic structures; they extend, move about and retract in a matter of minutes. Many of them make contact with the surface of other cells. If a filopodium adheres weakly to such a surface, it retracts into its growth cone. If it adheres strongly, it persists, and its subsequent contraction generates tension that guides the leading tip of the growth cone toward the point of attachment. Thus growth cones in tissue culture can be guided to particular surfaces by the differential adhesion of their filopodia.

The questions we raised at the outset can now be framed in more explicit terms. How are neuronal growth cones guided to their targets in a developing embryo? To what extent can growth cones and filopodia specifically recognize the surfaces of other neurons during development, and to what degree are those surfaces differently labeled? What is the molecular code of the surface labels and how is it deciphered by developing growth cones? To answer such questions many of us who hope someday to understand how the human brain is wired during development have begun by studying the far simpler brains of invertebrate animals. At Stanford University we and our colleagues have been investigating the development of neuronal specificity in the embryo of two insects: the grasshopper *Schistocerca americana* and the fruit fly *Drosophila melanogaster*.

The central nervous system of these and other insects includes both the brain (which has perhaps 50,000 neurons) and a chain of simpler segmental ganglia, or groups of nerve cells, that reflects the animal's segmented body plan. Each ganglion has two hemisegments: identical sets of about 1,000 neurons, one set on each side. The ganglia are linked by large bundles of axons called connectives. (Axons are the major neuronal processes, or extensions, that deliver inputs at synapses, the sites of contact and communication between neurons; dendrites are typically shorter processes, largely responsible for receiving these inputs.) Within each ganglion there is a thin layer of cell bodies near the ventral (lower) surface and a large dorsal (upper) region, called the neuropil, where all the axonal and dendritic processes projecting from the cell bodies intertwine and interconnect synaptically. Most of the 1,000 neurons in each hemisegment can be identified individually because of the unique shape of their axons and dendrites and their unique pattern of synaptic connections with the processes of other neurons. These "identified neurons" are identical from animal to animal within a species.

Of all insect nervous systems the grasshopper's is the best understood because its neurons are particularly large. An individual cell can easily be penetrated with a microelectrode, either to record nerve impulses and determine synaptic connectivity or to inject a dye that fills the cell body and its processes, thereby revealing the cell's structure in detail. For example, Keir G. Pearson and his colleagues at the University of Alberta have studied two identified neurons, designated *C* and *G*, in the second thoracic (*T*2) ganglion. These two neurons illustrate some of the variety in cell morphology, or structure, and connectivity found among the 1,000 neurons in a single segmental ganglion. The *C* neuron makes synaptic connections with particular interneurons and motor neurons and has a role in initiating the insect's jump behavior. The *G* neuron, on the other hand, has a very different behavioral role and makes quite different synaptic connections.

Such differences in function and connectivity are reflected by each neuron's distinctive morphology, the most strik-

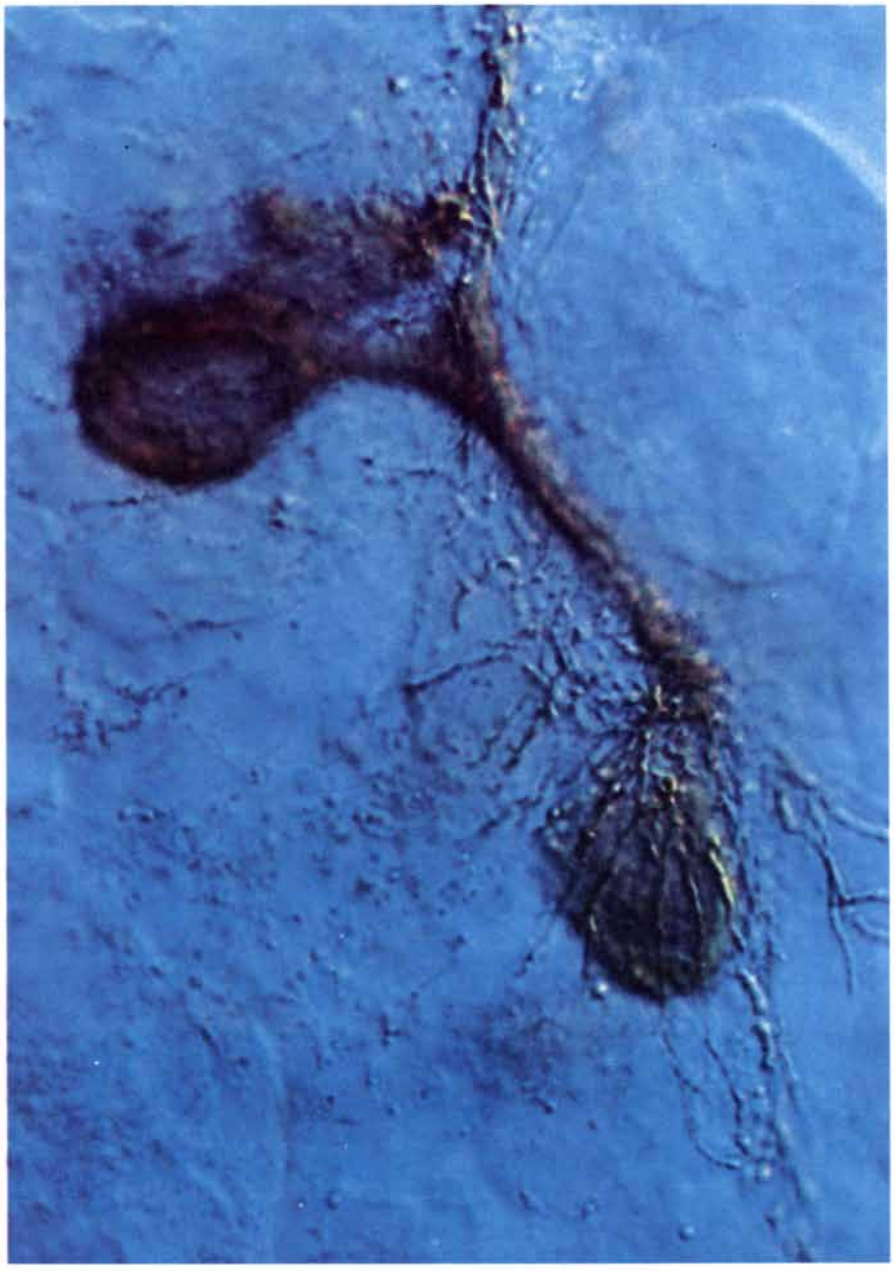
ing difference being the particular paths its axon and dendrites take within the neuropil. For example, in every grasshopper the *G* neuron's primary axon extends forward in a certain tract, or large bundle of fibers, and its two primary dendrites extend forward in a symmetrically arrayed pair of other tracts. Two organizational principles emerge from studies of identified neurons in the adult grasshopper. Each neuron extends its processes in particular tracts in a pattern that is specifically characteristic of each cell; within the neighborhoods established by these tracts, each neuron makes connections only with a cell-specific subset of neuronal processes.

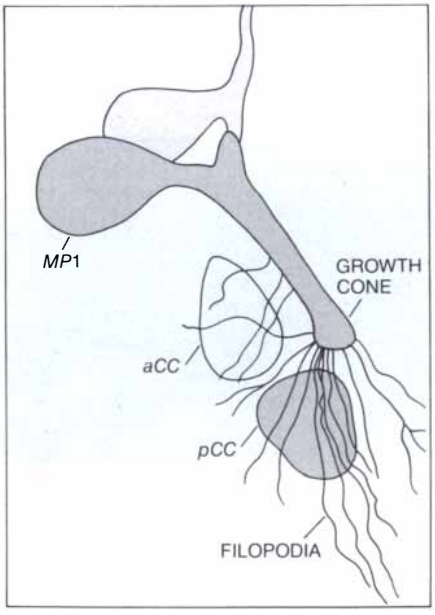
These principles have profound implications for the wiring of the grasshopper's nervous system during development. As in the adult, so also in the grasshopper embryo is the nervous system made up of relatively large, accessible cells. The segmental ganglia develop from a platelike region, called the neuroepithelium, that runs through the embryo from head to tail. Within this region certain cells differentiate to become neuronal precursor cells. In 1976 Michael Bate, now at the University of Cambridge, observed that a stereotyped pattern of neuronal precursors is repeated almost identically in each segment of the neuroepithelium. A typical segment has two symmetric lateral plates of 30 neuroblasts, arrayed in seven rows of from two to five cells per row, and one median neuroblast; seven other precursor cells, called midline precursors, are arrayed along the midline.

Each midline precursor divides once to yield two neuronal progeny. In contrast, each neuroblast serves as a stem cell, dividing repeatedly to give rise to a chain of smaller ganglion mother cells; each of these divides in turn, generating two ganglion cells that differentiate to become neurons. A single neuroblast thus contributes a family of from six to 100 or so neuronal progeny to the developing ganglion. The stereotyped pattern of some 1,000 identified neurons in each adult hemisegment is largely generated during development from an equally stereotyped pattern of 30 neuroblasts.

In 1977 Nicholas C. Spitzer and one of us (Goodman), working at the University of California at San Diego, set out to learn whether cell lineage determines some aspects of cell fate. We first asked: Do particular identified neurons arise reliably at specific branch points in neuronal family trees? To undertake this study we needed to follow individual neurons from their origin (the division of particular precursor cells) to the stage at which each displays its distinctive shape, revealing its unique identity.

Whereas earlier workers examined fixed sections cut from the embryo, we found a way to dissect the neuroepitheli-



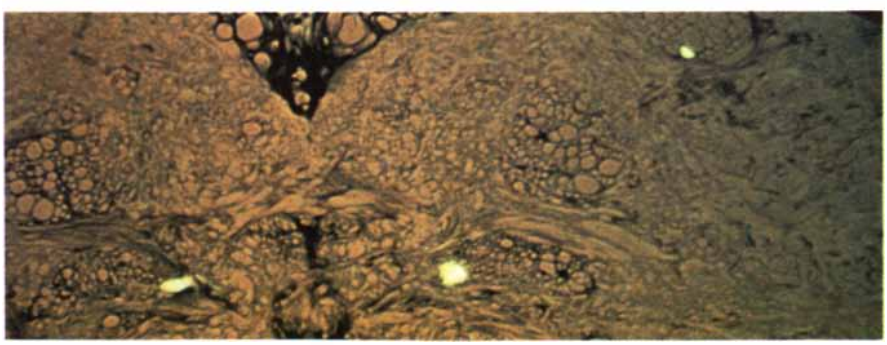


GROWTH CONE of a grasshopper neuron designated *MP*1 bypasses another nerve cell, *aCC*, and goes on to recognize the surface of a third neuron that it seeks, *pCC*. So that this sequence of events could be observed *MP*1 was injected with the dye Lucifer yellow. A brown-staining antibody to the dye renders *MP*1 visible. The photomicrograph, interpreted by the map at the left, shows how the thread-like filopodia that branch from the end of the growth cone and guide its course have selectively made contact with the *pCC* neuron in preference to *aCC* and many other neurons in the environment. The filopodia presumably make close contact with *pCC* because they recognize a molecule that labels its surface. The selective contact is further demonstrated by dye coupling: the dye injected into *MP*1 has been introduced into *pCC*, staining it brown.

um from a living embryo and place it on the stage of a compound microscope. The neuroepithelium is thin and transparent, so that cells, axons and in some cases even their individual growth cones could be visualized. We were able to identify individual neurons and follow them from their birth to maturation in the living embryo. By penetrating cells and their processes with microelectrodes and by injecting intracellular dyes, we were able to describe the line of descent and the temporal sequence of differentiation of the first progeny of the median neuroblast. We showed that a particular neuroblast does indeed give rise to a coherent family of identified neurons.

The destiny of these neurons might be set by their ancestry—the successive cell divisions of the neuroblast and ganglion mother cells in their particular family tree—or by their position in the developing ganglion and consequent interactions with particular neighbors. One can begin to distinguish between these alternatives by ablating, or killing, either a cell's presumptive precursor or its neighbors and noting the effect. A way to do that, developed by John E. Sulston of the Medical Research Council Laboratory of Molecular Biology in Cambridge, is to ablate single neurons by focusing a laser microbeam on them. Ablation experiments done by our colleagues Chris Q. Doe, John Y. Kuwada and Paul H. Taghert showed that when a neuroblast begins to divide, lineage does play a major role in determining its immediate progeny, the ganglion mother cells. The two sibling neurons produced by the final division of each ganglion mother cell, however, are at first equivalent; they acquire unique fates only as the result of interactions with each other before they extend growth cones. In other words, both cell lineage and cell-to-cell interactions contribute to determining each neuron's unique fate.

SINGLE NEURON, designated *G*, is made visible by the fluorescence of Lucifer yellow in a photomicrograph of the second thoracic ganglion of the adult grasshopper's segmented central nervous system. *G* is an "identified neuron": one that is recognizable in every grasshopper on the basis of the shape and location of its processes, axons and dendrites, and the connections they make with other neurons. The cell body, at the lower left, is one of 2,000 or so cells in the ganglion. The primary axon crosses the ganglion and extends forward (upward in the micrograph); a smaller secondary axon extends to the rear. Two symmetric primary dendrites extend foward along the middle of the ganglion. The *G* neuron is enlarged about 100 diameters in the micrograph, made by Keir G. Pearson and John D. Steeves of the University of Alberta.

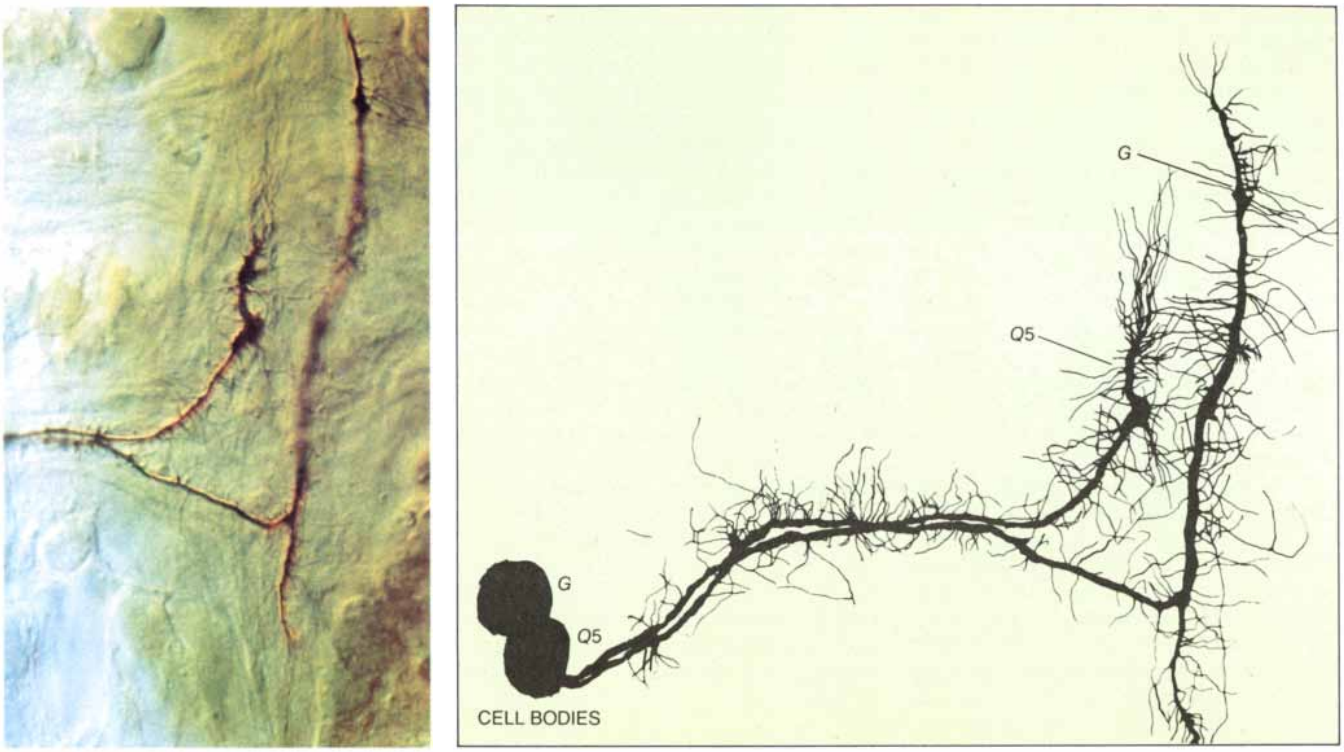


PROCESSES OF *G* NEURON are stained with Lucifer yellow in a micrograph, made by Pearson, of a cross section of the neuropil: the region of the ganglion in which the axons and dendrites of many thousands of neurons intertwine and interconnect. Here the sectioned primary axon of the *G* neuron is seen at the top right, within a particular tract, or bundle of axons and dendrites. The symmetric dendrites are seen at the lower left and center, in different tracts.

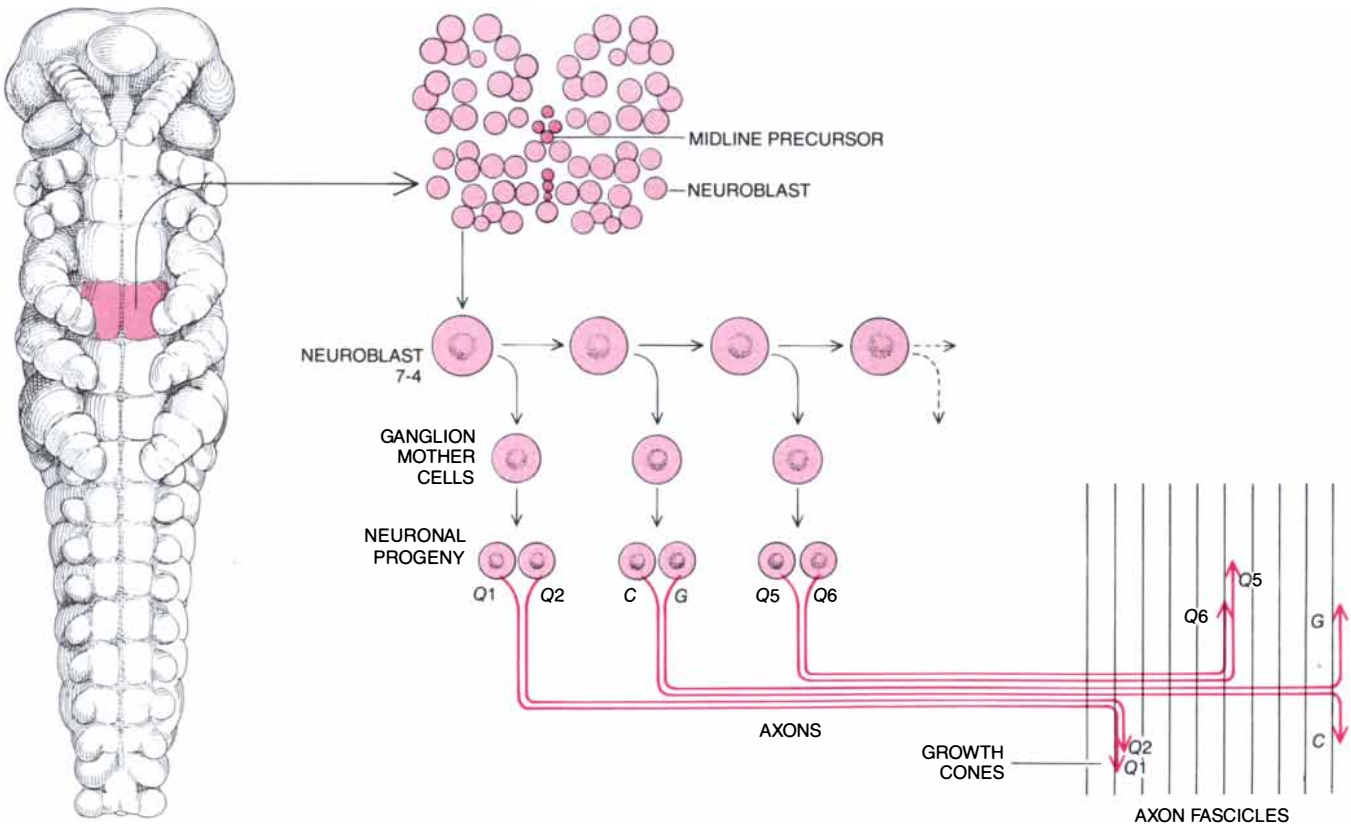
Having outlined some of the early events in neuronal development, we can turn to what happens when the cells begin to extend their growth cones. How do individual neurons recognize one another as their growth cones make a series of specific pathfinding decisions? To begin to answer that question Jonathan A. Raper and we studied in detail the early development of the first six progeny of the neuroblast designated 7–4. They are the neurons *Q*1 and *Q*2, *C* and *G* (described above in the adult) and *Q*5 and *Q*6. The growth cones of these neurons make divergent, specific pathway choices at about 40 percent of development. (The embryo takes 20 days to develop, so that one day is equivalent to 5 percent of development.) With Frances C. Thomas we examined these choices by injecting the neurons with dyes and reconstructing their axons, growth cones and filopodial contacts from serial electron micrographs of thin sections of embryonic tissue.

The growth cones find themselves in a forest of axons belonging to previously differentiated neurons, some 100 of which in each hemisegment have extended their axons into the developing neuropil by this stage. The axons are grouped into transverse and longitudinal fascicles, or bundles. Within each segment these fascicles form a roughly square orthogonal scaffold, so that the chain of segmental ganglia assumes a ladderlike pattern. Initially the growth cones of the first six progeny of neuroblast 7–4 behave in the same way: they extend across to the opposite side of the neuropil by fasciculating on (selectively growing along) a single runglike transverse bundle of axons. When they reach the other side of the neuropil, however, each growth cone chooses a different longitudinal fascicle to follow.

At this choice point the growth cone of the *G* neuron radiates profuse tufts of



GROWTH CONES at the leading end of the axons of the *Q5* and *G* neurons are seen in a photomicrograph (*left*) as they extend forward along their specific pathways. The two cells were injected with the enzyme horseradish peroxidase, which was then subjected to a chemical reaction that stains the cells and their processes brown. The drawing (*right*), covering a larger field, shows how the axons originate at the cell bodies and how filopodia radiate from the growth cones, searching the environment for the pathway each growth cone recognizes.



GRASSHOPPER EMBRYO (*left*) has 17 segmental ganglia, each with a virtually identical pattern of two kinds of neuronal precursor cells: 30 neuroblasts on each side, one median neuroblast and seven midline precursors. Whereas a midline precursor divides once to yield two progeny neurons, a neuroblast divides repeatedly to generate ganglion mother cells, each of which divides in turn to yield two sibling neurons. The neuroblast designated 7–4 has some 100 neuronal progeny; the origin of the first six of them is shown here. The primary growth cone of each of these neurons follows a specific pathway as it recognizes a fascicle (bundle of axons) and joins it (*right*).

filopodia that make contact with the surface of some 25 different axon bundles, which at this stage include about 100 axons. Although the *G* growth cone has access to nearly all these different neuronal surfaces, it invariably chooses to join a particular discrete bundle composed of the axons of four neurons: *A*1, *A*2, *P*1 and *P*2. Within this *A*/*P* fascicle the two tightly juxtaposed *P* axons are twisted around the two *A* axons. Yet the tip of *G*'s growth cone seems always to be closely associated with the *P* axons, not with the *A* axons. Apparently *G* is able not only to distinguish the *A*/*P* fascicle from the other 25 fascicles but also, within that fascicle, to distinguish *P* axons from *A* axons.

It is the filopodia of the *G* growth cone in particular that first recognize the *P* axons. They adhere selectively to the surface of the two axons and wrap around them. At this stage of development filopodia extend laterally all along the length of the axons as well as from their growth cones. We found to our surprise that, within the tangled web of filopodia that fills much of the embryonic neuropil, *G*'s filopodia can recognize not only the *P* axons but also their filopodia. Whatever the recognition labels on neuronal surfaces may be, they are apparently displayed on filopodia as well as on axons and growth cones.

The selective fasciculation mediated by growth cones and filopodia has two roles in wiring the embryonic nervous system. First, the fascicles serve as highways that guide growth cones to particular local regions of the nervous system. Second, it is within the local neighborhoods established by the fascicles that neurons subsequently choose their synaptic partners. Early in development, before the neuropilar felt is too densely woven, neurons can make contact with and recognize one another at great distances as filopodia from one cell encounter filopodia from another cell. Such contacts establish patterns of selective fasciculation. Later, when synaptic connections are forming, the distance over which neurons can make contact with one another is probably reduced by the larger size of the neuropil, the density of its processes and the lack of space for filopodial exploration. The result is that a neuron's choice of potential partners is limited to neurons whose processes are within reach in the immediate neighborhood.

How do the filopodia recognize other neurons and identify appropriate pathways and targets? On the basis of our studies of fasciculation by the *G* growth cone we and Raper proposed a labeled-pathways hypothesis. It posits that neighboring fascicles in the embryonic neuropil are uniquely labeled by "recognition molecules" displayed on their surfaces. At 40 percent of development *G*'s filopodia are within reach of some 25 axon bundles. Consequently the hypothesis predicts that the *A*/*P* fascicle, and the *P* axons in particular, have a surface label shared by none of the other nearby longitudinal bundles. We tested the prediction by selectively ablating the *A* or the *P* neurons or both sets and noting the effect of each ablation on the behavior of the *G* growth cone.

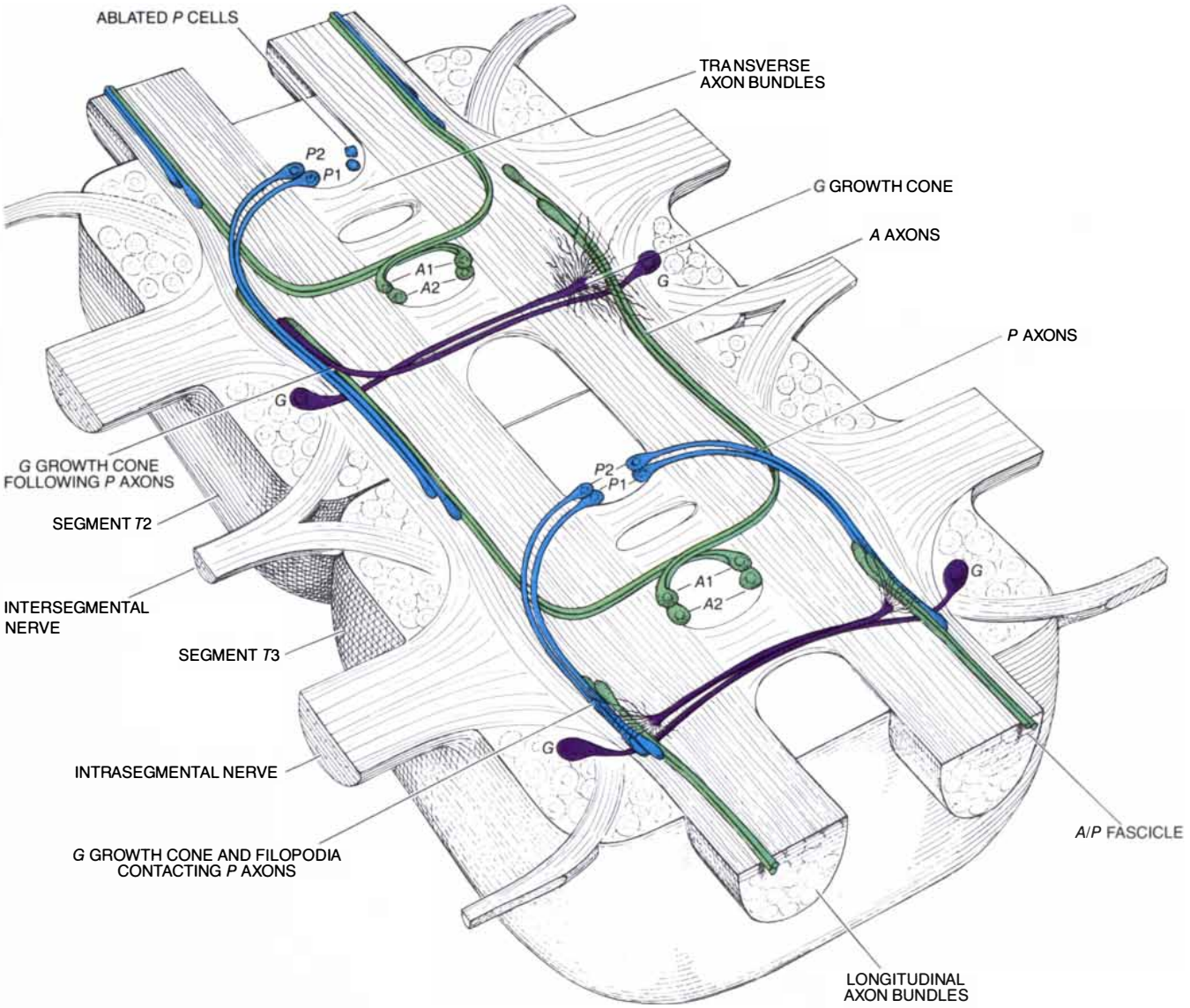
When both the *A* and the *P* neurons are ablated, most of the 100 or so other neurons in the hemisegment develop normally. The *G* neuron does not. In the absence of the *A*/*P* fascicle the *G* growth cone behaves as if undirected, branching abnormally without showing high affinity for any other fascicle. When only the *A*'s are ablated, the growth cone behaves normally, fasciculating on the *P* axons. When only the *P*'s are ablated, however, it shows no affinity for the *A* axons and fails to fasciculate.

These results suggest that the mere proximity of axons cannot be the major determining factor, since (even in the absence of the *P* axons) the *A* axons remain in place in the scaffold. The results also argue against determination by some subtle timing mechanism. The experiment supports instead the notion that the surface of the *P* axons carries a label that is qualitatively different from those displayed on any of the other 100 axons in the neighborhood.

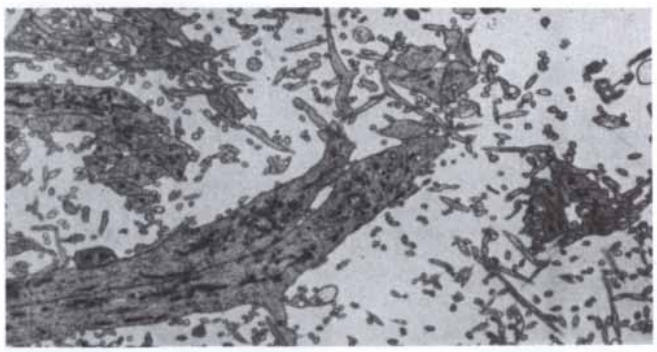
The *G* growth cone makes contact with some 25 axon bundles, and at least one of them (the *A*/*P* fascicle) has two differently labeled components. We therefore think the axons in this part of the neuropil at this stage of development are specified by at least 25 and perhaps as many as 50 different surface recognition labels. Such a high degree of specificity and large number of predicted molecular labels gave us pause. Perhaps the 40 percent stage of development, with some 100 neurons interacting, was already too complex for precise cellular and molecular analysis. We decided to look at an even earlier stage.

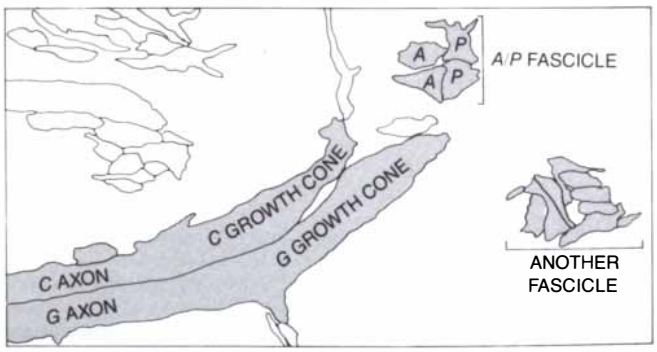
We turned our attention to a stage (30 to 35 percent) when the first seven growth cones in this region of the embryo are able to distinguish one another's surfaces and, through their specific interactions, fasciculate selectively to form the first three longitudinal axon bundles. One bundle consists only of the axon of the neuron called *vMP*2; another includes the axons of *MP*1, *dMP*2 and *pCC;* the third includes those of *U*1, *U*2 and *aCC*. With Sascha du Lac we studied the divergent choices made by the growth cones of the *pCC* and *aCC* neurons, which are the sibling progeny of a single ganglion mother cell.

ORTHOGONAL SCAFFOLD of axon fascicles in a single segment of the grasshopper embryo is seen from above. It consists essentially of two arrays of longitudinal fascicles (one on each side), connected by transverse fascicles joining the two symmetric sides, or hemisegments. At this stage of development about 100 neurons in each hemisegment have extended their axons, which have become associated with one another to form some 25 longitudinal fascicles. Most growth cones find themselves in this environment, surrounded by the axons of other neurons.



SELECTIVE FASCICULATION of the *G* growth cone with the *A/P* bundle, composed of two *A* axons and two *P* axons, is traced in two adjacent segments, each of which is at a slightly different stage of development. In the lower segment the growth cones of the two symmetric *G* neurons (one in each hemisegment) have crossed the neuropil and are at their "choice point," where they will select a longitudinal bundle with which to fasciculate. Their filopodia, having explored the surfaces of about 100 axons in 25 fascicles, have made selective contact with the *P* axons. Ten hours later in development the *G* growth cone has climbed onto the *A/P* fascicle and is extending forward along it (*upper left*). Within its chosen fascicle the growth cone associates specifically with the *P* axons rather than the *A* axons, suggesting that it recognizes a surface molecule specific to the *P* neurons. This was established by Jonathan A. Raper's ablation experiments, in which the *A* or the *P* neurons (or both sets) were killed, so that their axons failed to develop. When only the *A* neurons are ablated, the *G* growth cone extends forward normally by fasciculating on the remaining *P* axons. Ablation of the *P* neurons, however, makes the *G* growth cone behave abnormally. It branches haphazardly, and it shows no particular affinity for any other fascicle (*upper right*).

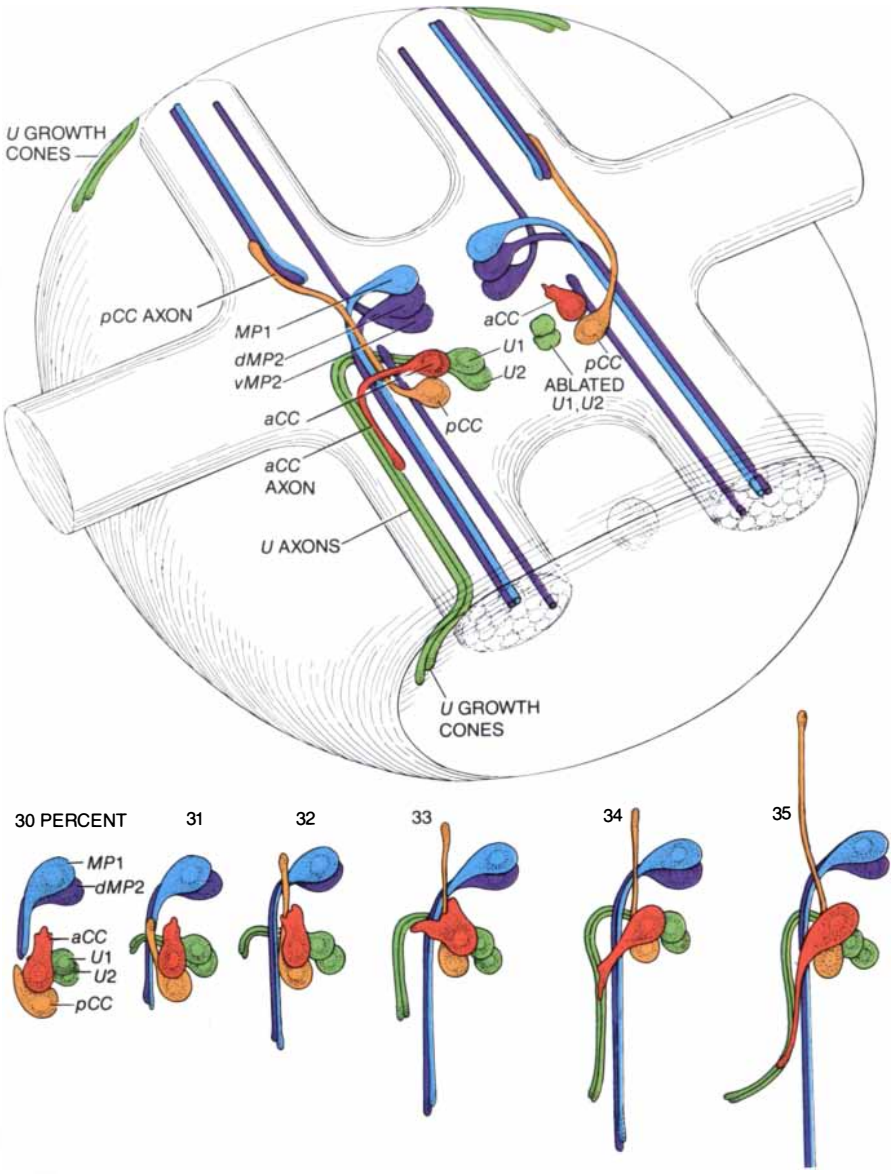




G **NEURON'S GROWTH CONE** is seen extending toward the *A/P* fascicle in this electron micrograph, in which a cross section of the neuropil is enlarged some 4,000 diameters. The growth cone is suspended in the neuropil by its extensive filopodial contacts with the fascicle. Within a few hours the tip of the *G* growth cone will have joined the fascicle and be closely juxtaposed with the *P* axons.

The surfaces of these siblings must be differently labeled even before the neurons extend their growth cones. This is shown by the fact that the filopodia of the *MP*1 growth cone, which have equal access to both neurons, selectively adhere to the *pCC* cell body and not to *aCC*. The difference between the two cells is even clearer when their growth cones begin to extend. The *pCC* growth cone extends forward as it fasciculates with the *MP*1 and *dMP*2 axons. The *aCC* growth cone points forward, but instead of extending it stands still for some 10 or 15 hours. Then, as the *U*1 and *U*2 axons traverse the region within its filopodial reach, it appears to respond: it turns, moves toward the two *U* axons and joins them as they extend rearward. To test the labeled-pathways hypothesis, du Lac ablated the *U*1 and *U*2 neurons with a laser microbeam. In their absence the *aCC* growth cone just stayed there pointing forward, showing no affinity for any of the other four axonal surfaces within reach. Similarly, ablation of the *MP*1 and *dMP*2 neurons left the *pCC* growth cone just standing still, pointing forward and showing no affinity for the other axons.

These examples of exquisite specificity, one at the 40 percent stage and the other at the much simpler 30-to-35 percent stage, convinced us that many different recognition molecules are expressed on the surfaces of embryonic axons and that growing neurons are guided to their targets by the selective adhesion of their filopodia to the labeled axons. This observation led us to predict that small subsets of neurons whose axons fasciculate together share common surface molecules.



EARLY IN DEVELOPMENT the first three longitudinal fascicles take shape and the growth cones of the sibling neurons *pCC* and *aCC* choose which one to join. The *pCC* growth cone quickly fasciculates with the *MP*1 and *dMP*2 axons and extends forward. The *aCC* growth cone seems to wait, pointing forward, until the two *U* axons pass nearby. Then it turns to join them as they move rearward in the embryo, as is shown at the left and in the series of detailed drawings representing six stages of development (*bottom*). Sascha du Lac found that ablation of the two *U* neurons leaves the *aCC* growth cone stranded, as is shown at the right in the large drawing. The growth cone points forward and fails to fasciculate. Apparently these early axon bundles are already differently labeled; *pCC* and *aCC* can distinguish among them.

One way to find these postulated recognition molecules is to inject embryonic cells into a mouse and let the mouse's immune system generate monoclonal antibodies against all the cell-surface molecules. Each antibody binds specifically to only a single such molecule, its antigen. By screening thousands of monoclonal antibodies one can hope to find an antibody that is specific for some molecule whose temporal and spatial expression can be correlated with the choices made by a particular growth cone. Such a molecule is likely to be one that labels a specific pathway. We chose to work with the 40 percent grasshopper embryo. At this stage the nerve cells are not yet synthesizing neurotransmitters or other proteins produced by fully differentiated neurons. Their main business is extending growth cones and recognizing pathways, and so we hoped it would be easier to generate antibodies against the surface molecules we think are involved in those tasks.

Kathryn J. Kotrla injected mice with the neuroepithelium of 40 percent embryos, fused the mouse spleen cells with malignant myeloma cells and screened the resulting "hybridoma" cells for their ability to synthesize antibodies against neuronal surface antigens. She found several monoclonal antibodies that recognize surface molecules displayed only on small subsets of fasciculating axons, just as our hypothesis predicted.

Two of these antibodies, designated *Mes*-3 and *Mes*-4, bind to surface molecules that distinguish a single longitudinal axon bundle from other fascicles both at 40 percent, when there are about 25 different fascicles, and at 33 percent, when there are only three. In both cases the two antibodies recognize the *MP*1/*dMP*2 fascicle—the one that, as described above, is chosen by the *pCC* growth cone and not by the *aCC*. In other words, an individual fascicle has been shown to be antigenically distinct from all others within the reach of an individual growth cone.

So far we have drawn a rather static picture of a developmental process that is in fact dynamic and interactive. For example, we described how at a certain stage the *G* growth cone and filopodia have a selective affinity for the two *P* axons. Somewhat later in development, however, three new growth cones emerge from the *G* axon. Two of them extend forward to become bilaterally

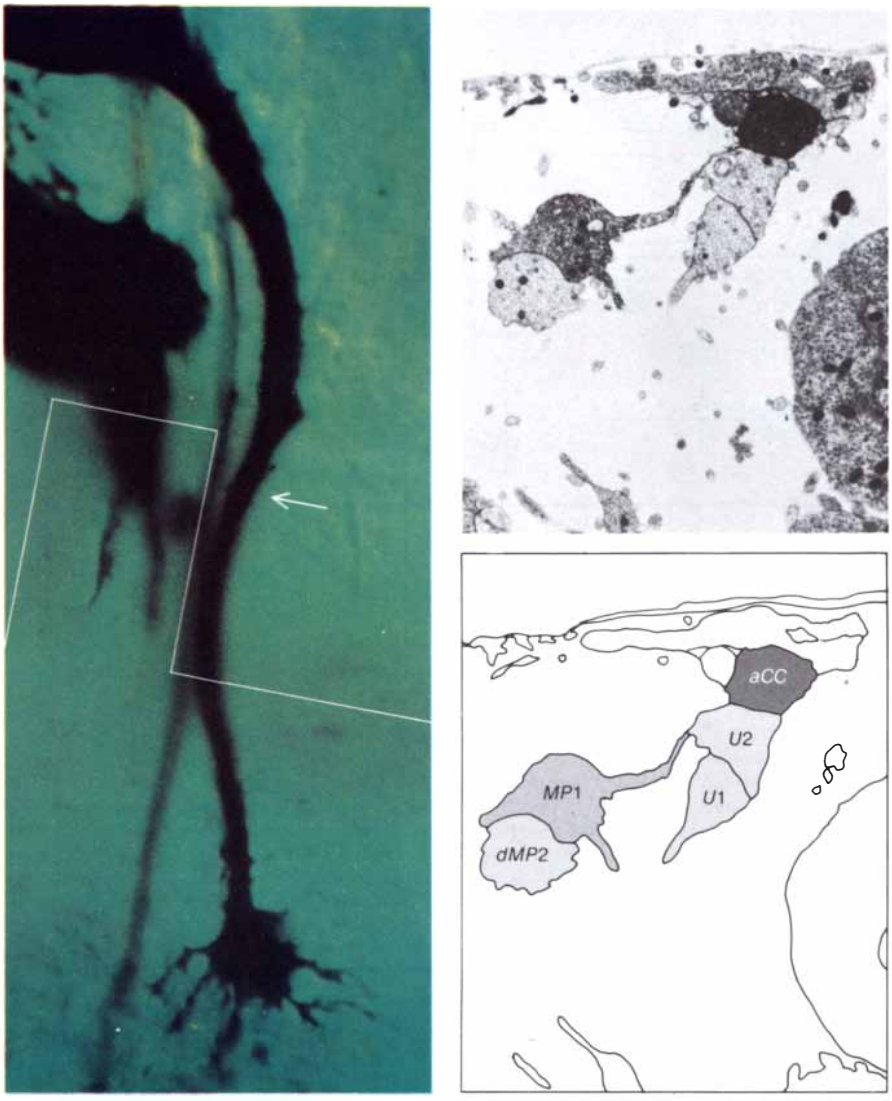
symmetric dendrites and the third extends rearward to become a secondary axon. These new growth cones fasciculate with different bundles, and in each case they are bundles for which the initial growth cone showed no affinity. Clearly the surface affinities of a single neuron's growth cones must change over time, presumably as the result of both the growth cones' interactions with other cells and the neuron's intrinsic program. For example, we think sequential changes in surface affinity cause an individual growth cone to switch from one fascicle to another as it moves toward its final target. How does a cell's biochemical machinery "know" where the growth cone is and with which neurons it has interacted?

The answer may lie in selective filopodial insertion, an interaction we discovered while examining electron micrographs for evidence of contact between filopodia and specific cell surfaces. We described above the selective adhesion of the *G* filopodia to the surfaces of the *P* axons and filopodia. It was interesting to find that, conversely, filopodia from the *P* axons make contact with the *G* growth cone. They thereupon insert themselves into it and in the process induce the formation of coated pits and coated vesicles, structures that ordinarily form when molecules are taken into a cell. The insertion is highly specific. Filopodia from some 40 other nearby growth cones and axons make contact with the *G* growth cone's surface, but none of them penetrate it. We think this filopodial insertion may induce a change in the expression of surface molecules on the *G* growth cone. Perhaps it sends a signal back to the *G* cell body, where such molecules are synthesized, saying in effect, "Your growth cone has found the *P* axons; prepare for the next choice point."

An experiment with a monoclonal antibody demonstrates this kind of change in specificity. The *Mes*-2 antibody recognizes an antigen that is expressed on the surfaces of only four of the 1,000 neurons in each hemisegment (two motor neurons and two interneurons). Moreover, it is expressed only transiently, at a particular stage of embryogenesis. The motor neurons are called *FETi* and *SETi*. Their axons fasciculate together outside the central nervous system and go on to innervate the same leg muscle. Although the two motor neurons arise from different neuroblasts, they alone among their family members share a final axonal pathway and express the *Mes*-2 antigen.

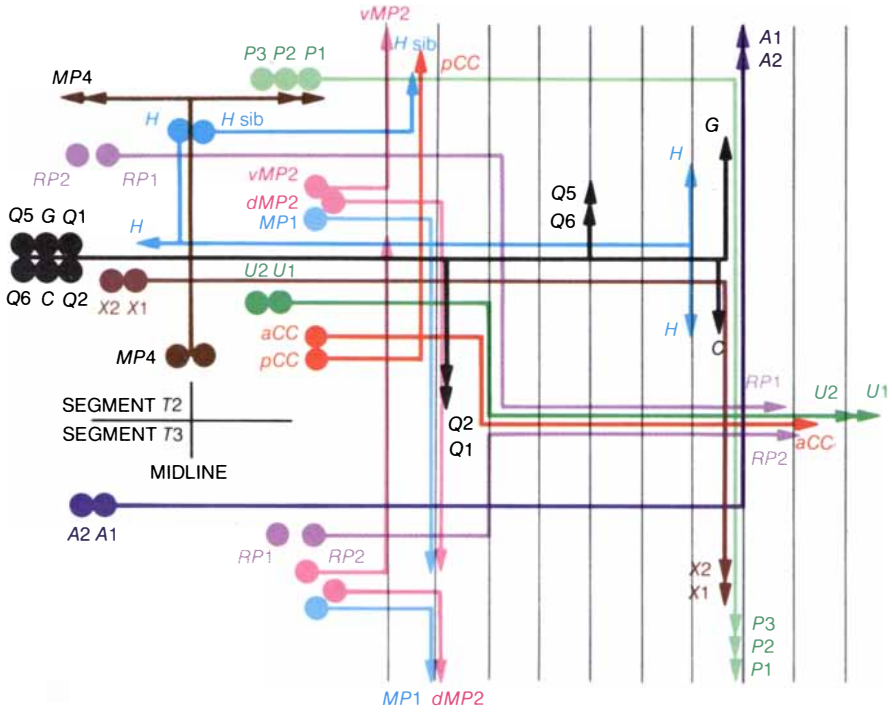
When the growth cone of the *FETi* axon first meets the *SETi* axon at the edge of the central nervous system, the two do not fasciculate—and neither cell expresses the *Mes*-2 antigen. Later, however, after having encountered several other cells, the growth cone and axon meet again farther out in the developing limb bud. This time they behave quite differently. *FETi*'s growth cone fasciculates with *SETi*'s axon and the two axons extend together to the target muscle. We find that the *Mes*-2 antigen begins to be expressed on both neurons just before this second encounter. Still later, after the two axons reach and innervate their common muscle, expression of the *Mes*-2 antigen decreases sharply, and eventually the antigen disappears.

We were excited to discover this antigen's localization on only four neuronal surfaces and its transience of expression. These features reflected the degree of specificity predicted by the labeled-pathways hypothesis. At the same time we felt frustrated because we knew it would be extremely difficult to isolate such an ephemeral molecule and to test its function. To do that we would need to identify the gene encoding it and then study and manipulate the gene's expression by exploiting the tools of molecular genetics. That would be very difficult in the embryo of the grasshopper, an insect whose genetic apparatus has not been intensively studied. We turned to the *Drosophila* embryo, in which molecular genetic approaches are more feasible.

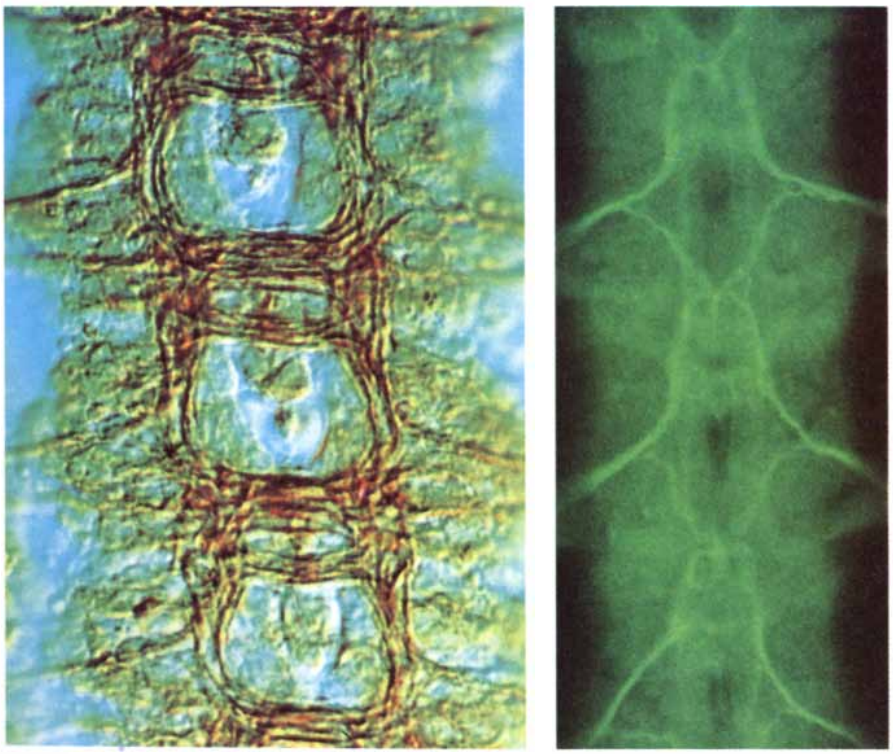


AXON OF *aCC* NEURON crosses over two other bundles before fasciculating with the *U* bundle. The photomicrograph montage (*left*) is of an embryo in which *aCC* (*top left*), *MP*1 and a structural glial cell (*upper left*) had been injected with horseradish peroxidase. The *aCC* axon crosses and then runs parallel with the lightly stained *MP*1 axon but does not join its bundle, having fasciculated instead with the *U* bundle (*unstained*). A thin section at the site indicated by the arrow is enlarged about 6,500 diameters in the electron micrograph (*right*).

Unlike the grasshopper, the fruit fly has what biologists call "advanced genetics." Its genes and their expression have been studied in detail since the 1920's. Thousands of mutant strains have been identified, so that particular genes can be associated with particular functions. Genetic studies in the fruit fly, notably those done by Seymour Benzer of Caltch and his colleagues and students, have made important contributions to knowledge of nervous-system development. Yet the small size and in-



DIVERGENT PATHWAYS chosen by the growth cones of identified neurons in one hemisegment are shown schematically. At this stage of development some 100 neurons (26 of which are shown here) have extended their axons. The 100 axons are organized into 25 longitudinal axon fascicles, 10 of which are shown. The circles are cell bodies and the arrows are growth cones of primary axons. The diagram covers parts of two segments, so that some neurons are represented more than once. Related neurons (descended from the same precursor cell) are shown in the same color. In spite of their common lineage and although they are confronted by the same environment, they often diverge to select different fascicles in the developing neuropil.



ORTHOGONAL PATTERN of axon bundles seen in the grasshopper is duplicated in the fruit fly *Drosophila*, but on a smaller scale; three identical segments are seen in a photomicrograph of a 12-hour fly embryo labeled by an antibody to the axonal protein tubulin (*left*). A monoclonal antibody made by Stephen L. Helfand binds to a molecule displayed only on a subset of embryonic fruit-fly neurons. Applied to a similar 12-hour embryo and indirectly labeled with a fluorescent dye (*right*), the antibody traces the *aCC* axon and other axons that fasciculate with it as it extends out of the central nervous system in the intersegmental nerve.

accessibility of *Drosophila*'s embryonic neurons had made it impossible to study cell recognition and neuronal specificity at the level of resolution we attained in the grasshopper.

We have been able, however, to scale down the methods developed in the grasshopper embryo and do the same kind of experimentation in *Drosophila*. In collaboration with John B. Thomas and with Bate at Cambridge, we found the early fly embryo's central nervous system to be a miniature replica of the grasshopper's. The resemblance is striking. There are homologous identified neurons in both embryos; their growth cones extend in the same directions and make the same fasciculation choices as they move through the same kind of ladderlike scaffold of axon bundles. For example, there is a *G* neuron in *Drosophila*. Its growth cone extends across the neuropil in a transverse axon bundle and turns forward along a longitudinal one. We found the longitudinal bundle consists of two *P* and two *A* axons and that the tip of the *G* growth cone associates specifically with the *P*'s, just as it does in the grasshopper. These results and a large number of others suggest that early patterns of cell recognition have been highly conserved in the course of insect evolution.

The ability to work with identified neurons, their growth cones and their patterns of fasciculation in the central nervous system of the *Drosophila* embryo makes it possible to exploit monoclonal antibodies, recombinant-DNA techniques and genetic analysis to unravel the mechanisms of cell recognition and neuronal specificity. In our laboratory Stephen L. Helfand has generated monoclonal antibodies that recognize small subsets of fasciculating axons. One antibody, for example, binds specifically to a molecule expressed on a few axons that join a single bundle: the *Drosophila* version of the grasshopper's *U* fascicle. In doing so the antibody distinguishes between the *aCC* and the *pCC* neurons, as would be expected on the basis of our cellular analysis in the grasshopper. The antigen it recognizes is therefore a prime candidate for the role of a cell-recognition molecule involved in selective fasciculation.

With Stephen T. Crews, Denise M. Johnson, Linda McAllister and John Thomas we are exploiting such antibodies and other molecular probes in an effort to isolate the genes encoding cell-recognition molecules. Eventually an understanding of the mechanisms underlying cell recognition by from 10 to 100 neurons in the grasshopper and the fruit fly embryo should provide a model applicable to the 1,000 pairs of neurons that eventually develop in each segmental ganglion of an insect, and perhaps even to the billions of neurons that develop in mammalian nervous systems.

The birth of a new generation.

A new coal gasification complex opened April of this year in Kingsport, Tennessee, making Kodak's Eastman Chemicals Division the first manufacturer in the United States to use modern coal conversion technology to produce industrial chemicals commercially from coal.

This method of manufacturing a new generation of chemicals saves us the equivalent of one million barrels of oil annually. A fact that makes us pleased. And just a little proud.

Using nearby Appalachian coal mines as a ready source of supply, the new plant can gasify about 900 tons of coal a day. That amounts to annual production of around 500 million pounds of acetic anhydride—a chemical needed to produce cellulose acetate, used in the manufacture of photographic film base, fibers, plastics and other products. Conventional technology, which uses ethylene produced from petrochemical feedstocks as the raw material, would consume the equivalent of a million barrels of oil to achieve the same results.

While some of the syngas processes were developed by others and licensed to Eastman Chemicals Division, new technological breakthroughs developed by us made the venture work.

Our innovations include: an energy-efficient method for producing refined methyl acetate, and a new process and catalyst system to produce acetic anhydride.

These achievements in chemical engineering and technology are steps in the right direction. Not only for ourselves (as coal gasification appears to be more economical), but for our country, too. We're now one step closer to independence from foreign oil.

To learn more about construction of a coal-gasification facility, write for our brochure *"Eastman* Chemicals from Coal" to Tennessee Eastman Company, Public Relations Dept, PO Box 511, Kingsport, TN 37662.

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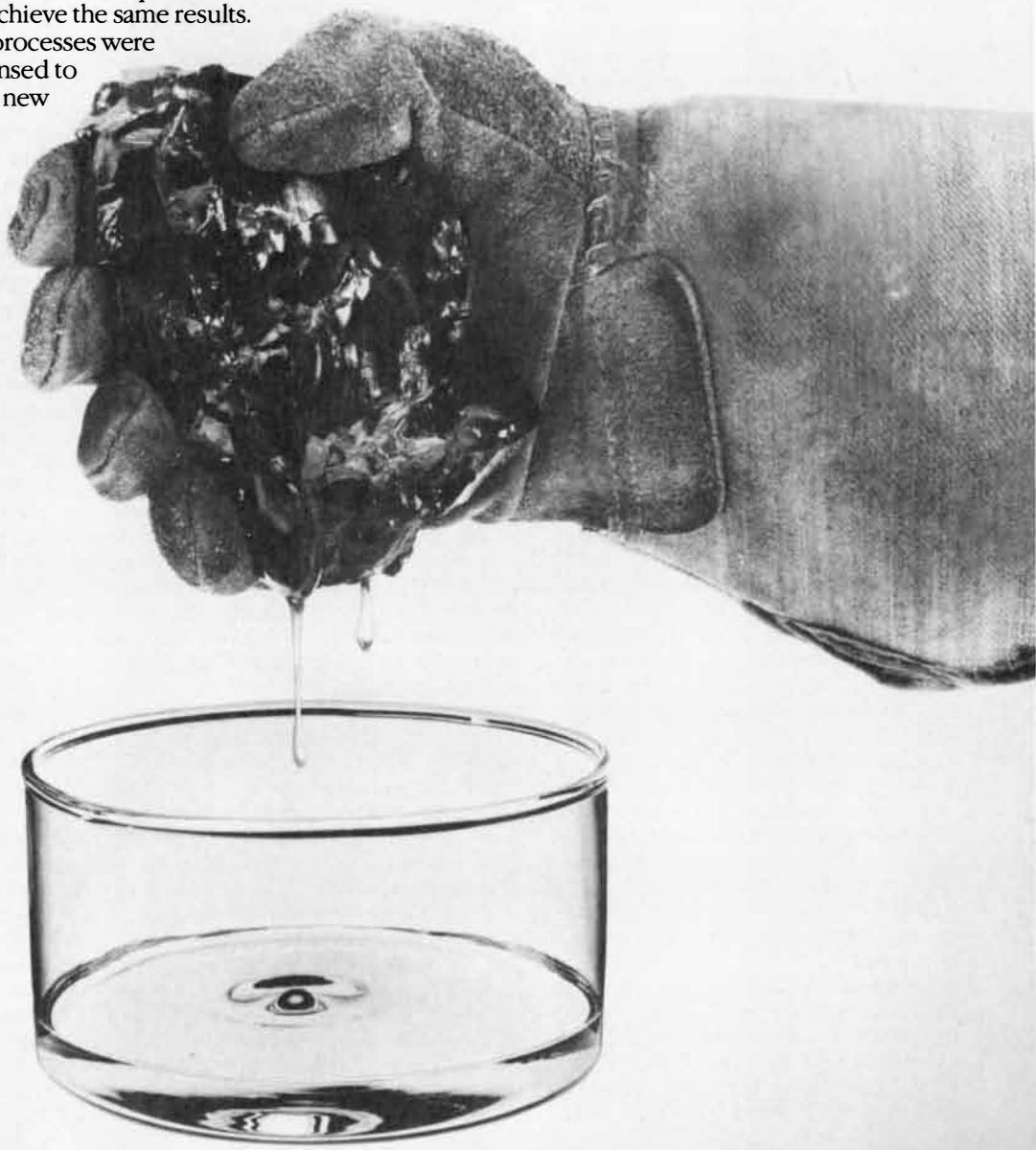


SCIENCE AND THE CITIZEN

Nuclear Winter in Paris

The growing awareness of the potential long-term climatic effects of nuclear war has elicited a rash of studies by investigators in various countries, including the U.S. and the U.S.S.R. Stimulated largely by the accumulation of evidence in support of the "nuclear winter" hypothesis, the surge of research activity has come to encompass a much broader range of concerns.

The expansion of the scientific agenda was evident at a recent international meeting in Paris devoted to an ongoing consideration of the latest findings in the field. In addition to papers on the main issue in question—the validity of computer models of the effects of clouds of smoke, dust and other nuclear-explosion debris on the transmission of sunlight and infrared radiation through the atmosphere—there were a fair number of reports on related topics, such as the projected impact of radioactivity on both human and nonhuman biota in the altered nuclear-winter environment.

The Paris meeting, which was attended by more than 60 scientists from 16 countries, was one of a series of interdisciplinary workshops sponsored by the Scientific Committee on Problems of the Environment (SCOPE), which has been charged by its parent body, the International Council of Scientific Unions, with conducting a major international review of the entire issue of the environmental consequences of nuclear war. The last such workshop was held in May in Leningrad; the next one is scheduled for February in Hiroshima. The SCOPE project, which is headed by Sir Frederick Warner of the University of Essex, is expected to release a lengthy report on its findings at the group's final session in Washington in September, 1985.

The study that resulted in the original nuclear-winter forecast (called the TTAPS study, after an acronym formed from the initials of the authors' surnames) was completed more than a year ago. Since then several other computer studies of the climatic effects of multiple nuclear explosions have been undertaken. Based on sophisticated two- and three-dimensional models of the general circulation of the atmosphere, they have been carried out by workers at the National Center for Atmospheric Research in Boulder, Colo., the Computing Center of the U.S.S.R. Academy of Sciences in Moscow and the Lawrence Livermore Laboratory. In general the results of these studies have tended to confirm the predictions made in the original TTAPS report (see "The Climatic Effects of Nuclear War," by Richard P. Turco, Owen B. Toon, Thomas P. Ackerman, James B. Pollack and Carl Sagan; SCIENTIFIC AMERICAN, August).

Criticism of the nuclear-winter studies done so far has consisted mostly of cautionary remarks about the many simplifying assumptions and estimates that inevitably enter such calculations; disputes over the likelihood of the various nuclear-war scenarios on which the models are based and differences of opinion about the advisability of sharing any of this information with the general public before more of the uncertainties can be resolved. Workers in the field point out that the resolution of such uncertainties will not necessarily reduce the predicted nuclear-winter effects, as some of the critics seem to assume; it is at least as likely, the workers say, that the initial TTAPS predictions will turn out to be understated.

One measure of the seriousness with which the nuclear-winter findings are being taken is the decision by the Reagan Administration to launch a large-scale research project aimed at clarifying the issue; estimated to cost some $50 million over the next five years, the effort will be coordinated by the National Climate Program Office of the National Oceanic and Atmospheric Administration (see "Science and the Citizen," October). The findings of the SCOPE review panel can be expected to influence the future course of all such longer-term research efforts.

A possible factor limiting the ultimate impact of the SCOPE report has been the apparent reluctance on the part of the Soviet representatives to share the details of their latest climate-modeling work. At the recent Paris meeting, for example, no mention was made of recurrent informal reports that workers at the Moscow computing facility had succeeded in constructing and testing an "interactive" three-dimensional computer model of the general circulation of the atmosphere that takes into account the effects of moving clouds of smoke and other nuclear pollutants. Also conspicuously absent from the agenda was any further discussion of a possible joint large-fire experiment, a project the scientific establishment of the U.S.S.R. had been said to look on favorably. With or without such contributions, one participant at the Paris meeting commented, the SCOPE report is likely to be one of the most momentous environmental impact statements ever prepared.

Secret Struggle

The danger that scientific inquiry may become a victim of Federal regulations designed to deprive a potential adversary of militarily useful technology resembles the heads of the mythical hydra: each time the issue is resolved in one area it materializes in another.

In 1983 the Department of Commerce drafted a revision of its Export Administration Regulations. The draft treated not only merchandise (microelectronics in particular) but also information. Specifically the draft formulated a category of "critical technical data": data not classified as secret but nonetheless not "publicly available," which would require a license for export. In the opinion of a panel convened by the National Science Foundation, the proposed regulations would require that a license be obtained for such activities as U.S. research in which foreign nationals participate, the presentation of scientific papers at U.S. conferences attended by foreign nationals, the presentation of scientific papers at conferences abroad and the submission of scientific papers to foreign journals.

The NSF panel recommended that the U.S. concentrate not on the uncertain goal of "protecting what we have" but on advancing "[our] strategic lead time." It suggested that "technical data" should not be confused with the "store of scientific knowledge on which the application concept is based." It recommended that restrictions be embodied in research contracts, not in regulations.

As the NSF waited for a response to its proposals the issue surfaced at the Department of Defense. The department's 1984 Authorization Act empowers it to keep from the public "unclassified technical data with military or space application" that is "in the possession of, or under the control of, the Department of Defense." Such data are judged to "contain critical technology": technology that makes "a significant contribution to the military potential of any country or combination of countries and that may prove detrimental to the security of the United States." The NSF panel argued that such restrictions are likely to affect "an enormous amount of cutting-edge research."

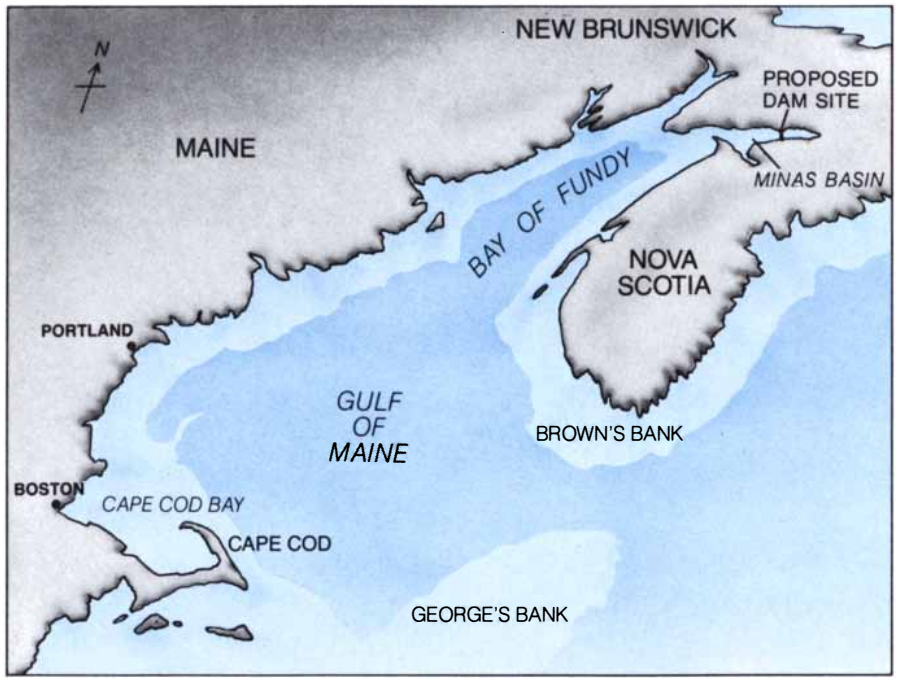
The Defense Department now appears to have reached an accommodation with its critics. Richard D. DeLauer, Under Secretary of Defense for Research and Engineering, released a memorandum setting department policy for the publication of "fundamental research" sponsored by the department. It states that "no controls other than classification may be imposed on fundamental research and its results when performed under a federally supported contract." DeLauer's memorandum cites the draft of a National Policy on the Transfer of Scientific and Technical Information prepared by the National

Security Council. The draft notes that "the acquisition of advanced technology from the United States by Eastern Bloc nations for the purpose of enhancing their military capabilities poses a significant threat to our national security.... At the same time, our leadership position in science and technology is an essential element in our economic and physical security....the free exchange of ideas is a vital component." According to Administration policy, the draft concludes, only classified research done under Government contract would be restricted.

Meanwhile, however, the Department of Energy has created a category of "Unclassified Controlled Nuclear Information." The Department of State for its part is drafting revisions to ITAR: the International Traffic in Arms Regulations. The regulations are meant to govern the sale and export of arms and ammunition. There is, however, enough leeway in them so that they affect information. Thus sparring has begun over the language of the draft. Testimony has been submitted to the State Department on behalf of the American Physical Society and the Association of American Universities.

It is a closely argued struggle. For example, the draft ITAR revisions exempt "general mathematical and engineering information which is only indirectly useful in the defense field." This leaves the possibility that "some types of general mathematical and engineering information... are directly useful." Instead the American Physical Society and the Association of American Universities suggest that "fundamental research [should] be distinguished from research relating to the performance characteristics of military systems or to manufacturing technologies that are unique and critical to defense." The draft revisions define "defense services," which under the draft regulations would require a Federal license, to include "the furnishing of assistance to foreign persons in the design, engineering, development, production, processing, manufacture, operation, overhaul, repair, maintenance, modification, or reconstruction of defense articles." The language seems safe. Yet "the instruction of a foreign person in university courses in microelectronics, for example, could be construed as prohibited assistance in the design or engineering of defense articles."

The American Physical Society and the Association of American Universities suggest that the State Department draft should be made to conform with the policy under review at the National Security Council. The testimony asks the State Department to remember "that nuclear weapons, radar, lasers, semiconductor technology, and computers—to name just a few technologies of military significance—had their roots in open scientific inquiry."



A power plant in Minas Basin could raise tides in Cape Cod Bay

A Dam Shame

Tidal power seems an environmentalist's dream: it converts a completely renewable fuel source into pollution-free energy. Theoretical modeling done in New England and Canada shows, however, that a tidal power plant proposed for the Bay of Fundy may more closely resemble an environmental nightmare.

The North Atlantic tide, with a period of about 12 hours 25 minutes, drives the tides in the Gulf of Maine and the Bay of Fundy. The natural period of this smaller system (the period with which the water in the Gulf of Maine–Bay of Fundy region would wash back and forth if it were set in motion and then left undisturbed) is about 13 hours—different enough so that it does not fully resonate with the larger system.

The proposed station would detrimentally change that relationship. The plant would consist of a dam built across the Minas Basin, the eastern tip of the Bay of Fundy. Sluice gates in the dam would be opened during the incoming tide, allowing water to flow into the basin. When the tide turned, the sluice gates would close, and outgoing water would flow through turbines to generate electricity.

According to a model developed by David A. Greenberg of the Bedford Institute of Oceanography in Dartmouth, Nova Scotia, such a dam would shorten the natural resonant period of the Gulf of Maine–Bay of Fundy system, bringing it closer to the period of the North Atlantic tides. Because the two systems would be in almost perfect resonance, the difference between high and low tides in the Gulf of Maine—which includes areas as far south as Cape Cod Bay—would increase by 10 percent.

In a report to the Maine State Planning Office, Peter F. Larsen of the Bigelow Laboratory for Ocean Sciences points out that increased water levels would endanger coastal roads and bridges as well as waterfront houses. He predicts that as many as one-fourth of Maine's waterfront communities would suffer from well-water contamination. Salt-marsh areas would be flooded. Lower low tides could make some harbors and docking areas unnavigable.

As Robert W. Rudolph of the University of Rhode Island writes in a paper coauthored by Larsen and delivered at a symposium sponsored by the American Society of Civil Engineers, the Canadian project is "unique because some, perhaps the major, environmental impacts will occur in another country, i.e. the United States." One Canadian scientist has jokingly called the project "an answer to acid rain... our attempt at geophysical warfare." The joke may not play very well in northern New England, particularly if Canada takes the first step toward implementing the plan, a three-year precommitment study. The study is tentatively scheduled to begin in February, 1985.

A Time to Die

A panoply of drugs and electronic devices can sustain life or at least maintain vital signs. This technology can help a patient through a crisis or

give medical personnel an opportunity to apply definitive therapy. Such technology is also used by physicians, nurses and paramedics in self-defense. To terminate life support may expose both physician and hospital to criminal charges or to civil action. Faced with such a prospect many physicians choose to sustain life until death—or civil authorities—intervenes.

The extent to which the use of such technology represents the practice of defensive medicine is indicated in a preliminary report of a survey conducted by a group from the University of Florida College of Nursing. Gene Cranston Anderson and her students and colleagues report in *The New England Journal of Medicine* that most doctors and nurses, if they were terminally ill, would rather not have such procedures employed to prolong their own lives.

The main question on the survey concerned living wills, documents signed by healthy people that specifically restrict or forbid the use of artificial life-prolonging methods if the signer becomes terminally ill. Living wills have been recognized by 21 states and the District of Columbia. Earlier studies indicate that many doctors are in favor of living wills for their patients; Anderson wanted to find out what nurses and physicians would choose for themselves.

She and her collaborators sent anonymous questionnaires to 500 members of the American Medical Association and 500 members of the American Nurses' Association. Of the 277 respondents, a total of 65 percent essentially favored signing living wills: 18 percent had already signed such documents or made similar arrangements (sometimes both), 31 percent wanted to sign living wills and 16 percent thought they would like to sign living wills but needed more information. Only one of the respondents said that he or she would never sign a living will, and another respondent had already made arrangements for his or her life to be maintained by artificial means for as long as possible.

