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SCIENTIFIC AMERICAN

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THE ORIGINS OF IMMUNITY:
SHARKS, STARFISH AND OTHER SEA CREATURES SHARE THEIR SECRETS

The red planet as water world:
Mars had lakes, rivers and an ocean

SCIENTIFIC AMERICAN

November 1996 Volume 275 Number 5

NEWS AND ANALYSIS

Cold, dry and laced with carbon dioxide snow, Mars today is a desiccated world. Yet many times throughout its history, warm spells, volcanoes or meteorite impacts have abruptly thawed water frozen below ground. Catastrophic floods of carbonated water then carved valleys, triggered mud slides and perhaps even formed an ocean. These astrogeologist authors describe how climate on the red planet has changed and what the upcoming missions to Mars will try to learn.

THE EVOLUTION OF THE IMMUNE SYSTEM

The human immune system, one of the most sophisticated in existence, evolved from simpler systems in organisms such as sponges, starfish and worms. Remarkably enough, virtually every aspect of human immunity seems to have a cellular or chemical parallel among the lower orders.

Half a billion years ago creatures related to sharks and rays became the first to have highly adaptive immune systems. Sharks thus offer a window on how this immunity evolved. In some respects, sharks repel microscopic invaders more efficiently than we do.

REVIEWS AND COMMENTARIES

About the Cover
Long ago, when Mars was warmer, short-lived lakes may have shimmered in and around impact craters there. Meteorites can still release water frozen deep underground. Image by Edward Bell.

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FROM THE EDITORS

An Honest Quantum Con Job

Walk in the general vicinity of Times Square for about five minutes, and you will find New York's glorious reputation as the spiritual home of the con game kept alive by hucksters playing three-card monte on the sidewalks. You say you don't know how to play three-card monte? Well, step right up, my friend, this is your lucky day, because for the nominal fee of $5, I will teach you. In my hand I hold a playing card, the queen of spades. Watch closely now, as I place the queen face down between two other cards and, presto, shuffle them around. Keep your eye on the card, it's not that hard! Okay, my friend, where's the queen? Here? Let's take a look—oh, so sorry. Care to try again, for another fiver? Everybody walks away a winner....

NOTHING UP OUR SLEEVE, but quantum trickery still occurs.

The average honest citizen (a.k.a. victim) figures that he has at least a one-in-three chance of guessing right, probably better since he can watch how the cards are manipulated. The real odds are somewhat worse: zero, actually, because I've cheated you through sleight of hand, palming the queen and replacing it with another card. Hence the dim view that the police take of three-card monte and other variations on that old familiar con, the shell game.

But in this issue, you can read about a high-tech variation on the shell game, invented by physicists, that is absolutely on the level. Paul Kwiat, Harald Weinfurter and Anton Zeilinger describe it in "Quantum Seeing in the Dark," beginning on page 72. Their work involves another foray into the always weird world of quantum physics, where one can sometimes accomplish the seemingly impossible by creeping up on it probabilistically. In effect, these researchers and their colleagues have found how to determine whether an object is inside a closed box without peeking at it, touching it or otherwise interacting with it. Their approach exploits the fact that a laser beam bouncing through a series of mirrors can interfere with itself, and the quality of that interference contains information about the paths the beam did and did not follow. Unlike Schrödinger's cat and many other quantum-effect thought experiments, this one has been successfully tested on the lab bench.

For now, at least, the quantum-mechanical method of "seeing in the dark" is a curiosity, but in their article, the authors do speculate on how the technique could in theory be applied to some real-world measurements of highly delicate systems. So their discovery works out as both an intellectual entertainment and a potentially practical tool. Everybody does walk away a winner.

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LETTERS TO THE EDITORS

POETIC SCIENCE

The illustration on your July cover, for Stephen W. Hawking and Roger Penrose's article "The Nature of Space and Time," reminds me of a beautiful quatrain from the prologue to *Hellas, A Lyrical Drama,* written in 1821 by Percy B. Shelley, the English Romantic:

The curtain of the Universe
Is rent and shattered,
The splendor-wingèd worlds disperse
Like wild doves scattered.

THOMAS A. REISNER
Laval University
Quebec, Canada

THEORIES OF EXTINCTION

In his article "The Mother of Mass Extinctions" [July], Douglas H. Erwin suggests that the end-Permian mass extinction may have resulted from an abrupt drop in sea level. But new evidence increasingly constrains the time frame for the extinction, calling for a much more rapid mechanism. If an extraterrestrial cause (a comet or asteroid) is ruled out, a fast-acting terrestrial cause must be responsible. Heat from the main pulse of the Siberian traps could have abruptly released large quantities of methane. Although the lethal gas would have remained in the atmosphere for only about a decade before being converted to carbon dioxide and water, the methane—together with the resulting high levels of carbon dioxide—could have been responsible for the extinction event.

DAN DORRITIE
University of California at Davis

Erwin discussed various theories about the end-Permian mass extinction, including the intriguing volcano hypothesis. Although aerosols emitted by volcanoes do temporarily diminish the ozone layer, theoretically allowing more ultraviolet radiation to reach the earth's surface, levels of ultraviolet B radiation actually seem to decrease after a volcanic eruption. Apparently, the aerosols block the rays fairly efficiently. (Particles in smoke and severe air pollution also block rays of ultraviolet B.) It also turns out that ultraviolet B radiation is an effective bactericide and viricide, and some researchers have observed higher levels of infectious disease in regions with severe particulate pollution. Could the thick aerosol layers from the massive eruptions during the end of the Permian have blocked ultraviolet rays so effectively that the population of pathogens multiplied, thereby contributing to the extinctions of that era?

FORREST M. MIMS III
Seguin, Tex.

Erwin replies:

In my 1993 book, *The Great Paleozoic Crisis: Life and Death in the Permian* (Columbia University Press), I pointed out that based on the change in carbon isotopes observed in fossil records from the end-Permian, large quantities of methane may have been released to the atmosphere during that period. My recent account did not claim that a decline in sea level alone triggered the extinction but rather argued that multiple causes, possibly including the Siberian flood basalts, were involved. The mechanism suggested by Dorritie is possible. Yet because a short pulse of methane would not leave a unique signal in the geologic record (a change in carbon isotopes could be produced by a variety of other events), this theory seems a bit difficult to confirm. The rate of the extinction is simply not yet known, although at least the final phase of the extinction appears to have been fairly rapid.

Mims's idea is interesting but, again, virtually impossible to test. Both Dorritie's and Mims's theories depend on the eruption of the Siberian flood basalts at the Permo-Triassic boundary. Some uncertainty remains about this correlation, however: much of the eruption may have occurred during the early Triassic period. In this case, the eruption may have retarded the recovery rather than caused the extinction.

NORTHERN EXPOSURE

I read with interest John Horgan's article "'Peaceful' Nuclear Explosions" [News and Analysis, June]. But I must take issue with his statement that a nuclear device was detonated in Alaska as part of the Plowshare program to conduct PNE tests. To the best of my knowledge, a total of three nuclear tests have been conducted in Alaska, and none could be described as a PNE. But at least one Plowshare project was proposed for Alaska: Project Chariot was designed to demonstrate the feasibility of excavating harbors through the use of nuclear explosives. The site was to be Cape Thompson, southeast of the village of Point Hope. But after a number of studies—and increasing political awareness and activity on the part of Alaskan Natives—the test was canceled.

CHARLES E. DITERS
U.S. Fish and Wildlife Service
Anchorage, Alaska

Letters may be edited for length and clarity. Because of the considerable volume of mail received, we cannot answer all correspondence.

CLARIFICATION

In the article "Should Women in Their 40s Have Mammograms?" [Gina Maranto, September], the statement that "10 to 15 percent of women in any age group who walk away from a mammogram assured that they are free of cancer go on to acquire it within a year" is inaccurate. The sentence should read "Among women diagnosed with breast cancer within a year of a mammogram, 10 to 15 percent had negative mammograms and were assured that they were tumor free."

50, 100 AND 150 YEARS AGO

SCIENTIFIC AMERICAN

NOVEMBER 1946

In this best-fed nation in the world, one-third to one-half of the population lacks vitamin C. This vital food element—essential for vigor and efficiency—is now available in a new mass-produced synthetic form. Technicians have developed successful manufacturing processes based on combining ascorbic acid and sodium in water-free methyl alcohol. The new vitamin C is precipitated as a pure, white crystalline mass."

"Textile making is finding in electronics new methods to produce flawless fabrics. One application is the 'stop-motion' set-up that detects accidental thread breaks—which produce flaws and lower market prices—and immediately stops the looms. Threads entering textile machines pass through a hinged eyelet, called a drop switch, which is held open by the tension on the thread. When a thread breaks, the drop switch makes contact with a metal bar and a minute current flow to an electronic relay stops a machine almost instantly."

NOVEMBER 1896

An immense crowd assembled near the Hotel Metropole, London, November 14, to witness the departure of the motor carriages for their race to Brighton, 47 miles. The occasion of the race was the going into effect of the new law which opens the highways to the use of the motor carriages and doing away with the antiquated laws which have hitherto obtained. It is a curious fact that under the old law self-propelled vehicles were not allowed to go faster than six miles an hour and had to be preceded by a horseman waving a red flag. Nearly fifty carriages started in the race; it is a great satisfaction to know that the race was won by the American Duryea motor wagon. The distance was covered in four hours." [*Editors' note: The London to Brighton run has 680 antique cars entered for the centenary event.*]

"The removal by blasting and digging of 1,635,000 cubic yards of rock from the river Danube represents one of the most stupendous and difficult engineering works of modern times. At last the 'Iron Gates,' which barred this great natural inland waterway, have been unlocked. There are indications that Roman engineers studied the problem nigh upon eighteen hundred years ago. The present successful attempt extended over more than sixty miles of the river's length, and the canal will now give Vienna an unobstructed outlet to the sea for boats drawing 10 feet of water."

"More than 2,700 oil wells were bored in Indiana in 1895, and hopeful, well-informed men expect that enormous total will be surpassed in 1896. It is predicted that the State will soon rank with Pennsylvania and Ohio in the quantity of oil annually taken out of the ground. While 2,711 wells were completed, only 754 went dry in the year just passed."

NOVEMBER 1846

If there is any one crime which should excite universal indignation, it is the sneaking villainy of cutting the wires of the magnetic telegraph. This scoundrelism, if not checked by the vigilance of the whole community, appears likely to deprive the public of the important benefits to be derived from this greatest invention of the age. It is supposed by some that this mischief proceeds from sheer envy against the rapidly advancing honor and prosperity of our country, under a system of free institutions and unbridled enterprise."

"Butter has been supposed to be animal matter, but recent investigations have proved that butter may be produced from hay or grass, without depending upon the cow for its preparation. An expert chemist can produce fifteen pounds of vegetable butter from a hundred weight of hay, being nearly twice as much as can be produced from the milk of a cow for an equal quantity of hay. We may expect to see butter factories established in competition with the ordinary dairies."

"A correspondent from Loweville, N.Y., states that on November 11 the most remarkable meteor ever seen there made its appearance. It appeared larger than the sun and illumined the hemisphere nearly as light as day. It was in sight nearly five minutes, and finally fell in a field in the vicinity. A large company of the citizens immediately repaired to the spot and found a body of foetid jelly, four feet in diameter."

"Our engraving is a representation of the great Rosse telescope, one of the principal artificial wonders of the world. It has been recently completed by the Earl of Rosse at an expense of nearly 60,000 dollars. The tube is 56 feet long. The speculum is six feet in diameter and weighs nearly four tons; its composition is 126 parts of copper to 57 1/2 parts of tin. The telescope rests on a universal joint and is elevated or depressed by a chain and windlass. The telescope is at present of the Newtonian construction, and consequently the observer looks into the side of the tube at the upper end of the telescope."

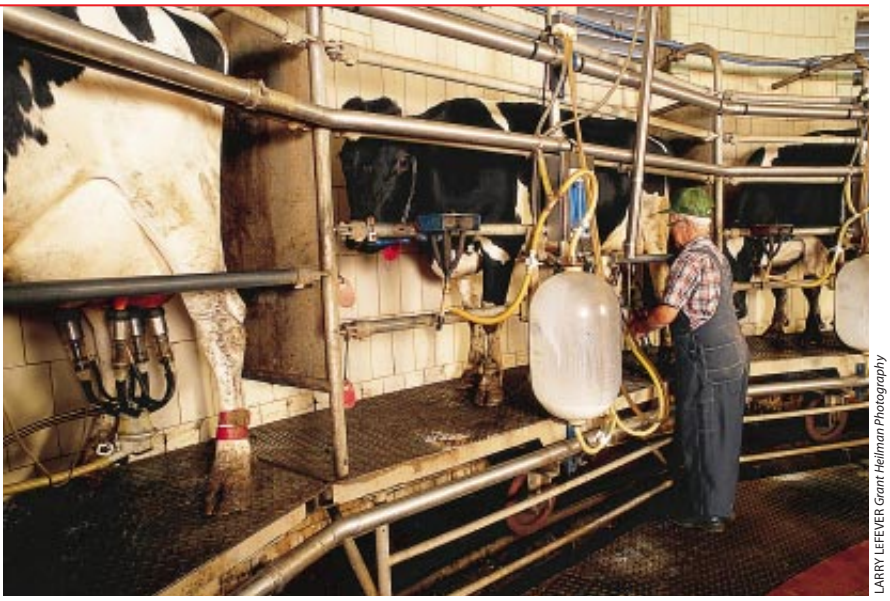
The great Rosse telescope

NEWS AND ANALYSIS

IN FOCUS

THE PRICE OF SILENCE

Does profit-minded secrecy retard scientific progress?



LARRY LEFEVER *Grant Heilman Photography*

***SOME COMMERCIAL DAIRIES** avoided Monsanto's growth hormone after charges of suppressed negative research.*

Asked in whom they trust, more Americans in 1994 professed great confidence in scientists and doctors than in any other professionals, including Supreme Court Justices and—by nearly five to one—journalists. Researchers owe their prestige to the image of science as an altruistic and trustworthy enterprise, generating reliable knowledge for the benefit of all humanity. Recently, however, a number of prominent scientists have begun voicing an alarm that increasing secrecy among academic researchers is delaying progress, diverting resources, suppressing good ideas and, most worrisome, undermining the credibility—and thus usefulness—of science as a whole. Steven A. Rosenberg, chief of surgery at the National Cancer Institute, argues that in medicine, at least, "it is a very clear moral issue. If you withhold information, you potentially delay progress. If you delay progress, you potentially delay the development of effective treatments, and humans beings suffer and die who need not have done so."

"There has always been secrecy in science, because recognition goes to whoever publishes first," observes Dorothy S. Zinberg of the Center for Science and International Affairs at Harvard University. "Watson and Crick kept their discovery of DNA's double helix under tight wraps because they were trying to beat out Linus Pauling." But the race to publish, she says, is being challenged by a race to patent.

As federal funding for academic research has slowed—annual increases averaging 4.2 percent in the 1980s have dropped to just 0.4 percent last year—industry has picked up some of the slack. Corporations paid for about 7 percent of university research in 1995, up from 4 percent in 1980. Schools are also trying to boost their budgets by aggressively patenting their employees' work: academia's share of the patent pie has doubled since 1991. "Columbia University now receives about $50 million a year in profits from patents. It expects that to rise to $100 million within five years," Zinberg says.

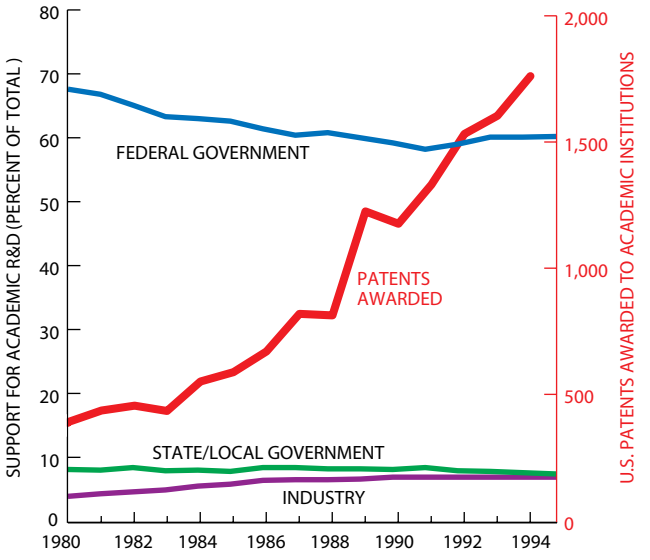
But the new money brings new restrictions. Rosenberg reports that when he recently asked a company for a gene that he needed, the company insisted that he first sign a contract

agreeing not to disclose the substance and "all results and data developed by [me] resulting from the studies"—for 10 years. He refused and consequently had to spend more than four months to clone the gene himself.

"At one time, if you found something exciting, you would run down the corridor and talk about it," reminisces Derry Roopenian, a biologist at the Jackson Laboratory in Bar Harbor, Me. "Now if you discover something but a commercial backer is interested in it, you can't say a word about it."

"The greatest effect seems to be on this informal network of scientific communication," agrees Robert W. Rubin, vice provost for research at the University of Miami. "But there is an effect on the formal network as well. Most of our contracts with companies give them 60 to 120 days to evaluate any data obtained with their backing before we can publish it. That can double or triple the time it takes to get results into the literature. And sometimes the contracts state that you cannot publish it at all without their permission. It is not unheard of for a company to just sit on an idea not because they want to develop it but because they don't want anyone else to."

In fact, Zinberg notes, "a 1994 study by researchers at Carnegie Mellon University reported that 53 percent of [scientists surveyed] had agreed to allow publications to be delayed. And 35 percent had signed agreements whereby the sponsors could require that information can be deleted from publication." Another survey that year found that 82 percent of life-sciences companies sometimes require scientists to keep results confidential for months until patents can be filed. About half said that academic researchers keep discoveries quiet even beyond the time needed to obtain a patent.



RISING INDUSTRIAL FUNDING
and academic patenting are changing the face of basic research.

This hush fell first over medicine and biotechnology, Rubin says. But it is gradually spreading throughout science. "Suddenly, the language in contracts for research in other fields sounds like that in biotech contracts," Rubin reports. Negotiating all these agreements diverts time and energy from science, frets Ronald R. Sederoff, director of the forest biotechnology group at North Carolina State University. "It has taken us a year and a half to work out an intellectual-property agreement for [an industry-funded] project to get all the expressed genes in a pine tree," he says.

Sederoff admits, however, that without industrial backing, the research effort would not be possible at all. Commercially restricted research may not be ideal, but isn't it better than doing without? "Biology has finally begun yielding useful products," counters Barrie J. Carter, research director for Targeted Genetics in Seattle. "But unless the federal government wants to develop these products, we have to rely on capital investors, and they need to protect their competitive advantages. It is not clear that science is worse for that."

But Zinberg and others worry that industry could be inadvertently undermining the creativity and independence that make academia worth exploiting in the first place. "Look at biotechnology," Sederoff argues. "The basic discoveries that led to the field were based on decades of academic, publicly funded research. I believe that if these discoveries had been subject to proprietary control and restriction, we wouldn't have created the field of molecular biology. So there wouldn't be anything to fight over now."

Two recent incidents suggest that companies' attempts to suppress research can backfire on them. Boots Pharmaceuticals gave Betty Dong of the University of California at San Francisco $250,000 to study Synthroid, a synthetic form of thyroid hormone taken daily by eight million people at an annual cost of some $600 million. Boots asked Dong to determine whether three generic forms of the drug were biologically equivalent to Synthroid, presumably expecting the answer to be no. When Dong discovered that the generics were equivalent and tried last year to publish her results, Boots invoked a clause in the research contract to force Dong to withdraw the paper. There the matter might have ended had the *Wall Street Journal* not uncovered the episode in April.

Monsanto has also been dogged for years by allegations that it tried to suppress data on the negative effects of bovine somatotropin (BST), its drug to boost cows' milk production. Scientists funded by Monsanto reported that cows given the drug suffered only a small increase in udder infections. When independent British researchers examined the company's data, they found that previously published reports had, curiously enough, analyzed figures from only part of the experiment. Pooling all the data together for a more comprehensive analysis, they concluded that cells associated with udder infections present in milk increased by about one fifth in cows given BST. But when they attempted to publish their results in a veterinary journal, Monsanto objected. So in November 1994 the investigators went on a national television news program in Canada. (The results have yet to be published.)

In part because of uncertainty about the drug's safety, the European Union, Australia and New Zealand have banned the sale of meat and milk from BST-treated cows. Analysts say sales have yet to overtake the cost of producing and selling the drug—never mind the huge investment in its development.

In the long run, Zinberg says, "we are all interested in the vitality of our universities." Rosenberg suggests that the best way to preserve that is "to talk about this issue and to find out how prevalent secrecy is and how it is affecting scientific progress. We need to develop new patent laws and regulations that allow for the free flow of information and still protect the intellectual-property rights of those who pay for and conduct research." It should be possible, he says, to have the best of both worlds. —*W. Wayt Gibbs in San Francisco*

JENNIFER C. CHRISTIANSEN

ASTRONOMY

HOT JUPITERS

Why do some giant planets hug their stars?

Last year, when Michel Mayor and Didier Queloz of the Geneva Observatory reported the first solid evidence of a planet circling a sunlike star outside the solar system, many astrophysicists were taken aback. These observations showed what could be a Jupiter-size planet orbiting quite close to the star 51 Pegasi; it was about seven million kilometers away—only a small fraction of the distance between the sun and Mercury. Yet existing theories for the development of planetary systems indicated that such giant planets should form at much greater distances from a star. What was a big planet doing so close in?

Some initially believed that the old theories were fine and that 51 Pegasi was simply the exception that proves the rule. After all, the technique that Mayor and Queloz had used was most sensitive to large planets in tight orbits. But further discoveries over the past year have uncovered nine other "extrasolar" planets, and three of these bodies, in addition to the one around 51 Pegasi, are rapidly circling at a celestial hair's breadth from their stars. Astronomers now surmise that such "hot Jupiters" might, in fact, be commonplace.

"I don't think any of us were prepared to see these three-day- or four-day-period Jupiters," says George D. Gatewood, director of the University of Pittsburgh's Allegheny Observatory, referring to the short times needed for such planets to complete their diminutive orbits. Indeed, just seven months before the discovery

FIELD NOTES

Bring Me a Shrubbery

I am on an experimental farm near Syracuse in upstate New York, standing next to dense thickets of a tall woody shrub that is bereft of any edible fruit and would certainly lose in an arboreal beauty contest. The shrub, a hybrid willow, sends out a vigorous green spray of whiplike stems that climb as high as 11 feet in a single year. Although the double rows of identical plants are five feet apart, the stands are impenetrable: the profusion of wood and leaves is literally arresting. The willow would seem an unlikely crop, but if Edwin H. White of the State University of New York's College of Environmental Science and Forestry has his way, it could become common in much of the northern U.S. By 2010, farmers may be growing 50,000 acres of the stuff in New York alone.

RANDI ANGLIN

Shrubbery would not normally warrant an intensive research effort, but to White and local power companies—and now the Department of Energy—the prodigious growth rate of these hybrid willows makes them a potential source of clean-burning fuel. They produce five to 10 times more wood every year than any natural forest. A 50,000-acre crop would be worth $20 million.

White, who is dean of research, has spent the past 10 years investigating how to cultivate the plant. He is convinced that the U.S. and other countries should make more use of wood for energy. Burning farmed wood in power stations reduces reliance on foreign oil and curtails emissions of carbon dioxide (although trees produce the gas when they are burned, they take it out of the atmosphere while growing).

Hybrid willow shrubs—which look nothing like the familiar tree—appear to be the most promising biomass fuel for the U.S., White says. Once established they are extremely hardy, tolerating marginal land with only irrigation and some added nitrogen. The basic cultivation scheme was developed in Sweden; 50,000 acres are now grown in Europe. The shoots, which readily grow from sticks, are cut back at one year, and the wood is harvested every three years thereafter for about 20 years. Researchers are studying a patchwork of varieties.

Burning wood is, of course, hardly a new idea, but its high cost means that very little is used in the U.S. New York State Electric and Gas Corporation (NYSEG) is one of a small number of power companies nationwide that have investigated using waste wood, chipped into two-inch lumps, for burning along with coal. Michael Tesla of NYSEG says he aims eventually to burn willow in 1/4-inch flakes.

Although willow will cost hardly less than coal for the same amount of energy when equipment costs are figured in, power companies see it as a valuable way of cutting about 10 percent from their sulfur emissions, which are limited by tradable permits, as well as emissions of nitrogen oxides, which may be limited in the future. The companies also recognize its potential as a hedge against the possibility that carbon dioxide emissions from fossil fuels might someday be taxed.

The federal government is offering willow a jump start. The DOE and the U.S. Department of Agriculture earlier this year signed an agreement with a consortium of New York power companies, agencies and academic institutions to establish 2,600 acres of willow as a demonstration project. The energy department will provide 36 percent of the estimated $14-million cost. Although in New York the project will initially focus on burning wood directly, in other states it will eventually include burning gas produced by heating the wood. White notes that there are 200 million acres of abandoned farmland in the U.S. I don't need to ask what he would like to see growing on them 20 years from now.

—Tim Beardsley

IN BRIEF

Making Voting a Science

Both leading presidential candidates have paid scant attention to science during the campaign, despite agreement that research stimulates growth.

AP/WIDE WORLD PHOTOS

ASSOCIATED PRESS

Bob Dole's pledge to lower taxes by 15 percent would demand large cuts in civilian research and development; Representative George Brown, a Democrat from California, projects reductions as large as 40 percent by 2002, with cuts falling especially hard on the Departments of Energy and Commerce. Nor does President Bill Clinton's balanced budget plan look auspicious: the American Association for the Advancement of Science says it implies a 19 percent drop in nondefense R&D over the same period. Congressional staff say total R&D as a proportion of gross domestic product is likely to fall from 2.4 to about 2.1 percent.

Sickle Cell Successes

This past summer it became clear that bone marrow transplants could probably cure some children suffering from sickle cell anemia, a genetic condition in which abnormally shaped red blood cells clog capillaries and cause life-threatening tissue damage. Recently hope has come to many more. In September researchers at Thomas Jefferson University reported on a new synthetic molecule—called a chimeraplast—that in laboratory tests can actually repair the responsible genetic malfunction. Clinical tests should begin soon.

Affirmative Reaction

What's good for the goose *is* good for the gander. In 1990 researchers at the Johns Hopkins School of Medicine initiated a series of changes—among them correcting salary inequities—to minimize sexual bias at the school. This year's follow-up found that while the changes made academic medicine an easier career choice for women, they also gave many more gifted men a chance at success. Those planning to leave the field fell by 63 percent among women and by 42 percent among men.