Nurses were generally more in favor of living wills for themselves than physicians were: more nurses than doctors responded to the survey (194 to 83), and 69 percent of the nurses rejected prolonged life support as opposed to 60 percent of the physicians.

Bells of Note

The notes of 2,400-year-old chime bells that resounded through Beijing's Huai-Ren Hall in a celebration marking the 35th anniversary of the founding of the People's Republic of China have shattered some notions about the history of music. The sounds of these bells make it crystal clear that modern scales and precise tuning methods were in use in ancient China.

The bells played in the performance are reproductions. Nevertheless, they preserve the acoustical character of the originals, which were unearthed in 1978 from the tomb of the Marquis Yi, ruler of an ancient principality called Zeng (in what is now Hubei province), who died in about 433 B.C. Almost perfectly preserved, the bronze bells number 65 and range in height from a few inches to five feet.

A filigree of gold-inlaid inscriptions details each bell's musical properties. The largest bells represent an unparalleled feat of metalworking. At the time of their casting, according to Ernest G. McClain, professor emeritus of music at the City University of New York, "the largest bells in the West were eight inches high."

Instead of exhibiting the circular cross section of European and Indian bells, the chimes, seen from below, are fusiform. Thus each clapperless bell produces two distinct tones when it is struck in different places. The design also causes vibrations of the bells to attenuate quickly, suiting them for use as musical instruments.

The tunes the bells sounded at the court of the Marquis Yi are lost, but the pitches of the bells preserve the musical scheme of the era. The set spans more than five octaves, from the lowest tone of a cello to the highest note of a flute. Through much of that range the notes approximate the modern chromatic scale, the 12-tone system represented by the seven white and five black keys of a piano. Until the discovery of the set many authorities believed Chinese musicians did not develop a full set of 12 tones until several centuries after the Marquis Yi's bells were cast.

Bell of Zeng

McClain thinks the bellmakers followed two different tuning schemes in determining the intervals between the notes. Known in the West as Pythagorean and just tuning, both systems specify the relative frequencies of different notes in terms of precise ratios of integers. The ancient Greeks knew both systems. McClain thinks just tuning originated with the Babylonians. The makers of the Marquis Yi's bells followed the two tuning formulas with impressive precision. The result, says McClain, is a series of intervals so accurate that "some of the octaves, fifths and fourths are as good as we could do today."

Many of the bells are tuned accurately not only with respect to one another but also by an absolute standard known as philosophical pitch, in which reference frequencies are governed by powers of 2; the philosophical pitch of middle C is 2^8, or 256, hertz. In the Zeng set the bell that sounds middle C vibrates at 256.4 hertz. McClain speculates that China in the fifth century B.C. may have had an acoustical science advanced enough to determine vibration rates—a capacity European science did not achieve for another 2,000 years.

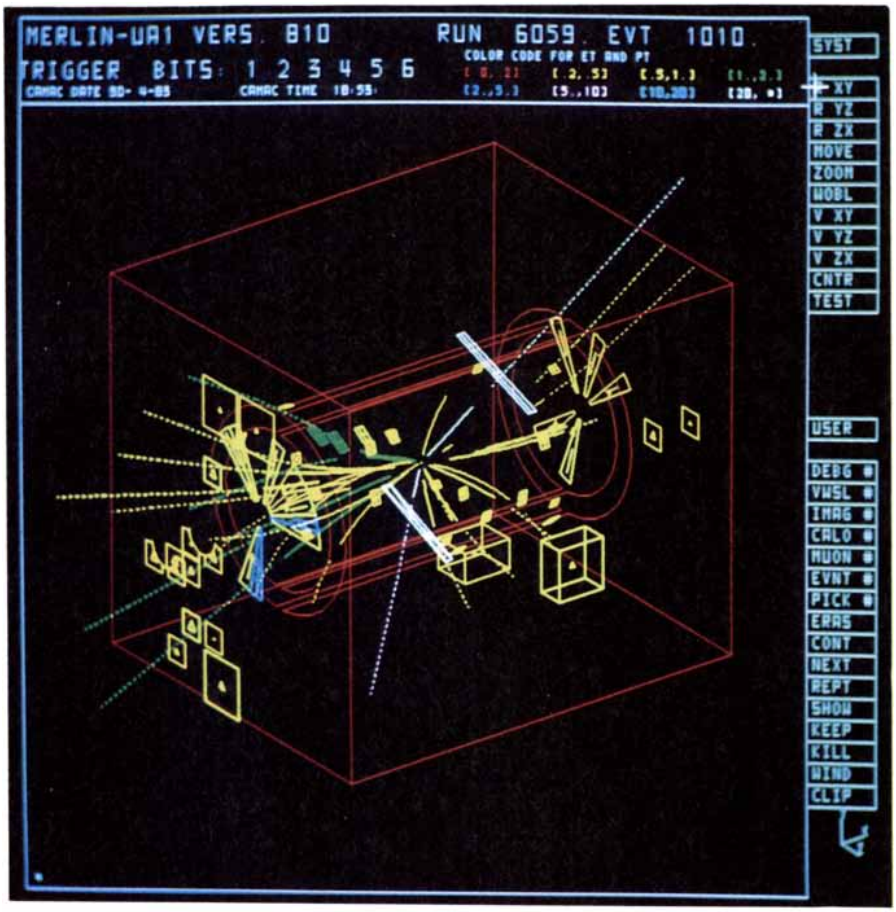
Nobel Prizes

Physics

The prize in physics symbolically recognizes the achievement of hundreds of physicists for the detection last year of the three particles that carry the weak nuclear force, the W^+, W^- and Z^0 intermediate vector bosons. The experimental proof for the existence of the three particles was a crucial step in the confirmation of the so-called electroweak theory, now widely regarded by physicists as one of this century's most important contributions to a unified understanding of the elementary processes of nature.

The award is to be shared by two of the most creative and energetic members of the experimental group: Carlo Rubbia of Harvard University and of CERN, the European laboratory for particle physics near Geneva, and Simon van der Meer, also of CERN.

Until about 15 years ago the four observable forces of nature (the electromagnetic force, the weak nuclear force, the strong nuclear force and gravity) appeared to be quite independent of one another. For example, the effects of the weak nuclear force are confined to a short range (about 10^{-16} centimeter, or about a thousandth the diameter of a hydrogen nucleus), whereas the range of the electromagnetic force is believed to be infinite. Nevertheless, the electroweak theory explains both the weak nuclear force and the electromagnetic



*An electron and a positron (***white lines***) provide first evidence for the existence of the* Z^0

force as two manifestations of a single underlying phenomenon.

According to the theory (which won Steven Weinberg, Abdus Salam and Sheldon Lee Glashow the prize in 1979), the three vector bosons detected at CERN serve as intermediaries between weakly interacting particles, just as the photon serves as an intermediary between two particles that are electrically charged. Unlike the photon, however, which has zero mass, each of the three intermediate vector bosons was predicted to be quite massive by the standards of elementary particles: between 80 and 90 billion electron volts.

Until recently existing particle accelerators were thought to be insufficiently powerful to create particles with such a large mass. Rubbia contributed the idea of converting the existing large accelerator ring at CERN, which smashed protons into a fixed target, into a colliding-beam machine: the accelerated protons are made to collide head on with a beam of antiprotons that are accelerated around the ring in the opposite direction. The energy liberated by each head-on collision is greater than that released when a proton collides with a stationary target.

Because antiprotons are difficult to generate, relatively few of them are available for the collisions; accordingly the beam must be highly collimated, or focused, if there are to be enough collisions to generate statistically usable results. Van der Meer contributed a new idea for "cooling" the beam of antiprotons, or reducing its random motions. At various points on the ring a sensor detects the scattering of the beam. A signal from the sensor is transmitted directly across the ring so that it reaches a device called a "kicker" before the circling packet of antiprotons arrives. The kicker applies an electromagnetic field that corrects the scattering of the packet.

Physiology or Medicine

In his autobiography Sir Macfarlane Burnet, who shared the Nobel prize for physiology or medicine in 1960, called Niels Kaj Jerne "the most intelligent immunologist alive." In October the Nobel committee awarded the 1984 prize to Jerne and two other immunologists. It recognized Jerne as "immunology's great theoretician" and called the development of monoclonal antibody technology by the other two, Cesar Milstein and Georges J. F. Köhler, "one of the most important methodological achievements in biomedicine of the 1970's."

Jerne, a Dane who worked in the U.S. and West Germany before becoming director of the Basel Institute for Immunology in Switzerland, was honored for originating three theories. His selective theory of antibody formation, published in 1955, helped to shape the current view of how the immune system protects the body against an enormous variety of foreign substances, most of which it cannot have encountered.

The surface of a virus, bacterium or other foreign substance (antigen) entering the body carries sites called epitopes, or antigenic determinants. When they encounter an organism's immune system, they elicit the proliferation of specific antibodies that bind to the antigen and set in motion a series of events that neutralize it. The "instructive" theories generally accepted in the 1950's held that a foreign antigen itself supplies the information for shaping a specific antibody able to fit and bind to the antigen.

Jerne's selective theory suggested that the advent of the antigen does not instruct immune-system cells to make a particular antibody but instead selects an antibody from a vast repertory of preexisting ones. Burnet went on to show that what the antigen selects is a particular clone of immune-system cells (*B* lymphocytes) already programmed to make the appropriate antibody.

A second Jerne theory sought to explain how another kind of immune-system cell, the *T* lymphocytes, mature in the thymus gland and learn how to distinguish "self" from "nonself."

Finally, Jerne's network theory, developed in 1973, held that the immune system must be regarded as a self-regulating "functional network" of interacting antibodies and lymphocytes (see "The Immune System," by Niels Kaj Jerne; SCIENTIFIC AMERICAN, July, 1973). He proposed that an organism has antibodies against antigenic determinants not only on foreign molecules but also on its own antibodies and its own *T* cells' receptors, and that the interaction of all these antibodies and anti-antibodies either stimulates or represses the immune system's response to a foreign antigen.

Milstein once wrote: "What if one could pluck out [a single] cell making a single specific antibody and grow it in culture?" It was for this feat that Milstein and Köhler shared the prize.

When an animal has been immunized with a foreign substance, its serum contains a mixture of many antibodies that bind more or less well to a number of antigenic determinants; it is impossible to isolate from the serum a specific antibody that will bind to a particular, known determinant. Yet every antibody is made by a single line of *B* lymphocytes, and that is what prompted Milstein's rhetorical question. The problem is that an ordinary antibody-producing cell will not grow in tissue culture. Milstein and Köhler solved the problem.

In 1975 Milstein was a senior scientist

at the British Medical Research Council Laboratory of Molecular Biology in Cambridge and Köhler was a postdoctoral fellow. (He later moved to Jerne's institute in Basel.) It occurred to them to fuse normal lymphocytes, from mice immunized with a particular antigen, with myeloma cells: malignant (and therefore immortal) cells from an immune-system tumor. The result of this fusion, a "hybridoma" cell, retains both the lymphocytes' capacity for synthesizing a particular antibody and the myeloma cells' property of growing indefinitely in culture. An individual hybridoma cell can be isolated and cultured, giving rise to a clone of cells. Such a clone produces large amounts of a single antibody that recognizes a single antigenic determinant: a monoclonal antibody.

Monoclonal antibodies have become standard tools for finding, identifying and isolating particular molecules in complex mixtures or in tissues. In medicine they give promise of serving as therapeutic guided missiles. The hope is to prepare a monoclonal antibody that binds only to an antigen on the surface of a particular kind of cancer cell. If such an antibody can be hitched to an anticancer agent, the resulting "immunotoxin" should home on the target cancer cells, enabling the drug to kill them without harming healthy cells.

Chemistry

A "simple and ingenious" idea for the automatic synthesis of proteins that "has created completely new possibilities in the field of peptide and protein chemistry . . . as well as in the field of nucleic acid chemistry," in the words of the award, has brought R. Bruce Merrifield of Rockefeller University the 1984 Nobel prize in chemistry.

During the late 1950's Merrifield began to develop an idea for assembling amino acids one at a time into chains called peptides. A peptide is a simple model of a protein, consisting of the same structural elements although fewer of them than are present in a complete protein. Consequently Merrifield's process makes possible the automated synthesis of the complete molecule. The first protein assembled (in 1965) by Merrifield and his co-workers was insulin.

According to Merrifield's method, the first amino acid of a peptide chain would be attached by a chemical bond to a polystyrene bead; then the remaining amino acid units would be added step by step in the proper order. The chain, once formed, is easily separated from the matrix.

This simple and ingenious idea has had profound consequences. It has enabled investigators to elucidate the effect of structure on the biological func-

tion of many proteins, including enzymes, hormones and antibodies. These insights are leading to significant applications in medicine.

Because the technique serves to make proteins or fractions of proteins, it has helped in the development of monoclonal antibodies (see preceding story). Solid-phase peptide synthesis is often employed to make antigenic peptides, which serve in turn for making the clone of hybrid cells that produce large amounts of antibody specific to that particular antigen.

A number of laboratories are exploring the possibility of making synthetic vaccines against such viral diseases as influenza, rabies and hepatitis. The idea is to synthesize the portion of the virus's protein coat that is antigenic and then employ that antigenic peptide to provoke antibody production in the patient. The technique would eliminate the hazard of vaccines made from killed or attenuated viruses, which may retain enough potency to give rise to disease.

Another application of solid-phase peptide synthesis is in making medically important peptides, among them the pituitary hormone ACTH and the thyroid hormone calcitonin. Merrifield's laboratory has synthesized glucagon, a protein obtained from the pancreas. The hormone increases the sugar content of the blood by raising the rate of breakdown of glycogen in the liver. The next step is to make glucagon analogues that could lead to the design and production of synthetic inhibitors of the hormone. They would compete with glucagon for activating sites in the liver but would not trigger the production of glucose. They would thus reduce the high blood sugar of diabetes and the amount of insulin a diabetic needs to take.

The work may also lead to the development of significant new drugs. A case in point is the laboratory's work on C3a anaphylatoxin, a polypeptide of 77 amino acids that mediates inflammation and other effects set in motion by the body's immune system in response to infection. In making synthetic peptides the laboratory found that the active part of the molecule is the last five amino acids. The goal of the study is to develop anti-inflammatory drugs that would neutralize C3a and help to minimize the damage to tissue caused by such diseases as asthma and rheumatoid arthritis.

Economics

How does one keep track of the billions of transactions between buyers and sellers that constitute the activity of a nation's economy? Until some 30 years ago there was no systematic way of doing so, and in efforts to formulate a picture of a national economy much information was lost or overlooked.

In the 1950's Richard Stone of the

University of Cambridge began to formulate a system of national accounts that is now in wide use. Industrialized nations use the system (now known as S.N.A.) for assessing their own economies; international organizations use it for comparing one national economy with another. This year the work brought Sir Richard (he was knighted in 1978) the Alfred Nobel Memorial Prize in Economic Science.

The transactions between households, business entities, the public sector and foreign countries formed Stone's starting point. He saw that such transactions were usually double-sided: the outlay of one party was the income of another. He devised a procedure through which the immense number of transactions in this double-entry bookkeeping system could be consolidated into meaningful account summaries according to sector.

A system of national accounts consists of precisely defined accounting categories that taken together summarize how a nation's gross national product is produced and how it is distributed and used. No specialized kind of mathematical statistics is required. The data that go into the compilation for the U.S. include the economic censuses prepared by the Bureau of the Census, the Internal Revenue Service's summaries of income, the Department of the Treasury's monthly statement of the receipts and expenditures of the Federal Government and the summary of the nation's balance of payments in foreign trade.

Wassily W. Leontief of the Institute for Economic Analysis at New York University, who won the Nobel economics prize in 1973 for his work on input/output analysis (an important component of systems of national accounts), described the award to Sir Richard as eminently deserved. Sir Richard is, he said, "one of the few economists in the last generation who has not just theorized or provided political advice but has contributed greatly to the advance of economics as an empirical science."

Cosmic Candle

Supernovas, the catastrophic explosions of dying stars, may help to settle the central question of modern cosmology: Is the universe perpetually expanding, or is it doomed to eventual collapse under the pull of its own gravitation?

Astronomers generally agree that the universe does not expand as rapidly as it once did. Whereas nearby galaxies are receding from this one at a velocity proportional to their distance, that relation does not hold for extremely remote galaxies; they are moving away faster than their distance would suggest. Because the light reaching the earth from these galaxies was emitted billions of years ago, this means that the expansion has

slowed since then. The fate of the universe depends on the difference between the current expansion rate and past rates: if the deceleration is large enough, the cosmos will at some time stop growing and collapse.

To measure the deceleration precisely one needs accurate gauges of the velocity of astronomical objects and of their distance from the earth; the expansion rate is simply the ratio of the two. The recession velocity of a light source can be derived from the red shift in its spectrum. Determining cosmological distances with precision has proved a more difficult problem, which the observation of supernovas may help to solve.

The classic approach to measuring distance was developed in the 1920's by Edwin P. Hubble, the discoverer of the cosmic red shift. According to this approach, the distance to a remote light source is estimated by comparing its apparent brightness with that of a nearby source of the same type whose intrinsic brightness is assumed to be the same and whose distance is already known. Objects whose intrinsic luminosities are believed to be uniform are known as "standard candles." Astronomers have used a series of standard candles, including the brightest stars in galaxies, to measure progressively greater distances, constructing what might be called the Hubble ladder, on which each step is calibrated by the previous one.

Some workers, notably Allan R. Sandage and Gustav A. Tammann of the Mount Wilson and Las Campanas Observatories, now argue that "Type I" supernovas could both extend the standard candle ladder and eliminate some intermediate steps; such stars are in principle observable in both nearby and remote galaxies. Sandage maintains there are good reasons for believing Type I supernovas have uniform luminosity. They are all thought to derive from the same process: the gravitational collapse of a white dwarf that has absorbed matter from a companion star. Furthermore, they show similar spectra and decreases in brightness with time.

By other methods Sandage and Tammann have calculated the distance to the nearest galaxy containing a Type I supernova and have thereby estimated the intrinsic Type I luminosity. According to Sandage, the estimate agrees well with recent theoretical calculations. The luminosity figure positions the other known Type I supernovas on a distance scale, and it leads directly to a value for the current expansion rate (also called the Hubble constant): roughly 15 kilometers per second per million light-years. To measure the cosmic deceleration, however, supernovas several billion light-years away must be observed. The feat, not yet accomplished, should be within the capability of existing telescopes. To this end several groups are now undertaking automated searches of remote galaxies.

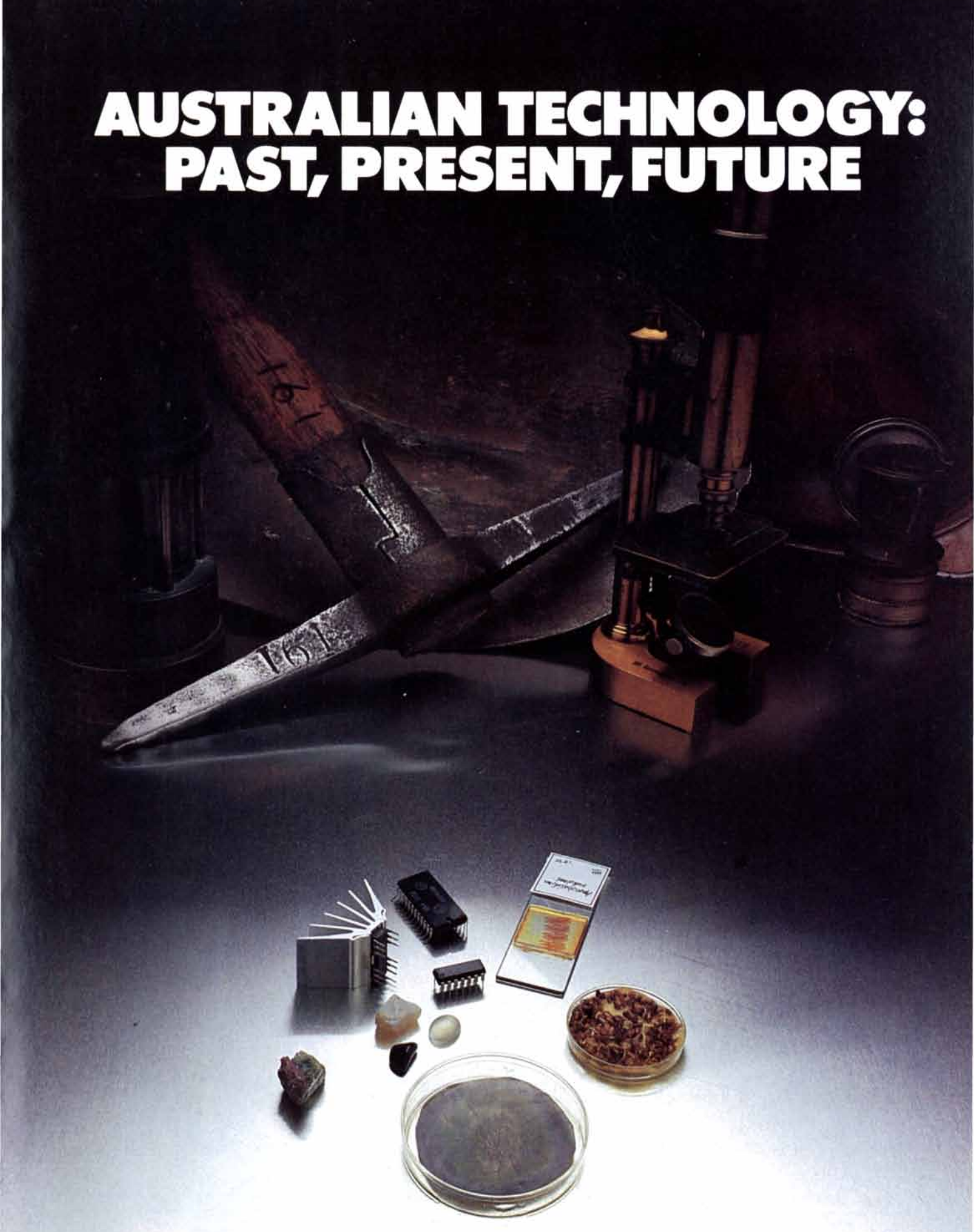
In the meantime the Sandage-Tammann estimate of the Hubble constant is by no means universally accepted; Gerard de Vaucouleurs of the University of Texas at Austin has arrived at a value twice as large. Other workers now believe the Hubble ladder, with or without supernovas, is intrinsically rickety, containing too many uncertainties to ever yield conclusive answers to cosmological questions. Robert V. Wagoner of Stanford University points out that calculating the cosmic deceleration by this approach requires the hard-to-verify assumption that supernovas in remote galaxies have the same maximum luminosity as ones closer at hand, even though such galaxies are observed at an earlier stage in their evolution.

Instead Wagoner urges the adoption of a different approach, based on a method of distance measurement first proposed by the German astronomer Walter Baade in 1926. The method depends on computing a supernova's angular size—the ratio of its radius to its distance—from the ratio of the flux received on the earth to the flux actually emitted by the supernova. Repeating the measurements at different times yields the angular expansion velocity of the exploding star. The linear expansion velocity can be determined from the Doppler shift in the star's spectrum, and the ratio of the two velocities then gives the distance.

Workers applying this method previously had to assume, in calculating the emitted flux, that supernovas radiate as black bodies, but Wagoner has now made this limitation unnecessary by developing a physical model of the supernova atmosphere. Recently he tested his model on a relatively nearby supernova and found that the spectrum predicted by the model closely matched the observed spectrum of the star.

Wagoner's method is not free of problems: like the standard candle approach, it depends on catching a supernova during the brief period of a month or so when the brightness is close to maximum. Another drawback is that it requires a precise measurement of the total flux from the star. With telescopes on the earth it is hard to distinguish the radiation of a distant supernova from the background of the galaxy it lies in, because atmospheric scattering smears the image; the atmosphere also blocks out valuable information from the ultraviolet range. Thus if the Hubble constant and the deceleration are to be determined by this approach, it will have to be with the help of the Space Telescope, scheduled for launch in 1986. Wagoner must now persuade the National Aeronautics and Space Administration that the fate of the universe is a question his method holds promise of answering.

AUSTRALIAN TECHNOLOGY: PAST, PRESENT, FUTURE



Australian Technology: Past, Present, Future

Researched and written by:

Jane Ford,
Scitech,
51 Boobialla Street,
O'CONNOR, ACT. 2601
Tel: (062) 47 7220

and

Tim Griggs,
Tim Griggs & Associates,
P.R. Consultants,
Suite 916, 185 Elizabeth Street,
SYDNEY, NSW 2000
Tel: (02) 2649414

Edited by Stephen P. Smith

Conceived and produced by: JOHN M. F. KEENEY and STEPHEN P. SMITH
International Media Representatives
2nd, Floor, Cordell Building,
160 Sailors Bay Road, NORTHBRIDGE, NSW 2063
Tel: (02) 958-1699. Telex: 74473 IMR

Front Cover Design: Vernon Oakley Design, London

Layout and Design: Dennis Mackay and Geoffrey Davis,
Xanadu Art & Copy Pty Ltd.

Contents

Australia is fast becoming aware that vast mineral and agricultural wealth is no longer enough to guarantee its future. The importance of scientific and technological expansion has become an issue of national concern. The following study presents a wide-ranging review of technology and its potential in Australia. The report contains two primary parts. A general survey, divided into past, present and future sections, provides historical background and organizational information on the nation's scientific enterprise. A series of focus articles examine specific companies, projects, regions, technologies and issues.

The Survey

Focus Articles

The Past: An agricultural and mining economy is founded and early innovation flourishes

Australia's development has resulted from the application of capital and labor to the natural resources of the continent. However, supplies of capital and labor have not always been sufficient, and development has been periodically thwarted by the severity of the climate. In exploration and development a prolonged battle has been waged against severe droughts and an extreme range of temperature.

Innovation has been an essential element in helping Australia to overcome such obstacles since its earliest pioneer days.

The economic impulse that opened up the continent originated in the wool industry, which for more than a century has supplied Australia's most valuable export. The first settlers, however, were interested in sheep as food rather than in their wool. When John Macarthur, both an officer in the New South Wales Corps and a farmer at Parramatta, suggested breeding sheep not for their meat but for the fleece, he met with derision from his fellow colonists. But when in 1797 Macarthur imported a small flock of Merinos, the more discerning farmers realized the potential value of the wool.

Governor King, an advocate of the development of the wool trade, wrote prophetically in 1800: "The introduction of a breed of Spanish sheep into the flocks of individuals has so much improved the fleeces that there is a promising appearance of a great quantity of wool being produced in a few years." In 1807 the first consignment of Merino wool, weighing 245 pounds, was shipped to England, where its fine quality attracted wide interest.

The Australian multimillion-dollar wheat export industry had its origin when William Farrer, Australia's pioneer of scientific wheat breeding, realized that English wheat varieties were potentially high yielding in Australia but matured too late to survive the long summer droughts. In 1886 he began breeding new varieties. By crossing Indian and English varieties he produced the breed called Federation, which combined early maturity with high yields. Because the wheat is grown under drier conditions, it is less susceptible to attack by rust.

Innovative farm machinery also vitally spurred Australia's development. In 1843 John Ridley, an Adelaide miller, invented the stripper: a combination grain-gatherer and thresher. The machine effectively combined two out of the three steps in the harvesting of grain; winnowing was still done separately with a hand-turned machine.

Thirty years later R. B. Smith's stump-jump plow, which became Australia's most well-known agricultural invention, further simplified farming. In 1884 Hugh Victor McKay, then 18 years old and working on his father's farm in Drummartin, Victoria, revolutionized the grain industry by constructing the first commercially successful combine harvester: it stripped, thrashed, winnowed and bagged the wheat in one continuous movement.

Captain Cook's arrival in Botany Bay aboard the Endeavour in 1770 marked the beginning of a strong scientific tradition in Australia. Cook had set sail at the behest of the Royal Society of London to plot the transit of Venus from Tahiti and to discover a new southern continent.

He did not discover a new continent but instead managed to explore the entire eastern coast of Australia, claiming the region for Britain. He amassed a superb collection of bizarre and primitive plant and animal specimens, which aroused enormous interest on his return to England.

Britain established the first penal colony at Port Jackson in 1788—now the site of Australia's largest city, Sydney. For 60 years or so science and technology languished under convict settlement conditions but in the 1840's penal transportation came to an end and innovative, educated settlers poured into the colony, fleeing Victorian England determined to make a new life.

The new settlers erected universities, museums, herbaria and astronomical and magnetic observatories, beginning an exciting period of innovation. They soon realized that the vast distances and isolation of Australia necessitated improved communication and transport systems. A 10,000-mile network of railway tracks was built across the continent and a transcontinental telegraph opened between Adelaide and Darwin in 1872, only 10 years after the continent was crossed for the first time from south to north. The telegraph was soon connected to the overseas cable, linking Australia to London and the rest of the Western financial and commercial world.

To farm the poor soils and drought-prone land new breeds of crops and animals were needed, and the great mineral wealth could only be tapped through new exploration and mining methods. Such were soon developed.

AUSTRALIA—FACTS AND FIGURES

Figures for 1981–82 unless indicated

AREA: 7,682,300 sq. km.

POPULATION: 15.2 million (70% urban)

STATES AND TERRITORIES	Area ('000 sq. km.)	Population ('000)	Capital	Population ('000)
New South Wales	802	5,305	Sydney	3,281
Victoria	228	3,994	Melbourne	2,804
Queensland	1,727	2,421	Brisbane	1,086
South Australia	984	1,331	Adelaide	952
Western Australia	2,526	1,334	Perth	918
Tasmania	68	430	Hobart	170
Northern Territory	1,346	127	Darwin	57
Australian Capital Territory	2	230	Canberra	246

CONSTITUTION AND GOVERNMENT

Federal System

Seats (1983)	House of Representatives	Senate
Labor	75	30
Liberal	32	24
National Party	17	4
Australian Democrat	—	5
Independent	—	1
Vacant	1	—

NATURAL RESOURCES

Mining ('000 metric tons)	
Iron Ore	86,236
Black Coal	100,428
Bauxite	24,987
Mineral Sands	1,901
Metallic Contents of Minerals	
Copper	249
Lead	654
Zinc	591
Nickel (1979)	72
Agriculture ('000 metric tons unless indicated)	
Wool (million kg.)	716
Wheat	16,330
Meat (excl. canned)	2,598
Sugar	3,434

NATIONAL ACCOUNTS

GDP	$ 148,235
Gross Fixed Capital Formation (1982: Percentage of GDP)	25.1

TRADE

Principal Exports (% of total value)
Coal 12, Wool 10, Wheat 9, Metals 8, Meat 7, Iron Ore 6.

Destination (% of total value)
Japan 28, U.S. 11, EEC (excl. U.K.) 8, ASEAN 8, New Zealand 5, U.K. 3, China 2.

Source: Australian Bureau of Statistics
Bureau of Agricultural Economics
Bureau of Mineral Resources
OECD

At the time of writing 1 Australian dollar equals .84 U.S. dollars.

All dollars are Australian dollars unless otherwise indicated.

AUSTRALIA

Australian Information Service

A string of meteorological stations set up across the continent and meteorological services established in each colony helped to keep track of the weather conditions.

The discovery of gold in 1851 provided an unexpected stimulus to Australia's development. Between 1840 and 1850 the population increased by 200,000 and in the following 10 years to 740,000, bringing the total to more than one million. The number of gold miners in the country peaked at 150,000 in 1858 and by 1865 had declined to 80,000. Company mining gradually replaced individual activity as equipment and processes became more complex.

Development of agriculture was slower than in America where the climate was more temperate, the land more suitable for farming and transport far better. Australia has few navigable rivers, and it was not until railways reached the wheat lands across the Great Dividing Range that the farmer could come into his own. Wool could be more cheaply transported and between 1861 and 1884 the area under crop in New South Wales increased from 300,000 to 700,000 acres, which were owned by a mere 40,000 farmers. Pastoralists improved their breeds by increasing the weight of the fleeces, began using better methods for washing, pressing and sorting the wool and marketing it more efficiently.

Farming made earlier progress in Victoria, where the climate is milder and transportation was more efficient. The area under crop increased from 400,000 acres in 1860 to 1.5 million acres in 1880. In South Australia the wheat-growers succeeded even better. Between 1862 and 1880 their crop constituted more than half the total wheat production of the continent; in 1881, more than eight acres per capita were planted with wheat.

Gradually, the need for a scientific study of agriculture was realized. The Roseworthy Agricultural College in South Australia was founded in 1884, followed in 1885 by the Dookie College in Victoria.

Pioneering Investment

Considerable capital investment in industry, mining, communications and other public works brought about additional development of Australia. In the 1860's Victoria protected its infant manufacturing industries with a tariff; under its shelter textiles, clothing, leather goods, foods, agricultural implements and foundry products were developed or manufactured.

Australia's great distance from Europe and America also provided considerable market protection and made possible the development of industries connected with rural production. Many of the major financial houses, insurance and pastoral companies and merchandising concerns that still dominate the Australian commercial scene were developed in this period. Mining

Australia's first windmill, built at The Domain, Sydney

was another important company activity. The development of the railways and the steamship increased the demand for coal, bringing prosperity to the collieries around Newcastle.

The greatest investors in the country were not Australian private businesses but various colonial governments. Australian companies began to build the railways, with high hopes in Victoria and New South Wales, but failed to complete the lines, and so the colonial governments took over construction.

The early difficulties were partly financial and partly technical. In the eastern colonies, for example, the railroad lines had first to cross the rugged mountain barrier, which obstructed the engineers and prevented local traffic, increasing costs and reducing revenue. But in the 1870's a period of optimism began, and so the railways rapidly advanced. In 1861 there were fewer than 250 miles of lines, in 1870 only 1,000 miles, but by 1890 approximately 10,000 miles were open at a cost of more than £100 million.

Telegraph lines began to cross the continent; by 1889, 40,000 miles were erected. In the cities tramways and waterworks were built, and in the 1880's the great irrigation works in Victoria were begun. Between 1860 and 1880 Australia's population doubled, rising from 1.1 million to 2.2 million. It rose by another million over the next 10 years, thanks to rapid natural increase and vigorous immigration programs.

The country prospered. But all the newcomers had to be housed, fed and clothed, and the governments extended transport facilities and public utilities to provide for them.

By the late 1880's, however, there were signs that the boom was coming to an end. Metal, wheat and wool prices continued to fall. The pastoralists were already in difficulty and the great strikes of 1891, led by the newly powerful labor movement, brought an unwelcome notoriety to Australia's problems. The confidence of British investors waned, and for the first time in many years the colonial governments failed to raise the money they needed on the London market. The banks had to restrict credit, and the governments had to economize. Public work gradually came to a standstill, causing unemployment to increase. Neither city speculators nor many pastoralists could repay their overdrafts, yet many depositors in land banks, building societies and even trading banks wanted their money in gold, for paper money was not yet in use as legal tender.

The building societies and then the land banks started to go bankrupt, and a run on the trading banks occurred. In April, 1892, the Commercial Bank of Australia suspended payment, and by the end of June of that year, 22 other banks had either suspended payment or failed; only 10 banks survived.

Recovery began with the expansion of wheat growing. The extension of the railways, low wool prices and in particular improved farming techniques led to the doubling of the area under wheat cultivation in New South Wales between 1894 and 1899 and a second doubling by 1911, when over three million acres were planted, producing a crop of 38 million bushels. This is roughly 10 times the crop of 1891, greater than that of any other state in Australia at the time and, as a consequence of the discoveries of William Farrer, with an increased yield per acre. Australia soon assumed a world role as a major wheat exporter.

In the 1890's development of Western Australia boomed. The discovery of major gold deposits at Coolgardie and Kalgoorlie resulted in the colony's becoming the country's major gold producer. The population rose from 40,000 to 180,000 in less than a decade, and as the diggers turned to the land in a short time more than one million acres were under cultivation.

Industrial development suffered a setback as a result of the financial crisis of the 1890's, but progress resumed when Australia gained self-government in 1901. The six colonies of Victoria, New South Wales, South Australia, Western Australia, Tasmania and Queensland were made into states under the new federal government of Australia. Import duties were imposed with the avowed intention of protecting Australian manufacturers from the competition of countries where the workers' wages and the conditions of work were inferior. One result of this was the near-doubling of the number of factory workers in Victoria and New South Wales between 1901 and 1914.

Nevertheless, much of Australian industry remained tied to primary production and to consumers' immediate needs: clothing, food and drink, agricultural machinery, woodwork, vehicles, books and printing. One notable development at this time was the construction of an efficient modern iron- and steelworks at Newcastle.

After World War I

World War I intensified industrial development. In 1916 the first major

industrial enterprise was established in Tasmania: the Electrolytic Zinc Company, which used hydroelectric power supplied from a new government power project.

After World War I profits in agriculture dropped markedly due to falling world prices and increased costs. Industries that had flourished immune from foreign competition demanded protection, and during the 1920's tariffs were steadily raised. Not all manufacturers were efficient, however, and most were handicapped by having to produce on a small scale. As a result the economy shifted to increased tertiary or service income earned from transport and distribution, construction, professions such as law and medicine, entertainment and other consumer services, which by 1928 comprised 56 percent of the national income.

The Depression

The world depression of 1929 brought near-chaos to the Australian economy. The government had been raising almost £30 million a year from overseas; the sudden cutoff of funds and the decline in export prices reduced the real national income by more than 10 percent and threw one-third of the labor force out of work.

With the recovery of world prices in the 1930's manufacturing expanded considerably. Despite a modest population increase between 1930 and 1940, the real value of secondary production was one-third above its predepression level.

World War II, like its predecessor, stimulated the Australian economy; the greatest advances took place in the metals and engineering industries. Tremendous postwar immigration brought more than half a million people to Australia between 1948 and 1953, seriously straining public services and housing. However, as world prosperity increased and the prices of food and primary products went up, Australian farmers experienced a period of extraordinary prosperity.

Early Science

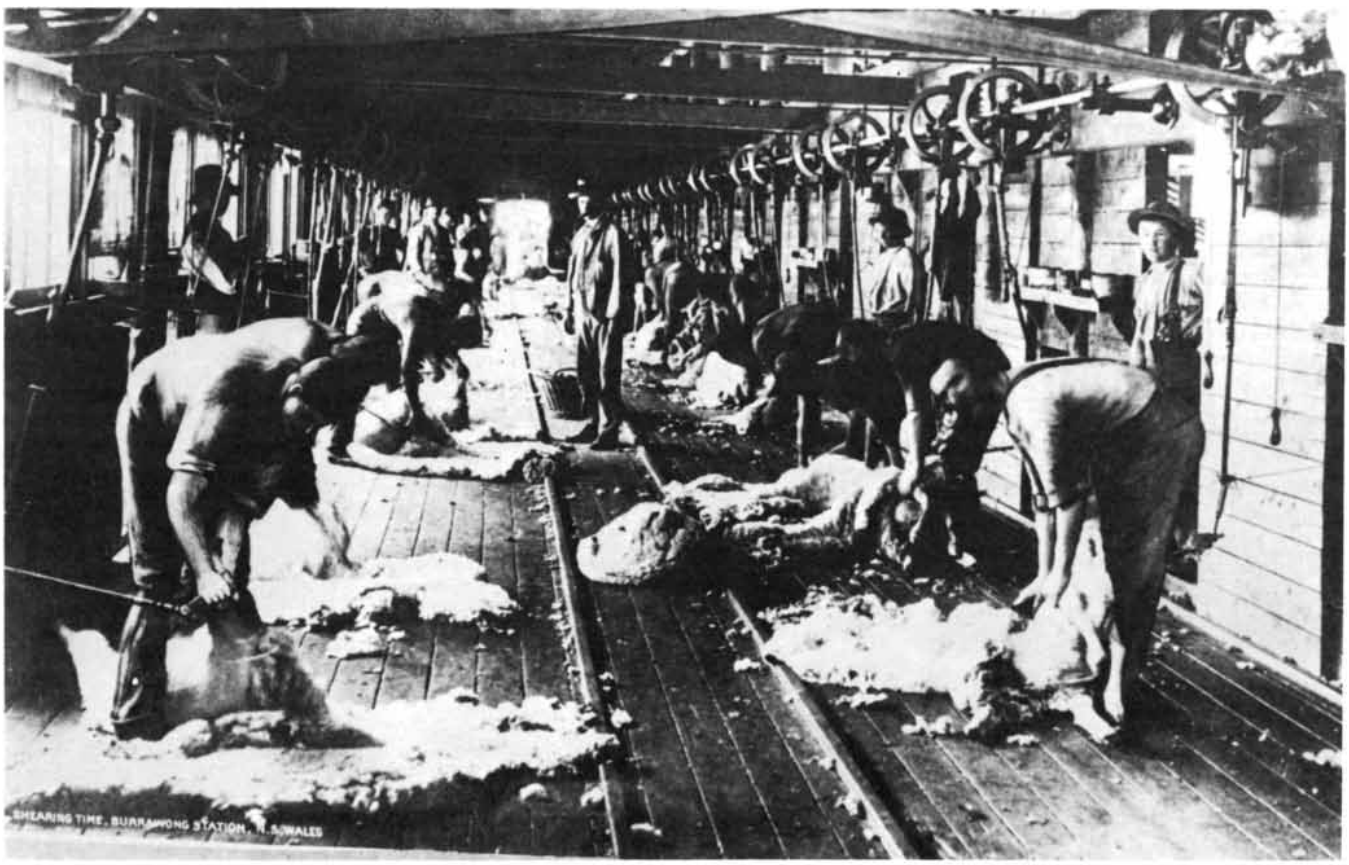
During the early years of Australia's development, numerous small observatories were built to observe the southern skies and in particular the center of the Milky Way. In the 1860's the Victorian government decided to build a major observatory and constructed the Great Melbourne Telescope—then the largest equatorially mounted reflector in the world. Well over a century later, substantially refurbished, it is still in operation at Mount Stromlo Observatory, near Canberra. This early interest in astronomy has led to Australia's remaining one of the world leaders in the field.

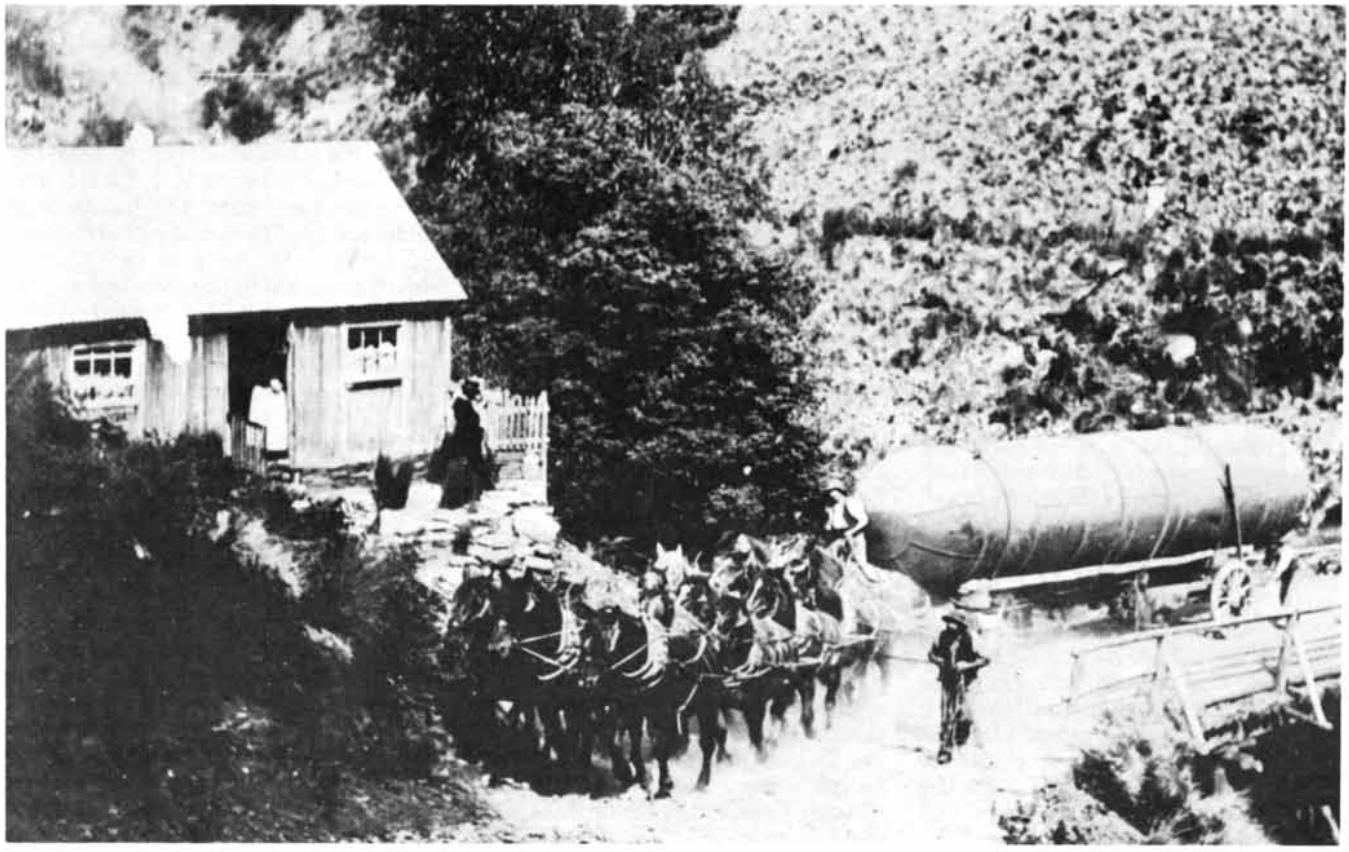
Naturalists were attracted to the country's unique plant and animal life, the majority of it long extinct in other parts of the world but preserved due to Australia's isolation. Native marsupials, such as kangaroos, koalas, possums and wombats, the hundreds of different species of native parrots and cockatoos and many of the 1,100 or more species of eucalyptus and wattles were collected and classified. Today the process of identifying Australia's wildlife is still going on; some scientists claim hundreds of species and subspecies may yet be discovered.

Geology was another colonial interest, because of the rich mineral deposits and also because of an extensive debate on the age of the continent. Australia is now acknowledged as one of the oldest land masses in the world. The igneous, sedimentary and metamorphic rocks of the Commonwealth, range in age from the earliest pre-Cambrian (three billion years) to recent geological times (one million).

Government funding for science started with support for geological and mineralogical surveys. The surveys were meant to be utilitarian searches for metals, in particular gold, but geologists also produced systematic geolog-

Shearing time at Burrawong Station, New South Wales circa 1900





Moving a compressor used to supply power for drills in early goldfields in Australia

ical, mineralogical and topographical maps, which formed the basis of the present-day delineation of the country's mineral resources.

The country is now the largest bauxite and alumina producer in the world, with total identified resources of 6,284 million metric tons, and is the largest exporter of iron ore. It also has vast deposits of black coal, with identified recoverable amounts of 300,000 million tons, and extensive natural-gas reserves both on- and offshore. In comparison oil reserves are poor, and more than 30 percent of the country's needs must be imported.

Distinguished Innovators

Many innovators flourished in the heady atmosphere of growth and discovery, often developing inventions at the same time, if not before, their counterparts in Europe and the U.S. One such innovator was Henry Sutton, a music shop proprietor, who designed an electric continuous-current dynamo as early as 1870, constructed more than 20 different types of telephone systems at about the same time as A. G. Bell and carried out the first experiments with heavier-than-air materials for flight in the 1870's.

Another was Lawrence Hargrave, who, despite his isolation from mainstream science and technology, was at the forefront of aeronautical research in the 1880's and 1890's. In 1889 he developed the radial rotary airscrew engine, which formed the basis of the first engines used to power European planes in the early 20th century.

Australia achieved world recognition for the first feature-length narrative film, which perhaps presaged the nation's current vigor in motion picture production. In 1906 a Melbourne impresario, Charles Tait, produced a film of Ned Kelly that ran for nearly 90 minutes. A commercial success in a time when other films ran for only about 20 minutes, it was also the first film to include interior photography.

Government Activity

The organization, sponsorship and goals of science began to change after Australia gained self-government in 1901. A number of Commonwealth government scientific organizations were established, such as the Bureau of Meteorology in 1907, which is now Australia's major forecasting and meteorological research body. In 1926 the Science and Industry Research Act was passed, leading to the most significant development in Australian science—the establishment of the Council for Scientific and Industrial Research (CSIR), which in 1949 became the Commonwealth Scientific and Industrial Research Organisation (CSIRO).

Since its inception in 1926 and particularly since World War II the organization has been responsible for many new scientific developments, particularly in mining and agriculture, including the downstream processing of farm products.

A self-twist spinning machine, 15 to 20 times faster than conventional machines, has revolutionized wool knitting around the world. Another process, Sirospun, has almost halved the cost of weaving yarn. Other processes have made it possible for wool to be shrink-proofed, mothproofed, permanently pleated and given wash-and-wear properties.

Important advances in the control of livestock diseases have been achieved, new cattle for the Tropics have been bred and new pasture plants for eastern and northern Australia have been developed, along with novel methods of biological control. CSIRO has also significantly contributed to the success of the Australian mining and mineral-processing industry with new exploration and processing technologies. ▲

Nilcra Ceramics

Ceramics are set to be the new material of the future and one innovative Melbourne company, Nilcra Ceramics Pty Ltd, has already gained a world lead with what is believed to be the toughest and strongest of the new ceramics – partially stabilized zirconia or PSZ.

The company, a joint venture between one of Australia's leading resource companies, CRA Ltd, and powder metal engineers, Nilsen Sintered Products, is already using the new ceramic to manufacture extrusion dies, computerware parts and other specialized products for export markets in the United States and Europe.

It has an exclusive worldwide licence for PSZ and Nilcra's General Manager Mr David Servent believes that the market possibilities are enormous, ranging from components for scientific instruments through to the new generation of adiabatic diesel engines.

Cummins Diesel in the United States have shown particular interest and have already tested Australian produced PSZ piston caps, cylinder liners, valves and valve guides extensively. Tests have also been carried out by General Motors, Ford, Saab, Volvo and diesel engine manufacturers in Japan. All say PSZ is an excellent material.

This high performance ceramic arose from work by CSIRO scientists in the 1970s. Researchers from the Division of Materials Research found that they could overcome the normal propensity of zirconia to be very brittle and to shatter under rapid temperature changes by only partially stabilizing it.

This involved forming a zirconia consisting of monoclinic crystals in a cubic lattice, rather than a stabilized form which had merely a cubic crystal structure.

The researchers found that by careful selection of the performing conditions they could produce a powerful and previously unknown strengthening effect. The secret lay in producing at room temperature a fine dispersion of tetragonal crystallites – the type that normally predominate only above 1200°C – in a cubic lattice.

These tiny, lens-shaped specks, less than 250 atoms across, act as built-in shock absorbers making the ceramic tough and not brittle. When the material is subjected to stress by impact, abrasion or cracking, the specks absorb energy by changing into the common monoclinic form.

This is accompanied by a 4% increase in volume of the ceramic in the region of stress and an increase in strength of up to 25%. The ceramic, like others, cushions the impact by undergoing some microscopic cracking, but unlike the other products, the cracks effectively close up preventing them from spreading destructively.

The end result is an extremely strong and tough ceramic which can withstand extremely high temperatures, is very wear resistant, has a low coefficient of friction against steel, low thermal conductivity and is chemically inert.

This means that PSZ is an excellent material for use in areas of high corrosion, friction, heat and pressure and makes it very suitable for extrusion dies for pharmaceutical presses, nozzles for sandblasting equipment, dry bearings in the minerals industry, hot and cold extrusions of copper and brass, wear pads and pump parts and, of course, diesel engines.

Nilsen Sintered Products first became involved with CSIRO in the development of ceramics in 1975, first with calcia stabilized zirconia, which proved unsuccessful, and later with magnesia stabilized zirconia – or PSZ. In 1977 Nilsen began work with Cummins on the adiabatic diesel engine and in 1979 it signed a joint partnership agreement with CSIRO, giving the company exclusive world rights to PSZ.

Shaped hot brass rod extrusion

Round hot brass rod extrusion

Since then development has moved ahead rapidly with the company expanding into the US in 1981 with the opening of Nilsen (USA) Inc, now Nilcra Ceramics (USA) Inc, in Chicago, construction of new research and development facilities and manufacturing plant in Melbourne and the formation of the joint venture between Nilsen Sintered Products and CRA Ltd – Australia's second largest company with assets of more than $8 billion – last year.

Nilsen has maintained a 70% ownership in Nilcra, while CRA has paid $2 million for its 30% interest and agreed to contribute a further $5 million over five years for further research and development. On top of this CRA has agreed to provide an extra $10 million over the next five years if required which would allow it to take additional equity in the company.

This has given Nilcra an extremely strong base for further research and development. For the last 18 months the company has been manufacturing and exporting extrusion dies to the US and Europe, along with a number of specialized products such as pump valves and bearings and brushes. Most recently it has won a substantial contract to supply computerware parts to a US company.

Mr Servent also sees growing markets in the scientific equipment and medical equipment fields, the pharmaceutical industry and pump and valve industry. He estimates the market will grow to between $50 million and $60 million within ten years with the company continuing to develop new export markets for an expanding range of products.

On a wider scale the development of PSZ in Australia is part of a broader plan by the Federal Government to develop an integrated zirconia industry. Australia has 80% of the world's zircon locked up in its mineral sands and under an agreement signed this year ICI and CSIRO are to set up a zirconia processing and manufacturing plant in Australia to produce the basic powder for PSZ, which now has to be imported, as well as develop extensive export markets. Nilcra has made no commitment to purchase the processed zirconia from the new venture but sees the initiative as an added benefit to the company's aim to maintain technological leadership in the field of advanced ceramics. ▲

In Support of Industrial Growth

Victoria is the center for a growing number of high-technology industries, particularly in the fields of biotechnology, scientific instruments, microelectronics and new materials such as ceramics.

These strengths are due in part to the overall encouragement given to new industries by the Victorian Government, and also to the concentration of world class research institutes involved in advanced technology within the State.

This is particularly true of biotechnology, with several major research institutes, including the Walter and Eliza Hall Institute of Medical Research and the Howard Florey Institute of Experimental Physiology. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) has five of its biotechnology-related research divisions in Victoria. Victoria is also the base for the nation's major manufacturer of biological products, the Commonwealth Serum Laboratories. There are also at least ten State research laboratories, as well as major research programs at four universities and a number of institutes of technology.

These research resources have led to the development of an expanding biotechnology industry, with the establishment of a number of new companies such as Gene Link and Silenus, which are building international markets for their products.

The State has been the center of a thriving scientific instrument industry for a number of years and in the past decade has experienced rapid growth.

A number of companies are world leaders in the production of a range of optical, chemical analysis and medical instruments, and have developed strong export markets for their products.

One of the world's most advanced ceramics, PSZ or partially stabilized zirconia, is being manufactured by a Victorian company, Nilcra Ceramics Pty Ltd and other advanced materials such as special polymers are also under development by research institutes in the State.

The Victorian Government is strongly promoting the development of these new industries and recently released a ten year economic strategy for Victoria which places emphasis on technology development and research.

Key elements of the strategy include plans to set up a number of joint Government/industry companies to commercialize biotechnology research, moves to free up more venture capital to boost the development of new as well as existing industries, and measures to encourage new education and training schemes in the State.

An ovum pick-up at the Royal Women's Hospital in Melbourne. Australia is a world leader in ***in vitro*** *fertilization*

A special technology support program has been developed which aims to upgrade and maximize the use of appropriate technologies by industry in the State.

Specific initiatives have included the setting up of the Victorian Centre for Technology and Design which is providing initially an industry-technology information and liaison service. Later this will be expanded to cover technology transfer and development services.

An innovation brokerage service has also been established to co-ordinate information on investment, manufacturing, and research and development resources available in the State. A range of computerized registers are being compiled, including one covering companies wishing to invest, manufacture, license, purchase, market or put together an investment proposal for new or high-technology products. Others cover consultants in the field, and new business opportunities.

Funds are provided to help a number of technology support agencies which provide advice and assistance to developing companies. 'Seed capital' is available to help inventors and innovators to develop their ideas to a stage where they can attract investment through the development of working models, prototypes or detailed business plans.

The Government is also providing equity funds to form a number of joint companies with the private sector and major research institutes to take new technology projects through the commercial stages.

The Government plans to take only a minority shareholding in the companies but wants each to be broadly based across a number of private companies and research institutes to draw together the maximum research skills and research development expertise and minimize the risks.

Among the companies in which Government has already taken equity is Prologic Pty Ltd which has developed high quality computer courseware on a wide range of curriculum subjects for primary and secondary schools.

Emphasis is being placed on increased communication and information transfer between Government, industry and academia through regular forums, technology briefing sessions and technology transfer publications.

Moves are under way to upgrade the education skills base in the State. A major review of post-compulsory education and training is being carried out to identify weaknesses so that extra funds can be supplied for training programs.

Currently Victoria has a significantly higher proportion of engineering, science, mathematics and management graduates compared to other states and it plans to use this advantage as a base for further expansion.

A number of specialized centers and support agencies have been set up by Government and tertiary institutes to help industry to understand and introduce new technology as well as to improve its management skills.

For instance, the Royal Melbourne Institute of Technology (RMIT) has set up a Microelectronics Applications Centre, a Centre for Innovation Development, and an Industry Technology Centre.

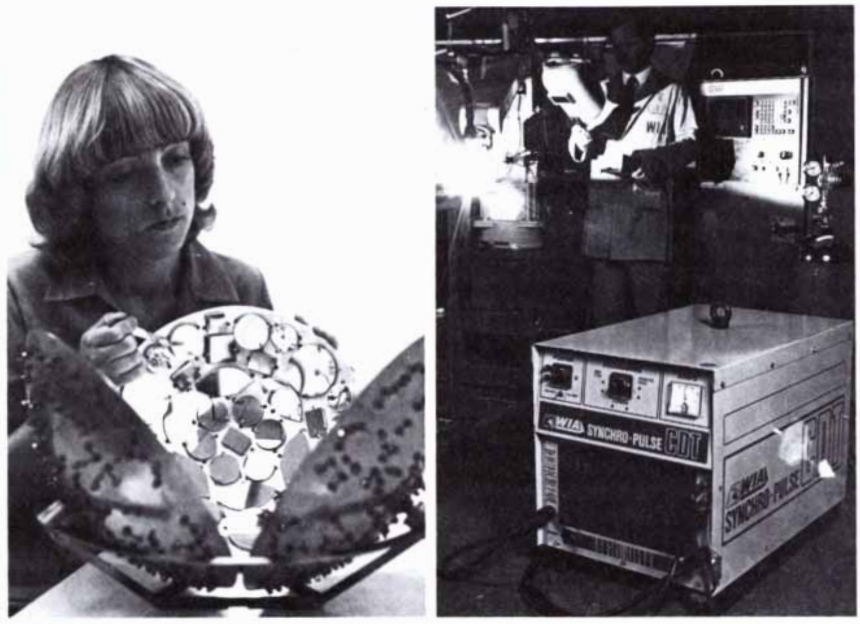
A microelectronics development center, operating in conjunction with the University of New South Wales, aims to boost the Institute's already world class capabilities in developing and fabricating chips, computer-aided design and software for integrated circuits.

On the other hand, RMIT has one of the two innovation centers in the State which aim to help innovative companies develop new products and processes through direct advice, business analysis and planning, or assistance in finding manufacturing.

At the Chisholm Institute of Technology, Australia's first Centre for the Development of Entrepreneurs has been established and a number of CAD/CAM centers are springing up to help the manufacturing sector to introduce new technology.

However, the State already has a number of companies at the leading edge of world development, particularly in the fields of medical technology, scientific instruments, biotechnology and new materials.

New technologies are being applied in Victoria, not only to specialized scientific instrument industries, but also to traditional manufacturing



Left: Components for the Victorian-designed and built Varian Techtron spectrophotometers. The replication and aluminizing of diffraction gratings and other optical components demand the high quality control levels for which the Victorian scientific instrument industry is renowned internationally

Right: Controlled drop transfer pulse welding equipment developed jointly by Welding Industries of Australia Pty Ltd and the Commonwealth Scientific and Industrial Research Organisation's Division of Manufacturing Technology. The equipment uses pre-set programmed circuit boards and interfaces with robotic devices

For instance, Scientific Glass Engineering now exports in excess of 90% of its production of microsyringes, gas chromatography and mass spectroscopy equipment, and special lamps for atomic absorption and atomic fluorescence spectroscopy.

The company's philosophy is never to design a major piece of equipment already being produced by other scientific equipment manufacturers but to develop new, better and often simpler ancillary equipment which enhances the main instruments produced.

It now employs more than 100 people, has offices in London, Paris, West Germany, and Austin in Texas, a network of authorized distributors in over 60 countries and a worldwide reputation for the quality of its products.

Moldflow (Australia) Pty Ltd is another innovative company which specializes in preparing and marketing application software for the plastics injection molding industry. The programs predict the flow pattern of the plastic into an injection mold during the filling process. The company is an undisputed world leader in the technology which is now used by many major international companies. Moldflow has branch offices in the United States (Bridgeport, Connecticut and Kalamazoo, Michigan) and a subsidiary company in Kent, UK.

Victoria has produced a large specialist software industry of which Moldflow is just one example. It also has a well-established general software industry with companies such a IMS Pty Ltd and King-Smith and Associates Pty Ltd selling well into the USA markets.

Some of the world's most novel designs in computers have emerged from Victoria. The AMUST briefcase computer and the Dewhirst Corporation's special designs for large database applications are just two examples. Many companies demonstrate enviable diversity such as Labtam International which produces not only a range of inductively coupled plasma spectrophotometers, but also its own networking microcomputer, export sales of which account for 90% of its production.

Melbourne is also the home of Varian Techtron, the world's second largest manufacturer of atomic absorption equipment and a major manufacturer of UV-visible spectrophotometers.

The company, then Techtron Appliances, began in the 1950s building components for CSIRO while that organization was developing the atomic absorption technique – what is often called the most significant advance in chemical analysis this century.

Later the company obtained a licence to build the instruments and took over the research, design, manufacture and marketing of the instrument, which can now detect 66 different elements and make up to 1700 analyses of different samples a day.

The company was acquired by the US corporation Varian Associates in 1967 and now has sales in excess of $25 million a year and employs more than 300 people.

Silenus Laboratories is another innovative Melbourne company which has pioneered the development of diagnostic antisera for medical and veterinary purposes as well as the development of diagnostic instruments.

It is working mainly in the areas of polyclonal antisera producing immunodiagnostic kits for the major hospitals and is continuing development work on monoclonal antisera. Demand for the antisera is growing rapidly worldwide due to the company's products' reputation for purity and quality.

It has also developed an innovative clinical viscometer which can detect very small changes in blood viscosity and is very cheap, accurate and fast. It is particularly valuable in giving early indication of pregnancy-induced hypertension and has allowed advanced research into mental abnormalities in children.

Most recently, ICI Australia acquired a 50% share in the company which will allow the company to boost its research effort and improve its marketing operations in Japan and North America.

In the biotechnology field, another burgeoning company is Gene Link, which is marketing a range of biotechnology products, particularly in the diagnostic kit area overseas.

It has rights to a number of innovative products including a diagnostic test for genital herpes and a new fermentation technique which promise to generate multi-million dollar income for the company.

Overall, the State is moving ahead rapidly to become a major high-technology center with a growing number of innovative companies, backed up by a large pool of research expertise at universities and research institutes and by a Government determined to encourage new-technology industries in the State.

Further information about Victoria's technology-related achievements and companies may be obtained from the Victorian Centre for Technology and Design, 228 Victoria Parade, East Melbourne, VIC 3002. Telephone (03) 418 8200. Telex AA33832 ▲

The Present: The Government leads research expenditure as private companies specialize

CSIRO is now Australia's largest scientific research establishment. The organization employs over 7,500 people in more than 100 laboratories around the country, consumes more than a third of the total government science budget and carries out research in all areas but nuclear energy.

Australia's defense research effort began in 1916 with the establishment of an arsenal and a supporting defense laboratory. This effort gradually expanded through the establishment of defense research laboratories, mainly based at Salisbury in South Australia, and through the establishment in the 1970's of the Defence Science and Technology Organisation (DSTO), which now employs over 1,000 professional scientists and engineers.

Another major milestone was the creation of the Australian Atomic Energy Commission (AAEC) in 1953 to help with the exploration, mining and treatment of uranium, the use of nuclear power and the use of radioisotopes for medical purposes.

The organization had its heyday in the 1960's and early 1970's, when there was a strong possibility that Australia would build a nuclear power station and move into enrichment and conversion of uranium oxide.

However, under the policies of the new Labor government, the nuclear research effort is being wound down and work is concentrating on the medical and environmental uses of radioisotopes and on nuclear waste disposal.

Universities also provide research facilities. There are now 19, twice as many as 10 years ago, and despite the increase there are still quotas on student admissions. However, enrolments in engineering and the physical sciences are low, causing concern over future manpower, particularly for high-technology industry and resource development.

Tertiary education is backed by more than 50 vocational colleges and more than 200 technical colleges.

Overall, Australia's science and technology effort is still strongly biased toward the colonial model of astronomy, natural sciences, meteorology, agriculture and geology, although it is also extremely strong in medical research, the development of scientific instruments and mining engineering.

The industrial research effort in Australia is extremely low in comparison with that of other OECD countries: only .2 percent of the gross domestic product was spent on research by industry in 1978-79, compared with 1.9 percent in countries of relatively comparable population such as Switzerland and Sweden.

However, government spending on R & D as a percentage of GNP compares extremely well with that of other OECD countries, at .8 percent. For both Canada and Switzerland the figure is only .6 percent.

This imbalance is accentuated by the relatively large sums that still go to agricultural research, despite the sector's declining input to overall production, contributing only about 10 percent in recent years. However, it still accounts for about 40 percent of export income.

The imbalance is highlighted by CSIRO, which still spends more than a third of its annual budget of over $300 million on agricultural research. In comparison, mineral and energy research receives less than a sixth of the total budget and high-technology about a tenth.

Moves are under way to channel more funds into the manufacturing and high-technology sectors, but a change in direction can only be slow and many argue that CSIRO should continue to concentrate its effort on the primary industry sector, which has served the nation so well. However, the Minister for Science and Technology, Mr. Barry Jones, is also pressing for CSIRO to change its emphasis and, he says, "come out of the closet."

The disparity has prompted government action to try to boost industrial research through a number of grant schemes, in particular the Industrial Research and Development Incentives Scheme (IR&DI), operated through the Department of Science and Technology. It had a budget of $71.6 million in 1983-84 and made grants to a wide range of industrial research projects, many by emerging small companies. Its budget for 1984-85 is $67.45 million.

Efforts are in progress to establish more specific industrial research funding schemes, particularly in the high-technology area. For instance, earlier this year the National Biotechnology Program was launched specifically to provide funds for the commercial scale-up of biotechnology research.

A similar energy research scheme, operated by the National Energy Research, Development and Demonstration Council (NERDDC), has been in existence since 1978 and has made grants totalling almost $100 million in a wide range of fields from coal exploration to wind power.

At the hub of Australia's research effort is the Department of Science and Technology, formed from two separate departments in 1981. The department, with a total budget of $595.9 million for this financial year, is responsible for a number of Australia's major scientific bodies such as the Bureau of Meteorology, the Antarctic Division, the Australian Government Analytical Laboratories and the Patent, Trade Marks and Design Office.

The Department of Science and Technology is also the main source of policy advice to the minister and is responsible for the government's major industrial innovation and technology development programs. It administers a number of grant schemes, including the Australian Research Grants Scheme (ARGS), which funds basic research, the Marine Sciences and Technologies Research Grants Scheme, the Industrial Research and Development Incentives Scheme and the new Australian Biotechnology Scheme.

Australia's major tropical marine research body, the Australian Institute of Marine Science (AIMS), based at Townsville, Queensland, also reports to the department. AIMS was established in 1972 to carry out a wide range of multidisciplinary research projects, particularly on the Great Barrier Reef. It now has a budget of $7.3 million and its main projects include work on marine food chains, reef-building organisms and coral reefs, tropical oceanography and marine pollution.

The Department of Science and Technology administers Australia's space programs, which include NASA's deep-space communications complex at Tidbinbilla.

Tidbinbilla's main facility is a 64-meter antenna supported by a 26-meter dish, and the station has taken part in many deep-space missions, including the Mariner, Pioneer, Viking and Voyager flights.

Another element of Australia's space program is the Australian Landsat sta-

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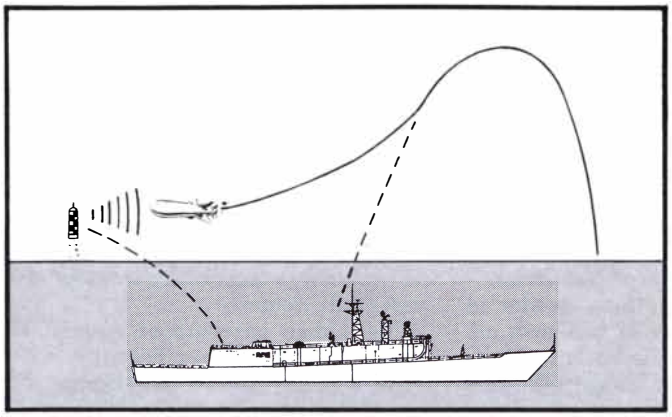
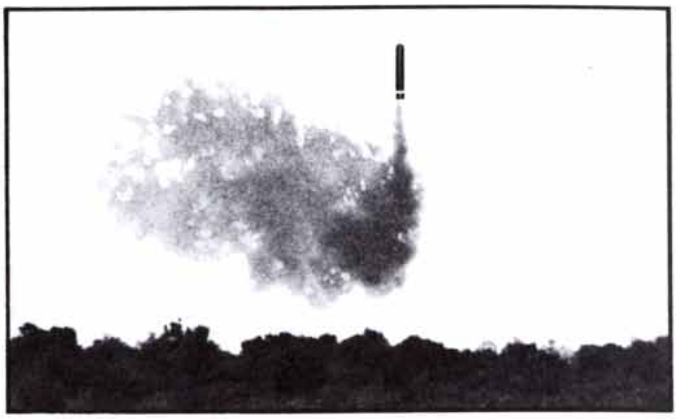
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION:

The Answer to Exocet



Winnin: A decoy for deadly missiles



Successful flight trial of decoy vehicle

The Defence Science and Technology Organisation (DSTO) is an important element in Australian defence capability. The relatively small Australian Defence Force (ADF) relies extensively on modern technology to multiply its effectiveness in grappling with the problem of defending the large, sparsely populated Australian continent with its long stretches of coastline. DSTO supports the ADF by maintaining the advanced technological base necessary for providing informed advice, capability to modify systems to meet special Australian needs, and where appropriate, indigenous development.

Indigenous Development

The Winnin anti-ship missile decoy is an example of an indigenous development initiated by the DSTO. Recognizing over a decade ago that there were no reliably effective counter-measures available overseas to protect ships against sea-skimming missiles such as Exocet and Harpoon, DSTO scientists set out to develop an effective system for ship protection. The need for a successful development was underscored by the dramatic success of Exocet in the Falklands conflict.

Winnin is an active expendable decoy which can be deployed from a ship within seconds of detecting an in-coming threat missile. Basic to the success of the Australian development is the ingenious use of a solid rocket-powered vehicle which enables rapid deployment of the decoy in operational conditions yet which also has the necessary – but difficult to achieve – capability of hovering above the sea and mimicking the slow movement of a ship. The ability of the decoy vehicle to maneuver in controlled flight is achieved by a sophisticated thrust control mechanism operation under the command of an auto-pilot to regulate the thrust from the rocket motor both in magnitude and direction. Successful flight trials of the vehicle without a single failure have already demonstrated convincingly the impressive potential of this system. At the heart of the decoy is an electronic payload which utilizes the latest traveling wave tube technology to seduce the in-coming missile using radar transmissions. After launch, the decoy moves slowly away from the ship along a selected trajectory, luring the missile away from its intended target.

DSTO and the Australian defense industry are co-operating to develop Winnin. As with other developments, DSTO aims for maximum participation by Australian industry in prototype development and long term production. Negotiations are in train to form an international partnership for final development and production.

Other recent developments born in DSTO in response to some of Australia's unique requirements are the Mulloka high frequency shipborne sonar, adapted to the warm waters around Australia, the Jindalee over-the-horizon radar, the Barra air-dropped sonobuoy and the Karinga high-performance cluster bomb. These representative developments which are acknowledged to lead the world in their particular area firmly demonstrate the skills and expertise of the Australian DSTO.

Supporting Role

Besides the specialized research and development necessary to originate high-technology systems such as these, DSTO must maintain a broad coverage of current defense technology since the majority of DSTO effort goes into providing solutions to the myriad technological problems which confront the ADF. Because of Australia's small population, economics dictates that much of its defense equipment must be bought overseas. DSTO must possess the scientific and technological knowledge needed to enable it to assist the ADF in making the best purchases and in maintaining and operating its equipment in the most effective manner. Conditions in Australia, both on land and in its surrounding waters, are generally different from conditions in the colder northern climates for which much of the overseas equipment is designed. DSTO must therefore be capable of coping with the sometimes substantial adaptations which may be required for making equipment suitable for the Australian environment.

The Future

Although DSTO comprises over 1000 professional scientists and engineers in a total staff of some 4400, located in nine establishments across the country, its expertise must be stretched over the whole spectrum of defense technology, from aerodynamics to electronic warfare, from design of sonar systems to the development of new materials. Consequently Australia must be selective in the developments it undertakes and judicious in pursuing technologies which promise the most effective return. Current areas where advanced technologies offer Australia significantly increased defence effectiveness include wide-area surveillance, electronic warfare, terminally guided munitions and battlefield computer systems.