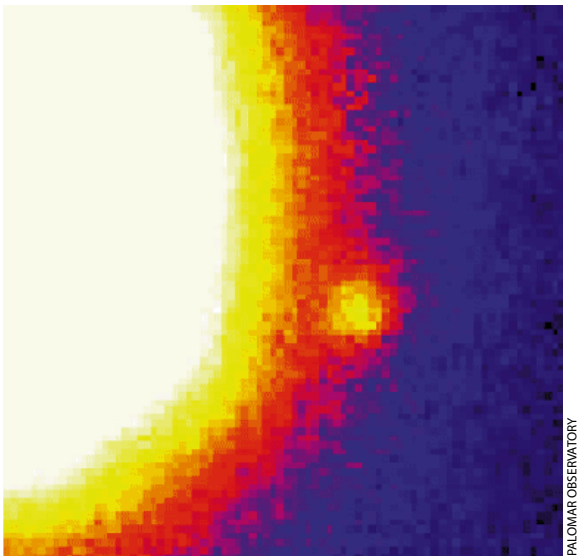
Continued on page 24

of the planet around 51 Pegasi, Alan P. Boss, a theoretical astrophysicist at the Carnegie Institution of Washington, showed that Jupiter-like planets most likely form at approximately five times the Earth-sun separation (an often used yardstick called the astronomical unit, or AU, a distance of about 150 million kilometers), even when the parent star is quite small.

Recently Douglas N. C. Lin of the University of California at Santa Cruz and two colleagues offered one way around the conundrum. They argued in the journal *Nature* that a Jupiter-like planet would form at about 5 AU and then gradually spiral inward, along with the disk of dust and debris (called the planetary nebula) out of which the planet originally formed. This inward migration is inferred from the basic physics governing the motions of orbiting material.

Yet the mechanism for halting that orbital decay remains somewhat speculative. Lin and his coworkers offer two possibilities. In one scenario, the decay continues until the large planet is brought sufficiently close to raise a tidal bulge on the central star. If this star rotates faster than the planet orbits, the tidal bulge would tend to spin ahead of the planet. The massive bulge would then exert a gravitational pull that helps to speed the planet along in its orbit, counteracting the ongoing tendency to spiral inward. The second possibility involves the magnetic field of the star, which could sweep the inner region of the nebula clear of dust and gas. Once the planet had spiraled to a position within this open zone, its propensity to lose momentum to nearby parts of the nebula would wane. Therefore, the tendency for the planet to slow and its orbit to decay further would be greatly reduced. According to Lin and his colleagues, "the migration effectively stops near 0.05 AU." Although heated intensely by the star in this final position, a giant planet would have sufficiently strong gravity to keep many of the volatile substances that would otherwise be difficult for a hot planet to hold.

Some astronomers do not accept either of Lin's explanations. "The Lin hypothesis is nice, but it's a hypothesis," remarks R. Paul Butler of San Francisco State University, a member of one of the several groups turning up new planets around distant stars. He points out that rather than being gaseous bodies like Jupiter (which could have formed only in the outer, cooler parts of the primordial nebula, where ices and gases abound), they could be "giant nickel-iron bowling balls." And so like Mercury, they may have originated from the refractory particles that existed in the hot, inner parts of a planetary nebula. Similarly, Jack J. Lissauer, a planetary astrophysicist at the National Aeronautics and Space Administration Ames Research Center, believes that although the theory makes good sense, the case for inward planetary migration is still not settled.



PALOMAR OBSERVATORY

ORBITING COMPANION *of the star Gliese 229 resembles a "hot Jupiter."*

The origin of these massive bodies critically affects the evolution of these planetary systems. Boss notes in a recent issue of *Physics Today* that if the newly discovered planet around 51 Pegasi indeed migrated from a distant formation zone to its current position, it "would have ejected or otherwise destroyed any Earth-like planets it might have encountered." But Lin points out that other Earth-like planets could have formed in its wake. So perhaps the prospects for finding far-flung counterparts to our home planet is not compromised. At this point, with theoreticians struggling to catch up with the rush of new discoveries, the variety of extrasolar planetary systems remains anyone's guess. As Butler says, "It's all brand-new and all very wild." —*David Schneider*

In Brief, *continued from page 22*

Treating the Common Cold

Physicians at the Cleveland Clinic Foundation in Ohio recently found that patients taking zinc gluconate–laced lozenges suffered most cold symptoms for half as many days as did untreated individuals. Why the metal-containing medicine works is as yet unclear. But in vitro zinc can, among other flu-fighting activities, impair viral replication.

Jurassic Jawbreakers

Tyrannosaurus rex was no slack-jaw—judging by the teeth marks in a 70-million-year-old triceratops fossil. Researchers from the University of California at Berkeley and Stanford University poured putty into a punctured dinosaur pelvis and cast a set of *T. rex* dentures. Next they measured how much pressure it took to sink the serrated falsies into cow hipbones. The results showed that *T. rex* could clamp down with a force of some 3,000 pounds. The only modern-day predator with a similar bite is an alligator.

DAVID SCHINNER *Bruce Coleman Inc.*

Nitrates and Lymphoma

Since 1973 the incidence of non-Hodgkin's lymphoma has risen some 75 percent in the U.S., in large part because of the AIDS epidemic. Recent findings by the National Cancer Institute and others, though, have uncovered another explanation. Among people in rural Nebraska, those consuming the largest amounts of nitrates in their drinking water face the greatest risk of disease. How these chemicals, commonly used in fertilizers and pesticides, cause cancer in people is not understood. But nitrates can combine with amino acids in water to form known carcinogens.

Tracing True 3-D Images

Don't throw away those red-and-green movie glasses just yet, but scientists can now cast true three-dimensional pictures in a crystal cube using infrared lasers. Where the invisible beams intersect, rare-earth elements embedded in the cube fluoresce in red, blue or green. In this way, the beams trace outlines in space, just as electron beams trace flat scenes on television screens. The catch? Rendering realistic 3-D images may require far more data than any computer could ever supply in real time.

Continued on page 28

MENTAL HEALTH

MULTICULTURAL STUDIES

Rates of depression vary widely throughout the world

Over the past few decades, scientists have drifted toward an increasingly hard-wired model of the human psyche. A recent article in *Newsweek* reflected this trend. Studies of identical twins, the magazine reported, suggest that happiness stems almost entirely from nature rather than nurture; our mood depends more on our genes than on our love lives, careers or other circumstances.

But a new international survey indicates that cultural influences may play a large role in triggering the most common mood disorder, depression. The study, in which 17 researchers gathered data on 38,000 subjects from 10 countries, found that rates of major depression in different countries varied by a factor of more than 10. The results "suggest that cultural differences or different risk factors may affect the expression of the disorder," the group concludes in the *Journal of the American Medical Association.*

The lead author of the study, the largest of its kind ever conducted, is Myrna M. Weissman, a psychologist at Columbia University. After she supervised a large survey of depression in the U.S. in the 1980s, researchers in other countries independently started similar projects. Weissman realized several years ago that these studies "would be a great opportunity for a cross-national comparison." Previously, such comparisons have been complicated by the fact that investigators from different countries employed divergent methodologies.

Weissman eventually teamed up with colleagues from nine other countries. They employed the diagnostic criteria for depression set forth in the third edition of the *Diagnostic and Statistical Manual of Mental Disorders,* or *DSM-III;* the major symptoms include loss of energy, insomnia and thoughts of death and suicide.

ELI REED *Magnum*

WAR-WRACKED LEBANON
was found to have the highest incidence of depression in a new study.

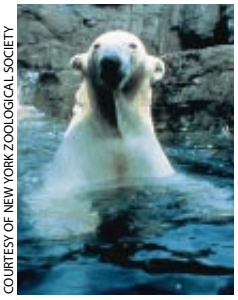
The lifetime risk of depression (defined as the probability that a subject will suffer at least one episode lasting a year or more) ranged from 1.5 percent in Taiwan to 19 percent in Lebanon. In between, in ascending order, were Korea at 2.9 percent; Puerto Rico, 4.3; the U.S., 5.2, Germany, 9.2; Canada, 9.6; New Zealand, 11.6; and France, 16.4.

The researchers acknowledged that "some, but not all" of the variation may stem from reporting artifacts. For example, the reported reluctance of Asians to acknowledge mental distress as com-

In Brief, *continued from page 24*

In the Swim

New York City is a colder—and cleaner—place for the Arctic animals at the Wildlife Center in Central Park these days. The zoo is currently testing a new electricity-based water-treatment system, which relies on ozone to eliminate bacteria, viruses and odors from their aquatic displays. An added benefit is that the polar bears can now hunt for food as they would in the wild. Using ozone enables zoo officials to fill the exhibits with live fish, which cannot tolerate chlorine-treated tanks.



COURTESY OF NEW YORK ZOOLOGICAL SOCIETY

FOLLOW-UP

Killing Fields

In flagrant violation of national law—and, most likely, the international treaty banning ivory trade as well—poachers slaughtered more than 200 elephants in the forests of the Congo this past summer. Wildlife Conservation Society researcher Michael Fay first spotted the accumulating bodies, many of them pregnant females and juveniles, while making routine flights over a remote watering hole 500 miles north of Brazzaville. When a television news crew went in by helicopter in September, the extent of the carnage became clear. Congolese officials had only recently put the area under the protection of the nation's largest game park. (See December 1994, page 94.)

Making Taxol in Bulk

Japanese scientists have described a new way to make taxol, the anticancer drug now in high demand for treating breast and ovarian cancers. The compound, first isolated in piddling amounts from the Pacific yew tree, is notoriously difficult to make in large batches. The highest yields are currently had from cell cultures of taxol-producing plants, such as *Taxus media*. The Japanese group used this same basic approach but greatly increased their culture's yield by adding a strong promoting substance, called methyl jasmonate. The workers hope the tactic will help more taxol reach the market at lower prices. (See June 1996, page 94.)

—Kristin Leutwyler

pared with people from western cultures could account in part for the strikingly low incidence of depression in Taiwan and Korea. But the team asserts that other factors are also probably responsible. Taiwan and Korea have very low rates of divorce and separation, which are associated with high risks of depression in virtually every country.

The high rate of depression in France and New Zealand, conversely, could be attributed to the higher rate of failed marriages in those populations. Although divorce and separation are rare in Lebanon, its high rate of depression is not surprising given that it has been "besieged by war for the past 15 years," the authors note.

Some patterns held across national borders. In every country, women were roughly twice as likely as men to suffer from depression. On the other hand, separated or divorced men were in general more likely to become depressed than women in the same condition; these results correlate with previous U.S. studies. The average age at which depression first occurred fell within a relatively narrow range, from 24 years in Canada to 34 in Italy.

The researchers gathered data not only on depression but also on bipolar disorder, or manic-depression, in which depression alternates with states of extreme mental agitation and even psychosis. The rates of manic-depression showed much less cross-national variation than those of depression, ranging from 0.3 percent of the population in Taiwan to 1.5 percent in New Zealand. These data are consistent with previous research showing that manic-depression has a stronger genetic component than simple depression. *—John Horgan*

PHYSICS

SCIENCE WITH BRASS

Unusual movements from tiny metal balls

The oscillon is rather a modest beast, a pile of tiny brass balls that jiggles up and down and joins with other piles to form patterns. Still, its discovery has caused quite a stir. In a breathless tour of buzzwords, the *New York Times* recently linked oscillons with the origin of life, self-organized criticality, fractals, human individuality and complexity. Who knows, the amazing oscillon may yet help finance a 15 percent tax cut.

But even stripped of such ambitions, the oscillon remains a curious creature. The object appeared when Paul B. Umbanhowar of the University of Texas at Austin and his colleagues vibrated a tray of brass balls up and down. The balls, each less than 0.1 millimeter in radius, together resemble sand. As anyone who has tried running on a beach can testify, motion in such a medium damps out very fast. In the physicists' experiment, the vibration, at between 10 to 100 cycles per second, feeds energy constantly to the balls, allowing ripples and other features to form at the surface.

Different patterns form as the vibration is varied. When the powder is shaken at about two-and-a-half times the acceleration due to gravity, square and

PAUL B. UMBANHOWAR

OSCILLONS *do not yet explain consciousness but are spurring the search for a theory of granular media.*

stripe patterns appear on the surface, pulsing up and down like standing waves in a fluid. The oscillons—isolated peaks or valleys—form at lower frequencies. Sometimes, Umbanhowar says, one can start an oscillon by touching the "sand" surface with a pencil. The initial depression pushes up into a peak and then collapses back into a valley. It alternates between hill and crater at half the frequency at which the tray is being driven. The oscillon drifts around slowly and lives indefinitely.

If two or more oscillons vibrate in phase—that is, become hills at the same time—they repel. Three such oscillons can arrange themselves into triads. But if two oscillons vibrate out of phase, so that one reaches its peak when the other is a crater, they attract. If they come within 1.4 diameters of each other,

BY THE NUMBERS

Global Forest Cover

Forests remove carbon dioxide from the air, conserve soil and water, and are home to a variety of species. They are also repositories of potentially valuable new products, such as pharmaceuticals, and as a source of building material and firewood they provide employment for millions worldwide.

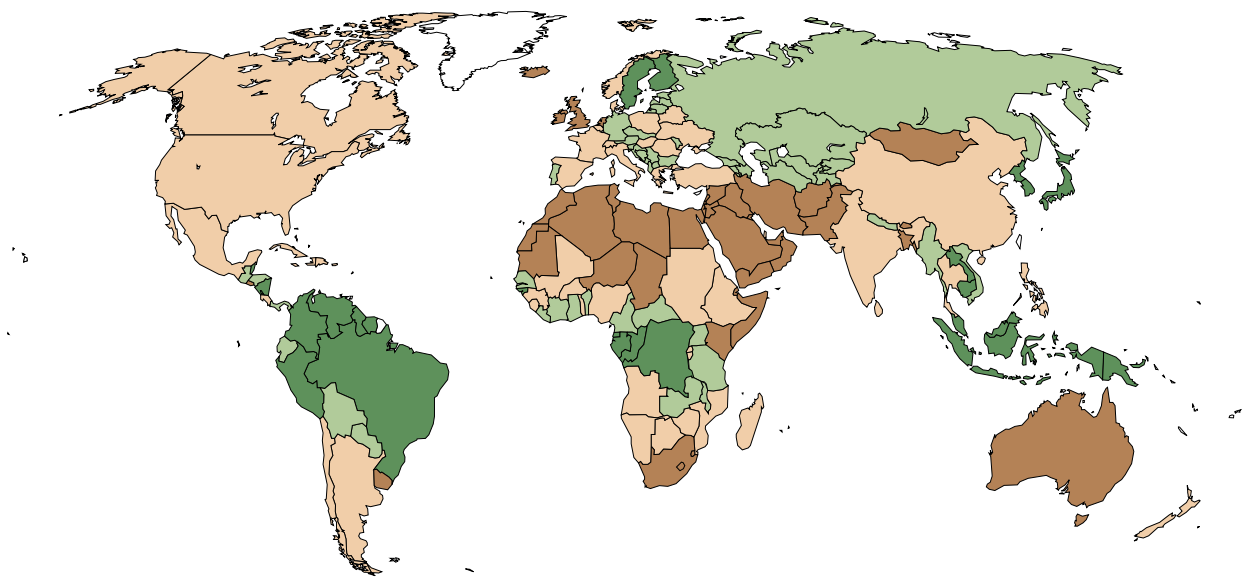
In 1990 forests took up about a quarter of the planet's land surface (not including an additional 13 percent of other woody vegetation, such as sparsely covered woodland and brushland). Russia accounts for perhaps a fifth of the globe's forest, Brazil for about a seventh, and Canada and the U.S. each for 6 to 7 percent. Historically, virtually all countries have experienced deforestation, mostly because of the need for new farmland, pasture, fuelwood and timber. In the U.S., forest now covers 22 percent of the land area, a decline of perhaps 40 percent since European colonization began. (Forest acreage, however, has remained about the same since 1920 as rising agricultural productivity moderated the need for new cropland.) Among the most pressing concerns today in the U.S. are declining biodiversity of forests and stagnant or declining productivity of commercial timberland.

In Europe, west of the former U.S.S.R., forest covers about 30 percent of the land, roughly half its original extent. A major problem there, particularly in eastern Europe, is defoliation, apparently caused mostly by air pollution. Forests in the former U.S.S.R. once blanketed about half the land but now cover about a third. Forest degradation is most serious there not only because of air pollution but also because of a lack of effective conservation policies, such as replanting.

Among other temperate regions, North Africa and the Middle East in 1990 had less than 2 percent forest cover, a decline since 1980. In contrast, China, through a massive tree-planting program, recently increased forest area, which now takes up 14 percent of its land.

The biggest changes have been in the tropics, where the natural forest dropped by a fifth from 1960 to 1990 as a result of population pressure, large-scale government development projects and commercial logging. The greatest decline was in tropical Asia, which lost a third of its forest. Almost all tropical countries lost ground in the 1980s except India, whose forest expanded by 5 percent. Brazil, which accounts for almost a third of the global tropical cover, suffered a 5 percent decline in the 1980s. There was a loss of 137 million hectares (338 million acres) of tropical forest worldwide, equal to the total land area of Spain, France and Germany. Agricultural expansion accounted for somewhat less than half the tropical forest contraction.

—Rodger Doyle



SOURCE: World Resources Institute. Because of differing definitions of forest cover, the amount of forest in developing countries is overstated by an average of 7 percent relative to that in developed countries.

RODGER DOYLE

these out-of-phase oscillons pull together into a bound pair or join with other such pairs into chains or square lattices. The entire pattern pulsates in a way characteristic of forced oscillations.

Although this behavior may have inspired unwarranted hype, the oscillons are still intriguing because they look a lot like—and are yet unlike—excitations in other media. A tray of viscous fluid vibrated up and down acquires a variety of surface patterns, including peaks and craters. But these excitations are not as isolated as those observed in the brass-ball tray. Moreover, there is no theory to describe the dynamics of a bronze granular substance. Analogies with fluids are tempting but fall apart under closer scrutiny. For example, a fluid has a temperature—a measure of the amount of random motion of its particles. But because the grains in a sand-like medium just sit around, their temperature is effectively zero. Vibrating the tray imparts motion to the grains, but a highly ordered one that cannot be directly translated into temperature.

In short, the discovery is spurring theorists in their search for an equation of motion for sand and keeping experimenters busy documenting oscillon antics. What more could a physicist ask for? *—Madhusree Mukerjee*

SOCIOLOGY

DIFFERENT STROKES

A book intimates why we gossip

Evolutionary psychologists believe they can explain why the ratings for *Oprah* consistently best coverage of a congressional hearing on welfare reform legislation or a documentary on the lemurs of Madagascar. It all relates to why we no longer spend much of our waking time poking, scratching and stroking one another—the type of grooming behavior characteristic of chimpanzees, baboons and other primates.

The evolutionary case for *Oprah*-like gossip as a substitute for a good fondle has been laid out in a new book, *Grooming, Gossip and the Evolution of Language,* published earlier this year in Britain and scheduled for release in the U.S. next spring by Harvard University Press.

The author, Robin Dunbar, a professor of psychology at the University of Liverpool, and other academics have ruffled a few well-groomed feathers in the staid linguistics community. Their gossip-grooming hypothesis asserts that our big brains and a unique ability to communicate through language did not evolve as a means to plan for the daily exigencies of food gathering, as suggested by some earlier theories. Instead language—and in particular gossip—emerged to furnish the social glue needed to bind large groups. It thus substitutes for grooming: the probing of fur for dead skin, matted hair or dead leaves. (Even today the word "stroking" has become slang for currying favor—a means of grooming with words.)

Dunbar made his own contribution to this growing body of work by finding a correlation between the dimensions of the neocortex—the part of the brain engaged in conscious thought—and the size of different groupings of mammals. (A group in this context is defined as animals that eat, mate and travel together.) The neocortex may have expanded to track the complex web of social relationships that emerged as clans grew, perhaps to accommodate increasingly nomadic ways of life.

In humans, Dunbar found, the size of the neocortex predicts groupings of about 150 people. This number happens to conform to the approximate membership of the clan within hunter-gatherer societies; the company unit within the military; and the aggregate of employees within a business that can be managed without an elaborate bureaucracy. The figure of 150, Dunbar writes, represents the maximum number of individuals with whom "we can have a genuinely social relationship, the kind of relationship that goes with knowing who they are and how they relate to us."

As groups start to swell into the many dozens, the idle practice of grooming suffers. To pick burrs from enough friends' hair to maintain social cohesiveness, a hominid would have had to spend about 40 percent of its time in making nice to others, an investment of energy that would have been diverted from essentials of survival such as foraging and hunting. Language became the means to provide the social cement that had once been furnished through the act of grooming. Consequently, most talk involves shooting the breeze. Gossip, however, is more than mere idle chatter. "It's saying that I'd rather be

ARCHIVE PHOTOS

GOSSIP AND GROOMING
are themes in a new book on the origins of language by British psychologist Robin Dunbar.

here with you than over there with Joe Blow," Dunbar quips. Research at British universities, he notes, has shown that even nominally serious academics spend about two thirds of their conversation time chitchatting.

Many linguists have yet to embrace these arguments fully, but Dunbar remains undaunted. He contends that the work combines a novel set of insights from academic disciplines ranging from animal behavior to evolutionary biology. These ideas, he is convinced, will supply a deeper understanding of the roots of language, the reason for our swollen brains as well as a rationale for the continued popularity of the banal programming on daytime television. *—Gary Stix*

ANTI GRAVITY

On Presidents and King

If familiarity does indeed breed contempt, there are two things you are no doubt sick of by now: the hoarse windiness of Bill Clinton and the grievous monotone of Bob Dole. One of those voices, however, will be our choice to deliver the next batch of State of the Union addresses. According to research recently published in the *Journal of Personality and Social Psychology,* a particular vocal quality, revealing who has the higher social status, may be instrumental in guiding that choice.

Stanford W. Gregory, Jr., a sociology professor at Kent State University, and his colleague Stephen Webster have long studied the nonverbal aspects of speech involving the communication that goes on outside of mere words. Research in this field has shown that when people talk to one another, their speech characteristics tend to converge—pitch patterns, pause lengths, pronunciations.

In 1992 Gregory acquired an instrument called a fast Fourier transform (FFT) analyzer, which can break down complex sounds and represent them in the form of a spectrum. As a first step in using the instrument to look at vocal patterns, he wanted merely to generate a few spectra. "I thought that good test material would be interviews," Gregory recalls, "and I didn't want to do a bunch of them myself for test purposes, so I thought, well, what about Larry King? He's a pretty good interviewer—there's a lot of data there, it's a clear signal."

Gregory set the FFT analyzer to work on tapes of 25 King interviews and produced band spectra of the low-frequency part of the human voice. That region, below 500 cycles per second, is a key nonverbal area of convergence. "I found just by looking through the stats that some of the interviews tended to cluster together," he says. These clustered voices belonged to major movers and shakers, such as then President George Bush and then candidate Clinton, and megacelebrities Barbra Streisand and Elizabeth Taylor. (Although women's voices are usually higher in pitch than men's, they still have a full presence in this low-frequency band.)

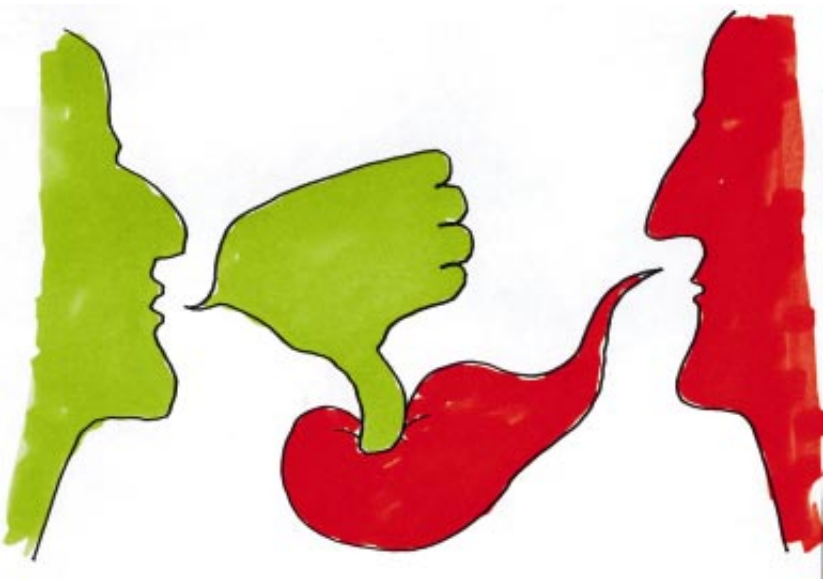
Intrigued by the clustering, Gregory examined the data more closely. A complete statistical workup of the low-frequency spectra agreed with Gregory's eyeball interpretation and revealed that other celebrities' vocal qualities differed widely from the biggest of shots. Jimmy Carter, for example, finished in a virtual tie with Julie Andrews, von Trapped in the middle of the celebrity pack. Meanwhile Garrison Keillor's and Spike Lee's voices placed near the bottom of the list, perhaps revealing that Lake Wobegon is Crooklyn without the courtside seats at a New York Knicks game.

Analysis of King's voice, the common element in all the interviews, showed that he adjusted his low-frequency band to have it converge with those of the Barbras and the Bushes, thus accommodating these highest-status guests. Keillor and Lee, in contrast, modulated their voices to accommodate Larry's.

Gregory also conducted a survey in which students were asked to assign celebrity status to the subjects of the King interviews. The students' ranking agreed nicely with the relative positions of the vocal spectra and tendency to accommodate, showing that the low-frequency vocal band may indeed be a marker for social status.

This kind of vocal analysis, comparing status and deference, should be of great interest to politicians and their handlers. Assume, for example, that low-frequency vocal analysis showed Clinton dominating Dan Rather, but Dole deferring to the anchorman. The Dole team might veto Rather from any panel asking questions at a debate between those two, aware that the audience could pick up on the candidates' relative status as brokered by the questioner. (Not to mention that "What's the frequency, Kenneth?" would take on a new significance.)

Perhaps all this explains the early withdrawal from the current presidential race of the possessor of the voice responsible for once saying, "If we do not succeed, then we run the risk of failure." Dan Quayle finished dead last on the King guest list, differing from the top vocal spectra by the widest margin and accommodating Larry's voice more than any other interviewee in the study. Quayle also once said, "The American public will judge me on what I am saying," unaware that the judgment may lie as much in how he was saying it. *—Steve Mirsky*



MICHAEL CRAWFORD

CYBER VIEW

The Rosetta Hack

Step by slow step, computers are breaking down the barriers of language. In Canada the Meteo system automatically translates weather forecasts into both English and French. In Europe the Systran system helps bureaucrats make rough translations of administrative documents. But even as machines make progress in translating the jargon of specific tasks, the grand dream of universal understanding recedes farther into the distance. And with it, too, recedes the chance that electronic media will not have a dramatic impact on the world's languages.