DSTO will continue to update its skills and its technology base so that it can continue to advise the Australian Defence Forces wisely, provide effective solutions to the technological problems confronting them, and enhance the force-multiplier effect by the intelligent application of high-technology. It will strive to maintain areas of excellence so that as the need arises it will have people capable of realizing concepts just as creative as the Winnin decoy. ▲

DEPARTMENT OF SCIENCE AND TECHNOLOGY:

Sunrise Industries and Technological Autonomy

by Hon. Barry O. Jones, Minister for Science and Technology

Australia is an urbanized, technologically sophisticated nation with a strong agricultural base, rich mineral resources, a historic record of developing its intellectual capacity and substantial achievements in agricultural and medical research. The challenge to be faced in the 1980's and 1990's is this: can a nation with only 15 million people, a mere 4 percent of the English-speaking world, whose high-technology industries are overwhelmingly under foreign control, make a transition toward the newly developing brain-based high-technology ("sunrise") industries as wealth generators, to compensate for the long-term decline in employment in traditional manufacturing industries? Can new technologies be used to regenerate smokestack industries?

In the late 19th century Australia began to adopt the colonial model of technology transfer, exchanging gold, wheat and wool for technological artifacts and know-how. There were important exceptions: Australia was a world leader in agricultural machinery, refrigerated ships and building and mining techniques. We had some of the first electrified cities, electric cables and telephones. Before 1950 Australia produced pharmaceuticals, automobiles, aircraft, electronic equipment and one of the earliest stored-memory computers (CSIRAC). However, under the long Menzies era, foreign corporations were encouraged to establish themselves in Australia, often taking over locally owned companies.

The commanding heights of the Australian economy are in foreign hands, including motor manufacturing, oil, computers, electronics, chemicals, plastics and pharmaceuticals. This leads to a major disincentive to investment in research and development by heavy industry in Australia, with a few notable exceptions.

Australian industry and society face massive threats, but also great opportunities. We can be locked into a global economy in a dependent role, with diminishing power to maintain our technological autonomy, or we can develop our own high-technology industries and attempt to penetrate niches in the world markets. The revolutionary productive techniques of the 1970's, if they are adopted wholeheartedly, could overturn much of the conventional economic wisdom about economies of scale, which have excluded many Australian products from the world markets. On the other hand, rapid adoption of the new technologies in existing industries could cause a massive loss of jobs, so that consideration must be given to choosing technologies selectively and distinguishing between "old" and "new" industries.

As a major international trader in raw materials Australia has been adversely affected by the shift in Western economies from a resources base to a skills base. We can no longer assume with the confidence we had in the 1960's that minerals, wheat and wool alone will carry "the lucky country" toward higher living standards. We have to diversify and extend our skills base and our international market commodities.

Since 1965 Australia has had a post-industrial economy. Virtually all new jobs created since then have been in "services." As early as 1900 a majority of Australia's labor force worked in services and the figure is now more than 75 percent. A four-sector labor force analysis showed that more Australians now work in "information" than in farming, mining and manufacturing combined (27 percent).

To complete the transition to an *active* information society, Australia will strengthen its knowledge base and technological skills. There is already a strong foundation to build on. The Commonwealth Scientific and Industrial Research Organisation (CSIRO) was founded in 1926, employs 7,500 people and has an international reputation for research in agriculture, animal and plant genetics, mining, earth sciences and radio astronomy.

Australia has 19 universities and 22 technologically based colleges of advanced education, and many departments have international reputations for research. So have the Walter and Eliza Hall Institute, the Howard Florey Institute, the Baker Institute and the Garvan Institute in medical research, where Australia developed an early expertise, probably because of the tyranny of distance.

Australia, with .3 percent of the world's population, produces 2.0 percent of the world's scientific papers each year. With one-eighth the population of Japan, Australia has produced the same number of Nobel prizewinners in the sciences (Florey, Burnet, Eccles and Cornforth). However, past policies failed to encourage commercial exploitation of scientific discovery. Many managers have preferred to acquire licenses to foreign products and assemble them here behind high tariffs rather than develop our own skills in invention and product innovation and aim at an export market. We had the ideas, but until now we were lacking in product development. The greatest problem in technology transfer was essentially *domestic*.

The Labor government elected in March, 1983 came to office with a detailed recovery and reconstruction policy aimed at promoting Australia's technological autonomy. The science and technology policy identified 16 "sunrise" industries—all of them where Australian research is at the leading edge or where we are appropriately placed to exploit significant markets in our region. The list of 16 leads off with biotechnology, in which Australia has a very strong skill base in the universities and CSIRO. There are a number of major developments in biotechnology that seem likely to penetrate world markets: much of our research funding comes from abroad and the final stages of product development may be carried out offshore. Three microelectronics-based "sunrise" industries were nominated: computer software, custom-made VLSI chips and personal computers, although local developments are occurring so rapidly that it now seems unwise to limit the list to three. CSIRO's industrial ceramic PSZ (partially stabilized zirconia) performs better than metal alloys and steel under heat and stress. Solar technologies are well advanced in Australia, and we have significant exports in scientific instrumentation and medical technologies.

These and other "sunrise" industries will not be major employers in themselves, but we expect them to be major wealth generators, like mining, that will generate significant second- and third-order effects in employment.

The Government is providing funds for research in the key areas of biotechnology, genetic technologies and advanced industrial materials. The Government has also taken steps to create a venture capital market to encourage the creation of new industries.

The State is changing direction, and there are good prospects that its development of human skills will generate higher levels of economic growth than could be produced by physical resources alone. ▲

Tech Strategy Helps R and D, Education, Management

Growing emphasis is being placed by the Commonwealth Government on the crucial role of technology in Australia's future development, and its importance in encouraging new industries and in restructuring the existing manufacturing sector.

A key element is the development of a National Technology Strategy to provide a framework for new policies covering not just technology but education, industry development, employment and trade.

The basis for the Strategy was laid at a National Technology Conference in September 1983 and attended by industrialists, academics, unions, business people and community groups. It was organized by the Commonwealth Department of Science and Technology.

Analysis of the material presented at the Conference resulted in the development of a draft Strategy which was released earlier this year and distributed to more than 8000 organizations, groups and individuals. It has been widely discussed and over 200 responses have been received from a broad cross-section of government, industry and the community generally.

Overall, the Strategy sets four main goals:

- revitalization of the economy through new technology
- equitable sharing of the costs and benefits of technology throughout the community.
- effective cooperation between all sectors of the economy
- strengthening of Australia's technology infrastructure to cope with future technological development.

Priority areas of action are identified in the fields of education, employment, industry restructuring and industry-science sector interaction.

Specific goals are set, such as: by 1995 50% of students should complete secondary school, with 20% moving on to tertiary education and at least 1% of the workforce undergoing retraining every year.

It also advocates bridging the gap between research and industry through for example: 1.5% of GDP being spent on research and development by 1990, rising to 2% by 1995 with a substantial increase in private sector effort.

Responses to the draft Strategy have, in general, been supportive and suggestions are now being analyzed to improve and expand the document into a final National Technology Strategy which should be available early in 1985.

The Department is also moving ahead on a number of other fronts with its main initiative earlier this year being the introduction of a Management and Investment Companies program aimed at encouraging the development of a venture capital market in Australia.

Under the plan, companies are licensed by an independent Board set up by the Government. These companies are able to invest in eligible small, high growth enterprises approved by the Board. Investors in the companies can claim a 100% tax deduction in the year the capital is subscribed, provided the investment is kept for four years.

In May 1984 the Board issued seven licences with approval to raise $50 million in venture capital. It is intended that additional licences will be issued in succeeding years.

The scheme has attracted wide interest from a broad range of groups including established banking organizations, accountants, state governments, industry and new venture capital companies. It has stimulated the growth of a venture capital market outside the scheme as well as bringing about the listing of Australia's first high-technology companies on the stockmarket.

The Department of Science and Technology is also responsible for grants for basic, mission-oriented and industrial research. The Australian Industrial Research and Development Incentives Scheme (AIRDIS), with a 1984/5 budget of $67.45 million, is the major industry R and D funding program. While AIRDIS awards grants to help companies set up a basic research capability, its main funding assistance is through Project Grants which go to companies with an established research and development capability. These grants are for specific projects and are awarded on the basis of the project's ability to improve the international competitiveness of Australian industry, to advance technology and take advantage of economies of scale or improve productivity.

This financial year a total of $38.28 million is available for Project Grants and it is expected that about 300 projects will be funded.

A sum of $11.4 million will be available for Public Interest projects. These are major industrial research projects involving a degree of risk, but which are considered to be in the public interest and usually involve the commercialization of public sector research results.

Among the Public Interest projects supported to date are the establishment of an algal biotechnology industry in Western Australia; development of an implantable hearing prothesis for nerve deafness; setting up of an optical fibers sensor industry in Australia; and commercial exploitation of a CSIRO water purification technique which decolorises and clarifies turbid water cheaply and effectively.

Mission oriented scientific research is supported through measures such as the National Biotechnology Program and the Marine Sciences and Technologies Research Grants Scheme, while basic research is funded through the Australian Research Grants Scheme. ARGS has a budget of $23.88 million and will be supporting 1229 projects of excellence at Australian universities in 1985.

The Department also operates a number of programs aimed at boosting innovation, technology development and entrepreneurial skills. It has helped set up a number of innovation centers in state capitals and provided assistance for the establishment of technology application centers at a number of tertiary institutes.

One of the most successful initiatives is the Department's enterprise workshop program in innovation and entrepreneurship aimed at providing practical experience in commercial exploitation of Australian inventions to graduates in commercial and technological disciplines.

The workshops are held specifically to build up a pool of people with training and experience to develop and manage enterprises based on the latest technologies. The program was begun in 1980 and has since expanded to involve industry, state governments and educational institutions.

The Department is also placing emphasis on information technology and recently published for public discussion a consultancy report that puts forward a proposal for a $170 million, five-year program to develop a substantial information technology industry based on specialized areas of hardware and software.

Overall, the Commonwealth Department of Science and Technology is working to develop a strong technological base from which Australia can move into new advanced technology areas and exploit new export markets through programs closely integrated with the country's economic and educational policies. ▲

(continued from page A12)

tion with a data acquisition facility at Alice Springs and a processing facility in Canberra. It has been modified recently at a cost of $600,000 to receive some data from the Landsat 4 satellite, but there is disagreement as to whether an additional $10 million should be provided to upgrade it to receive high-resolution data from the new series of Landsat and French Spot satellites.

The Minister for Science and Technology is also responsible for CSIRO. The organization is split into five institutes and a bureau. These include the Institute of Biological Resources, Energy and Earth Resources, Industrial Technology, Animal and Food Sciences and Physical Sciences and the Bureau of Scientific Services. Within this structure are 40-odd divisions and units concentrating on specific areas of research from radio astronomy to manufacturing technology.

Current high-priority research areas include biotechnology, plant pathology, energy, manufacturing industry, water and soils, information technology and oceanography.

Under pressure from the Minister for Science and Technology the organization is redirecting its work into a number of specific areas of industrial research,including the use of computer technology and microelectronics for industrial processes, flexible manufacturing systems, advanced-process and quality-control technologies, advanced materials, mineral-processing technologies, environmental-monitoring and mineral-exploration instrumentation, communication technologies and agricultural chemicals, veterinary vaccines and medical pharmaceutical products.

CSIRO has also established a new contract research company, Sirotech, to help transfer CSIRO innovations from the research laboratory into commercial manufacture.

However, CSIRO is not the prime source of science and technology policy advice to the government. Since 1977 this has been the role of the Australian Science and Technology Council (ASTEC), which is responsible directly to the Prime Minister.

ASTEC is headed by Professor Ralph Slatyer of the Research School of Biological Sciences at the Australian National University and a former Australian ambassador to UNESCO.

Apart from the Department of Science and Technology, another 12 or so federal government departments are involved in science and technology initiatives–accounting for total federal government spending on science of $1,722 million in 1983-84.

The Defence Science and Technology Organisation (DSTO) within the Department of Defence, is Australia's second-largest research organization after CSIRO, with a budget of $162.5 million for this financial year–about 3 percent of the total defense budget. It employs about 1,000 professional scientists and engineers and an additional 3,400 technical and support staff at 10 research establishments around Australia. Research is mostly in the physical sciences and engineering, but is also undertaken in food sciences, environmental psychology and operational research.

Another department heavily involved in science and technology is the Department of Resources and Energy, spending $102.7 million over the last financial year. It is responsible for both the Australian Atomic Energy Commission (AAEC) and the Bureau of Mineral Resources (BMR).

The bureau, with a budget of $31.1 million for 1984-85 is the country's main geoscience research organization. It carries out a wide range of geological studies both on- and offshore and in Antarctica. It is organized into five divisions: continental geology, geophysics, marine geoscience and petroleum geology, and petrology and geo-chemistry; the fifth division is devoted to the assessment of Australia's mineral and energy resources.

The AAEC is a statutory authority with a budget of $41.9 million this financial year. With a staff of about 1,000 it is the largest energy research body in Australia.

In the past the AAEC has concentrated almost a quarter of its staff on uranium-enrichment research, but this has now been wound down in line with the Labor government's policy on uranium mining and use. Research is now being concentrated on waste disposal, radioisotope use and production, nuclear physics and fusion and environmental programs.

The government has plans to split the commission into three separate authorities in the future: one responsible for regulatory matters, including environmental protection, health and nuclear safeguards; a second, a government corporation to produce and market radioisotopes, and the third, a nuclear research science authority.

The Department of Health is responsible through the National Health and Medical Research Council (NH and MRC) for the majority of medical research funding in Australia,which this year has a budget of $44.2 million, 16 percent more than last year.

Last year the Australian Science and Technology Council recommended great revisions in the funding, coordination and planning of medical research, pressing for the abolition of the NH and MRC and the establishment of a Medical Research Council. This action was strongly opposed by the Australian Medical Association and no decision has been made.

The state governments are all heavily involved in science and technology development. In the past this has been mainly limited to agricultural research and extension services and medical research, but more recently it has extended to the support of high-technology development.

All of the states are moving strongly into this area by establishing technology ministries, technology parks, innovation centers, special technology funds and information services.

The universities receive a great deal of their funding for basic research through the Australian Research Grants Scheme (ARGS). However, the funding for this, $23.88 million for 1984, is considered far too low to support an adequate level of pure research in the country.

Recently the chairman of ARGS, Professor Peter Sheehan, has called for a substantial increase in funding to at least $40 million even if only the most promising projects are to be supported.

The colleges and institutes have been more successful in attracting funds

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Tidbinbilla tracking station, near Canberra

Sunrise in the West

The City of Perth

Western Australia, for long the hub of Australia's resource development, is moving rapidly towards a new role as a major center for advanced technology development in the South East Asian region.

This does not mean abandoning the traditional mineral industries which have made the State one of the world's largest producers of iron ore, bauxite and diamonds, but a new emphasis on brain-intensive industries based on high value-added products.

With South East Asia, in particular Singapore, as close if not closer than the capital cities of the eastern states, Western Australia is gearing up to develop high-technology products for a market which it sees as the largest and fastest growing in the world over the next two decades.

The new technological thrust has been highlighted by Australia II's success in the America's Cup. The victory of the Perth-based challenge was made possible only through advanced navigation and communications systems, computer control, new metals technology and ultra modern synthetic sail fabrics.

It is being spearheaded by the Western Australian State Government and in particular its Minister for Industrial Development and Technology, Mr Mal Bryce, who sees enormous potential in technology for the State.

"We have made the decision that the level of technological expertise already developed needs to be progressed and further developed in some vitally important brain-intensive industries which will become major wealth generators in the next decade," he says. "Our ambition is to convert what has been a traditionally tonnage mentality into a tonnage and technology approach to the State's development."

Mr Bryce is also Deputy Premier and his determination and enthusiasm to transform the State into an advanced technology center for the South East Asian region has led in less than 18 months to a host of initiatives.

To begin with the Government has introduced new legislation in the form of the Technology Development Act to set up a framework for the new technological thrust.

This has established three new bodies.

The WA Science, Industry and Technology Council is a policy advisory agency. The WA Technology Development Authority is a commercial agency which manages technology parks in the State, runs a technology information center, handles promotional activities, and recommends to the Minister ways of providing high-tech incentives. The WA Technology Directorate carries out research and coordinates the total development strategy.

The Council has members drawn from key groups in the community including the universities, industry, the business sector and public interest groups and has the role of providing independent advice and making recommendations to the Government.

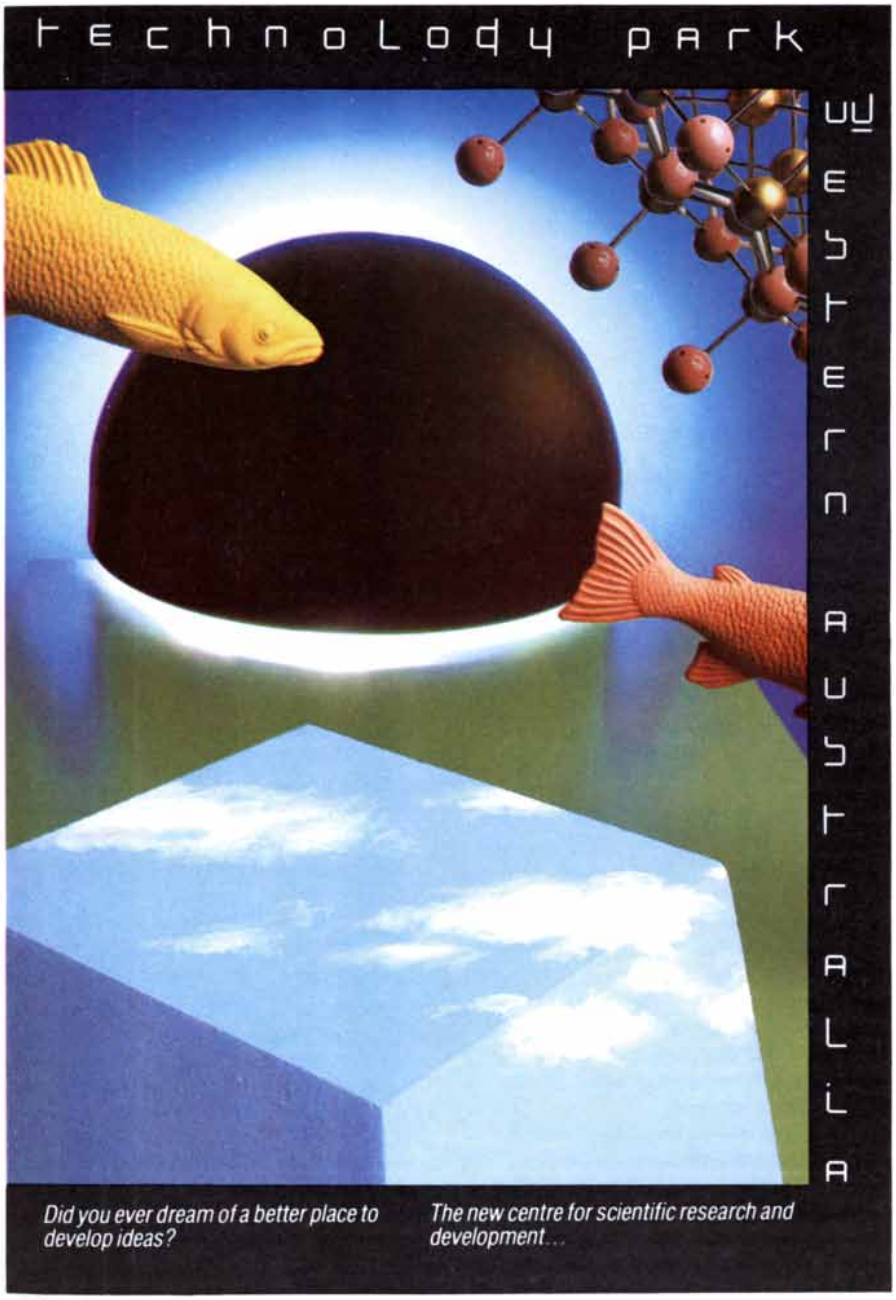
Already it is carrying out studies in a number of areas including space-related technology, energy policy, intellectual property and innovation and the social impact of new technology, and is developing recommendations on priorities and methods of stimulating technological advances.

The Directorate on the other hand is a small group of experts in electronics, biotechnology and information technology as well as overall technology policy who are working closely with the Minister researching, coordinating and developing policy.

As well, the Government has set up Australia's first Department of Computing and Information Technology which will have overall responsibility for all aspects of the Government's computer and information systems.

Its aim is to advise the Government, promote effective planning of computer use, encourage education and training in information technology and help in the marketing of Government-developed computing systems.

On top of this the Government is moving to attract new-technology industries to the State through a number of new initiatives. These include special



W.A. Technology Park. 32 St. George's Terrace Perth Western Australia Telephone 011 619 325 0231

incentives for specific preferred industries, such as electronics, the encouragement of a venture capital market and the construction of a technology park to provide a base for struggling new local industries as well as large overseas companies willing to transfer technology to the State.

The technology park is the centerpiece of the new thrust with work already well under way on two core buildings and numerous companies impatiently waiting to move in.

It will cover a 32 ha site next to the Western Australian Institute of Technology and will cater for three types of companies –

- the young 'incubator-type' operations which require practical support and encouragement in their early years as they develop new products and processes;
- established medium sized companies working in high–technology fields such as electronics, information technology or biotechnology with a strong commitment to research and development; and
- large established overseas companies capable of introducing new technologies into the State.

The core buildings should be completed late this year and will provide not only a home for small innovative companies but also a center for communications, secretarial work, word processing and technology assessment, innovation advice and financial assistance.

More than 40 companies have already expressed interest in moving in to the park, including Medical Incorporated – a large US medical technology company.

The company specializes in body replacement parts and plans to set up a $50 million research and production facility, initially specializing in heart valves. Later it is likely to move into areas such as artificial kidney dialyzers, artificial lungs, blood filters and other advanced products.

The facilities, which will employ up to 250 people, will be the company's headquarters for the Asian region and it aims to develop a new multi-million dollar market in the Asian and Pacific areas.

The Government is also encouraging established industries to modernize and restructure through the introduction of new-technology information systems and communications networking.

Compared with the eastern states, WA is lucky as it has none of the traditional smokestack industries. This means it can concentrate the majority of its resources on encouraging new industries.

"Western Australia is not going through the agonies of restructuring manufacturing industry which gives us an opportunity to leapfrog a whole stage of economic growth and makes us a typical modern sunbelt economy," says Mr Bryce.

The big emphasis is on developing new export markets for high-technology products particularly in South East Asia. The Government is establishing a South East Asian Marketing Corporation to act as a training house specifically for this purpose and to help WA companies develop suitable high-technology products for the market.

"We recognize this as the largest and most exciting growth market in the world for the 1980s and 90s and Perth is the ideal spot to develop it from."

He believes WA could become the headquarters for many local and overseas companies wishing to trade with Asia. "We are on the same time zone, we are only two hours plus one movie away and it is easy to do business from here," says Mr Bryce.

The other major thrust has been into developing a venture capital market in the State. The Government has 10% equity in one of Australia's first licensed venture capital firms – or more correctly management and investment companies – Westintech Innovation Corporation Ltd.

Other shareholders include local businessmen, industry and the three main tertiary institutes – Murdoch University, the University of Western Australia and the WA Institute of Technology.

It plans to invest through equity in local high growth industries with export potential in a range of areas from electronics through to advanced agricultural equipment and mineral processing technology.

The company is now listed on all stock exchanges throughout Australia and is planning to apply for a further licence to allow it to increase its capital base for investment.

Other venture capital companies are springing up in the State and a secondary market has been established at the Perth Stock Exchange to allow smaller companies to raise funds through the stockmarket.

The Government is also prepared to invest in new embryonic companies to give them time to carry out research or develop their products further before commercial marketing as well as to ensure that the technology stays with Australia.

"It needs to be recognized that encouragement of high technology industry involves high risks, both for companies and for governments. But if we shrink from the need to take those risks, we will be among the also-rans," says Mr Bryce.

One of its first equity investments has been in the small computer company, Formulab Technology (Australia) Pty Ltd (see box) and a number of others are expected in the future.

A major impetus for technological development in the State is the defence of the America's Cup in 1987 – an event WA is already gearing up for.

Mr Bryce believes that more than ever before the next race will be a technological race and he hopes to set up the infrastructure which will allow the State to play a major role in the design and development of the next Cup defender.

"We're taking the defence of the America's Cup very seriously. We see it as a scientific and technological challenge and part of the State's overall technological thrust."

With this in mind the Government plans to set up the first marine technology park in the Southern Hemisphere.

It will house marine companies with expertise in yacht design, advanced satellite navigation systems, new materials, hull construction and marine electronics and communications.

There will also be a large scale marine test tank plus hull and wind testing facilities and a communications network and administrative complex for the Cup defence.

"We intend to keep the Cup well into the next decade and beyond," says Mr Bryce. "If we are to do this we will need to develop the best technology.

"It will give us a new base for advanced technology and the marine industry and provide a center for excellence in marine design incorporating the latest in computer techniques."

This rapid change of direction in the State over the last 18 months has created a sense of excitement and a feeling that the State is moving rapidly ahead across a broad front of technological development.

But Mr Bryce stresses that the Government's major role is not to play a direct part in the development but to provide the support and backing and act as a catalyst so that the bulk of the effort comes from the private sector.

"Our role is catalytic, one in which we provide the environment in which the private sector can set itself the task of generating wealth."

The 1984 America's Cup winner. Perth gearing up for 1987 challenge on home ground ▲

Formulab Technology Pty Ltd – A Revolutionary new Computer Memory System

For the last three years a small Perth computer company, Formulab Technology (Australia) Pty Ltd, has been developing a revolutionary new computer memory system which is now set to capture huge markets in the United States and Europe.

The new system does away with floppy disks, can store huge quantities of data and is fast, flexible and, most important – very inexpensive.

Earlier this year after a 12 month evaluation the Western Australian Government was so impressed with the technology that it decided to take up a 1/6 equity share in the company.

The Government's support has allowed the technology to remain in the State and given the small, innovative company a chance to carry out further research and development and mount a major marketing drive to the United States.

The company, headed by Mr Tony Richter, is now negotiating joint venture agreements in the United States which will allow the technology to be transferred to a US company that will produce and market the system in the States. Later Formulab will set up at the WA technology park and begin production for local and overseas markets, outside the US.

The new system has a wide range of uses and the company so far has produced a high speed graphics recorder, a portable memory pack which has potential for use by the defence forces, and a security control system.

The key to the new system, which is called Hi-Q, is a solid state memory bric onto which data can be directly written, stored and then read by the user, so eliminating the need for floppy disks.

The system is non-volatile, eliminating the risk of loss of information commonly encountered on normal systems, and is extremely cheap to produce.

At the heart of the memory bric is a large scale integrated custom chip developed in the US which has been used to integrate both the hardware and software for the system.

"Our secret is that we are able to produce the system and its ancillary devices in an extremely compact form and at only a fraction of the cost – perhaps only 5% – of the equipment that might perform similar functions."

The graphics recorder, according to Mr Richter, makes it possible for high speed storage of more data than ever before in an extremely compact form.

"One solid state memory bric alone has the capacity of eight standard microcomputers and the recorder's capacity can easily be trebled."

The recorder can produce extremely high quality graphics for promotional or teaching purposes and can also record whole books on one memory bric allowing them to be played back cassette-style on the screen.

It can also be used for electromechanical control of machine tools and for security systems.

Also during the development the team have perfected a new computer language, which they have named Confluent.

"The capability of the language and the unique hardware combine to produce one of the most cost efficient systems in the world," says Mr Richter. ▲

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from industry. There are now 30 Tertiary Consulting Companies–only three based in universities–carrying out work for private enterprise. Some have been so successful that they now earn fees in excess of $2 million a year for consulting.

Other organizations involved in policymaking are a number of professional bodies such as the Institute of Physics and the three science academies. These include the Australian academies of science, technological sciences and social sciences.

A number of research associations, such as the Australian Welding Research Association and the Sugar Research Institute, support research in their particular industry area. Currently, the government supports four out of the 14 research associations through a special budget allocation. ▲

Australian Company Profiles

Broken Hill Pty. Co. Ltd.

The Broken Hill Pty. Co. Ltd. (BHP) is Australia's largest publicly owned company and has developed beyond a mining company to an integrated steel and metal products manufacturer. Its interests include oil and gas exploration, coal mining and creation of a new type of internal combustion engine.

BHP's manager for new technology, Dr. John Parrott, believes Australia is evolving beyond its historical role as the quarry of the world. We are now managing our own resource deposits and applying technology to that management process," he says. BHP has developed novel processes with the $26 million budget it allocates to research and development.

A central research laboratory is maintained at Shortland, New South Wales, about nine kilometers from the company's Newcastle steelworks. The major aim of the laboratory is research into the raw materials and processes used in all of BHP's operating divisions. Of particular interest is work being done on the hydrometallurgical and electrometallurgical processing of ores and concentrates.

In the Melbourne suburb of Clayton, BHP operates a research laboratory devoted to work on the maintenance and expansion of the company's existing markets. Nearly half the research effort at Clayton is devoted to improving the properties and quality of existing steel produced by BHP and to the development of new steels.

BHP scientists are involved in the research being conducted on the conversion of natural gas and light hydrocarbons into liquid transport fuels. (Australia's natural gas reserves are known to exceed 9×10^9 cubic meters.)

Dr. Parrott says the basic technology used by BHP in commercially developing liquid fuels from natural gas was researched and patented by CSIRO. The process does not use the production of methanol as an intermediate step but rather synthesizes hydro-carbon molecules directly from methane via butane. "The work in this area was a spinoff from our coal-to-oil project," Dr. Parrott says. Although BHP admits it may be too early to define the commercial prospects for the process–production costs are an inhibiting factor–the company believes the process has exciting long-term potential.

Gammatron Media Feed

The South Australian company Gammatron has developed a low cost micro-computer which is ideal for demonstrating the first principles of microprocessors to students studying electronics, engineering and technical courses.

The kit is exported to South East Asia and the Middle East and interest is currently being shown in Canada.

Some units were taken up by the University of California, Berkeley, in the communications engineering facility.

The Datum kit was developed by the South Australian Institute of Technology to introduce students to the versatility of microprocessor systems.

The self-contained kit features a MC 6802 microprocessor, programmed in assembly language with 1 K bytes of RAM, 2 K bytes of EPROM and an onboard LED Logic Probe.

Because of its structure it is also suitable for process control, in applications such as temperature, pressure and complex monitoring processes.

The Datum is widely used as a simple teaching aid by universities and technical colleges in Australia.

It has the capacity for expanded memory and cassette memory storage and the capability of analog-to-digital or digital-to-analog conversion.

A RS 232 interface provides facility for teletype or VDU functions.

Fairey Australasia

Fairey Australasia Pty. Ltd. has grown to become a leader in the production and management of high-technology defence equipment, particularly in the area of electro-optic systems.

The field services division staffs and manages the operation of the Australian Landsat receiving and processing facility, the US-Australian joint space defense communication station and the RAN's Jervis Bay target range facility. During the period 1974-1983 the group managed the operation of the Australian network of NASA tracking stations.

The company has made optical equipment for the Rapier program, night vision sights, night mission goggles, night vision systems for tanks, artillery directors, laser test equipment culminating in the recent successful bid together with Ferranti (UK) for the design and manufacture of the laser range finder system for the F/A-18 fighter plane.

Mount Isa Mines Ltd.

Mount Isa Mines Ltd. (MIM) operates one of the largest copper and zinc-lead-silver mines in the world at the isolated township of Mount Isa in the far west of Queensland. The site also produces copper anodes, crude lead and zinc concentrate, which are further processed by associated companies in Australia and the UK Group annual revenues are more than $750 million. Operating more than 1,000 kilometers from the nearest major town, MIM has had to develop a high degree of self-sufficiency. In doing so, it has also developed a number of techniques that have found ready acceptance in other major mining companies elsewhere in the world.

Where MIM is not losing a competitive advantage, positive efforts have been made by the company to market its innovations. One of the best examples of this was a process control software program developed by the company for enhancing the control of various processing stages of the ore it mined. The value of the package was recognized by Hewlett-Packard Co., the major US-based computer and instrumentation company.

MIM developed the software in response to its own need for a system suitable for direct digital control, supervisory set point control and model-based control system applications. The company also needed a system that was easy to use and could be connected to a wide variety of instrumentation. MIM decided to implement the system on a Hewlett-Packard computer.

HP bought and further developed the software, adding a few features and slightly altering the configuration to achieve a more flexible package. Now known as Process Monitoring and Control 1000, the package has been acquired by Exxon, Northern Telecom, General Motors, Kodak and Rockwell in the US. General Electric has acquired PMC/1000 for divisions in the U.S. and Canada, and Agfa-Gevaert is also using the program in Belgium.

MIM and its associated companies have also sold technology to US and European metal-producing companies and have licensed for manufacture and

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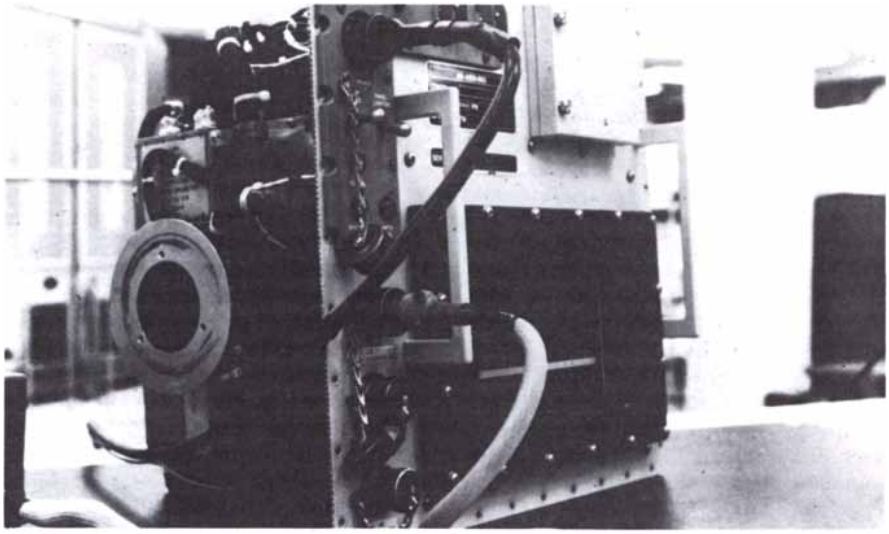
BAeA Wins Avionics Contracts



AFTA undergoes bench tests at BAeA

British Aerospace Australia can trace its origins to the 1950s and the establishment by UK firms of facilities at the Woomera rocket test range in South Australia.

Thirty years on, the company has grown into one of Australia's most advanced defense electronics suppliers, with a staff of nearly 400 and its own design, manufacturing and comprehensive test facilities within the Defence Research Centre at Salisbury near Adelaide.

Most of the recent strong growth of BAeA has been achieved through the active part it has taken in establishing the company's skills in the Federal Government's Australian Industry Participation (AIP) and Offset schemes. Both are designed to increase Australia's level of technology and self-reliance.

In BAeA's case, these initiatives have led to considerable manufacturing activity not only on defense hardware bought by Australia, but on equipment made for other countries too.

For example, the company is now the sole supplier of vital avionics equipment for all P3C Orion aircraft now being built by Lockheed in the US – not just for those Orions bought by the RAAF. Since 1977 BAeA has built some 120 'shipsets' of such avionics for the US manufacturer.

Similarly, the Australian company now supplies equipment to the UK for the British Rapier missile system. This arrangement grew from an original deal under which BAeA would build parts of those Rapiers bought by the Australian Army.

Now BAeA is working on a number of high-technology projects associated with the purchase of F/A-18 strike aircraft from the USA.

The most remarkable of these is the avionics fault-tree analyzer (AFTA) – a portable military computer which revolutionizes fault-finding the avionics and provides role configuration in the new generation of combat aircraft.

"AFTA plugs into the F/A-18's databus," explains marketing executive David Williamson, "it is coded to gain access to the various avionics on board, and can interrogate them and pinpoint exactly which shop-replaceable assembly within an avionics unit is faulty."

Being extremely rugged and only the size of a suitcase, AFTA could be rushed into action at a few moments notice – it even uses the aircraft's own power supply, so that access to an external generator is not needed.

British Aerospace Australia designed and built AFTA under a $10 million contract to the F/A-18's makers, McDonnell Douglas Corporation, and are thought to be the first Australian firm ever to win a substantial defense design contract from the US. AFTA has already proved to be a success. McDonnell Douglas offers it as an option with the F/A-18 and the Spanish Airforce has already ordered nine of the computers.

BAeA is developing an advanced version of its already proved aircraft fatigue data analysis system (AFDAS) for the new tactical fighter.

AFDAS monitors fatigue damage to aircraft structures, using strain gauges to measure stress at critical points. Earlier AFDAS models are fitted to the RAAF's Mirages, and the new version will be standard equipment on all Australian F/A-18s.

AFDAS allows experts not only to monitor physical damage, but to tell virtually at a glance how far through its design life an individual plane has progressed. A log of flying hours can only give an approximate answer to that question.

BAeA expects worldwide sales of AFDAS, and the RAAF will be retrofitting many of their older aircraft with the system.

The company is also assembling and testing other avionics for the F/A-18. These include up-front control panels, head-up displays and multi-purpose displays, and flight control computers.

BAeA's expertise in electronics testing has in fact become so well recognized that it has developed into an export in its own right. The company has upgraded, manufactured and installed Rapier test facilities in Switzerland and Swingfire anti-tank missile test facilities in Egypt.

Work for the Army includes the TPQ-36 Firefinder system designed by the Hughes Aircraft Company, for which BAeA is building the 'shelter' electronics. The company is also manufacturing the operator-trainer and maintenance trainer for the system. Firefinder scans the radar horizon with pencil-beams, detects a rising projectile, determines the type of weapon which has fired it, and calls down counterfire.

Also for the Army, BAeA is working on a portable all arms calculator (PAAC) – an ingenious hand-held calculator which provides weapon-laying solutions in the battlefield. It could be used, for example, to target mortars, artillery or tank main armament.

For the Royal Australian Navy the company manufactures major elements of the Mulloka ship-mounted sonar.

Looking to the future, BAeA is working on projects associated with Australia's Starlab space telescope program, and sees the emergence of an indigenous space electronics capability as extremely important for the company's future.

"We are also hoping to be involved in electronics systems integration, and in hardware manufacturing and support, for the Australian submarine and helicopter contracts which are expected to be awarded soon," says David Williamson.

The company's engineers and technicians have now worked and continue to work in many parts of the world, exposed to the latest developments in defense high-technology. Through controlled expansion and selection of new programs and techniques, BAeA is tackling the new generation technology very successfully. ▲

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sale specialized environmental monitoring devices for use in the lead industry. Also in the lead industry, MIM has with Australia's CSIRO jointly patented a direct lead smelting process. The process is at the state at which a pilot plant is being built. MIM believes the technology will be commercially viable in the early 1990's, when it will reduce energy costs, increase metal recoveries and allow lower-grade ores to be mined.

Australian Mineral Development Laboratories (AMDEL)

AMDEL was formed in South Australia in 1960 to provide a scientific service to Australia's rapidly growing mineral exploration and development program and to the materials sciences.

Since this time the company has become the leading Australian manufacturer of high-technology instrumentation for the mineral processing industry.

The company produces in-stream analysis systems which have rapid pay-back times and will be offering its products to the United States in 1985.

In 1984 sytems were installed in the People's Republic of China, Chile, the USSR, South Africa and Australia. With 28 systems now in operation around the world AMDEL is recognized as a major supplier of high-technology instrumentation.

In addition to in-stream analysis systems it manufactures and installs nucleonic on-pipe gauges for liquids and slurries, mineral analyzers for single element analysis and radiometric truck discriminators for determining the uranium content in ore.

Wormald International Ltd.

Fire protection products play a crucial role in the protection of key sections of the Kennedy Space Center at Cape Canaveral, Florida. A computerized monitoring and surveillance center in the British city of Birmingham acts as a silent guard for a variety of industrial and commercial premises. In Brazil, the leading manufacturer of fire hoses is recognized for the high-quality agricultural fire hose it makes. The company behind these diverse projects is one of Australia's few multinational companies.

Wormald International Ltd. has its head office in Sydney and operates subsidiaries in more than 20 other countries. It is one of the few leading special-risk fire protection companies in the world. It has diversified into other forms of security and now claims to be uniquely placed to provide integrated fire and security installations in large commercial, industrial and governmental complexes. This integration involves extensive use of advanced computerized systems.

Wormald has shown that it is prepared to diversify in the quest for new products. Early last year it announced a joint-venture development company with the federal government-backed Australian Industry Development Corporation. The new company, Australia Biomedical Corporation Ltd., will develop and market Australian biomedical inventions for world markets. Although Wormald's senior management admits the new company is at a very early stage of development, they are confident it has considerable potential. Australian Biomedical Corp. has already attracted a number of inventors and institutes, which have agreed in principle to offer marketing rights covering about 30 products to the corporation. The initial range of products includes electronic patient-care equipment, medical and surgical equipment and home-health-care products.

CRA Ltd.

CRA Ltd. rides near the top of Australia's list of largest publicly owned companies. With sales of about $2.5 billion, its interests reach from the mining and processing of base and precious metals to biotechnology research. While CRA is often regarded as simply a resource development company, its vice-president of development, Dr. Geoff Bone, considers it a manufacturing concern.

CRA's history as a processor of raw minerals goes back to its origin as the Zinc Corporation Ltd., which was formed in 1905 to treat zinc-bearing tailings at Broken Hill, in the far west of New South Wales. The town is the site of one of the largest discoveries of zinc, lead and silver.

Broken Hill was arguably the first place in the world to develop the flotation process for the removal of metal-bearing compounds from raw mineral aggregates. A subsidiary of CRA, Broken Hill Associated Smelters, developed the first continuous lead refining process at Port Pirie, South Australia. The key to the continuous process is the addition of zinc to the impure lead at near melting point. The zinc and silver combination floats to the outer shell of a container called a desilvering kettle, and the lead is collected from the center of the vessel. In recent years Broken Hill Associated Smelters has also developed a process for removing bismuth from lead, thus improving the purity of the metal.

CRA's majority-owned subsidiary, Comalco, mines bauxite in the far north of Australia and processes it into aluminium products. Completing the company's portfolio of activities is its participation in a diamond mining operation in Western Australia.

Dr. Bone notes that most research in Australia tends to be of a "hands-on" nature. "In the future we are also likely to continue to focus on problem areas through the adaptation of existing technology rather than break new ground," he says.

Australasian Training Aids Pty. Ltd.

About 600 kilometers south of Sydney on the banks of the river Murray is the bustling country town of Albury, New South Wales. Albury is the home of one of Australia's most unusual companies, Australasian Training Aids Pty. Ltd. (ATA). It was formed in 1957 by its current managing director, Mr. Lyndsay Knight, and has established itself at the forefront of global technology in the complex field of military target training systems.

In the past five years, ATA has completed major contracts worth more than $60 million. It has done this in conjunction with wholly owned subsidiaries in the US and Britain. It is currently negotiating new sales with a total value of several hundred million dollars for completion within the next five years.

Recent developments by the 200-strong work force include a gunnery training system, which provides immediate down-range feedback on the fall of shots. It displays this information on visual display terminals at the firing point and the range control tower.

In the US ATA is currently negotiating for the installation of a semi-automatic infantry range system at Fort Jackson, South Carolina, and a computer-controlled infantry range system at Fort Polk, Louisiana.

AUSSAT

Australia will be one of the last major nations to establish its own domestic satellite communications system. The satellite itself is due for launching by the space shuttle in 1985. By then a network of earth stations will have been established together with telemetry and tracking stations in Sydney and Perth. The system will be operated by a partially government-owned company called AUSSAT.

The move to a domestic communications satellite system will certainly maintain within Australia a growing body of talent in space technology. Future demands for meteorological surveillance and resources development and defense-related issues are likely to be met through the use of available commercial systems or specially constructed systems suited to Australia's large size and extensive resources. ▲

Telecommunications Leader Opens NY Office

Australia is fast becoming the hub of an extensive communications network in South East Asia. International companies that have interests throughout the region are leasing private voice and data links that reach out from a sophisticated, computer-controlled switching center in Sydney.

This new development in high-technology is being managed by Australia's Overseas Telecommunications Commission (OTC) which opened its first overseas office in New York recently. There is strong competition for the business from the communications carriers of several other countries. OTC's success reflects Australia's highly developed communications infrastructure, and the country's long history of stable government.

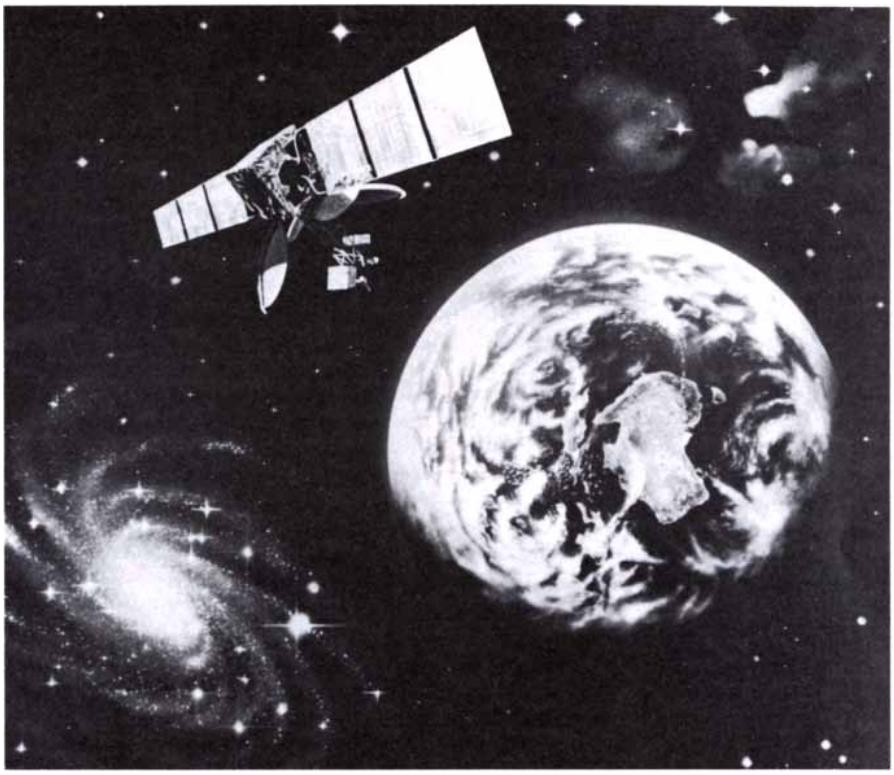
The network provides secure, dedicated links between companies' Australian operations and their South East Asian affiliates in the Philippines, Indonesia, Singapore, Malaysia, Thailand, Hong Kong and other regional sites. Further connections are being established in some cases to link the hub in Sydney to the US or to Europe to provide a worldwide network.

OTC expects this type of international networking for intracorporate traffic to grow, and it is actively working with several major multinational companies on a number of more specialized networks for the region, including an extensive international facsimile hookup.

Research done by OTC indicates that business managers in Australia and the US perceive the greatest challenge in communications to be how best to establish corporation-wide links, and that these improved internal communications will be a vital factor in forging a competitive edge.

The New York office, which is staffed by two senior executives, Trevor Duff and Ravi Bhatia, is on the 24th floor, 535 5th Avenue (Telex: 225584 IBC UR) and it reflects the importance which OTC places on servicing major US companies with communications needs in South East Asia and the Pacific.

OTC was formed to handle international communications in 1946, at the end of the war, because of public agreement that a nation's strategic communication links should be under government control. Thus the government acquired the private interests in the existing radio network and undersea cables. Since that time OTC has provided all of Australia's public overseas communications, progressing from the era of the telegraph cable to submarine telephone cables, to satellites and now fiber optics.



Australia is the sixth largest user of the global communications satellite system

OTC is the sixth-largest shareholder of the global communications satellite system, based on "user pays" arrangements. Australia is among the highest per capita users of telecommunications in the world, behind only the US, Britain and France in total use of the system.

In every sense, Australia is part of the global trend toward the information age. Social use of the telephone in Australia has been growing at a steady 30% per year, slowing only slightly during the recent economic downturn, and new business services have been introduced for high speed transmission of data across the country or across the world.

Since its formation, OTC has grown in stature in the international telecommunications community. It initiated the permanent leasing of international television broadcast transponders. Two major television networks in Australia now have 24-hour access to television program material, such as news reports, from North America, keeping Australians informed of the latest developments overseas.

Through its Intelsat involvement OTC is abreast of the progress being made in satellite communications, but it also shares the ownership and operation of substantial submarine cable systems around the world. Currently under construction is the $400 million ANZCAN cable linking Australia and New Zealand to Canada via Norfolk Island, Fiji and Hawaii. Australia is the major partner in this project. It is also involved in the planning and development of a cable system across the Indian Ocean, which is due to be completed in 1986.

OTC is test-marketing some novel forms of telecommunications. Together with the US, Japan, Canada and the UK, it is introducing an international videoconferencing technique that dramatically reduces the bandwidths and cost involved in satellite television transmission. The technique involves digitizing information and then transmitting only the information that changes from one picture frame to the next, not full frame information. OTC has also recently introduced the first electronic messaging services in Australia, based on the US Dialcom facility.

With an office now in New York, OTC's progressive attitude towards service innovation is significantly enhanced, with US corporations and communications carriers with business interests in South East Asian markets now having direct access to the company. ▲

The Development of Pharmaceutical Biotechnology in Australia

by Neville McCarthy, Director of the Commonwealth Serum Laboratories

The Australian pharmaceutical industry was accurately described in 1979 in the Ralph report, the "Pharmaceutical Manufacturing Industry Inquiry", as predominantly engaged in the marketing of products formulated and packaged from imported active ingredients.

This general description, although accurate, has its notable exception, the government-owned pharmaceutical manufacturer Commonwealth Serum Laboratories (CSL), founded in 1916. Initiated during World War I as a manufacturer of vaccines and antisera, CSL's biological product and national-interest missions have been key aspects of its operation.

The establishment of the Commonwealth Serum Laboratories Commission in 1961 as a statutory authority allowed for these dual tasks under legislation requiring that commercial operations be dominant and meet post-tax dividend criteria from trading profits and that non-commercial operations be undertaken only to the extent of allotted government budget funds.

Today, with an annual total revenue approaching $70 million, the commercial operations are responsible for more than 90% of total activity.

The worldwide pharmaceutical industry is known for its research and development investment, but apart from several short-lived ventures into R and D, the Australian subsidiaries of the multinational companies have not demonstrated this facet of their strength in Australia. Indeed, for an industry dependent on world markets and a critical mass sufficient to support many key activities, small national activities cannot be expected to be a miniature version of the full spread of parent company functions.

What, then, is the place for an Australian enterprise in this global industry, particularly when our nation has only 15 million people and is still largely remote from the rest of the developed world? The finding and exploiting of market niches built on the strengths available is the path to be pursued, but the path is often poorly marked, often only discernible because others have already trodden it, and it frequently leads to dead ends unless one can find the key to pass through to the main routes of world marketing and distribution.

At the applied level in biological medicine there has been a notable R and D effort at CSL, resulting in the large range of products they have made over the past 67 years. Many of the major advances of this century in therapeutics have been among the milestones of CSL's growth, for example industrial scale manufacture of insulin in 1923, diphtheria toxoid in 1927, snake antivenoms in 1929, tetanus toxoid in 1938, penicillin in 1944, human serum fractionation (Cohn) in 1952, Salk polio vaccine in 1956, sub-unit influenza vaccine in 1966 and interferon in 1981.

Biotechnology is therefore not new in Australia, but today there is widespread interest and optimism in the "new biotechnology" because it is seen that spectacular new advances and fortunes are the "glittering prizes" for those with the courage to enter the field.

Will the economies of biological product manufacture and marketing somehow be different in the next 20 years than they have been in the past 20 years? A belief that they will be is probably at variance with the attitude of the established industry, which over the past two decades has regarded biological product manufacture as the low profitability, high risk sector of the pharmaceutical industry. Indeed, it can still be said today that the new multinational pharmaceutical companies that have retained a strong presence in vaccines do not have the public visibility and media glamor enjoyed, if not promoted, by the venture capital entrepreneurs as they proclaim their pursuits.

Nonetheless, it is from the broadly based companies with deep financial pockets, manufacturing and marketing skills and extensive international distribution networks that the innovative pharmaceutical products from the new biotechnology are most likely to come during the remainder of this century. But as is the case with all commercial enterprise, there will be the exceptions as an occasional entrepreneur succeeds and grows to multinational viability and the industry loses established members who fail to adapt to changing technology and markets.

What is the situation today for investment in pharmaceutical biotechnology in Australia?

At the lowest level (but not implied to be unworthy) the argument I would strongly advance is that a presence in the field is of national importance.

This argument parallels that for support of basic or pure research in any field, which is an argument acceptable to governments (and therefore to the people) in most countries, as evidenced by the systems they develop for grants to train and employ researchers.

Downstream high-capacity protein purification

Through hands-on experience and a working presence the identification and exploration of prospects worthy of possible commercial exploitation can be best undertaken.

Some would argue that this task should be left to the market system, and so it would be if the market system worked freely or were allowed to so work. Most nations, however, do not allow the free market forces unfettered play in pharmaceuticals (if in any fields), and there are particular justifications for small nations making individual decisions on the grounds of protecting health and employment and buffering against complete dependence on overseas technology and the complex logistics of international supply networks.

Thus in Australia, with its small population and largely remote situation in the Southern Hemisphere, decisions can be appropriately made to support particular areas of technology and the manufacturing industry. The next question then has to deal with the identification of areas of support. The present discussion confines itself to pharmaceuticals, and so the answer need only relate to aspects of that industry.

The spectrum of drugs or agents regarded as lifesaving is now extremely broad; a simple list such as could have been compiled immediately following World War II is no longer possible. Concentration on treating indigenous diseases of particular national importance

could provide another approach, but such diseases amenable to control or calling for a local thrust more readily come to mind for Third World countries than for developed ones.

Hence, as in the approach to any marketing problem, the focus comes to be on product differentiation, that is, in what way an advantage can be exploited or even developed if it does not already exist.

This is not the place to debate whether a society can develop such situations through deliberate science programs or whether they emerge serendipitously, and then perhaps as a function of the quality or quantity of research. Existing skills and resources together with emergent new disciplines provide the logical base for a national effort if there is to be one, even though it may only be a microcosm of the efforts under way and well advanced in the populous developed countries of the Northern Hemisphere.

In Australia the base for pharmaceuticals is narrow, and in the research disciplines fundamental to products of biotechnology and in development and manufacture, there are few organizations with the appropriate depth of experience and demonstrated ability. The question of the choice of therapeutic area for human and veterinary product development therefore goes back to the technology and scientific strength married to the development and exploitation capability demonstrated by established manufacturing and marketing skills.

Thus a particular focus of activity can appropriately be the development of a malaria vaccine. In this instance Australia has public health experience in malaria epidemiology and control gained over generations, and the disease is of major consequence to the health of the people who are our northern neighbours. To this serious endemic disease problem can be brought the potential of the collaborative research in genetic engineering techniques utilizing the monoclonal antibody banks and gene cloning activities of scientists at the Queensland Institute of Medical Research (QIMR) and the Walter & Eliza Hall Institute of Medical Research (WEHI). A joint venture integrating the vaccine production skills of CSL and the research strength of Biotechnology Australia Pty Ltd (BA) to a co-ordinated R and D program with QIMR and WEHI now gives hope for the development of a malaria vaccine based on the blood-stage antigens. The plan then is for BA and CSL to undertake the challenge of commercial exploitation leading to production, marketing and distribution of the successful vaccine candidates. In this step the objective is to maximize the Australian equity and establish an ongoing role in production, but at the same time explore opportunities for international collaboration in a field where technology exchange and cross-licensing arrangements will form an essential part of goal realization.

Biological production control instrumentation

The malaria vaccine project is now critically poised and the prospects of the impressive Australian work leading to a successful product rest very heavily on the ability of the Australian Government to provide substantial support moneys. The extent to which Northern Hemisphere governments have given virtually open cheques to fund work of equal standing in their countries is the appropriate model for a project of this importance and magnitude.

Although malaria vaccine development is a specific case it serves well to illustrate that the question of "What to do?" is inextricably tied to the next one of "How to do it?" In discussing this key aspect the general case will again lead to a clear identification of a specific agency, CSL, as the vehicle for Government presence in health-related biotechnology.

Although public funding to support unprogrammed research in the biological sciences must continue with some encouragement to "areas of need" as identified by the National Health and Medical Research Council over the past decade, there has emerged an allocation of public funding by Government for biotechnology programs leading to product development. This orientation toward industrial applications introduces the need for protection of intellectual property and technical know-how, which previously has been of little concern to academics. At the same time industry and academia have very limited experience in working together. The situation is more complex when public funds bring the private sector and academic research institutes together, but there is no alternative to such arrangements, particularly when basic research abilities are diffusely spread across the nation in places such as the universities and CSIRO divisions.

Typical fermentation plant

We should note, however, that publicly funded developments in other countries have taken advantage of existing national organizations in which the Government has equity, or that such developments occurred through the establishment of Government presence in joint venture arrangements with major private sector institutions. Through CSL, with its strengths at critical levels of product developmental steps, there is a unique opportunity for both public and private sector research innovations and ideas to find the path to successful commercial exploitation.

I would argue that an already-existing R and D-based biological product manufacturer with a strong national marketing presence and an international linkage through vigorous export performance and licensing arrangements can be the prime focus of pharmaceutical biotechnology in Australia. This is particularly so when Government policy is supportive of national effort in this area. The Commonwealth Serum Laboratories meet all the criteria to be that prime focus. ▲

The Future: Traditional expertise offers promise as declining productivity urges diversification

Since coming to power in March 1983 the Labor Government has adopted a strong new policy boosting industrial innovation and development. The intention is to stimulate the development of new high-technology industries and to encourage the introduction of new technology to improve traditional industries. Such measures are seen by the government as a major way of boosting economic growth and lifting the productivity of Australia's declining manufacturing sector.

As the Prime Minister, Mr. Bob Hawke, said at the opening of Australia's first national technology conference in September 1983: "The effectiveness with which we use new technology will determine whether we can reverse the long downward slide in our living standards relative to those of other countries – from one of the highest per capita incomes in the world 30 years ago to one of the lowest of the industrial countries."

This rapid decline in productivity, employment, exports and economic growth is one of the major concerns of the government. Between 1962 and 1980 only four out of 24 OECD countries had a GDP growth rate per capita lower than Australia, and Australia's ranking in terms of GDP per capita fell from ninth to twelfth.

The decline is particularly apparent in the manufacturing sector, where Australia's percentage share of GDP has slipped from 28.8 percent in 1963 to 21 percent in 1979 and is still falling. This is also reflected in the very low ratio of exports to imports relative to other OECD countries and the particularly low level of exports of technology-intensive products.

In 1980 Australia exported US$81 per capita in high-technology goods compared with US$2,584 for Switzerland, US$1,378 for the Netherlands (countries with smaller populations than that of Australia) and an average US$468 for the OECD. This is again reflected in the extremely low level of research and development carried out by private industry, which when measured as a percentage of GDP, is one of the lowest among OECD countries.

The Government is determined to reverse these trends and is moving to restructure existing industry and encourage the establishment of new enterprises through the introduction of new technology.

Initiatives have also been introduced to encourage the establishment of a venture capital market in Australia which is seen as essential for providing risk capital to get innovations from the research stage through to commercialization.

The Government is particularly keen to get industry to provide a much larger share of research funds and is encouraging it to enter into joint projects with CSIRO and tertiary institutes and has called on universities to seek a larger share of their funding from the private sector.

The key element is the development of a national technology strategy which will lay the framework for new policies covering not only technology but also industry development, industrial relations, trade, economics and education. After extensive discussions with industry, business, government and the unions the strategy should be completed by early 1985.

However, the momentum of technology development has slowed in recent months with an extremely tight budget which has led to cuts in many areas, in particular CSIRO and industrial and basic research funding.

There are now fears that the initial optimism engendered by the Government in its early days in power has been misplaced, but the Minister for Science and Technology, Barry Jones, is still optimistic that a number of new initiatives particularly in the information technology field will get under way early next year.

Agricultural Research

Australia is now the world's largest exporter of wool and meat and the third largest exporter of wheat – all against the seemingly insuperable problems of a harsh climate, poor soils, extensive droughts and vast distances from export markets.

Pasture improvement provides the most striking example of how research by CSIRO, state departments and universities has transformed a country with the most limited natural resources into one of the world's major agricultural nations.

Introduction of legumes, subterranean clover and lucerne in the temperate regions and stylos, lucerne and siratro in the tropical regions has boosted soil fertility and enabled highly productive grass species to grow in combination with the legumes. This has made possible a fivefold increase in stocking rates, up to 100 percent increases in meat production as well as the sowing to pasture of an extra 20 million hectares over the past two decades.

Australian researchers now have a world reputation for their expertise in nitrogen fixation and *Rhizobium* bacteria and have built up a collection of about 4,000 grasses and 12,000 legumes and associated bacteria to help in research programs. New pasture species and management systems and crop improvement have contributed significantly to the production increases.

Improved livestock breeding has also played a major role in boosting production. A number of new breeds, such as the Belmont Red and the Australian Milking Zebu, have been produced for the tropical regions. *Bos indicus* blood has been gradually infused into breeding programs to produce crosses that combine the meat production qualities of the British breeds with the ability to tolerate heat, resist parasites and survive on low-quality feed of the zebu and brahman.

Selective breeding programs to improve the productivity of sheep, cattle and pigs under Australian conditions have also proved very effective, along with world-class work on twinning in sheep and improved wool production.

Australian researchers have built up a world reputation in ruminant nutrition, digestive physiology and wool biology, and work is under way on new chemical shearing methods for sheep. A unique robot sheep-shearing system is under development with support from the Australian Wool Corporation. It involves the production of an advanced robot system with a type of artificial intelligence that enables it to learn and remember from one sheep to the next and to adjust the cutters continually to keep them moving just above the skin.

In the past three years of research more than 200 sheep have been shorn and only about a dozen cuts have occurred. The corporation is to decide shortly whether the research should proceed to commercial production.

Biological control of plant and animal pests is another major area of Australian expertise. Much work is now

(continued on page A28)

RESEARCH LABORATORIES OF AUSTRALIA:

High-Tech Giants Come to South Australia

They call Adelaide the City of Churches.

It seems an unlikely place of pilgrimage for high-tech experts from some of the world's most successful companies. Yet since the 1950s firms at the forefront of reprographics and printing – Canon, AM International and Eastman Kodak among many others – have been sending teams here.

They come to work with Research Laboratories of Australia (RLA) which, since it was founded in 1959 by Adelaide businessman Donald G. Daw, has built up a world lead in specialist reprographic techniques. Head office is at 210 Greenhill Road, Eastwood, South Australia 5063.

RLA is a contract R and D operation, concentrating on the development of high quality reprographic systems and materials in close cooperation with major clients.

It has had some big successes.

Among the most recent and most exciting has been the development, with Coulter Systems Corporation (CSC) of the USA, of a unique system for producing top quality four-color pre-press proofs for the printing industry.

"It's the most elegant process for electrographic reprography to be found anywhere," says RLA's Technical Director Josef Matkan, "no other system can produce results of this quality."

The RLA method has involved the company over several years in developing film and plates capable of extremely high resolution, detailed reduction, continuous tone and high speed, using advanced technology liquid toners.

The pre-press proofs which result look exactly like the finished printed article, and are produced on the printing stock to be used. Until now such proofs have had to be produced on heavy glossy laminates which give the customer little idea of what the finished job will look like.

RLA has worked closely with Coulter and the US-Dutch joint venture Coulter-Stork on hardware design, and their fully automatic machines are already winning orders in Australia and Europe.

"We are now working with Coulter on their toner requirements for all aspects of reprography," says Matkan.

RLA can claim to have pioneered the development of liquid toners, which continue to occupy much of the company's R and D effort. It was RLA which developed the liquid toners for Canon's successful range of NP duplicators and for their laser-beam printer in the 1960s and 1970s.

RLA is also making new advances in the dry toner field, producing dry toners of the pressure-fixing type by a unique process of encapsulation.

Encapsulated toners of several colors require less pressure for image-fixing, which means lighter equipment construction. The inert shell of the capsule also reduces the likelihood of photoconductor contamination – so that the photoconductor can be re-used again and again – and that means that copiers, computer printers and other hardware will require less maintenance.

RLA does run a small production line of its own, which manufactures and exports toners for highly specialized applications. But the bulk of its work is for very large outside clients who need systems and materials developed specifically to meet their own needs or to work with their own equipment.

Such clients are prepared to buy-in RLA's expertise rather than to try to build up their own teams of researchers – recognizing the value of the Adelaide company's 25 years in the field.

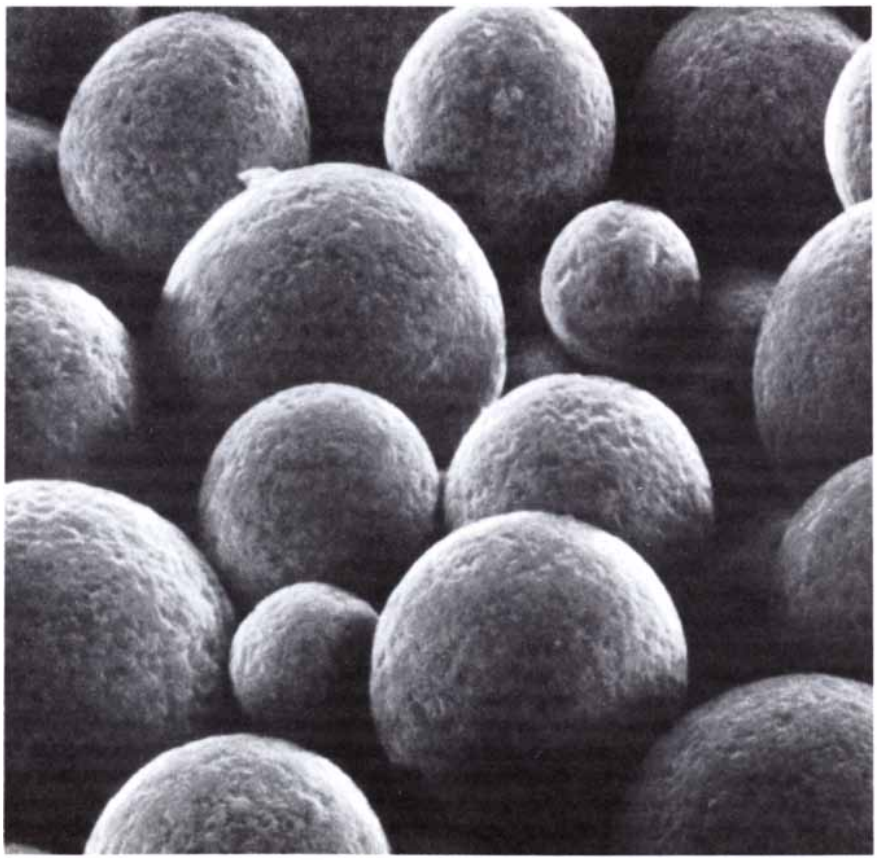
"We guarantee our clients total confidentiality," says founder Donald Daw, Chairman and Managing Director of RLA, "and we can virtually guarantee them success too. We never take on an R and D project unless we are confident we can come up with the right answers."

Donald Daw originally set up RLA to investigate the problems of coloring plastics. However, he soon recognized the potential of work in reprography which was under way at the Commonwealth Government's Defence Standards Laboratory in Adelaide as part of a research effort to find photo-sensitive materials which were not affected by radiation.

From then on the company rapidly gained in stature, and from its early days has been courted by a succession of US, European and Japanese giants.

Matkan estimates that RLA has probably been granted over 200 separate patents over the years, most of them in the names of client companies.

"We are not interested in volume production," says Donald Daw, "we are a highly specialized R and D company. We are the best in the world in our field, and we have the clients to match." ▲

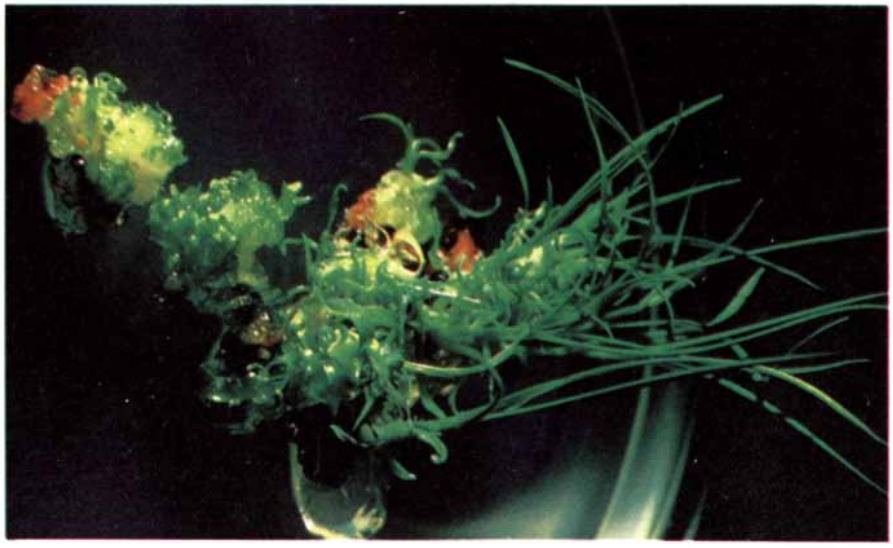


Enlarged encapsular particles – uniform size is critical

(continued from page A26)

concentrated on integrated systems of chemical and biological control and on computerized management systems such as the Siratac system for cotton. This is operated from an on-farm computer, which is fed information on pest numbers, crop maturity and weather conditions and provides farmers with daily advice on spraying or other management options.

Much research has also gone into ways of coping with drought and into new farming systems, such as minimum tillage, improved ways of handling crops after harvest, and into new crop species for the Tropics, such as kenaf, cassava and the pigeon pea.



Research into rapid breeding techniques conducted by the Division of Plant Industry

Synroc

A totally new concept for the safe disposal of high-level nuclear waste has been developed by a team of scientists from the Australian National University. It is based on a highly stable synthetic rock known as Synroc, which actually incorporates the radioactive elements into its crystalline structure, immobilizing them for thousands of years.

The synthetic rock consists of three naturally occurring minerals—zirconite, perovskite and hollandite—made from oxides of five simple elements—titanium, zirconium, calcium, barium and aluminium. These minerals can take into their crystal structure and immobilize almost all of the 50 or so radioactive elements present in high-level nuclear waste.

Synroc is the result of more than four years work by a research team led by Professor Ted Ringwood, head of the University's Research School of Earth Sciences. Tests carried out in Australia and overseas have shown that Synroc is much more stable than borosilicate glass under high temperatures and pressures.

A demonstration plant under construction at Australian Atomic Energy Commission headquarters at Lucas Heights near Sydney should be completed within the next 18 months. It will be capable of handling 20 kilograms of Synroc an hour, containing four kilograms of waste and would be able to solidify all the wastes from 25 1,000-megawatt nuclear power stations—about the number needed to generate all of Australia's electricity needs.

The AAEC has been responsible for scaling up the Synroc process since 1980 and developed a new technique called "in can" hot-pressing. This made possible production of 30-kilogram Synroc blocks from a 20 percent mix of simulated waste and the Synroc chemicals hot-pressed into stainless steel tubes or canisters.

The technique has been further refined and a new process of uniaxial hot-pressing in bellows-shaped containers developed. The powdered chemicals are transformed to Synroc at extremely high temperatures and pressures (30 Mpa and 1,150 degrees C.) and at the same time the bellows are compressed and collapse uniformly, remaining tightly sealed around the Synroc pancake. These containers can then be sealed and buried up to four kilometers underground in areas of impermeable rock. Borosilicate glass cannot be buried at these depths because it is unable to withstand high temperatures and is susceptible to leaching by groundwater over 100 degrees C.

The Antarctic

Australia's involvement in the Antarctic stretches back to almost the turn of the century, when many Australians took part in the British expeditions led by Scott and Shackleton. The first Australian expedition, mounted by Sir Douglas Mawson between 1911 and 1914, was responsible for establishing a number of bases as well as mapping over 1,000 kilometers of coastline. Many more expeditions followed, and laid the basis for Australia's present claim to sovereignty over almost half of the Antarctic continent—a claim that is contested by many countries. It came into force in 1936 when Australia took over responsibility for a six million square kilometer area stretching south of 60 degrees south between 45 and 160 degrees east longitude, now known as Australian Antarctic Territory.

Mainland stations were set up at Mawson in 1954, Davis in 1957 and Casey in 1969 and all of them have been continuously manned. A $60 million rebuilding program, to be completed by 1990, is now under way.

Each year about 100 men (and, more recently, women) live at the stations over the winter to carry out research in many fields, including glaciology, atmospheric physics, biology, geology, meteorology and medicine. In the summer they are joined by parties of expeditioners who carry out intensive research programs, returning to Australia before the winter pack ice closes in.

Currently, the stations can only be approached during the summer by three chartered supply ships, meaning that the winter expeditioners can be isolated for periods of up to 12 months. This inaccessibility has significantly reduced the effectiveness of Australia's research programs over the years, and there are now plans to establish a new intercontinental air link between Australia and Antarctica. This would involve the construction of three runways: a compacted snow runway at Casey station, a rock runway at Davis and an ice strip at Mawson, as well as the construction of a new Antarctic research vessel. The whole transport system is estimated to cost well over $60 million.

Overall, funding for the Antarctic increased only marginally in this year's budget. Many believe that Australia's present level of activity in the region is much too low to maintain its claim to such a large area of the continent. In fact, the chairman of the government's Antarctic Research Policy Advisory Committee (ARPAC), Professor David Caro, has called a number of times for substantially increased funding and levels of research in the region. In August he warned that if Australia is to remain a major Antarctic power, it must provide adequate transport and sufficient funds for a first-rate research program, saying, "If Australia cannot afford this level of activity, it would be more honest to move out or at least to reduce the number of stations to be supported."

(continued on page A30)

Australian Industry Development Corporation

Over the last 18 months the Australian Industry Development Corporation (AIDC), the Government's industry financing body, has been playing an increasing role in the funding of new advanced technology companies.

The charter of the Corporation, which is a statutory body operating independently of government, was changed last year to give it an expanded role in financing the development and restructuring of traditional industries and the creation of new technology-based enterprises.

This has led to it investing in a number of innovative projects ranging from computer software development through to biomedical devices and even advanced processing equipment.

The first was a joint venture with Wormalds International to set up the Australian Biomedical Corporation. This is now developing a range of Australian biomedical innovations to a stage where they can be marketed commercially both locally and overseas.

The AIDC contributed $500,000 to the venture which was matched by Wormalds and the aim is to develop a company which is a reliable and profitable world supplier of high quality biomedical products.

Initially it is focusing its resources on the commercial development of products and equipment which can provide improved clinical diagnosis either through new monitoring methods or diagnostic procedures, and on devices that will improve patient welfare or treatment.

Possible innovations are assessed by the Corporation's medical panel and once accepted the rights are handed over and the product developed to a commercial stage for marketing and distribution overseas through Wormald's extensive international business links.

The AIDC has also invested $5 million in Australia's largest biomedical group, Nucleus Ltd, to help it boost research and development, marketing and manufacture – particularly of its latest product, the Australian-developed bionic ear.

Commercial production of the device, under development since 1978, is well under way and the company hopes to have sold at least 80 – mostly in the United States – by the end of this year.

It uses sophisticated state-of-the-art electronics and a multichannel implant in the cochlea to convert normal sounds into electrical impulses inside the ear. This helps nerve-deaf people with a profound or total hearing loss to recognize speech and to hear again.

The AIDC investment in Nucleus is redeemable within five years or can be converted into ordinary shares, giving the Corporation a 16% interest in the company.

The Corporation has also invested in a number of computer projects. The first was a $1 million investment in Mica Associates, a small Canberra company developing and manufacturing a range of intelligent display computer terminals.

The investment has given the AIDC a 50% interest in the company and is being used for further research and development and in boosting marketing and manufacturing effort.

The company's equipment is IBM-compatible, has a seven-color display capacity and is marketed as a stand-alone or cluster system and has already won a number of orders overseas and locally.

In another venture the AIDC has invested $500,000 in a small Sydney software house, Fawnray Pty Ltd, as a first step in establishing a major Australian software publishing house specializing in UNIX operating systems.

The aim is to develop the company into an export business, initially based on its own products but later developing, packaging and marketing other Australian software both locally and overseas.

The Corporation has also invested $1.5 million in a new advanced chip design and manufacturing company, Austek Microsystems Pty Ltd, set up in Adelaide earlier this year by a former leading CSIRO computer engineer, Dr Craig Mudge.

The company, which is backed by United States and Australian investors, is concentrating on producing custom-designed Very Large Scale Integrated (VLSI) chips. Initially these will be designed in Australia and sent overseas for fabrication and manufacture but eventually it is hoped to set up a manufacturing plant at the Adelaide Technology Park.

One other initiative has been a $1.3 million investment in Bioquip Australia Pty Ltd, a Sydney-based company set up to develop advanced food processing equipment developed by CSIRO in conjunction with Howden Equipment Pty Ltd.

The company is developing a new process called counter current extraction which gives extremely high yields of fruit juice and can be used for everything from juice extraction through to compost regeneration.

Ran Data's "Electronic Envelope".

A high-technology company based in Perth, WA, has developed what is hailed as the world's most dynamic encryptor – an information scrambling device suited to facsimile machines and general data processing. The company, Ran Data Pty Ltd, now leads international competitors in the development of secure encryption systems.

Mr Monte Sala, regarded as the 'father' of the Western Australian electronics and computer industry, established Ran Data in 1980. The purpose was to develop Mr Sala's concepts into identifiable products and systems which would pave Ran Data's way into the expanding market of data security.

Ran Data's encryptor has been evaluated by government cryptanalysts, universities, financial institutions and independent consultants, as rating higher than any competitive device. The internationally acclaimed cryptanalyst, Professor Adi Shamir, formerly of MIT, has accredited Ran Data's algorithm, the complex coding formula utilized within the encryptor, and reported it as statistically uncompromisable. He says that overall security is superior to that of the data encryption standard algorithm set by the US National Bureau of Standards, and developed by the US Government and IBM researchers.

Ran Data Pty Ltd now provides better than 95% of non-military encryption equipment used in Australia, and leads the field of surveillance telemetry systems.

In 1982, Ran Data's technologies captured the interest of major stockbrokers, Merrill Lynch Pierce Fenner & Smith, who invested in the company.

Today, the organization is 80% owned by Ran Data Corporation Limited, a company listed on the Australian Stock Exchange. It is expected that the securities of Ran Data Corporation Ltd will trade under American Depository Receipts.

Monte Sala has pushed Ran Data into the US market, which is estimated as being currently worth in excess of $20 million a year and should balloon to $4 billion a year within five years. The company is now poised to capture the Asian and European markets.

Monte Sala, an Italian-born civil engineer, formed Ran Data after a successful association with NASA. For his outstanding achievement in the field of electronics, he appeared on the Queen's Honors List and was awarded the coveted 'AM' – Member of the Order of Australia. ▲

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Australia's future activities in the region now much depend on the importance the government decides to place on its claims to the region, given the potentially rich mineral and marine resources. This is likely to be a decision that will be made outside the science and technology portfolio and within the government's overall foreign affairs policy.

Astronomy

Australia has been at the forefront of international optical and radio astronomy for almost 40 years, due in part to its unique position to observe the southern skies but also because of the wealth of major astronomical instruments that have sprung up in the country since the 1950's.

From 1945 to 1960 a team of CSIRO scientists was responsible for a string of new discoveries, which culminated in the construction of the 64-meter Parkes radio telescope in New South Wales by CSIRO in 1961. It was one of the most advanced radio telescopes in the world, and it was used to make many major discoveries, including the detection of the first quasar.

The Parkes telescope has now been superseded by a number of more sophisticated instruments in the Northern Hemisphere, and this led the federal government last year to fund the construction of a new $30-million synthesis telescope. It will link major telescopes across the continent to form one of the most sensitive high-resolution radio telescopes in the world.

Six new 22-meter antennas are to be built, five of them in a 6-kilometer line at Culgoora Observatory in New South Wales and the sixth at Siding Spring Observatory. These will be linked with the existing Parkes telescope, and operating together they will form a single telescope with a dish diameter equivalent to 300 kilometers.

Further links with dishes at Carnarvon in Western Australia, Alice Springs, Tidbinbilla near Canberra, Sydney University and Hobart will extend the telescope to a dish diameter of 3,000 kilometers, spanning the entire continent. It will be known as the Australia Telescope and begin operation in the bicentennial year, 1988.

Optical astronomy has also flourished with the construction of a number of new instruments in the 1960's and 1970's, in particular the 3.9-meter Anglo-Australian telescope, which is jointly operated by Britain and Australia. This telescope has dominated optical astronomy since its first use in 1974; it has been responsible for many new discoveries, including the Vela Pulsar in 1977 and most recently the identification of the fastest spinning pulsar known in the universe, PSR 1937-21.

The Anglo-Australian telescope is at the Siding Spring Observatory near Coonabarabran in New South Wales, which is the major optical astronomy site in the Southern Hemisphere and the home for other instruments. These include the U.K. Schmidt telescope, which has played a significant role in mapping the southern skies.

A new 2.3-meter optical telescope is nearing completion at the observatory, which has been built to a totally new design devised by scientists from the Mount Stromlo Observatory near Canberra. It combines three major technological advances—a rotating building, a large, thin mirror and an altazimuth mounting—into a single telescope, cutting the cost to a tenth of that of a conventional instrument. This makes the telescope extremely versatile and will make possible its use 24 hours a day, operating in the infrared during the daytime.

In all, Australia has about 40 optical and radio telescopes, and in addition a number of X-ray, infrared and cosmic-ray instruments.

The country is also moving into the field of space astronomy and is currently looking for a third partner for the Starlab project: a joint initiative with the U.S. to launch a space telescope aboard the space shuttle in 1990. Australia is responsible for designing the central element of the telescope – the instrument package, which contains a unique ultralarge-format photon-counting array developed by scientists from Mount Stromlo Observatory.

Medical Research

The pioneering *in vitro* fertilization work by Professor Carl Wood and his team from Monash University in Melbourne has highlighted worldwide the excellence of Australian medical research. The work has led to the birth of the first test tube baby, the first test tube twins and triplets and the implantation of the first frozen embryo earlier this year.

Major advances have included work by Sir Macfarlane Burnet on viral vaccines, the establishment of the effects of thalidomide by Sir William McBride and pioneering work by Sir Norman Gregg on the effects of maternal Rubella on the developing baby.

There are now 10 medical schools in Australia, plus the John Curtin School of Medical Research at the Australian National University, 14 private or hospital research institutes and half a dozen government health laboratories. Funding comes from the government, private sources and overseas research grants and in 1982–83 topped an esti-

AUSTRALIAN RESEARCH ORGANIZATIONS

CSIRO Headquarters, PO Box 225, Dickson, ACT 2602, tel: (062) 48 4211
CSL 45 Poplar Rd, Parkville, VIC 3052, tel: (03) 389 1911
AMDEL Head Office, Flemington, Frewville, SA 5063, tel: (08) 79 1662
AERONAUTICAL RESEARCH LABORATORIES PO Box 4331, Melbourne, VIC 3001, tel: (03) 647 7511
DEPARTMENT OF SCIENCE AND TECHNOLOGY PO Box 65, Belconnen, ACT 2616, tel: (062) 64 1155
ANTARCTIC DIVISION Channel Highway, Kingston, TAS 7150, tel: (002) 290209
AUSTRALIAN ACADEMY OF SCIENCE PO Box 783, Canberra, ACT 2601, tel: (062) 48 6011
AUSTRALIAN ACADEMY OF TECHNOLOGICAL SCIENCES 191 Royal Parade, Parkville, VIC 3052, tel: (03) 347 3166
AUSTRALIAN ATOMIC ENERGY COMMISSION Lucas Heights Research Laboratories, Private Mail Bag, Sutherland, NSW 2232, tel: (02) 543 0111
AUSTRALIAN MINERAL INDUSTRIES RESEARCH ASSOCIATION 11th Floor, 63 Exhibition St, Melbourne, VIC 3000, tel: (03) 63 7393
AUSTRALIAN SCIENCE AND TECHNOLOGY COUNCIL PO Box 52, Canberra, ACT 2600, tel: (062) 72 4655
BUREAU OF METEOROLOGY 150 Lonsdale St, Melbourne, VIC 3000, tel: (03) 662 0311
BUREAU OF MINERAL RESOURCES PO Box 378, Canberra, ACT 2601, tel: (062) 49 9111
HOWARD FLOREY INSTITUTE University of Melbourne, Parkville, VIC 3052, tel: (03) 345 1844
MATERIALS RESEARCH LABORATORIES PO Box 50, Ascot Vale, VIC 3032, tel: (03) 31 7222
NSW SCIENCE AND TECHNOLOGY COUNCIL 151 Macquarie St, Sydney, NSW 2000, tel: (02) 27 3978
SOLAR ENERGY RESEARCH INSTITUTE OF WA GPO Box R1283, Perth, WA 6001, tel: (09) 326 4157
WALTER AND ELIZA HALL INSTITUTE Post Office, Royal Melbourne Hospital, VIC 3050, tel: (03) 347 1511
AUSTRALIAN SCIENTIFIC INDUSTRIES ASSOCIATION C/o Regional Administrative Office, 9 Queens Rd, Melbourne, VIC 3004, tel: (03) 268 7111
AUSTRALIAN INSTITUTE OF MARINE SCIENCE Cape Ferguson, PMB No. 3, Townsville MSO, QLD 4810, tel: (077) 78 9211
AUSTRALIAN COAL INDUSTRY RESEARCH LABORATORIES 14 Delhi Rd, North Ryde, NSW 2113, tel: (02) 887 5341
VICTORIAN SOLAR ENERGY COUNCIL 151 Flinders St, Melbourne, VIC 3000, tel: (03) 654 4533

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Wool Finds New Safety Markets

A project to develop protective clothing for volunteer fire fighters in Australia has opened the way for a whole range of industrial safety clothing.

The first Wool Protective Coveralls developed by the Australian Wool Corporation (AWC) went into service in early 1984 with the Victorian Country Fire Authority. Since then the number of applications for this basic garment has multiplied dramatically.

Commercial enquiries are being received from offshore oilrig operators, aircraft service and maintenance operations, civil emergency services, police helicopter crews, ambulance and paramedic groups, TV news teams, and firms which transport volatile liquids – among others.

AWC textile technologist Dougal Pleasance believes that the garment owes its success not only to the natural qualities of wool itself, but also to design aspects of the AWC garment which can be altered to accommodate a wide range of industrial applications.

Wool's most obvious advantage is its resistance to flame and heat. It resists ignition, is slow to burn, and self-extinguishes once the fabric is horizontal. Even when it does burn it reduces to a non-sticky ash which cools rapidly.

It is also remarkably resistant to high temperature flashes, such as might be expected from exploding volatile liquids. This is partly because of the 16% moisture content retained naturally by wool under normal atmospheric conditions. Even when exposed to extreme flash conditions the wool surface merely chars to a non-flammable ash, which itself shields the rest of the fabric and the wearer.

Wool is also a poor conductor of heat, and forms a natural protection against radiant heat, especially when used in thick, low-density fabrics. This is why foundry workers wear heavy woollen garments.

There is no doubt that some synthetic fibers, such as Nomex and Kevlar, are more flame resistant than wool. But factors such as cost and wearer comfort must also be taken into account.

The ability of wool fiber to take up moisture from the body surface and transfer it to the external fabric surface is a vital factor in wearer comfort and a clear advantage over flameproof synthetics.

The AWC garment uses fine Australian wool in a high-twist worsted yarn. It is fine enough to be worn in direct contact with the bare skin. It also features removable padded shoulders which help to support loads such as knapsack sprays, portable radios and restraining harness.

The generous cut, removable shoulder pads, and the provision of an action back and elasticized waist in the AWC garment mean that 95% of wearers can be fitted with five basic sizes – far fewer than is normally the case with cotton or synthetic fibers.

The wool fabric is treated to allow the garment to be machine-washed and tumble-dried, but dry cleaning presents no problem. It is only necessary to ensure that hot alkaline solutions are not used for washing: wool resists acids and organic solvents but it is damaged by alkalis. Wool-safe detergents are available from many manufacturers.

Basic garment construction remains constant regardless of intended use so that the most efficient garment fabrication techniques can be utilized and the price kept down. However for individual orders low cost options are available, such as the method of front closure, and style of pockets and epaulettes.

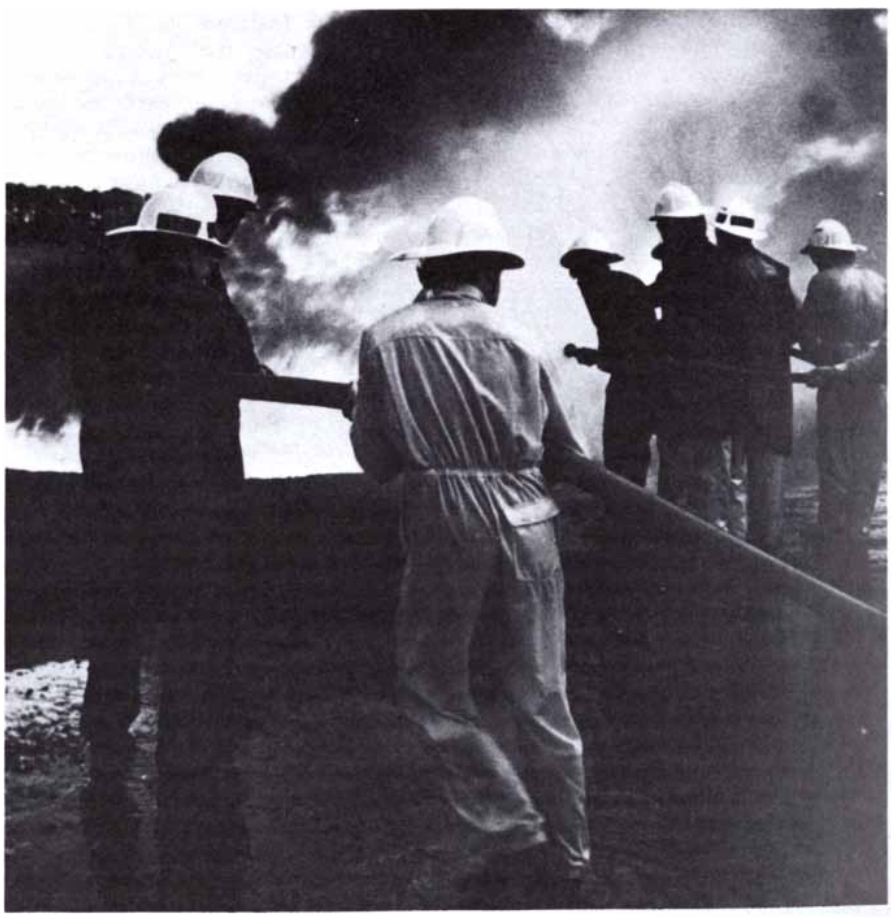
Fabric weight is also variable. Alterations to the weaving patterns produce fabric weights of 305, 270 and 200 g/m^2.

Obviously, the heavier the fabric the greater the protection against fire. However, some protection is often better than none and in many hazardous occupations – especially in hot climates – comfort assumes considerable importance. The lightweight versions of the AWC garment, which offer comfort as well as a good level of protection, will fill a clear void in the field of industrial safety.

Bush fire fighters' garments are produced in an internationally accepted high visibility yellow. But it is possible to produce the garments in a wide range of colors without the need for large yarn or fabric stocks.

Company logos, and departmental and individual identification, can be provided by embroidery, heat-fixed transfer, screen printing and so on without much extra cost.

The manufacturing program followed by the AWC means that with a minimum inventory commercial orders can be met within four to six weeks. ▲



Safety with wool

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mated $90 million.

Compared with other areas of science and technology, medical research is relatively generously funded by the government: a total of almost $60 million was provided in 1982–83.

The major government-funded research center is the John Curtin School of Medical Research, which has a budget of over $10 million and a staff of more than 300. The largest of the private medical research institutes is the Walter and Eliza Hall Institute of Medical Research, set up in 1919 and now a world leader in immunology, cancer and molecular biology research. The institute has recently been responsible for isolating malaria antigens, which will be used in developing a malaria vaccine in Australia.

Other major private medical research institutes include the Howard Florey Institute of Experimental Physiology and Medicine, which specializes in endocrinology, hypertension and behavior and has done much pioneering work on the human birth hormone relaxin, and the Baker Medical Research Institute in Melbourne, which concentrates on cardiovascular research, atherosclerosis and hypertension.

In Sydney, independent research institutes, such as the Kanematsu Research Institute, are at the forefront of leukemia research, and others, such as the Garvan Institute of Medical Research, are pioneering work into metabolic disorders such as diabetes.

Major advances made by Australian medical researchers in recent years include the determination of the link between analgesics and kidney damage, detailing of the natural history of melanoma and the mechanism of the inheritance of malignant hyperthermia. Other outstanding work has included the discovery of rotavirus as the cause of infantile diarrhea in both developed and developing countries, the use of transfer factor to slow down the progression of multiple sclerosis and work on tissue rejection and the transplantation of pancreas islets in the treatment of infantile diabetes.

The use of ultrasound as an investigative tool in cancer and the development of a number of new ultrasonic techniques have been pioneered by the Ultrasonics Institute in Sydney.

Medical research, particularly as preventive medicine, is a major priority in Australia and government support is likely to continue at a relatively high level.

Biotechnology

Despite a strong research base, world class researchers and a number of major advances in biotechnology, Australia has lagged behind in the establishment of a commercial biotechnology industry.

The Government, however, has identified biotechnology as a major area of high-technology development, and has earmarked funds specifically for biotechnology research and industrial scale-up. A total of $2.1 million has been provided to support the National Biotechnology Scheme, aimed at commercializing university and other research. This is seen as totally inadequate to meet the demand, but it is hoped it will act as a catalyst to get the industry off the ground.

So far, major activity has been in the field of monoclonal antibodies. A number of diagnostic kits for animal and human diseases should soon reach the market. A number of genetically engineered animal vaccines, including one for scours in pigs and another for fleece rot in sheep, are also nearing commercial production.

One of the most exciting projects is the plan to develop a malaria vaccine in Australia, following the successful isolation of antigens from one of the deadliest strains of malaria, *Plasmodium falciparum,* by a research team from the Walter and Eliza Hall Institute for Medical Research in Melbourne.

The institute; the government-owned Commonwealth Serum Laboratories; a private company, Biotechnology Australia Pty Ltd., and the Queensland Institute of Technology hope to develop the vaccine locally over the next five years. This represents a major step forward, as until now much of Australia's best work has had to go overseas for commercial development. For instance, most recently further work on the human pregnancy hormone relaxin, successfully isolated by a team from the Howard Florey Institute in Melbourne, was handed over to Genentech in the U.S.

Another major area of expertise in Australia is in plant genetics. Researchers at CSIRO's Division of Plant Industry have isolated a transposable element, or more colloquially, "jumping gene," in maize that is capable of moving from place to place on a chromosome or between chromosomes. It could be used to insert new desirable genes into the plant to combat disease or promote drought resistance.

In other work, the Australian National University's Centre for Recombinant DNA Research is investigating the transfer of nitrogen fixation genes from legumes to nonlegume crops. The work is being supported with a $1.8 million grant from Agrigenics Corporation of Boulder, Colorado. Already the team has managed to isolate a number of genes that enable bacteria to interact with the plant to form a root nodule and genes that make possible nitrogen fixation, thus putting the center at the forefront of world research in the area.

The center also recently has been responsible for cloning the human blood pressure hormone renin for the first time. This work is being supported by California Biotechnology Inc. in the U.S. The aim is to eventually design an inhibitor of renin that can be used as a hypertensive agent for treatment of high blood pressure.

The center is also involved in a collaborative project with the University of New South Wales and the Garvan Institute of Medical Research in Sydney to produce commercial quantities of human growth hormone for the Australian market. Novel biological insecticides, animal hormones and vaccines, animal breeding, waste treatment and ore leaching are other areas of active research.

The future development of a biotechnology industry in Australia now depends on how effective new venture-capital tax incentives and increased research grants are in mobilizing the industry and freeing finance for commercial development. Currently, regulation of biotechnology research and development is purely voluntary. The federal government has established the Recombinant DNA Monitoring Committee, responsible to the Department of Science and Technology, which has laid down voluntary guidelines for laboratory and industrial research. These specify various levels of laboratory containment, reporting procedures, the setting up of laboratory safety committees and approval procedures aimed at eliminating or minimizing risk from the work. The guidelines are based on those laid down by the National Institutes of Health in the U.S.

Lawyers, theologians and a number of concerned scientists have raised community concern over the use of recombinant DNA techniques and have called for legislation to control the new technology. However, at present it looks as if regulation of the embryo industry will remain voluntary.

Scientific Instrumentation

Australia's most successful and well-known invention is the atomic absorption spectrophotometer, which has revolutionized chemical analysis around the world. It was the result of a flash of inspiration in a Melbourne garden one Sunday morning back in 1952, when Dr. Alan Walsh realized that the best way of detecting minute quantities of metallic elements was to measure their absorption rather than their emission of radiation. By the following morning he had set up a successful experiment at his laboratory at CSIRO's Division of Chemical Physics, which laid the basis for what is now called the most significant advance in chemical analysis

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TELEX COMPUTER PRODUCTS:

New Name – New Opportunities

Telex Computer Products of Sydney has proved that the Australian high-technology industry is fully capable of manufacturing computer equipment as efficiently and as cheaply as the US – or anyone.

The company has grown into one of Australia's most successful makers – and most enterprising exporters – of control units, intelligent displays and keyboards.

Now a change of ownership has opened up even greater opportunities.

Until May of 1984, the Australian operation was a subsidiary of the US-based giant, Raytheon.

It was Raytheon who in 1979 began sending components of their computer products to Australia for assembly. The experiment proved so successful that the Australian company was soon handling virtually the entire manufacture of some product lines aimed principally at the Australasian market place – the first time Raytheon products had been made outside the US.

When Raytheon decided to get out of the computer business in May in order to rationalize their commercial operations, the Telex Corporation was quick to seize the opportunity. Telex bought Raytheon Worldwide entire, including the Australian company.

"It was a bit of a shock at first," admits John Schofield, Managing Director of the renamed company, "we were doing very well and had been making excellent profits. But we will soon start manufacturing Telex products in Australia too, and that has opened up a lot of doors for us."

The new company will continue to make its highly successful PTS-1/4000 range of products inherited from Raytheon. Its series of control units, basically equivalent to the IBM 3274 and 3276, are built entirely in Australia except for the plastic shell. Its intelligent display unit, equivalent to an IBM 3278, now has some 70% Australian input.

Telex Computer Products employs about 150 people in Australia, with branch offices in every major city and across Asia. Its factory is in Adelaide, but most of its work is subcontracted out to other Australian firms.

So rapidly has the volume of work risen in recent months that in some cases subcontractors are having to devote 60% or more of their production lines to meeting the Telex orders, especially for printed circuit boards.

The company has won some significant domestic orders over the past two years. It has grown large enough to claim 35% of the annual market share for IBM 3270 type equipment – which challenges IBM itself.

It is particularly strong in sales to the Federal Government. The Health Insurance Commission, running Medibank Private and Medicare, has taken 4000 devices. The airlines too have been important customers for display terminals and software.

"To be successful, you have to build in volume," says Schofield, "with a market as small as Australia's that means exports."

By the end of the current financial year Telex Computer Products expects to export equipment worth $1.5 million or more. Among significant overseas sales it has already clinched were finished airline display terminals to Singapore (that contract alone was worth $500,000), 1700 keyboards to Germany in the last three months, and about 400 printer control units to the UK, Germany and Scandinavia.

But as Telex equipment is added to the production lines, Schofield expects exports to leap to between $2 million and $4 million during the 1985/6 fiscal year. By then exports would represent from 20-25% of Telex's Australian output.

Among other devices, the company will be building the brand-new Telex 078 display terminal and the logic board for the 079 color display terminal. Schofield estimates that about 60% of these new products will be Australian made.

In the months ahead the new company will be exploring possibilities in the software market too. It has already invested $500,000 in a major software development for airline ticketing, which would run on Telex or other hardware.

The system will allow travel agents access to the computer booking files of more than 20 airlines worldwide, and will give them the facility to have complex multiple-stage tickets printed out instantly for customers. Schofield expects the system to be fully functional by next year, and hopes to export the software to Asia and beyond.

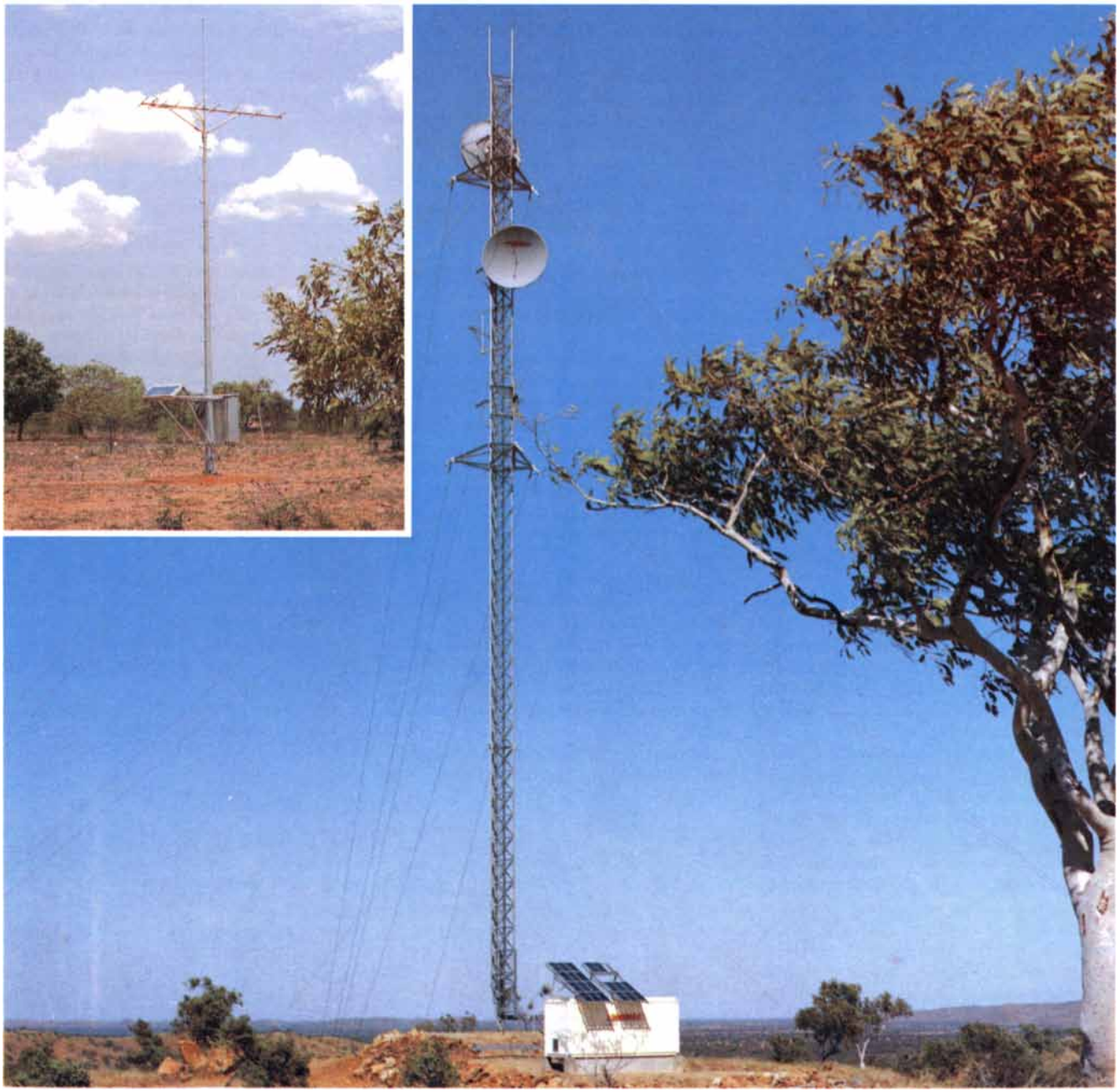
John Schofield is well-fitted for the task of helmsman of what looks certain to be one of Australia's brightest high-tech manufacturing and exporting operations. An Australian himself, he worked for Raytheon for 15 years until the takeover, ending up as Vice-President with Raytheon's Central Division in the US, with responsibility for sales to the western half of the country.

"I always had faith in Australia's ability to make cost effective high-tech products," he says, "and we are proving that I was right." ▲

Testing and repair at Telex's Adelaide plant

TELECOM AUSTRALIA:

Solving the Isolation Problem



Solar powered microwave repeater station in remote NW Australia
Inset: Automatic telephony comes to the outback via digital radio and solar power

By 1990 every single Australian, even in the most distant Aboriginal communities of the Northern Territory, will be able to dial the world direct or even call up an international data bank.

This is an extraordinary feat for a sparsely populated country the size of the United States or Europe, and is only being made possible through advanced communications technology developed by Telecom Australia.

Despite the problems of distance, extreme climates, vast unpopulated areas and small market size, Australia now ranks seventh in the world on the basis of telephones per 100 people.

And the number is growing daily particularly as Telecom begins the last and hardest task of bringing a modern, automatic telephone service to every person in outback Australia.

To do this Telecom's Research Laboratories in Melbourne have developed uniquely Australian technology involving digital radio systems and solar power to combat the problems of providing an affordable automatic service over vast distances.

The organization has begun a $400 million Rural and Remote Areas Program to bring telephone services to the remaining 44,000 Australians who live beyond Telecom's existing network and to convert the remaining 26,200 manual services to modern automatic technology.

It will be a major engineering feat involving 5 million man-hours of engineering effort plus hundreds of

thousands of hours of customer consultation, design and other work.

By 1990 everyone will have access to not only STD and ISD services but also telex, videotex, data services, facsimile and electronic mail.

This will involve a range of technologies from the simple extension of underground cables where customers live 30 km from the nearest exchange to the new digital radio concentrator technology developed by Telecom.

Between 6000 to 8000 services will be provided using the new technology which will involve the construction of 1200 solar powered repeater stations about 50 km apart across vast areas of the Northern Territory, Western Australia, Queensland, New South Wales and South Australia. Victoria and Tasmania are fully automatic.

Automatic digital exchanges will be built where 60 to 1000 lines are required to be linked into the system and up to 13 repeater stations will be used to link customers up to 600 km away from each exchange.

Each repeater station will consist of three units – a weatherproof cabinet to house the radio equipment and batteries, a solar array to power the system and a mast to support the antennae.

There will be at least two antennae, one an omni-directional antenna for communicating with the customer and downstream repeaters and the other a directional antenna for communication with the next upstream repeater.

Each customer will require a digital radio transceiver and associated equipment plus a nine to ten metre high antenna mast, all powered by solar panels.

The small automatic digital exchanges – another first for Telecom technology development – are being designed by Telecom in conjunction with L.M. Ericsson and will be available by 1986/87.

One of the major users of the new service will be distant Aboriginal communities. They do not conform to the normal pattern of telephone use and Telecom has carried out a number of studies to determine their particular needs.

Another feature of the system will be a two-way teleconferencing facility which will allow all remote students now using correspondence courses or the School of the Air to be linked by teleconferenced classes.

One distant group which is not likely to be serviced by terrestrial means is the mining and exploration industry, which often needs a range of services at short notice in very difficult localities such as on offshore oil rigs.

Australia's domestic communications satellite will be called in to help and Telecom will provide a new ITERRA satellite network service to satisfy these more specialized needs.

Customer earth stations will link up via the satellite and the main earth station in Victoria into the main terrestrial telephone network.

ITERRA will be able to provide a range of services from ordinary phones through to data and text facilities and will come into operation in 1986.

This final linking of Australia's remaining population into the telephone trunk network is a last step in a massive effort by Telecom over the last decade to conquer the tyranny of distance.

It began in the 1970s with a major commitment to convert manual exchanges to automatic and to link distant towns in northern, western and central Australia via new solar powered microwave links.

In fact Telecom pioneered the use of solar energy for communications systems initially with the construction of the 580 km Alice Springs to Tennant Creek microwave link and most recently with construction of the longest solar powered microwave network in the world – the 1595 km Kimberley project in Western Australia.

This links one of the most vast, remote and rugged regions of Australia into the main trunk network. It starts at Port Hedland and then goes on to Broome and Derby, finally linking up to Kununurra and Wyndham in the far north of the State. There are now plans to continue this on to Darwin.

Construction was not easy due to the extreme climates, flooded rivers, lack of access roads, cyclones and extreme humidity. It began in 1981 and the first stage ended at Derby on schedule in November 1982. The second stage, through the most difficult terrain, was finished ahead of schedule in September 1983.

A total of 43 solar powered repeater stations were built at 40 km or so intervals along the route. Each 20 to 85m high mast with its antennae were specially stabilized to withstand high cyclonic winds.

The solar power unit at each repeater consists of a standard shipping seatainer, housing a bank of batteries which are charged by an array of solar cells mounted on top of the seatainer.

Telecom is a world leader in solar power and in conjunction with the Japanese, carries out extensive testing at its Research Laboratories in Melbourne.

This is just a small part of the total research program employing around 500 people to investigate optical fibers, satellite communications, very large scale integrated circuits, telephone switching, cellular radio and a number of other new communications technologies.

One of the next most exciting projects is the introduction of optical fiber links between the main cities. Field trials have been carried out in Victoria and now Telecom has announced a plan to link Sydney and Melbourne by a 60,000 channel optical fiber cable by the beginning of 1988.

A much longer and more ambitious program to link Adelaide and Darwin by optical fibers is also planned and work should get under way shortly.

Telecom's public data packet switched service, known as Austpac, came into operation in late 1982. This is a high performance data switching service, targeted at the emerging technologies such as electronic mail and electronic funds transfer.

The digital data service is also being developed extensively and provides leased line data circuits to support the computer networks of a rapidly growing number of businesses and organizations.

Early next year Telecom will introduce a national videotex service to be known as Viatel, based on Prestel technology.

Telecom will provide the basic infrastructure for the service while a number of private companies will supply the bulk of the information services either directly through the Telecom database or externally through a gateway facility.

Telecom is also introducing two new text services – Telememo and Teletex – in mid-1985.

Teletex will allow high speed transmission between word processors at around 2000 words a minute and Telememo will give anyone with a personal computer, word processor or electronic memory typewriter access to an electronic mail box.

In other moves a major extension of the cellular mobile telephone network is planned for 1986/87. Tenders have been called for the service which will be installed initially in Sydney and progressively extended across the country.

The overall aim is to provide Australians everywhere with one of the most advanced telecommunications systems in the world.

Telecom is also moving out to market its expertise and technology overseas, particularly its remote area systems which are at the forefront of world developments. Many countries, particularly in the Pacific and Asia regions, have already expressed interest in Telecom's answers to communications problems. ▲

The Austek Microsystems Story

by Dr J. Craig Mudge
VLSI Program

Austek is the vision of Dr J. Craig Mudge, a South Australian who until recently worked for Digital Equipment Corporation in the USA developing the architecture for their very successful VAX range of computers.

Following his time at DEC, he was invited by the CSIRO to return to Australia to establish and run a program to train Australian scientists and engineers in VLSI chip design and to conduct VLSI research. This program culminated in the development of a 102,000-transistor voice recognition chip and a VLSI strategy for Australia. On completion of this task, Mudge left to set up Austek; as the three-year VLSI Program had met its goals, the CSIRO team was able to join him.

Mudge describes Austek as a venture chip manufacturer.

"In the financial world there are both traditional bankers who lend on gilt-edged security, and venture capitalists who share in the financial risks and rewards of the business. Similarly in the chip manufacturing business there are traditional chip designers who work for fees: the design house does the work and the design passes to the customer on payment. Austek has introduced venture chip manufacturing to the world, with significant benefits to customers. Austek shares the development of the custom chip with the customer, but the chip remains the property of Austek which provides chips as required. The customer is saved considerable front-end investment and has the benefit of all the advanced technology that has been developed. Both companies share in the risks and rewards of the business; this is as it should be since both parties are directly motivated to see the product succeed."

The Adelaide Location

Adelaide was chosen as the location for Austek's headquarters for a number of reasons. Adelaide offers a high quality of life, arguably the best in Australia, and possesses a sophisticated infrastructure capable of supporting a wide range of high-tech activities.

People and their families are happy to move to Adelaide, so staff turnover is reduced. Being further away from the main high-technology centers overseas, there is less employer competition so staff turnover is minimal and wage rates very competitive.

Austek leases its premises at Technology Park Adelaide in Innovation House, a multi-tenant, multi-function building designed specifically for high-tech start-ups.

Negotiations have just been concluded with the Singapore Government to set up a design center in that country and advertising is under way for engineers. Similarly, negotiations are under way to locate a design center in California's Silicon Valley.

These will be supported from Adelaide providing top design skills, libraries of circuits for large projects, coordination of mask manufacture and production runs through semiconductor foundries in the USA and Japan. The regional design centers will perform customer designs and will work closely with customers' engineers.

Communications

"Communications are clearly vital to us in such a competitive, fast growing, and rapidly changing industry as microelectronics," says Mudge.

"We will be installing a highly effective international communications system. The backbone is Teknet, an Austek proprietary computer communications network which allows employees and vital customers to exchange electronic messages between Austek locations around the world. File and other data can be transferred in the same way.

"This reduces problems caused by conflicting time zones in that messages can be sent from one office to await the start of work next morning at the destination. In this way a project can be engaged on around the clock."

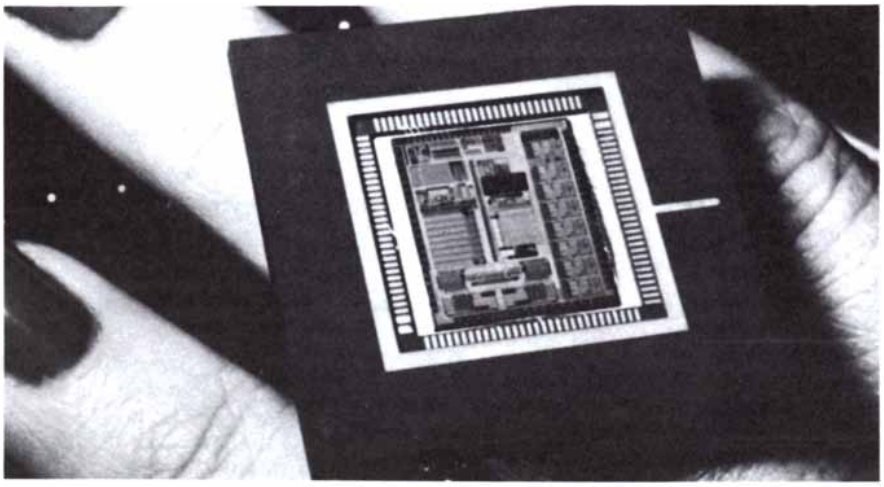
People

Teknet is the work of Dr Bruce Nelson, formerly of Xerox Palo Alto Research Center in California. Other key personnel at Austek include:

- Dr Rob Clarke, who was the lead designer of CSIRO's word-recognition chip, managed AUSMPC, Australia's first multi-project chip implementation system, and is now leading major design projects for Austek.
- Marcus Paltridge, who has 13 years of circuit design, process technology, and production experience with Philips and CSIRO.
- Dr Rob Potter, who has 17 years experience in the computer and electronics industry in the USA and Canada with Control Data Corporation, and in Australia with Thorn-EMI Electronics and the CSIRO.
- Antony Simpson, who worked with Cresap, McCormick, and Paget, Inc, a New York-based consulting firm, where he had four years of marketing, organizational, and finance experience in the US, Australia, UK, Holland, and the Middle East.

Although microelectronics is not a large direct employer of people, Austek has the potential to contribute significantly to the Australian economy. Ninety percent of revenue is projected to come from overseas, with a target revenue of $50 million within five years. Moreover, the ready availability of Austek VLSI technology to local industry will provide an important impetus to the wider adoption of microelectronics, with its consequent productivity and efficiency benefits.

Austek's establishment at Technology Park Adelaide is a significant development both as a demonstration of Australian technological achievement and as evidence of Adelaide's claim to be Australia's high-tech capital. ▲



CSIRO's first VLSI chip. It contains 102,000 transistors and was designed for recognizing the human voice. However, the chip is not intended for commercial use, but rather to demonstrate the VLSI design technology
Innovation House, Technology Park, Adelaide, South Australia

SOUTH AUSTRALIA:

Determined High-Technology Development

South Australia and the capital city of Adelaide have had a head start in the battle to attract high-technology companies; its vast empty interior attracted the UK and Australian Governments to set up a rocket range and nuclear bomb testing site there in the late 1940s and early 1950s. These moves into advanced technology occurred at about the same time the State was expanding its manufacturing base. From this defense-related activity sprang a diverse range of high-technology enterprises, which the state is determined to capitalize on.

About a 20-minute drive from the center of Adelaide lies the largest electronics research establishment in the Southern Hemisphere. The Defence Research Centre, Salisbury (known as DRCS), forms part of the Australian Government's Department of Defence. DRCS employs 2700 people in three major research laboratories: electronics, weapon systems and advanced engineering, working on indigenous defense equipment development and modification and evaluation of overseas equipment. This center has advanced skills over a wide range of high-technology areas such as optics, infrared, radar, aeroballistics, fluid dynamics, propulsion, guidance and control systems, electronic warfare, underwater detection, communications, precision mechanisms and many others.

DRCS involves industry in projects at an early stage. As a result, a number of private companies have developed around the organization. Some of these companies are almost completely devoted to defense work whereas others are also involved in commercially oriented high-technology work. Major companies such as Thorn-EMI Electronics, British Aerospace Australia, and Fairey Australasia provide equipment to US and European defense contractors. This has given South Australia more of a 'tech' flavor to its industry, concentrated in innovative R and D and complex systems development and manufacture, than any other state in Australia.

The South Australian Government is keen to exploit and build on the advanced level of existing high-technology expertise. The areas of expertise are considerable, but they cover in the main defense-related technologies, electronics and optoelectronics, biotechnology, mining-related technology, agriculture-related technology and remote sensing. In addition to highly capable, indigenous high-technology companies, South Australia boasts such international names as British Aerospace, Philips, Telex, Texas Instruments, Andrew Antennas.

In the area of biotechnology, South Australia has extensive expertise particularly through the University of Adelaide with its National Centre for Gene Technology and the internationally known Waite Agricultural Research Institute, Flinders University, Roseworthy Agricultural College, the South Australian Institute of Technology and various CSIRO divisions based in Adelaide. The majority of grants recently made under the Federal Government's new national biotechnology program have been awarded to Adelaide-based researchers reinforcing Adelaide's position at the international forefront of biotechnology research.

The State Government has established Australia's only industrial/office park complex designed to meet the needs of high-technology manufacturers and organizations involved in research and development, and established the Technology Park Adelaide Corporation to promote the development of high-technology. Set in a landscaped area near DRCS and next to the main campus of the South Australian Institute of Technology, Technology Park Adelaide is ideally suited to meet the needs of technology-intensive companies.

The size of Adelaide and its excellent infrastructure is conducive to a flow of high-tech start-up ventures, a number of which have already established at Technology Park Adelaide. One of the most exciting areas under development at the Park is the area of very-large-scale integrated circuit design. The establishment recently of Austek Microsystems, a group specializing in custom VLSI design, has drawn attention to the depth of state-of-the-art microelectronics expertise in academic and commercial organizations in Adelaide.

Adelaide is also the base of the Australian Mineral Development Laboratories (AMDEL). Similar to the US Colorado School of Mines, AMDEL is Australia's largest mining-related contract research and technical consulting organization and a successful exporter of sophisticated instrumentation for the mining industry.

Aside from the support available from the well-established tertiary institutions, Technology Park Adelaide is also likely to benefit from the existing manufacturing structure in the State. Heavy involvement in automobile and whitegoods manufacturing has developed skills in areas that include molding and extrusion of plastics, toolmaking, presswork and aluminium casting, electroplating and sheet metal working capabilities.

Although labor costs in the State and elsewhere in Australia are similar to those in other advanced Western countries including the US, South Australia has a marginally lower cost structure and a significantly lower rate of industrial disputes. This brings the overall labor rates in the State well below those in the other Australian states.

Housing costs are also generally lower than in other parts of Australia and considerably lower than, for example, those in the Santa Clara Valley region of California.

Adelaide was once described by The New Yorker magazine as "possibly the last well-planned, well-governed and moderately contented metropolis on earth." It certainly has less of the bustle of Sydney or Melbourne, more sophistication than Brisbane and perhaps a touch less brashness than Perth. Its excellent cultural facilities and biennial Arts Festival give Adelaide an international flavor usually found only in larger less liveable cities. ▲

Innovation House, Technology Park, Adelaide, South Australia

(continued from page A32)

of this century.

At the time, no one either in Australia or overseas was interested in developing the instrument, but it was finally taken up by a small Melbourne company, Techtron Appliances. This was taken over by Varian Associates in 1967, and now Varian Techtron in Melbourne is the world's second-largest maker of spectrophotometers and a major producer of UV-visible spectrophotometers. Sales exceed $25 million a year, and nine out of 10 instruments are exported to Europe and the U.S.

Atomic absorption spectrophotometers can now detect 66 different elements, and a single apparatus can make up to 1,700 analyses of different samples a day.

Another major Australian achievement, also in the 1950's, was the invention of the flame ionization detector, which made the then-new technique of gas chromatography 10,000 times more sensitive virtually overnight. It was invented by Mr. Ian McWilliam of ICI Australia's Melbourne laboratories, who realized that the components of a sample mixture could be detected by conductivity measurements if they were ionized as they left the column. The development has made an enormous contribution to environmental protection around the world, and every day thousands of laboratories use the device to measure impurities in the air, water, drugs, food and chemicals.

Victoria is now at the heart of scientific instrument manufacture in Australia and has a number of firms such as GBC Scientific Equipment, Labtest Australia and R&D Instruments directly involved in spectrophotometer development.

Another Melbourne company also involved in the field is Scientific Glass Engineering, which has developed a number of microsyringes for gas chromatography and has chalked up a world first by using glass-lined stainless steel tubing.

Another company, Selbys Scientific, is producing novel optical fiber nephelometers for taking high turbidity measurements, such as the concentration of metallic wear particles in engine oil; another, Silenus, has developed a highly sensitive clinical viscometer, which uses an innovative magnetic stabilizing system.

Australia also excels in astronomical instrumentation, as shown by its involvement in the design and development of the Starlab instrument package (the joint project to launch a space telescope aboard the shuttle in 1990), the design of the Parkes telescope and the new Australian Telescope.

Another example of this expertise was the construction in the 1960's of a unique solar radioheliograph (the only one of its kind in the world) at CSIRO's Culgoora Observatory in New South Wales. It consisted of 96 aerials set around a 10-kilometer circle, which performed as one huge dish 3 kilometers wide and photographed the sun once a second, providing a continuous record of the rapid outbursts of solar radiation. This could be played back as a fast-motion movie film. Unfortunately, CSIRO had to close the observatory due to budget funding cuts.

CSIRO's Sirotem, a computerized direct digital borehole logging system and data processing center, can detect ore bodies covered by thick layers of conductive material

Mining and Mineral Processing

Australian-developed mining equipment and mineral processing techniques are now in use throughout the world, from the remotest parts of Africa to the heart of the U.S.. Many of the developments have revolutionized resource exploration and extraction methods, allowing much greater quantities of ore to be extracted, cutting costs, improving safety and increasing the economics of many projects.

One of the first innovations to have widespread impact around the world was the development of the flotation process for the separation of minerals, first patented in 1901 by a Melbourne brewer and chemist, Charles Potter. It was soon in use at Broken Hill, and by 1912 a selective flotation process for the separation of lead from zinc had been developed. It was further refined and is now the most widely used method in the world for mineral extraction and is used for the concentration of practically every mineral mined.

Since 1959 much of the work has been supported by the Australian Mineral Industries Research Association (AMIRA), which has a membership of 70 resource companies. AMIRA initiates and coordinates jointly sponsored R&D, which it contracts out to groups such as CSIRO.

One major advance of the 1960's was the development of a new system of on-stream analysis for measuring the different grades of ore in the raw mined material as it passed through the processing plant. The Australian Atomic Energy Commission pioneered the work, developing radioisotope X-ray and gamma-ray probes, first to determine the lead content in process streams and later to pinpoint a range of metals, including zinc, tin, copper, nickel and iron. The technique was later taken up by AMIRA in conjunction with the Australian Mineral Development Laboratory and the electronics group Philips, and a range of radioisotope immersion probes were developed to measure the levels of various metals in slurries.

Automatic computerized process control of mineral extraction now in use throughout the world has also been pioneered in Australia by MIM Holdings at its Mount Isa mine. Crushing, grinding and flotation of ores is computer controlled, which greatly improves the efficiency of processing, increases the level of metals recovered from the ore and allows the grade of mineral concentrate produced to be predicted.

One of CSIRO's successful inventions has been Sirotem—a computerized direct digital borehole logging system and data processing center, which can detect ore bodies covered by thick layers of conductive material.

The portable system was developed in the early 1970's by CSIRO's Division of Mineral Physics and is now in use in many parts of the world, including

Scandinavia, Canada and China.

Another successful CSIRO development, QEM SEM (quantitative evaluation of minerals by scanning electron microscopy), is a fast, comprehensive mineral analysis system that can scan an ore sample and identify the number of minerals present, their types, quantities and position.

Others include Sirosmelt, a direct lead smelting technique, which cuts energy costs and increases metal recovery; Siroash, a gauge for on-line determination of ash in coal; Sirolog, a series of nuclear probes for accurately determining the grade of ores and the way minerals are arranged in rock, and Stratosnoop, for measuring the thickness of mudstone or shale in underground coal mines.

Australia is at the forefront of world soil and rock mechanics research and development, particularly in the design of open-cut mines. Techniques for the mining of very large openings, digital monitoring systems to detect slippage in high-wall or spoil heaps, new methods of underground mining and explosive technology and innovative ways of dealing with spoil heaps, tailing dams and general reclamation of mined land have been developed.

Research is under way in a number of other areas such as slurry pipelining of coal, new gold recovery techniques, the use of remote sensing for mineral exploration, coal hydrogenation and pyrolysis, new hydrometallurgical and electrometallurgical processing techniques, coal outbursts and drainage, improved control of sintering, the stability of underground and open-cut metal and coal mines and the use of aquatic plants to purify mining wastes.

Conclusion

Australia, as it enters 1985, is at a crossroads, faced with far-reaching decisions on its economic and technological future. Should it continue as a resource-based economy dependent on income generated by its mineral and rural exports or should it take a new course and establish a skill-based economy founded on new high-growth, high-technology enterprises?

Opinion is mixed and debate widespread on whether the federal government should back the establishment of new "sunrise" industries or continue with its high protection policies for the declining traditional manufacturing sector.

Mr. Barry Jones, minister for science and technology, is leading a strong push into the new technology field arguing that unless Australia moves rapidly to adopt new technology and set up new industries its economic base will contract, its skill levels deteriorate and its standard of living will further decline.

He maintains that Australia has already entered a postindustrial society and that it must reject all hopes of what he describes as "nostalgia-led or obsolescence-led recovery" based on traditional manufacturing.

He says that Australia has already undergone a paradigm shift in its economic base and is experiencing much more than an industrial decline that can be fixed with temporary support. A new type of society based on a different economic base—knowledge and skills rather than raw materials and muscle power—must be developed.

He believes Australia must rapidly establish new high-technology industries as wealth generators to compensate for the decline in employment in the sunset of smoke stack industries.

But this view is not shared by all and many of the more conservative elements of industry, business, the financial community and government argue that Australia should continue to concentrate on more traditional areas, such as mining and agriculture, and to prop up its declining manufacturing sector with more protective tariffs. Their only concession is that perhaps new technology should be introduced to some of these industries.

They argue strongly against giving extra support to the new emerging industries, believing that this should be left to market forces.

But, under the strong influence of Mr. Jones, government opinion is shifting more toward the support of new technology, as seen by the recent decision to introduce a new tax-incentives scheme to boost a venture-capital market in Australia and moves to direct more money into high technology.

But government, business and community attitudes have a long way to go before they become aligned with those of Mr. Jones.

Management is still reluctant to invest in research and development or in new technology, financiers are wary of taking risks and backing new enterprises and unions are opposed in many cases to the introduction of new technology. However, attitudes are changing and unions are becoming more willing to negotiate with employers on the introduction of new technology, recognizing that it represents a choice between adopting new practices and company closure. Management and financiers are also slowly sensing the possibilities.

Australia also has other major problems to overcome in developing a technology-based economy, in particular its small domestic market, its distance from export markets and the predominance of foreign-owned companies in Australia.

The latter has led to increasing dependence by Australia on overseas technology as well as to the low level of private-sector industrial research and development, with multinationals preferring to carry out their research in their home countries.

This lack of technological sovereignty is a major concern of the government, as is the loss of much Australian-developed technology overseas due to the reluctance of Australian industry to take the risk to develop it locally. Another concern is the need to adapt Australia's educational structure to a skills-based economy, with more leisure, less people employed and a large sector of the work force concentrated in service and information industries.

Mr. Jones believes there will have to be radical changes in attitudes to the work ethic and total redefinition of work and the ways it is organized.

He admits that new technology will reduce employment but believes that Australia should start looking at alternatives such as early retirement, recurrent education, a diversity of lifestyles based on individual autonomy, a guaranteed income scheme and a redefinition of work to include domestic work and hobby activities.

He sees the first step as the "shock of recognition" that technological change is under way, that Australia is entering a new economic era and that new ideas and attitudes must be adopted. How successful Mr. Jones and the new government will be in moves to transform Australia from a resource to skill-based economy is still debatable—but it is sure that the next few years will be among the most interesting for science and technology in Australia since the early pioneering days.

As Prime Minister Hawke said at the national technology conference, "We have in this country the intellectual wherewithal to adopt a new attitude that allows us to make better use of new technology for our national purposes.

"We have good schools and universities, stable government and the obvious potential to build a great future, based on the development and appreciation of innovative industrial structures.

"Some will say to this that Australia is not yet ready, that the cost of adjustment is unacceptably high, that protection must be provided against the growing power of overseas competition. To them I simply say 'I hear you, but cannot agree.' " ▲

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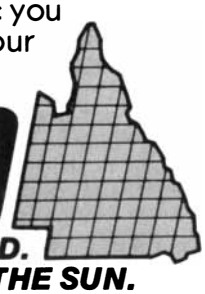

The Director *Department of Commercial & Industrial Development MIM Building, 160 Ann Street Brisbane, Q, 4000, Australia Phone (07) 227 8176*

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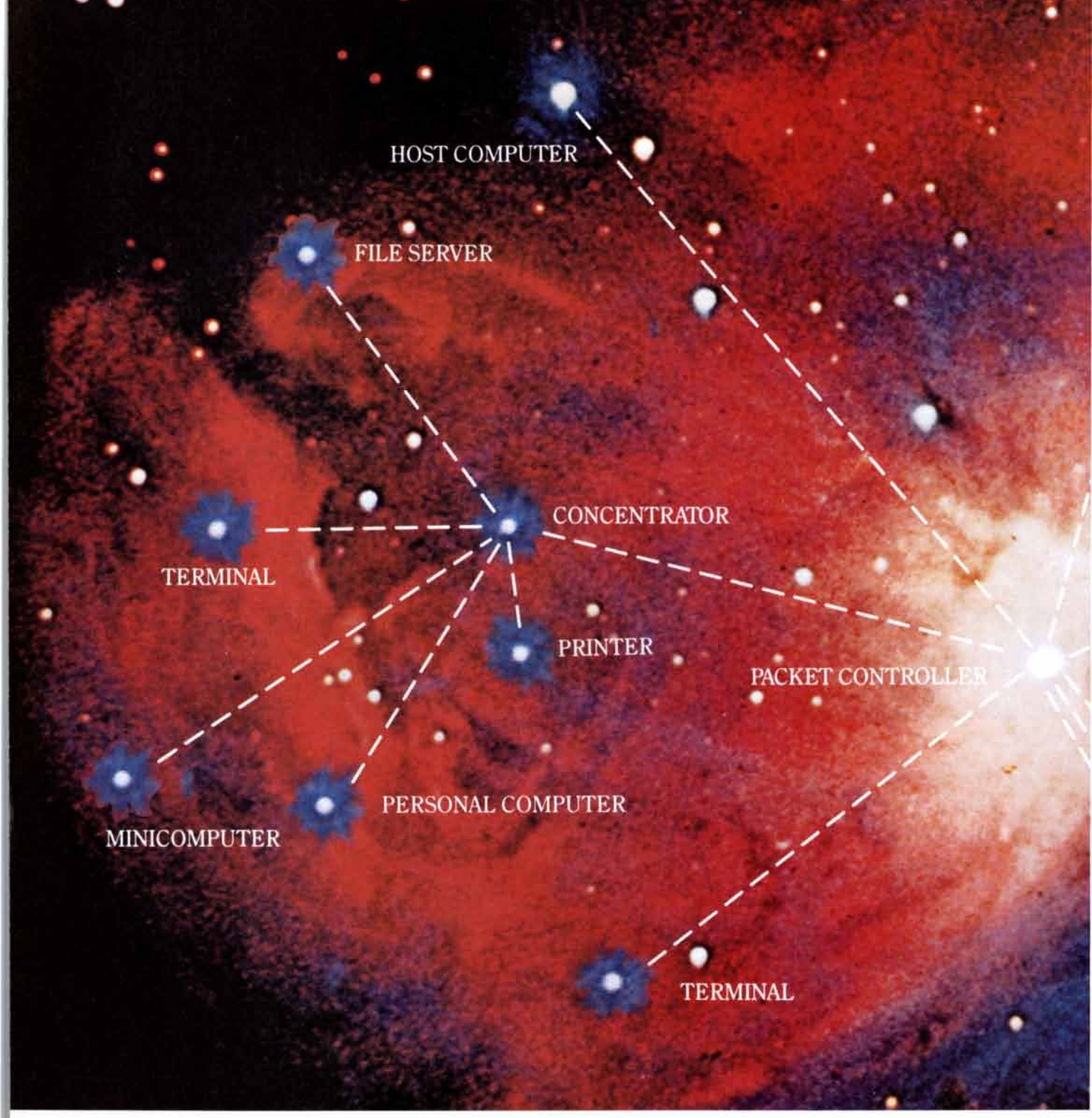

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The Digital Reproduction of Sound

By recording sound as a series of discrete numbers superior reproduction can be gained; so can a dramatic enhancement of recordings of performances made with other technologies

by John Monforte

It is now possible to hear Enrico Caruso in a recording that is far superior to any made during his lifetime. The reason is that the old wax-cylinder records have been digitized: the musical tones were reproduced as a series of discrete numbers rather than as the analogue, or continuously varying, waveform of earlier recordings. The digitized signal was processed by a computer to remove the artifacts of the recording horn. In other words, the sound of Caruso's voice has been enhanced. Although the venture was an experiment and the process needs improvement, a contemporary listener can clearly hear the greatness of this tenor voice.

Digitization may someday serve to enhance the recordings of other great artists of the past, but its main function is to make superior recordings of contemporary musical performance.

The digital process is an entirely new way of storing, processing and even generating audio signals. The phonograph is the first component of audio systems to benefit from this procedure, but in time every component of the chain from recording to reproduction will be replaced by a counterpart that handles sound as digital data. Digital processing can also be employed to compose and render music using sounds that have no conventional instrumental counterpart.

A typical digital recording might come to the consumer in the form of an aluminized disc 120 millimeters ($4\frac{3}{4}$ inches) wide. The digitized sound is preserved as a series of microscopic pits and smooth areas. The playback device, replacing the pickup or stylus of older record players, is a laser beam. Amplifiers and speakers bring the sound to the listener.

Part of the reason for the superior sound of such a recording is that digitization overcomes many of the limitations of analogue recording. In an analogue recording the signal (music or some other sound) can be described as a continuous variation of amplitude over time. Depicted as a curve on a graph, the signal is a series of irregular waves. Each recording device passes such a waveform and acts on it in a way defined by the device's transfer function (a mathematical description of how the device reproduces sound, including the characteristic noises and distortions the device imparts to the signal passing through it). Ultimately the device emits an electrical acoustic output waveform that is a replica of the input waveform.

The transfer function is applied to such devices as an amplifier, which merely increases the signal in amplitude, or a transducer, which changes a signal from one form of energy to another (as a loudspeaker changes electrical energy to acoustical energy). The transfer function is designed to be as linear as possible, that is, to follow as exactly as possible the waveform representing the original sound. Any deviations from linearity impress distortion on the waveform. All analogue systems exhibit some degree of nonlinearity.

The Problem of Noise

Noise is also a pervasive problem in an analogue system. When a signal is transformed by a transducer such as a microphone, the output level is very close to the level of the thermal noise caused by random vibrations of the electrons in the transducer. This unfortunate result proceeds from the fact that the efficiency of a transducer is about 1 percent. When the signal is stored in a recording medium, the medium itself becomes a source of noise. The cause is the granular nature of the medium. Granularity arises from such factors as the size of the magnetic domains in a recording tape or roughness on the surface of a record. This noise puts a lower limit on the resolving power of the storage medium.

Every component of an audio system also has an upper limit. The signal can increase in size only as long as the system is not overloaded. This limitation is universal, whether it is found in an amplifier that can deliver no more power, a loudspeaker whose sound-producing element can move no farther or a record groove that cuts over to an adjacent groove. A yardstick of fidelity (but not the only one) is the difference between the largest signal possible and the noise floor. The difference is called dynamic range and is measured in decibels.

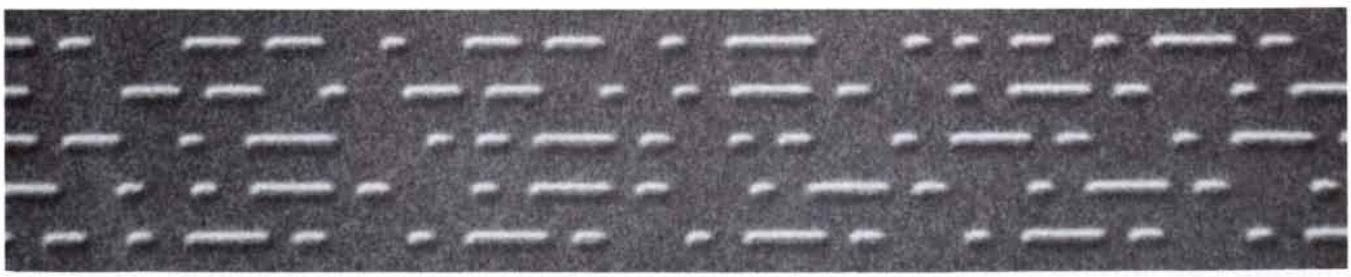
Another fundamental limitation present in all recording devices is in bandwidth. It can be described as a limit on how quickly the system can respond to the rapid changes in amplitude that are characteristic of sounds. Whether the cause is mechanical inertia, electrical factors or a variety of other sources, a limitation will be imposed defining the highest passable frequency.

All sound challenges the bandwidth (or frequency range) of an audio system severely. A sound consists of one frequency (the fundamental) that enables the hearer to perceive the pitch and of a variety of higher-frequency components (the overtones). Overtones determine the timbre of the sound. All these elements exist simultaneously. In the least dissonant musical tones the overtones are arranged in a series of frequencies that are (or are almost) even multiples of the fundamental. For an audio system to be useful it is preferable to make it capable of responding to the full range of frequencies the human ear can hear, namely a bandwidth of about 20,000 hertz.

The process of digitization was developed at the Bell Telephone Laboratories in the 1920's with the aim of overcoming the limitations of analogue recording. Such technological advances as computer processing and versatile microchips, however, have only recently made it possible to develop the technique to the point where digital systems are actually superior to analogue systems and are competitive in cost. The trend has surely not run its course.

In a digital audio system the waveform is reduced to a series of numbers that describe the shape of the waveform. The numbers are then handled by a computer, which may store them for retrieval later or may process them by

DIGITAL REPRODUCTION for the consumer usually takes the form of a Compact Disc, 120 millimeters wide and 1.2 millimeters thick. The digital data are stored on it in the form of microscopic bumps and smooth areas, representing respectively the binary digits 1 and 0. A 1 is the beginning or end of a bump; a 0 is represented by an area in which there is no change. A laser beam serves as the equivalent of the pickup or stylus of a conventional record player. The Philips Corporation of The Netherlands in cooperation with the Sony Corporation of Japan developed the Compact Disc. The disc's 500-megabyte capacity constitutes the densest form of data storage.



BUMPS representing the stored data mark the surface of a Compact Disc. They are .16 micrometer high and .6 micrometer wide. The signal recorded in the section of a disc shown here is silence; consequently the pattern is quite repetitive, interrupted only by the digital words that serve to correct errors and frame data groups. The view in this micrograph is from the side of the disc read by the laser beam.

means of mathematical algorithms in order to modify for musical or sonic effect the waveforms they represent. The digital signals that represent the numbers may accumulate noise and distortion as they are stored or manipulated. As long as they are not lost and remain reasonably recognizable, however, they will serve to reconstruct the original waveform with little loss in quality.

The first step in digital recording is to digitize an audio signal. The device that does the task is called an analogue-to-digital converter. Since the waveform of an analogue signal is a two-dimensional function of amplitude v. time, one must develop a digital signal that describes both dimensions accurately.

First, the signal is sampled at regular intervals determined by a standardized sampling frequency; the data are thus collected at a predetermined rate. When the time comes to reconstruct the data as an analogue signal, the information must be delivered at exactly the same rate in order to avoid changes in speed or pitch.

The voltage that represents the amplitude of the signal at the moment of conversion is then stored in an analogue manner long enough to be measured and assigned a number that represents the voltage value. This step is called quantization. Each sample generates a new number, thereby forming a stream of data that can be handled by any digital system.

In order to reconstruct the signal the data are presented to a digital-to-analogue converter at the sampling rate. The converter develops a voltage that represents the data value and holds the voltage until a new data word is received. The resulting signal is a replica of the original waveform.

Sources of Error

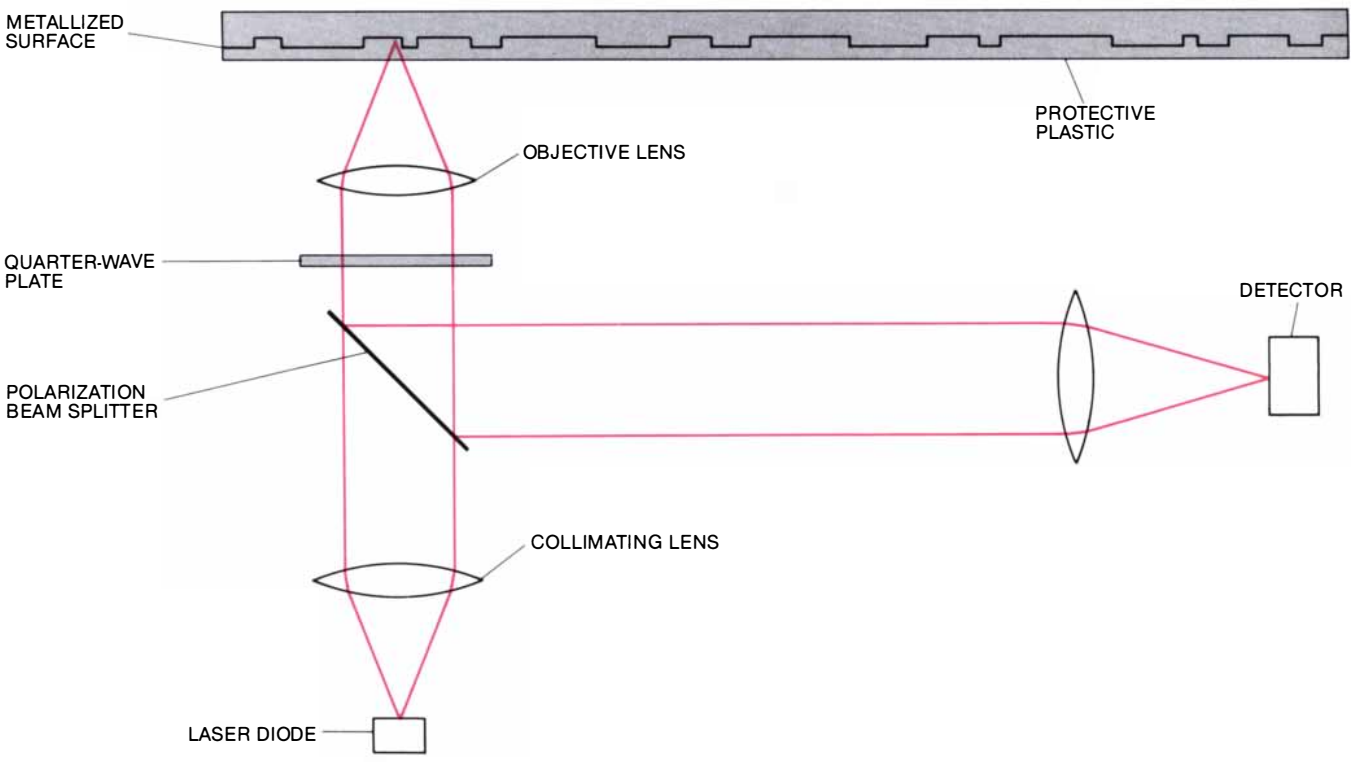
There are two ways the signal can be distorted by inadequate sampling, one way relating to the frequency of sampling and the other one to quantization. Each problem can be resolved by more thorough sampling, but the cost is a greater capability for handling data. Even so, there is no way to avoid these distortions completely, because the analogue waveform is a continuous function in both amplitude and time and any digital representation must be discrete. Once the signal has been digitized, however, it can be transmitted or copied indefinitely without accumulating any more distortion or noise than was present at the time of digitization.

The first way a signal can be distorted is through infrequent sampling. If the sampling is not done often enough, the amplitude of the signal may change by an amount greater than one quantum during the sampling interval. (A quantum is the smallest step size used in describing the signal.) In effect the signal is changing too fast for the system to record it accurately. When the signal is reconstructed, this change is omitted and information has been lost.

Such rapid changes of amplitude are caused by components of the sound that are at a frequency higher than half the sampling frequency. The presence of these components causes the reconstructed signal to appear to contain a frequency component that is the sampling frequency minus the original frequency. This phenomenon is called aliasing or foldover. The undersampled components of the signal are reproduced as totally new and inharmonically related components.

The sound resulting from aliasing is nonmusical. Indeed, it is quite bizarre. To avoid this result one must sample often enough to include all the important overtones of the signal. It is also essential to put a filter ahead of the sampler to forcibly limit the bandwidth and eliminate all unwanted components. The filtering must be done in the analogue domain, before any digitization takes place.

Finally, the signal must be filtered af-



LASER PICKUP MECHANISM converts the pattern of recording on a disc into changes in the intensity of a collimated, monochromatic beam of light. A laser diode generates the beam, which passes through a collimating lens that corrects the beam's tendency to diverge. A polarized beam splitter divides the concentrated beam, sending part of it to a detector (*right*); the rest of the beam passes through another filter that rotates the axis of polarization by 90 degrees. An objective lens focuses the beam on the disc surface. The bumps on the disc, which are complementary to the pits made in the mastering process, are comparable in size to the wavelength of the incident light. (Here the bumps have been exaggerated for clarity.) Therefore they scatter the light, preventing it from returning to the detector. The detector senses this decline in beam intensity. Variations in intensity are read by the system as a string of binary digits, or 1's and 0's.