By overcoming time and distance, communications technology is creating a vast experiment among the planet's languages. People who used to live secluded in Welsh-speaking valleys or on Navajo-speaking mesas are now connected to English-dominated information on the airwaves and the Net. Universal translation would have allowed them—and everybody else, for that matter—to have all the world's knowledge and information at their fingertips no matter what language they spoke. Sadly, information, knowledge and language are not so easily disentangled.

"Few informed people still see the original goal of fully automatic high-quality translation of arbitrary texts as a realistic goal for the foreseeable future," writes Martin Kay, a longtime machine-translation researcher at the Xerox Palo Alto Research Laboratories, on the excellent "human language technologies" site—http://www.cse.ogi.edu/CSLU/HLTsurvey/HLTsurvey.html—on the World Wide Web. The problem, as Kay sees it, is that dreams of universal translation depend crucially on two related hypotheses. The first and most important is that some kind of metalanguage could represent all ideas expressible in any human tongue. The second is that translation depends more on the technicalities of language than on real understanding of the underlying ideas in a text. Frustratingly, neither is turning out to be true.

A universal language, or interlingua, would vastly simplify the task of translating among the globe's 5,400 or so languages. To make a language automatically comprehensible, a translator would just convert to and from the interlingua. (Connecting all the extant languages without an interlingua would require more than 30 million translators.)

But nobody has yet come up with a useful interlingua. BSO, a Dutch software and consulting firm, tried to use Esperanto as an interlingua in its DLT translation system. The Dutch electronics giant Philips and others have attempted more abstract representations of languages. And Robert Berwick and his students at the Massachusetts Institute of Technology have explored the idea that so-called principle-based parsing techniques might provide access to deep, universal structures underlying all

DAVID SUTER

grammar. To one extent or another, all have rediscovered an old piece of wisdom: some things are easier to say in some languages than others. Yiddish apparently has words to describe subtle gradations of the concept "simpleton" that would require entire essays in any other tongue.

Worse, however, is the problem that some ideas are not actually in language at all. The French word *mouton,* for example, means both "sheep" and "mutton." To decide whether a particular *mouton* is eating or being eaten, a translator has to understand the context and to comprehend the kinds of things that humans routinely know. Artificial-intelligence researchers have been trying to re-create such commonsense reasoning for 40 years. They are not even close.

Given these limitations, machine translation currently is used mostly for screening text—that is, producing rough automated translations so that the interested experts can determine whether it is worth asking a human to make a proper translation. One of the biggest users of such machine translation is the European Commission, which relies on Systran. Usage has increased steadily: Systran translated 4,000 pages of documents in 1988 but today converts hundreds of thousands a year, although the quality is still rough.

Improvements can sometimes be achieved in machine translation by limiting the scope of translation to specific types of information. Weather is a prime example. The output of the Meteo system is broadcast more or less verbatim on Canadian television and radio. But such specialized systems, which still require humans to polish machine-translated text, are only worth producing for well-known subject areas that have a high demand for translation. Christian Boitet, a language researcher at Joseph Fournier University in Grenoble, estimates that translators are not economical unless there are at least 10,000 pages to translate. In practice, Boitet reckons, this makes machine translation suitable mostly for technical manuals.

The irony is that the failed dream of universal understanding highlights the intertwining of ideas and words that creates the subtleties and beauty of language, even as it makes the demise of some languages all the more likely. In his book *The Language Instinct,* M.I.T. linguist Stephen Pinker estimates that most of the world's languages are threatened with extinction. Each generation faces a starker choice: learn and use the language of its heritage or learn a language like English, which represents today's business and scientific information.

Without easy, universal translation, the same kinds of evolutionary pressure come to bear on language as those that have driven most of the world's computers to run Microsoft Windows. English runs the most software. And there are some irrational reasons for adopting it as well. As Michiel Bakker, an executive at MTV Europe, points out, "English is the default language of rock and roll." MTV's audience research shows that European youth don't even like their music videos introduced in their mother tongue. It's just not hip enough. Perhaps someday the only translation needed may be making one generation's slang comprehensible to another.

—John Browning in London

MATERIALS SCIENCE

PRESSURE TO CHANGE

Supercritical carbon dioxide to toughen common materials

About 2,000 years ago construction workers used the latest high-tech materials to pour an enormous concrete dome for a new temple in Rome. Millennia later the Pantheon's roof is still intact—in fact, it is hardening as calcium compounds in the structure gradually react with carbon dioxide in the atmosphere to form limestone and other minerals that are even stronger than concrete. In May a construction engineer from Reno, Nev., patented an inexpensive way to shorten that hardening process from several thousand years to just a few minutes. Preliminary studies suggest the innovation could yield products ranging from less expensive wallboard to safer radioactive waste disposal.

Concrete normally hardens so slowly because water seals its pores against carbon dioxide in the air. "But an article in *Scientific American* on the use of [high-pressure] CO_2 for making cheaper plastics got me thinking," recalls Roger H. Jones, an engineer with Materials Technology Limited. "I took my pressure cooker, wrapped it in wire and tried an experiment." Jones discovered that exposing concrete mixed with portland cement to high-pressure CO_2 drove water out of the material and changed its chemical composition. Standard compression tests, he says, show that on average the treatment increases the strength of portland cement by 84 percent. Subsequent experiments at Los Alamos National Laboratory have demonstrated that the process can transform a wide range of inexpensive materials—including some that are currently considered waste products—into stronger, more useful forms.

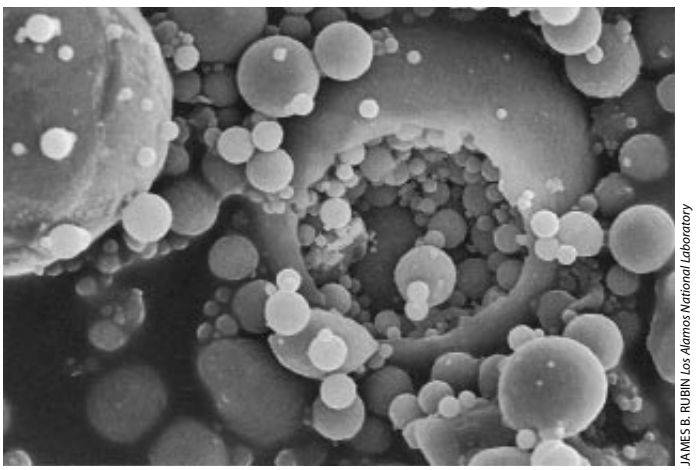
The process is so simple, says F. Carl Knopf, a professor of chemical engineering at Louisiana State University, that it is surprising no one hit on it before. Raised to about 75 times normal atmospheric pressure and to at least 31 degrees Celsius, carbon dioxide becomes as dense as a liquid yet remains compressible like a gas. In this so-called supercritical state, observes Craig M. V. Taylor of the supercritical fluids facility at Los Alamos, the CO_2 has no surface tension and so can permeate the pores and cracks in a substance without resistance. Reactions that typically take aeons run their course in a matter of minutes. "There is no question that this makes cements harder," Knopf says.

Ultratough cement has plenty of practical applications. Taylor suggests, for instance, that the process could prevent dangerous leaching from nuclear waste that has been mixed with conventional cement for storage. Yet finding wider uses for the supercritical cement process won't be easy, predicts Thomas J. Pasko, director of the office of advanced research at the Federal Highway Administration. "Our construction industry is very traditional and brute-force-oriented," he points out. "We very seldom look for new materials to solve problems. So you have to come up with something that is the same cost or cheaper than existing products."

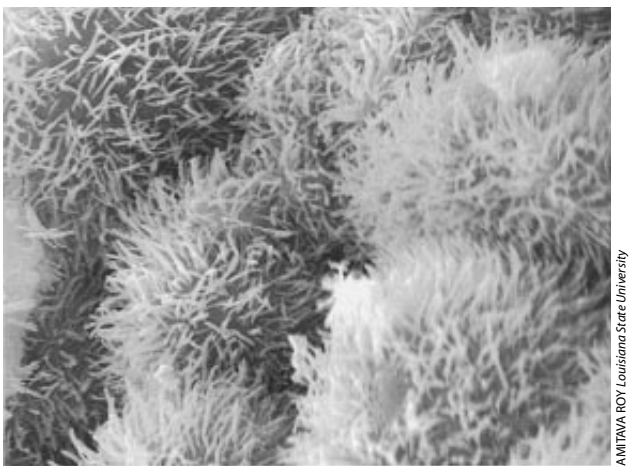
Jones and Taylor have a plan to do just that. They are treating concrete roofing tiles for Boral in Rialto, Calif. Concrete tiles are more durable and fire-resistant than most shingles, but in order to meet strength requirements they must be so heavy that they overwhelm most houses' frames. Tiles treated with CO_2 rather than fired in ovens appear to be light enough to compete with shingles.

In addition to hardening conventional cement, Jones wants to make building materials from the fly ash produced by coal-fired power plants. Mixed with sodium silicate, calcium oxide and water, the ash forms a paste that dries into a weak, water-soluble board. "But when we react this stuff with supercritical CO_2," Taylor says, "it comes out very strong, very stable and completely insoluble in water. A 12-inch test span can support 650 pounds, comparable to fiberglass-reinforced cement," which is commonly used in flooring.

"The vision here," Taylor continues, "is to build a processing facility next to a power plant. The power company is already producing lots of CO_2 and fly ash. They will pay you to take the ash, since they have to landfill it otherwise. You also get cheap electricity to run your facility. And you can use the plant's exhaust heat for free." Moreover, Jones



JAMES B. RUBIN *Los Alamos National Laboratory*



AMITAVA ROY *Louisiana State University*

FLY ASH PARTICLES

(left) ***are altered by high-pressure CO_2 into filamentary forms to produce a dense, more durable building material*** **(right).**

adds, "we can distribute finished products on empty coal cars as they leave the plant." Jones has hired a firm to scale up his process using high-pressure equipment such as that used to decaffeinate coffee and to remove fats from foods. He says he has already begun negotiating with a power company and a wallboard manufacturer.

"This opens up an entirely new area of materials science," Taylor claims. In recent experiments, he and Jones have shown that by dissolving metals or plastics into the supercritical fluid, they can impregnate cements with other compounds to make them more flexible, durable or electrically conductive. "The best part of this process," Taylor notes, "is that it permanently removes a greenhouse gas from the atmosphere and waste products like fly ash from landfills and transforms them into materials to build homes out of. If you really want to push industry into helping out the environment, you have to make it profitable. This helps do that."

—W. Wayt Gibbs in San Francisco

DEFENSE TECHNOLOGY

NEEDLES IN A COLD WAR HAYSTACK

Pointless secrecy obstructs a potential economic boost

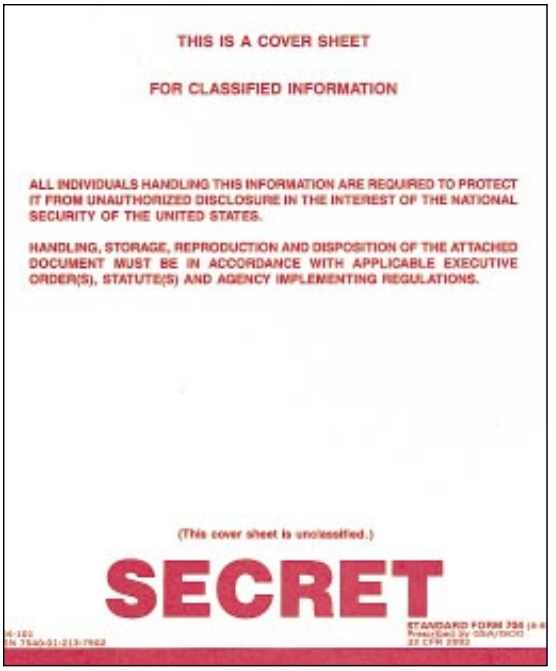
Within the U.S. government's massive stockpile of classified documents are the usual necessities of national security, such as blueprints for developing high-tech weaponry. They will, of course, remain under lock and key for many years to come. But the archives also contain taxpayer-funded research that no longer needs to be guarded and in many cases should have been released long ago. Such technical know-how, if made available, could give the American economy a boost without compromising the country's defense, argue business leaders, scientists and other advocates of less secrecy.

One such advocate is Michael Ravnitsky, technical director of the Industrial Fabrics Association International in St. Paul, Minn. He has been trying to pry information out of the Defense Technical Information Center (DTIC) in Alexandria, Va., for the past nine years. "Decades of work done by the Defense Department and its contractors in the area of safety and protective fabrics would be of enormous use to our industry," Ravnitsky says. The data could aid the development of protective clothing, helping companies make more fire-resistant tents, sleeping bags and children's clothing.

Even defense contractors who build supersecret weapons systems urge more openness. Jack S. Gordon is the president of Lockheed Martin's famous Skunk Works, which developed the U-2 spy plane and F-117 stealth fighter. Last year he told a government commission that a "culture of secrecy" often leads the military to classify too much and declassify too little. "The consequence of this action directly relates to added cost, affecting the bottom line of industry and inflating procurement costs to the government," he wrote.

Ravnitsky is in a better spot than most. He knows what he wants—he just can't get to it. Others are convinced there are numerous areas in which classified government research could help the private sector, but they aren't sure what or where it is.

"We don't know what we don't know, so it's hard to be too definitive about what buried treasures might be in the various archives," says Steven Aftergood, director of the Federation of American Scientists's Project on Government Secrecy. "On the other hand, the government has spent many millions of dollars on classified research and development over the past few decades, and you would think there would be one or two things in there that would be useful, that would have commercial value."



STANDARD DOCUMENT COVER conceals government information.

Steven Garfinkel, director of the government's Information Security Oversight Office, agrees. Yet he doesn't know what valuable secrets might be hidden in government archives, and if he doesn't know, no one can. "It may be a mother lode," Garfinkel says. "We don't know for sure."

The government is well aware of the potential payoff in declassification and less secrecy. In 1970 the Pentagon produced a study showing that "the U.S. lead in microwave electronics and in computer technology was uniformly and greatly raised after the decision in 1946 to release the results of wartime research in these fields." The same study said nuclear reactor and transistor technology development also benefited from an open research policy.

Kurt Molholm, administrator of the DTIC, states that it is Defense Department policy to "make available to the general public as much scientific and technical information as possible," but Ravnitsky and others believe the government, and especially the Pentagon, actually releases as little as possible.

They are not supposed to be holding back. Under the terms of an executive order signed in April 1995 by President Bill Clinton, government agencies must, by this past October, have declassified 15 percent of documents older than 25 years, with some exceptions. Many agencies will not make it, and some won't even come close. The executive order was intended to make bulk declassification—removing the secrecy tag from massive bundles of related documents without inspecting every single page—the norm. Although some agencies have made progress, others are well behind. The U.S. Navy, for example, says it will need to have $1 per page to declassify 500 million docu-

ments—a price no one is willing to pay.

Of course, information that should stay secret can be protected under the executive order's "state-of-the-art" technology exemption to the bulk declassification rule. But that introduces another concern. "The issue is, what does state-of-the-art technology mean?" Garfinkel asks. "We're going to have to establish some rules rather quickly."

There are some signs that the government is trying, at least. Garfinkel notes that in 1995, for the first time in many years, declassification outpaced classification. Still, critics want the government to start releasing large numbers of older documents immediately, while reforming the current system to ensure that the secret stockpile does not continue to grow.

"The truth is that most government documentation is worthless within minutes of its production and certainly after the passage of time," Aftergood argues. "The problem is that I don't want the government deciding what I as a citizen should be interested in and what I should not be interested in."

—Daniel G. Dupont and Richard Lardner in Washington, D.C.

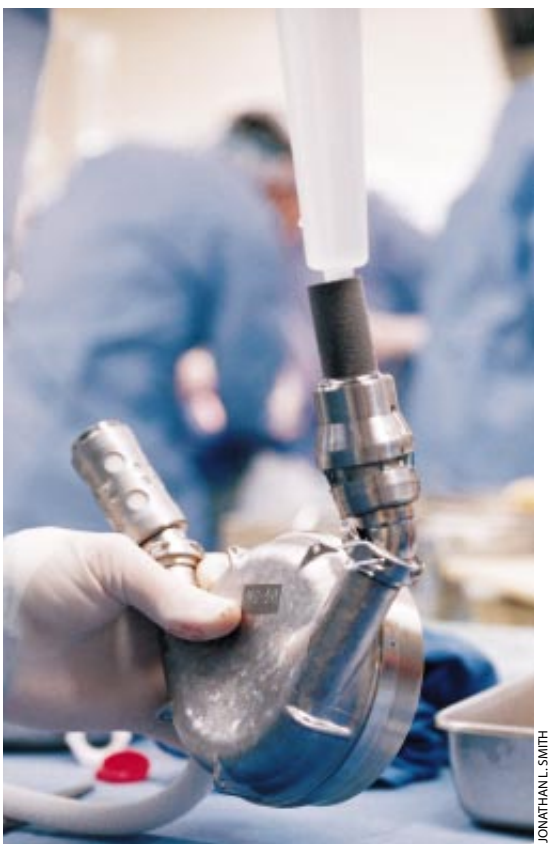
CARDIOLOGY

PUMP IT UP

A new implant sustains heart patients waiting for transplants

If not for a device that pumped blood from his left ventricle into his aorta, Robert Berkey would not have lived to celebrate his 20th birthday. During his final exams at Clarkson University in upstate New York last year, Berkey collapsed, unable to move. A chest x-ray revealed that his heart, engorged with blood, had blown up to the size of a volleyball. Doctors placed Berkey on a heart-transplant waiting list, but to keep him alive in the interim, surgeons at Columbia-Presbyterian Medical Center in New York City implanted an LVAD, or left ventricular assist device.

This pump, produced by Thermo Cardiosystems in Woburn, Mass., is the fruit of research that began in the 1960s. The technology is just now beginning to realize its potential to keep defective hearts pumping—sometimes for as long as 17 months—until a donor becomes available. Approximately 800 of the 3,500 people on the list for transplants die every year, according to the United Network for Organ Sharing; thousands more who need the organs are not even placed on the overburdened list.



JONATHAN L. SMITH

***TEMPORARY HEART PUMP** can keep patients alive for more than a year.*

Last year the Food and Drug Administration approved another use for LVADs: transplant alternatives. "Ever since we started this project, our goal has been to use these devices not only as a bridge to transplant but also as a long-term treatment of end-stage heart disease," explains Eric A. Rose of Columbia-Presbyterian. According to the National Institutes of Health, as many as 35,000 people in the U.S. could benefit from the combined uses for LVADs.

Of the two biotechnology companies working on these implantable devices, Cardio-

systems's is the only one that has FDA approval. The company's LVADs come in two forms. Both consist of a titanium pump with three protruding valves: one is connected to the left ventricle, one to the aorta, and one to an external power source. The older version, which has been implanted in more than 600 people, is powered with compressed air generated by a console about the size of a stereo receiver. This version requires that patients stay in the hospital. The newer device—which Berkey received as part of a clinical trial and which has been implanted in 124 people so far—is driven by a beeper-size battery.

Despite their promise, LVADs have drawbacks. They can lead to infections around the heart and stomach (where they are often placed) in 10 percent of recipients as well as to blood clots. Further, they are costly. The entire procedure can run up to $200,000—including $50,000 for the device. Medicare has agreed to pay for implants of the air-driven Cardiosystems LVAD, and a number of private insurers—including Blue Cross/Blue Shield and Aetna Life and Casualty—have agreed to reimburse patients either partially or completely. Berkey's medical costs amounted to more than $250,000 after he received his donor heart this past spring. His father's insurance company footed part of the bill. The rest came from his neighbors in Chittenango, N.Y. —*Gunjan Sinha*

CHEMICAL ENGINEERING

MOLECULAR MOLDS

Plastic replicas mimic complex molecules

While some biochemists have struggled to synthesize complex macromolecules to mimic natural compounds, others have been taking a simpler road—to cast the desired molecule in plastic. Many polymers consist of molecular building blocks that are small enough to be linked together to approximate the crannies and bulges of a drug, enzyme, antibody or other biologically active structure.

For the better part of 20 years, researchers have been attempting to realize this elegant approach, which suffers from a number of difficulties: the molecule from which the cast is being taken must be removed safely from the poly-

mer after the process is finished, and it also must not be distorted unduly while the cast is being made. But in the past two years investigators have begun to meet with success. This summer Klaus Mosbach of the University of Lund cast holes in the shape of corticosteroids (anti-inflammatory drugs that typically contain several dozen atoms) and discovered that the resulting plastic could bind the steroids from a solution containing a mixture of similar compounds. Mosbach also imprinted polymers to recognize diazepam (the active ingredient in Valium). Because the plastic's properties change when its cavities are filled, it can serve as a highly specific biosensor.

The technique that appears to work best involves monomers (the polymer building blocks) that incorporate an extra chemical group capable of reacting, albeit weakly, with the template molecule. These reactions stabilize the monomers in place around the template while the polymer is solidifying. Once polymerization is complete, researchers can add solvents, bases or acids to undo the binding and remove the template.

Using a similar technique, Kenneth J. Shea of the University of California at Irvine says his group has developed molecularly imprinted membranes that can even distinguish between versions of a single compound that differ only in their symmetry, or chirality. "Left-handed" versions of a drug can be made to pass through the membrane much more easily than "right-handed" ones, or vice versa. This selectivity could be extremely important for pharmaceutical companies because chirality often determines a drug's activity. (Perhaps the most famous case is thalidomide, whose right-handed version has shown great promise as a nontoxic anticancer agent, but whose left-handed version caused the deformation of thousands of children born to women who took the drug in the 1950s and 1960s.)

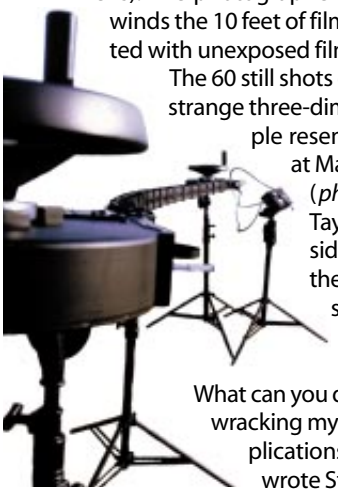
Imprinted polymers could also act as catalysts by holding organic molecules in particular configurations where they can react more easily, Shea notes. Because they are made of relatively durable plastics rather than amino acids, such "artificial enzymes" could find use in industrial processes by which their natural counterparts would quickly be destroyed by heat or corrosive conditions. If the casting process fulfills its promise, the synthesis of new molecules may rely on nanoscopic molding techniques rather than on the theoretical modeling that currently consumes so many hours of computer time around the globe. *—Paul Wallich*

SPECIAL EFFECTS

Pictures Worth a Thousand Cameras

Kurt Vonnegut's *Cat's Cradle* depicts a world in which a substance called ice-nine causes water molecules to freeze solid. As a consequence, any living organism that touches it turns into a statue of ice. When Hollywood decides to make the movie version of the book, the cinematographer might want to contact Dayton Taylor. The New York City–based production manager for independent filmmakers has devised a special-effects technique able to produce frozen images eerily similar to the ones concocted from Vonnegut's imagination.

For his system, Taylor cobbled together in his kitchen an array of 60 interconnected cameras (*below*). All the cameras share a common film magazine: each one contains an unexposed frame of the same strip of motion-picture film. To take a picture, the camera shutters all open at the same time. The film registers 60 separate photographs of the same image; only the viewing angle varies slightly (1.5 inches separates the center point of each lens). The photographer then turns a hand crank that winds the 10 feet of film until each camera is again fitted with unexposed film.



The 60 still shots can be shown in sequence as a strange three-dimensional movie in which people resemble the models encountered at Madame Tussaud's Wax Museum (*photo sequence at right*). One of Taylor's images reveals the right side of a youth jumping in midair, then slowly moves to show his left side. A similar right-left perspective highlights drops of champagne spurting from a bottle.

What can you do with 10 feet of cameras? "I'm wracking my brain trying to think about applications for this art form/technology," wrote Steven Spielberg to an acquaintance after witnessing a videotape of Taylor's invention. Taylor believes the main use will be for special effects in films—and, in fact, a French production company used a similar technique in crafting a music video for the Rolling Stones. Apple Computer's QuickTime VR also allows a computer user to navigate through photographic scenes in a similar three-dimensional way.

Taylor's camera array, for which a patent is pending, is limited because it records only an instant or two of activity before the film must be wound forward. As the cost of digital photography and the size of cameras diminish, this limitation may disappear. A camera array, perhaps containing thousands of tiny units, could record a three-dimensional perspective of an event as it progresses over time, thus providing a novel form of interactive video. Engineers could build camera arrays into the cylindrical wall of a space shuttle, enabling students around the U.S. to move about the interior of the spacecraft by manipulating a joystick. A television viewer might choose to watch the finish of the 100-meter dash from in front of or behind the runners during the Olympics in Sydney in the year 2000. The promise of such an interactive system may allow designers to drop the adjective from "virtual reality." *—Gary Stix*

PHOTOGRAPHS BY DAYTON TAYLOR

Examples of this special effect can be viewed at http://www.sciam.com/

PROFILE: THEREZA IMANISHI-KARI

Starting with a Clean Slate

For someone whose lack of organization has become a topic of conversation throughout academe and beyond, Thereza Imanishi-Kari has a strikingly tidy office. The Brazilian-born scientist was this past summer cleared of all charges of scientific misconduct arising from a tangled, decade-old controversy that reached into the halls of Congress and forced Nobelist David Baltimore, one of Imanishi-Kari's co-authors in a disputed scientific study, to resign as president of the Rockefeller University. Because of his indignant defense of Imanishi-Kari, the case became known as the "Baltimore affair," even though she was the only one of six collaborators to be accused of wrongdoing. Intense news coverage turned the saga into the most sensational case of alleged research fraud in U.S. history: three books about it are now in progress.

Recently reinstated as an assistant professor in the pathology department at the Tufts University School of Medicine, Imanishi-Kari, currently in her early fifties, seems remarkably unbitter. Casually dressed and in an ebullient mood in her small room at the top of a cramped laboratory building in the New England Medical Center, she displays no anger toward her accusers, concluding that they should look to their consciences: "We all have to live with our mistakes." She finds it "very sad," however, that some scientists, notably Mark Ptashne of Harvard University, publicly sided with her accusers without ever discussing the evidence with her.