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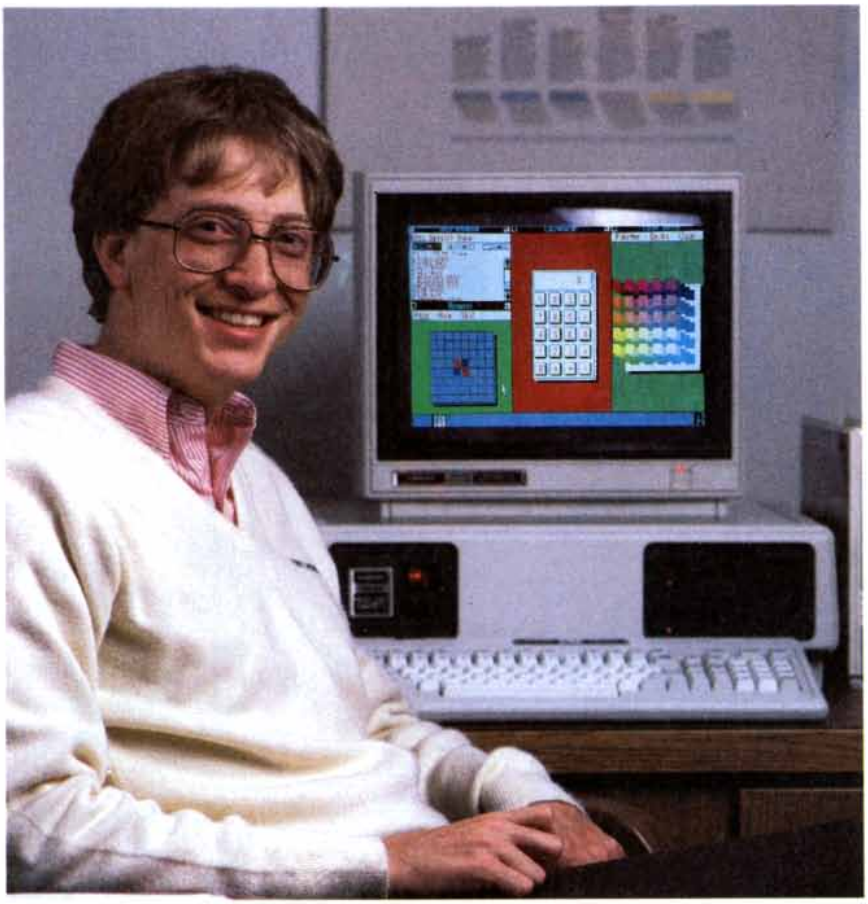

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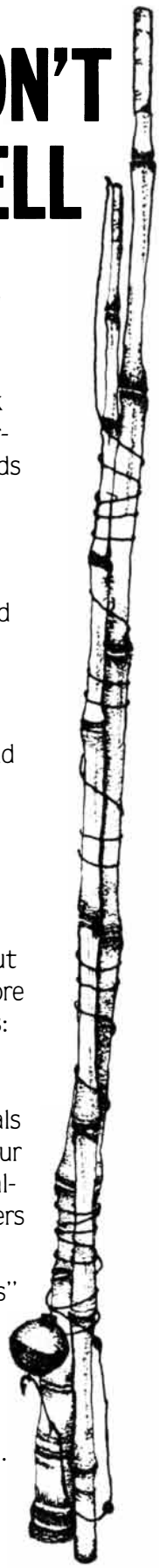

There was a time when with a little luck and a little patience, you could pull a fair-sized fish out of Twitchell Creek on Woods Lake in the Adirondacks.

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ter it has been reconstructed. The reason is that the replicated signal has a stair-step characteristic caused by the discrete sampling process. These sharp edges represent high-frequency components that were not in the original signal.

Quantizing Error

The second form of distortion is referred to as the quantizing error. It arises when the digital word is not large enough to describe the amplitude in sufficient detail. When the amplitude level is between two adjacent quanta, the digitizer is forced to choose between them, causing an error.

Over the long term these errors are random. The sound is similar to noise except that it occurs only in the presence of a signal. What one hears is a buzzing that seems related to the signal. The solution is to mix analogue noise of a certain amplitude with the input signal to mask the quantization noise. After this has been done the noise sounds random and the perceived distortion is substantially reduced.

Once the amplitude of the signal at a given instant is represented by a number, the value must be stored. Since the data are handled by a digital computer, a binary word is formed. The commonest format is named linear pulse-code modulation, an idea developed by A. H. Reeves of Bell Laboratories in 1939.

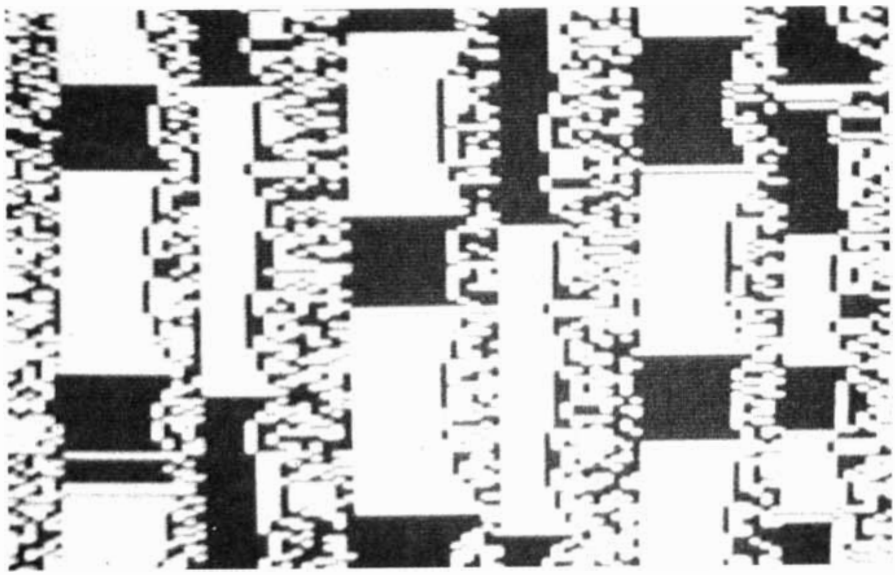
The number is typically represented as a 16-bit word. Each step size (the quantum) is equal in magnitude to the others. The value that is half of the full value (1000000000000000) represents the "no-signal condition," silence. The number increases toward all 1's as the wave goes in one direction (positive) from rest and toward all 0's as it goes in the other direction (negative). The 16-bit linear system is embodied in most digital discs sold through retail stores. It is capable of a dynamic range of 96 decibels, exceeding the capability of analogue recorders by about 20 decibels and phonograph records by about 30.

Although linear pulse-code modulation is the commonest conversion method, it is by no means the optimum one for all applications. Other methods of conversion are available. One of them, which reduces the quantity of information needed to represent the signal, is to store only the difference between a given sample and the preceding one. The technique is called delta (for difference) modulation.

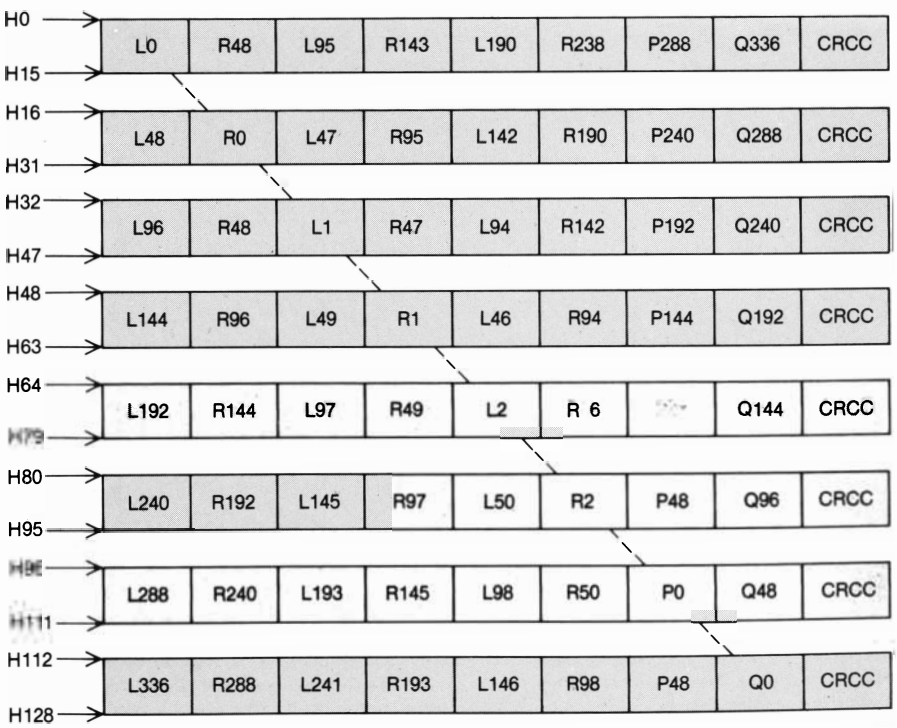
Delta modulation assumes that the signal being sampled is for the most part a continuous one and that large changes occur over a longer period of time. This assumption is particularly valid for music because the amplitudes of the overtones of musical instruments tend to be smaller than the amplitude of the fundamental.

One can encounter debate over which method of encoding yields the most realistic sounds. The linear method is the simplest. As long as the signal is sampled often enough and is represented by a substantial number of bits, a very high degree of fidelity can be achieved.

On the other hand, the linear method is not necessarily the most efficient way to use storage space. The brain tends to ignore sensory signals that persist for a long time and to be more concerned with changes. (You are aware when you put your shoes on or take them off but tend not to notice them during the day.) Hence it can be argued that delta modulation makes the most efficient use of storage. The space saved by storing smaller words can be filled by more frequent sampling, which in turn relaxes



DIGITAL STORAGE by means of videotape, an alternative to the disc, gives rise to a display such as this on a television screen. The black and white dots represent the binary digits.



STRUCTURE OF FRAME of digital data recorded on videotape consists of 245 horizontal lines resembling the 128 represented here. Each group of 16 lines contains three words of data from the left channel (*L*) of the tape, three from the right channel (*R*), two words associated with the form of error correction called parity checking (*P, Q*) and one word of code for the error-correcting technique called the cyclic redundancy check code (*CRCC*). Since videotape tends to lose entire horizontal lines at once, the data are interleaved (*diagonal line*). The scattered error-correction words can be employed to reconstruct any data that may be missing.

the requirement for filtering and reduces the chance of overloading caused by rapidly changing signals.

Storing the Data

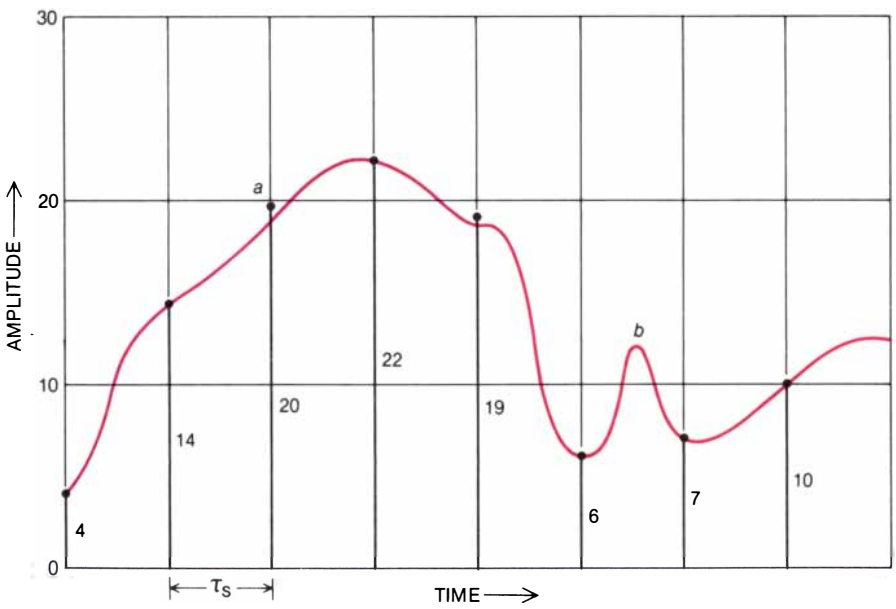
There are several ways to store data obtained from sampling. The simplest and most direct way is to put the information in the same storage systems a digital computer uses. The great volume of data, however, makes this type of storage impractical. A digital signal sampled at a rate of 40 kilohertz would fill more than 200 megabytes of storage in one minute. Moreover, the random-access capability of computer memory is not needed for music, which is inherently sequential.

The common method of sequential storage in digital computers is magnetic tape. Many audio recorders employ the technology (and sometimes the components) found in the magnetic-tape drives of digital computers. Audio recorders differ in that they are fed more than one stream of data at a time (from several converters) to be stored on adjacent tracks. In this way the engineer can record the individual musical parts at different times and combine them later.

Another common technique is to store digital data on videotape. A video recorder has a bandwidth that is necessarily large in order to accommodate the huge amount of information needed to describe the range of brightness in a video picture. In audio recording each bit is represented by a single pixel, or picture element, which is black or white depending on whether the bit is 0 or 1. The digital signal is converted into a standard video signal so that any normal video recorder can be used.

When it comes to the kind of mass dissemination entailed in making digital recordings available to retail buyers, magnetic tape is not an ideal medium. The reason is that each copy must be made from a master recording, transferring one moment of the recorded sound at a time. Efficiency of production requires a medium analogous to the phonograph record, where entire programs are stamped all at once in a metallurgical process.

The system now in use is called the Compact Disc or CD. It was developed by the Philips Corporation of The Netherlands in cooperation with the Sony Corporation of Japan. The disc is 120 millimeters in diameter and 1.2 millimeters thick. One side will store 74 minutes of programming. Digital data are stored originally as a series of pits or the absence of pits, representing respectively 1 and 0. A 1 is where a pit begins or ends and a 0 is where there is no change. The recorded surface is cast in plastic from a mold formed from a master recording. The pits therefore become bumps. The surface is aluminized to give it reflectivity (the playback device is a laser beam) and sealed in a layer of clear plastic.



DIGITIZING PROCESS begins when an analogue-to-digital converter receives an analogue waveform (*color*). The waveform consists of a voltage that varies continuously over time. The converter samples the waveform some 48,000 times per second, producing a sampling rate (τ_s). Each sample is represented by a dot. The amplitude of the sampled sounds is shown here in decimal numbers. Sources of inaccuracy include sample gradations that are too large (*a*). Here the true value is less than 20 but more than 19. The system, unable to resolve such fine differences, arbitrarily assigns the closest value; a reproduction will contain this "quantizing error." Another inaccuracy (*b*) can appear when the signal changes by more than one quantum (the smallest step size). Such a change will go undetected because the sampling rate is too low. Smaller quanta and more frequent sampling will reduce these errors, but at the cost of generating more data words and also larger ones, thus requiring the system to handle more data.

When the disc is played, the laser beam will strike either a smooth area or a bump. If it hits a smooth spot, it is reflected toward an optical sensing device. If it hits a bump, it is scattered. The sensor registers changing intensity as 1, unchanging intensity as 0. It is evident that the disc surface must remain flat enough and the optical system steady enough so that the distance between the laser's objective lens and the disc does not change. Otherwise the beam will lose focus and strike an area larger than a pit. Servo systems in the optical mechanism make small adjustments to keep the distance constant.

Correcting Errors

The density of storage in audio systems tends to be a great deal higher than that of conventional computers. Therefore highly sophisticated means of detecting errors and making corrections are required. Since each storage system has its own modes of failure, the type of error correction brought into play depends on the method of storage employed. Data stored by pulse-code modulation are particularly sensitive to random losses of bits. The vulnerability proceeds from the fact that the individual bits represent different orders of magnitude and consequently a distinctive unit of information. The higher the order represented by a damaged bit is, the more the resultant output is corrupted. What one hears in such a case is a rather explosive sound.

All error correction is done through the formation of new words that are included with the original data words. Hence the new words are susceptible to the same sources of error as the original ones are. The propagation of errors cannot be completely eliminated. A method of error correction is required that leaves a reasonably small probability that an error will persist.

In order for the data to be checked for errors the recorded information must be stored temporarily in a dynamic memory buffer. The buffer must be large enough to store both the data word and the words put in for checking errors. In addition the algorithms utilized to find errors and fix them must be carried out fast enough so that the corrected data will leave the buffer at a speed acceptable by the recording system.

Most of the error-correction systems contain some combination of a few basic strategies. The simplest one relies on brute force: each word is repeated once. There are some obvious drawbacks. The amount of space needed for storage is doubled. Moreover, it is not possible to decide which of the two words is correct without making some assumptions.

One assumption may be that an imperfection in the recording medium will take out a chunk of data at a time, with

the result that the errors will be concentrated in a specific area. The phenomenon, called burst error, is commonly caused by imperfections in the medium. If the words and their duplicates are scattered around as they are recorded (the practice is called interleaving), an examination of errors may show that one word of each corrupted pair tends to be a neighbor of other similarly damaged words. In order for redundancy to be an effective technique the check words must be widely scattered and several questionable pairs must be examined to determine the correct values. Such a technique requires a large buffer and a fairly complex algorithm.

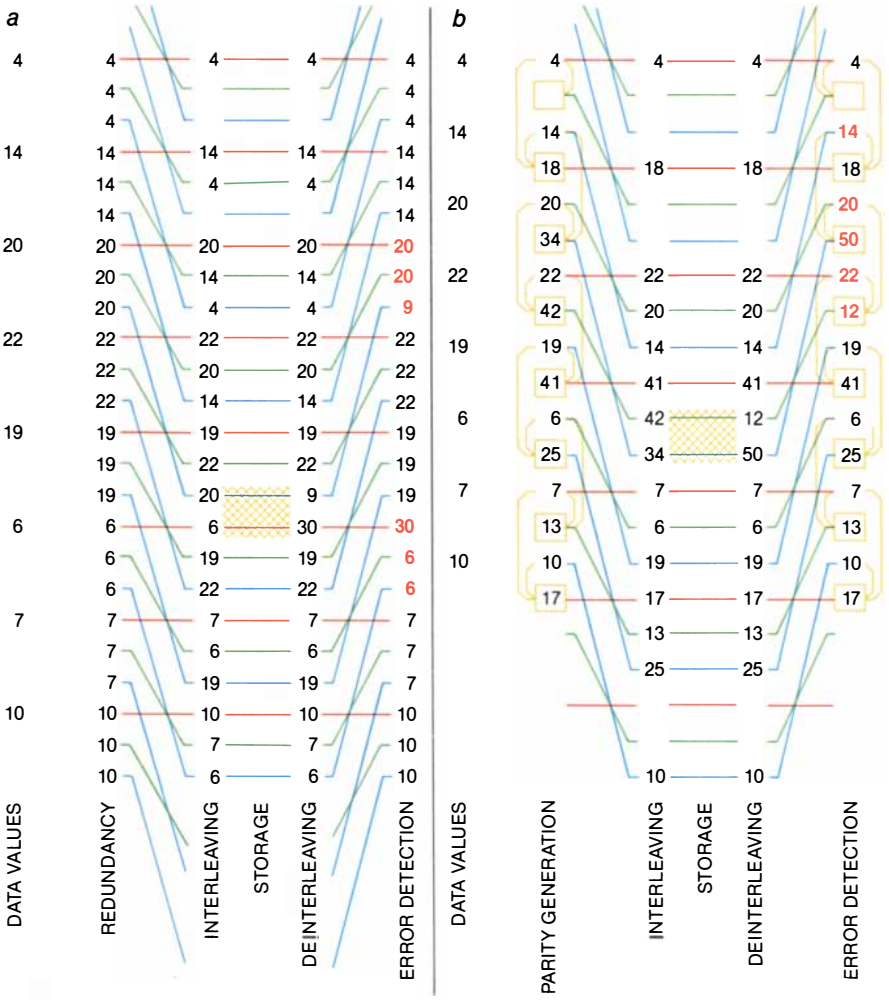
Many more elegant techniques are available. One popular method entails the generation of cyclic redundancy check words. (The technique is known in the recording business as CRC.) Such a word can be formed by summing two data words to generate a new word one bit larger than the originals. Every data word is used twice to form a check word, each time with a different companion. If two of the three words are undamaged, the third word can be calculated. Even if all three words are damaged, it is still possible to decipher the correct values from the other sums formed. Unfortunately the number of necessary calculations is increased, and there may not be enough time to do them.

Another method is parity checking. This is a common method of correcting errors in the computer industry. Two words are added one bit at a time without performing a carry operation when one would normally be called for. The result is a new word that has the same number of bits as the parent words have. If any one of the three words is found to be erroneous, the remaining two will serve to calculate the third. The results can be obtained in one machine cycle, making the parity check a highly useful tool.

There are many possible combinations of these techniques and related ones. All of them entail compromises between the amount of storage space needed, the probability that an error will go undetected and the speed with which errors can be corrected. In order to ensure compatibility a standard method must be developed for a given storage medium.

Since each type of medium has unique error modes, a different method can be selected for each format. The method employed for the Compact Disc is capable of correcting burst errors that are as large as 14,000 bits. The errors caused by drilling a two-millimeter hole in the disc can be successfully corrected to yield a perfect output. Fewer than .005 percent of the erroneous words have a chance of getting through undetected.

In order to make error-free copies the stream of data must be decoded, cor-



CONTROL OF ERROR can be achieved in various ways. Two methods are applied here to the data obtained in the sample shown in the illustration on the opposite page. One is redundancy (*a*). This method requires that the data words, which are in the column at the left, be made redundant (*second column*) through repetition. Since the storage medium tends to lose data in bursts, it is not wise to store the redundant words next to the original data. The data are therefore interleaved according to a predetermined pattern, shown by the colored lines. Interleaving is done before storage (*third column*). The fact that errors have been introduced (*hatched area*), so that 20 is read as 9 and 6 as 30, becomes apparent on deinterleaving (*fourth column*), as is shown by the numbers in color (*fifth column*). In the second method (*b*) the same data values are given cyclic redundancy check words. Here the words, which are enclosed in rectangles, are generated by summing each pair of data words. Errors are detected on retrieval when the sums do not match. In the examples here 14 + 20 appears as 50 and 20 + 22 as 12. Because each data word contributes to two cyclic redundancy check words, it is possible to determine which values are incorrect and then to derive the proper values, thereby eliminating the errors.

BEFORE STORAGE:

	DATA WORD #1 19→	010011
+	DATA WORD #2 6→	+ 000110
	PARITY WORD	010101 = "21"

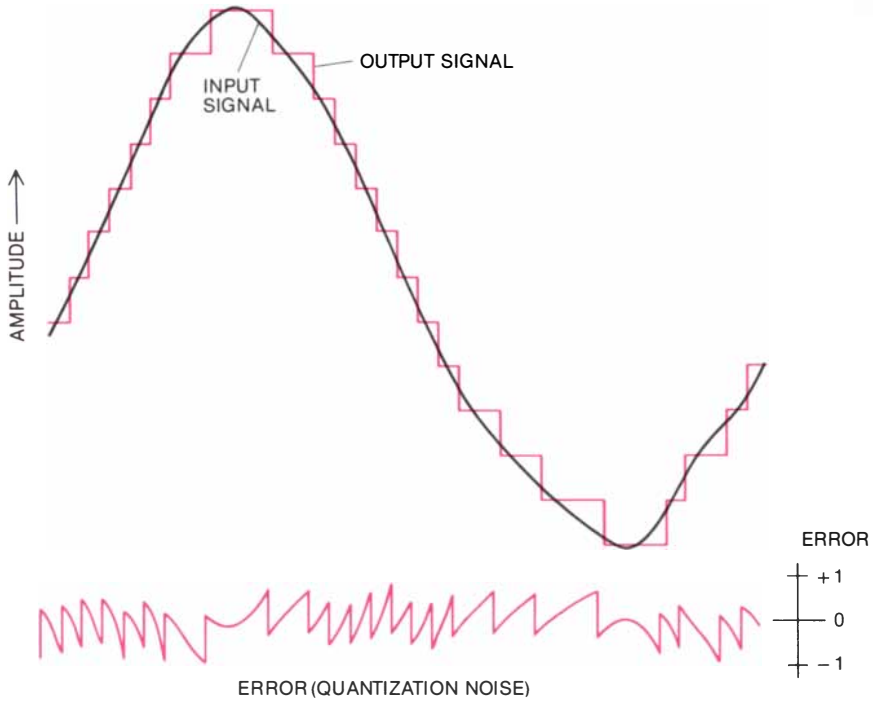
AFTER RETRIEVAL:

WORD #1 MISSING:		WORD #2 MISSING:		PARITY WORD MISSING:	
PARITY WORD	21→010101	PARITY WORD	010101	DATA WORD #1	010011
− DATA WORD #2	6→000110	− DATA WORD #1	010011	+ DATA WORD #2	000110
DATA WORD #1	010011	DATA WORD #2	000110	PARITY WORD	010101

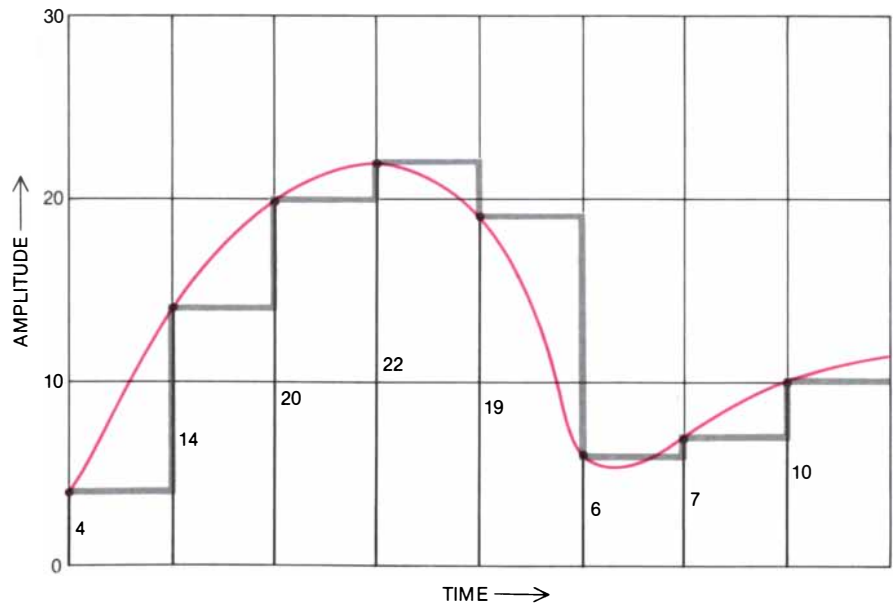
PARITY CHECKING provides another way of protecting against error. Here binary data words with values of 19 and 6 are added without the normal carrying step to yield a parity check word of 21. If after retrieval of the recorded data any of the three words contains an error or is missing, it can be refigured (*bottom*) as long as the remaining words are intact.

rected and then encoded to the copying format, even if it is identical with the original. As long as no errors slip through, the copy will sound identical with the original. Moreover, a worn master recording can be "refreshed" through copying. This process can be repeated as many times as wanted, and every generation will be indistinguishable from the first. In contrast, an analogue recorder accumulates noise and distortion with each generation.

Sometimes the original words and the check words have been so badly damaged that a detected error cannot be corrected. At this point one must resort to some form of error concealment. The easiest (but also the most drastic) method is simply to mute the output. Most systems do this when they encounter long periods of unintelligible data.



QUANTIZATION NOISE is the difference between the actual analogue (continuous) signal and its digital representation (*colored stepped curve*). The errors are never larger than one step size. The difference between the output signal and the original signal constitutes noise because its amplitude is small and its waveform is unlike the waveforms of the signals that caused it. Unlike noise in an analogue system, this form of noise is absent when the signal is absent. The result is a buzzing sound that occurs only in the presence of a recorded sound. The relation can be masked by adding "dither" (analogue noise of small amplitude), which cancels the buzz.



CORRECTED DATA STREAM is sent to a digital-to-analogue converter. There the analogue values represented by the numbers derived from the original sampling are generated at the proper time intervals (the original sampling rate) to deliver the continuous, steplike signal shown in gray. A filter removes the stair-step artifacts that result from the discrete nature of digital data. In this way the output signal (*color*) closely approximates the original waveform.

Repairing Errors

A preferable solution is to synthesize a new word to replace a lost one. Although the faking of material is unacceptable in the computer world, it is an ancient and widely employed practice among musicians coping with a lapse of memory. One approach is to repeat the preceding word. Since musical signals remain relatively constant from one moment to the next, this type of error concealment is regarded as acceptable.

A more sophisticated practice is to interpolate a value from the preceding word and the next word. The technique requires a brief algorithm to compute the average. Although the algorithm is not complex, it must do its job before the data word has to leave the buffer.

More complex means are available for correcting damaged data. One is autocorrelation, a method of image enhancement employed to remove noise from digitized pictures sent to the earth from space vehicles. Autocorrelation is a versatile mathematical tool that can separate a signal into two sets, one set containing the components with regularity or pattern (the signal) and another containing the random components (the noise). A digital computer can apply this algorithm or any other one to a digitized audio signal. Even if an algorithm is too large and complex to be done in conjunction with a musical performance as it is in progress, it may well serve to restore a badly damaged recording.

Opportunities for Composers

Mathematical algorithms can also be applied to modify undamaged data so that the signal can be processed for musical or sonic effect. The modification could take the form of a change in the bass or treble balance, the addition of reverberation or the mixing of two or more signals. It is also possible to speed up or slow down the signal without changing the pitch or to modify the pitch without changing the tempo. Indeed, it is possible to process signals in ways not yet imagined, opening up new creative opportunities for composers.

Composers will not be limited to new forms of signal processing. With digital techniques it is now possible to generate sounds employing the computer as a music synthesizer. The variety of musical sounds and special effects available to the composer employing software designed to generate music digitally is theoretically limitless.

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Prey Detection by the Sand Scorpion

This nocturnal hunter of the Mojave Desert does not see or hear the insects it feeds on. Instead it has receptors on its legs that are extraordinarily sensitive to subtle disturbances of the sand

by Philip H. Brownell

One evening several years ago Roger D. Farley of the University of California at Riverside and I were standing on a sand dune in the southern Mojave Desert, near Palm Springs, watching sand scorpions feed on insects. Occasionally a moth attracted to our lanterns would touch the sand near a scorpion; the scorpion would then quickly turn and run toward the moth, often capturing it. Gentle disturbances of the sand with a twig also triggered a vigorous attack, but a moth held squirming in the air a few centimeters from the scorpion did not attract its attention. Apparently it was not responding to visual or aural cues. Rather, it seemed to be sensing mechanical vibrations in the sand, deriving from them the information it needed to locate its prey.

At the time there were several reasons for believing the sand scorpion *Paruroctonus mesaensis* might have an unusual prey-detection mechanism. For one thing, it is a rather primitive arthropod (a phylum that includes insects, arachnids and crustaceans), and it lacks the sophisticated visual, auditory and olfactory senses that guide other predators to their prey. Furthermore, scorpions are nocturnal animals, emerging from their burrows only at night to feed and mate. Given their poor eyesight, it is thus unlikely that visual information could account for their effectiveness as night hunters. Finally, one of the most dramatic examples of the scorpion's hunting prowess is its ability to detect subsurface prey, which it exhumes with its large pincers, the pedipalps. Surely a scorpion could not see, hear or smell a buried insect.

And yet the notion that the scorpion might be locating its victims by sensing the vibrations they generate in the sand was a surprising one. Behavioral biologists had long assumed that animals may be alerted by substrate movements but are not able to determine the nature and location of the disturbance, any more than human beings can pinpoint the epicenter of an earthquake when they feel the ground shaking. This inability is in sharp contrast to the acute sensitivity of many animals to sound waves transmitted through air or water. In those mediums an animal locates the source of a signal by detecting and interpreting minute differences in the time or amplitude of stimulation of spatially separated sensors. In solids, however, mechanical disturbances travel much faster and their wavelengths are longer. As a result the differences in arrival time and amplitude at the different sensors of an individual animal are much more subtle—too subtle, biologists have believed, for detection by the animal's nervous system.

Sand seemed particularly unlikely to transmit usable information because it was thought to strongly attenuate mechanical motions. The success of the scorpion as a hunter was thus a puzzle, and so we decided to study the animal's behavior in detail, first by observing it in the field. To further resolve the mechanism of prey detection and to understand the properties of sand that make this mechanism feasible, it was then necessary to do experiments in the controlled environment of the laboratory.

The sand scorpion's habitat, the southern Mojave Desert, is one of the hottest and driest ecosystems in North America. On summer days the temperature at the surface of the dunes often exceeds 70 degrees Celsius, and the relative humidity is close to zero. The sand absorbs enough moisture, however, to support drought-resistant shrubs such as mesquite as well as several species of annual grasses. These plants stabilize the dune against the wind and provide water and food for an abundant variety of animals.

Most of the dune animals are nocturnal arthropods. During the day these arachnids and insects escape the desiccating conditions at the surface by "swimming," or burrowing, into the sand; at a depth of about 10 centimeters the temperature drops to a tolerable 40 degrees C., and the humidity rises above 90 percent. Gary A. Polis of Vanderbilt University has found that the sand scorpion is one of the commonest of the dune arthropods as well as one of the largest, growing to a length of eight centimeters and a weight of four grams over the course of its five-to-six-year lifetime. As such it occupies a terminal position in the food chain. As a rule a scorpion eats anything it can hold onto long enough to paralyze with the neurotoxic sting at the end of its tail. This includes a great diversity of insects, as well as smaller members of its own species, which form a major part of its diet.

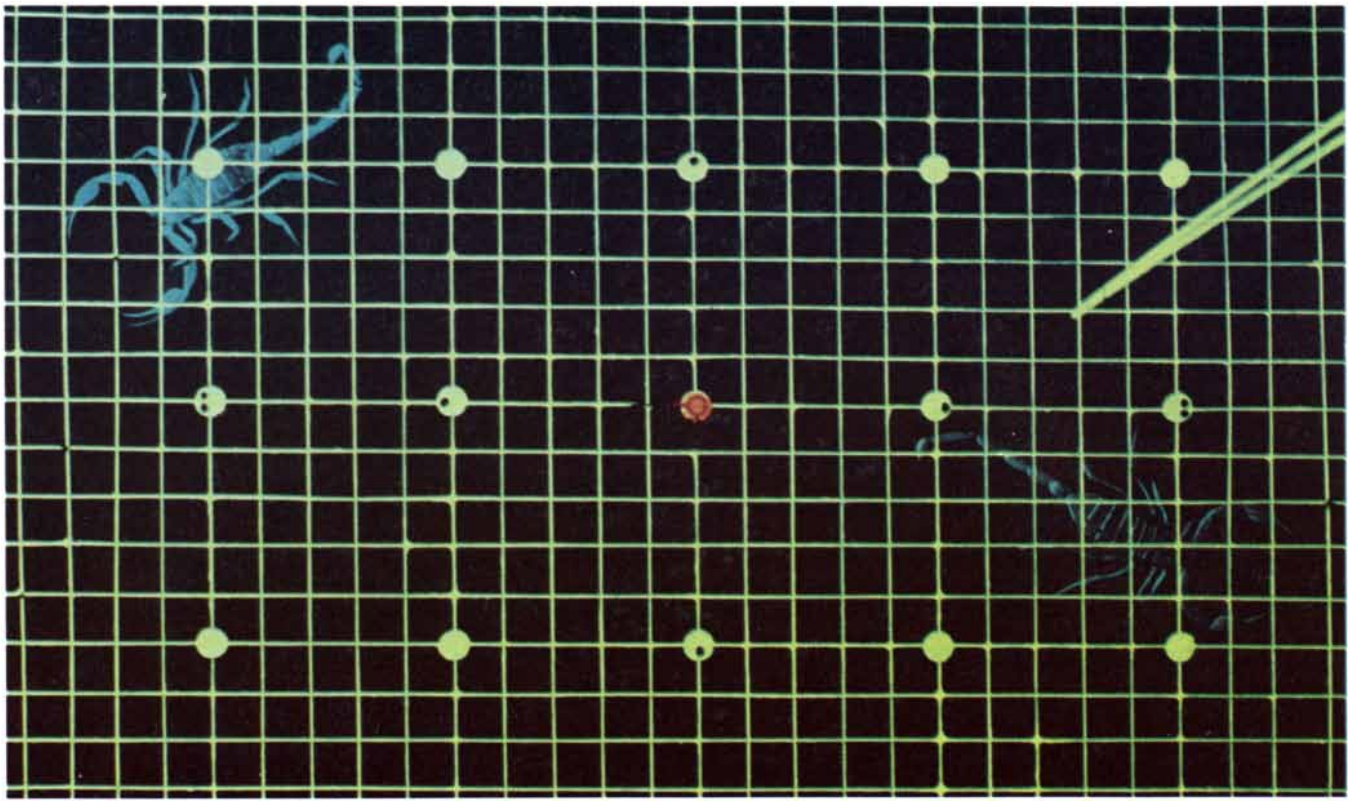
On a typical evening of hunting the scorpion emerges from its burrow and perches on the sand nearby, waiting in ambush for prey that pass within range. If unsuccessful, it may remain motionless for hours before returning to its burrow for one to several days. Stanley D. Yokota of the University of Arizona has shown that a scorpion can accommodate a low rate of hunting success by effectively "turning off" its metabolism while remaining inactive in its burrow. In this way it can survive for several weeks and even months on a single meal.

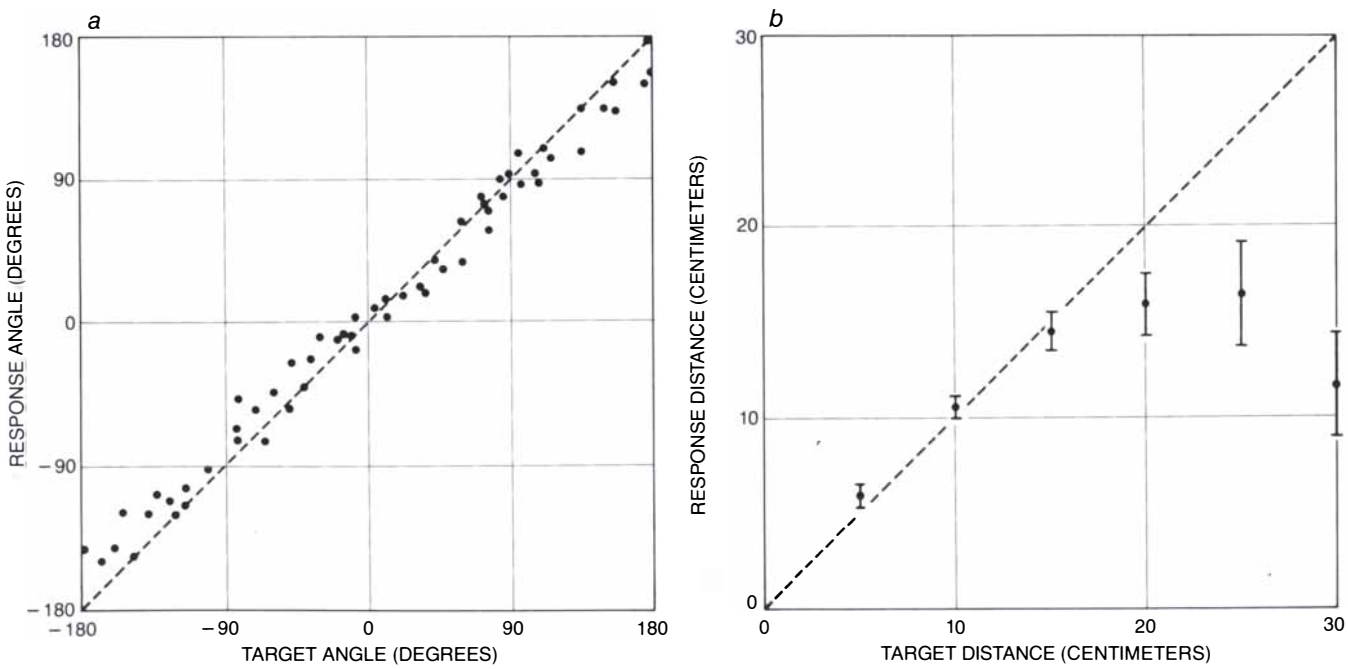
When a suitable prey enters the scorpion's territory, however, the scorpion's behavior changes dramatically. First it exhibits an alerting response: the pedipalps, or prey-capturing pincers, open and extend forward as the scorpion raises its body off the sand. Each subsequent movement of the prey triggers an orientation response, in which the scorpion quickly turns its pedipalps toward the prey and moves several centimeters closer to it. If the pedipalps fail to make contact, the scorpion pauses, motionless, until the prey moves again. A pursuit sequence usually lasts for only a few seconds and may include from one

SAND SCORPION occupies a terminal position in the food chain of the Mojave dunes. At maturity it can be up to eight centimeters long and weigh as much as four grams. It feeds on insects and other arthropods, which it captures with its large pincers (the pedipalps) and paralyzes with the neurotoxic sting at the end of its tail. The photograph, made at night, illustrates an unusual characteristic of the scorpion cuticle: it fluoresces under ultraviolet light. As a result the predatory behavior of this nocturnal arthropod is readily observed in the field.

to five orientation responses, each one clearly preceded by a period of stillness during which the prey must disturb the sand before the scorpion reacts.

A particularly remarkable example of the scorpion's stalking ability is seen in its pursuit of the desert burrowing cockroach, *Arenivaga investigata,* a root-eating insect that tunnels just below the sand surface. When a cockroach burrows to within half a meter of a hunting scorpion, the scorpion responds with the usual sequence of orienting movements until it is positioned directly above the prey. At that point further movements of the cockroach may confuse the scorpion, causing it to turn in circles and lunge about as if it were pursuing surface prey. Within a few seconds, however, its behavior changes; elevating its rear, it repeatedly jabs its pedipalps into





TIME-EXPOSURE PHOTOGRAPH, made in the field at night under ultraviolet light, shows a hunting scorpion's response to gentle prodding of the sand with a stick: it quickly turns and moves toward the disturbance. If its response does not carry it to the target, the scorpion waits for the target to move again. Each square on the superposed fluorescent grid is one centimeter across. From repeated trials it is possible to measure the scorpion's accuracy at estimating the angle and distance of preylike substrate disturbances. At a distance of eight to 10 centimeters the animals turn toward the target with high accuracy: in most trials the response angle is nearly equal to the target angle (*a*). Scorpions are also proficient at estimating target distance out to about 15 centimeters (*b*). At greater distances the response deviates significantly from perfect accuracy and is more variable. (Each dot in the graph represents the mean response at that distance.)

the sand until they touch and grasp the cockroach. It then exhumes its prey with the same rototilling motion it uses to excavate a burrow.

Because scorpions are active only at night, it might seem difficult to make a quantitative estimate of their range and accuracy in locating prey. Fortunately the animal's cuticle has a unique characteristic: under ultraviolet light it fluoresces a bright yellow-green, such that the scorpion is visible from several meters away. To measure scorpion behavior we arranged a black light and a camera on the same tripod, with a fluorescent reference grid attached under the camera. We could then position the tripod over a hunting scorpion and record, in time-exposure photographs, the animal's orientation responses to preylike disturbances (a light poking of the sand with a stick).

Our measurements showed that scorpions can detect disturbances as far away as 30 centimeters. At distances of 10 centimeters or less their estimates of target angle and distance are virtually perfect: their first response to the disturbance takes them directly to the target. How do they do it?

To answer the question I decided to study the scorpion's orienting behavior in the laboratory, and that presented a problem: when placed in a terrarium, a scorpion shows no inclination to chase prey. Luckily the animal has another type of orientation behavior that is easily studied. Normally a scorpion flees from threatening situations. If sufficiently harassed, however, it raises its rear and arches the sting out over its head toward the threatening stimulus. Any subsequent disturbance of the substrate evokes a vigorous turn in the direction of the stimulus, just as in the predatory response but without the forward movement.

A series of simple experiments exploiting this defensive orientation response confirmed our impression that visual and aural stimuli did not guide the orienting behavior. Covering all eight of the animal's eyes with opaque paint had no effect on either the scorpion's sensitivity to threatening stimuli or on the accuracy with which it turned toward them. Inserting sound-absorbent tiles between the stimulus and the scorpion also did not affect its response.

On the other hand, when I blocked the transmission of mechanical waves through the sand by inserting an air gap in the substrate, the animal's behavior did change, even though the air gap did not interfere with visual and auditory signals. When an agitated scorpion was placed on one side of the gap and a stimulus was presented on the other, the scorpion showed no response even when the disturbance was only a few centimeters away. If at least one of the scorpion's legs touched the substrate on the stimulated side, however, the animal immediately turned toward that side. This simple test proved the scorpion had to be in mechanical contact with the disturbed substrate in order to detect a stimulus.

Furthermore, the angle of the defensive turning response depended only on the combination of legs touching the stimulated surface. For example, when all right legs and all left legs were on opposite sides of the air gap, stimulation of the sand at various angles to the left of the scorpion always evoked turns to the left, but with a strong bias in a direction perpendicular to the gap. The air gap did not diminish the scorpion's sensitivity to vibrations, but it did reduce the accuracy with which the animal pinpointed the source direction. The responses suggested that the scorpion ordinarily determines the turning angle by integrating the input from all its legs. By selectively eliminating part of the input, I had systematically disrupted the animal's perception of source direction.

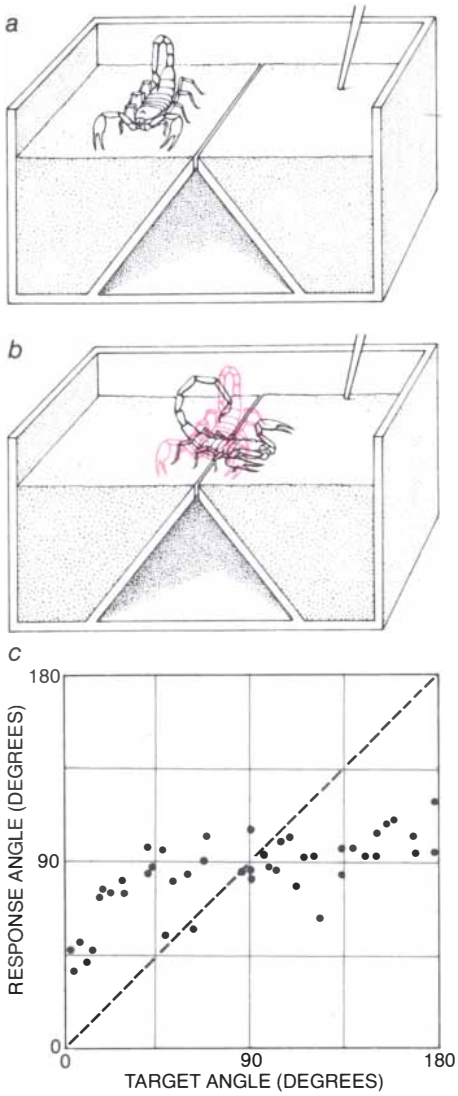
The air-gap experiments showed that the scorpion derives the information it needs to locate prey from signals transmitted through the substrate and that it probably detects these signals with sensors in its legs. I still had to determine the nature of the sensors and, before that, the nature of the information-bearing mechanical signals that are conducted by sand.

The latter question was particularly intriguing because geophysicists have long considered sand a poor conductor of mechanical waves, for two reasons. First, sand is a granular, disaggregated medium in which neighboring particles are not stuck together rigidly. Whereas in an aggregated solid such as rock a stress applied to one particle displaces the next one, and the displacement propagates as an elastic wave, in sand the kinetic energy quickly dissipates as friction because the grains can slip past one another. This form of inelasticity tends to dampen low-frequency, long-wavelength oscillations in particular.

On the other hand, at higher frequencies wavelengths become so short that they approach the dimensions of the sand grains. The grains reflect and scatter such signals, effectively filtering high-frequency components from the propagating wave. The result of these two effects—low-frequency damping and high-frequency scattering—is that sand will only transmit mechanical waves in a limited range of frequencies, if at all.

Yet the scorpions were obviously receiving some signal, and so I decided to investigate the conductive properties of sand in more detail. To do this I placed piezoelectric seismometers—quartz-crystal disks that generate an electric current when pressure is applied to their flat sides—at various depths and on the surface of a box of sand. I then used another piezoelectric transducer to generate a repeatable pulse of substrate movement at some distance from the seismometers. The first recordings from the seismometers confirmed what the scorpion's behavior had suggested all along: at distances of up to several decimeters, sand is a reasonably good conductor of mechanical vibrations.

Still to be determined, however, was exactly what the seismometers were recording. Four types of elastic wave can



AIR-GAP EXPERIMENTS demonstrate that scorpions respond to substrate vibrations rather than visual or aural cues in locating their prey. A scorpion positioned on one side of the air gap, which blocks the transmission of vibrations through the sand, shows no response to a disturbance several centimeters away on the opposite side (*a*). When its left legs are in contact with the stimulated substrate (*b*), the scorpion turns to the left, but the angle of turning is strongly biased in the 90-degree direction (perpendicular to the air gap), regardless of target angle (*c*). This indicates that sensory input from all eight legs is required to judge target direction accurately.

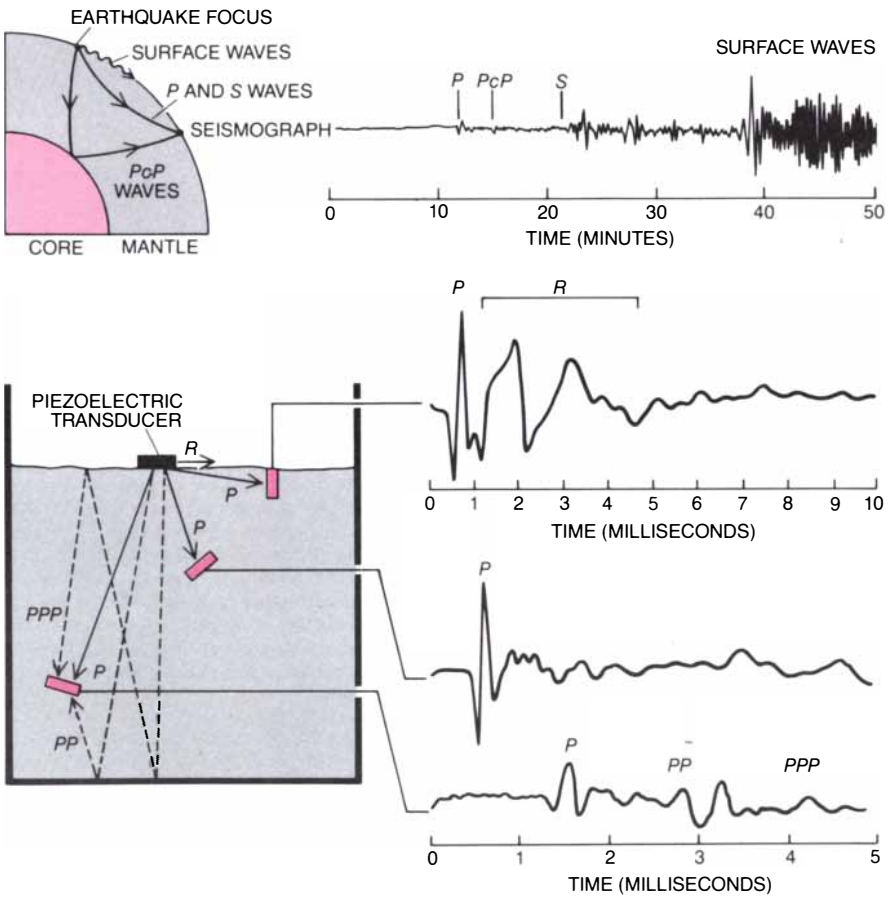
propagate in solids. Two of the four, compressional and shear waves, are body waves: they propagate as spherically expanding fronts throughout the body of the medium. Compressional waves (sound) cause particles to oscillate back and forth along the direction of wave propagation, whereas shear waves involve particle motion perpendicular to the direction of travel. The other two types of elastic disturbance propagate along the surface. Of these, only Rayleigh waves are of importance here; they cause particles to move in a retrograde elipse whose plane is perpendicular to the surface and parallel to the direction of travel.

The piezoelectric detectors recorded two strong signals propagating through the sandbox: a relatively fast wave conducted both along and below the surface of the sand and a slower wave recorded at the surface only. By orienting the sensitive axis of the detectors at various angles to the direction of signal propagation, I was able to identify the particle motions associated with each of the two waves. The fast wave turned out to be a compressional wave, and the slower surface wave was a Rayleigh wave. Particle motions consistent with shear-wave propagation were not detected, which was not surprising: shear wave conduction depends entirely on shape-restoring forces between neighboring particles, and these forces are likely to be minimal in a granular medium such as sand.

Thus contrary to its reputation as a strongly absorbent medium, sand conducts at least two types of wave. Furthermore, the physical properties of these signals—their frequency range and propagation velocity—were such that animals with appropriately sensitive receptors might be able to detect and glean information from them at ranges of several decimeters.

To determine just how well waves of different frequencies and wavelengths propagate through sand I analyzed the waveforms of compressional signals recorded at various distances from a constant signal source. This procedure, called Fourier analysis, enables one to determine the degree to which the various frequencies that make up a complex signal are attenuated as the signal travels through the medium. I found that sand acts as a reasonably good conductor of mechanical waves in the .1-to-five-kilohertz bandwidth. In particular the dominant frequencies of signals recorded relatively far from the source were near one kilohertz, a frequency to which most animal mechanoreceptors are highly sensitive. Furthermore, in sand the wavelengths corresponding to these frequencies are short enough (a few centimeters) for small animals such as scorpions to be able to distinguish separate arrival times of the wave at different receptors.

Perhaps the most surprising characteristic of the signals was their low velocity of transmission. The high velocity of elastic waves in most other natural solids is one of the primary reasons behavioral biologists have tended to dismiss substrate vibrations as potential orientational cues. High velocity, like long wavelength, prevents an animal from detecting differences in arrival time or amplitude at different receptors and therefore from using these characteristics to locate the signal source. The measurements showed, however, that the compressional-wave velocity in loose surface sand is only about 120 meters per second, less than half the speed of sound in air; in compacted sand it is about 200 meters per second. That is roughly one order of magnitude slower than the sound-wave velocity in most other solids. Rayleigh waves in sand travel slower still, at an astonishing 40 to 50 meters per second.



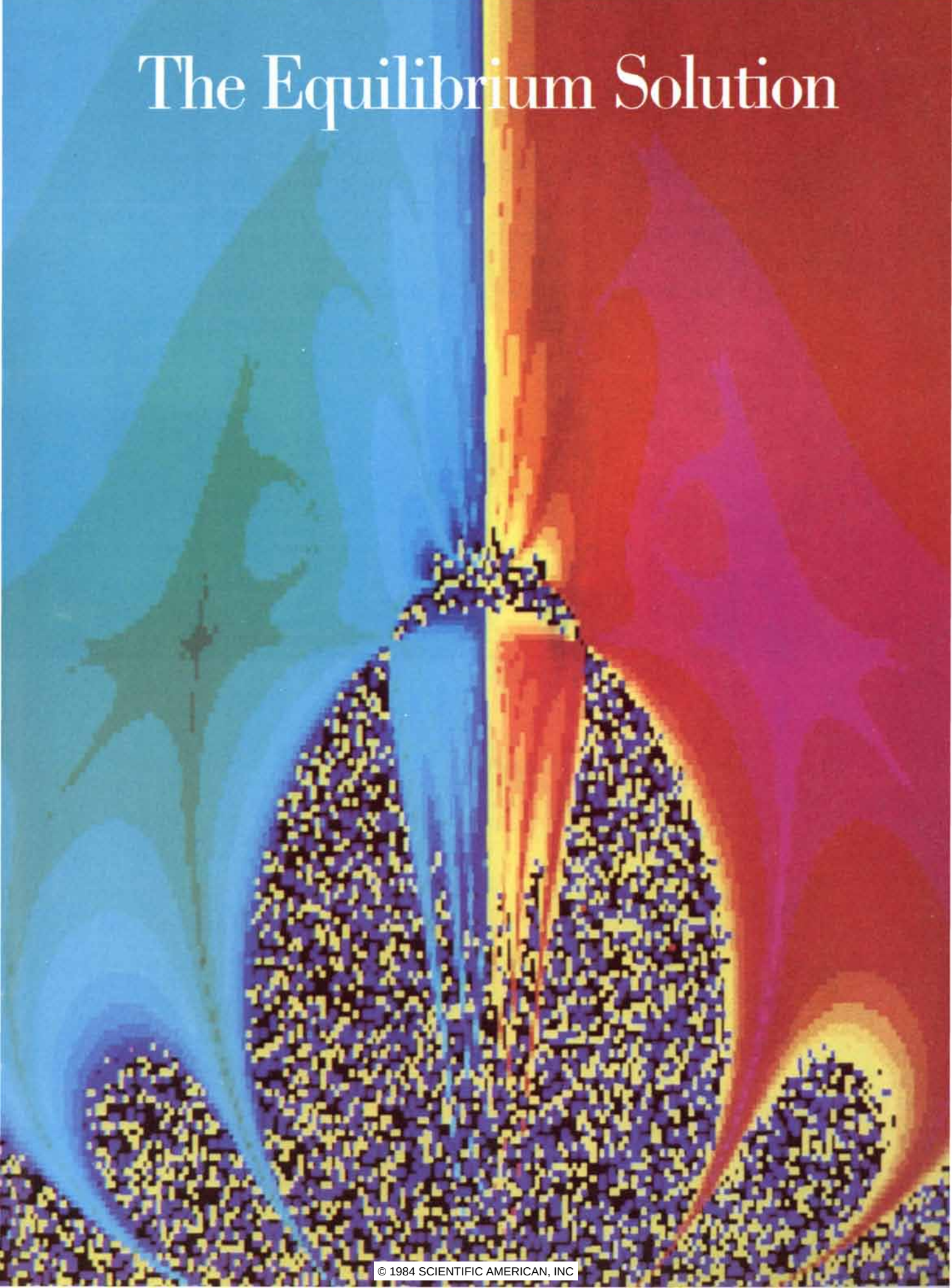
MECHANICAL WAVES from an earthquake are detectable by a seismograph thousands of miles from the focus (*top*); the same types of wave propagate over short distances through sand in response to the subtle vibrations of a piezoelectric transducer (*bottom*). Earthquakes emit two types of body wave, compressional (*P*) and shear (*S*), and two types of surface wave, Rayleigh and Love. *P* waves travel fastest and so arrive first at the seismograph, followed by their reflections off the earth's core (*PcP*) and then by the shear waves and the surface waves. Sand conducts only *P* waves and Rayleigh waves. Both are detected by a piezoelectric sensor (*color*) at the surface of the sandbox. At depths of six centimeters and 19.5 centimeters only *P* waves are detected, but sand conducts them well enough for reflections to be measured.

Both the compressional and the Rayleigh waves might thus be detected by scorpions and used to find prey. The next step was to find out which vibrations the animals actually sense, and with what receptors.

A reasonable place to look for vibration sensors was on the scorpion's tarsal leg segments—its "feet"—because our studies had shown they are the only part of its body that must be in contact with the substrate in order for the scorpion to orient itself. Each of the eight legs bears several cuticular structures that might function as mechanoreceptors. These include hair sensilla, spurs, claws and a peculiar structure called the slit sensillum that is common to all arachnids. The slit sensillum was a particularly interesting candidate because the homologous structure in spiders, called a lyriform organ, was known to mediate those arachnids' extraordinary sensitivity to web vibrations.

It was easy to show that the tarsal slit sensilla are in fact a crucial element of the mechanism by which the scorpion detects its prey. When all the tarsal slit sensilla on a scorpion were punctured with a fine pin, the animal behaved entirely normally, except that it had be-

The Equilibrium Solution



The Equilibrium Solution

Rapid, reliable methods for solving chemical equilibrium equations have long been sought by scientists asking fundamental questions about systems as varied as the atmosphere, the human body, and the internal combustion engine. An interdisciplinary collaboration at the General Motors Research Laboratories has produced a breakthrough with potentially universal applications.

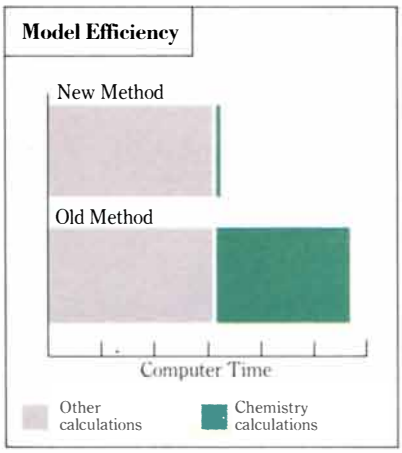
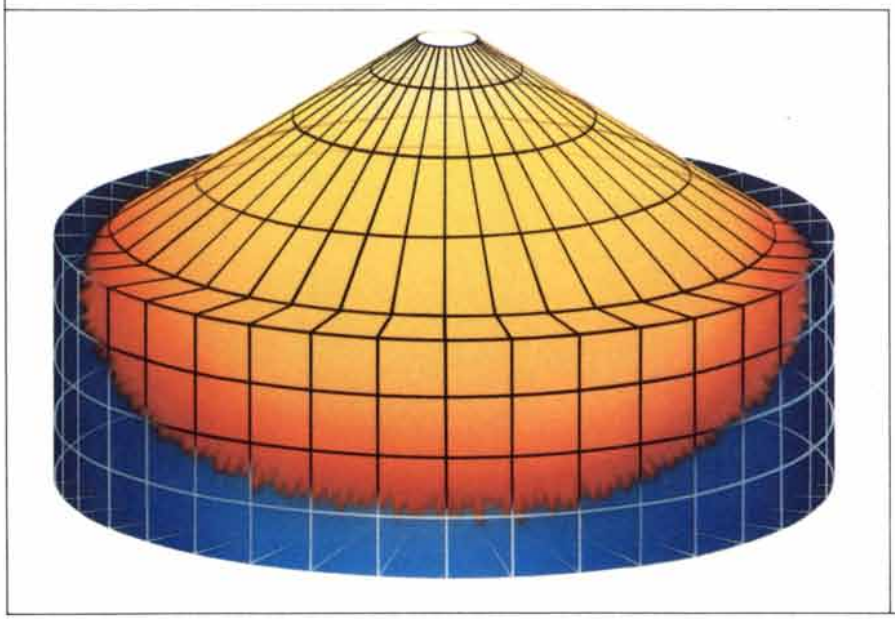


Figure 1: Computer time required by an engine combustion model. Time required for chemical calculations decreased greatly with the new methodology.

Figure 2: Artist's illustration of a chemically reacting flow. The physical space is divided by a latticed network into units of volume, and the solution must be recalculated for each grid point at each instant of time.



WHEREVER CHEMISTRY is involved, the need to solve chemical equilibrium equations arises. Although methods for solving such equations have existed for some time, they do not offer the speed demanded by the most challenging problems. For example, predicting the composition of gases inside an engine cylinder may require as many as a million equilibrium calculations per cycle. Two researchers at the General Motors Research Laboratories have developed a systematic way to reduce the mathematical complexity in these problems, thus making it possible to solve them rapidly.

Chemical equilibrium occurs when the rates of a forward and reverse reaction are equal. Mathematically, this statement usually translates into a system of nonlinear polynominal equations. Until now, there has been no fast reliable method for solving such systems. Solutions to particular problems have demanded thorough familiarity with the physical conditions. In most cases, this means partial knowledge of the answer.

Dr. Keith Meintjes of the Fluid Mechanics Department and Dr. Alexander Morgan of the Mathematics Department began their research by considering recent advances in the theory of continuation methods. They concluded that a suitable continuation algorithm could be relied on to solve the nonlinear polynomial equations that make up chemical equilibrium systems. In this insight lies the realization that the solution can be obtained without any knowledge of the physical nature of the problem.

In seeking the most efficient implementation of the continuation method, the researchers discovered that chemical equilibrium equations can always be systematically reduced to a substantially simpler mathematical form. The reduced systems have fewer unknowns and a smaller total degree. The total degree of any system is the product of the degrees of each of its equations. Reducing the total degree makes a system easier to solve. A typical combustion problem with ten equations and total degree of 192 was reduced by the researchers to two cubic equations with a total degree of nine.

The reduced systems can then be systematically scaled to fit within the limits imposed by computer

arithmetic. The range of coefficients in chemical equilibrium systems tends to be too large or too small for the arithmetic of the computer. Consequently, the solution process can fail. By construction of an effective scaling algorithm, this arithmetic constraint can be eliminated. Suitably reduced and scaled, the equilibrium systems can then be solved reliably by the continuation method.

THUS, Drs. Meintjes and Morgan accomplished their original goal of developing an innovative reliable approach to solving chemical equilibrium equations. They also made a final, unexpected discovery. Certain standard solution techniques, which fail on the original systems, can be made absolutely reliable when applied to the reduced and scaled systems. These methods, which are variants of Newton's method, are also many times faster than continuation.

This research has produced an extremely effective solution strategy—reduction of the equations, followed by scaling of the reduced systems, followed by the application of a suitable variant of Newton's method. The simplification of the systems, which was originally formulated to facilitate the implementation of the continuation method, proved to be the critical factor enabling the use of fast techniques.

In one application, the chemical equilibrium calculations are part of a model which predicts details of the flow, turbulence, and combustion processes inside an engine. By using their methodology to develop an equilibrium solver for this application, the researchers greatly increased the model's solution efficiency (see Figure 1).

"It was the characteristic structure of equilibrium equations," says Dr. Meintjes, "that allowed us to perform the reduction. The unexpected mathematical simplicity of the reduced systems suggests that even more efficient solution methods may be discovered."

"Critical to this research," says Dr. Morgan, "was the dialogue between disciplines. I hope that this dialogue will continue as scientists and engineers in diverse fields explore the capabilities of this new methodology."

THE MEN BEHIND THE WORK

Dr. Keith Meintjes, a Staff Research Engineer in the Fluid Mechanics Department, joined the General Motors Research Laboratories in 1980. Dr. Alexander Morgan, a Staff Research Scientist in the Mathematics Department, joined the Corporation in 1978.

Dr. Meintjes (left) was born in South Africa. He attended the University of Witwatersand, where he received a B.Sc. and M.Sc. From 1973 to 1975, he taught fluid mechanics and engineering design at the university. He then went on to study at Princeton University, where he received an M.A. and Ph.D. in engineering. His doctoral thesis concerned numerical methods for calculating compressible gas flow.

Dr. Morgan (right) received his graduate degrees from Yale University in differential topology. His Ph.D. thesis concerned the geometry of differential manifolds. Prior to joining General Motors, he taught mathematics at the University of Miami. His book, "Applications of the Continuation Method to Scientific and Engineering Problems," will soon be published by Prentice-Hall.

SCIENCE/SCOPE

A spacecraft orbiting Venus will be used to observe Halley's Comet during the comet's closest approach to the sun in early 1986. NASA's Pioneer Venus Orbiter will be reoriented next year to examine Halley between December 1985 and February 1986, when the comet and Venus will be on the far side of the sun from Earth. The Hughes Aircraft Company-built spacecraft has been making radar maps and performing other scientific studies since arriving at the cloud-covered planet in 1978. In April the Orbiter, designed to operate just one year, proved it could conduct the Halley mission when it viewed Comet Encke for eight hours. During the test, the spacecraft's ultraviolet spectrometer surprisingly revealed that Encke is losing water through evaporation at a rate three times higher than expected, based on previous observations.

A system that detects and snuffs explosions in less time than it takes to blink can be used in any enclosed spaces, including armored personnel carriers, helicopters, aircraft, paint lockers, and engine compartments. The Dual Spectrum™ fire sensing and suppression system is carried by the U.S. Army's M1 Abrams main battle tank and the two versions of the Bradley Fighting Vehicle. At the start of an explosion, the system detects the fireball and triggers the release of a gaseous-liquid substance. The snuffing occurs in one tenth of a second—well before heat or energy can do any damage. By comparison, an eye blinks in one fourth of a second. The system is produced by the Santa Barbara Research Center, a Hughes subsidiary, and is licensed to Wormald International of Australia.

A family of redundant control units for satellite communication uplink amplifiers has been introduced by Hughes. The new control units, designated the 9300HA series, are designed to provide fully automatic monitoring and switching for redundant operation of two or more high-power amplifiers (HPAs). The units consist of one rack-mountable drawer containing an RF-switched, high-power load. They can operate at C, X, or Ku band, and are compatible with the complete line of Hughes HPAs.

After slowing from 107,000 miles per hour to subsonic speeds in just two minutes, NASA's Project Galileo Probe will take the first direct samplings of Jupiter's atmosphere later this decade. During its plunge through the brightly colored clouds, much of the Hughes-built probe's forward heat shield will be eroded by temperatures of several thousand degrees. Once the probe has slowed, a mortar in the rear heat shield will fire to deploy a parachute. This parachute will pull off the back cover, releasing in turn the main parachute. Small explosives will release the front heat shield from the descent module. The parachute will slow the descent as the shield continues into the interior of the planet. Data will be transmitted to an orbiting spacecraft for relay to Earth. Project Galileo is set for launch in May 1986 and is scheduled to arrive in August 1988.

Hughes Ground Systems Group is preparing to apply its airspace management experience to the exciting challenges of worldwide air traffic control. These systems will be designed to ensure service 24 hours a day, 7 days a week. They will support distribution of processing among multiple computers linked via local area networks. The many challenges include design and development of hardware and software to support advanced display and man-machine interface technology, and using satellite technologies for future ATC applications. To help design the next generation of air traffic control systems, send your resume to Hughes Ground Systems Group, Employment Dept. S2, P.O. Box 4275, Fullerton, CA 92634. Equal opportunity employer. U.S. citizenship required.

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come "blind" to all but the most intense stimulation of the substrate. On the other hand, when only the sensors on the left legs were punctured, the scorpion behaved much as it did when it was straddling the air gap: it tended to turn 90 degrees to the right, toward the remaining sensors, whenever the substrate was disturbed. The similarity of the two behavior patterns suggests that destroying the left-side slit sensilla was equivalent to eliminating all sensory input from that side.

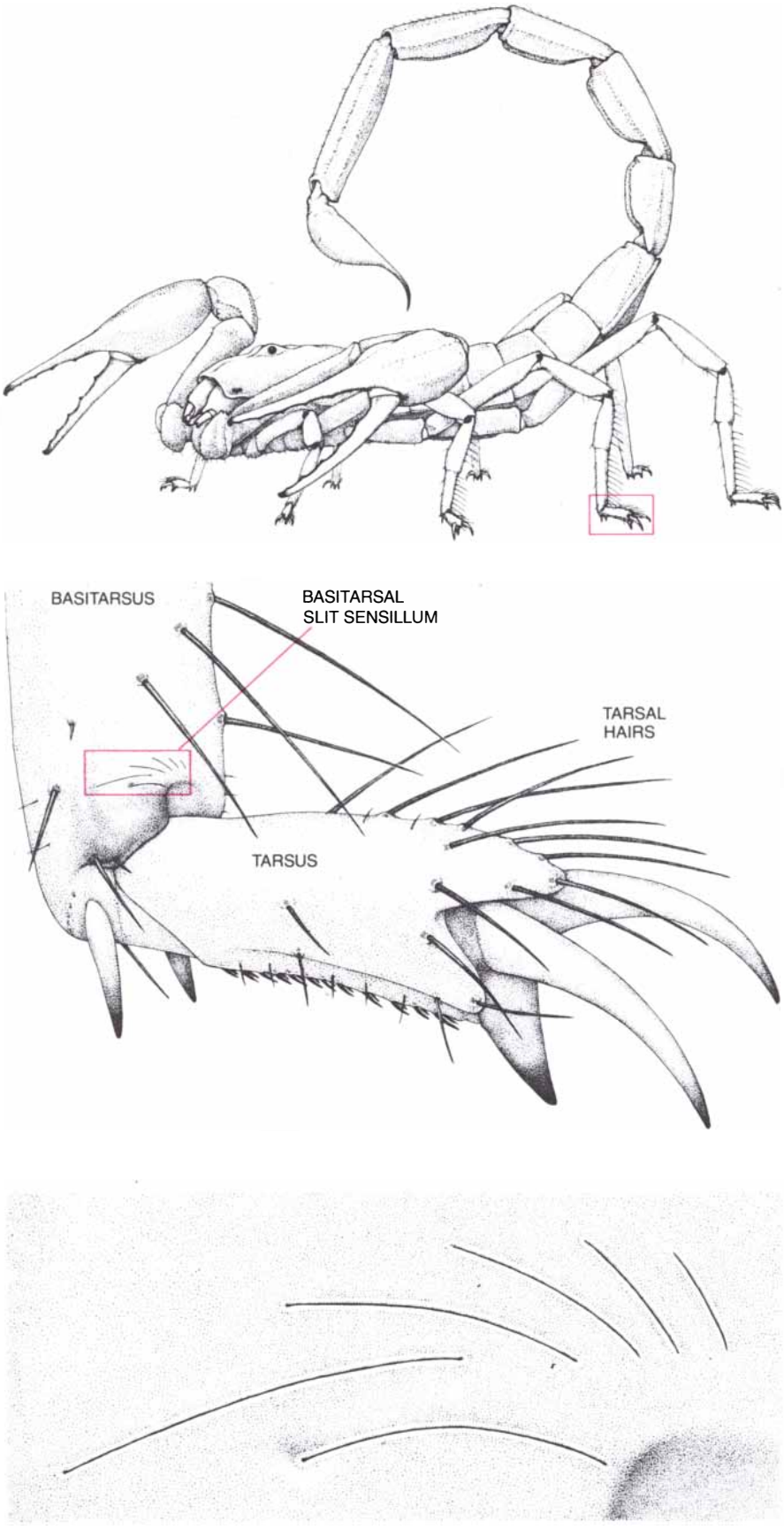
Similarly, when only two adjacent slits were excised, the orientation response remained reasonably accurate except in the case of targets presented near those legs. Finally, when all but two adjacent sensors were destroyed, the scorpion invariably turned in the direction of those sensors, regardless of target position. Sensory input from all the slit sensilla was clearly essential for the scorpion to determine source direction accurately.

Because the scorpion's legs are relatively large, it was possible to insert fine wires into the terminal segments and to record the action potentials, or bioelectric signals, transmitted from the receptors to the brain. The recordings showed action potentials of two sizes. The larger of the two occurred early in the response to vibrational stimulation and was associated with the arrival of the relatively fast-moving compressional waves at the tarsus. The smaller action potentials occurred later in the recordings, in conjunction with the arrival of the slower Rayleigh waves.

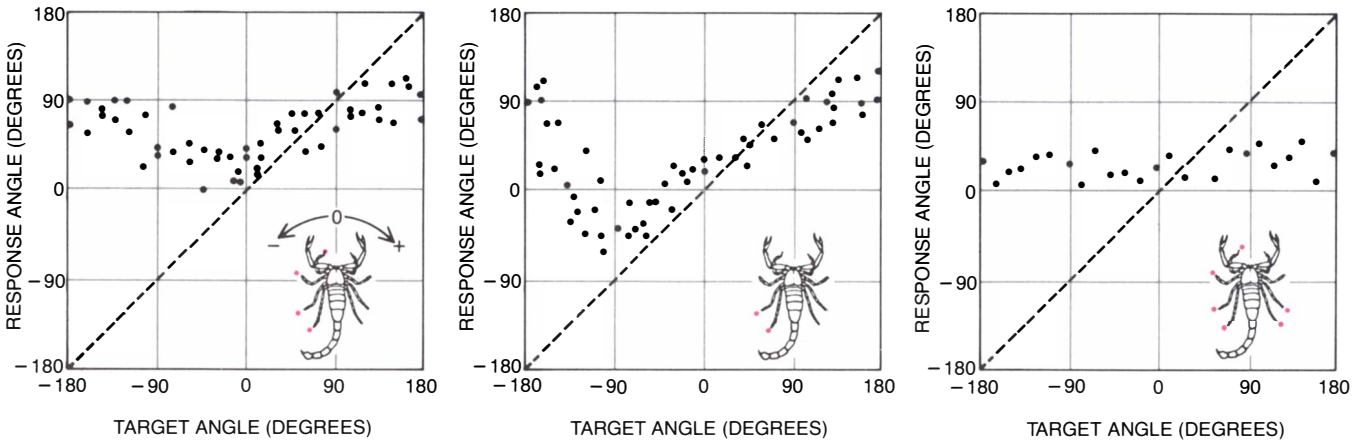
By selectively stimulating each of the different tarsal mechanoreceptors I could then isolate the ones responsible for the two distinct bioelectric signals. Such experiments revealed that the larger potential is a response to stimulation of sensory hairs on the tarsus, while the smaller ones originate in the slit sensilla. Thus the hairs detect the compressional waves, and the slit sensilla register the arrival of Rayleigh waves.

The difference in sensitivity of the two sensors is reasonable when one considers the different particle movements associated with the waves they detect. Friedrich G. Barth and his colleagues at the Johann Wolfgang Goethe University in Frankfurt, West Germany, have shown that slit sensilla are particularly sensitive to forces that compress the slits in a direction perpendicular to their long axis. A passing Rayleigh wave would do just that, because its vertical motion displaces the terminal leg segment upward. The hair sensilla, on the other hand, protrude from the sides and bottom of the leg into the sand and are therefore positioned to detect the horizontal particle motion of compressional waves.

There is more to locating prey, however, than simply detecting motion in



TWO TYPES OF MECHANORECEPTOR on the tarsal (terminal) leg segment of the scorpion are sensitive to subtle vibrations of the substrate. Hairs protruding from the sides and bottom of the tarsus rest on and between sand grains. The basitarsal slit sensillum consists of regions where the cuticle folds in on itself. The slit sensillum is particularly sensitive to vibrations that compress the slits in a direction perpendicular to their long axis; it is capable of detecting movements in the substrate that have amplitudes of about one angstrom unit (10^{-10} meter).

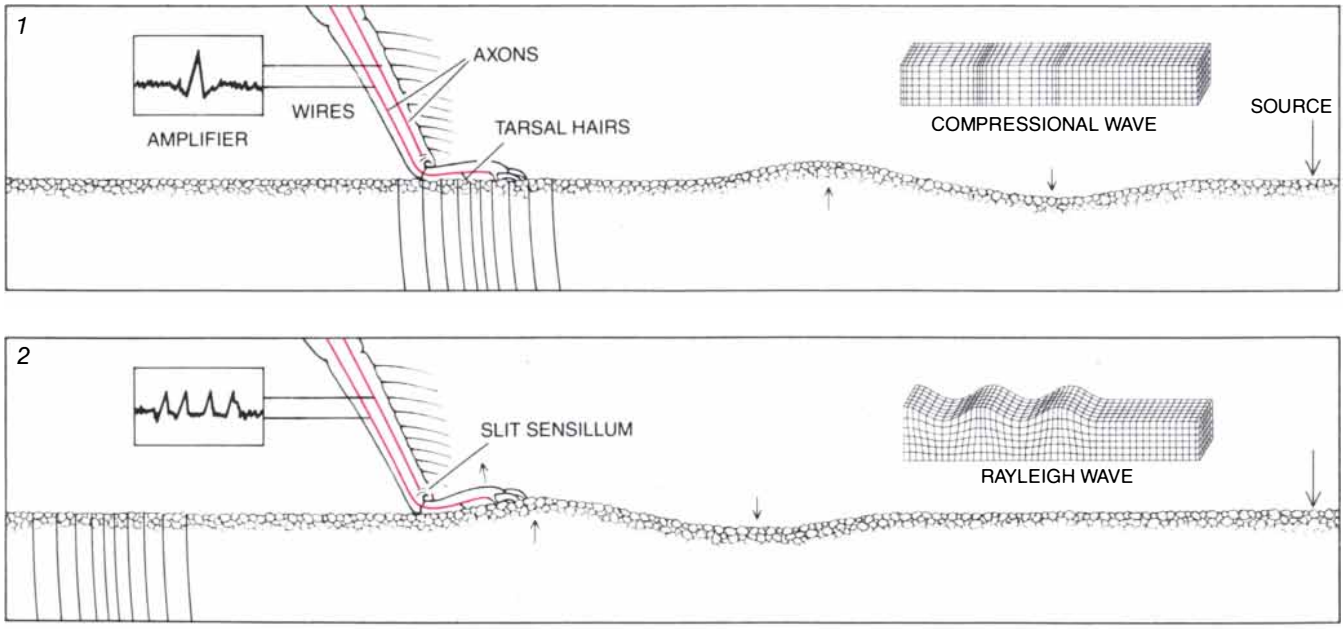


CRUCIAL ROLE OF SLIT SENSILLA in determining target direction is suggested by experiments in which some or all of the slit sensilla are pierced (*colored dots*) and the substrate is then stimulated at various angles to the scorpion. When the slit sensilla on all eight legs are ablated, the scorpion is "blind" to all but the most intense substrate vibrations. Selective ablation induces a bias (toward the undamaged legs) in the angle of the scorpion's turning response; the bias increases with the number of ablated sensilla. For example, when the four left legs are damaged (*left*), the scorpion always turns right, even when the disturbance is to the left. These observations suggest the scorpion normally integrates input from all eight slit sensilla in determining the direction of the target whose movements triggered the vibrations.

the sand; somehow the scorpion extracts information from the waves and uses it to determine the position of the source of the disturbance. Since the slit sensilla's role in determining source direction is essential, Rayleigh waves are likely to be the vibrational cue from which target angle is derived. Yet nothing about the anatomy or the physiological response of either the slit sensilla or the sensory hairs could be considered directional. In other words, the scorpion's vibration sensors are equally responsive to waves arriving from any angle. The animal's determination of prey direction must therefore involve a comparison of the responses of two spatially separated sensors as a wave passes under it.

The adult scorpion's eight legs form a roughly circular "sensory field" about four to six centimeters across. The scorpion might exploit this relatively large span in one of two ways. First, it might determine the direction of a wave source from the time delay between stimulation of sensors close to the source and those farther away; that is, the scorpion might simply turn in the direction of the sensors that are stimulated first. Assuming a sensory field five centimeters in diameter, this time delay would be about one millisecond for a Rayleigh wave traveling at 50 meters per second. For a compressional wave traveling at 150 meters per second the delay would be about .3 millisecond. Many animals use smaller time delays to locate the source of compressional waves propagating through air; human beings, for example, can easily judge the direction of a sound source on the basis of a time delay between the two ears of less than 10 microseconds.

Alternatively, a scorpion might gauge the direction of a wave source from dif-



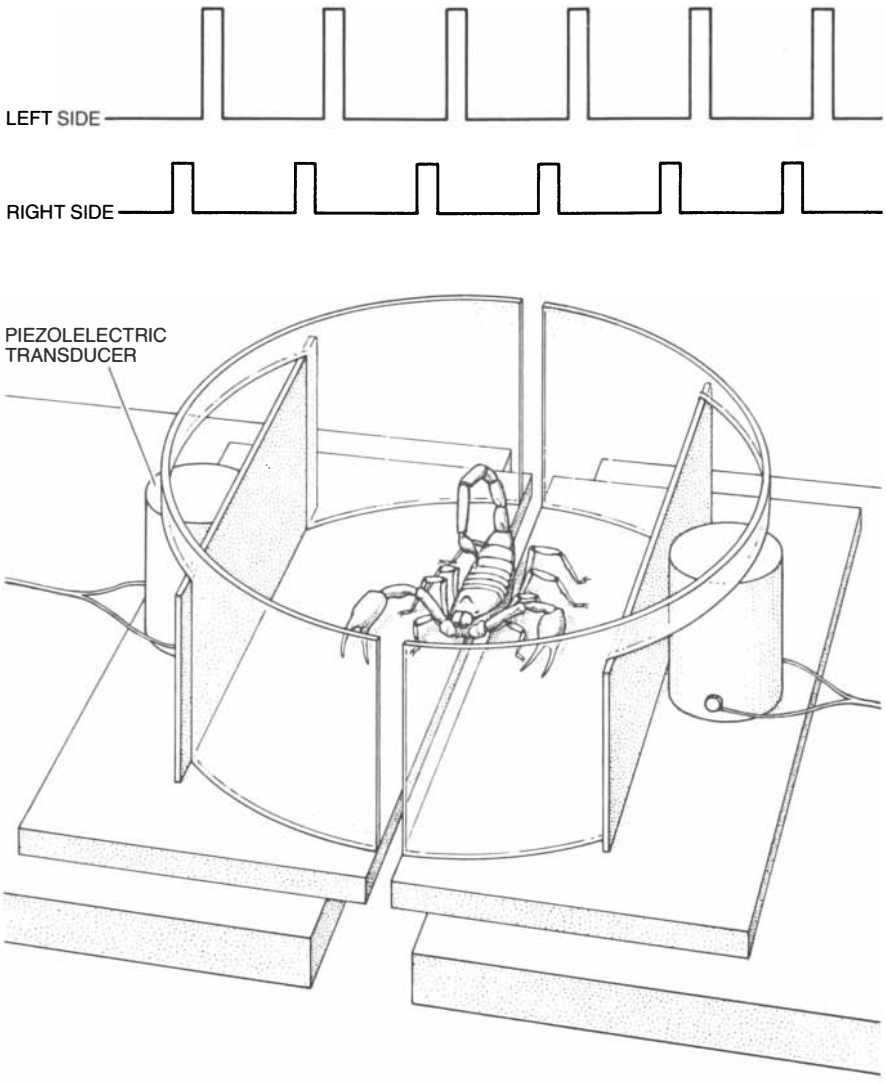
MECHANOSENSORY RESPONSE of a scorpion to waves propagating through sand can be observed by inserting fine wires into the terminal leg segments and recording the bioelectric signals (action potentials) transmitted along the leg nerve. A piezoelectric sensor (not shown) placed in the sand near the tarsus records the waves. When the sand is disturbed, the first signals to arrive at the tarsus are compressional waves (*1*), which stimulate the tarsal hairs, causing large-amplitude action potentials to ascend the leg nerve. A few milliseconds later (*2*) the vertical particle motion associated with the slower-traveling Rayleigh waves compresses the slit sensillum, triggering smaller-amplitude signals. Rayleigh-wave stimulation of the slit sensilla appears to be the basis of the scorpion's perception of target direction; it may judge distance from the time delay between the stimulation of the two types of mechanoreceptor by the two types of wave.

ferences in the intensity with which the wave stimulates different sensors. As a wave propagates, its amplitude decreases, partly because the wave front expands geometrically, spreading out the energy of the wave, and partly because the signal is absorbed by the medium. Sensors nearest the source should thus be stimulated most intensely.

To test which of the two cues was more important to the scorpion, I constructed a platform divided down the middle by a narrow gap. Each half of the platform could be made to vibrate independently by its own mechanical stimulator. With a scorpion placed astride the gap, the timing and intensity of vibrations reaching its left and right legs could be varied independently.

The device enabled me to present the scorpion with a dilemma. In natural situations the legs closest to a wave source are stimulated first and also most intensely. With the divided platform, however, it was possible to excite the right legs first but only half as intensely as the left legs, thereby forcing the scorpion to choose the most important cue. In repeated trials the scorpion consistently turned to the right regardless of how intensely the left legs were stimulated. This result proved that arrival time, and not relative intensity, is the cue the animal uses to determine source direction.

Moreover, the scorpion was quite good at deciding which of its legs were stimulated first. Time delays of one to two milliseconds generally produced the best simulation of a natural wave, as evidenced by the speed and accuracy with which the scorpion turned left or right; one millisecond is about how long it would take a surface wave to travel the five centimeters across a scorpion's sensory field. Delays as small as .2 millisecond, however, also elicited accurate turning responses.



SCORPION PERCEIVES TARGET DIRECTION by determining which of its legs are stimulated first by a passing Rayleigh wave. In the experiment shown the scorpion straddles the gap in a divided platform, such that its right legs can be stimulated independently of its left legs. An oscilloscope records the stimulus pulses applied to each side of the platform. The scorpion always turns in the direction of the legs that are stimulated first, even when the other legs are stimulated more intensely. This proves that the time delay between stimulation of opposite legs and not the relative intensity of stimulation encodes the information used to determine source direction. The platform experiments also show that scorpions can detect time delays as small as .2 millisecond, but they respond most consistently to delays of one millisecond to two milliseconds—roughly the time it takes for a Rayleigh wave to traverse the span of their legs.

That leaves only the question of how the scorpion perceives the distance to its prey. Our original field observations showed that it can judge the distance to prey out to about 15 centimeters and that it rarely misses at 10 centimeters or less. Unfortunately, because the animal is reluctant to hunt in the laboratory, the mechanism by which it perceives distance is not easily studied and is still a matter of speculation. Like the determination of source direction, however, the determination of distance must involve the detection of small differences in the time or amplitude of stimulation of different receptors.

It also seems likely that information from compressional waves, which does not appear to contribute to the orientation response, is an important factor in the scorpion's ability to perceive distance. One possibility is that the animal times the delay between the stimulation of the tarsal hairs by compressional waves and the stimulation of the slit sensillum by the slower-moving Rayleigh waves. The delay would be proportional to the distance of the source. A second possibility would involve sensing the attenuation of these signals. The amplitude of mechanical waves drops off rapidly as they spread through the sand; this is particularly true of compressional body waves, because their energy dissipates over a spherical wave front rather than the circular one characteristic of surface waves. When a scorpion is close to a wave source, it should sense a much greater difference in stimulus intensity between its near and far legs than it does when it is far from the source.

In retrospect it seems a remarkable contradiction of common intuition that an animal, particularly one that lives on sand, could rely so exclusively on information transmitted through the ground. Nevertheless, the sand scorpion's use of waves propagating through a solid is probably not unique. Other natural substrates—a leaf, say, or an apple or the trunk of a tree—might, by virtue of their peculiar shapes and physical properties, transmit information of importance over short distances appropriate to the small world of the animals living on them. Indeed, the sand scorpion is only one example from a growing list of organisms, including the trapdoor spider, the ant lion and the fiddler crab, that orient themselves toward the source of motion in a solid substrate, "listening" as well as walking with their feet.

The World's Deepest Well

Now at 12,000 meters, a research well at Kola in the Soviet Arctic has revealed the cause of a seismic discontinuity and has pioneered drilling techniques for the deep exploration of the earth's crust

by Ye. A. Kozlovsky

Since 1970, on the barren rock of the Kola Peninsula 250 kilometers north of the Arctic Circle in the Murmansk region of the Soviet Union, a drilling derrick as tall as a 27-story building has been driving a well into the Baltic continental shield. The drill bit, grinding through crystalline rock for more than half of its journey, has now carried the bottom of the well to below 12,000 meters. The Kola "superdeep" well is the world's deepest. It is deeper by far than the 1,500- to 7,000-meter wells usually driven to prospect for or to extract oil, coal, iron, the nonferrous metals, diamonds and other treasures of the earth.

The first treasure sought by the Kola well is understanding of the deep structure of the continental crust and the forces that have shaped it through four billion years of geologic history. Present understanding derives in large part from the sample of the earth's crust, about 15,000 meters of its average 30,000-meter depth, that is exposed here and there at the surface. The velocity of seismic waves, increasing with the depth of burial but varying with the constitution of the rock, and the readings of instruments flown by aircraft and earth satellites that sense the gravitational and electromagnetic fields of the earth all tell a great deal more about what is hidden below. There is no substitute, however, for direct observation of what is deep in the earth and what is going on down there now.

The Kola well has traversed 1.4 billion years of earth history through the Proterozoic era into Archean rock 2.5 to 2.7 billion years old. It has exposed half a dozen cycles of crust building that brought new igneous rock into the crust from the molten mantle below, then broke it down by weathering and glaciation, sorted it and redistributed it in sedimentary strata, and then reconsolidated it to crystalline rock again in the metamorphism induced by the heat and pressure of the next intrusion of igneous rock. The rock samples, brought to the surface with difficulty that has increased with depth, establish a general thermal model of the evolution of the crust through the period when the main features of the earth's continental shields were laid down. The record makes it possible to determine the composition of the primitive crust at Kola, at least; that proves to have been granodiorite, an igneous rock somewhat poorer in quartz than granite is.

A major objective of the Kola well was to penetrate through the upper crustal layer of granite into the underlying basement rock of basaltic composition. Basalts are less often found at the surface, and the presumed basaltic basement is nowhere exposed on the continents. The boundary is thought to be marked by an abrupt increase in the velocity of seismic waves that has been observed around the world at midcrustal depths. At the Kola Peninsula the shift in velocity occurs at 9,000 meters. The Kola well was the first to cross that boundary. It did not, however, find basalt below it.

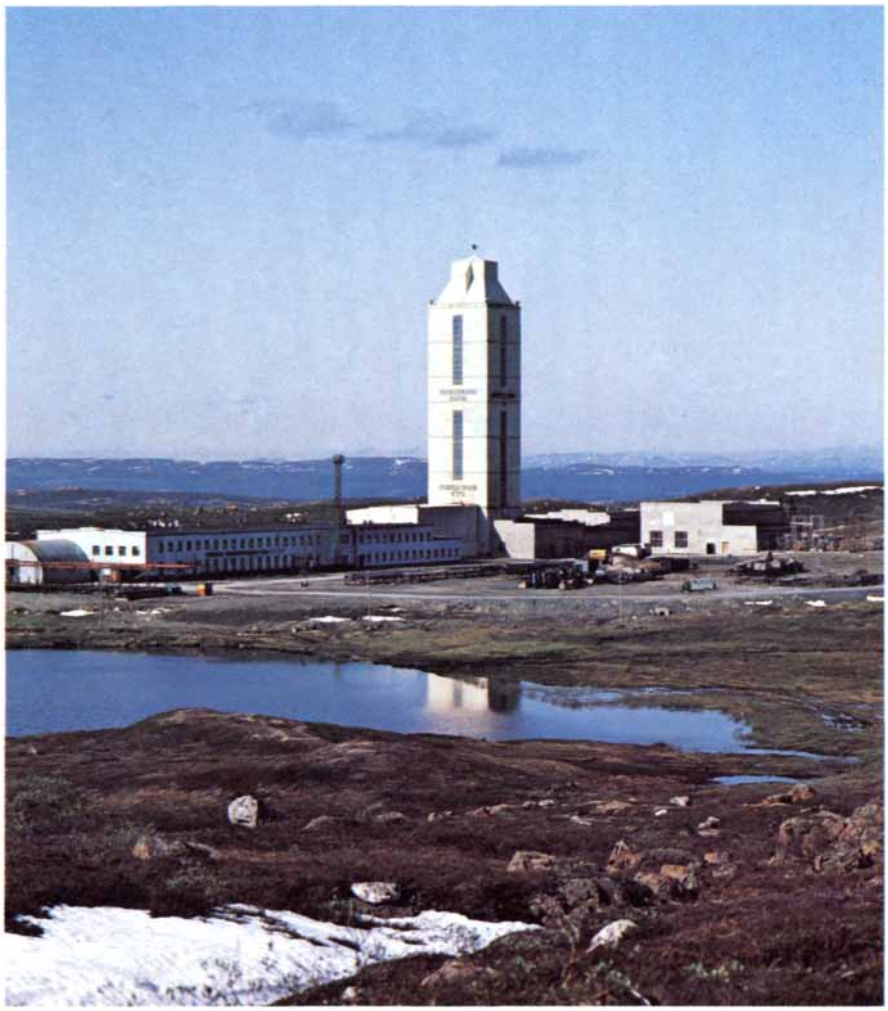
Instead the well had come to the bottom of an anomalous zone of disaggregated metamorphic rock it had first penetrated at 4,500 meters. As it worked its way through this zone the well encountered surprising, copious flows of hot, highly mineralized water. Such water—"water of crystallization"—comes from minerals making up crystalline rock; it is released as the constituents undergo dissociation and reassociation in the kneading and baking of metamorphism. Metamorphic water plays a major role in the genesis of ores. Ordinarily it finds its way out of the metamorphic formation and deposits its mineral burden higher in the crust. At Kola the water was trapped at the site of its liberation by layers of overlying impervious igneous rock two kilometers thick. To squeeze the water back into the rock would require pressure that is found only deeper in the crust or in the upper mantle. Since the tensile strength of the rock is a fraction of this hydraulic pressure, its dehydration was accompanied by microfracturing. This phenomenon of the hydraulic disaggregation of metamorphic rock, never before observed, may have a significant place in the structure of continents.

In the flows of mineralized water encountered in the zone of disaggregation and in thin, sharply defined formations below, and in the evidence of mineral deposits that was revealed at other levels, the Kola well demonstrates that man has barely scratched the surface in his search for minerals. Immense resources lie at depths awaiting the technology to reach them.

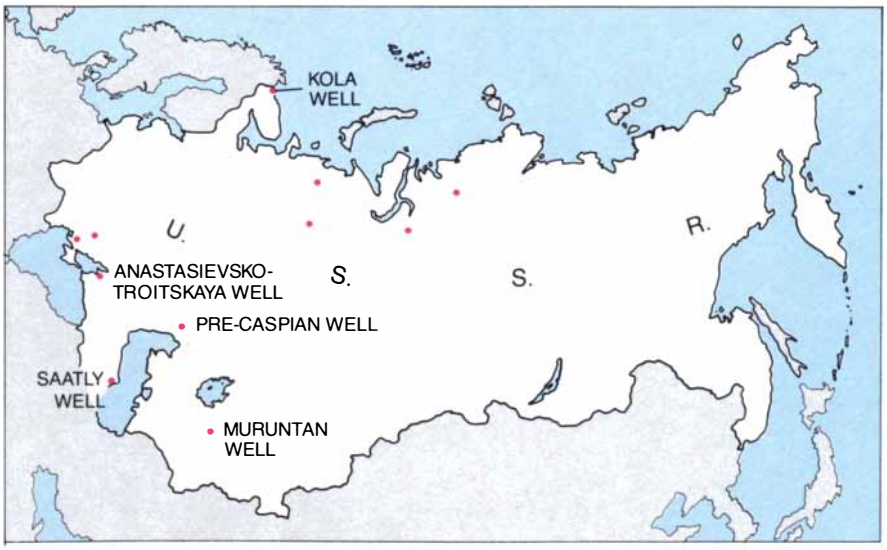
The descent of the well also released flows of gas at all levels. Among the gases identified are helium, hydrogen, nitrogen, methane and other hydrocarbons, and carbon dioxide. The light elements in these gases came, of course, from the crystal structure of the rock by the same metamorphic processes that freed the water. That there were two sources for the carbon dioxide is suggested, however, by its carbon-isotope composition. The presence of fossil microorganisms in the Proterozoic rocks, hundreds of millions of years old, indicates that the second source of the carbon dioxide was biogenic.

The drilling of the Kola well inaugurated a long-term program of systematic drilling of the deep structure of the earth's crust in the territory of the U.S.S.R. that will continue into the next century. Under the auspices of the Interdepartmental Council for the Study of the Earth's Interior and Superdeep Drilling, geologists and mining engineers undertook in 1962 to develop the technology for the drilling and study of deep wells. In 1970 drilling began at Kola and at Saatly in the Baku oil and gas district on the Caspian Sea, where the well has penetrated to 8,500 meters. A deep seismic survey of the Soviet territory has meanwhile helped to establish the sites of the other deep and su-

WELLHEAD AT KOLA is flanked by sections of aluminum-alloy drill pipe. The photograph was made within the drilling derrick that rises above the wellhead and supports the drill string; the structure is 86 meters high, with a capacity of 400 metric tons. The power unit for the drill, situated at the bottom of the well, is a turbine driven by the high-pressure flow of drilling mud pumped from the surface.



DERRICK HOUSING stands 30 stories above the tundra at the Kola site, 250 kilometers north of the Arctic Circle. The enclosure keeps the wellhead above freezing for year-round drilling.



DRILLING SITES selected for a comprehensive study of the earth's crust dot the U.S.S.R. With technology developed in the drilling of the 12,000-meter well at Kola and the Saatly well on the Caspian Sea, which has reached a depth of 8,500 meters, three more wells will be drilled to depths of more than 7,000 meters at the labeled sites. At the same time wells of lesser depth will be bored at other locations (*unlabeled dots*). The wells all lie at the intersections of recent seismic profiles and will add to an understanding of the genesis of ore and hydrocarbon deposits.

perdeep wells that are now to be drilled.

A better understanding of the deep structure of the crust will yield methods for predicting the occurrence of and prospecting for mineral deposits and oil and gas fields at depths far below those exploited today. As the Kola well has shown, mineral resources may be found at great depth. An essential objective of the research enterprise, therefore, is to develop technology for penetrating the earth's interior to depths of 10,000 to 15,000 meters.

On the global scale the earth's crust is thin enough: a mere 35 kilometers in a radius of 6,000 kilometers. Seismic and other indirect evidence seems to confirm the hypothesis, put forward in 1926 by the British geophysicist Harold Jeffreys, of a three-layered—sedimentary, granitic and basaltic—continental crust. The correlation of the density of rock samples measured in the laboratory with the velocity of seismic waves observed in the field gives a density of 1.8 to 2.5 grams per cubic centimeter and a velocity of about five kilometers per second for sedimentary rock. Density and velocity rise to 2.5 to 2.75 grams per cubic centimeter and five to six kilometers per second in granitic rock. At the so-called Conrad discontinuity the velocity of seismic waves rises to six to seven kilometers per second; this has been taken to mark the transition to the basaltic layer with a density of 2.75 to three grams per cubic centimeter. The granitic layer, composed of the lighter elements oxygen, silicon and aluminum, was laid down in the Archean era and is widely developed on the surface of the continents. While the continental crust may thicken to 70 or 75 kilometers under mountain ranges, the oceanic crust has a depth of only five to 10 kilometers; it is commonly thought to be composed of the basaltic layer overlain by deposits of sediment.

Below the continental and oceanic crust the Mohorovičić discontinuity in the velocity of seismic waves locates, it is supposed, the top of the mantle. The velocity rises abruptly to 7.8 kilometers per second and increases in jumps to 13.6 kilometers per second down through the upper (35 to 300 kilometers), the middle (300 to 950 kilometers) and the lower mantle (950 to 2,900 kilometers). The density of the mantle rock ranges correspondingly from 3.3 to 5.9 grams per cubic centimeter. From the direct evidence of volcanic rock as well as from indirect evidence supplied by meteorites and geophysical and astronomical data, the mantle is thought to be composed of magnesium and iron silicates down to a depth of 1,100 kilometers. At lower levels sulfides and oxides of iron, copper, zinc, lead, mercury, antimony and bismuth, as well as selenium, tellurium, gold, silver and other

heavier metals, predominate. Temperatures in the upper mantle range apparently from 1,000 to 1,500 degrees Celsius, and the pressure at those depths reaches 100,000 atmospheres.

To test and extend the picture of the earth's crust put together from indirect evidence, geologists have yearned to sink wells to the Conrad and the Mohorovičić discontinuity beyond. The Kola Peninsula was chosen for the present enterprise because the Baltic shield there is representative of the ancient granitic continental plates of India, North America, southern Africa, western Australia, Antarctica and Greenland. The well site also lies in the Pechenga copper- and nickel-ore mining region, and it was hoped that a well there would throw light on the genesis of those ores. The region, exposed to glaciation and weathering for hundreds of millions of years, has lost 5,000 to 15,000 meters of the upper portion of the granitic layer by erosion. Thus the 12,000-meter geologic section of the Kola well corresponds to an "average" continental layer at depths of between 8,000 and 20,000 meters below the surface.

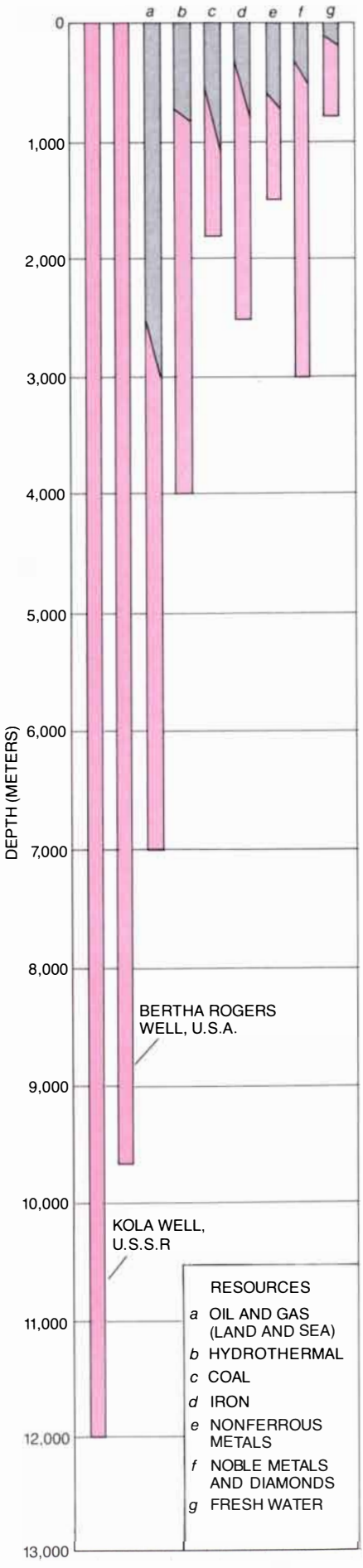
The sinking of the Kola well has induced significant innovations in drilling technology. Below 10,000 meters conventional rotary drilling, which turns the bit at the bottom by rotating the entire drill string, encounters disabling difficulties. The 800- to 900-metric-ton weight of the steel-pipe string sets up enormous stresses at the surface and amplifies the forces resisting rotation of the string. In the Kola well a bottom-hole turbine, driven by the flow of the drilling mud, turns the bit. Rotation of the string is eliminated entirely or is reduced to a few turns per minute, summoned to back up the turning of the bit by the turbine.

The drilling mud in an ordinary well is pumped down the inside of the drill string to cool the grinding bit and entrain the cuttings; it returns to the surface by way of the annular space between the drill string and the wall of the well and in the process helps to maintain the integrity of the wall. In the Kola well the mud is pumped to the turbine at a pressure of 250 atmospheres. A reducing gear under the turbine in the string lowers the rotation of the bit three or four times below that of drills in conventional wells to an optimal 80 to 150 revolutions per minute and correspondingly increases its rotation moment. A hydraulic feedback line in the pumping system, transmitting pressure surges in the drilling mud at 1,500 meters per second, controls the rotation of the turbine and the string and thereby the speed and moment of the drill bit. Noise filters of original design ensure reliability of control at a depth of 12 kilometers.

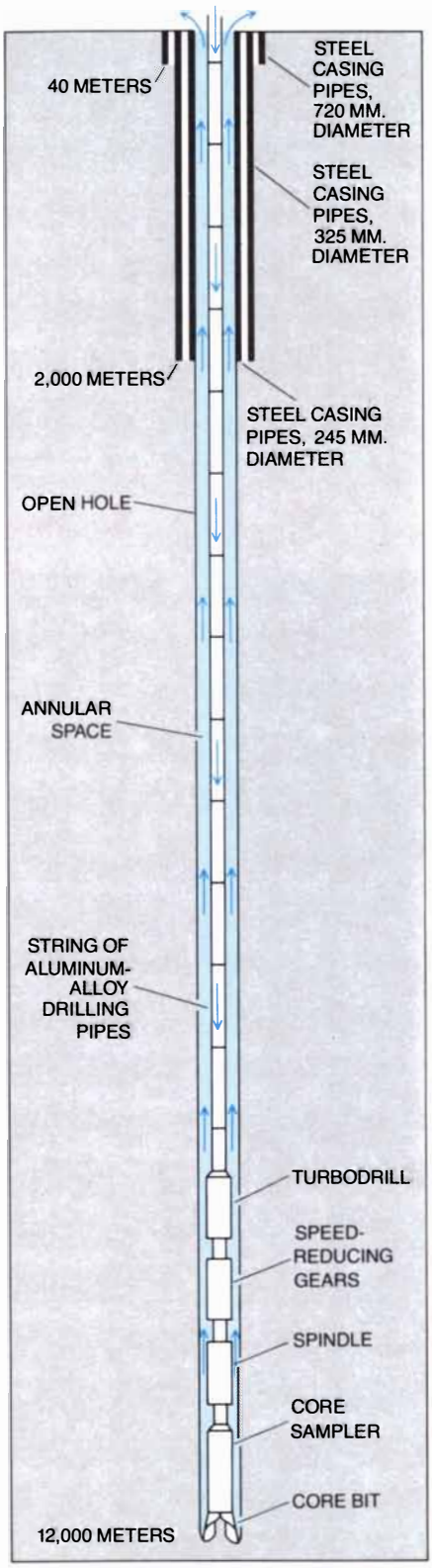
The drill string, made of a high-strength aluminum alloy, weighs only 400 or 500 metric tons. This is a great advantage, since the replacement of worn-out bits or the recovery of core samples requires that the entire string be pulled to the surface and lowered to the bottom again hundreds of times. To accomplish the penetration of the Kola well to 11,000 meters, the total length of drill pipe run through the well mouth in the course of such round trips exceeded 25 million meters. Apart from reduction of the burden on the derrick, the lighter weight of the string decreases the wear on the string itself and on the casing and wall of the well brought about by friction in all this travel. That wear can be considerable, for drilling never proceeds perfectly vertically. The Kola well drifted from the vertical by an average of five degrees down its passage to a maximum of 17 degrees at 10,000 to 10,500 meters; at that point the drill bit was 840 meters to one side of the wellhead [*see illustration at right on next page*].

The design of the Kola well itself had to respond to unpredictable changes in conditions as the drill bit worked its way down. While the first two kilometers of the well were cased [*see illustration at left on next page*], it became evident that greater freedom of movement and decision making would be necessary farther down. The result was the strategy of "open-hole advanced drilling." Below 2,000 meters the entire well has been drilled without casing.

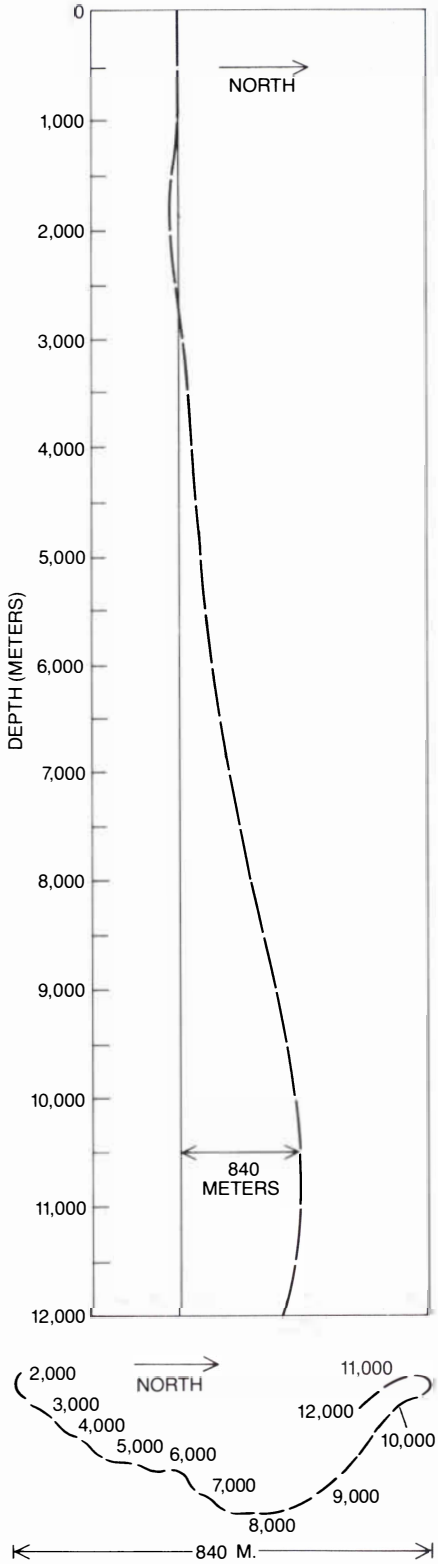
Every piece of rock extracted from the deep earth has its value. As the Kola well deepened it became increasingly difficult to bring cores to the surface. Ordinarily cylindrical core samples 60 to 80 millimeters in diameter enter the drill tube as the bit erodes the ring of rock at the bottom; the core remains there in the barrel until the drill string is hauled to the surface. At sufficient depth, however, the rock "bursts" from the release of internal forces when the drill bit relieves the compression of the overlying rock strata that sets up those forces. If ordinary sampling equipment were used at such depths, pieces of the core would block the entrance to the core barrel, and 90 to 95 percent of the core would be ground into the drilling mud. A new core-sampling tool that diverts some of the mud stream into the core barrel catches the pieces of the burst core and carries them



WELLS AND MINESHAFTS vary in depth according to the resource sought. The bar graphs compare the median (*gray*) and maximum (*color*) depths to which shafts of each type have been sunk with the depth of the Kola well and the Bertha Rogers well in Oklahoma. That borehole, the world's second-deepest, was a gas well; drilling stopped at 9,674 meters when bit struck molten sulfur.



SCHEMATIC OF THE WELL shows the progressive narrowing of the hole. To a depth of 40 meters the hole was drilled with a bit nearly a meter across and walled with pipe 720 millimeters in diameter. Drilling proceeded with a 214-millimeter bit. The first 2,000 meters of the hole was eventually widened and cased with 325-millimeter pipe to control collapses. At greater depths the hole is uncased but is shored up by the pressure of the drilling mud, which flows down the pipe and back to the surface in the space around the pipe.



BOREHOLE TRAJECTORY, mapped in profile (*top*) and as horizontal wander in relation to the wellhead (*bottom*), departs from the vertical by a maximum of 840 meters, at a depth of 10,500 meters. Some drill-hole wander is inevitable, but it increases friction as the drill string is lowered into a borehole or removed for the recovery of core samples or the replacement of worn-out bits. Sensors incorporating gyroscopes and plumb bobs were used to measure the inclination of the hole and steer the bit in an attempt to reduce wander.

into a special chamber, clearing the entrance for new samples.

The technology now demonstrated at the Kola well opens the possibility of drilling to between 15 and 17 kilometers. New problems must, however, be anticipated. Ordinary aluminum alloys lose their strength at temperatures of between 110 and 150 degrees C. We have succeeded in developing alloys to withstand temperatures of between 230 and 250 degrees. Powder metallurgy promises aluminum alloys with temperature stability at the 270 to 300 degrees that must be anticipated as the well goes deeper. Titanium-alloy drill pipes may be made to withstand the 400-degree temperature that occurs at even greater depths.

Along with high temperatures, technology for deep drilling must anticipate pressures reaching 3,000 atmospheres, corrosive chemical effects from highly mineralized trapped water, loss of stability in the rock mass around the borehole and deviation of the hole from the vertical. Retrieval of core samples to the surface becomes increasingly tricky. To solve this problem it is necessary to design a means to core and to transport rock samples in sealed containers that will preserve conditions prevailing at the hole bottom, including the saturation of the rock there with gas and water. A pressure chamber is now being developed in the laboratory to simulate the conditions that prevail at depths of 15 to 20 kilometers, that is, temperatures of 300 to 400 degrees C. and pressures of 2,000 to 3,000 atmospheres.

The earth history penetrated by the Kola well must, of course, be read from the bottom up. In the Archean complex, between 12,000 and 6,842 meters, the first stage saw the accumulation of thick sedimentary strata from the weathering of the primal granites, the weathering being punctuated by intrusive flows of plutonic granite. That these granites were rich in iron and titanium is evidenced in the concentration of magnetite and ilmenite ores, which reaches 40 to 50 percent of the rock at 8,711 meters. In the second stage the rocks underwent folding, metamorphism and ultrametamorphism at temperatures of 750 to 900 degrees C. and pressures of 5,000 to 11,000 atmospheres.

Geologists are able to reconstruct history in this way because rocks are highly sensitive recorders of temperature and pressure. From the same starting material supplied by the mantle, metamorphic rocks develop a variety of distinguishing characteristics, "facies," which may include variation in elemental composition, depending on the pressure and temperature at their formation. In general, metamorphism results in the production of denser rock with less bound water from more hydrous rock.

Elements not incorporated in the new crystal phases go into solution with the newly freed water.

Radiocarbon dating places the culmination of the Archean metamorphism in the Kola Peninsula at 2.7 to 2.8 billion years ago. It was followed by deep erosion by water and accumulation of sediments of the weathering crust in isolated depressions. In some regions of the world, notably South Africa, immense deposits of metal-bearing conglomerates are associated with such sedimentary deposits.

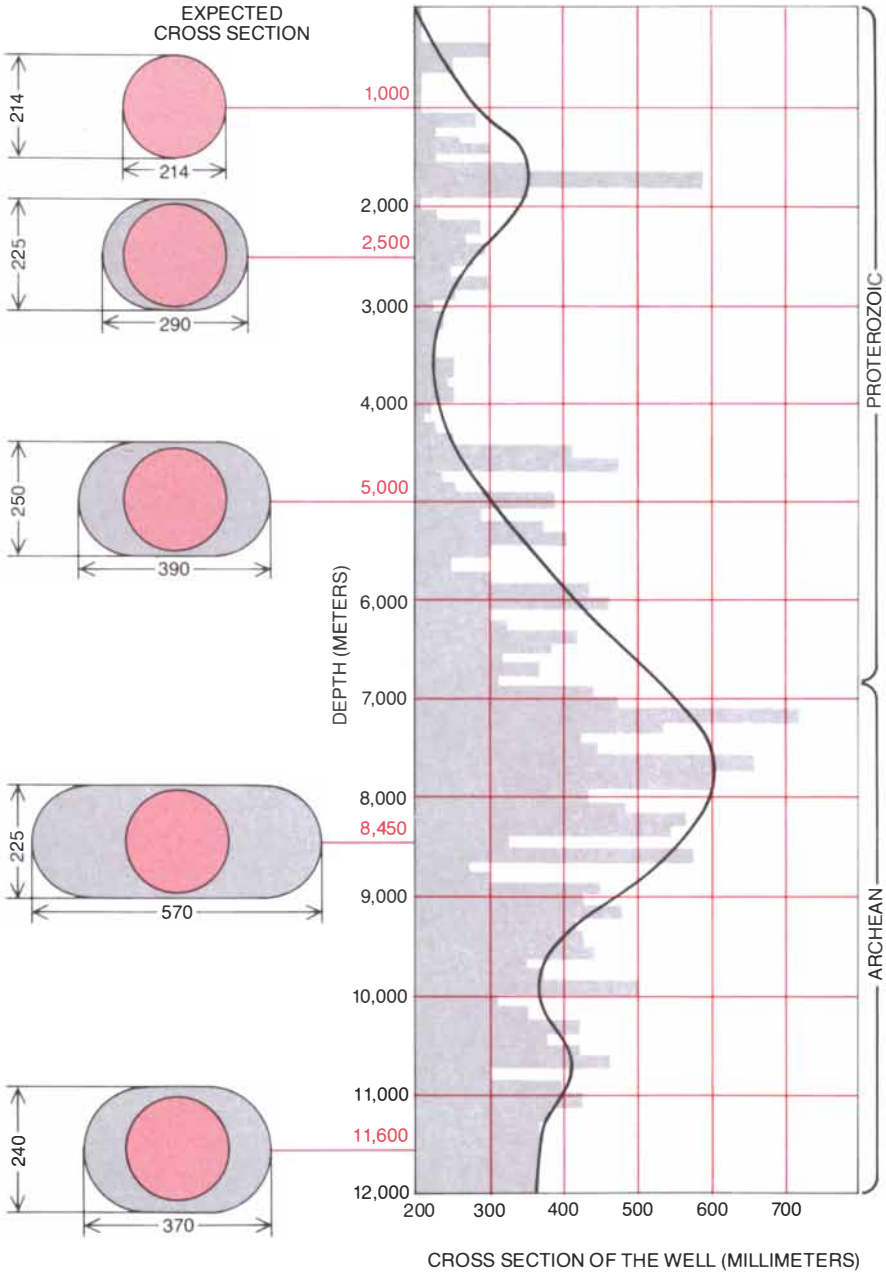
The Proterozoic complex, from 6,842 meters to the surface, began to build up on the Archean basement 1.1 billion years ago. The rock records four major phases in the buildup of the continental crust during this period. During the first phase, sedimentary volcanic material was deposited on the Archean floor. The gravelly strata show abrupt changes in thickness, indicating they were deposited by streams in ancient valleys. The first of two cycles of plutonism brought intrusion of granitic rock, devoid of metallic elements, that overlaid the previously formed rocks and brought them under alteration through low-temperature metamorphism. In the second cycle the mantle contributed rock rich in metallic elements. These ore-bearing intrusions laid down the copper-nickel sulfide deposits that outcrop in the Pechenga region. The Kola well found such deposits at intervals down to a depth of 1,500 to 1,800 meters. The fourth phase of the Proterozoic era brought on the anomalous episode of "closed" metamorphism that resulted in the hydraulic disaggregation of the metamorphic rock first observed in the Kola well through the zone 4,500 meters thick that crosses into the Archean basement.

Core samples show the content of chemically bound water remaining constant, at 4 percent of the rock, to 4,500 meters from the surface. There, quite abruptly, the water content of the rock decreases to 2.1 percent. It is there that the zone of disaggregation begins, with microfracturing of the rock increasing its porosity by three or four times over that observed in the rock above and correspondingly reducing the density of the rock mass from 3.1 grams per cubic centimeter to 2.9. The freed water trapped in the interstices of the fractured rock, calculations show, forced the initial total volume of rock and water to increase by 1.7 percent. The enormous hydraulic pressure thus exerted caused the microfracturing that must initially have increased the porosity of the rock to 10 times that of the overlying strata.

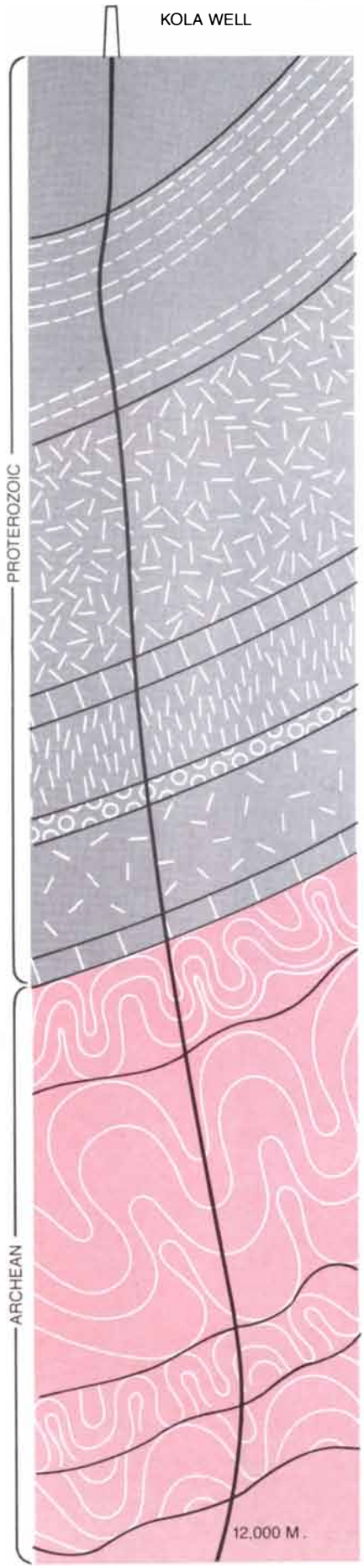
The lower boundary of this zone, at 9,000 meters, is marked by an increase in the velocity of the seismic waves. This proved, of course, not to be the presumed Conrad discontinuity from granitic to basaltic rock. The increase in elastic-wave velocity simply marks the bottom of the zone of disaggregation with the return to rock of normal density and the cessation of the inflow of thermal water into the well.

The value of a firsthand look at the interior of the earth is amply demonstrated by this discovery. Hydraulic disaggregation of metamorphic rock may explain the geologic nature of boundaries marked by changes of elastic-wave velocity and reflection of such waves observed around the world in the upper part (down to 15 or 20 kilometers) of the earth's crust. Moreover, this phenomenon must substantially change notions about water circulation in the continental crust and the nature of the subsurface hydrosphere.

The high mineral content of the fissure waters and the flow of gases in the well show that active gas-water processes proceed in crystalline rock at great depths. The prospects for the discovery of new ore deposits at those depths are raised correspondingly. In the zone of



CROSS SECTION OF THE BOREHOLE changes with depth, although bit diameter was constant. The bar graph (*right*) shows caliper measurements of the hole across its greatest diameter at each depth; the curve charts the trend. The generally elliptical shape of the hole represents the resolution of unequal horizontal compressive forces in the rock; the hole's short axis corresponds to the direction of the greatest force. The rock spalled and burst along the axis of lesser force, widening the hole and yielding fragments that were swept to the surface in the drilling mud. The magnitude of the effect varied with changes in rock pressure and character.



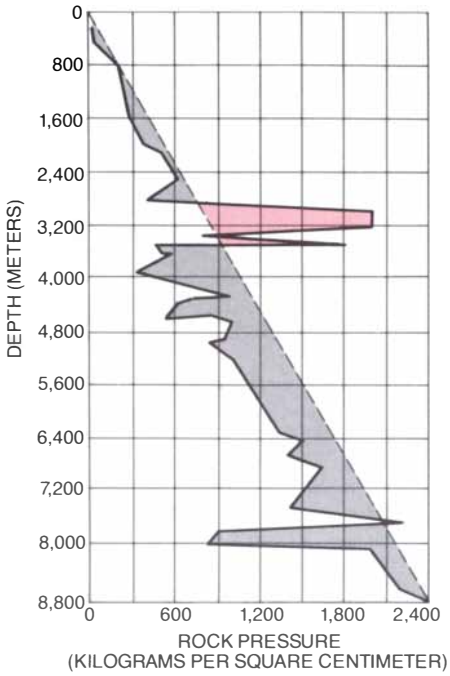
GEOLOGIC STRATA through which the borehole passes encompass 1.4 billion years of earth history. The sedimentary and volcanic rocks found at depths of up to 6,800 meters (*gray*) date from the Proterozoic era, which began 2.4 billion years ago. The deeper granitic strata (*pink*) were laid down as long ago as 2.7 billion years during the Archean era, the first era of geologic time. It was expected that the well would pass from granitic rocks into a basement layer of basalt at a depth of 9,000 meters, where an abrupt change in seismic-wave velocity occurs. Instead it was found that the velocity change marks the base of a 4,500-meter-thick zone of rock that has been shattered by the pressure of water driven from crystalline minerals during metamorphism.

disconsolidation in the Kola well the rock fragments are cemented by sulfides of copper, nickel, iron, zinc and cobalt. The relatively low temperature of formation of these sulfides and the isotopic composition of the sulfur, which resembles that of meteorites, suggest these sulfides were generated by the mantle. Favorable conditions for the formation of hydrothermal ore deposits thus prevail through an extensive vertical range in the continental crust.

Direct measurement of temperatures in the well compels revision of ideas about the distribution and flow of heat in the earth's interior. It has been supposed that in a tectonically stable region such as the Baltic shield the temperature would increase only slowly with depth, rising to 50 degrees C. at 7,000 meters and perhaps 100 degrees at 10,000 meters. In fact the measured temperature gradient fit the expected one-degree increase every 100 meters down only to 3,000 meters. From there temperature began to rise by 2.5 degrees every 100 meters. At 10,000 meters it reached 180 degrees. Hundreds of cubic meters of cold drilling mud pumped into the well returned to the surface heated to 45 degrees. Since the radioactivity of the rocks traversed by the well can make only insignificant contribution to this heat flow, it must plainly come from the mantle below.

The success of the Kola well has instilled new confidence in plans for the systematic deep and superdeep drilling of the earth's crust encompassed by the borders of the U.S.S.R. [*see bottom illustration on page 100*]. Sites for the wells have been chosen at the crossing points of a network of interlinked seismic profiles, including the contributions from an extensive program of deep seismic soundings that has been carried out over the past decade.

The drilling of the wells will help, in turn, to perfect the interpretation of seismic data. Direct readings on conditions and core samples from the wells will establish secure correlation between geodynamical boundaries in the earth's crust and upper mantle and observed structural and compositional boundaries and contacts. This work will help also to improve the resolution and accuracy of seismic recordings and thereby increase the amount of information that can be extracted from indirect geophysical observation. Anomalies in the propagation and velocity of seismic waves not correlated with structural data from the wells may present significant new questions for study.



ROCK PRESSURE, derived from measurements of acoustic-wave velocity through the rock near the hole, frequently deviates from the linear increase with depth (*dotted line*) expected in homogeneous material. The zone of anomalously high pressure at a depth of 3,200 meters reflects the high density of impervious strata at that depth. The disproportionately low pressures from about 4,000 to 9,000 meters mark a zone of fractured rock.

Drilling will continue at the Kola and Saatly wells. They will serve as laboratories for intensive study of the physiology as well as the anatomy of the crust at those sites. The next three superdeep (more than 7,000 meters) wells are to be drilled at Muruntan, Anastasievsko-Troitskaya and near the Caspian Sea. The drilling of six deep (more than 4,000 meters) wells will proceed simultaneously, three of them in gas- and oil-bearing regions and three in ore-bearing regions. Thus in addition to answering fundamental questions about the structure of the continental crust, the deep seismic profiles combined with direct observation in the deep and superdeep wells will assess major geotectonic elements in the U.S.S.R. considered to hold significant resources.

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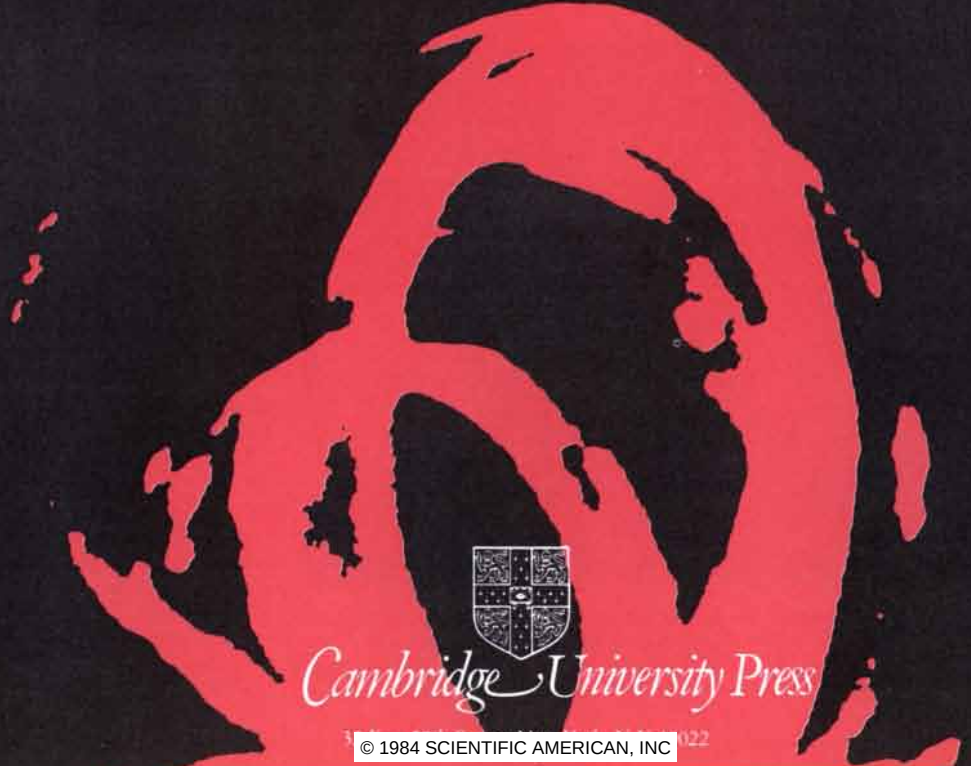


Turning Something Over in the Mind

The imagined rotation of an object mirrors a physical rotation. The mental process can be investigated objectively, yielding quantitative information about one form of spatial thinking

by Lynn A. Cooper and Roger N. Shepard

What is thinking? Introspection supplies preliminary answers. Some thought is verbal: a kind of silent talking to oneself. Other mental processes seem to be visual: images are called to mind and wordlessly manipulated. Evident though they are, the mechanisms of thought long eluded experimental analysis and quantification. How can these seemingly inaccessible, subjective processes be measured and investigated scientifically?

We have begun to provide an answer to this question by devising experiments to probe the nature of one mode of thinking: imagined spatial operations. Our results confirm empirically what is subjectively apparent: that the mind can model physical processes, subjecting them to the geometric constraints that hold in the external world. Evidence of such mental operations abounds in everyday life. Consider this question: How do you take a card table through a narrow doorway without folding up its legs? Most people report that they must envision the process of turning the table on its side, putting two of the legs into the opening, then turning and moving the table so that the legs, the top and the other pair of legs pass through the door.

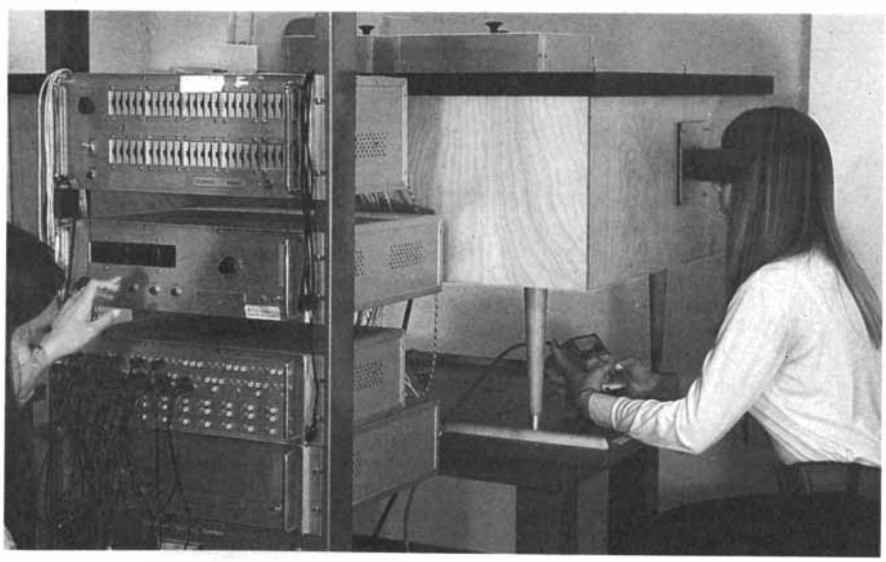
This kind of spatial imagination may not be peculiar to human beings. One of us witnessed a German shepherd retrieving a long stick that had been thrown over a fence from which one vertical board was missing. The dog bounded through the gap, seized the stick in its mouth and plunged headlong back toward the narrow opening. Just as catastrophe seemed imminent the dog stopped short, paused and rotated its head 90 degrees. With the stick held vertically it passed through the fence without mishap. The operation that took place in the mind of the dog in the moment before it turned its head presumably was not verbal. Might it not have been a preparatory mental rotation of the stick? (And was it not by spatial visualization rather than verbal deduction that you, the reader, understood how catastrophe threatened and was averted?)

The ability to represent objects or arrangements of objects and their transformations in space clearly is valuable in managing the concrete realities of everyday life, making it possible to plan actions and to anticipate outcomes. It may also play an important role in abstract thought. Many scientists have testified that their greatest achievements grew from imagined spatial relations and transformations. Two well-known cases are Friedrich Kekulé's image of the structure of the benzene molecule and James Watt's visualization of the mechanism of the condensing steam engine. Albert Einstein even remarked that he arrived at the theory of relativity by "visualizing . . . effects, consequences and possibilities" through "more or less clear images which can be 'voluntarily' reproduced and combined."

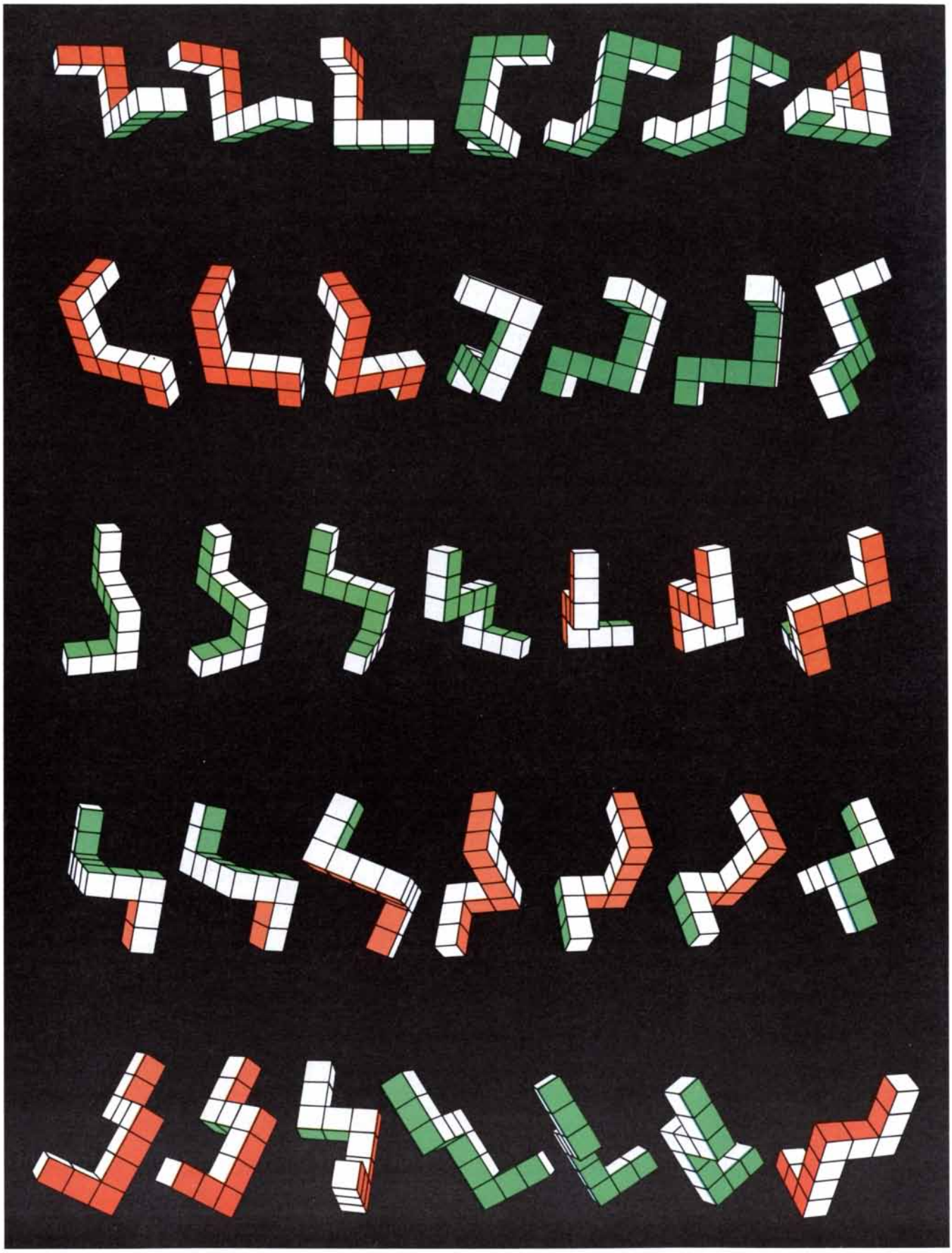
Yet subjective and qualitative assessments, even those made by scientists, cannot substitute for an objective and quantitative understanding. As the distinguished physiological psychologist K. S. Lashley put it in 1923, "introspection may make the preliminary survey, but it must be followed by the chain and transit of objective measurement." Such systematic inquiry into spatial imagination has been slow in arriving.

For the first half of the 20th century theoretical barriers stood in the way. During this time American behaviorists from J. B. Watson to B. F. Skinner tried to sever psychology from its introspective origins in philosophy and establish it on its own empirical foundations. They insisted that all theoretical terms correspond to objectively specifiable stimuli and responses and banished such references to subjective phenomena as the terms consciousness, mind, thinking and imagining. Laboratory studies focused on physically recordable events such as bar pressing by rats and lever pecking by pigeons rather than on the hidden workings of the mind.

During the second half of the century new developments began to erode the barriers the behaviorists had erect-



TACHISTOSCOPE enables an investigator to time a subject's responses to visual stimuli. When the investigator closes a switch, a display is illuminated, revealing the images, and a timer begins to run. The subject's reaction, registered in the illustrated case through hand-held controls, stops the clock to yield a precise record of the interval between stimulus and response.



THREE-DIMENSIONAL SHAPES rotated in space are depicted in computer-generated perspective drawings. When the subjects were shown pairs of line drawings portraying the same shape in different orientations, the time they took to recognize that the shapes were identical was proportional to the angular difference in the orientations shown. The linear increase in comparison time with difference in orientation suggested that subjects had to imagine one shape rotated into the orientation of the other in order to check for a match.

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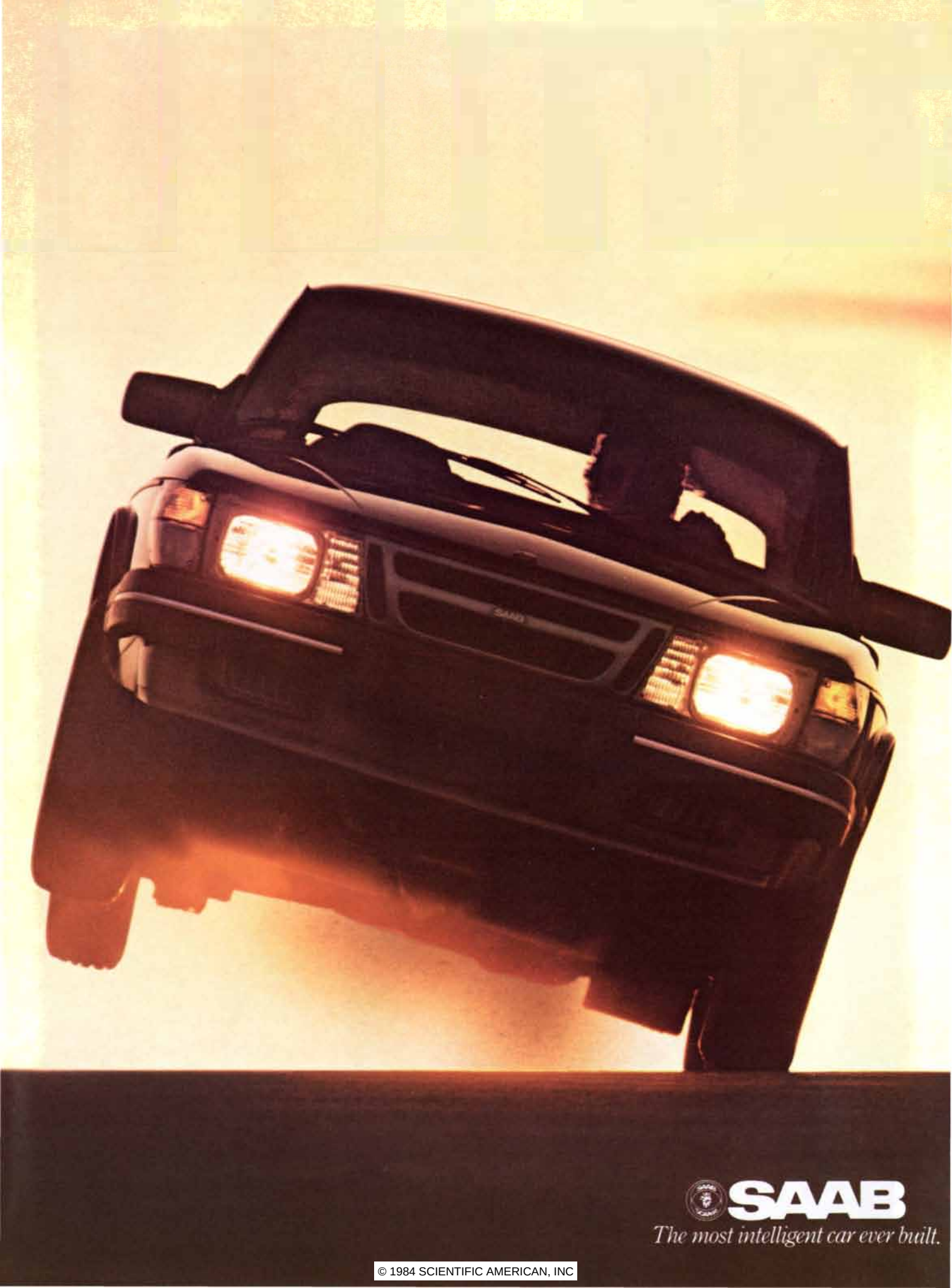
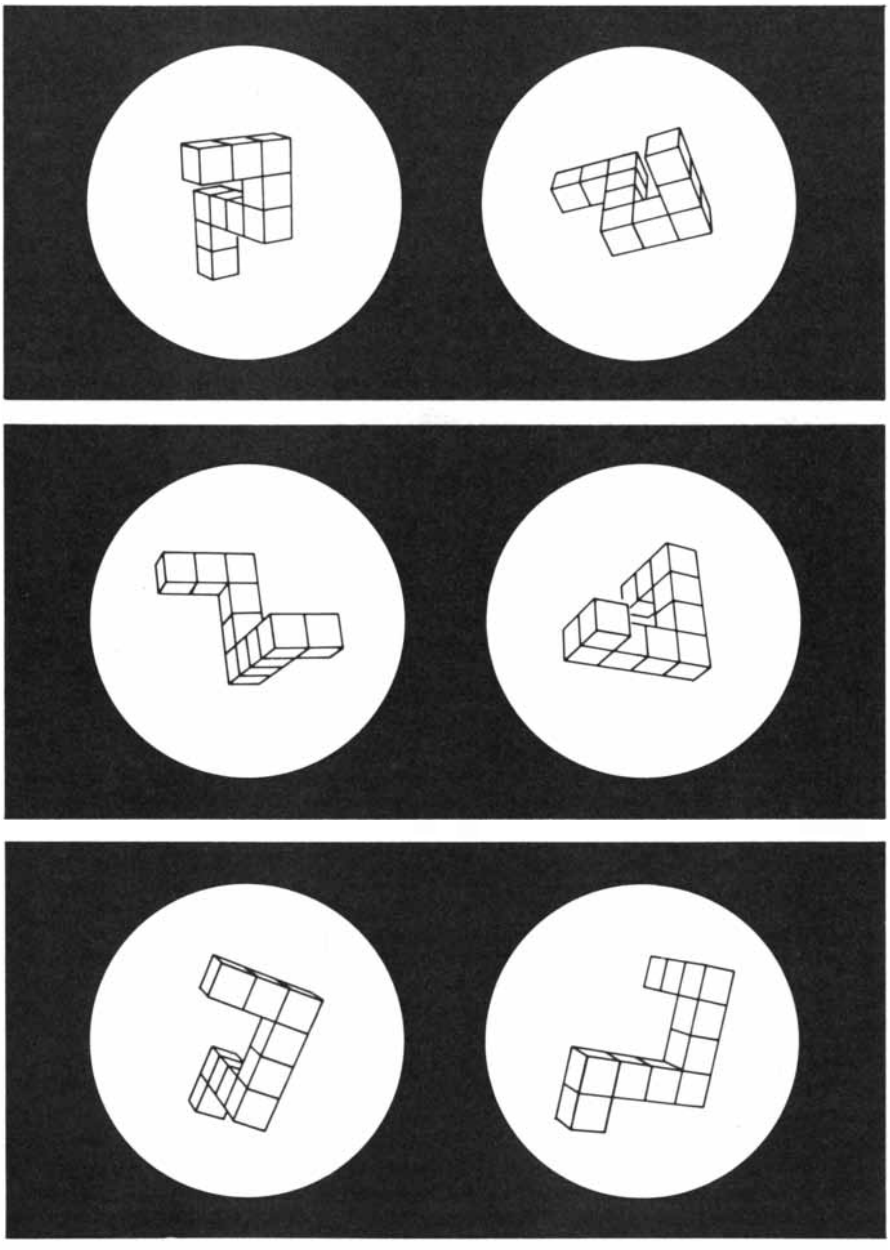


ed against the study of the structures and processes of thought. The linguist Noam Chomsky made a forceful argument that language behavior is guided by innate schematisms that had gone completely unrecognized by the behaviorists. And experimental psychologists produced increasingly compelling demonstrations that mental processes could be inferred and even quantified from patterns in objectively recorded data.