Moreover, press coverage of the controversy, Imanishi-Kari says, was "irresponsible"; she singles out the *New York Times* for handing out blame in 1991 on the basis of a condemnatory draft report by the Office of Research Integrity (then the Office of Scientific Integrity) of the Department of Health and Human Services. That leaked document became public before she knew the details of the allegations against her and before her lawyers had cross-examined witnesses. At that time, she says, she doubts "whether the scientists who were overseeing the investigation at the Office of Scientific Integrity actually had seen the evidence." She expresses agitation only in decrying the lack of due process that made that situation possible.

The research at the heart of the dispute, published in the journal *Cell* in 1986, concerned antibodies produced by genetically engineered mice. Imanishi-Kari, then at the Massachusetts Institute of Technology, and her co-authors reported that the addition of a gene to the mice made them produce a range of antibodies that was altered in a surprising way. The arguments started within a month, when Margot O'Toole, a researcher whom Imanishi-Kari had hired to extend the experiments, came to suspect that Imanishi-Kari's own studies did not support the published account. Early inquiries by scientists at the involved universities and by the National Institutes of Health found errors in the paper—it overstated the power of a key reagent, for example—but the errors did not threaten the paper's main conclusions, and the investigators found no evidence of misconduct. But in 1989 O'Toole upped the ante by charging that data reported in a published correction to the paper had been fabricated, and the NIH, under pressure from Congress, reopened its investigation of the affair.

The panel concluded that much of the evidence was "internally inconsistent, lacked reliability or foundation, was not credible or [was] not corroborated."

The case against Imanishi-Kari turned on her laboratory records, which she has always agreed were not kept up-to-date and in good order. She readily admits that when she could not remember exactly what day she did an experiment, she "probably did" put vaguely remembered dates on records, months after the fact. That habit may explain why the matter went as far as it did: the Secret Service, called in by then Representative John D. Dingell of Michigan to investigate Imanishi-Kari's notebooks, concluded by analyzing paper and ink that their pages were not written when the dates on them indicated. That finding forced the Department of Health and Human Services to dig further. Imanishi-Kari has acknowledged that when the NIH first investigated her, she pulled together loose papers and incorporated them into her principal notebook in an attempt to organize the record. (She sent along to the NIH the empty manila folders that had earlier contained some of the data, she says, but never saw them again.)

Imanishi-Kari's career bottomed out five years later, when in 1994 Tufts asked her to take a leave of absence. The request came after the Office of Research Integrity issued a "final report" concluding that she had "intentionally and deliberately fabricated and falsified experimental data and results," a finding that rested heavily on the Secret Service's notebook analysis as well as on statistical analyses of data. Imanishi-Kari argued that there was no reason she should stop her research until her appeals were exhausted, but she had to accept a demotion to contract researcher. As a result, she could no longer teach.

Looking back—something Imanishi-Kari says she does not often do—she laments the loss to her science and to her private life. "It was just a lot of pain," she recounts. Her daughter, former husband and faculty colleagues were "very supportive," and, until she lost her teaching responsibilities, her students injected enthusiasm for learning that, Imanishi-Kari says, "kept me going." Her research during the blighted years proceeded slowly, especially when she was supported only by small grants from the American Cancer Society and the Leukemia Society. She denies harboring anger over her loss of earnings since 1986: although her salary "never increased very much" during the several investigations of her, she says she "never wanted to be rich." Lawyers worked on her defense pro bono, and scientific supporters met some of the legal expenses.

At this point in our conversation, I learn the truth about her neat-looking office: it has, she confesses, been tidied and organized in honor of my visit. The appeals panel that cleared Imanishi-Kari of all charges of misconduct did criticize her for sloppy record keeping, as well as her collaborators for allowing the paper to be published "rife with errors of all sorts." Besides the overstatement of the reagent's power, there were clerical mis-

takes and an incorrect description of the cells used in one set of tests (some of the errors have since been corrected). Imanishi-Kari says she is not sure that the disputed *Cell* publication has any more errors than most papers, a thought that might make scientific editors blanch.

Some observers have speculated that Imanishi-Kari's accented and imperfect English may have been a significant factor in the case (she came to the U.S. in 1980, having previously lived in Brazil, Japan, Finland and Germany). Miscommunication between the collaborators on the disputed paper accounted for at least one misstatement in the paper. But Imanishi-Kari insists that once the investigations started, she and her colleagues "did listen very carefully" to all O'Toole's concerns.

Imanishi-Kari is defiant about her innocence, but she regrets not having insisted that all charges, discussions and findings be formally recorded right from the earliest stages. Some initial meetings about O'Toole's accusations were not recorded, she says, and Imanishi-Kari believes that if they had been, things might have gone differently. "In my own head, I didn't see at that time that it was going to turn into such a nightmare," she declares. At first, according to Imanishi-Kari, discussions centered on which data had been used in the *Cell* paper, and she provided reasons for her selections. She now advises all scientists who get caught up in any disputes that go beyond normal scientific discourse to record allegations, rebuttals and findings and to get a lawyer as soon as fraud or misconduct is mentioned.

MARY ELLEN MARK

The exonerated geneticist Thereza Imanishi-Kari

Lawyers, whom as a breed scientists love to hate, finally got Imanishi-Kari off the hook after scientists working alone had failed. The research integrity appeals panel, consisting of two lawyers from the Department of Health and Human Services and an academic immunologist, concluded this past June after a six-week hearing that much of the evidence against Imanishi-Kari was "internally inconsistent, lacked reliability or foundation, was not credible or [was] not corroborated." The panel was the first body not set up to look for misconduct to weigh the Secret Service's challenge to Imanishi-Kari's data. The panel's decision is scathingly critical of the Office of Research Integrity's findings, stating that the evidence is unreliable, in large part irrelevant and "disconnected from the context of the science." Many of the anomalies the office identified were in data that were never published, for instance. The office has lost all its recent big cases on appeal, and the secretary of health and human services is now considering options for changing the agency's responsibilities.

O'Toole, too, has paid a substantial price: she has said that as a result of her whistle-blowing she was unable to find work in science for four years. (She now works for Genetics Institute, a biotechnology company in Cambridge, Mass.) After the decision of the appeals board, she was quoted in *Science,* saying, "Given that this board tossed out the evidence, it is not surprising that they cannot believe that what I say happened, happened."

Imanishi-Kari, who if found guilty would have been barred from receiving federal funds, says she intends to continue her career in research. "Now I don't have to think about the investigation, I should be putting all my energy into something productive and something good," she remarks. She has published recent papers on the same system that was explored in her infamous 1986 publication, and although the effects she was studying are now no longer in the scientific spotlight, she expresses the hope that she might one day collaborate again with Baltimore. "You never end finding things," she reflects. "I think there's a lot of things we don't know."

—Tim Beardsley in Washington, D.C.

The Case for Electric Vehicles

New technological developments have put practical electric cars within reach, but politics may slow the shift away from internal-combustion engines

by Daniel Sperling

Cars account for half the oil consumed in the U.S., about half the urban pollution and one fourth the greenhouse gases. They take a similar toll of resources in other industrial nations and in the cities of the developing world. As vehicle use continues to increase in the coming decade, the U.S. and other countries will have to address these issues or else face unacceptable economic, health-related and political costs. It is unlikely that oil prices will remain at their current low level or that other nations will accept a large and growing U.S. contribution to global climatic change.

Policymakers and industry have four options: reduce vehicle use, increase the efficiency and reduce the emissions of conventional gasoline-powered vehicles, switch to less noxious fuels, or find less polluting propulsion systems. The last of these—in particular the introduction of vehicles powered by electricity—is ultimately the only sustainable option. The other alternatives are attractive in theory but in practice are either impractical or offer only marginal improvements. For example, reduced vehicle use could solve congestion woes and a host of social and environmental problems, but evidence from around the world suggests that it is very difficult to make people give up their cars to any significant extent. In the U.S., mass-transit ridership and carpooling have declined since World War II. Even in western Europe, with fuel prices averaging more than $1 a liter (about $4 a gallon) and with pervasive mass transit and dense populations, cars still account for 80 percent of all passenger travel.

Improved energy efficiency is also appealing, but automotive fuel economy has barely budged in 10 years. Alternative fuels such as methanol or natural gas, burned in internal-combustion engines, could be introduced at relatively low cost, but they would lead to only marginal reductions in pollution and greenhouse emissions (especially because oil companies are already spending billions of dollars every year to develop less polluting formulations of gasoline).

Electric-drive vehicles (those whose wheels are turned by electric motors rather than by a mechanical gasoline-powered drivetrain) could reduce urban pollution and greenhouse emissions significantly over the coming decade. And they could lay a foundation for a transportation system that would ultimately be almost pollution-free. Although electrically driven vehicles have a history as old as that of the internal-combustion engine, a number of recent technological developments—including by-products of both the computer revolution and the Strategic Defense Initiative (SDI) in the 1980s—promise to make this form of transportation efficient and inexpensive enough to compete with gasoline. Overcoming the entrenched advantages of gas-powered cars, however, will require a concerted effort on the parts of industry and government to make sure that the environmental benefits accruing from electric cars return to consumers as concrete incentives for purchase.

Efficiency Improves

The term "electric-drive vehicle" includes not only those cars powered by batteries charged with household current but also vehicles that generate electricity onboard or store it in devices other than batteries. Their common denominator is an efficient electric motor that drives the wheels and extracts energy from the car's motion when it slows down. Internal-combustion vehicles, in contrast, employ a constantly running engine whose power is diverted through

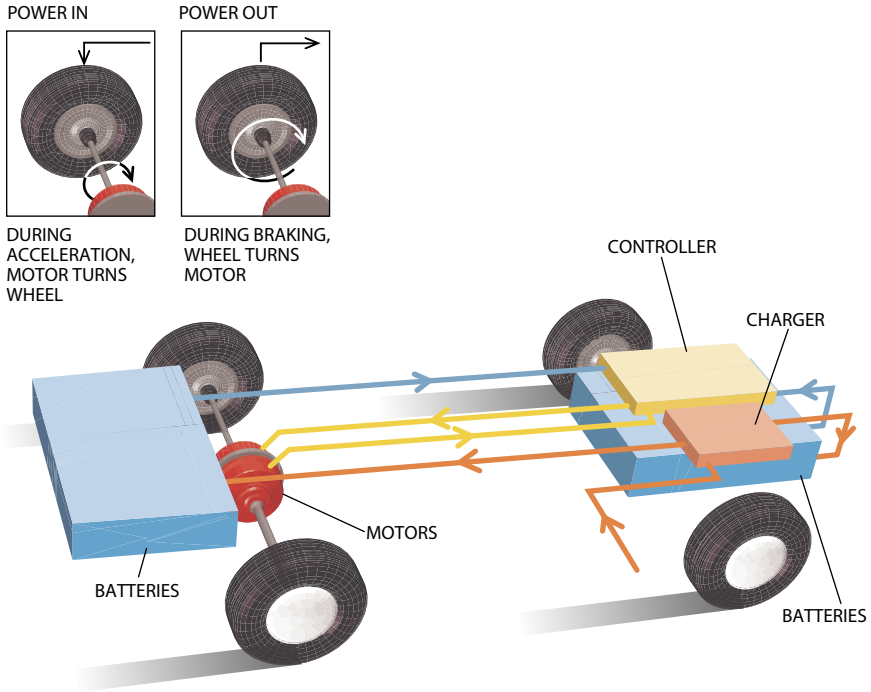
a series of gears and clutches to drive the wheels and to turn a generator for the various electrically powered accessories in the car.

Electric vehicles are more efficient—and thus generally less polluting—than internal-combustion vehicles for a variety of reasons. First, because the electric motor is directly connected to the wheels, it consumes no energy while the car is at rest or coasting, increasing the effective efficiency by roughly one fifth. Regenerative braking schemes—which employ the motor as a generator when the car is slowing down—can return as much as half an electric vehicle's kinetic energy to the storage cells, giving it a major advantage in stop-and-go urban traffic.

Furthermore, the motor converts more than 90 percent of the energy in its storage cells to motive force, whereas internal-combustion drives utilize less than 25 percent of the energy in a liter of gasoline. Although the storage cells are typically charged by an electricity-generating system, the efficiency of which averages only 33 percent, an electric drive still has a significant 5 percent net advantage over internal combustion. Innovations such as combined-cycle generation (which extracts additional ener-

ELECTRIC VEHICLE built by Renault is made from lightweight components that reduce the load its motor must carry. Short-range "urban vehicles" may be one market niche particularly suited to the characteristics of electric cars.

GAMMA LIAISON



KEY COMPONENTS of an electric vehicle are energy storage cells, a power controller and motors. Transmission of energy in electrical form eliminates the need for a mechanical drivetrain. Regenerative braking (*inset*) uses the motor as a generator, feeding energy back to the storage system each time the brakes are used.

gy from the exhaust heat of a conventional power plant) will soon make it possible for the utility power plants from which the storage cells are charged to raise their efficiency to as much as 50 percent. This boost would increase proportionately the fraction of energy ultimately delivered to the wheels of an electric vehicle. Fuel cells, which "burn" hydrogen to generate electricity directly onboard an electric car, are even more efficient.

Further air-quality benefits derive from electric drives because they shift the location from which pollutants disperse. Conventional cars emit carbon monoxide and other pollutants from their tailpipes wherever they travel, whereas pollution associated with electric power generation is generally located at a few coal- or oil-burning plants at a distance from urban centers.

Battery-powered electric vehicles would practically eliminate emissions of carbon monoxide and volatile unburned hydrocarbons and would greatly diminish nitrogen oxide emissions. In areas served by dirty coal-fired power plants, they might marginally increase the emissions of sulfur oxides and particulate matter. Pollution associated with the modern manufacture of batteries and electric motors is negligible, however.

Hybrid vehicles (those combining small internal-combustion engines with electric motors and electricity storage devices) will reduce emissions almost as much as battery-powered electric vehicles; indeed, in regions where most electricity is generated with coal, hybrids may prove preferable. The impact of electric vehicles on air pollution would be most beneficial, of course, where electricity is derived from nonpolluting solar, nuclear, wind or hydroelectric power. Among the chief beneficiaries would be California, where most electricity comes from tightly controlled natural gas plants and zero-emission hydroelectric and nuclear plants, and France, where most electricity comes from nuclear power.

These environmental benefits could be very important. Many metropolitan areas in the U.S. have air significantly more polluted than allowed by health-based air-quality standards, and most will continue to be in violation of the law in the year 2000. Pollution in Los Angeles is so severe that even if every vehicle were to disappear from its streets, the city would have no chance of meeting the standards. Many other regions in this country have little prospect of meeting their legal mandates, even with much cleaner-burning gasoline and improved internal-combustion engines. And elsewhere in the world, in cities such as Bangkok, Kathmandu and Mexico City, air pollution is more severe than in Los Angeles.

Energy Storage Is the Key

Electric vehicles now on the market rely on lead-acid batteries charged from a standard wall plug. They are unlikely ever to take the market by storm. Not only are lead-acid batteries expensive and bulky, they can drive a car little more than 150 kilometers between charges. This problem, however, is often overstated. First, there appears to be a significant market for short-range vehicles; second, new energy storage devices are even now making the transition from laboratory to production line.

A regional survey that my colleagues at the University of California at Davis and I conducted suggests that about half of all households owning more than one car—the majority of U.S. households, accounting for more than 70 percent of new car purchases—could easily adapt their driving patterns to make use of a second car with a range of less than 180 kilometers. Many respondents indicated a willingness to accept even much shorter ranges. Environmental benefits and the advantage of home recharging (many people actively dislike refueling at gasoline stations) compensate for the limited range.

Batteries are likely to play a diminishing role in electric vehicles. Among the replacements now being developed are ultracapacitors, which store large amounts of electricity and can charge and discharge quickly; flywheels, which store energy in a spinning rotor; and fuel cells, which convert chemical fuel into electricity, emitting water vapor.

Ultracapacitors owe much of their early development to the SDI's ballistic-missile defense program. Advanced manufacturing techniques can eliminate the tiny imperfections in a conventional capacitor's insulating film that allow charge to leak away. New materials make it possible to interleave a capacitor's carbon and liquid electrolyte much more finely than before. As a result, ultracapacitors can store about 15 watt-hours (enough energy to run a one-horsepower motor for about a minute) in a one-liter volume, and a one-liter device

can discharge at a rate of three kilowatts. Ultracapacitors are already available in small units for calculators, watches and electric razors.

Flywheels first saw use in transportation in the 1950s. Flywheel-powered buses traveled the streets of Yverdon, Switzerland, revving up their rotors at every stop. Since then, designs have changed substantially: now composite rotors spin at up to 100,000 revolutions per second, a speed limited only by the tensile strength of their rims. Magnetic bearings have reduced friction so that a rotor can maintain 90 percent of its energy for four days. The first high-powered ultracapacitors and flywheels are likely to appear in commercial vehicles around the year 2000. Because they can provide power very rapidly, they will be paired with batteries—the batteries will supply basic driving needs, and the capacitors or flywheels will handle peak requirements when the car accelerates or climbs a hill. This combination will allow the use of smaller battery packs and extend their service life.

Even the most optimistic projections for advanced energy storage technologies still do not compare with the 2,100 kilojoules stored in a 38-liter (10-gallon) tank of gasoline; for this reason, many researchers have predicted that the most popular electric-drive vehicles will be hybrids—propelled by electric motors but ultimately powered by small internal-combustion engines that charge batteries, capacitors or other power sources. The average power required for highway driving is only about 10 kilowatts for a typical passenger car, so the engine can be quite small; the storage cells charge during periods of minimal output and discharge rapidly for acceleration. Internal-combustion engines can reach efficiencies as high as 40 percent if operated at a constant speed, and so the overall efficiency of a hybrid vehicle can be even better than that of a pure electric drive.

Perhaps the most promising option involves fuel cells. Many researchers see them as the most likely successor to the internal-combustion engine, and they are a centerpiece of the ongoing Partnership for a New Generation of Vehicles, a collaboration between the federal government and the Big Three automakers. Fuel cells burn hydrogen to produce water vapor and carbon dioxide, emitting essentially no other effluents as they generate electricity. (Modified versions may also use other fuels, including natural gas, methane or gasoline, at a cost in increased emissions and reduced efficiency.) Although the devices are best known as power sources for spacecraft, an early fuel cell found its way into an experimental farm tractor in 1959. Prototype fuel-cell buses built in the mid-1990s have demonstrated that the technology is workable, but cost is still the most critical issue. Proton-exchange membrane (PEM) fuel cells, currently the most attractive for vehicular use, cost more than $100,000 per kilowatt only a few years ago but are expected to cost only a few thousand dollars after the turn of the century and perhaps $100 a kilowatt or less—competitive with the cost of internal-combustion engines—in full-production volumes. Daimler-Benz announced in July that it could start selling fuel cell–equipped Mercedes cars as soon as 2006.

Sustainable Transportation

Fuel cells will generally be the least polluting of any method for producing motive power for vehicles. Furthermore, the ideal fuel for fuel cells, from both a technical and environmental perspective, is hydrogen. Hydrogen can be made from many different sources, but when fossil fuels become more scarce and expensive, hydrogen will most likely be made from water using solar cells. If solar hydrogen were widely adopted, the entire transportation-energy system would be nearly benign environmentally, and the energy would be fully renewable. The price of such renewable hydrogen fuel should not exceed even a dollar for the equivalent of a liter of gasoline.

In addition to the power source, progress in aspects of electric vehicle technology has accelerated in recent years. A technological revolution—in electricity storage and conversion devices, electronic controls, software and materials—is opening up many new opportunities. For example, advances in power electronics have led to drivetrains that weigh and cost only 40 percent of what their counterparts did a decade ago. Until the early 1990s, virtually all electric vehicles depended on direct-current motors because those were easiest to run from batteries. But the development of small, lightweight inverters (devices that convert direct current from a battery to the alternating current that is most efficient for running a motor) makes it possible to abandon DC. AC motors are more reliable, easier to maintain and more efficient than their DC counterparts; they are also easier to adapt to regenerative braking. Indeed, the electric-vehicle motor and power electronics together are now smaller, lighter and cheaper to manufacture than a comparable internal-combustion engine.

Every major automaker in the world is now investing in electric vehicle development as well as improvements in less critical technologies such as those underlying car heaters and tires. The re-

Electric Vehicles Reduce Pollution

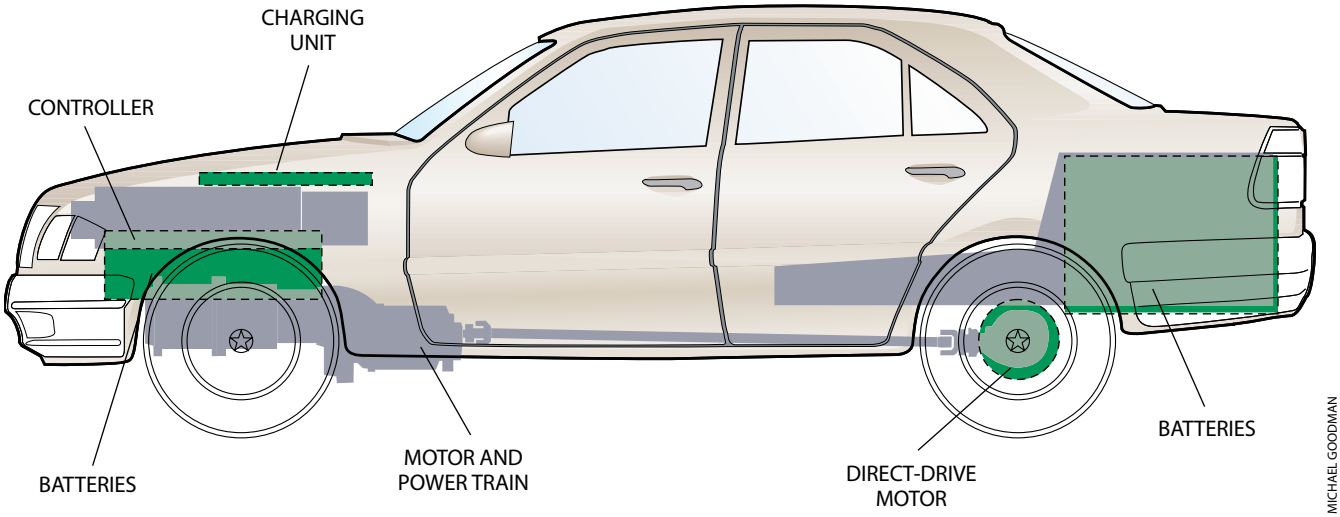
(Percentage Change in Emissions)

	HYDROCARBONS	CARBON MONOXIDE	NITROGEN OXIDES	SULFUR OXIDES	PARTICULATES
FRANCE	–99	–99	–91	–58	–59
GERMANY	–98	–99	–66	+96	–96
JAPAN	–99	–99	–66	–40	+10
U.K.	–98	–99	–34	+407	+165
U.S.	–96	–99	–67	+203	+122
CALIFORNIA	–96	–97	–75	–24	+15

JOHNNY JOHNSON

SOURCES: Choosing an Alternative Fuel: Air Pollution and Greenhouse Gas Impacts *(OECD, Paris, 1993). U.S. estimates are from Q. Wang, M. DeLuchi and D. Sperling, "Emission Impacts of Electric Vehicles,"* Journal of the Air and Waste Management Association, *Vol. 40, No. 9, pages 1275–1284; September 1990.*

BATTERY-POWERED electric cars, if they were accepted universally, would slash production of major urban pollutants, according to simulations. Pollution from power plants, however, would in some cases partially offset these gains or even increase certain kinds of pollution, especially in countries (such as the U.K. and the U.S.) that rely heavily on coal and oil.



MINIATURIZATION of electronics and advances in batteries and motors have cut the weight of electric-vehicle storage cells and drive components by as much as 60 percent during the past 10 years (older devices are shown in gray in the schematic above, newer ones in dark green and the overlap in light green). This reduction has in turn decreased the weight required for the car's suspension and structural components, making it possible to achieve equivalent performance with even smaller components.

sulting advanced components will be the building blocks for very clean and efficient vehicles of the future, but in the meantime many of them are finding their way into internal-combustion vehicles.

Although automakers worldwide have spent perhaps $1 billion on electric vehicles during the 1990s, in the context of the industry as a whole this investment is relatively small. The auto industry spends more than $5 billion a year in the U.S. alone on advertising and more than that on research and development. And oil companies are spending about $10 billion in the U.S. this decade just to upgrade refineries to produce reformulated low-emission gasoline.

Much of the investment made so far has been in response to governmental pressure. In 1990 California adopted a zero-emission vehicle (ZEV) mandate requiring that major automakers make at least 2 percent of their vehicles emission-free by 1998, 5 percent by 2001 and 10 percent by 2003. (These percentages correspond to the production of about 20,000 vehicles a year by 1998.) Failure to meet the quota would lead to a penalty of $5,000 for every ZEV not available for sale. New York State and Massachusetts enacted similar rules shortly thereafter.

The major automakers aggressively opposed the ZEV mandate but rapidly expanded their electric-vehicle R&D programs to guard against the possibility that their regulatory counterattack might fail—and that markets for electric cars might actually emerge either in the U.S. or abroad. Their loudest complaint was that the rules forced industry to supply an expensive product without providing consumers with an incentive to buy them—even though local, state and federal governments were enacting precisely such incentives.

This past March California regulators gave in to pressure from both the automobile and oil industries and eliminated the quotas for 1998 and 2001, leaving only a commitment to begin selling electric vehicles and the final goal for 2003. Industry analysts expect that U.S. sales will be no more than 5,000 vehicles total until after the turn of the century.

One crucial factor in determining the success of electric vehicles is their price—a figure that is still highly uncertain. General Motors's newly introduced EV1 is nominally priced at $33,000; Solectria sells its low-volume-production electric vehicles for between $30,000 and $75,000, depending on the battery configuration. (Nickel-metal hydride batteries capable of carrying the car more than 320 kilometers add nearly $40,000 to the price of a lead-battery vehicle.) The adversarial nature of the regulatory process has encouraged opponents and proponents to make unrealistically high or low estimates, so it will be impossible to tell just how much the vehicles will cost until they are in mass production. Comparisons with the price history of other products, including conventional automobiles, however, suggest that full-scale production could reduce prices to significantly less than half their present level [*see illustration on opposite page*].