Our own experiments were designed to probe the kind of mental process the behaviorists ignored in a way that meets the behaviorists' demand for objective and quantitative data. The first of our inquiries into the process of spatial imagination, undertaken in 1971 by one of us (Shepard) with Jacqueline Metzler, a graduate student, met both criteria. Each experimental trial was objective in the sense that the subject's response to a stimulus was either objectively correct or incorrect, and quantitative in the sense that the variable of interest was the time it took the subject to respond correctly.

The subjects of the experiment compared computer-generated perspective line drawings presented in pairs. Each drawing portrayed a three-dimensional object composed of 10 cubical blocks joined face to face to form an armlike structure exhibiting three right-angled bends [*see illustration on page 107*]. Certain of the pairs showed identical structures, usually presented in different spatial orientations; others, randomly mixed with the first type in the series of trials, showed structures that differed in both shape and orientation. These pairs portrayed enantiomorphic structures, which differ by a reflection in space, much as a left hand differs from a right.



PERSPECTIVE VIEWS displayed in pairs to the subjects of the authors' first experiment differed in three ways. In the first case (*top*) the drawings showed identical objects in positions that differed by a rotation within the plane of the picture. In the second (*middle*) the orientations portrayed differed by a rotation in depth. Subjects determined the identity of the objects in pairs of both types equally quickly, which suggests that in both cases they imagined the objects as three-dimensional solids rotating in space in order to compare them. A third kind of drawing pair used in the trials depicted enantiomorphic, or mirror-image, shapes (*bottom*).

In each trial the subject looked into a tachistoscope, a darkened box in which visual stimuli placed at the back could be displayed at precisely controlled times. The experimenter inserted a pair of drawings and closed a switch to illuminate them, simultaneously starting a clock. The subject then compared the drawings as quickly as possible and responded by pulling one of two levers: a right-hand lever for pairs that showed the same shape and a left-hand lever for pairs that showed different shapes. Either response stopped the clock, thus recording the time taken for comparison.

Because the pairs of drawings represented objects that either were identical or differed by a reflection in space, subjects could not base their comparison on superficial features of the stimuli. The numbers of blocks between successive bends, for instance, were identical in both drawings whether the structures were identical or enantiomorphic. A short-cut search for obvious differences was ruled out. Subjects reported they could compare the shapes only by imagining one of the two objects rotated into the same orientation as the other and then checking for a match. Typically they said they imagined the object on the left turned until its top arm paralleled the corresponding arm of the right-hand object; they then mentally checked to see whether the extension at the other end of the object projected in the same direction as the analogous section of the companion structure.

The reaction times, measured from the moment the drawings were displayed until each subject responded by pulling a lever, provide objective evidence in support of the subjective accounts. The times increased as a linear function of the angular difference between the orientations portrayed. When like objects were displayed in the same orientation, subjects took about a second to detect identity; with increasing angular difference the response times rose steadily, up to an average of 4.4 seconds for the maximum possible angular difference of 180 degrees. Each of the eight young adults who took part showed a linear increase in reaction time, but the slope of the function varied among individuals.

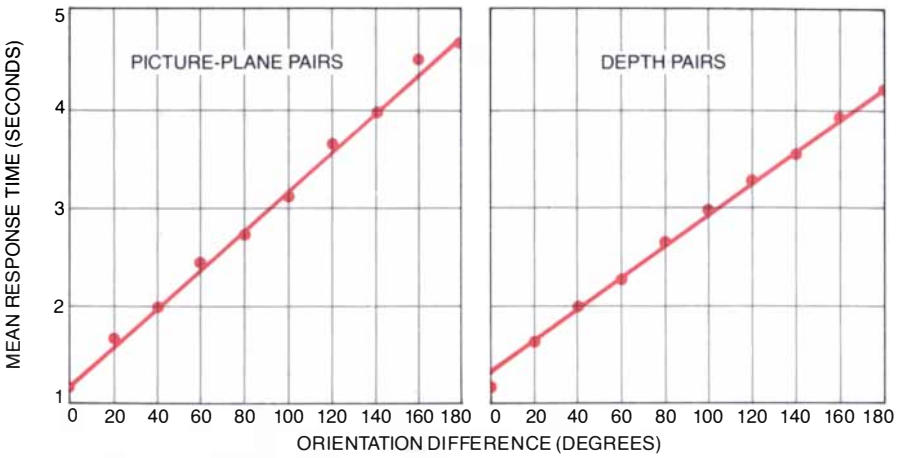
The linear increases suggest that the subjects compared the objects by imag-

ining one object rotated into the orientation of another at a steady rate that swept out 180 degrees in an average of 3.4 seconds (4.4 minus the second needed to compare two objects in identical orientations), that is, at an average rate of 53 degrees per second. Other methods can be conceived for the discrimination of identical and enantiomorphic objects, but none would take an amount of time proportional to the angular difference. Excluded, for example, is the possibility that subjects analyzed each drawing of a pair separately to reduce its structure to a code of some kind and then compared the coded descriptions. One kind of code might describe the number of blocks and the directions of successive bends, starting at one end of the object: 2R2U2L1 for "two blocks, right bend, two blocks, upward bend, two blocks, left bend, one block," for example. The time needed to generate such a code might depend on the orientation of each object. But because the codes are computed independently, the sum of the times needed to generate codes for two objects need not vary with the angular difference between them.

The results not only point to mental rotation as the basis of this kind of comparison; they also indicate that the subjects' mental images represented the three-dimensional structure of the objects portrayed and not simply the two-dimensional features of the drawings. In half of the same-shape pairs the orientations shown differed by a rotation within the two-dimensional plane of the picture; the two drawings thus were identical except in position in the plane. The other half of the pairs portrayed objects differing by rotations in depth [*see illustration on opposite page*]. Although the three-dimensional objects depicted by each pair of this second set of drawings were identical, the drawings themselves, as two-dimensional arrangements of lines and angles, often differed considerably: a rotation in depth simultaneously shifts some features of a three-dimensional object into the plane of a drawing while removing other features from the picture plane.

Yet the slope of the reaction-time function was no greater for the pairs corresponding to a rotation in depth than it was for those in which the drawings differed by a picture-plane rotation. The rate of imagined rotation was as fast when the transformation portrayed involved three dimensions as it was when the rotation appeared to take place in two dimensions. The results are consistent with subjects' reports that they interpreted all the drawings, whatever the relative orientations, as solid objects in three-dimensional space. The subjects therefore found all rotations equally easy to imagine.

The progressive and spatial nature of imagined rotations, established in the first experiment, suggests that the process is analogous to transformations in the physical world. It is tempting to view the imagined rotation as the internal simulation of an external rotation. Such a description, however, would be justified only if we could demonstrate that the internal process passes through intermediate states corresponding to the intermediate orientations of a physical object rotating in the external world.



MEAN RESPONSE TIMES increased in direct proportion to the angular difference in orientation of identical objects presented for comparison in pairs of drawings. The linear relation suggested that a process of mental rotation underlies such comparisons. The slope of the function, from which the rate of the imagined rotation can be estimated, was no greater for orientations differing by a rotation in depth than for those differing by a rotation in the picture plane.

To gather this additional evidence for the analogue nature of mental rotation one of us (Cooper) did a series of experiments in which subjects responded not to a pair of objects but to a single figure, displayed at intervals and in a variety of orientations. By triggering an imagined rotation with a single stimulus and then presenting the same or a different object in any orientation and after any delay, we could probe the mental transformation as it was taking place.

Before exploring the ongoing process of rotation, however, an initial question required resolution and therefore a brief experimental digression. We had to establish that the single-stimulus technique causes subjects to imagine the same progressive mental rotations as the paired drawings of the first test did. To evaluate the one-stimulus procedure we again asked subjects to discriminate between an object and its mirror image. In this case we used two-dimensional plane figures rather than the three-dimensional solids of the earlier experiment. Consequently all the orientations shown differed by rotations in a plane.

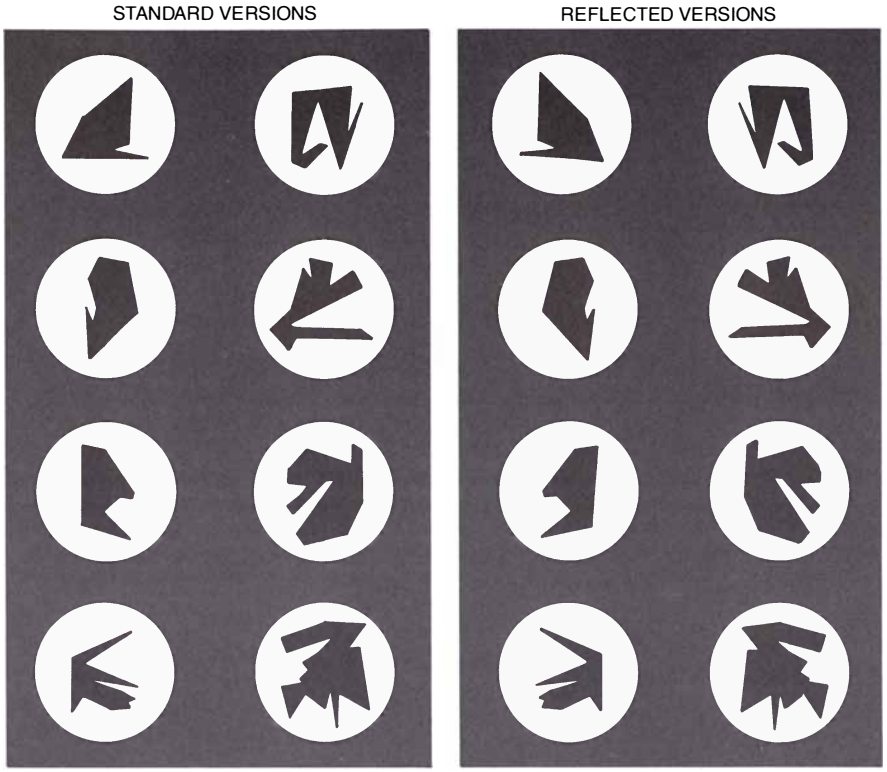
The subjects first learned to differentiate standard from mirror-image versions of each of eight polygons, the orientations of which were kept constant throughout this training [*see top illustration on next page*]. Once the subjects had learned the eight discriminations the experimental trials began.

In each trial a subject was shown one of the polygons in an orientation that either matched the training position or differed from it by some multiple of 60 degrees. The subject's task was to determine whether the shape was the standard or the reflected version of the polygon; to make the discrimination the subject presumably had to imagine the polygon rotated until it either matched or did not match the mental representation of the standard shape that had been learned during the training. In the case of a match the subject pressed a right-hand button for "standard"; when there was no match, the subject pressed a left-hand button for "reflected."

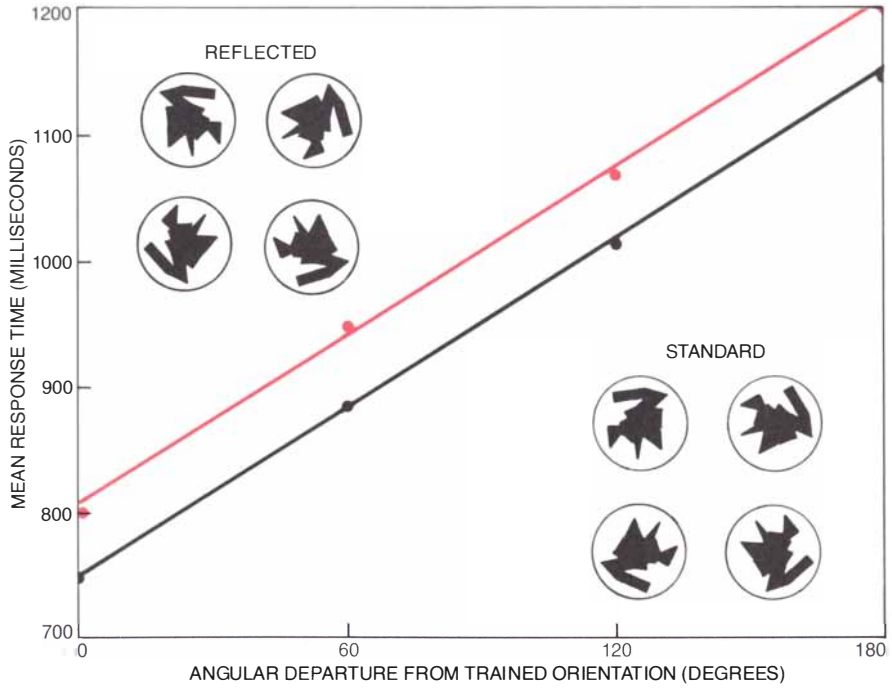
Like the paired-stimulus procedure, this test yielded a linear increase in reaction time with increasing angular departure—departure, in this case, from a learned position rather than from the orientation of an object displayed simultaneously. Subjects responded to the standard versions of the test polygons a constant 60 milliseconds faster than they did to the reflected versions; it appeared that subjects first compared the transformed test shape with a memory of the standard shape and could react to a match immediately but needed an extra interval to initiate the "reflected" response if the shapes did not correspond.

The slopes of the response-time functions for both standard and reflected test shapes were identical, however. The inferred average rate of mental rotation was 450 degrees per second, considerably higher than the 53 degrees per second estimated in the earlier two-stimulus experiment. Evidently the use of plane images presented one at a time allowed swifter responses by enabling subjects to focus their attention on a single stimulus. In spite of quantitative differences the results of this procedure parallel those of the earlier one.

Having determined that the one-stim-



ASSORTMENT OF TWO-DIMENSIONAL TEST SHAPES includes eight different polygons and their mirror-image versions. Prior to a set of experiments in which subjects were shown one of the shapes in an unfamiliar orientation each participant learned to discriminate the "standard" (*left*) from the "reflected" (*right*) version of each shape in a particular orientation. The eight shapes vary in the number of points defining their perimeters, a characteristic that may correspond to psychological complexity. Yet the complexity of a shape had no effect on the speed with which subjects later discriminated its standard form from its reflected form.



LINEAR RELATION OF RESPONSE TIME TO TEST ORIENTATION was found when subjects viewed a familiar polygon in a new orientation and determined whether it was the standard version (*lower graph*) or the reflected version (*upper graph*) of the shape. To evaluate the test shape subjects apparently had to imagine a rotation of the standard shape until it either matched or did not match the shape displayed. If there was no match, it took subjects a consistent extra increment of time to indicate that the shape before them was the reflected version.

ulus, two-dimensional test requires a mental rotation like that required by the two-stimulus comparison, we could modify the procedure to scrutinize more closely the hypothesis that mental rotation is analogous to rotations in the physical world. The second of the single-stimulus experiments directly tested subjects' statements that they appraised a stimulus by imagining its turning until it matched the learned shape. In effect we reversed the earlier sequence of events: instead of presenting subjects with a stimulus for comparison with a learned shape, thus requiring them to imagine a corrective rotation, we first asked them to imagine the rotation of a learned shape and only then presented a stimulus for comparison.

All the subjects in this experiment had taken part in the earlier one-stimulus experiment and were familiar with the test shapes. In each trial a subject viewed an outline drawing of one of the eight standard polygons that was displayed in the training orientation. The outline was followed by a circle containing a pointer positioned in one of six equally spaced angular increments from zero degrees to 300 degrees of clockwise rotation. The subject then imagined the outlined shape rotated into the orientation indicated by the pointer. In half of the trials the subjects had been instructed to do a clockwise mental rotation; in the other half they had been told to imagine the displayed shape rotated in a counterclockwise direction.

To indicate that the mental operation was complete the subject pressed a button, thus stopping the clock that recorded preparation time. Simultaneously a version of the outlined polygon appeared in the orientation indicated by the arrow and a second clock started. As quickly as possible the subject announced whether the drawing showed the standard or the reflected version of the shape by saying "S" (for "standard") or "R" (for "reflected") into a microphone. A voice-activated relay then stopped the second clock.

Each trial hence yielded two times: the time required to effect the mental rotation and the interval then necessary for the subject to classify a test stimulus. Both sets of results confirmed earlier findings. The time needed for the preparatory mental rotation increased linearly with the angular departure from the training orientation, as earlier results had led us to expect. Moreover, in previous experiments the direction of mental rotation was not specified and the greatest testable rotation was 180 degrees. Here the linear increase in preparation time extended to the maximum clockwise or counterclockwise rotation of 300 degrees, providing further evidence that the mental operation was analogous to a physical rotation. The

inferred rate of the preparatory rotations, an average of about 370 degrees per second, was comparable to the 450 degrees per second estimated from the earlier one-stimulus experiment.

The second set of times, which recorded the interval required for subjects to respond to the test stimulus appearing after they signaled readiness, confirmed that the act of mental rotation did in fact prepare them to make the discrimination. On the average they classified each test shape as standard or reflected in less than half a second, regardless of its angular departure from the learned position. If the subjects had needed to do further mental operations after they confronted the test stimulus, response times presumably would have increased with the angular departure of the test stimulus, as they had done in earlier experiments where there was no opportunity for a preparatory mental rotation.

The experiments described so far all document characteristics of completed mental rotations. We found that the time required increases in direct proportion to the angle of rotation, and we confirmed that having imagined a shape rotated into the orientation of a physical stimulus, a subject can determine identity or difference with uniform speed, whatever the degree of rotation. But to characterize the mental process as analogous to physical rotations we still had to show that the mental process passes through stages corresponding to the intermediate angles of a physical rotation. If such a correspondence does exist, the angle at which a displayed shape will elicit the quickest response from an individual who is imagining an ongoing rotation of the shape should change steadily and progressively with time, in step with the mental rotation.

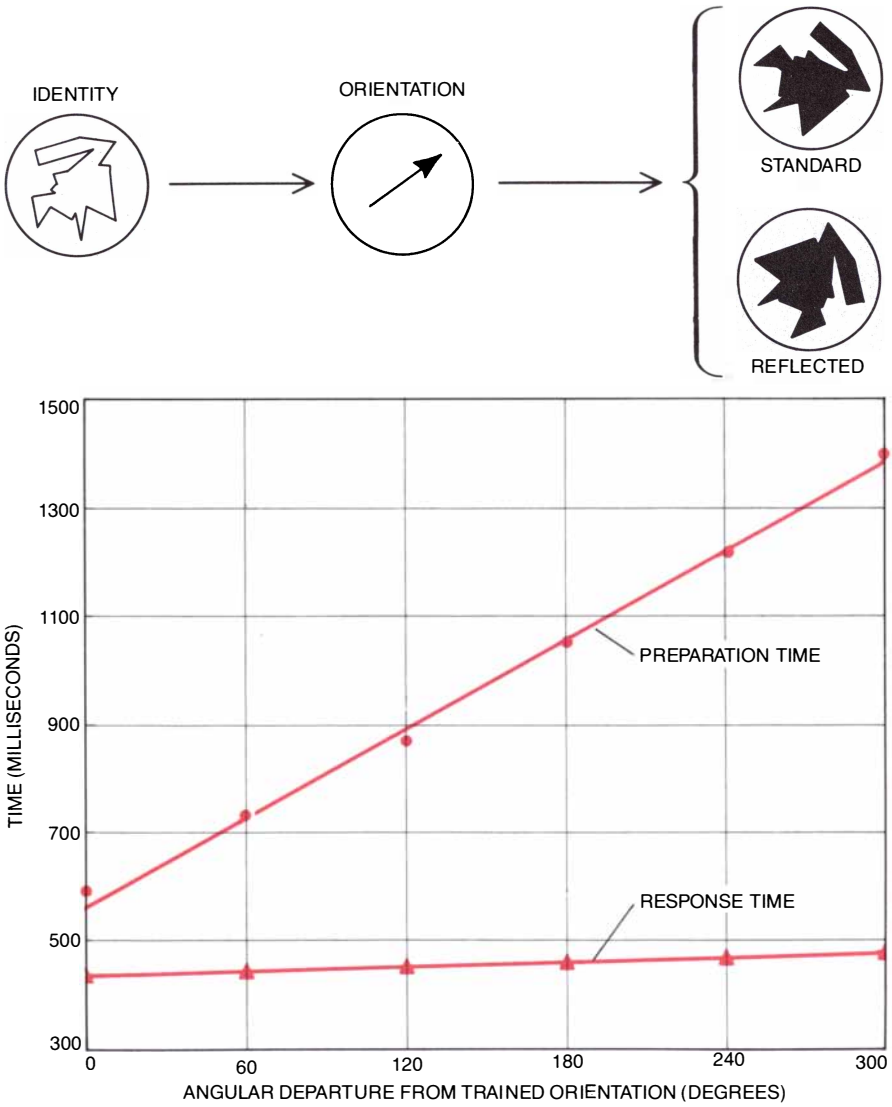
The subjects of a further experiment, designed to test that hypothesis, were all veterans of the two earlier single-stimulus experiments and were familiar with the eight test polygons. On each trial a blank circular field appeared in the tachistoscope and the subject was asked to imagine a specified polygon rotating within the field at the subject's natural rate. After an unpredictable interval that shape or its mirror image appeared; the subject then identified the version as quickly as possible.

Because we already had extensive data on each individual's rate of rotation, we could tailor the trials to the individual subjects. From the earlier experiments we inferred the times and angles at which each subject should be most ready to respond to a test shape. In half of the trials, called the probe-expected trials, the test shape was presented at an angle and time intended to match precisely the ongoing mental rotation. In the other trials the shape was displayed in an orientation that differed by varying angles from what was calculated to be the orientation imagined at that moment. We termed this second kind of trial probe-unexpected.

If a subject necessarily imagines an object in intermediate orientations in the course of mental rotation, the response to a properly timed and oriented probe should be uniformly fast whatever the angle tested is. The reaction times in the probe-expected trials were consistent with our hypothesis: the response times for trials in which the probe was displayed in an expected orientation were virtually constant at about half a second for every angle.

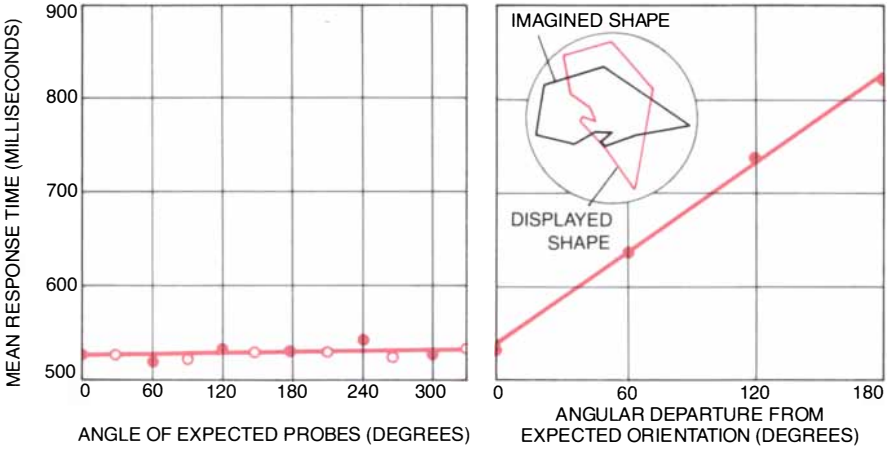
Another feature of the probe-expected trials is instructive. The orientations of half of the probes were multiples of 60 degrees—the same orientations that were used in the earlier one-stimulus experiment. The other "expected" probes were displayed at unfamiliar angles, all odd multiples of 30 degrees. If, as we propose, mental rotation does not jump discontinuously from angle to angle but instead progresses steadily through states corresponding to intermediate angles, the response times to properly timed probes in the unfamiliar angles should approximate those for probe angles in which the subjects were well versed. Nearly identical response times at familiar and unfamiliar orientations bore out the hypothesis.

When the probe deviated from the expected orientation, reaction times in-

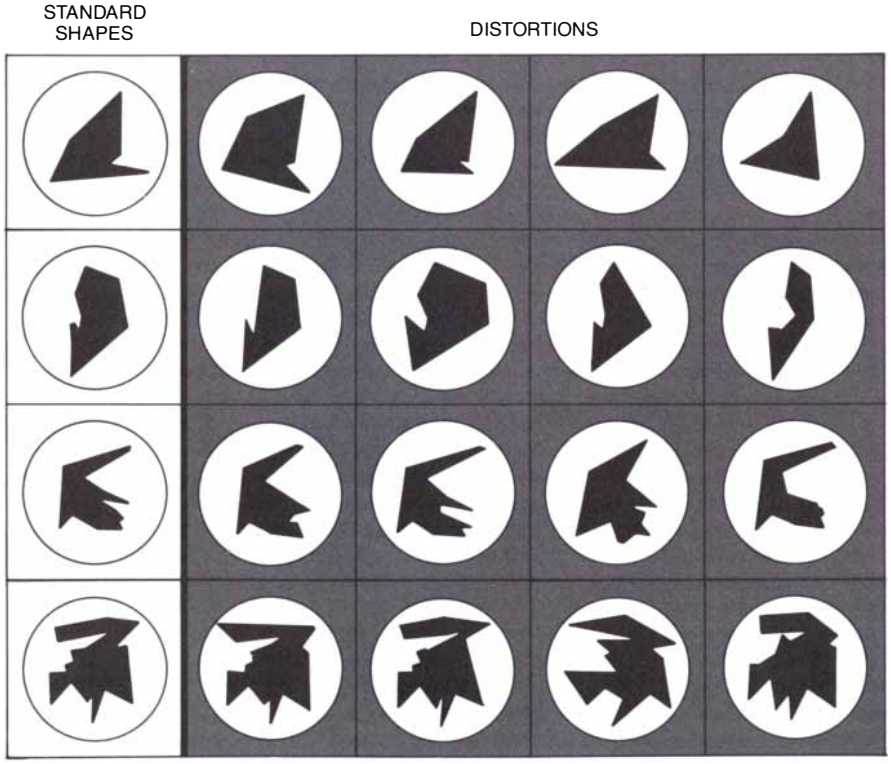


PREPARATORY ROTATION TIMES were measured in the experiment shown schematically at the top; the results are plotted above. Subjects first viewed an outline drawing of one of the eight standard polygons, followed by an arrow. They imagined the shape, now present only in their memory, rotated into the orientation indicated by the arrow. When the mental operation was complete, they signaled by pressing a button, causing a test shape to appear in the designated orientation, and determined as quickly as possible whether the shape was a standard or a reflected version. The time required for the preparatory mental rotation (*upper graph*) increased linearly with the angle; the consistently fast response to the test shape (*lower graph*) confirmed that the process of mental rotation prepared subjects to judge the reoriented shape.

creased linearly with the angle of the discrepancy. Clearly subjects had to imagine a further, correctional rotation when they were presented with a test shape that did not match their current mental representation; the correction took time proportional to the angle of the deviation. The finding provides additional evidence that a correspondence between the imagined and the displayed orientations, and not the subjects' familiarity with the shapes in all orientations, was crucial to the short and constant response times. The correction times indicate that, although the test subjects were practiced, they could not evaluate the displayed shapes without first doing a mental rotation.



EXPERIMENT PROBING ONGOING MENTAL ROTATIONS yielded the results displayed in the graph. When a subject imagined a shape rotating and the presentation of a test shape was timed so that its orientation matched the momentary orientation of the imagined shape, response times were consistently fast at every angle probed (*left*). The results were not affected by the fact that some of the probes (*open dots*) depicted orientations the subjects had not seen in earlier experiments; instead of skipping between learned positions, objects are imagined as passing through intermediate orientations just as objects rotating in the physical world do. When the investigators deliberately mismatched the probe and the orientation the subject was imagining (*diagram and graph at right*), response times increased with the angular discrepancy. Subjects presumably had to imagine a compensatory rotation to evaluate the test shape.



DISTORTIONS OF THE STANDARD SHAPES tested the fidelity with which the features of a physical stimulus are retained when it is rotated mentally. After indicating an orientation into which the subjects were to imagine one of the standard shapes as having rotated, the experimenters presented the reoriented standard shape or one of various distortions of it. Subjects could detect even minor variations from the standard shape, which suggests that in the process of mental rotation much of the structural richness of the original shape is preserved.

Taken together, our results amount to objective evidence of a mental process that models the rotation of objects in the physical world. The two central findings are the linear relation of reaction time to orientation difference when two stimuli are compared for intrinsic shape, and the uniform rapidity of response when a test object is presented in a position calculated to match the steadily changing orientation that is imagined in a mental rotation. We have gathered precise and reproducible data on a seemingly subjective phenomenon of the kind that in the past was considered to lie outside the proper scope of experimental psychology.

Questions still remain about the nature of the mental transformations we have studied. Although we have established that determining the identity of objects displayed in differing orientations can require imagining a rotation through intermediate orientations, we do not contend that the rotation is continuous in the strict mathematical sense, which requires that it sweep through all possible intermediate angles. The neurophysiological basis of the mental images and of their internal manipulation is not known.

Still other questions remain: How much detail from corresponding physical objects do the mental images preserve as they are transformed? Recent experiments suggest that mental representations can preserve much of the structural richness of their material counterparts. In research conducted by Cooper and Peter Podgorny (a former student) subjects were able to discriminate rotated test shapes from standard shapes not only when the probes differed by reflections in space but also when the distinction was a matter of subtle, unpredictable local perturbations [*see bottom illustration at left*].

In spite of some unresolved issues, the close match we have found between mental rotations and their counterparts in the physical world leads inevitably to speculations about the functions and origin of human spatial imagination. It may not be premature to propose that spatial imagination has evolved as a reflection of the physics and geometry of the external world. The rules that govern structures and motions in the physical world may, over evolutionary history, have been incorporated into human perceptual machinery, giving rise to demonstrable correspondences between mental imagery and its physical analogues. We begin to discern here a mental mechanics as precise and elegant as the innate schematism posited by Chomsky as the foundation of language.

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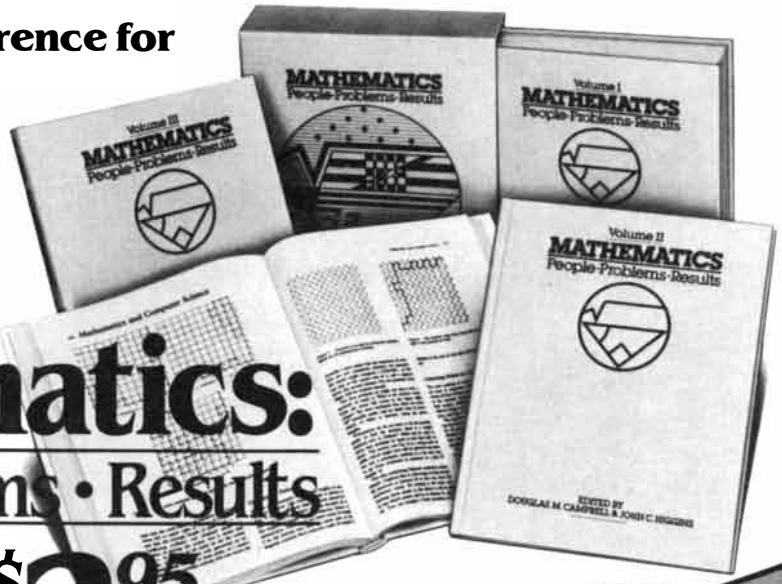

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Scientific American 12/84

The Spanish Ship of the Line

Pride of place among the greatest warships of the age of sail is generally accorded to the English. Yet Spain's "Santísima Trinidad" was the largest and most formidable ship of the era

by John D. Harbron

On October 21, 1805, in the last and bloodiest naval battle of the age of sail, the English navy led by Admiral Lord Horatio Nelson smashed the combined squadron of the French and Spanish fleets off Cape Trafalgar. The defeat marked the end of Spain as a sea power and seems to have reserved for the English all honors for 18th-century naval architecture, ship design and seakeeping qualities. Yet to the sailors and ship captains of the period the most fearsome warship present on the afternoon of the battle was the *Santísima Trinidad* (Most Holy Trinity), a 1,900-ton floating cannon platform with sides of mahogany two feet thick, manned by some 1,200 sailors and marines. The *Santísima Trinidad* was praised on more than one occasion by Nelson himself, and it was admired by many other maritime enemies of Spain for its design and its sturdiness at sea. One measure of its success as an instrument of war is its fate following capture by the English during the battle. Afraid it would be recaptured by the escaping remnant of the Spanish force, and unable to tow it in its battle-scarred, storm-damaged condition, the English scuttled it two days after the battle. Our knowledge of this splendid ship must therefore be based on reconstructions from contemporaneous accounts.

History has neglected Spanish shipbuilding because of Spain's naval defeats during the 18th century. The defeats, however, were a consequence of superior naval tactics and more disciplined seamanship by the English, not failure of ship design. What is ignored in such biased historical assessment is Spain's success in establishing and maintaining merchant shipping routes to the New World.

Spanish sailors of the late 15th and early 16th centuries, imbued with the religious zeal of the counterreformation, made astonishing progress in the exploration of the world. Moreover, as early as 1600, only 80 years after Hernán Cortés first landed in Mexico, there were between 40 and 50 settled sites throughout Spanish America. Most of the settlements could be serviced and defended only from the sea; the success of the settlements is at least in part attributable to a tradition of superb ship construction that persisted for nearly 300 years.

The colonization of the New World could not have been accomplished with the aid of the ship that is generally given undue prominence in historical accounts of Spanish shipbuilding: the *galera,* or galley, a flat-built ship, driven by both oars and sails, that dominated naval warfare in the Mediterranean Sea throughout the Middle Ages. (The last great battle of the age of oar, in which a combined fleet of Spanish and other European galleys defeated a Turkish fleet, was fought off the coast of Greece at Lepanto in 1571.) The *galera* was hardly suitable for the long and often difficult Atlantic crossings. Columbus and subsequent explorers used varieties of the so-called round ship, and by the late 16th century this design had completely replaced the *galera* in the Spanish fleet. The much larger hull of the multidecked round ship meant that it could carry more supplies, more men, more guns and more sail, all of which were necessary for long voyages of commerce and discovery. In addition, because the hull was rounded, widened at the bottom and tapered inward along the upper decks, the round ship was more seaworthy.

The round ship carried three masts, and the basic design was built in two specialized versions, the *galeón* and the *navío.* The *galeónes,* or Spanish galleons, were commercial vessels that carried large cargoes of gold, silver and supplies, as well as substantial numbers of crew and passengers. The *navíos* were warships, built with thick hulls and outfitted with cannons; the most powerful and durable *navíos* were the ships of the line, which occupied a forward position in any engagement. (A synonymous term is "line-of-battle ship"; hence the origin of the modern word "battleship.") The large Spanish *navío* of the mid and late 18th century was the culmination of centuries of building the three-masted round ship. The *Santísima Trinidad* was the finest example of the *navío.*

How was the 18th-century *navío* constructed? The techniques adopted by the Spanish were similar to the ones employed by the other European naval powers. The backbone of the ship's skeleton was the keel and the keelson, a supporting structure that was built above the keel to strengthen the surrounding framework. The keelson ended at the stem in the bow and at the sternpost in the stern. Frames or ribs of the ship's skeleton were attached to the keel, and the entire structure was locked together with various kinds of planking, both inside and outside the skeleton. The planking included wales, which were large timbers that girded the skeleton around the frames, and transverse deck beams, which fastened the frames on one side of the ship to their counterparts on the other side.

The framework was held together by nails of oak or mahogany and by bolts of wrought iron, all made on site at the royal shipyards. In a large warship such as the *Santísima Trinidad* the iron bolts were up to six feet long. The bolts were driven through holes drilled in the timber, and they were held in place by wrought-iron or wood nuts. As the construction proceeded in drydock, sails were sewn by hand from flax canvas, and hemp was woven into rigging and line that would guy the masts and secure the sails.

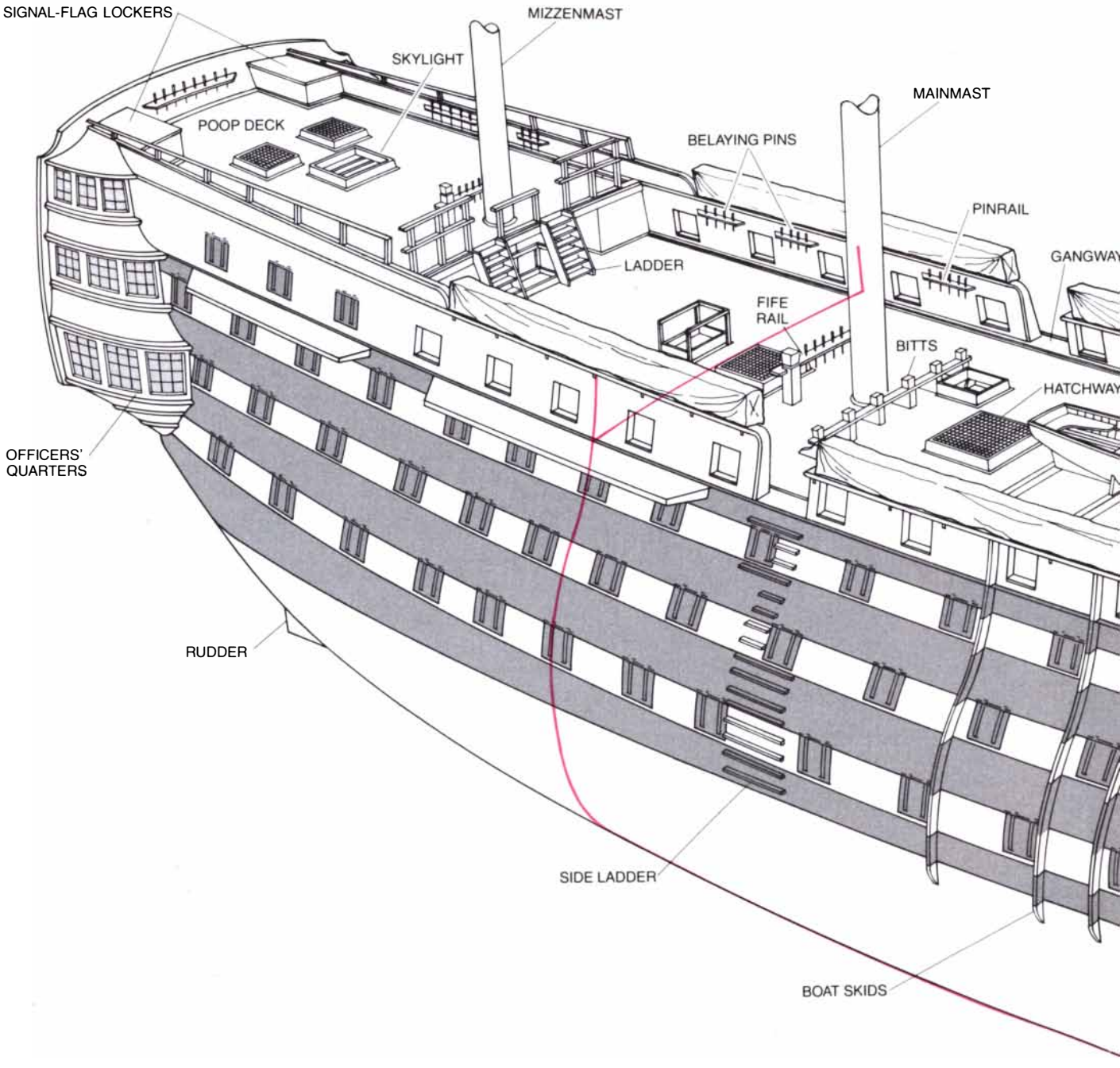
Most important to the sailor was how the entire structure, wood hull, sails and rigging, would work together at sea. The effect of the constantly changing stresses of wind and ocean waves on thousands of pieces of timber held together by wood pegs and iron bolts was to make the *navío,* much more than the sailing ship of today, a system rather precariously balanced in a dynamic equilibrium that was under constant adjustment by the captain and the crew. The *navío* creaked, groaned, splashed and heaved its way through the world's oceans in a

SANTÍSIMA TRINIDAD, **the largest ship at the Battle of Trafalgar, is depicted under sail in a contemporaneous painting by Don Alejo Berlinguero de la Marca y Gallego. It was built in the Spanish naval shipyard at Havana in 1769 out of mahogany and pine grown in Mexico and Central America. Windows visible in the stern look out from the officers' quarters, which were elegantly appointed but poorly protected. Naval tactics of the 18th century often called for an attacking warship to maneuver in such a way that the opening cannon salvo could be aimed at the stern. The fourth gun deck shown in the painting was added during a later refitting, which made the *Santísima Trinidad* the most heavily armed warship of the 18th century. It also carried a crew of 1,200 sailors and marines into battle. Although it was subjected to punishing broadsides from English cannon fire, it was never sunk in battle. The painting is in Madrid's Museo Naval.**

manner no longer experienced by seafarers. Even those who sail today's tall ships enjoy the comparative rigidity of a steel hull.

The key to the success of the Spanish *navío* was the superior materials available to Spanish shipbuilders. The hulls of the French and English warships of the period were built out of oak, and the masts and yards were constructed out of pine. The Spanish American empire, on the other hand, kept the *Armada Española* supplied with sturdier hardwoods such as mahogany, grown in Cuba and in the coastal forests of what is now Honduras. Mahogany is far more resistant than oak to dry rot, a fungal growth that consumes the cellulose in seasoned timber and leaves behind a skeleton that is easily reduced to powder. All wood ships are subject to its effects, and so a reliable source of hardwood was essential to a navy not only for the construction of new ships but also for the refitting of the old.

The ready availability of a hardwood that could function at sea for a relatively long interval between refittings was therefore a decided advantage for a naval power. At a time when both the English and the French were beginning to wonder seriously about their ability to grow or obtain enough oak and pine to build and maintain their fleets, Spain remained amply supplied with hardwoods

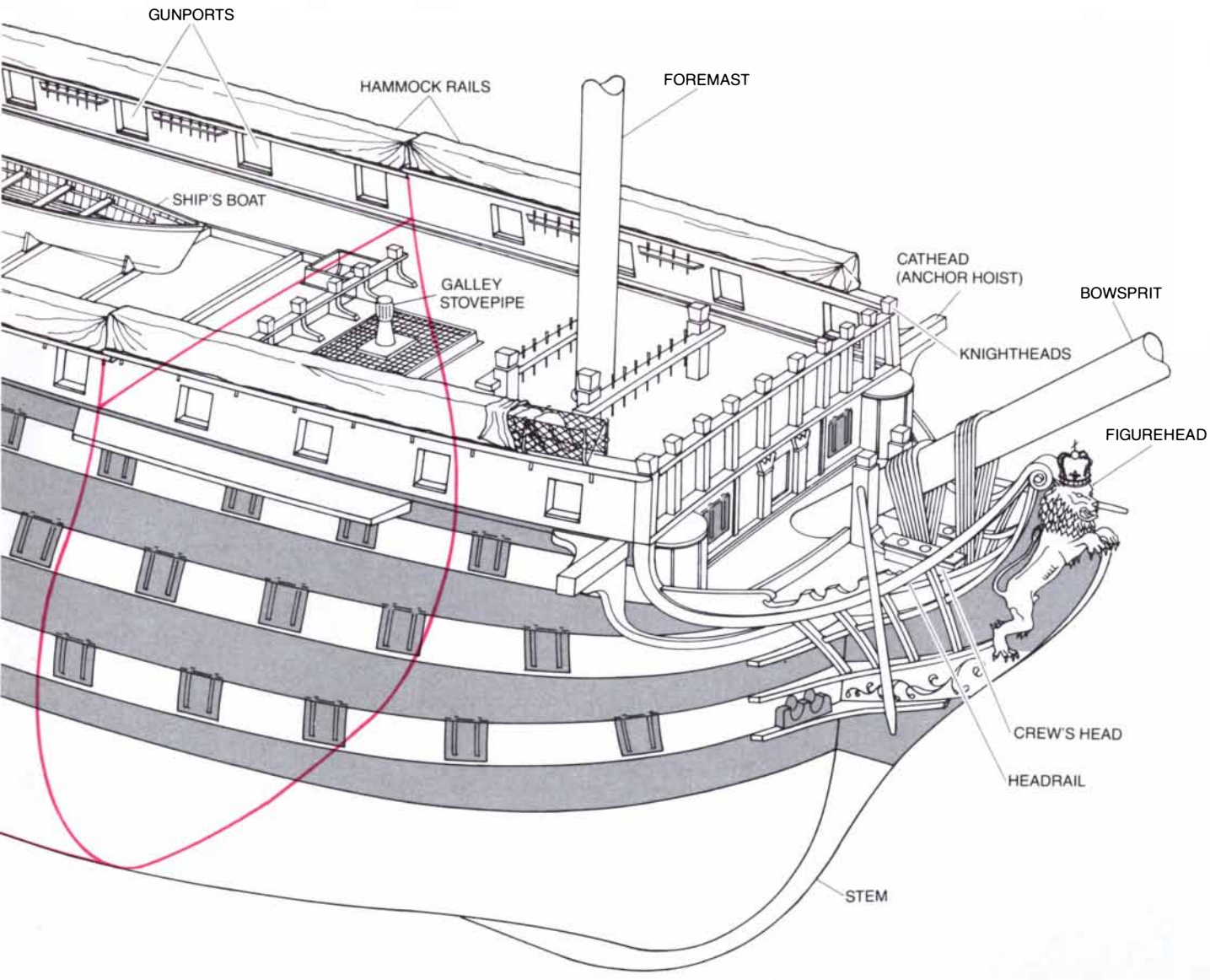


SCHEMATIC RECONSTRUCTION of the *Santísima Trinidad* is based on a rendering by Don Rafael Berenguer Moreno Guerra of the administrative branch of the Spanish navy (a rendering that was in turn based on contemporaneous descriptions). The ship was 204.5 feet from bow to stern and weighed some 1,900 tons; after the fourth gun deck was added the vessel may have carried as many as 144 cannons, more than any other warship. Belaying pins, bitts and knightheads to which running rigging could be made secure were placed at strategic points on the deck. Hammocks not in use by the crew were stored during the day in the hammock rails along the sides of the top deck. The colored lines indicate the boundaries of the cutaway view of the ship shown in the illustration on page 122.

from its American empire. Much of the lumber was transported to the royal shipyard in Havana, which built 74 of the 221 three-masted *navíos* launched by Spain during the 18th century and which by the 1770's had become the world's largest builder of ships of the line. The *Santísima Trinidad,* whose hull and decks were constructed entirely of Cuban and Honduran mahogany, was launched at Havana in 1769.

The amount of wood consumed in the construction of warships was immense. Some 3,000 trees, each with a yield of 600 board feet, were needed to build the so-called third-rate warship, the workhorse of the European fleets. Pine for the masts and yards, or crossbars on which the sails were rigged, was grown largely in what is now Mexico. As many as 40 pine trees were needed to make the 22 yards in a third-rate, three-masted warship. The shipyard was the largest manufacturing entity in the preindustrial era at the close of the 18th century, and there is little doubt that the great ships of the line were the largest manufactured items in regular production before the Industrial Revolution. Nevertheless, the 60 three-decked and three-masted ships that fought at Trafalgar together weighed no more than 120,000 tons, or about the dead weight of a modern supertanker.

When refitting was needed it was not limited to decks, cabins, masts and sails,



The uses

Summary:

Even the smoothest voice is discontinuous, especially in conversation. Data communications has bursts of message and periods of silence, too. Even TV has some "bursty" traits. GTE scientists are isolating silences and inserting other messages into them. This permits voice and data to coexist on the same channel at the same apparent time. The development stems from parallel research in microelectronics, silence detection, speech, voice compression and signal processing.

Without basic change, or vast growth, telephone networks will be unable to cope with the anticipated traffic of the 1990's. The proliferation of personal computers and data terminals has already placed a strain on switching and transmission facilities. It has also placed demands on networks that are much different from the original voice-communications concept, in which average time of connection was three minutes.

Today, far shorter and far longer connections abound, more subscriber lines are in demand, and there are growing needs for enhanced services and faster switching.

Out of research dating from 1979, GTE has developed a switching system that promises not only to triple present transmission capacity but also to process calls 20 times faster. The system is called Burst Switching.

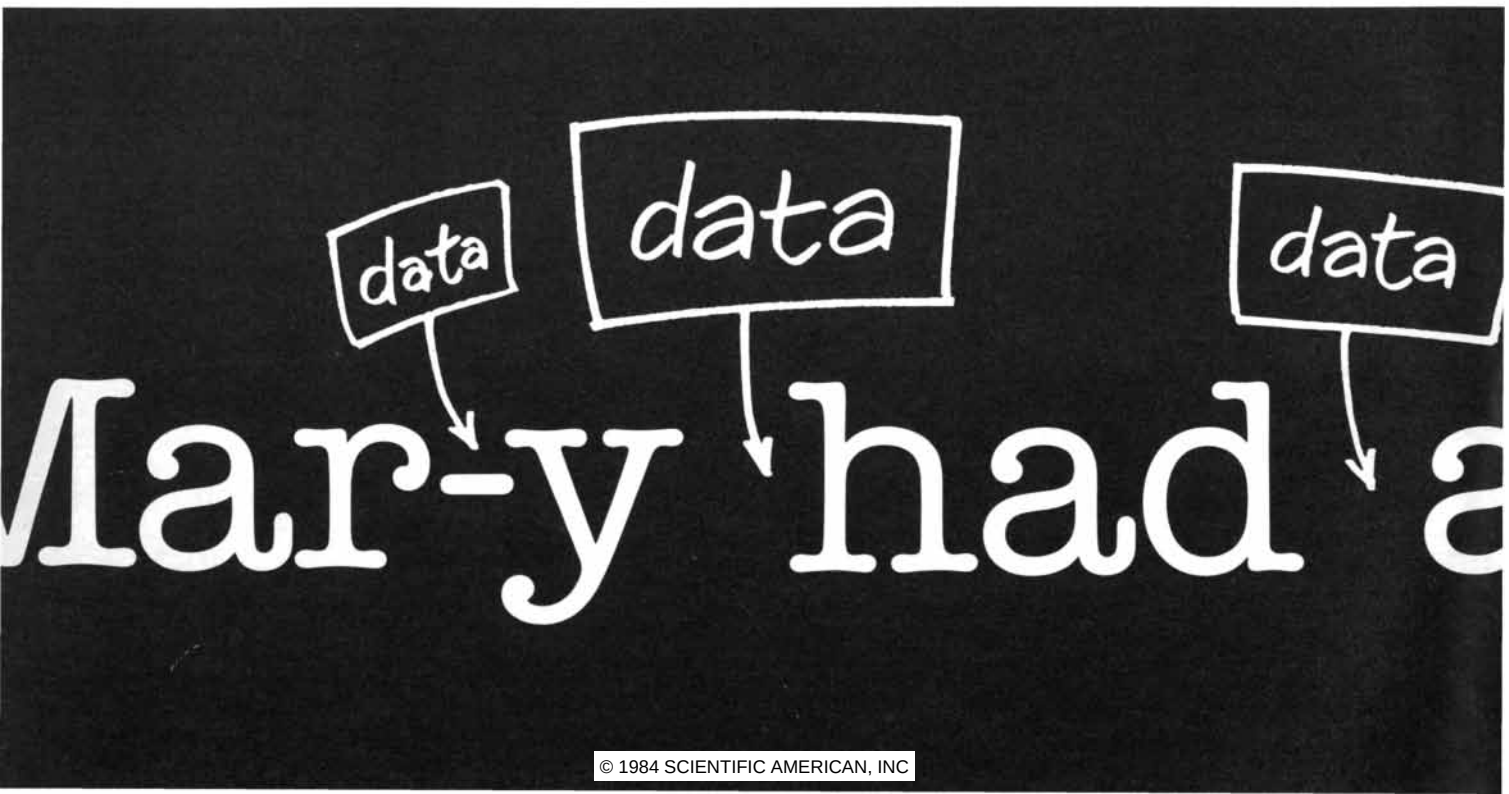
The nature of speech.

Our world is full of holes. Matter is mostly empty space. Conversation is mostly silence. But, even though speech is 2/3 silence interspersed with bursts of sound from 0.1 to 1.5 seconds long, if that speech goes over a telephone line, the line is locked up for the duration.

But, with Burst Switching, we can shoehorn other messages into the silences, automatically easing the pressure on transmission facilities. Theoretically, in fact, we triple transmission capacity.

VHSIC.

Through Very High-Speed Integrated Circuits (in which we are currently researching devices with submicron feature size), we are able to make and break telephone connections at increasingly high speeds. Voice lines need be dedicated only for the very brief duration of voice bursts. At other times, channels are available for other voice messages, or for data streams which are also "bursty" in nature. In addition, video, because of its built-in redundancy, can be considered to have bursts, too.



# of silence.

Message compression.

The capacity needed to transmit speech can be made even smaller if the information that must be sent to make it recognizable can be minimized. Our scientists have reduced the 64 kb/s signals to 16 kb/s while retaining high quality.

Thus, transmission-capacity requirement is reduced by a factor of four.

We are working, as well, on techniques for compressing video signals from 90 Mb/s to 64 kb/s. This will have special relevance for such activities as video conferencing.

So transmission capability grows and switching becomes faster—and we can now envision future telephone systems able to carry billions of simultaneous calls.

The box at the right lists some of the pertinent papers GTE people have published on Burst Switching and related subjects. For any of these, you are invited to write GTE Marketing Services Center, Department TPIIE, 70 Empire Drive, West Seneca, NY 14224.

Burst Switching experimental model.

Pertinent Papers.

Burst Switching—An Introduction, IEEE Communications Magazine, November 1983.

New Switching Concept Integrates Voice and Data Bursts, PROFILE, September 1983.

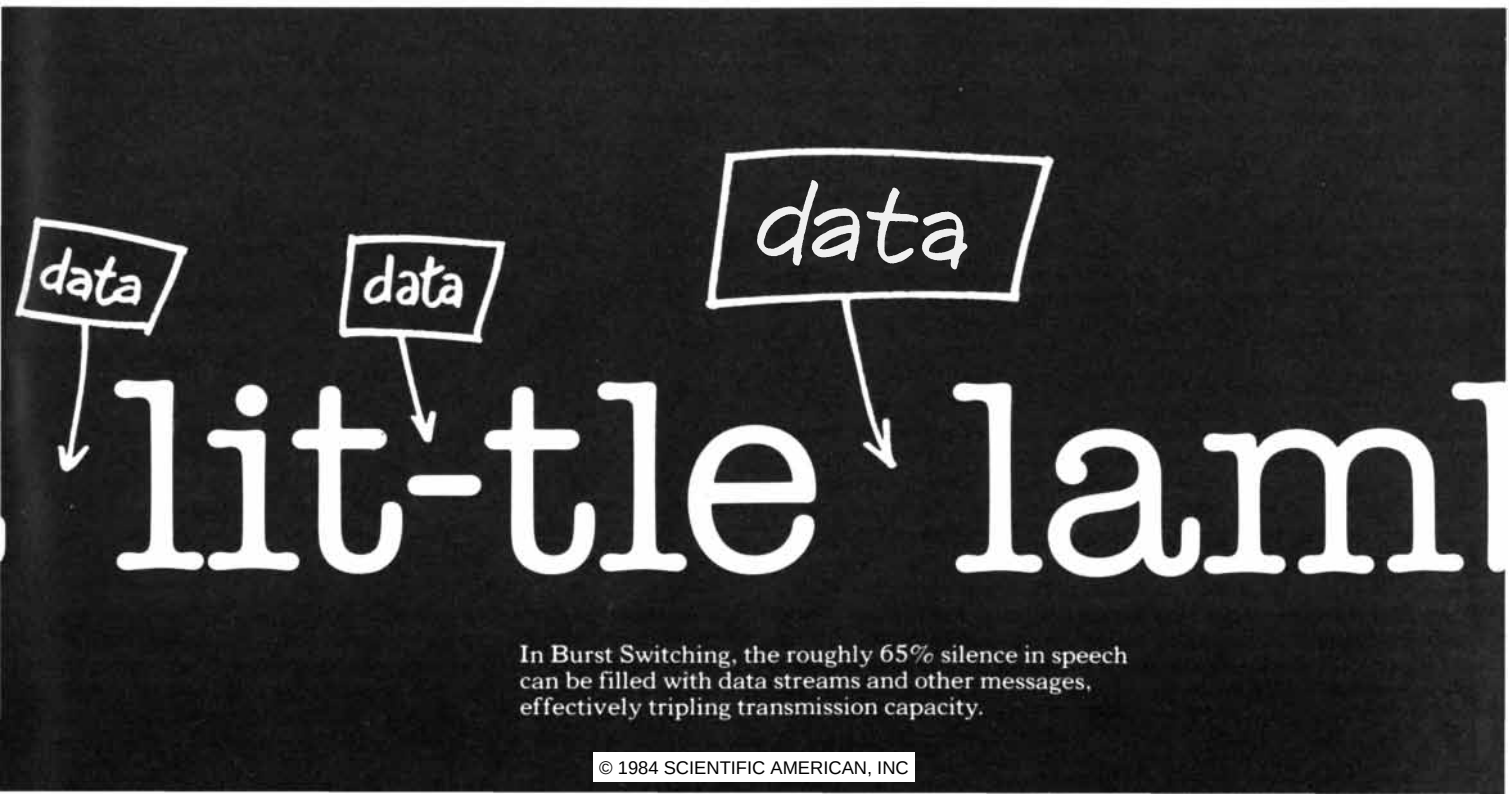
A PCM Frame Switching Concept Leading to Burst Switching Network Architecture, IEEE Communications Magazine, September 1983.

Application of the Burst Switching Technology to the Defense Communications System, Proceedings 1983 IEEE Military Communications Conference, MILCOM '83, Washington, D.C.

Performance Evaluation of a Distributed Burst-Switched Communications System, Proceedings Second Annual Phoenix Conference on Computers and Communications, March 1983.

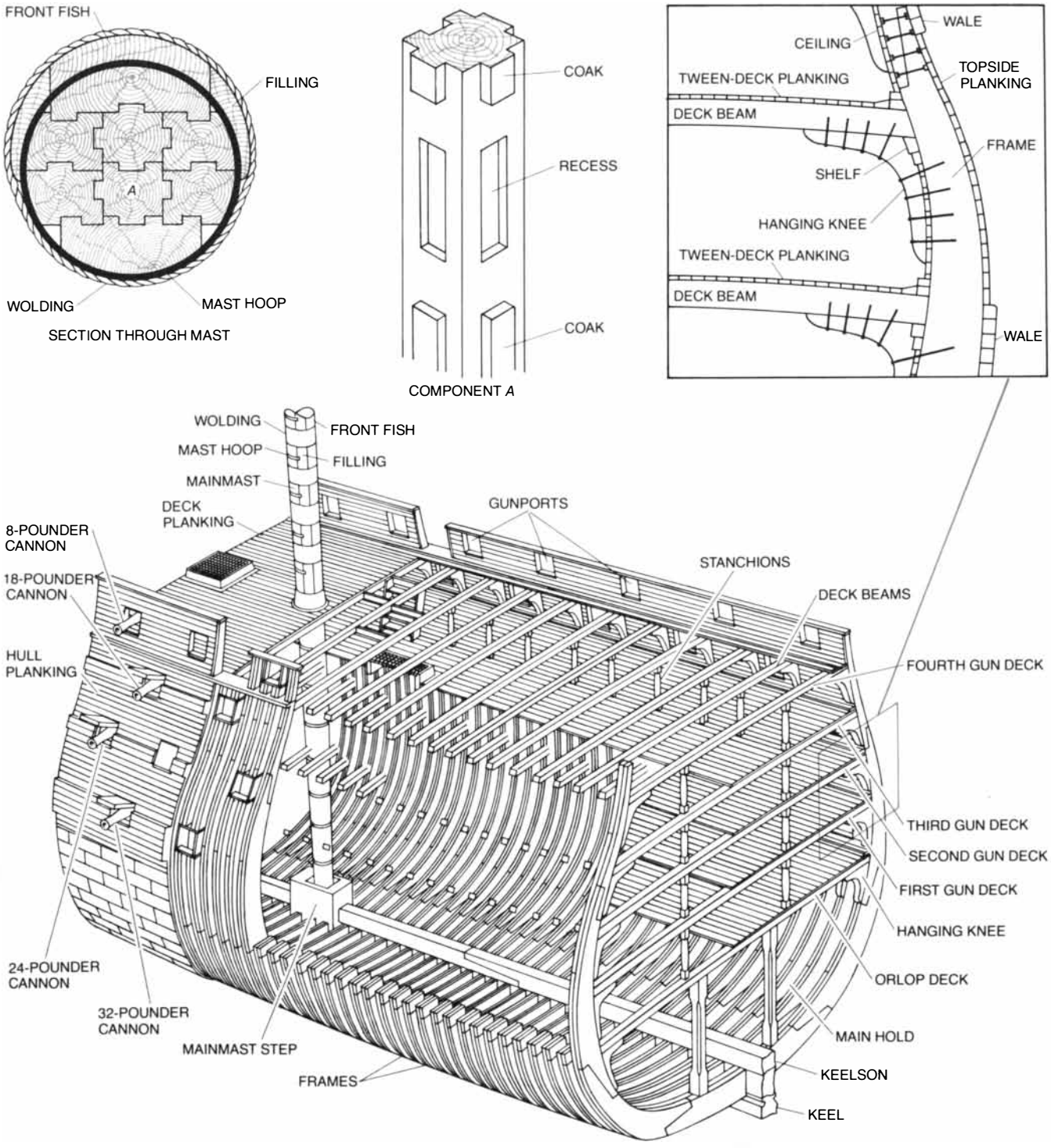
A Complementary Speech Detection Algorithm, Proceedings of GLOBECOM '83, November 1983.

GTE



In Burst Switching, the roughly 65% silence in speech can be filled with data streams and other messages, effectively tripling transmission capacity.

as it is for the steel, plastic, fiberglass or aluminum-hulled ships of today. Maintenance of the 18th-century warship required periodic replacement of the basic framework of the hull; indeed, the warships that fought at Trafalgar were not the same ships as the ones first launched and built. The method would be familiar to modern yachtsmen. Pulleys on shore were attached to the appropriate lines of the ship's rigging, and, after the guns were removed, the *navío* was careened, or heaved onto its side. The work of replacing rotten timbers could then begin; when replacement was not needed, the hull was merely scraped of marine growths and painted with various antirot preservatives. The bottom was often sheathed with copper for additional protection against rot as well as against the teredo woodworm.



CUTAWAY VIEW of the *Santísima Trinidad* shows the framework and deck arrangement amidships, exposed along the planes indicated by the lines in color in the illustration on pages 118 and 119. Construction was begun by laying the keel and the keelson; the frames were then added to the keel and keelson and held in place by stanchions, deck beams and wales. Most of the supplies for a voyage were stored in the main hold. The orlop, or overlap, deck housed the surgeon's facilities and a changing magazine, which stored premeasured powder charges for the guns. The largest and heaviest cannons were mounted on the lower gun deck, immediately above the orlop deck. Living quarters for the crew were primarily on the middle and upper gun decks; the men slung the hammocks between the cannons.

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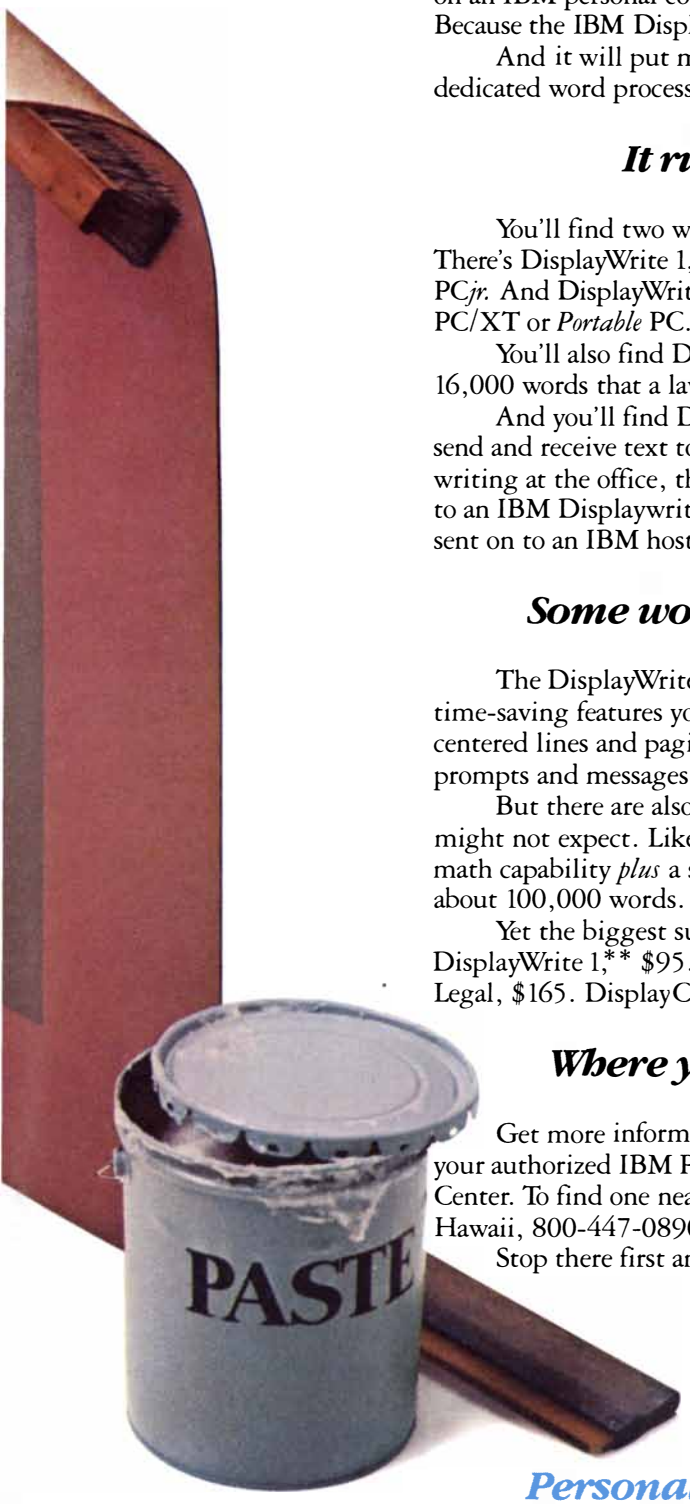

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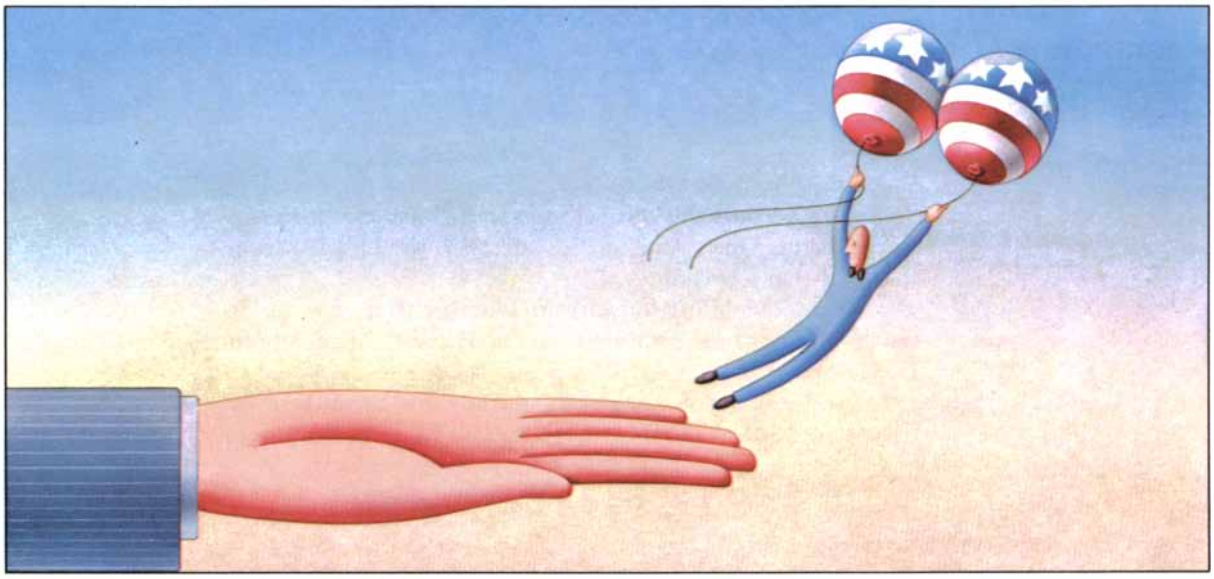

ENERGY INDEPENDENCE

Can homegrown energy free us from foreign dependence?

America still consumes a lot of energy from other countries. Greater use of nuclear energy and coal, which are domestic sources of our electricity, reduces this risky dependence.

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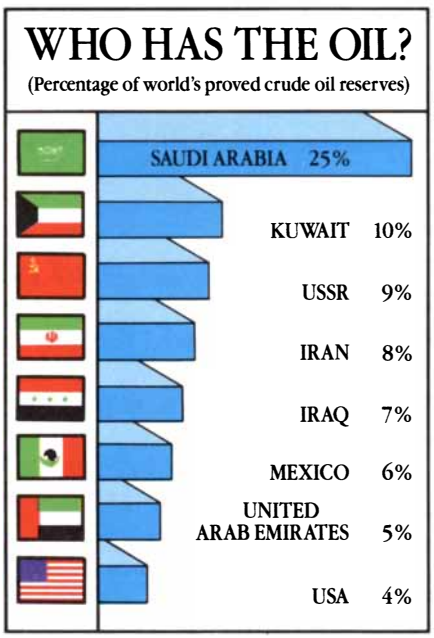
Without the 85 plants now operating, most of their electricity would come instead from more power plants burning coal, natural gas, and oil.

Nuclear-generated electricity has already saved this country roughly 2 *billion* barrels of oil. Completing the nuclear plants now under construction will help save billions more by the turn of the century.

Also, electricity from coal and nuclear plants is being used instead of oil for such things as home heating, manufacturing, and materials production.



America ranks eighth in proved oil reserves. Our reserves have been declining for years, despite a big increase in exploratory drilling. Source: Energy Information Administration/ U.S. Dept. of Energy; Petroleum Information International.

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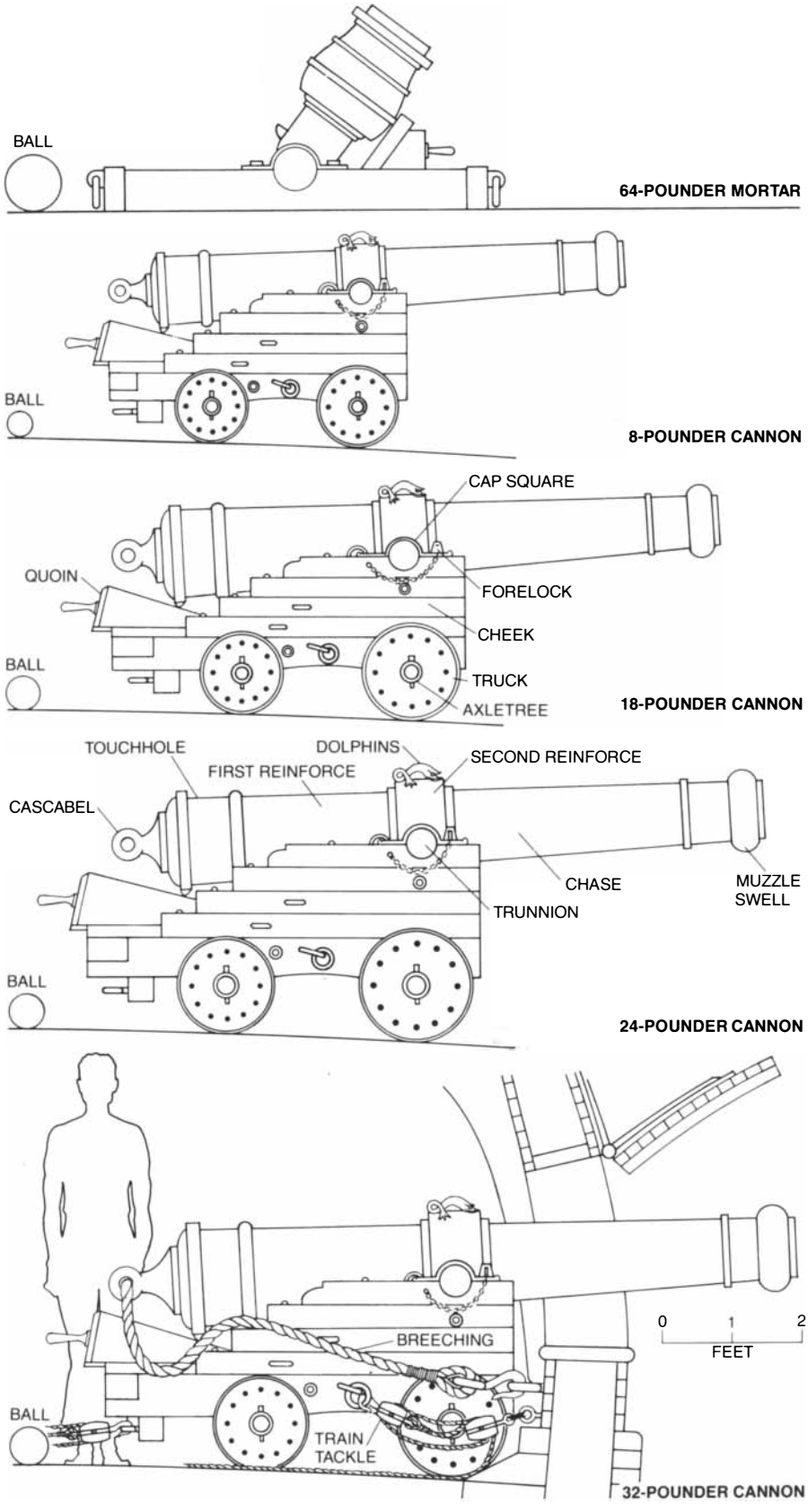
Such overhauling, of course, earned a longer life for the ship: the *Santísima Trinidad* was 36 years old when it was scuttled at Trafalgar, and Nelson's flagship, H.M.S. *Victory,* was 40. A clean ship bottom also made the vessel far more useful to the captain. When it was unencumbered by the ever present marine growths, a copper-sheathed warship sailed faster and could be maneuvered more easily into action. The consequences of speed, however, were not always beneficial. It is reported that at the Battle of Trafalgar the newly copper-sheathed English warship H.M.S. *Royal Sovereign* sailed far ahead of two lines of Royal Navy ships and closed in alone on the larger, 112-gun Spanish *navío,* the *Santa Ana.* The *Santa Ana* returned a murderous fire.

The cost of overhauls was a significant factor in the wartime economies of the European maritime states. For example, the economic historian José P. Merino Navarro of the Spanish University Foundation in Madrid has estimated that H.M.S. *Victory,* which cost about 63,000 pounds sterling to build in 1765, cost the English roughly 372,000 pounds to maintain until the end of the Napoleonic wars in 1815. Nevertheless, to protect its interests in the Americas and in the Spanish Philippines, Spain maintained more careening and overhaul centers around the world than either the French or the English, and Spanish ships were usually in a much better state of repair than their English counterparts. The English Admiral Lord Cuthbert Collingwood, one of the great sea captains of the era, sent dispatches more than once to Nelson and to the Admiralty about the rotten state of the English ships of the line. Some naval historians have written that England could not have fought and won another battle like Trafalgar without first clearing the Royal Navy of dry rot. It seems evident that such a task would have strained the financial resources of the nation.

The 18th-century renewal of Spain's navy was part of a modernization of all Spanish institutions carried out by King Charles III, one of the "enlightened despots" of the century. Charles III brought improved methods of management and long-term planning to all Spanish industry, including the royal shipyards. One of the most effective improvements was the standardization of warship designs. At the beginning of the 18th century each ship had been the unique creation of the ship designer. By the 1770's, however, *navíos* were grouped into six major rates, or classes, and ships within each class were constructed according to common architectural drawings. Moreover, designs for ships of differing rates called for similar hulls, gun-deck structures and sail pat-



CANNONS AND MORTARS carried by 18th-century warships are shown. On its lower gun deck the *Santísima Trinidad* carried 30 32-pounders, so named for the weight of the cannonball that was ordinarily fired. The 32-pounders were the largest cannons in naval service at the end of the 18th century; they were 10 feet long and could occasionally hit a target a mile and a half away. The middle gun deck of *Santísima Trinidad* carried 32 24-pounders, and the upper gun deck carried a mixture of 32 18-pounders and 26 eight-pounders, as well as mortars. When the fourth gun deck was added, the number of cannons aboard was increased from 120 to 144. Rigging used for moving the guns into place is shown schematically for the 32-pounder.

terns. The result was a dramatic increase in the efficiency of the shipyard, at a time when Spain needed a quickly expanding fleet of new ships to defend a far-flung empire in its protracted conflict with England.

Each of the six designs was one solution to the unavoidable trade-off between the need for a stable, floating gun platform and the ability to maneuver quickly and make fast headway under sail. The rate classification was based primarily on the number of gun decks in a ship and the number of guns on board. The first-rate *navíos* such as the *Santísima Trinidad* were the largest warships and carried the most powerful artillery. The *Santísima Trinidad* may have carried as many as 144 guns, and it was the only warship in service with four gun decks. All other first rates had three gun decks and three masts. Second rates carried 80 to 98 guns on three gun decks, and third rates carried 74 to 80 guns on two gun decks. The three highest rates were the ships generally designated ships of the line.

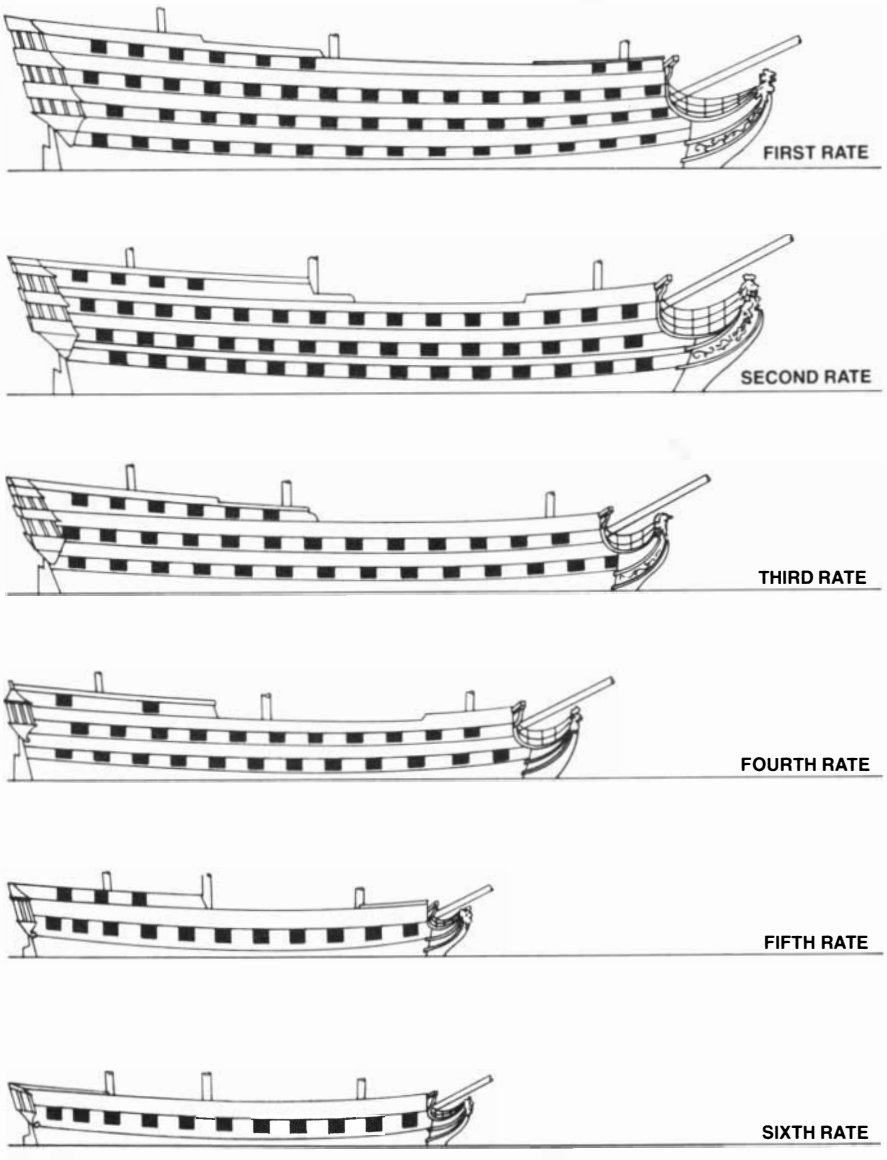
The fourth, fifth and sixth rates were customarily assigned to cruiser squadrons; with fewer guns to carry they could make better speed. The fourth rates carried between 50 and 60 guns on two decks, fifth rates between 32 and 44 guns on one deck and sixth rates between 20 and 28 guns on one deck. The sixth rates were the fastest ships in the Spanish navy, and they were often relied on to carry mail and royal instructions between Spain and its distant colonies.

From keel to upper deck a Spanish *navío* was as tall as an amply built five-story building. Above the bilge in the typical first rate of the day was the main hold, and above that was the orlop, or overlap deck. The three main gun decks, simply designated lower, middle and upper, were built above the orlop. The top-heavy weight of the three gun decks sometimes caused the ship to roll in heavy seas, at which times the lower gun deck, particularly in the English ships of the era, was often below the waterline.

The orlop was the safest deck in the ship. Consequently it housed the surgeon's facilities for treating wounds and performing the many immediate amputations necessary during the bloody sea battles. On English ships the orlop was usually painted bright red to hide the rivers of blood that flowed from the surgeon's table. On the *Santísima Trinidad* a large crucifix was mounted on the bulkhead above the table, a symbol of the religious conviction for which many a man gave an arm, a leg or a life. The orlop also housed a changing magazine, which stored premeasured and ready-to-use powder charges for the cannons.

In order to counter the tendency of the ship to roll, the hull of the Spanish *navío* was broader across the beam of the lower gun deck than it was across the middle and upper gun decks. Accordingly the lower gun deck was the stablest one, and it housed the largest cannon on the ship, a 10-foot-long killer that fired 32-pound shot. The *Santísima Trinidad* carried 30 of these cannons, 15 on each side. At close range its shot could penetrate an oak hull three feet thick, and it could cause even more damage to an enemy ship when the shot was doubled or tripled. At long range the 32-pounder could occasionally hit a target a mile and a half away.

In addition to the guns, the middle and upper gun decks included most of the meager living quarters allotted to the crew. Hammocks were slung between the guns, and they had to be stowed prior to battle. A galley was placed amidships, and there a single stove was available to the crew for cooking food and boiling water. The Spanish *navíos* were also excessively crowded: Spanish naval tactics called for a large number of troops, which gave rise to a frequently unmanageable mix of landlubbers and professional sailors. At the Battle of Trafalgar the *Santísima Trinidad* was severely overmanned with 1,200 sailors and marines, many of whom were still recovering from the epidemics of malaria and cholera that had swept southern Spain between 1802 and 1804. In comparison the English first rate H.M.S. *Victory,* which was itself overcrowded, carried only 900 men, all of whom were professional seamen.



RATINGS OF SHIPS were based largely on the number of guns and the number of gun decks. First rates were the most powerful warships; most of them carried from 80 to 110 cannons on three gun decks. Second rates carried 80 to 98 cannons on three decks, and third rates carried 74 to 80 cannons on two decks. Only the first, second and third rates were designated ships of the line. Fourth, fifth and sixth rates were lighter and therefore faster ships that served as cruisers and couriers. Fourth rates mounted 50 to 60 cannons on two decks, fifth rates had 32 to 44 cannons on a single deck and sixth rates had no more than 20 to 28 cannons on a single deck.

The living quarters of the officers aboard the *navío* were quite plush, reflecting the strict hierarchical structure of Spanish society. Officers had their own cabins, and they lived and dined in almost the same comfort they were accustomed to on land. The table in the after cabin in the stern was set with good food and wine. Fine cabinetry held china, decanters of port and navigational charts. All this luxury was frequently churned to rubble in a fight, however, particularly given the English practice of maneuvering their ships for sweeping salvos at the stern of a *navío*.

A large crew was necessary even outside of battle because almost all the work of running the ship was carried out by hand. At the beginning of a voyage everything on board, including ship's stores, ammunition, provisions and even the heaviest cannons, had to be manhandled into place. When the ship was under way, sailors were constantly sent aloft to furl and unfurl the dozens of sails. Pumps mounted on the middle gun deck to keep the bilge at a safe level were operated by hand, and during battle additional pumps were kept running to put out fires and to wash blood off the decks. Pulleys on board lightened the load somewhat, and capstans were used to lower and weigh anchors and to trim heavy sails; they too, however, were operated by hand.

Unlike the English, the Spanish and the French considered their warships to be fighting platforms for soldiers at sea, as well as gun platforms in their own right. That strategy, as I have suggested, often led to an undisciplined crew, which probably contributed decisively to the defeat of the Spanish at Trafalgar. In principle the tactic of the Spanish captains was to fire into the rigging in order to bring down the enemy's masts. Thus disabled, the enemy ship was to be boarded and taken in hand-to-hand combat.

The English tactic was to fire directly into the hull of the enemy ship. Partly because their ships rolled more severely, the English were quicker than the Spanish to replace the traditional match with the flintlock to fire their guns. The flintlock ignited the charge almost instantaneously, which gave the gunner a more certain chance that his shot would be on its way to the target before the ship began to roll.

In either case battle plans were drawn with the understanding that the firepower of the 18th-century warship was most effective at point-blank range. When a *navío* was successfully maneuvered into position astern of an enemy ship, a single volley from the 32-caliber cannons would obliterate the ornately decorated but thinly protected stern. Furthermore, such a barrage could clear the opposing gun deck of gunners, unseat the heavy cannons and send thousands of wood splinters flying around the deck, each splinter a lethal weapon in its own right.

When two ships of the line found themselves alongside in battle, the gun muzzles would be withdrawn through the gunports and into the ship; the guns were then fired from the inside. The result was sheer devastation. Gun decks only six feet high compressed the noise of the firings into a roar that caused permanent deafness for the crews. Cannonballs heated to red had to be loaded into the guns with hand tools, and the guns, whose heat was also a great risk to exposed flesh after a few rounds of firing, had to be manhandled back into firing position after each recoil. Smoke from the guns filled the deck, and crew members were often mangled to death when they were caught under a recoiling gun that they could not see through the dense fumes.

In spite of the formidable firepower, the *navíos* themselves were able to withstand hours of battle at close range. The *Santísima Trinidad,* for example, served as a Spanish flagship during the blockade of Gibraltar in 1779–82 and fought at Cape St. Vincent in 1797 as well as at Trafalgar. Double- and triple-shot broadsides from the English warships could not sink it. Although the English finally prevailed in battle, the greater Spanish firepower made a shambles of many English ships of the line.

It would be unjust to deliver a final historical verdict on the success of the Spanish *navío* without mentioning its role in exploration and discovery. Scientific voyages commissioned by Charles III circumnavigated the globe and were as scientifically useful as the much better known voyages of the English captains James Cook and George Vancouver. The Spanish expeditions undertook studies of marine biology, oceanography and navigational technique. Ship captains as well as botanists, geographers and cartographers who traveled aboard the *navíos* prepared detailed reports of their observations.

The Spanish naval captains were not simply military strategists. Two of the 18 captains who served at Trafalgar were among the best navigators, explorers, cartographers and mathematicians of their era. Dionísio Alcalá Galiano was an innovative navigator whose name is commemorated in various place-names along the west coasts of Chile and Canada. Brigadier Don Cosmé Damián Churruca was a Basque who rewrote many of the Spanish navy's navigational texts, explored the west coast of South America and made important contributions to mathematics. Like Lord Nelson, their English contemporary and adversary, both men were killed in action aboard their ships on the bloody afternoon at Trafalgar.

THE AMATEUR SCIENTIST

Edge waves form a spokelike pattern when vibrations are set up in a liquid

by Jearl Walker

Edge waves are poorly understood structures that form a spokelike pattern around a solid object vibrating in a liquid. They were first recorded by the eternally curious Michael Faraday on July 1, 1831. He had set up a long, rectangular piece of wood (he called it a plate) fixed in place at the top and extending a short distance into a bowl of water. When he made the plate vibrate, he noted that "apparently permanent elevations formed, beginning at the plate and projecting directly out from it to the extent of 1/3 or 1/2 an inch or more, like the teeth of a very short coarse comb."

The next day Faraday, who is usually remembered for his pioneering work on electromagnetic theory, produced edge waves by generating vibrations in a large glass container nearly filled with water. Wetting his finger, he drew it around the rim until the container wall vibrated. Extending radially from the wall were the ridges of the edge waves. You can see the same pattern in a glass holding wine or some other liquid when you rub a finger along the rim in order to generate a hum.

In discussing the nature of edge waves I draw on modern studies by C. J. R. Garrett, then at the Institute of Geophysics and Planetary Physics of the University of California at San Diego, and J. J. Mahony, B. J. S. Barnard and W. G. Pritchard of the University of Essex. In addition Robert E. Apfel of Yale University recently sent me a manuscript describing his investigations of edge waves. I begin with Faraday's experiments because they are easily reproduced in the kitchen. Then I shall describe my own experiments employing a wave maker that is standard equipment in high school physics classes.

In Faraday's first experiment he made the plate vibrate by tapping its center with his finger or by touching the center with a glass rod that vibrated when it was stroked with a wet finger. Waves developed as the lower end of the plate oscillated parallel to the water surface.

Water waves come in two general types. If the motion is governed by gravity, they are called gravity waves. They have long wavelengths. If the motion is controlled by surface tension, they are called capillary waves. The wavelengths are short. The waves spreading from Faraday's vibrating plate were normal capillary waves.

In addition four ridges of edge waves formed perpendicular to the face of the plate. Faraday quickly noted that although the ridges were fixed in position, they were not always present. Instead they formed and shrank rapidly enough to give the illusion of being continuous. Actually adjacent ridges were out of phase with each other: when one grew larger, the other shrank.

Faraday's next experiment involved vibration in a large glass nearly filled with water. As he rubbed a wet finger along the rim the finger skipped periodically, setting up vibrations in the glass wall to generate edge waves. At any instant the waves were either absent or weakest in four regions of the rim. One region was immediately next to the finger. The other regions were 90, 180 and 270 degrees from the finger. Between these regions the waves were strong. As the finger moved around the rim the locations of strong and weak edge waves moved accordingly.

Faraday also generated edge waves by making a tuning fork vibrate and dipping it slightly into the water. When the fork vibrated too vigorously, the water surface erupted into a confusion of drops. When the vibration was too weak, only normal capillary waves were created. Their interference sometimes yielded a stationary pattern between the two limbs of the fork, but this pattern did not constitute edge waves. Edge waves formed when the fork vibrated with proper vigor. They extended out from the fork and sometimes even obliterated the interference pattern of the normal capillary waves.

The vibrating fork also generated edge waves in ink, mercury, warm oil and thin (liquid) jelly. In mercury they did not last long because the density of the metal quickly damped the vibration of the fork. Edge waves did not appear in cold oil, apparently because the material is quite viscous.

Faraday then returned to the arrangement in which a vertical object vibrated horizontally. He set up a wood rod that extended from a vise down into a bowl of water. It generated edge waves when he made it vibrate. As Faraday lowered the rod deeper into the water the waves were fewer but more pronounced. When the rod vibrated too vigorously, the water surface broke up into drops.

Next Faraday attached a board to the lower end of the rod. The face of the board measured seven by three inches. When the rod was made to vibrate, the board oscillated horizontally through the water. Faraday spotted many ridges of edge waves across both faces of the board.

Adjacent ridges on a face oscillated out of phase with each other. The ridges on opposite sides of the board seemed to be unrelated. When the board dipped only slightly into the water, it vibrated rapidly and there were many ridges. When the board was deeper, the vibration was slower and there were fewer ridges.

Faraday investigated the flow of water within the region of edge waves by sprinkling lycopodium powder and tiny bits of cork over the water surface. Neither test revealed any repeated pattern of motion, implying that there were no established currents in the waves.

Edge waves can also form from vertical oscillations. Faraday arranged a horizontal wood rod with one end in a vise. He glued a cork to the other end so that it extended down into a bowl of water. The rod was set to vibrating so that the cork oscillated vertically. A "beautiful store of ridges formed all around it, running out 2, 3 or even 4 inches." When the cork was lowered farther into the water, the ridges became weaker.

Apfel described how he observed edge waves in a glass of wine whose rim he stroked with a wet finger. The finger periodically slips and sticks on the rim, producing vibrational waves in the glass wall. Most of the waves travel through the glass, accomplishing little, but one wave has a frequency that forces the wall into a strong, repeating pattern of radial oscillations. This wave is said to have the resonant frequency for the wineglass.

During resonance the glass wall has four regions, equally spaced around the rim, that are lacking in vibration. Between them the glass oscillates vigorously along a radius. The motion against the wine at these points creates prominent edge waves.

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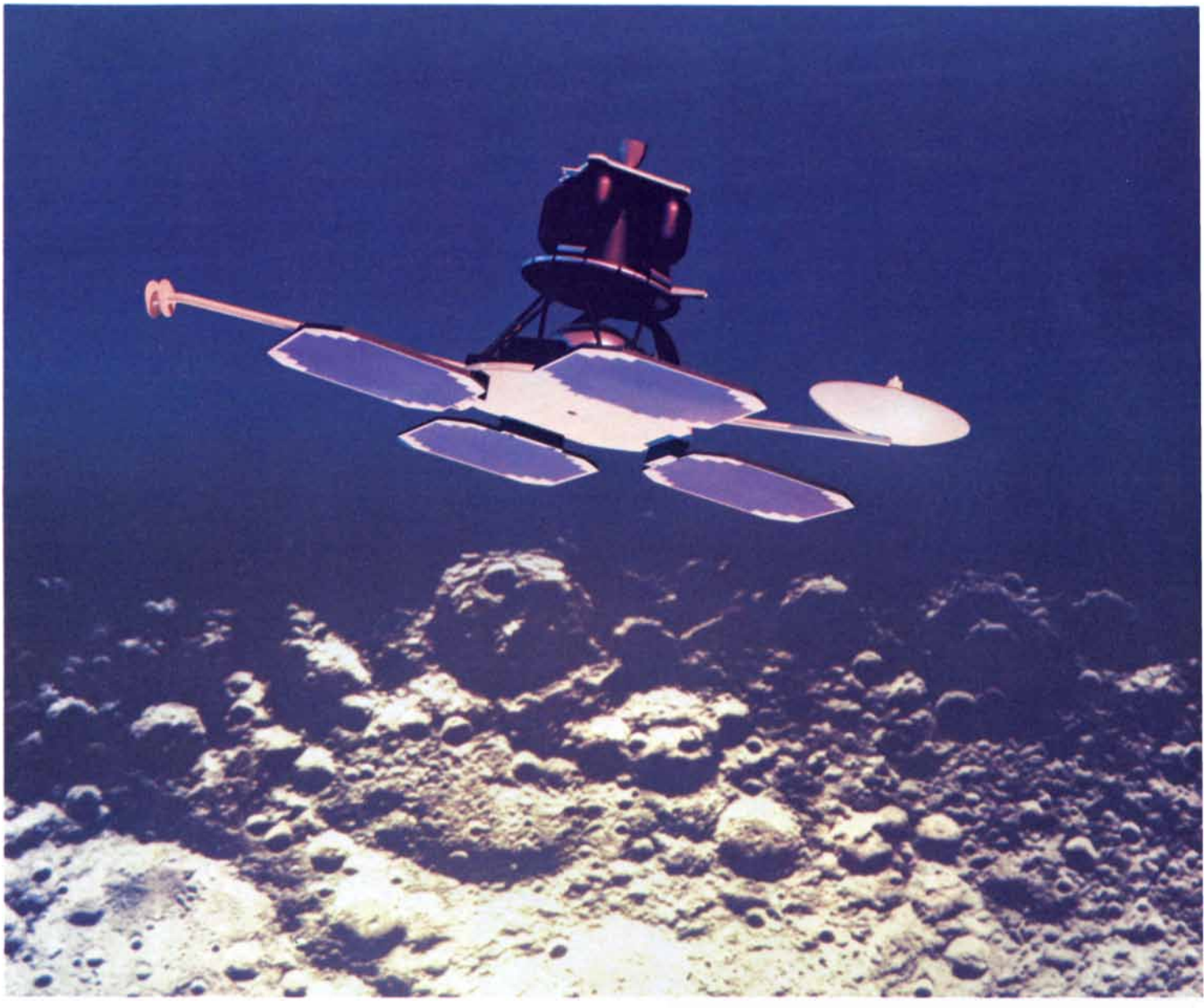

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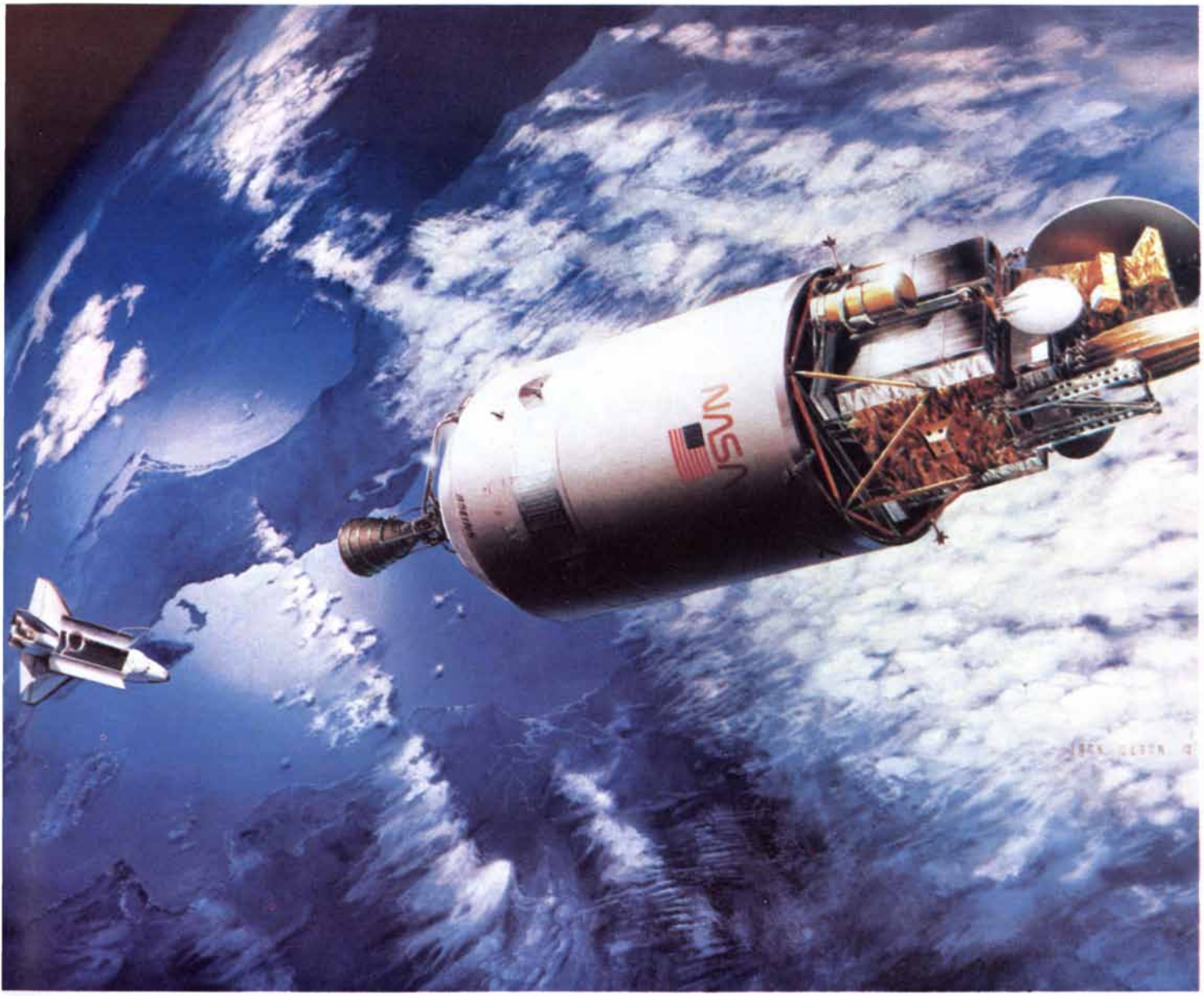

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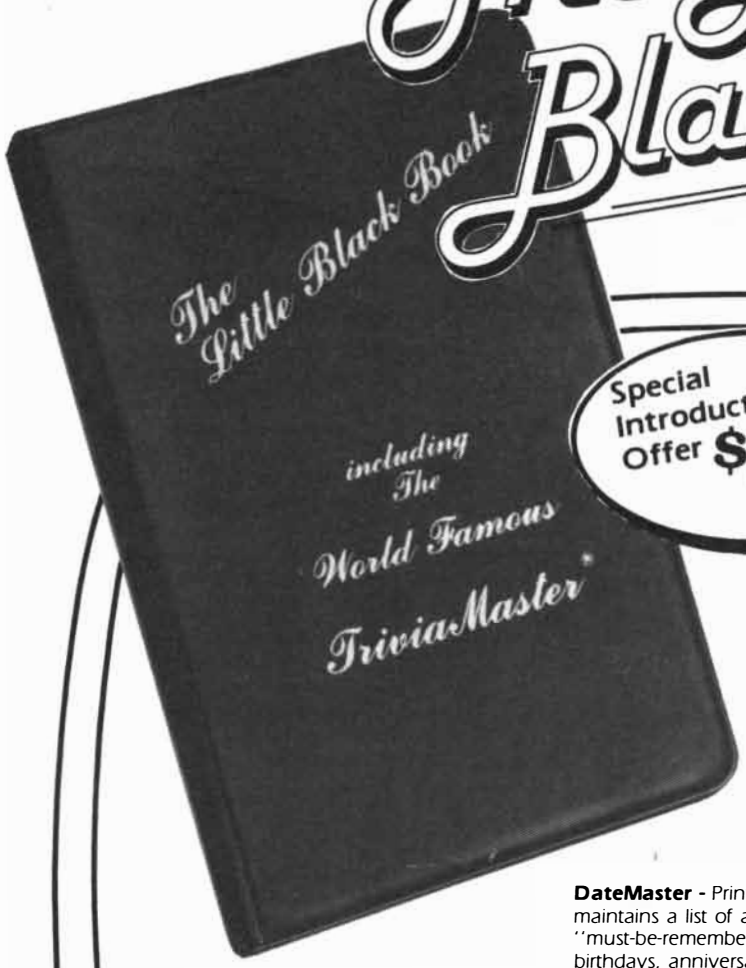

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the glass is nearly full, because only the upper portion of the glass wall vibrates strongly during resonance. The bottom of the wall is held almost rigid by the stem of the glass.

The resonant frequency of a wineglass depends on the structure and size of its wall and on how much wine is in the glass. An empty glass has a high resonant frequency. As wine is added the additional mass slows the oscillation of the glass walls, decreasing the resonant frequency.

The pattern of strong and weak edge waves moves along with the finger, making observations difficult. To keep the pattern stationary Apfel mounted a wineglass on a rotating turntable (a record player). To make the pattern clearer for photographs he painted the glass black. With the glass nearly full of water he held a wet sponge against the glass wall to set up the vibrations. For another photograph Apfel replaced the wineglass with a dessert dish containing ethylene glycol. The dish was 20 centimeters wide and had a resonant frequency of about 200 hertz.

Barnard and Pritchard did experiments with edge waves in a water tank 30.6 centimeters wide, 16 centimeters deep and 2.7 meters long. They generated waves by means of a flap hinged along the bottom of one end of the tank. It extended above the water surface. A sloped beach at the other end of the tank absorbed capillary waves reaching it so that they could not reflect back into the region of edge waves. The flap was made to oscillate by an electromagnetic vibrator driven by an amplified signal from an electronic oscillator operating at low frequency. Great care was taken in stabilizing the oscillation frequency so that the creation of edge waves was repeatable.

At certain frequencies the ridges of edge waves appeared along the exposed face of the flap. As in the experiments by Faraday the ridges were perpendicular to the face. Faster oscillations generated more ridges. The highest ridges were closest to the flap; away from it the height diminished.

Edge waves did not appear in any place except in the vicinity of the flap. Strangely, they did not form as soon as the flap began to oscillate. (The normal capillary waves did.) When they did form, sometimes after as long as a minute, they grew slowly at first and then rapidly. The ridges oscillated vertically and their maximum height varied periodically. Typically the maximum height of a particular ridge varied from maximum to minimum and back every 50 seconds or so.

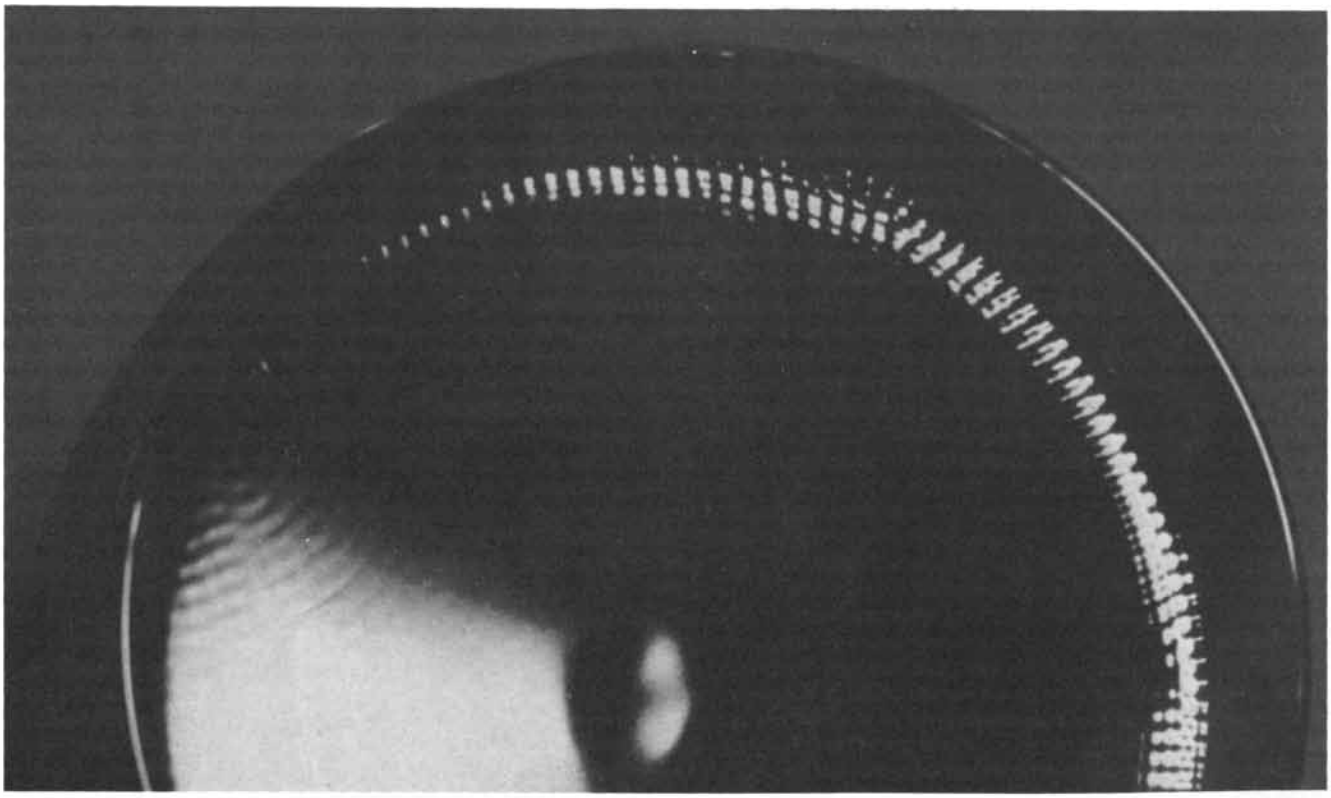
The recent theoretical work by Garrett and Mahony explains some of these experimental results. They concluded that edge waves can be generated only by a wave maker such as an oscillating paddle or a flap. The waves are not generated by the train of normal capillary waves propagating away from the wave maker, otherwise they would be seen whenever capillary waves move over a water surface.

The pressure field created by an oscillating paddle sets up an instability in the water surface. The production and propagation of the normal capillary waves is one way the instability can be relieved. Apparently the creation of a stationary pattern of edge waves is another means. The ridges of the edge waves extend only a short distance from the paddle, limited not by dissipation of their energy but by the extent of the pressure field created by the paddle.

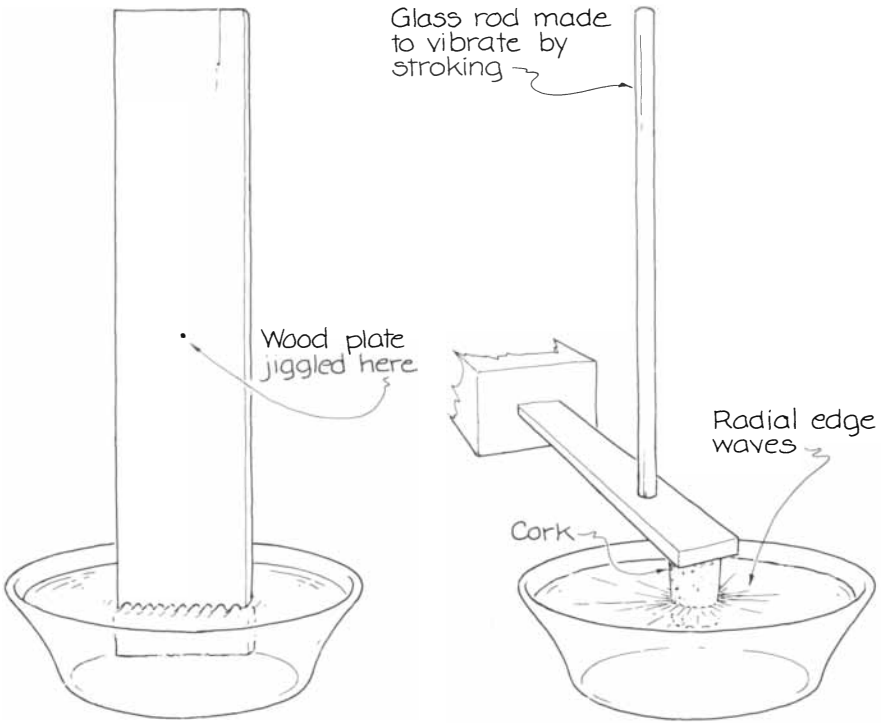
The edge waves are said to be an example of parametric resonance, a term derived from the type of differential equation describing their motion. A characteristic of such a resonance is that one motion (here the edge waves) has half the frequency of another motion (here the paddle). The paddle pushes against the water in front of it, creating a region of stress. The stress is partially relieved by the formation of the edge waves oscillating at half the frequency of the paddle.

Each push by the paddle feeds more energy into the edge waves. They soon reach a limit, however, and then the energy flow is reversed.

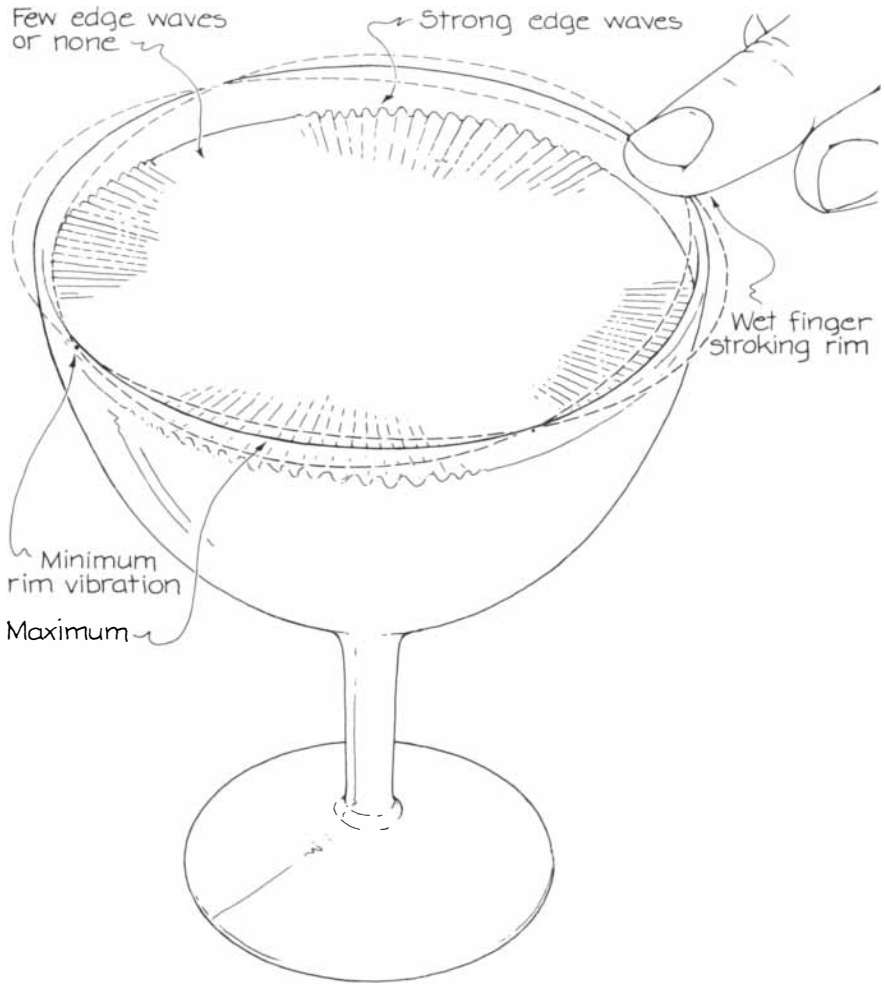
This periodic transfer of energy between systems is also characteristic of parametric resonance. The transfer is the reason the maximum ridge height in



Edge waves caused by vibrations in a liquid



How Michael Faraday experimented with edge waves



Setting up edge waves in a wineglass

a pattern of edge waves varies. The height is greatest when the paddle is energizing the wave, least when the wave is energizing the paddle.

I first did some simple experiments with edge waves in a wineglass filled with water. I could excite the waves by carefully rubbing the rim with a wet finger. To ensure that they would remain in sight longer, I excited the glass with a speaker driven by an amplified signal from an audio oscillator. The base of the glass was taped to the top of a table. The open cone of the speaker touched the rim. In this way I could control the frequency and strength of the oscillations.

When I tuned the audio oscillator to the resonant frequency of the glass, circular capillary waves immediately spread inward from the edge of the glass. Some 30 or more seconds later edge waves rose up out of the water along the edge, extending inward about a centimeter. They seemed to grow slowly at first, then much faster. They were quite fragile, disappearing when I shook the table slightly while taking notes. The waves soon reappeared. When the audio oscillator operated at a low level, the edge waves surrounded a center of relative calm. As I increased the signal strength they extended into the center of the liquid, forming a complex design of ripples.

I then turned the speaker cone to face the ceiling and placed on it a watch glass partially filled with water. No edge waves appeared, probably because I could not set up a resonance in the watch glass.

Next I tried to generate edge waves with a massaging apparatus that is essentially a simple oscillator. I put the oscillator in a bowl of water; circular capillary waves propagated from it almost immediately and a pattern of edge waves also sprang up around it. This pattern migrated slowly clockwise, apparently because the oscillator vibrated asymmetrically.

I did my remaining experiments with an oscillator I salvaged from an old water-wave apparatus of a type commonly used in classrooms to demonstrate wave interference. I removed the motor and its housing and clamped them to a ring stand. A vertical rod ran from the shaft of the motor. When I ran the motor on direct current, the lower end of the rod oscillated horizontally.

To make a paddle for the rod to drive I cut a flat rectangle out of sheet metal and sprayed it with black paint so that water waves could be seen against it. I glued a nail to the top of the piece at the center and ran the point of the nail through a small hole in the lower end of the rod hanging from the motor. A threaded bolt held the nail in place.

I lowered the clamp holding the mo-

tor until the piece of sheet metal dipped a few millimeters into a rectangular container of water (a glass baking dish). When I turned on the power, the piece of sheet metal acted as a paddle as it oscillated horizontally. By increasing the voltage from the power supply I could increase the frequency at which the paddle oscillated.

I must warn you that this arrangement can be quite dangerous. Be careful to keep the motor dry and to keep all electrical connections well away from the water. If the paddle starts to throw drops of water out of the container, shut off the current immediately.

In my experiments I increased the current gradually until the motor began to respond. Then I turned the current up slightly more and examined the face of the paddle for edge waves. Since the waves do not appear immediately, I waited several minutes before I increased the current further.

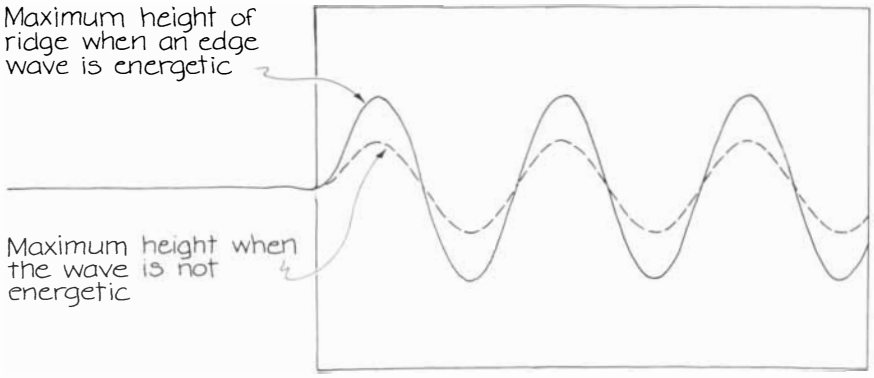
Eventually the paddle oscillated rapidly enough to make an edge-wave pattern rise out of the water surface. Four ridges appeared along the face of the paddle and extended away from it about a centimeter. The same pattern appeared on the other side of the paddle. The next increase in the oscillation frequency created five ridges across the face of the paddle.

I sprinkled ground black pepper on the surface of the water to aid a search for circulation patterns. Like Faraday I found none. I examined the edge waves from the side (with the paddle moving left and right in my view). The nearest ridge resembled a squared-off hump that extended away from the blur of the paddle. I probed the waves with several items including another strip of sheet metal. They were quite stable even when an obstacle was placed directly across all of them.

In order to make the edge waves more visible I turned off the room lights and turned on a stroboscopic light. When the flash rate matched the paddle frequency, the paddle was frozen in place. Since the edge waves oscillate at half the paddle frequency, they continued to be seen in motion. If there are four ridges in front of the paddle, two of them can be seen during a flash. If the leftmost ridge is one of them, the ridge normally just to the right of it is missing, the next one to the right is present and the rightmost one is missing. In the next flash the roles are reversed.

Although the oscillation of the ridges should be visible in stroboscopic light, it was too fast for me to follow. I could not solve the problem by halving the flash rate. The paddle was again frozen in place, but each flash revealed the same set of ridges.

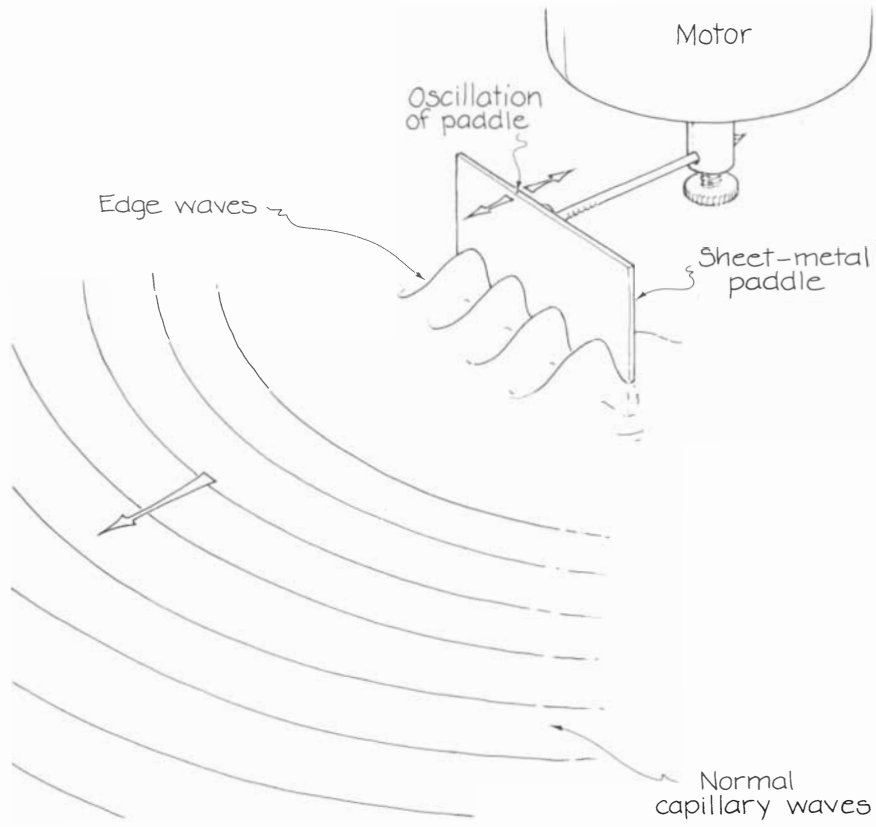
I finally chose a flash rate slightly less than half the paddle frequency. Each of the successive flashes revealed a slightly changed set of ridges. The set I saw first gradually diminished as the other set grew up out of the water. Once the new set reached its maximum height it began to diminish as the original set reappeared. This variation was slow enough for me to follow.



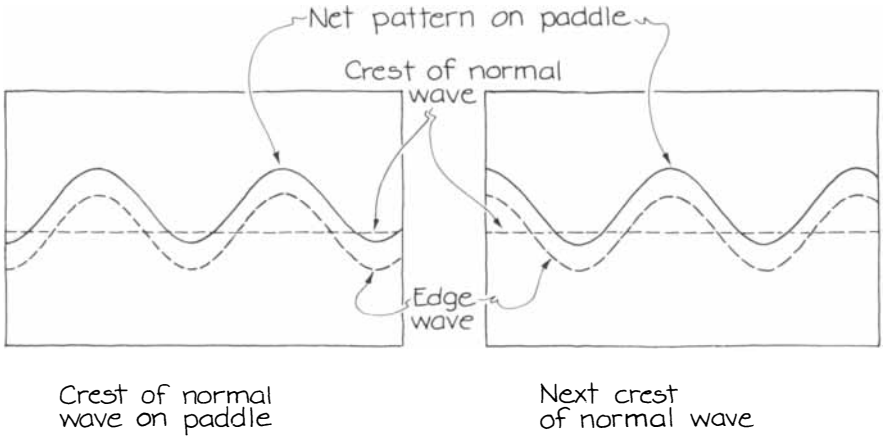
Variations in the height of the ridges

With the flash rate set I finally understood how the ridges form. They result from a combination of the normal capillary waves and the edge waves. The top illustration on the next page shows two cases where the paddle is fully forward and the crest of a capillary wave is along its face. In the first case the edge wave along the face is at a maximum on the left side of the paddle. This maximum combines with the crest of the normal wave to produce a ridge on the paddle. Another ridge is created somewhat farther to the right.

In the second case the paddle has retreated and then advanced again so that the crest of the next normal wave lies along its face. Again the ridge pattern results from a combination of the edge wave and the normal wave. Since the edge wave oscillates at half the frequency of the normal wave, it has not gone through its full cycle. On the left side of the paddle the edge wave is now at a minimum. The ridges resulting from the combination of the two types of waves are displaced from the ridges that appeared in the previous advance of the



A homemade apparatus for studying edge waves



How ridges are formed

paddle. On the next advance the initial ridges are re-created.

I made several more paddles to replace my flat one. I curved one into a semicircle, gluing the head of the nail to the convex portion. Edge waves appeared on both sides of the paddle. Another paddle was S-shaped so that on the front side (opposite to the nail) the paddle presented both convex and concave surfaces. A strong ridge appeared in the concave portion and a weaker one in the convex portion. In another flat paddle I cut a small notch in the center of the lower edge. Still the edge waves formed.

Another paddle formed three sides of a rectangle, with the nail glued to the center of the convex side. Edge waves appeared on both sides of the middle section but not along the areas that slipped through the water with little cross section.

My final paddle was a small metal hoop from my kitchen. When the motor drove the hoop horizontally through the water surface, edge waves appeared along the interior wall and also at some places along the exterior wall. They were not well formed because the motor, laboring to drive such a heavy object, was unstable.

I then remounted the flat paddle and investigated the onset of edge waves by slowly increasing the voltage of the power supply in order to increase the frequency of the oscillation. With each increase I paused because edge waves develop slowly.

Once the waves appeared I decreased the voltage and thereby the oscillation frequency. The edge waves persisted, even when the voltage was much lower than the amount required to initiate them. Apparently the paddle frequency needed to maintain edge waves is lower than the frequency needed to initiate them, probably because a good deal of energy is required to generate them. When I decreased the voltage somewhat more, the waves slowly died out, taking approximately as long to disappear as they do to appear when the voltage is higher.

I checked the periodic exchange of energy between the edge waves and the paddle while the edge waves were well established. I turned on the room lights so that I could see the ridges continuously. Then I estimated the time required for them to change from the maximum to the minimum height on the paddle face and back. A typical time for this was 14 seconds.

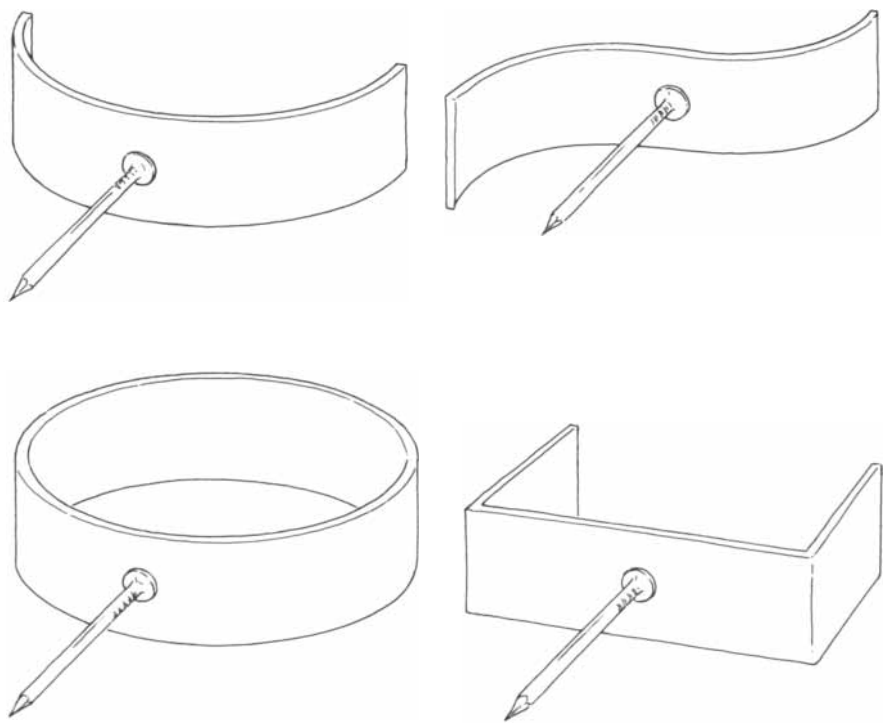
Next I poured corn oil on the water as I monitored the edge waves. The first drops spread into a thin layer. Thereafter the corn oil collected in large pools until eventually it was several millimeters thick.

The edge-wave pattern did not seem to change until several minutes after I had added the last oil. Then the pattern disappeared. At first I thought the oil was too viscous to support edge waves. Then I figured they probably disappeared because of the raft of small water drops and air bubbles churned up by the paddle. I checked this notion by waiting until the raft had had time to disintegrate into a smooth layer of oil. When I turned on the paddle, edge waves soon appeared.

I also wondered if edge waves could form at the interface of water and oil. By carefully extending the baking dish out over the edge of a table I managed to examine the interface from the bottom. I could find no evidence of an edge-wave pattern there, even when the edge waves on the top surface of the oil were quite prominent.

In my final experiments I poured a can of STP Oil Treatment over the water. This fluid is highly viscous. Edge waves did not appear. Either the fluid was too viscous or the motor was too weak to move the paddle vigorously enough through such a thick medium.

You might enjoy searching for edge waves on other liquids. Perhaps you could find waves at the interface of two immiscible liquids. The task may prove to be difficult, however, because such an interface will not support much wave motion.



A variety of paddles for setting up oscillations

The diffraction patterns I asked readers to identify last month spelled MORISN. They were intended to suggest the name of Philip Morrison, the book editor of SCIENTIFIC AMERICAN.

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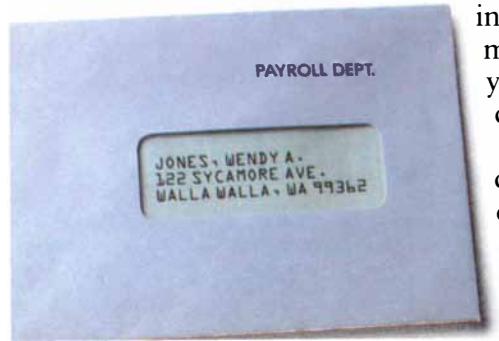

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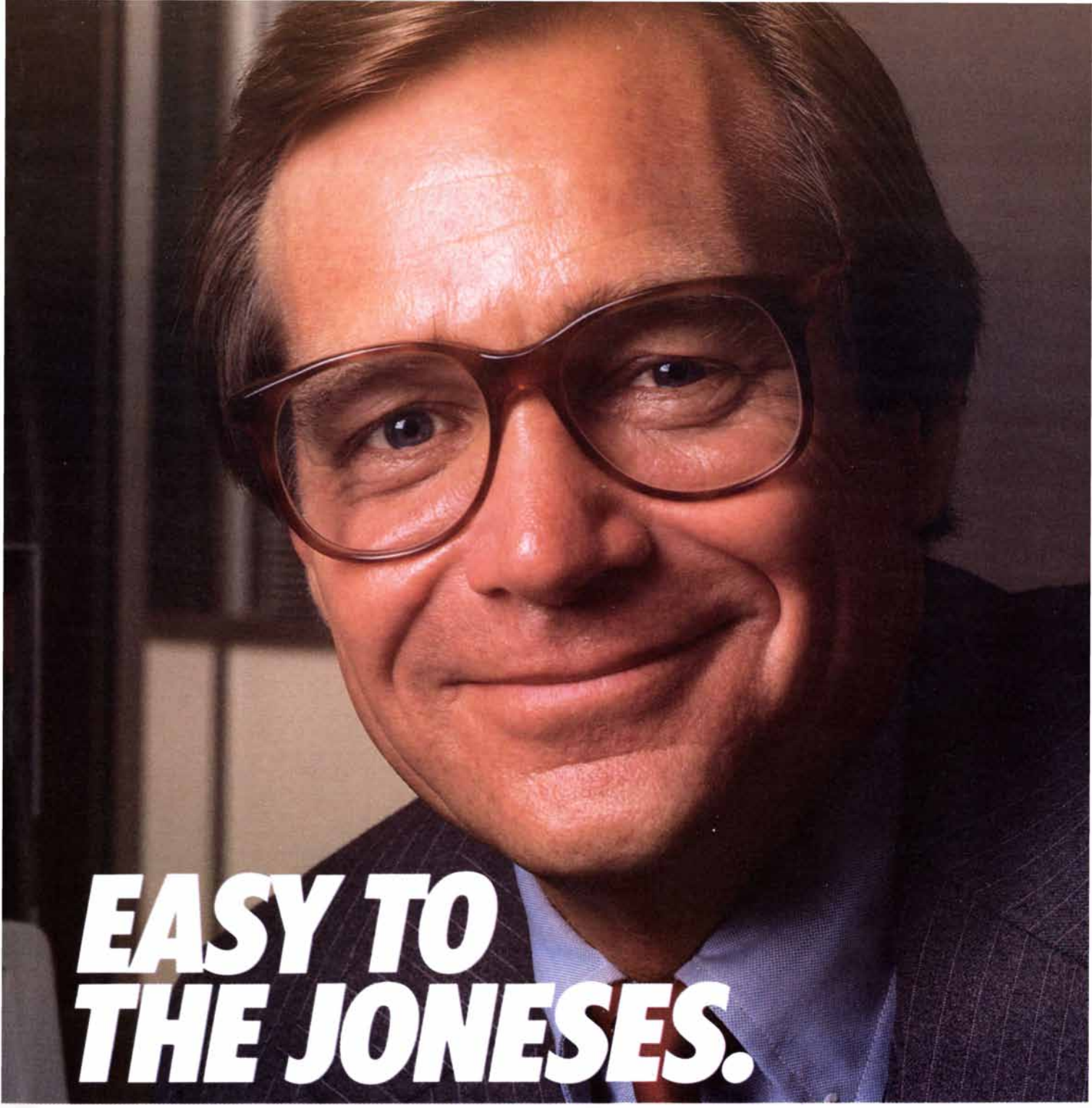

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THE AMATEUR SCIENTIST

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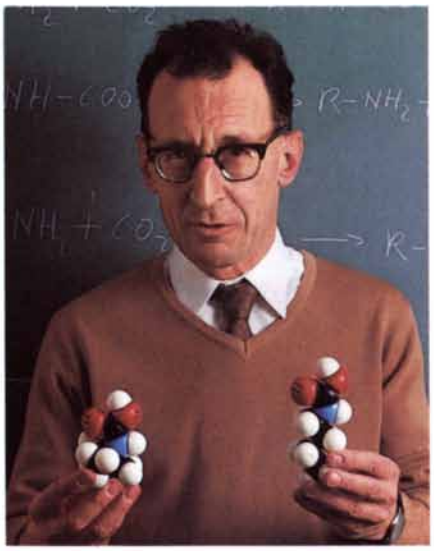
How Exxon developed can double the productivity

Guido Sartori's work on hindered amines may impact an entire industry.



Removing impurities such as carbon dioxide and hydrogen sulfide from natural, refinery, and synthesis gases is an expensive, energy-consuming process.

But at Exxon Research and Engineering Company a new chemistry discovery, and cross functional teamwork, have led to the development of a new technology—one that significantly decreases the cost and increases the capacity of commercial gas treating processes.

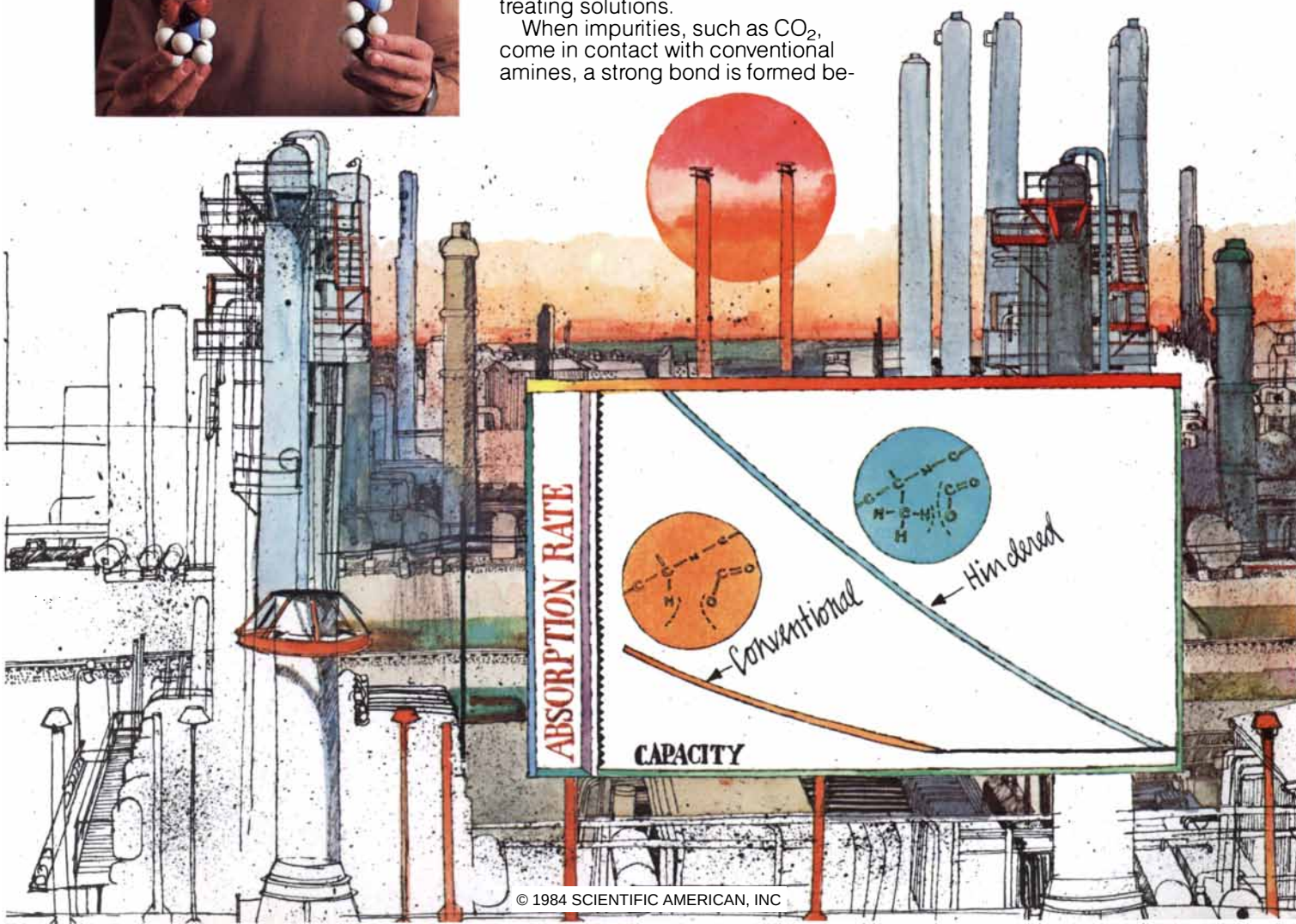
Research Led to a Discovery

Guido Sartori, a chemist in Exxon Research and Engineering Company, had been conducting research on amines—organic nitrogen-containing molecules—to increase both the absorption rate and capacity of gas treating solutions.

When impurities, such as CO_2, come in contact with conventional amines, a strong bond is formed between the CO_2 and the nitrogen atom of the amine. This strong bond ties up a disproportionate amount of useful amine. Sartori theorized that both the absorption rate and capacity of the amine would be improved if the bond at the nitrogen site could be weakened. Continuing research revealed the advantages of a whole new class of amines, which he called hindered amines.

Observing Molecular Behavior

Sartori and others began a comprehensive evaluation of the discovery, utilizing the company's advanced analytical capabilities. To understand the behavior of hindered amines, and to monitor reactions, Sartori employed the results of carbon-13 nuclear magnetic resonance spectroscopy, a



new molecules that of gas treating plants.

state-of-the-art technique not previously used for this purpose.

Further research confirmed the hindered amines' capability to substantially increase the rate and capacity of carbon dioxide absorption through the formation of low stability bonds. Low stability was achieved by placing a bulky substituent next to the nitrogen sites, thereby hindering bond formation with CO_2. Building on this new understanding, he synthesized new molecules to meet the performance requirements for specific applications.

Integrated Innovation

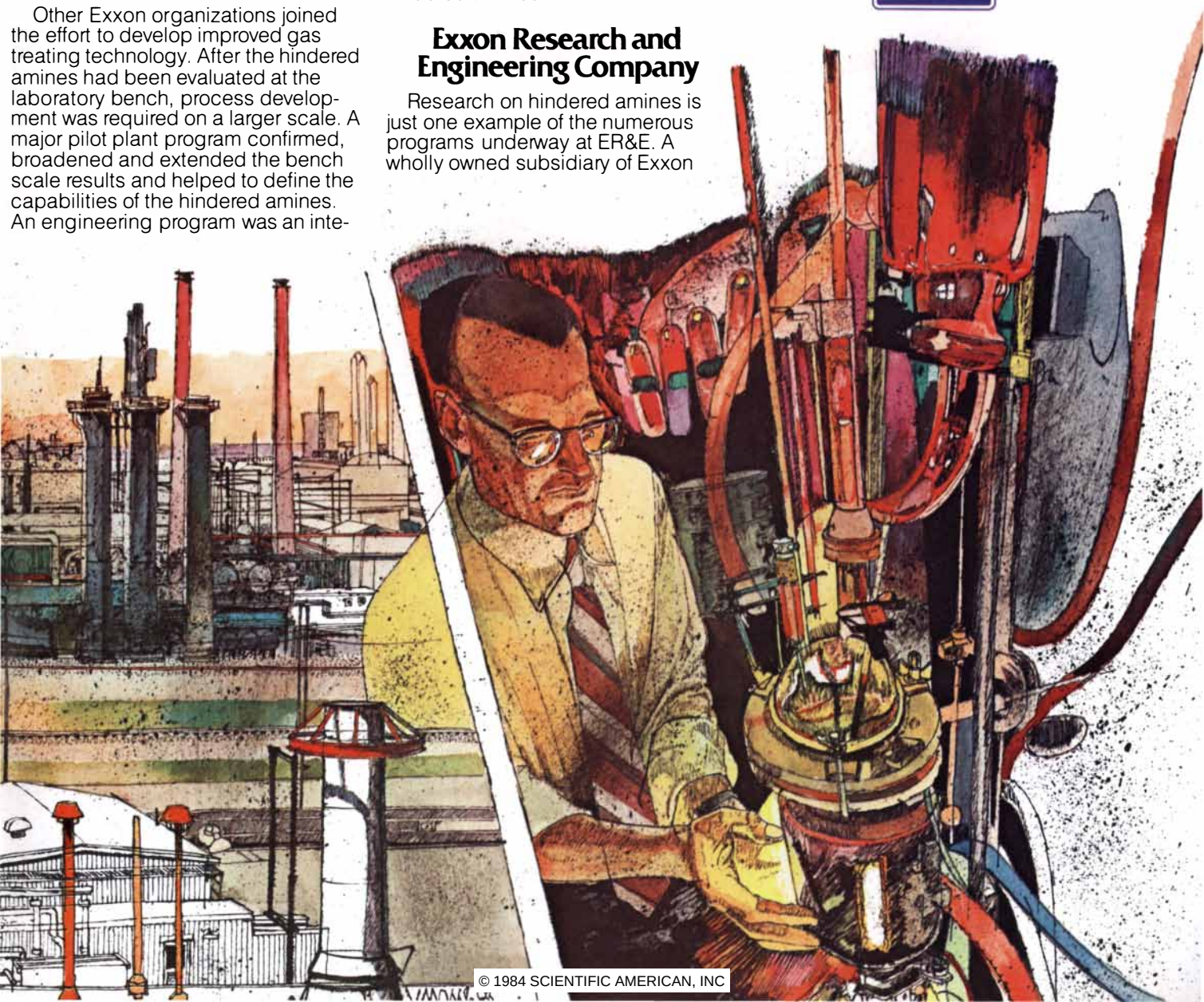
Other Exxon organizations joined the effort to develop improved gas treating technology. After the hindered amines had been evaluated at the laboratory bench, process development was required on a larger scale. A major pilot plant program confirmed, broadened and extended the bench scale results and helped to define the capabilities of the hindered amines. An engineering program was an integral part of the research and development required to convert these laboratory discoveries into commercially feasible technologies. Capacity increases of 50% have been achieved commercially using this technology with no added facilities.

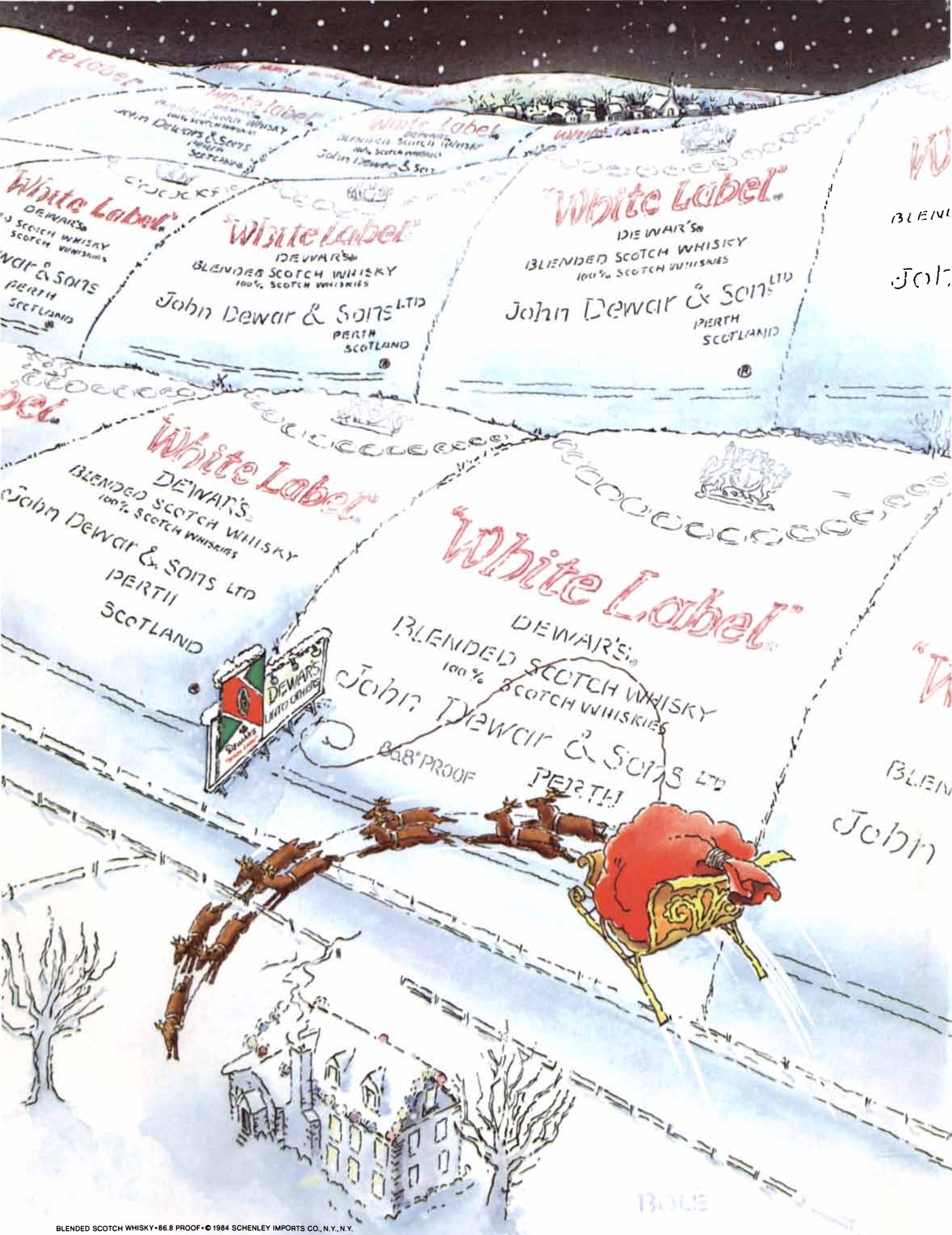
Through integrated innovation–the combined efforts of the company's basic research, process development, and engineering staffs–hindered amine technologies advanced from scientific discovery through commercial use in less than three years. Further research has enabled ER&E to identify or synthesize other practical hindered amines.

Exxon Research and Engineering Company

Research on hindered amines is just one example of the numerous programs underway at ER&E. A wholly owned subsidiary of Exxon Corporation, ER&E employs some 2,000 scientists and engineers working on petroleum products and processing, synthetic fuels, pioneering science and the engineering required to develop and apply new technology in the manufacture of fuels and other products. For more information on Exxon's hindered amine technology or ER&E, write Dr. E. E. David, President, Exxon Research and Engineering Company, Room 805, P.O. Box 101, Florham Park, New Jersey 07932.

EXXON





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