An Uncertain Road

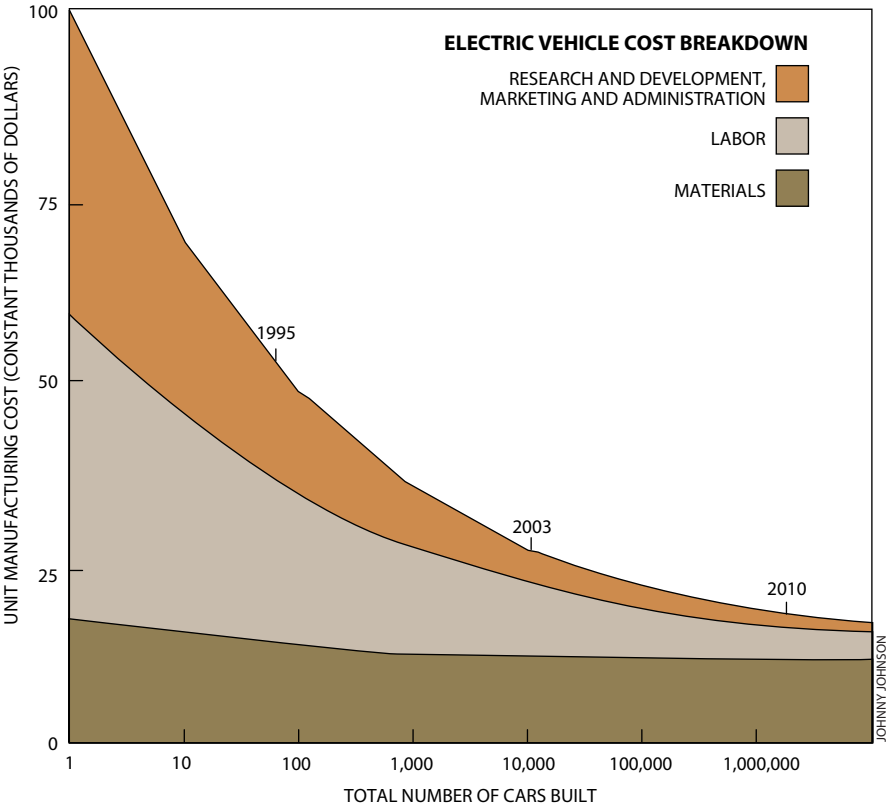
Faced with the inevitability of electric vehicle production, automakers are devising strategies to produce them inexpensively. Many (including Peugeot in Europe) are simply removing engines, gas tanks and transmissions from the bodies of existing gasoline vehicles and inserting batteries, controllers and electric motors with minimal modification. Others, including Ford, are selling "gliders" (car bodies with no installed drive components) to smaller conversion companies that then fit them with an electric drive. A third strategy is to build very small vehicles, such as the Mercedes Smart—known popularly as the Swatchmobile—targeted at the emerging market niche for limited-range urban vehicles. Of all the major manufacturers, only General Motors has thus far committed to mass production of an ordinary car designed from the ground up for electric drive.

The cost of batteries (and fuel cells) will probably always render electric vehicles more expensive to purchase than comparable gasoline vehicles. On a per-kilometer basis, however, the cost of an

electric and internal-combustion vehicle should eventually be about the same. Fuel for electric vehicles is inexpensive, maintenance is minimal, and it appears that electric motors last significantly longer than gasoline engines. Taking into account the cost of air pollution, greenhouse gases and other market externalities (that is, factors that society at large must now pay for) would tip the scale in favor of electric vehicles in many circumstances.

The challenge for policymakers and marketers is to assure that consumers take into account these full costs, a goal that has thus far been difficult to pursue. In California, where powerful air-quality regulators have led the way toward electric vehicles, progress has been slowed by opposition from both auto manufacturers and oil companies. On a national level, early hopes for the Partnership for a New Generation of Vehicles have foundered on inadequate funding, political infighting and excessive caution. As a result of this internal conflict, vehicles to be built in 2004 will ostensibly have their designs set in 1997, making it likely that the partnership will embrace only the smallest of incremental improvements rather than spearheading the introduction of fuel cells and other radically new technologies.

Nevertheless, it seems certain that electric-drive technology will eventually supplant internal-combustion engines—perhaps not quickly, uniformly nor entirely—but inevitably. The question is when, in what form and how to manage the transition. Perhaps the most important lesson learned from the current state of affairs is that government should do what it does best: provide broad market incentives that bring external costs such as pollution back into the economic calculations of consumers and corporations, and target money at innovative, leading-edge technologies rather than fund work that private companies would be doing in any case.



ECONOMIES OF SCALE should enable manufacturers to reduce the prices of electric vehicles once production volumes increase beyond their current level of a few vehicles a day. Eventually the cost of materials will dominate the total cost of electric vehicles. (These estimates are derived from experience with conventional vehicle manufacturing, in which a typical factory produces 100,000 or more vehicles a year.)

The emergence of electric vehicles has important economic implications. Whoever pioneers the commercialization of cost-competitive electric vehicle technologies will find inviting export markets around the world. Electric vehicles will be attractive where pollution is severe and intractable, peak vehicle performance is less highly valued than reliability and low maintenance, cheap electricity is available off-peak, and investments in oil distribution are small. Indeed, if the U.S. and other major industrial nations do not act, it is quite possible that the next generation of corporate automotive giants may arise in developing countries, where cars are relatively scarce today. SA

The Author

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Further Reading

NEW TRANSPORTATION FUELS: A STRATEGIC APPROACH TO TECHNOLOGICAL CHANGE. D. Sperling. University of California Press, 1988.

CHOOSING AN ALTERNATIVE TRANSPORTATION FUEL: AIR POLLUTION AND GREENHOUSE GAS IMPACTS. Distributed by OECD Publications and Information Center, Washington, D.C. OECD, Paris, 1993.

THE KEYS TO THE CAR. James J. MacKenzie. World Resources Institute, 1994.

TAKING CHARGE: THE ELECTRIC AUTOMOBILE IN AMERICA. Michael Brian Schiffer. Smithsonian Institution Press, 1994.

FUTURE DRIVE: ELECTRIC VEHICLES AND SUSTAINABLE TRANSPORTATION. D. Sperling. Island Press, 1995.

TESTING ELECTRIC VEHICLE DEMAND IN "HYBRID HOUSEHOLDS" USING A REFLEXIVE SURVEY. Kenneth Kurani, Thomas Turrentine and Daniel Sperling in *Transportation Research*, Part D, Vol. 1, No. 2 (in press).

Immunity and the Invertebrates

The fabulously complex immune systems of humans and other mammals evolved over hundreds of millions of years—in sometimes surprising ways

by Gregory Beck and Gail S. Habicht

In December 1882 a 37-year-old Russian zoologist named Élie Metchnikoff took a fateful stroll along the beach in Messina, a town on Sicily's northeastern coast. Returning to his cottage with the tiny, transparent larva of a common starfish, he pierced the creature with a rose thorn. When he examined it the next morning, he saw minute cells covering the thorn and attempting to engulf it.

He immediately recognized the significance of this observation—the cells were attempting to defend the larva by ingesting the invader, a process known as phagocytosis. Phagocytosis was already known to occur when certain specialized human cells encountered bacteria or yeast, but Metchnikoff's great realization was that phagocytosis actually plays a much broader role. It is in fact a fundamental mechanism by which creatures throughout the animal kingdom defend themselves against infection. With this keen insight and a subsequent lifetime of research, Metchnikoff created the discipline of cellular immunology. For this pioneering work, he shared the 1908 Nobel Prize in medicine with Paul Ehrlich, an early proponent of the importance of the other fundamental component of immunity, known as humoral immunity.

Impressive as Metchnikoff's achievement was, it was not the extent of his accomplishments. Significantly, his landmark experiment's subject, the starfish, was an animal that had remained virtually unchanged since its appearance at least 600 million years ago. After he punctured the starfish, Metchnikoff viewed a spectacle that was not much different on that December day in Sicily than it would have been in the earth's primordial sea tens of millions of years *before* the first living things with backbones—vertebrates—appeared.

Metchnikoff was well aware of this fact, and his studies would eventually show that the host defense systems of all modern animals have their roots in countless creatures that have populated this planet since life began. Thus was born yet another scientific discipline: comparative immunology. By studying various organisms—some very ancient—comparative immunologists gain unique insights that enable us to see from a different perspective one of the most complex and wondrous of all evolutionary creations: the immune systems of humans and other higher mammals. The discipline also often leads to insights into the nature of evolution itself: that invertebrates make up more than 90 percent of all the earth's species attests to the efficacy of their ostensibly "primitive" host defense mechanisms. Moreover, comparative immunology has enabled researchers to uncover several immune-related substances that seem to show promise for use in humans.

Recent advances in our knowledge and in the tools of immunology have engendered a fertile period in comparative immunology, a second golden age, as it were. Using molecular and cellular biological tools developed in recent years, researchers have built up an impressive body of knowledge on the host defense systems of such disparate animals as starfish, insects, sharks and frogs.

How Immunity Works

To appreciate fully the evolutionary twists and turns taken by immune systems over hundreds of millions of years, it is necessary to understand how they work. The most basic requirement of any immune system is distinguishing the cells, tissues and organs that are a legitimate part of the host body from foreign things, called "nonself," that

PHAGOCYTES attempt to engulf a rose thorn inserted into the transparent larva of a starfish. In 1882 the Russian zoologist Élie Metchnikoff (*photograph at right*) first noted this example of an innate host defense response. His subsequent studies established the field of cellular immunology.

might be present. The second job is to eliminate those nonself invaders, which are often dangerous bacteria or viruses. In addition, the immune system can recognize, and usually eliminate, "altered self"—cells or tissues that have been changed by injury or disease such as cancer. Most immunologists would agree that the immune systems of mammals, such as humans, have the most sophisticated mechanisms both for recognizing and for eliminating invaders.

Consider what happens when a weekend gardener pricks her finger on a rose thorn. Within minutes or immediately after the blood stops flowing, the immune system begins its work to eliminate undesirable microbes introduced with the wound. Already on the scene (or quick to arrive) are phagocytic white blood cells known as macrophages. These cells not only engulf and destroy any invading microbes but also release proteins that activate other parts of the immune system and alert other phagocytes that they may be needed.

This fast cellular response is sometimes called natural or innate immunity because the cells that execute it are already active in the body before an invader appears. All animals possess a defensive mechanism of this kind, which is believed to be the most ancient form of immunity. It was innate cellular immunity, for example, that Metchnikoff observed in that starfish larva.

Another component of innate immunity is known as complement. It is composed of more than 30 proteins in the blood. These proteins work in succession, in a kind of cascade, to identify and destroy invaders. Innate immunity usually suffices to destroy invading microbes. If it does not, vertebrates rely on another response: acquired immunity.

The soldiers of acquired immunity are the specialized white blood cells called lymphocytes that function together as an army. Moving through the blood and lymph glands, lymphocytes are normally at rest, but they become active and multiply if they encounter specific molecules called antigens that are associated with foreign organisms. Lymphocytes are of two classes—*B* and *T*. *B* lymphocytes secrete antibodies—defensive proteins that bind to antigens and help to eliminate them. The human body usually contains more than 100 billion *B* lymphocytes, each of which secretes an antibody that is different from most of the others. *T* lymphocytes serve a variety of purposes; they recognize and kill cells bearing nonself molecules on their surface, for example. They also help *B* lymphocytes produce antibodies.

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Acquired immunity is highly effective, but it takes days to mobilize because the response is so very complex. An invading microbe must come into contact with the right *T* or *B* lymphocytes; macrophages must be activated for assistance; the activated lymphocytes must divide; all the involved white blood cells must synthesize and release proteins that amplify the response; *B* cells must manufacture and release antibodies.

But acquired immunity also has a hallmark trait—immunologic memory—that can reduce the delay. Immunologic memory arises from the DNA-based mechanisms that allow the body's lymphocytes to recognize such a fabulous diversity of antigens even though each lymphocyte recognizes only one type of antigen. Essentially, each encounter with an invading microorganism stamps a genetic "blueprint" onto certain *B* and *T* cells. The next time these cells encounter that same invader, they use the blueprint in such a way that the response occurs faster and more powerfully than it did the first time. This phenomenon is what makes possible the familiar booster shots, or immunizations, given to children. The gardener of our example may with time forget her trivial cut, but her immune system never will.

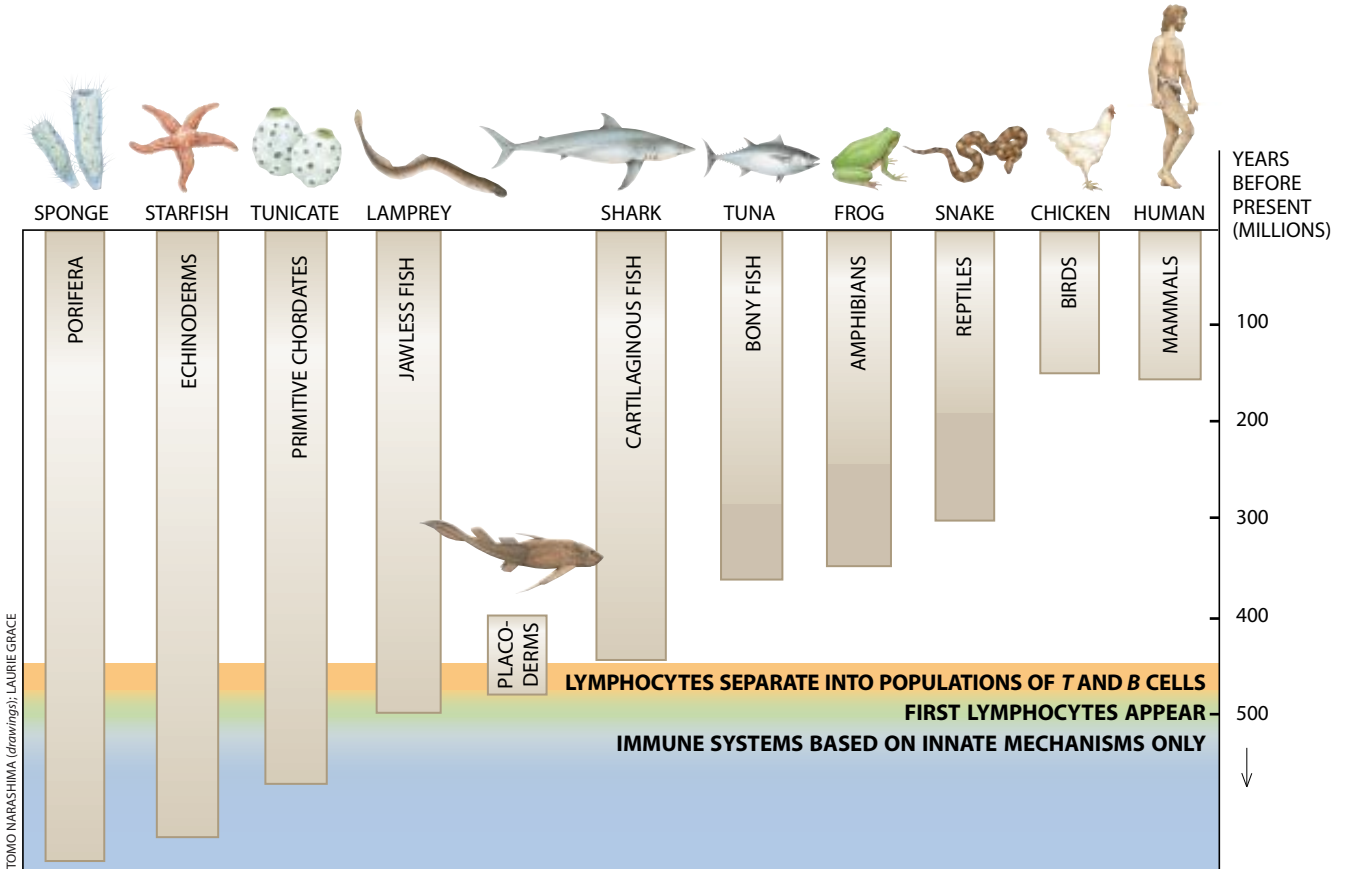
In the Beginning

As we have described, the immune systems of such higher vertebrates as mammals can be broken down into two major types of response: innate and acquired. The latter includes immunologic memory as a significant, distinguishing characteristic. The responses are mediated by many different agents: macrophages and other phagocytic cells, *B* and *T* lymphocytes, antibodies and a multitude of other participating proteins. One of the central questions of comparative immunology is: How many of these features—or similar ones—appear in other, older groups of organisms?

Quite a few of them do; in fact, certain elements of immunity are detectable in almost all living things (phagocytosis is an example). Through the aeons, some of these elements carried over basically unchanged from one creature to the next. Other features are unique to higher vertebrates but bear intriguing similarities to aspects of invertebrate host defense systems. These similarities are important because they suggest that the invertebrate mechanisms are precursors of the corresponding later, vertebrate ones. Collectively, these links may be the most compelling evidence that the immune systems of humans and other mammals evolved from more ancient creatures over hundreds of millions of years.

Not surprisingly, host defense systems began when life did: with the protozoans, the simplest of all living organisms. Protozoans, which go back about 2.5 billion years, are single-cell life-forms; in other words, they accomplish every physiological function in just one cell.

ROBERTO OSTI



IMMUNOLOGIC MILESTONES occurred around the time that the first creatures with backbones (vertebrates) appeared. One of the most important of these milestones was the emergence of the first immune systems based on lymphocytes, possibly in jawless fish roughly 500 million years ago. These lymphocytes then separated into the two distinct populations discernible in all higher vertebrates. Invertebrates have a family of cells that resemble vertebrate immune cells in some respects.

In protozoans, respiration, digestion, defense and other functions are performed, at least in part, by phagocytosis. In its defensive function, protozoan phagocytosis is not very different from that accomplished by the phagocytic cells found in humans.

In animals ranging from starfish to humans, phagocytic cells travel through a circulatory system or (in the case of starfish) through a fluid-filled body cavity, or coelom. In multicellular animals that lack a body cavity and a circulatory system (such as sea sponges), the wandering phagocytic cells patrol the tissues and surrounding spaces.

Another fundamental aspect of immunity—the ability to distinguish self from nonself—also dates back to early in life's history. Some protozoans live in colonies of thousands of creatures and must be able to recognize one another. It is difficult to conceive of how either life in a colony or sexual reproduction could occur without the ability to distinguish self from nonself; thus, it is very likely that protozoans have this ability. Even the sponge, which in the view of some scientists is the oldest and simplest metazoan (multicellular animal), can distinguish self from nonself: its cells attack grafts from other sponges.

This rejection response is not identical to that found in vertebrates, however. In vertebrates, because of immunologic memory, if one graft from a donor is rejected, a second graft from the same donor will be rejected more quickly. In sponges and jellyfish, however, the second rejection is no faster than the first. These results suggest that the memory component of the immune response, a cornerstone of the vertebrate system, is missing. This conclusion is supported by experiments with starfish and other higher invertebrates, which also lack immunologic memory.

Two other features of the vertebrate immune system—complement and lymphocytes—are also missing from invertebrates, but for both there seem to be invertebrate analogues. In place of complement, several phyla of invertebrates, including various insects, crabs and worms, exhibit a similar response, called the prophenoloxidase (proPO) system. Like the complement system, proPO is activated by a series of enzymes. A cascade of reactions ends with the conversion of proPO to the fully active enzyme phenoloxidase, which plays a role in encapsulating foreign objects. Kenneth Söderhäll of the University of Uppsala in Sweden and Valerie J. Smith of Gatty Marine Laboratory in Scotland have shown that the system serves other purposes as well, including blood coagulation and the killing of microbes.

Invertebrates lack lymphocytes and an antibody-based humoral immune system. Nevertheless, they do have mechanisms that seem to be precursors of those aspects of vertebrate immunity. For example, lymphocytelike cells have been found in earthworms—which probably appeared 500 million years ago. Perhaps more significantly, all invertebrates have molecules that appear to function much like antibodies and may be their forerunners. These molecules, a group of proteins called lectins, can bind to sugar molecules on cells, thereby making the cells sticky and causing them to clump. Lectins must have evolved quite early because they are ubiquitous; they are found in plants, bacteria and vertebrates, in addition to invertebrates.

The role of lectins in immune responses is not known exactly; they appear to play a part in tagging invading organisms, which are probably covered with different sugar molecules. Lectins isolated from earthworms, snails, clams and virtually every other invertebrate animal participate in the coating of foreign particles, thus enhancing phagocytosis. Numerous lectins with different sugar specificities can be found in each animal phylum. Lectins isolated from the flesh fly, *Sarcophaga peregrina,* and from the sea urchin are related to a family of vertebrate proteins called collectins. In humans, collectins serve important roles in innate immunity by coating microbes so they can be more easily identified by phagocytes and by activating immune cells or complement.

And although antibodies are not found in invertebrates, molecules that are structurally and even functionally similar to them are. Antibodies (also known as immunoglobulins) belong to a very large, very old family of molecules—the immunoglobulin superfamily. Molecules in this group all have a characteristic structure called the Ig fold. They serve diverse functions but in general are involved with recognizing nonself as well as other types of molecules.

The Ig fold probably emerged during the evolution of metazoan animals, when it became necessary for specialized cells to recognize one another. The fold could have originally been a pattern-recognition molecule involved in identification of self; later, it evolved into something that could recognize antigens as well, setting the stage for the emergence of true immunoglobulins.

Hemolin, a protein isolated from the blood of moths, is a member of the immunoglobulin superfamily. It binds to microbial surfaces and participates in their removal. Studies have identified other superfamily molecules in several invertebrates (grasshoppers and flies), as well as in lower vertebrates. These observations suggest that antibody-based immune responses, though restricted to vertebrates, have their roots in invertebrate defense mechanisms.

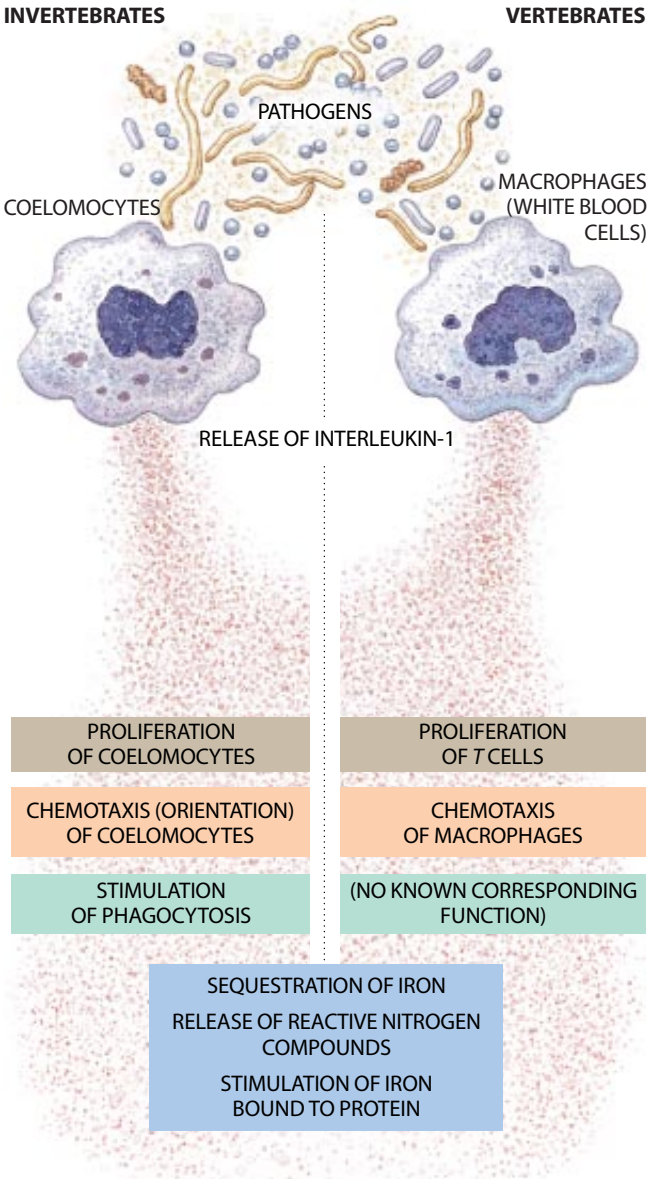
Precursor of Immune Regulation

Evolution seems to have conserved not only many aspects of host defense mechanisms found in invertebrates but also many of the control signals for these mechanisms. Our own work has recently focused on isolating molecules in invertebrates that resemble the cytokines of vertebrates. Cytokines are proteins released by various activated immune (and nonimmune) cells that can either stimulate or inhibit other cells of the immune system and have effects on other organs as well. Cytokines include the interferons, the interleukins (such as IL-1 and IL-6) and tumor necrosis factor (TNF). These molecules are critical regulators of every aspect of vertebrate immunity.

We suspected that invertebrates would have IL-1 or a similar ancestral cytokine for several reasons. First, these molecules regulate some of the most primitive mechanisms of vertebrate immunity. Second, the structure and defensive functions of IL-1 are similar in many different vertebrates, suggesting that the molecules evolved from a common precursor. Finally, macrophages, the type of white blood cells that produce IL-1, are ubiquitous throughout the animal kingdom.

From the coelomic fluid of the common Atlantic starfish *Asterias forbesi,* we isolated a protein that behaved like IL-1 in many respects: its physical, chemical and biological properties were the same; it stimulated vertebrate cells responsive to IL-1; and antibodies that recognized human IL-1 recognized this protein, too. Subsequently, we have found that many invertebrates possess molecules related to vertebrate cytokines. Worms and tunicates (sea squirts) carry substances similar to IL-1 and TNF. One of us (Beck) has found molecules resembling IL-1 and IL-6 in the tobacco hornworm. Thus, invertebrates possess correlates of the three major vertebrate cytokines.

The invertebrate cytokines seem to perform functions similar to those in vertebrates [*see illustration at left*]. We found that in starfish, cells called coelomocytes (the equivalent of macrophages) produce IL-1. In experiments conducted with Edwin L. Cooper of the University of California at Los Angeles and David A. Raftos, now at the University of Sydney, we showed that IL-1 stimulated these macrophage equivalents to engulf and destroy invaders. Invertebrate cyto-



CYTOKINE RELEASE can stimulate many functions in invertebrates and vertebrates alike, including dozens aimed at defending the host. Recently the authors found that the cytokine interleukin-1 serves defensive functions in the starfish that are either analogous or identical to those it serves in vertebrates.

kines therefore appear to orchestrate much of their host's defensive response, just as vertebrate cytokines do in innate immunity.

Medicine from a Frog

Comparative immunology does not consist solely of looking for the analogues of vertebrate defenses in invertebrates. On the contrary, studies of invertebrates have sometimes uncovered novel types of defenses that were only later identified in vertebrates as well.

For instance, key defensive molecules in invertebrates are the antibacterial peptides and proteins. These molecules—some of which have potentially significant applications as medications for humans—are usually released from an organism's blood cells early on in the innate response. The most widespread antibacterial protein isolated from invertebrates is lysozyme, which was also the first to be isolated. Insects produce lysozyme when infection sets in or when exposed to proteins that make up bacterial cell walls. Interestingly, lysozyme is also part of the innate defense in humans. For example, in saliva it acts to defend the oral cavity against bacteria.

In 1979 a group at the University of Stockholm led by Hans G. Boman discovered peptides with bacteria-eliminating properties in the silk moth, *Hyalophora cecropia*. This class of peptides, which they named cecropins, can kill bacteria at concentrations low enough to be harmless to animal cells. They act by perforating the bacteria, causing the cells to burst. Recently five different molecules related to cecropins were isolated from the upper part of the pig intestine, where they help to regulate the bacterial contents of that animal's digestive tract. They are currently being developed as antibacterial agents for use in humans.

Jules A. Hoffmann and his colleagues at the CNRS Research Unit in Strasbourg have been studying another group of antibacterial peptides, called defensins, in insects. Defensins have been isolated from several insect orders and appear to be the most common group of inducible antibacterial peptides. Like cecropins, defensins are relatively small protein molecules. Unlike cecropins, the way in which they kill bacteria is not well understood. Mammalian defensins are also small but have little else in common with insect defensins. These facts suggest that small antibacterial peptides are a fundamental part of the animal front line of rapidly deployed defenses.

Lower vertebrate species are yielding unique host defense molecules as well. In 1987 Michael Zasloff, then at the National Institutes of Health, noticed that African clawed frogs required no antibiotics or other treatments to completely recover from nonsterile surgery—in spite of the fact that they recuperated in bacteria-laden water. Searching for the source of this extraordinary protection, he eventually isolated two peptides—which he termed magainins 1 and 2—from frog skin. ("Magainin" is derived from the Hebrew word for shield.) The compounds exhibit a broad range of activities against bacteria, fungi and protozoa. Antibodies that bind to magainin also bind to cells of human epithelial tissues, such as the skin and intestinal lining, which suggests that humans synthesize similar molecules as a first-line defense against pathogens.

Pervasive Legacy

The fact that peptide antibiotics (along with other unique host defense strategies) were originally discovered in invertebrates may help stimulate the study of esoteric defense systems that have languished in the "tidal pools" of immunology research. Who knows how many potentially lifesaving compounds remain to be discovered?

It is surprising that so little attention has been focused on the host defense systems of invertebrates, because such studies pay off in so many ways. New and diverse defense functions characteristic of all living things are being discovered, and by looking at ancient, ancestral organisms, we are learning about their evolutionary descendants as well.

In the end, the intricacies of the vertebrate immune response can only be fully understood by analyzing less complex systems, such as those found in invertebrates. Surely this work has extensive implications for understanding not only basic evolution but also more immediate problems of human health and disease. In these and other endeavors, Metchnikoff's legacy is pervasive. SA

ROBERTO OSTI

The Authors

GREGORY BECK and GAIL S. HABICHT began working together in 1989, when Beck was a graduate student and Habicht his thesis adviser at the State University of New York at Stony Brook. Beck is now assistant professor of biology at the University of Massachusetts at Boston. He earned a B.S. from S.U.N.Y. at Albany in 1982 and his Ph.D. from S.U.N.Y. at Stony Brook in 1994. Habicht, vice president for research and professor of pathology at Stony Brook, earned her Ph.D. from Stanford University in 1965. She held postdoctoral positions, first at the Rockefeller University and then at the Scripps Clinic and Research Foundation, between 1965 and 1971, when she moved to Stony Brook. This is their second article for *Scientific American*.

Further Reading

CELL-FREE IMMUNITY IN INSECTS. H. G. Boman and D. Hultmark in *Annual Review of Microbiology,* Vol. 41, pages 103–126; 1987.

PRIMITIVE CYTOKINES: HARBINGERS OF VERTEBRATE DEFENSE. G. Beck and G. S. Habicht in *Immunology Today,* Vol. 12, No. 3, pages 180–183; June 1991.

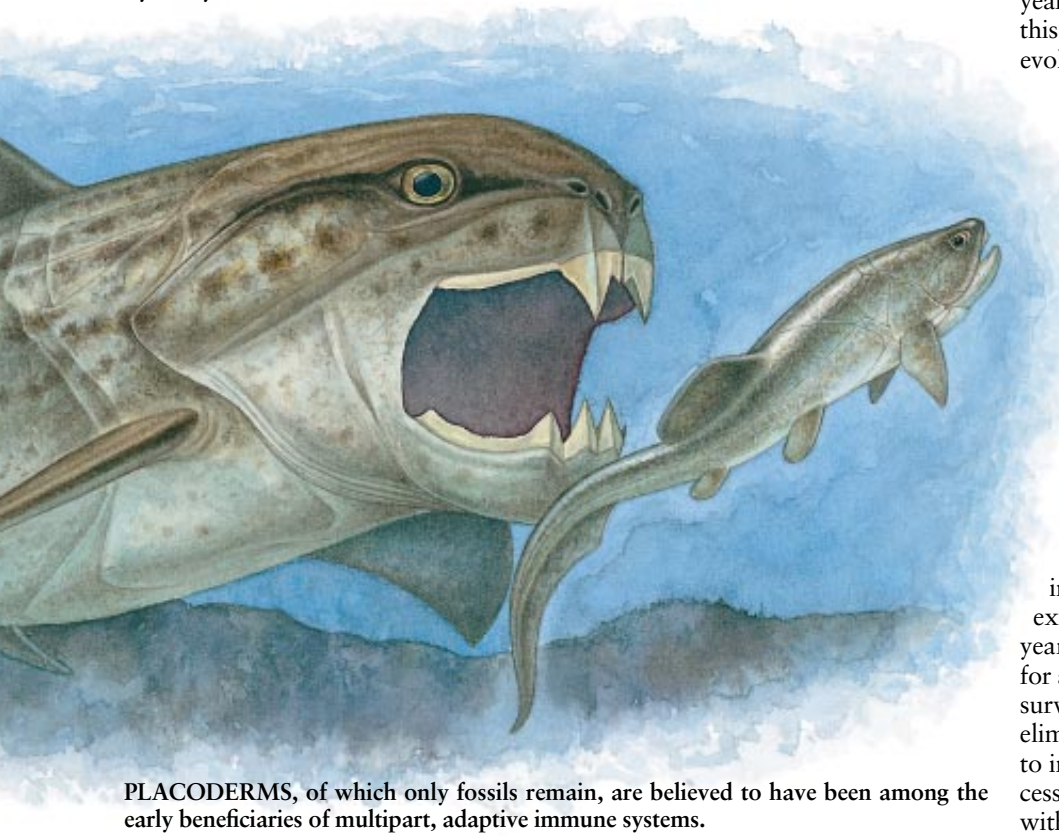
INSECT DEFENSINS: INDUCIBLE ANTIBACTERIAL PEPTIDES. Jules A. Hoffman and C. Hetru in *Immunology Today,* Vol. 13, No. 10, pages 411–415; October 1992.

PRIMORDIAL IMMUNITY: FOUNDATIONS FOR THE VERTEBRATE IMMUNE SYSTEM. Edited by G. Beck, E. L. Cooper, G. S. Habicht and J. J. Marchalonis. Special issue of *Annals of the New York Academy of Sciences,* Vol. 712; March 31, 1994.

Sharks and the Origins of Vertebrate Immunity

Sharks, which have existed for as many as 450 million years, offer glimpses of a distant period in the evolution of the immune system

by Gary W. Litman



PLACODERMS, of which only fossils remain, are believed to have been among the early beneficiaries of multipart, adaptive immune systems.

Some 500 million years ago the ancestor of all jawed vertebrates emerged in the warm waters of the earth's vast primordial sea. Although its identity is shrouded in mystery, some paleontologists believe that this ancestor resembled certain members of a later group of fish known as placoderms, which are known, at least, from the fossils they left behind. These ungainly creatures, some of which apparently grew to lengths of about seven meters, had a head and pectoral region encased in protective bony plates.

A living placoderm, or one of the other possible ancient vertebrate forerunners, would of course add immeasurably to our understanding of evolution. Perhaps most significantly, we would be able to see the workings of one of the most complex of bodily constituents—the immune system—that existed shortly after some vertebrates made the critical transition from jawless to jawed form. The transition is a key one in evolution because it is a link in the course leading to more advanced animals, including those that eventually crawled onto land and evolved into humans. It is likely that multicomponent, adaptive immune systems began with the first vertebrates. The immune systems of surviving invertebrates, which are probably similar to those of ancient ones, do not have the remarkable adaptive capabilities of vertebrate immunity.

Although the placoderms and their ancestors are long gone, we do have the next best thing: several of their phylogenetic relations, including sharks, skates, rays and ratfishes. These creatures—with immune systems that have also probably changed little if at all since their earliest appearance hundreds of millions of years ago—may provide a window onto this distant and extraordinary period in evolution.

During the past several years, my colleagues and I have studied the immune systems of some of these creatures. As might be expected, immunity in these living fossils is different from that in such later animals as frogs, monkeys and humans. Yet intriguingly, when it comes to protecting their hosts against disease, infection and other ills, these ancient immune systems appear to be every bit as effective—if not more so—than their more modern counterparts.

Perhaps this is not surprising; the subclass of elasmobranchs, which includes sharks, skates and rays, has existed for as many as 450 million years (*Homo sapiens* has been around for approximately half a million years), surviving several mass extinctions that eliminated countless species. It is hard to imagine how such evolutionary success could have occurred in creatures with immune systems that were anything less than unusually effective. Our efforts to identify the features that have made elasmobranch immunity so successful have had a valuable side benefit: insights into human immunity.

The Two Parts of Immunity

The adaptive immune system has two basic parts, called humoral and cellular. The agents of humoral immunity are known as *B* lymphocytes, or *B* cells. *B* cells produce protein molecules, or antibodies, that bind to foreign substanc-

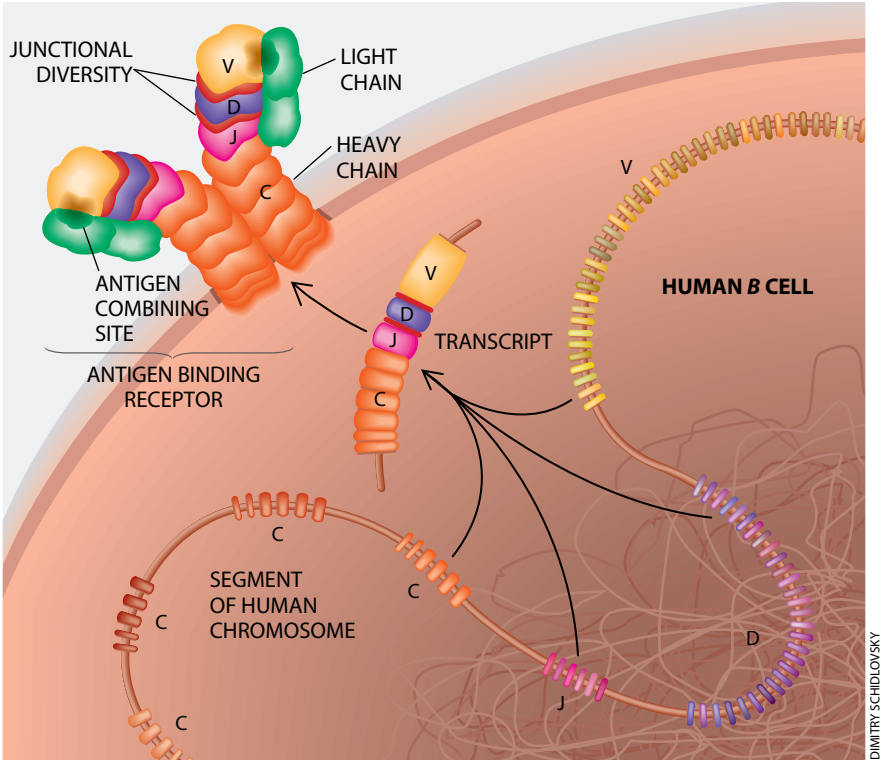
es, or antigens, on potentially harmful bacteria and viruses in the bloodstream. This binding enables other bodily entities to destroy the bacteria and viruses by various means. Antibodies are also known as immunoglobulins; humans have five major types of them.

All the antibodies on a single *B* cell are of the same type and bind to a specific antigen. If this antibody encounters and binds to its corresponding antigen, the *B* cell is stimulated to reproduce and to secrete its antibody. Most of the human body's billions of *B* cells make antibodies that are different from one another, because during the formation of each *B* cell a genetic process that has both random and inherited components programs the cell to produce a largely unique "receptor"—the part of the antibody that actually binds to the antigen. It is this incredible diversity among antigen receptors that gives such vast range to humoral immunity.

Cellular immunity is carried out by a different group of immune cells, termed *T* lymphocytes, or *T* cells. In contrast to *B* cells, *T* cells do not produce antibodies; rather they recognize antigens bound to a type of molecule on the surface of a different kind of cell. For this purpose, they are equipped with a specialized class of molecule, called a receptor. Typical manifestations of *T* cells at work include such diverse phenomena as the rejection of a foreign skin graft and the killing of tumor cells.

Antibodies, or immunoglobulins, and *T* cell receptors are the primary means by which the body can recognize specific antigens. Although humoral and cellular immunity have basically different functions and purposes, they interact during an immune response. *T* cells, for example, help to regulate the function of *B* cells.

In some ways, shark and skate immunity is similar to that of humans. These fish have a spleen, which, as in humans, is a rich source of *B* cells. When a shark is immunized—that is to say, injected with an antigen—*B* cells respond by producing antibodies. The similarities extend to cellular immunity. Like humans, sharks and skates have a thymus, in which *T* cells mature and from which they are released. Sharks also have *T* cell receptors. Recent work by me and Jonathan P. Rast, now at the California Institute of Technology, showed that, as in humans, diversity in these receptors arises from the same kind of genetic mechanisms that give rise to antibody diversity. Finally, skin grafted from one shark to another ultimately results in rejection.



HUMAN AND SHARK ANTIBODY GENE SYSTEMS have striking differences in the arrangement of the gene segments that recombine to specify an antigen binding receptor. Shown here is a simplified version of the process that specifies the "heavy-chain" molecule that makes up part of the antigen binding receptor. The receptor is part of a large antibody molecule known as IgM, which actually has five such recep-

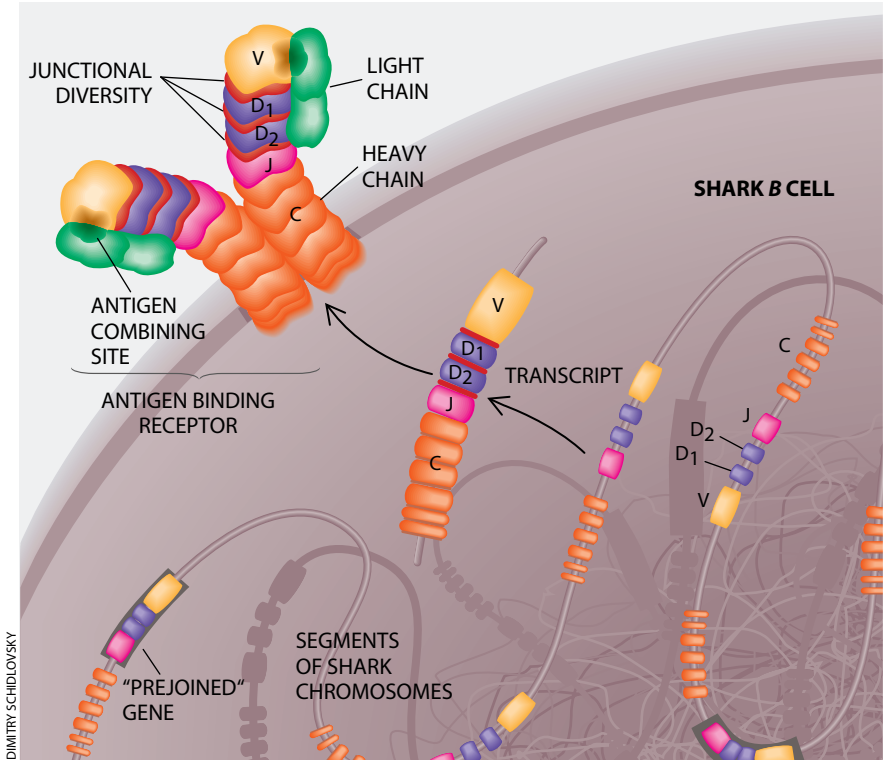
These similarities notwithstanding, there are some significant and fascinating differences between the immune systems of such cartilaginous fish as sharks and of humans. For example, cartilaginous fish have four different classes of immunoglobulin, only one of which is also among the five major types in humans. Furthermore, these shark antibodies lack the exquisite specificity that permits the recognition of, among other things, the subtle differences between two similar types of bacteria.

In addition, these antibodies lack the capacity of human antibodies to bind more and more strongly to an antigen during the course of a prolonged immune response—a decided advantage in fighting infection. A difference in cellular immunity is implied by the fact that sharks do not reject skin grafts vigorously and quickly, as humans do, but rather over a period of weeks.

Do these facts mean that the immune systems of sharks and skates are less suited to the needs of the host in comparison with those of humans and other mammals? Not at all. Indeed, the idiosyncratic nature of this ancient immune system illustrates well the twists and turns that occurred during the evolution of immunity. This sinuous course, moreover, suggests that evolution, at least where the immune system is concerned, may not have always proceeded in the inexorable, successive way in which it is often portrayed.

A Receptor for Every Antigen

Much of our work so far has been devoted to elucidating the humoral immune system of the horned shark, a spotted creature that usually grows to about a half meter in length. In this animal, as in all vertebrates, the diversity in antigen receptors has a genetic basis. Specifically, each antibody's antigen receptor is formed through the interactions between two amino acid chains, which are protein molecules, characterized as heavy and light. With few exceptions, the basic antibody molecule has two pairs of such chains and therefore two antigen receptor sites. Exactly which antigen a receptor will bind to depends on the type and arrangement



tors; it is the only antibody that humans and sharks have in common. In humans the gene segments that come together to specify the receptor are scattered along a relatively long length of one chromosome. In sharks the gene segments are already next to one another as a kind of package that can be on any one of several chromosomes. For simplicity, the details of the multistage transcripting process have been omitted.

of the amino acids in the chains that make up the receptor.

Regardless of where they are produced in the body, amino acid chains are created in cells and specified by genes—which act as a kind of blueprint—in the cell's nucleus. In the case of an antigen receptor, the amino acid chain is specified by gene segments, also known as antibody genes, in the *B* cell's nucleus. There are three types of gene segments for this purpose; they are designated V ("variable"), D ("diverse") and J ("joining"). The amino acids in the heavy chain are specified by all three types of gene segments; the light chain is encoded by the V and J only. A fourth type of gene segment, designated C ("constant"), determines the class of antibody.

In humans the functional V, D, J and C segments are found on a single chromosome. As in most higher vertebrates, the segments are located in clusters, with, for example, some 50 functional V, 30 D, six J and eight C elements in a single location, occupying roughly a million components, or "rungs," of the DNA molecular "ladder." (These rungs are the base pairs.) When a *B* cell's gene-reading mechanisms produce an antibody, various cellular entities first recombine single V, D and J segments adjacent to a C segment in a multistep process. This genetic material is then "read out" to the cell's protein-making systems. The recombination of these gene segments determines the antigen-binding characteristics of the antibody. In such higher vertebrates as humans, this joining of different V, D and J elements, which is called combinatorial diversity, is an important factor in antigen receptor diversity.

In sharks, too, antibody gene segments are organized in clusters. A shark heavy-chain cluster, however, contains only one V segment, two Ds, a single J and a single C. There are more than 100 such clusters, distributed on several different shark chromosomes. When the protein-making machinery in one of the shark's *B* cells produces an antibody, only the four gene segments (V, D1, D2 and J) from a single cluster are recombined (the C segment is already linked to the J). As in the mammalian case, their genetic message is read out and translated into a protein that makes up an antigen receptor.

Does the recombination of only the V, D1, D2 and J elements found in one cluster limit the shark immune system's ability to produce a great diversity of antigen receptors? It probably would, except (as mentioned earlier) there are hundreds of different antibody gene clusters spread over several different shark chromosomes. Furthermore, neither the shark nor mammalian immune systems depend solely on combinatorial diversity to generate many different antibodies. In fact, in sharks and other cartilaginous fish, two other phenomena are much more significant in fostering this diversity; they are termed junctional diversity and inherited diversity.

Where Diversity Comes From

To understand junctional diversity, we must return to the joining of V, D and J gene segments that specifies an antigen receptor chain. Junctional diversity occurs when, say, V and D or D and J segments come together. At the joining boundary where the two segments unite, before their actual fusing, several DNA base pairs are removed, and new bases are added in a nearly random manner. This localized alteration in genetic content ultimately changes the amino acid sequence and therefore the characteristics of the antigen receptors that are created.

Therein lies the real advantage of the extra D gene segment in the shark antibody-producing system. With four different gene segments, there are three places where this diversity can occur: between V and D1, between D1 and D2, and between D2 and J. Thanks to junctional diversity, millions of different variants of an antibody molecule, each possessing slightly different receptor structures, can be created from each cluster. In mammals, on the other hand, junctional diversity can occur typically in only two locations: between V and D segments and between D and J. Therefore, junctional diversity leads to somewhat less variation in mammals.

This ability to generate many different antibodies is conceptually attractive for protection against a vast array of foreign invaders. But a large—and potentially fatal—gap exists between the ability to generate antibody diversity and the efficient use of this diversity. In light of this fact, junctional diversity is a double-edged sword: in theory, it can generate enough antibody specificity to handle almost any situation. Yet broadly speaking, it could in practice take too

much time to generate enough antibodies, select the best ones, expand their numbers and then deal with the invading pathogen; in other words, the host could lose a race with the infectious agent.

To try to keep the host from losing that race, the body relies on mechanisms that rapidly select the "blueprint" of the immediately needed antibody gene. This blueprint is first expressed by one *B* cell among the body's billions. In mammals, specialized cellular compartments and complex intercellular communications mobilize and expand the immune system for this purpose.

Sharks, on the other hand, rely heavily on a form of inherited diversity. This form, the most distinctive feature of the shark immune system, allows the animals to avoid depending on a chance occurrence—for example, a fortuitous combination of DNA base pairs attained through junctional diversity—to generate the right antigen receptor at the right time. In a shark, a large percentage of the gene clusters in every cell are inherited with their V, D1, D2 and J gene segments already entirely or partially "prejoined."

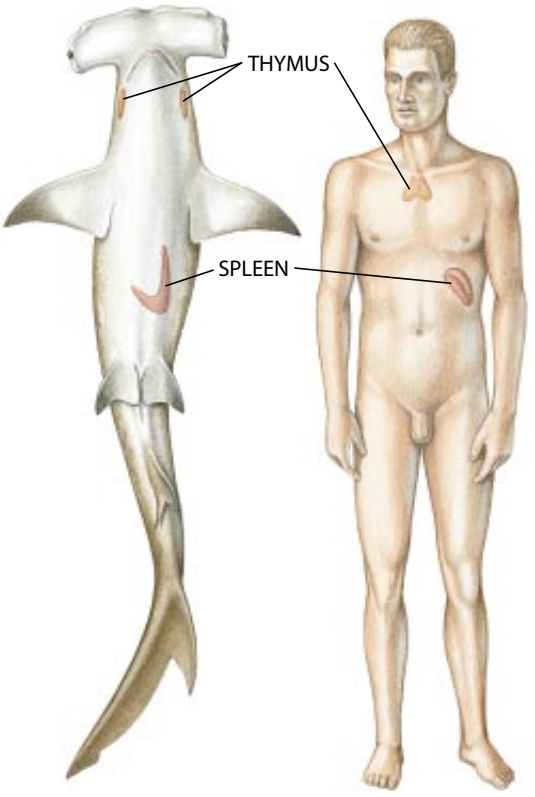
In such clusters, there is limited capacity, or none at all, for junctional diversification. Analyses of hundreds of these prejoined or partially prejoined clusters have shown their gene segments to be remarkably similar to those of ordinary clusters, suggesting that one type derived from the other at some point in evolution.

But why? As in so many areas, our knowledge of genetic mechanisms has far surpassed an understanding of their relation to function. Still, it would be entirely reasonable to theorize that the humoral immune systems of cartilaginous fish have evolved to combine the best of two possibilities: a large number of genes that can recombine and thus provide immunologic flexibility, as well as some genes with fixed specificities that can be mobilized quickly to make antibodies against pathogens that these species encounter all the time.

Combinatorial, junctional and inherited forms of diversity are not the extent of diversity-producing mechanisms. In addition, the two types of gene clusters undergo additional change through mutation, which occurs at a very high frequency in the antibody genes of higher vertebrates. These mutations are directed at altering the characteristics of the antigen receptor sites of antibodies.

One interesting conclusion from a comparison of human and shark humoral immunity is that some 450 million years of evolution did relatively little to change the molecules of antibody immunity; the protein structures of shark and human antibodies are very similar. Moreover, the V, D and J sequences of gene segments that specify the creation of antibodies are similar. What evolution did radically alter is the way these gene segments that specify antibodies are organized; it placed greater emphasis on junctional and especially inherited diversity in sharks, for example. Though relatively simple, the mechanisms of genetic diversification in the shark's immune system seem in many ways more efficient than those in such higher vertebrates as humans.

This finding confirms, not surprisingly, that evolution has a way of uniquely adapting systems to their hosts' immediate needs. In the case of immunity, evolution also has to provide for unexpected challenges as well. The surprise is that in order to make that efficiency possible, enigmatic evolutionary leaps of uncharacteristic magnitude apparently sometimes occur, at least in antibody immunity, over relatively short periods.



ROBERTO OSTI

SHARKS AND HUMANS share a number of immunologic features, including a thymus and a spleen.

Cellular Immunity

Many of the basic principles put forth in the discussion so far—the rearrangement of widely spaced gene segments scattered along a stretch of chromosome and the reading out and alteration of their genetic information to specify the creation of antigen receptors made up of amino acid chains—apply to cellular as well as humoral immunity. After all, *T* cells, just like the antibodies secreted by *B* cells, must also recognize and bind to an almost limitless assortment of antigens.

T cells and antibodies both have receptors that are specified by similar gene segments. The basic mechanisms of gene segment reassembly that produce antibody molecules also create *T* cell receptors. But a *T* cell receptor is found only on the cell's surface and only recognizes foreign material bound to a specialized molecule on a different cell. *T* cells' affinities for foreign materials are low in comparison to some antibodies, and they do not undergo mutation in the same manner as antibodies.

In the past, many immunologists believed that cellular immunity predated humoral immunity. Yet the aforementioned chronic nature of skin graft rejection in sharks suggests that, if anything, cellular immunity in the shark is not robust and possibly lacks specificity. This notion, in turn, implied to some observers that sharks do not have *T* cells.

In order to test this hypothesis, my colleagues and I set about determining whether the horned shark has *T* cells. Unequivocal proof of the existence of *T* cells requires identification of their antigen receptors. For this purpose, the conventional approaches available until recently were inadequate. The breakthrough came with the development several years ago of a technique known as the polymerase chain reaction (PCR), which can produce millions of copies of a small section of DNA. We used a form of the PCR technique as part of a process that produced great numbers of *T* cell receptor genes in order to character-

ize them. Recently we found all four classes of mammalian *T* cell antigen receptors in the skate and have evidence suggesting their presence in the shark.

Extensive characterization of one of the classes of shark *T* cell receptors showed it to be about as complexly diversified as its human equivalent. This finding surprised us, indicating that in contrast to antibody gene organization, *T* cell receptor genes seem to have undergone no major changes since the time of the divergence of the sharks from the evolutionary line leading to the mammals some 450 million years ago. The antibody gene system and the *T* cell receptor gene system may well have diverged from a common ancestor that more closely resembled the latter, although the opposite can also be argued—that it was an antibody-gene-like ancestor that gave rise to both categories of immune gene systems.

As the genomes of sharks and their relatives continue to be characterized, we now recognize a variety of different gene clusters. For example, a group led by Martin F. Flajnik at the University of Miami recently found gene clusters that resemble those of both antibodies and *T* cell receptors. Intriguingly, the genes in these clusters undergo extraordinary rates of mutation.

Ongoing studies have also suggested that immune system genes from different clusters have "mixed and matched" with one another during evolution. With hundreds of clusters and plenty of genetic backup, exchange between clusters may have been a very efficient means of generating novel gene clusters. It is quite possible, too, that our continuing studies will identify even more receptors in the shark immune system.

With respect to this exchange among different clusters, the peculiar redundancy of different immune receptor gene clusters in the shark—the groupings of essentially identical V, D1, D2 and J segments repeated over and over on various chromosomes—can be seen in an entirely new light. In short, this recombination, along with other unique features of the shark's genetic mechanisms, affords a means for rapidly evolving new families of receptor molecules. In mammals the gene segments are isolated to single chromosomes, and little structural redundancy is evident; these facts mean that the opportunity for this type of recombination is remote.

Furthermore, duplication of gene segments—the existence of multiple Vs, Ds and Js, a hallmark of the mammalian immune system—appears to come at the price of introduction and retention of significant numbers of nonfunctional genetic elements. In sharks and skates, on the other hand, nonfunctional elements are uncommon and probably are lost quickly from the genome.

As surviving representatives of a very ancient line, sharks, skates and their relations may be our only remaining link to the distant origins of *T* and *B* cell immunity. These fish offer a unique glimpse of a pivotal moment in the course of evolution. Through this window we may someday begin to see the elements that drove the evolution of a system that in different ways is as protective, if not more so, as the armor plates of the ancient placoderm.

If we are correctly reading the evolutionary record, several questions come to mind. Was it the relentless nature of the challenge from pathogens that led to relatively sudden, radical changes in the way that antibody genes are organized? Do these lessons from the prehistoric vertebrates and the profound differences seen in contemporary mammals suggest that the immune system is poised for quick change? This scenario may well be the case, forcing us to rethink our notions of evolutionary selection and adaptation. SA

MICHAEL SEXTON *All Children's Hospital*

HORNED SHARKS are among the most ancient creatures in which *T* cells, the agents of cellular immunity, have been conclusively identified.

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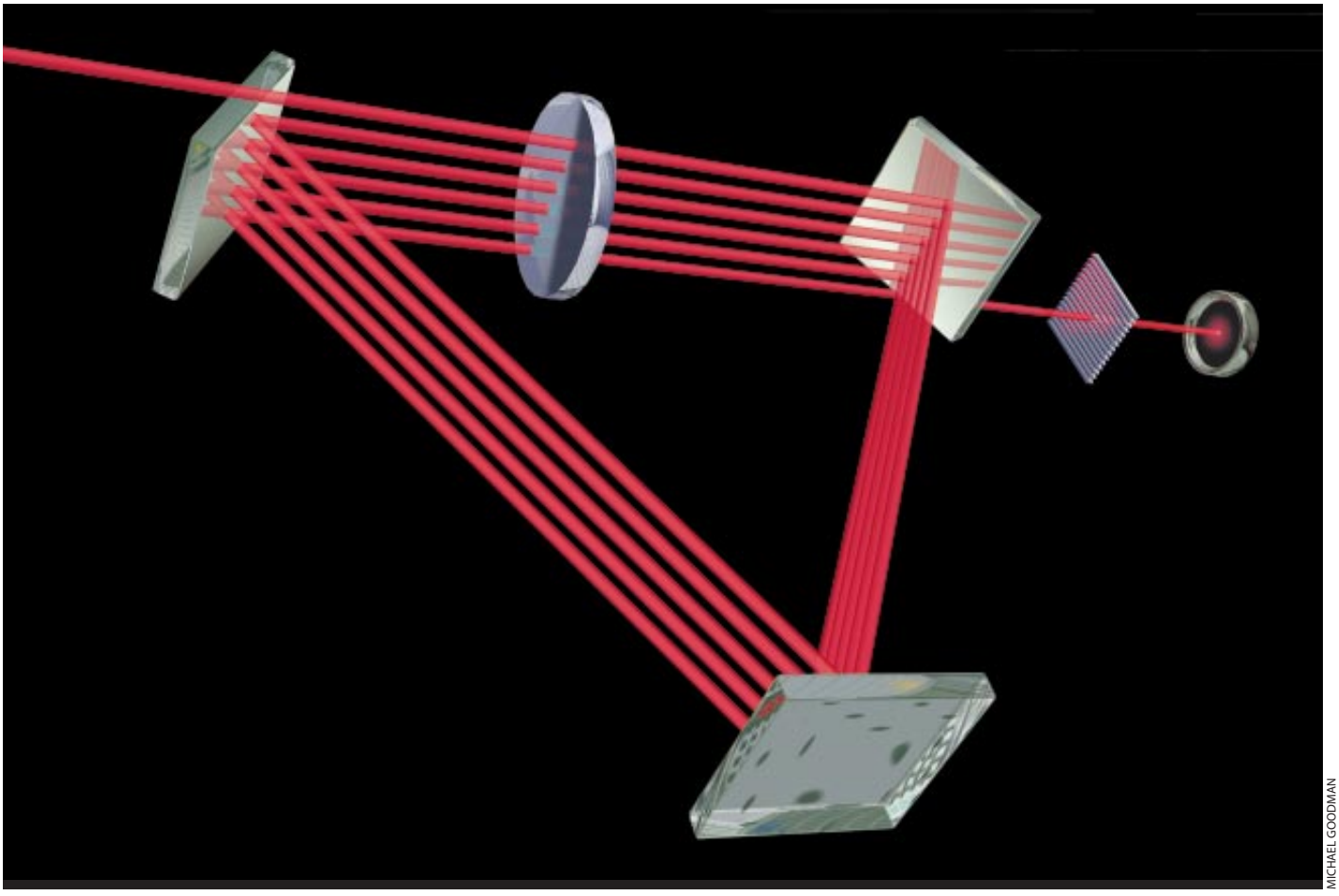
Further Reading

EVOLUTION OF THE IMMUNE SYSTEM. Louis DuPasquier in *Fundamental Immunology.* Third edition. Edited by William E. Paul. Raven Press, 1993.

HOW THE IMMUNE SYSTEM RECOGNIZES INVADERS. Charles A. Janeway, Jr., in *Scientific American,* Vol. 269, No. 3, pages 72–79; September 1993.

PHYLOGENETIC DIVERSIFICATION OF IMMUNOGLOBULIN GENES AND THE ANTIBODY REPERTOIRE. Gary W. Litman, Jonathan P. Rast, Michael J. Shamblott et al. in *Molecular Biology and Evolution,* Vol. 10, No. 1, pages 60–72; January 1993.

MOLECULAR EVOLUTION OF THE VERTEBRATE IMMUNE SYSTEM. Simona Bartl, David Baltimore and Irving L. Weissman in *Proceedings of the National Academy of Sciences,* Vol. 91, No. 23, pages 10769–10770; November 8, 1994.



MICHAEL GOODMAN

Quantum Seeing in the Dark

Quantum optics demonstrates the existence of interaction-free measurements: the detection of objects without light—or anything else—ever hitting them

by Paul Kwiat, Harald Weinfurter and Anton Zeilinger

In Greek mythology, the hero Perseus is faced with the unenviable task of fighting the dreaded Medusa. The snake-haired beast is so hideous that a mere glimpse of her immediately turns any unlucky observer to stone. In one version of the story, Perseus avoids this fate by cleverly using his shield to reflect Medusa's image back to the creature herself, turning *her* to stone. But what if Perseus did not have well-polished armor? He presumably would have been doomed. If he closed his eyes, he would have been unable to find his target. And the smallest peek would have allowed some bit of light striking Medusa to reflect into his eye; having thus "seen" the monster, he would have been finished.

In the world of physics, this predicament might be summed up by a seemingly innocuous, almost obvious claim made in 1962 by Nobelist Dennis Gabor, who invented holography. Gabor asserted, in essence, that no observation can be made with less than one photon—the basic particle, or quantum, of light—striking the observed object.

In the past several years, however, physicists in the increasingly bizarre field of quantum optics have learned that not only is this claim far from obvious, it is, in fact, incorrect. For we now know how to determine the presence of an object with essentially no photons having touched it.

Such interaction-free measurement seems to be a contradiction—if there is no interaction, how can there be a measurement? That is a reasonable conundrum in classical mechanics, the field of physics describing the motions of footballs, planets and other objects that are not too small. But quantum mechanics—the science of electrons, photons and

LASER BEAM following a spiraling path that leads to a photon detector can illustrate the so-called quantum Zeno effect, an element of interaction-free measurements.

other particles in the atomic realm—says otherwise. Interaction-free measurements can indeed be achieved by quantum mechanics and clever experimental designs. If Perseus had been armed with a knowledge of quantum physics, he could have devised a way to "see" Medusa without any light actually striking the Gorgon and entering his eye. He could have looked without looking.

Such quantum prestidigitation offers many ideas for building detection devices that could have use in the real world. Perhaps even more interesting are the mind-boggling philosophical implications. Those applications and implications are best understood at the level of thought experiments: streamlined analyses that contain all the essential features of real experiments but without the practical complications.

So, as a thought experiment, consider a variation of a shell game, which employs two shells and a pebble hidden under one of them. The pebble, however, is special: it will turn to dust if exposed to any light. The player attempts to determine where the hidden pebble is but without exposing it to light or disturbing it in any way. If the pebble turns to dust, the player loses the game.

Initially, this task may seem impossible, but we quickly see that as long as the player is willing to be successful half the time, then an easy strategy is to lift the shell he hopes does not contain the pebble. If he is right, then he knows the pebble lies under the other shell, even though he has not seen it. Winning with this strategy, of course, amounts to nothing more than a lucky guess.

Next, we take our modification one step further, seemingly simplifying the game but in actuality making it impossible for a player limited to the realm of classical physics to win. We have only one shell, and a random chance that a pebble may or may not be under it. The player's goal is to say if a pebble is present, again without exposing it to light.

Assume there is a pebble under the shell. If the player does not look under the shell, then he gains no information. If he looks, then he knows the pebble was there, except that he has necessarily exposed it to light and so finds only a pile of dust. The player may try to dim the light so that there is very little chance of it hitting the pebble. For the player to see the pebble, however, at least one photon must have hit it, by definition, implying that he has lost.

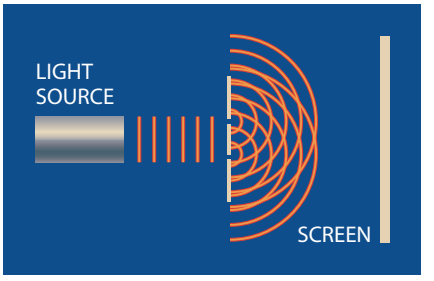
Elitzur, Vaidman and the Bomb

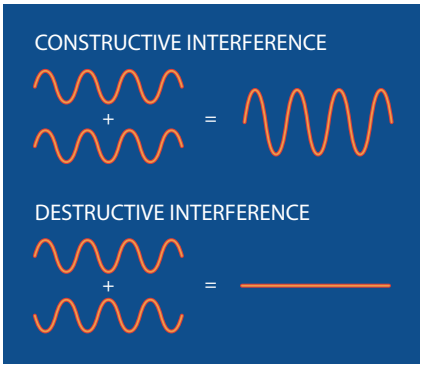
To make the game more dramatic, Avshalom C. Elitzur and Lev Vaidman, two physicists at Tel Aviv University, considered the pebble to be a "superbomb" that would explode if just a single photon hit it. The problem then became: determine if a pebble bomb sits under a shell, but don't set it off.

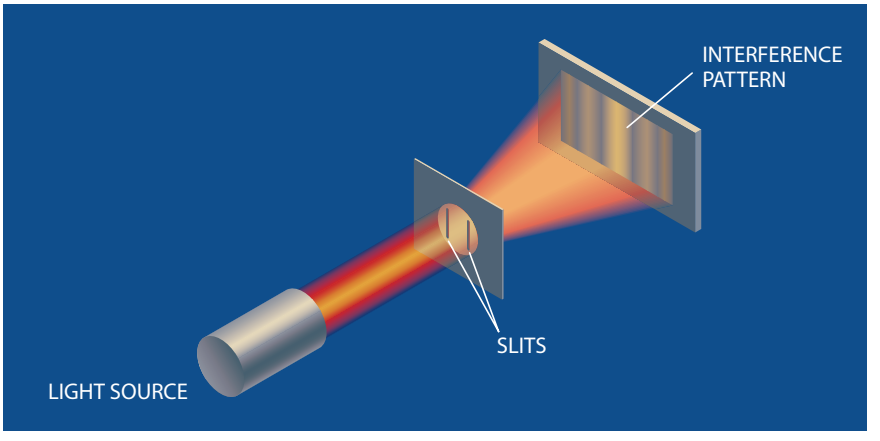
Elitzur and Vaidman were the first researchers to offer any solution to the problem. Their answer works, at best, half the time. Nevertheless, it was essential for demonstrating any hope at all of winning the game.

Their method exploits the fundamental nature of light. We have already mentioned that light consists of photons, calling to mind a particlelike quality. But light can display distinctly wavelike characteristics—notably a phenomenon called interference. Interference is the way two waves add up with each other. For example, in the well-known double-slit experiment, light is directed through two slits, one above the other, to a faraway screen. The screen then displays bright and dark fringes [*see illustration at right*]. The bright fringes correspond to places where the crests and troughs of the light waves from one slit add constructively to the crests and troughs of waves from the other slit. The dark bands correspond to destructive interference, where the crests from one slit cancel the troughs from the other. Another way of expressing this concept is to say that the bright fringes correspond to areas on the screen that have a high

INTERFERENCE occurs when a laser is shone through two slits, which generate concentric light waves that interfere with each other (*top*).The waves can add constructively or destructively (*middle*), yielding the characteristic interference pattern of bright and dark bands (*bottom*).







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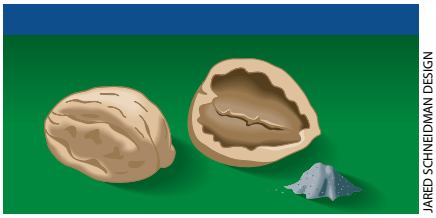

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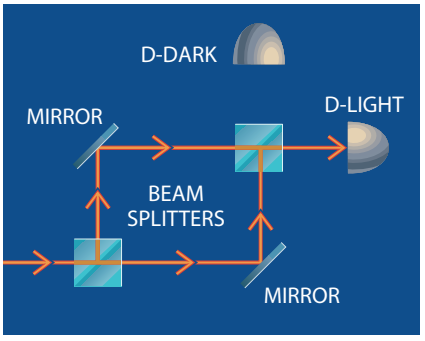
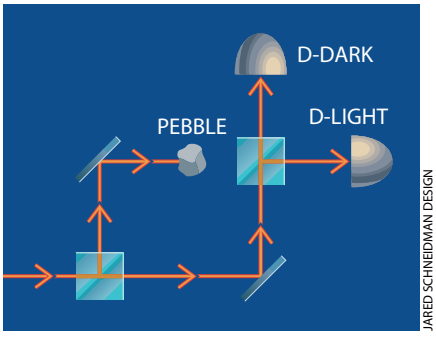
PHYSICIST'S SHELL GAME is a thought experiment that illustrates the potential of interaction-free measurements. A special pebble may be under a shell; if any light touches the pebble, it turns to dust. How can one determine which shell hides the pebble?

ELITZUR-VAIDMAN EXPERIMENT gives a photon a choice of two paths to follow. The optical elements are arranged (*top*) so that photons always go to detector D-light (corresponding to constructive interference) but never to D-dark (corresponding to destructive interference). The presence of a pebble in one path, however, occasionally sends a photon to D-dark (*bottom*), indicating that an interaction-free measurement has occurred.





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probability of photon hits, and the dark fringes to a low probability of hits.

According to the rules of quantum mechanics, interference occurs whenever there is more than one possible way for a given outcome to happen, and the ways are not distinguishable by any means (this is a more general definition of interference than is often given in textbooks). In the double-slit experiment, light can reach the screen in two possible ways (from the upper or the lower slit), and no effort is made to determine which photons pass through which slit. If we somehow could determine which slit a photon passed through, there would be no interference, and the photon could end up anywhere on the screen. As a result, no fringe pattern would emerge. Simply put, without two indistinguishable paths, interference cannot occur.

As the initial setup for their hypothetical measuring system, Elitzur and Vaidman start with an interferometer—a device consisting of two mirrors and two beam splitters. Light entering the interferometer hits a beam splitter, which sends the light along two optical paths: an upper and a lower one. The paths recombine at the second beam splitter, which sends the light to one of two photon detectors [*see illustration at left*]. Thus, the interferometer gives each photon two possible paths between the light source and a detector.

If the lengths of both paths through the interferometer are adjusted to be exactly equal, the setup effectively becomes the double-slit experiment. The main difference is that the photon detectors take the place of the screen that shows bright and dark fringes. One detector is positioned so that it will detect only the equivalent of the bright fringes of an interference pattern (call that detector D-light). The other one records the dark fringes—in other words, no photon ever reaches it (call that detector D-dark).

Pebble in the Path

What happens if a pebble is placed into one of the paths, say, the upper one? Assuming that the first beam splitter acts randomly, then with 50 percent likelihood, the photon takes the upper path, hits the pebble (or explodes the superbomb) and never gets to the second beam splitter.

If the photon takes the lower path, it does not hit the pebble. Moreover, interference no longer occurs at the second beam splitter, for the photon has only one way to reach it. Therefore, the photon makes another random choice at the second beam splitter. It may be reflected and hit detector D-light; this outcome gives no information, because it would have happened anyway if the pebble had not been there. But the photon may also go to detector D-dark. If that occurs, we know with certainty that there was an object in one path of the interferometer, for if there were not, detector D-dark could not have fired. And because we sent only a single photon, and it showed up at D-dark, it could not have touched the pebble. Somehow we have managed to make an interaction-free measurement—we have determined the presence of the pebble without interacting with it.

Although the scheme works only some of the time, we emphasize here that when the scheme works, it works completely. The underlying quantum-mechanical magic in this feat is that everything, including light, has a dual nature—both particle and wave. When the interferometer is empty, the light behaves as a wave. It can reach the detectors along both paths simultaneously, which leads to interference. When the pebble is in place, the light behaves as an indivisible particle and follows only one of the paths. The mere presence of the pebble removes the possibility of interference, even though the photon need not have interacted with it.

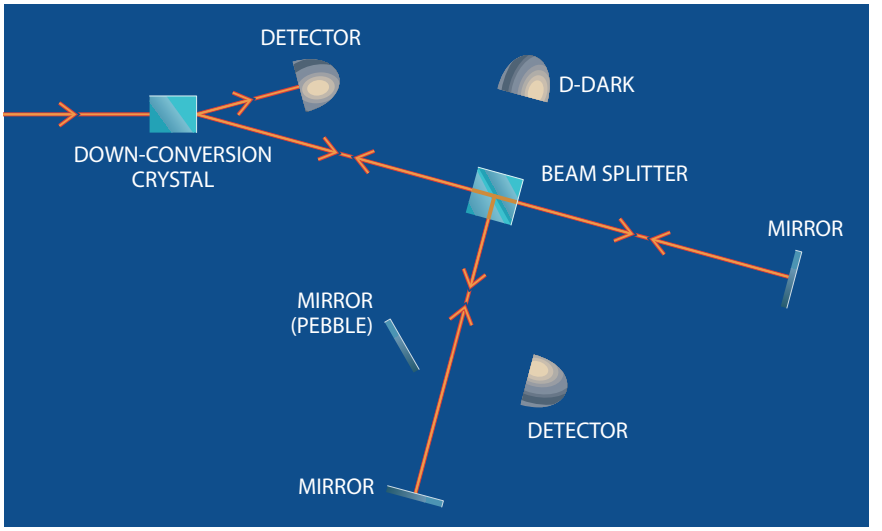
To demonstrate Elitzur and Vaidman's idea, we and Thomas Herzog, now at the University of Geneva, performed a real version of their thought experiment two years ago and thus demonstrated that interaction-free devices can be built. The source of single photons was a special nonlinear optical crystal. When ultraviolet photons from a laser were directed through the crystal, sometimes they were "down-converted" into two daughter photons of lower energy that traveled off at about 30 degrees from each other. By detecting one of these photons, we were absolutely certain of the existence of its sister, which we then directed into our experiment.

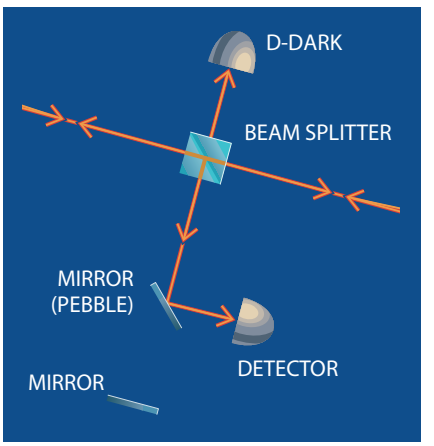
That photon went into an interferometer (for simplicity, we used a slightly different type of interferometer than the one Elitzur and Vaidman proposed). The mirrors and beam splitter were aligned so that nearly all the photons left by the same way they came in (the analogue of going to detector D-light in the Elitzur-Vaidman example or, in the double-slit experiment, of going to a bright

fringe). In the absence of the pebble, the chance of a photon going to detector D-dark was very small because of destructive interference (the analogue of the dark fringes in the double-slit experiment) [*see illustration at right*].

But introducing a pebble into one of the pathways changed the odds. The pebble was a small mirror that directed the light path to another detector (D-pebble). We then found that about half of the time, D-pebble registered the photon, whereas about one fourth of the time D-dark did (the rest of the time the photon left the interferometer the same way it came in, giving no information). The firing of D-dark was the interaction-free detection of the pebble.

In a simple extension of the scheme, we reduced the reflectivity of the beam splitter, which lessened the chance that the photons would be reflected onto the path containing the mirror to D-pebble. What we found, in agreement with theoretical prediction, was that the probabilities of the photons going to D-pebble and going to D-dark became more and more equal. That is, by using a barely reflective beam splitter, up to half the measurements in the Elitzur-Vaidman scheme can be made interaction-free (instances in which the photons leave the interferometer the same way they came in are not counted as measurements).





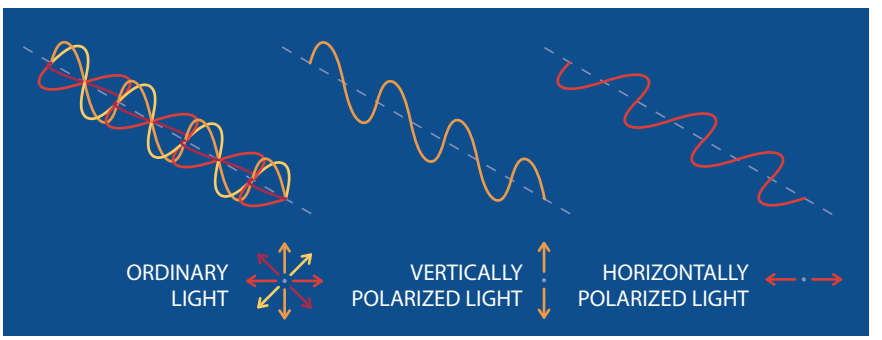
DEMONSTRATION of the Elitzur-Vaidman scheme uses light from a down-conversion crystal, which enters a beam splitter, bounces off two mirrors and interferes with itself back at the beam splitter (*top*). No light reaches D-dark (corresponding to destructive interference; constructive interference is in the direction from which the photon first came). If a mirror "pebble" is inserted into a light path, no interference occurs at the beam splitter; D-dark sometimes receives photons (*bottom*).

The Quantum Zeno Effect

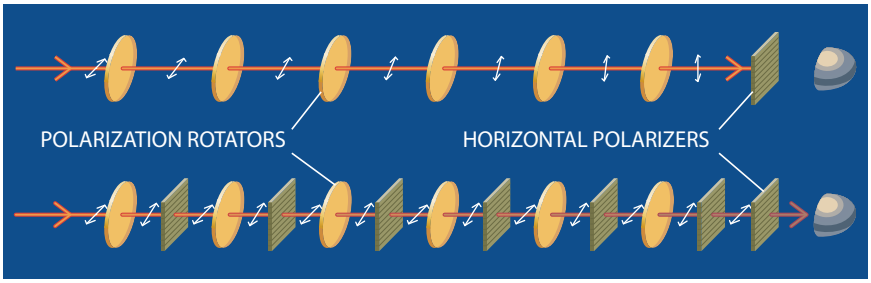
The question immediately arose: Is 50 percent the best we can do? Considerable, often heated, argument ensued among us, for no design change that would improve the odds was evident. In January 1994, however, Mark A. Kasevich of Stanford University came to visit us at Innsbruck for a month, and during this stay he put us on to a solution that, if realized, makes it possible to detect objects in an interaction-free way almost every time. It was not the first instance, and hopefully not the last, in which quantum optimism triumphed over quantum pessimism.

The new technique is more or less an application of another strange quantum phenomenon, first discussed in detail in 1977 by Baidyanath Misra, now at the University of Brussels, and E. C. George Sudarshan of the University of Texas at Austin. Basically, a quantum system can be trapped in its initial state, even though it would evolve to some other state if left on its own. The possibility arises because of the unusual effect that measurements can have on quantum systems. The phenomenon is called the quantum Zeno effect, because it resembles the famous paradox raised by the Greek philosopher Zeno, who denied the possibility of motion to an arrow in flight because it appears "frozen" at each instant of its flight. It is also known as the watched-pot effect, a reference to the aphorism about boiling water. We all know that the mere act of watching the pot should not (and does not) have any effect on the time it takes to boil the water. In quantum mechanics, however, such an effect actually exists—the measurement affects the outcome (the principle is called the projection postulate).

Kasevich essentially reinvented the simplest example of this effect, which was first devised in 1980 by Asher Peres of the Technion-Israel Institute of Technology. The example exploits yet another characteristic of light: polarization. Polarization is the direction in which light waves oscillate—up and down for vertically polarized light, side to side for horizontally polarized light. These oscillations are at right angles to the light's direction of propagation. Light from the sun and other typical sources generally vibrates in all directions, but



POLARIZATION refers to the vibrations of light waves as they move through space.



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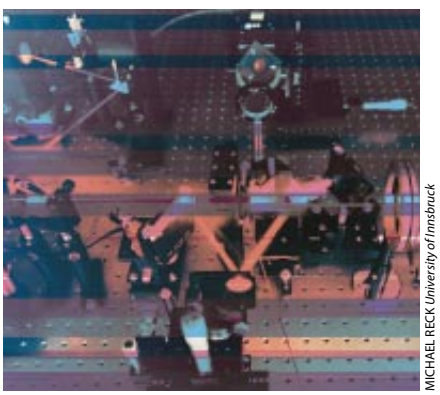
QUANTUM ZENO EFFECT can be demonstrated with devices that rotate polarization 15 degrees. After passing through six such rotators, the photon changes from a horizontal polarization to a vertical one and so is absorbed by the polarizer (*top row*). Interspersing a polarizer after each rotator, however, keeps the polarization from turning (*bottom row*).

EXPERIMENTAL REALIZATION of the quantum Zeno effect was accomplished by making the photon follow a spiral-staircase path, so that it traversed the polarization rotator six times. Inserting a polarizer next to the rotator suppressed the rotation of the photon's polarization.



MICHAEL RECK *University of Innsbruck*

here we are concerned mostly with vertical and horizontal polarizations.

Consider a photon directed through a series of, say, six devices that each slightly rotates the polarization of light so that a horizontally polarized photon ends up vertically polarized [*see illustration above*]. These rotators might be glass cells containing sugar water, for example. At the end of the journey through the rotators, the photon comes to a polarizer, a device that transmits photons with one kind of polarization but absorbs photons with perpendicular polarization. In this thought experiment, the polarizer transmits only horizontally polarized light to a detector.

We will start with a photon horizontally polarized, and each rotator will turn the polarization by 15 degrees. It is clear, then, that the photon will never get to the detector, for after passing through all the cells, its polarization will have turned 90 degrees (15 degrees for each of the six rotators) so that it becomes vertical. The polarizer absorbs the photon. This stepwise rotation of the polarization is the quantum evolution that we wish to inhibit.

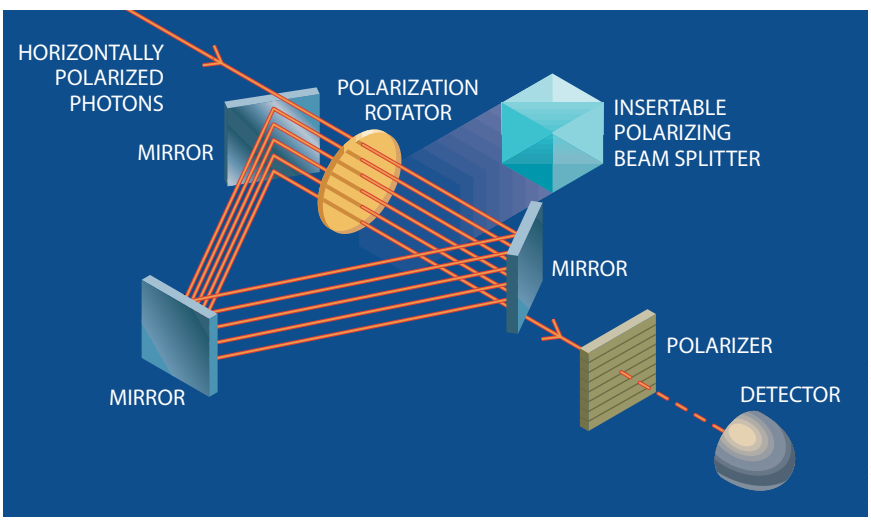
Interspersing a horizontal polarizer between each polarization rotator does the trick. Here's why: After the first rotator, the light is not too much turned from the horizontal. This means that the chance that the photon is absorbed in the first horizontal polarizer is quite small, only 6.7 percent. (Mathematically, it is given by the square of the sine of the turning angle.)

If the photon is not absorbed in the first polarizer, it is again in a state of horizontal polarization—it must be, because that is the only possible state for light that has passed a horizontal polarizer. At the second rotator, the polarization is once again turned 15 degrees from the horizontal, and at the second polarizer, it has the same small chance of being absorbed; otherwise, it is again transmitted in a state of horizontal polarization. The process repeats until the photon comes to the final polarizer.

An incident photon has a two-thirds chance of being transmitted through all six inserted polarizers and making it to the detector; the probability is given by the relation $(\cos^2(15 \text{ degrees}))^6$. Yet as we increase the number of stages, decreasing the polarization-rotation angle at each stage accordingly (that is, 90 degrees divided by the number of stages), the probability of transmitting the photon increases. For 20 stages, the probability that the photon reaches the detector is nearly 90 percent. If we could make a system with 2,500 stages, the probability of the photon being absorbed by one of the polarizers would be just one in 1,000. And if it were possible to have an infinite number of stages, the photon would always get through. Thus, we would have completely inhibited the evolution of the rotation.

To realize the quantum Zeno effect, we used the same nonlinear crystal as before to prepare a single photon. Instead of using six rotators and six polarizers, we used just one of each; to achieve the same effect, we forced the photon through them six times, employing three mirrors as a kind of spiral staircase [*see illustration at left*]. In the absence of the polarizer, the photon exiting the staircase is always found to be vertically polarized. When the polarizer is present, we found that the photon was horizontally polarized (unless the polarizer blocked it). These cases occurred roughly two thirds of the time for our six-cycle experiment, as expected from our thought-experiment analysis.

Next we set out to make an interaction-free measurement—that is, to detect an opaque object without any photons



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hitting it—in a highly efficient manner. We devised a system that was somewhat of a hybrid between the Zeno example and the original Elitzur-Vaidman method. A horizontally polarized photon is let into the system and makes a few cycles (say, six again) before leaving. (For this purpose, one needs a mirror that can be "switched" on and off very quickly; fortunately, such mirrors, which are actually switchable interference devices, have already been developed for pulsed lasers.) At one end of the system is a polarization rotator, which turns the photon's polarization by 15 degrees in each cycle. The other end contains a polarization interferometer. It consists of a polarizing beam splitter and two equal-length interferometer paths with mirrors at the ends [*see illustration at right*].

At the polarizing beam splitter, all horizontally polarized light is transmitted, and all vertically polarized light is reflected; in essence, the transmission and reflection choices are analogous to the two paths in the double-slit experiment. In the absence of an object in the polarization interferometer, light is split at the beam splitter according to its polarization, reflects off the mirrors in each path and is recombined by the beam splitter. As a result, the photon is in exactly the same state as before it entered the interferometer (that is, with a polarization turned 15 degrees toward the vertical). So, after six cycles, the polarization ends up rotated to vertical.

The situation changes when an opaque object is placed in the vertical polarization path of the interferometer. This situation is analogous to having the six polarizers inserted in the quantum Zeno effect experiment. So in the first cycle, the chance that the photon—the polarization of which has been turned only 15 degrees from horizontal—enters the vertical-polarization path (and is then absorbed by the object) is very small (6.7 percent, as in the Zeno thought experiment). If this absorption does not happen, the photon must have entered the horizontal path instead, and its polarization is reset to be purely horizontal.

Just as in the Zeno example, the whole process repeats at each cycle, until finally, after six cycles, the bottom mirror is switched off, and the photon leaves the system. Measuring the photon's polarization, we find it still to be horizontal, implying that a blocker must reside in the interferometer. Otherwise, the photon would have been vertically polarized when it left. And by using more cycles, we can make the probability that the photon is absorbed by the object as small as we like. Preliminary results from new experiments at Los Alamos National Laboratory have demonstrated that up to 70 percent of measurements could be interaction-free. We soon hope to increase that figure to 85 percent.

Applying Quantum Magic

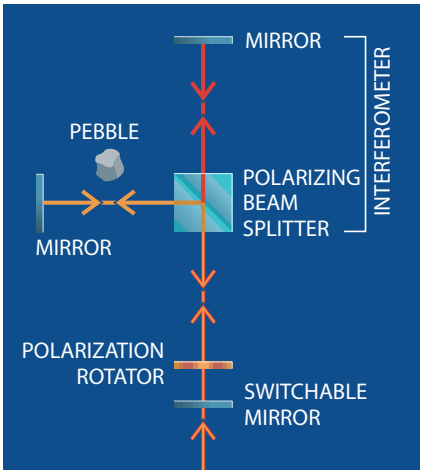
What good is all this quantum conjuring? We feel that the situation resembles that of the early years of the laser, when scientists knew it to be an ideal solution to many unknown problems. The new method of interaction-free measurement could be used, for instance, as a rather unusual means of photography, in which an object is imaged without being exposed to light.

The "photography" process would work in the following way: Instead of sending in one photon, we would send in many photons, one per pixel, and perform interaction-free measurements with them. In those regions where the object did not block the light path of the interferometer, the horizontal polarization of the photons would undergo the expected stepwise rotation to vertical. In those regions where the object blocked the light path, a few of the photons would be absorbed; the rest would have their polarizations trapped in the horizontal state. Finally, we would take a picture of the photons through a polarizing filter after they had made the requisite number of cycles.

If the filter were horizontally aligned, we would obtain an image of the object; if vertically aligned, we would obtain the negative. In any case, the picture is made by photons that have never touched the object. These techniques can also work with a semitransparent object and may possibly be generalized to find out an object's color (although these goals would be more difficult).

A variation of such imaging could someday conceivably prove valuable in medicine—for instance, as a means to image living cells. Imagine being able to x-ray someone without exposing them to many penetrating x-rays. Such imaging would therefore pose less risk to patients than standard x-rays. (Practically speaking, such x-ray photography is unlikely to be realized, considering the difficulty of obtaining optical elements for this wavelength of light.)

A candidate for more immediate application is the imaging of the clouds of



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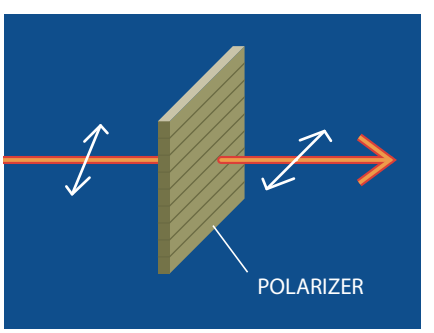
EFFICIENT MEASUREMENTS that are interaction-free combine the setups of the quantum Zeno effect and the Elitzur-Vaidman scheme. The photon enters below the switchable mirror and follows the optical paths six times before being allowed to exit through the mirror. Its final polarization will still be horizontal if there is a pebble in one light path; otherwise, it will have rotated to a vertical polarization.

The Projection Postulate

The postulate states that for any measurement made on a quantum system only certain answers are possible. Moreover, after the measurement, the quantum system is in a state determined by the obtained results. So a photon that has passed through a horizontal polarizer is necessarily horizontally polarized, even if it were originally polarized at a nearly vertical angle (the polarizer eliminates the vertical component of the polarization). The probability of transmission in this case, though, would be low.



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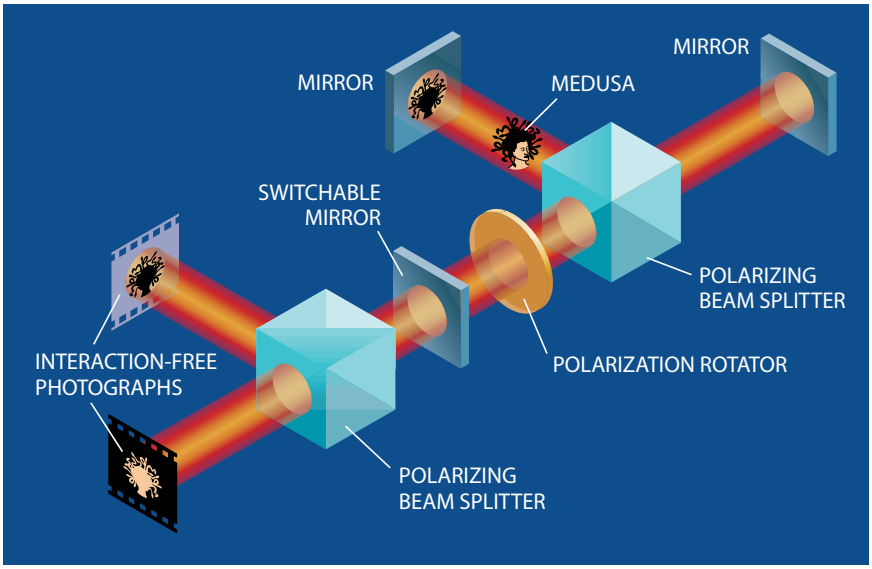

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PHOTOGRAPHY can also be done with interaction-free techniques. In this way, the object—a "Medusa" that must not be viewed directly—will absorb very few photons.

ultracold atoms recently produced in various laboratories. The coldest of these exhibit Bose-Einstein condensation, a new type of quantum state in which many atoms act collectively as one entity. In such a cloud every atom is so cold—that is, moving so slowly—that a single photon can knock an atom out of the cloud. Initially, no way existed to get an image of the condensate without destroying the cloud. Interaction-free measurement methods might be one way to image such a collection of atoms.

Besides imaging quantum objects, interaction-free procedures could also make certain kinds of them. Namely, the techniques could extend the creation of "Schrödinger's cat," a much loved theoretical entity in quantum mechanics. The quantum feline is prepared so that it exists in two states at once: it is both alive and dead at the same time—a superposition of two states. Earlier this year workers at the National Institute of Standards and Technology managed to create a preliminary kind of Schrödinger's cat—a "kitten"—with a beryllium ion. They used a combination of lasers and electromagnetic fields to make the ion exist simultaneously in two places spaced 83 nanometers apart—a vast distance on the quantum scale.

If such an ion were interrogated with the interaction-free methods, the interrogating photon would also be placed in a superposition. It could end up being horizontally and vertically polarized at the same time. In fact, the kind of experimental setup discussed above should be able to place a group of, say, 20 photons in the same superposition. Every photon would "know" that it has the same polarization as all the others, but none would know its own polarization. They would remain in this superposition until a measurement revealed them to be all horizontally polarized or all vertically polarized. The sizable bunch of photons stuck in this peculiar condition would show that quantum effects can be manifested at the macroscopic scale.

Lying beyond the scope of everyday experience, the notion of interaction-free measurements seems weird, if not downright nonsensical. Perhaps it would seem less strange if one kept in mind that quantum mechanics operates in the realm of potentialities. It is because there *could* have been an interaction that we can prevent one from occurring.

If that does not help, take comfort in the fact that, over the years, even physicists have had a hard time accepting the strangeness of the quantum world. The underlying keys to these quantum feats of magic—the complementary, wave-and-particle aspect of light and the nature of quantum measurements—have been known since 1930. Only recently have physicists started to apply these ideas to uncover new phenomena in quantum information processing, including the ability to see in the dark. SA

The Authors

PAUL KWIAT, HARALD WEINFURTER and ANTON ZEILINGER freely interacted with one another at the University of Innsbruck. Kwiat, now a J. R. Oppenheimer Fellow at Los Alamos National Laboratory, earned his Ph.D. from the University of California, Berkeley. He is a serious student of aikido and is trying to become a tolerable flautist. Weinfurter received his Ph.D. from the Technical University of Vienna and held a postdoctoral position at the Hahn-Meitner Institute in Berlin. He currently enjoys all the benefits and comforts of a fellowship from the Austrian Academy of Science as well as the relaxing lifestyle in Innsbruck and its surrounds. A member of the Austrian Academy of Sciences, Zeilinger earned his doctorate at the University of Vienna and has held numerous appointments worldwide. In his little free time, he plays the double bass and collects antique maps, particularly of the Austro-Hungarian empire.

Further Reading

QED: The Strange Theory of Light and Matter. Richard P. Feynman. Princeton University Press, 1985.

Quantum Mechanical Interaction-Free Measurements. Avshalom C. Elitzur and Lev Vaidman in *Foundations of Physics,* Vol. 23, No. 7, pages 987–997; July 1993.

Interaction-Free Measurement. P. G. Kwiat, H. Weinfurter, T. Herzog, A. Zeilinger and M. A. Kasevich in *Physical Review Letters,* Vol. 74, No. 24, pages 4763–4766; June 12, 1995.

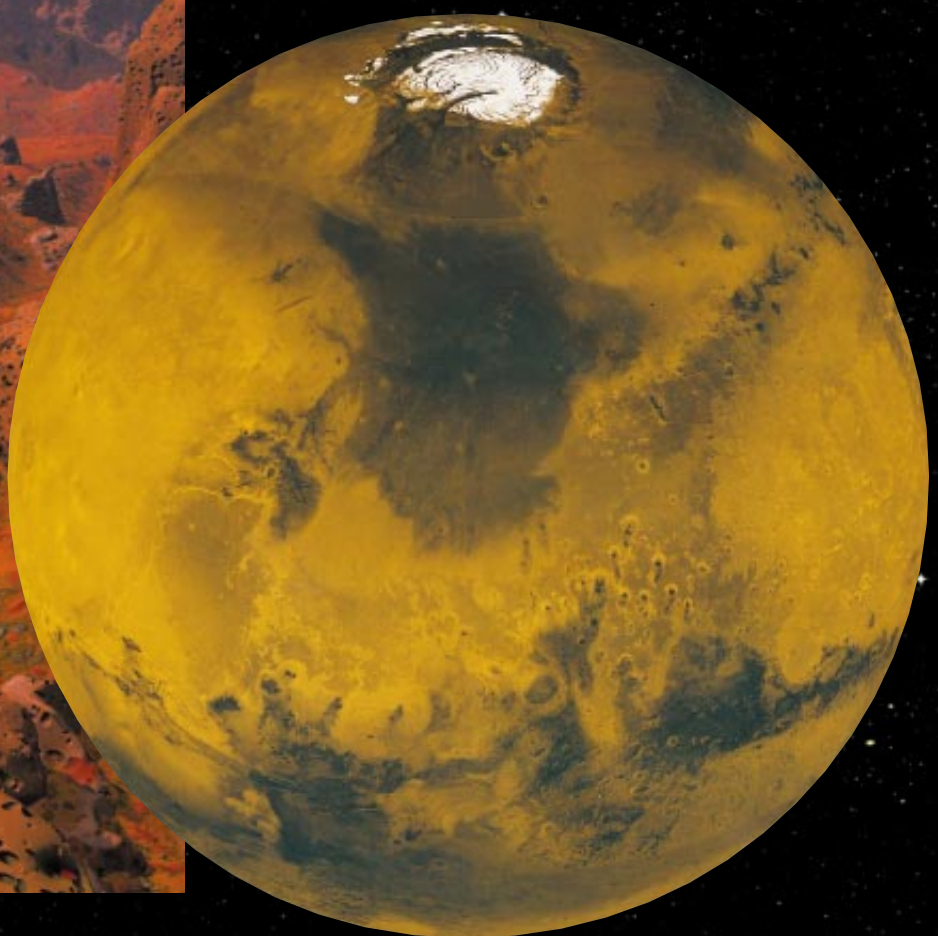
Discussions on experiments for interaction-free measurements can be found on the World Wide Web at http://info.uibk.ac.at/c/c7/c704/qo/photon/#Inter and at http://p23.lanl. gov/Quantum/kwiat/ifm-folder/ifmtext.htm

Global Climatic Change on Mars

Today a frozen world, Mars at one time may have had more temperate conditions, with flowing rivers, thawing seas, melting glaciers and, perhaps, abundant life

by Jeffrey S. Kargel and Robert G. Strom

To those of us who have spent a good part of our lives studying Mars, the newly discovered evidence that extraterrestrial microbes may have once lived in a rock cast off from that planet stirs feelings of awe. But the recent claim also evokes thoughts of Percival Lowell, a well-known American astronomer of the early 20th century, who turned his telescope toward Mars and saw a vast network of canals bordered by vegetation. His suggestion that Mars harbored such lushness had many people believing that the surface of the planet enjoyed conditions not so different from those on Earth. But in the 1960s three *Mariner* spacecraft flew by Mars and revealed the true harshness of its environment.



MARS TODAY presents a parched surface, as shown in this global mosaic of images obtained by orbiting space probes (*below*). The meager amount of water carried in the thin Martian atmosphere often condenses as frost, particularly near the north pole (*white area*), where it forms a permanent water-ice cap. (The southern polar region, where temperatures are colder, appears to be largely covered with carbon dioxide ice.) A typical Martian vista (*left*) would thus show no signs of water, except perhaps in a few patches of frost or in the shape of valleys cut by past floods.

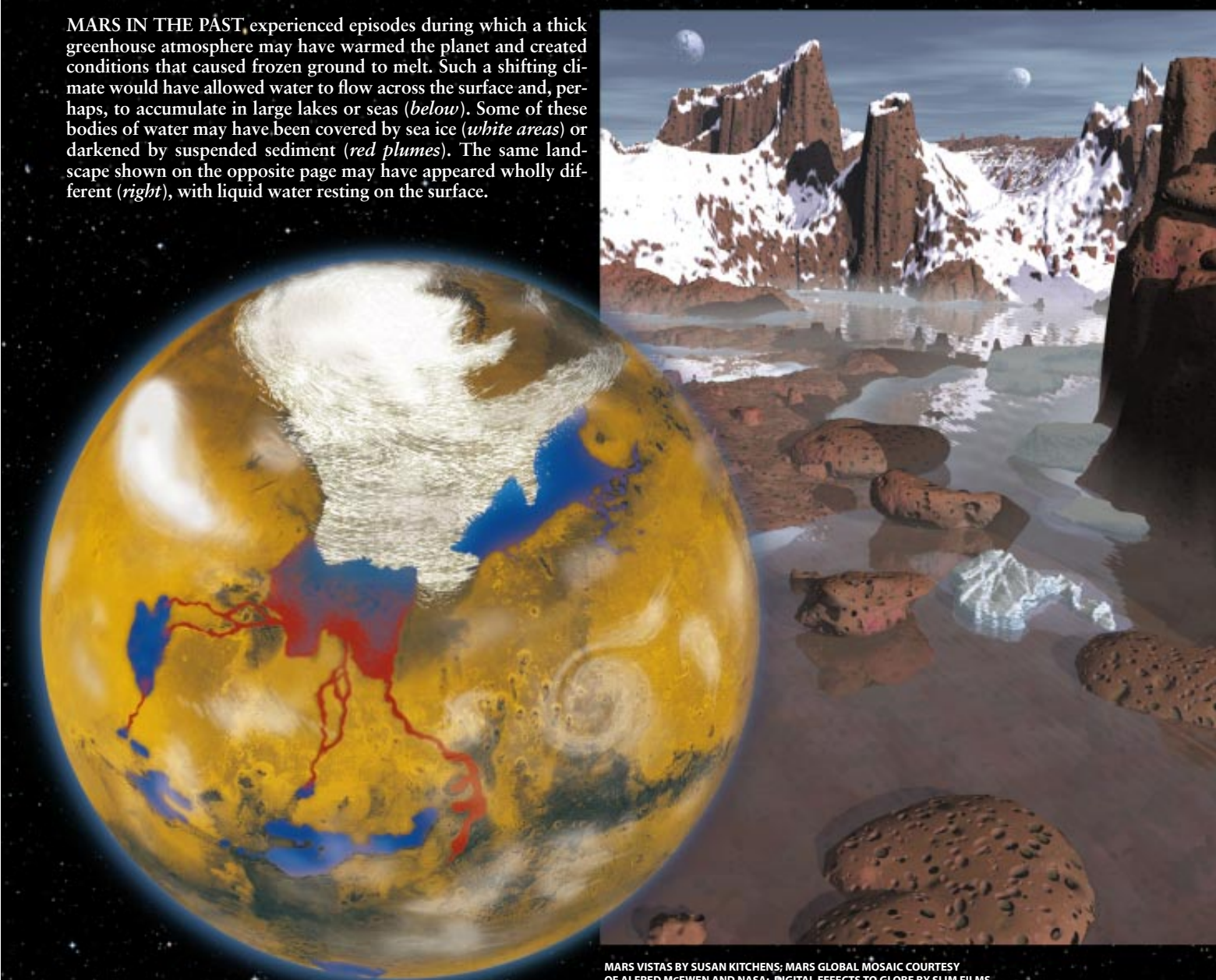
Observations from those unmanned probes indicated that Mars has an atmosphere that is thin, cold and dry. This tenuous shroud, composed almost entirely of carbon dioxide, provides less than 1 percent of the surface pressure found at sea level on Earth. The images radioed back during those first fleeting encounters three decades ago were fuzzy and few in number, but they were decidedly more accurate than Lowell's telescopic views. The *Mariner* cameras showed no canals, no water and no vegetation. They presented only a moonlike surface covered with craters. Sober scientists quickly dismissed any notion that the climate on Mars was sufficiently warm or wet to sustain life.

With its distant orbit—50 percent farther from the sun than Earth—and slim atmospheric blanket, Mars experiences frigid weather conditions. Surface temperatures typically average about –60 degrees Celsius (–76 degrees Fahrenheit) at the equator and can dip to –123 degrees C near the poles. Only the midday sun at tropical latitudes is warm enough to thaw ice on occasion, but any liquid water formed in this way would evaporate almost instantly because of the low atmospheric pressure.

Although the atmosphere holds a small amount of water, and water-ice clouds sometimes develop, most Martian weather involves blowing dust or carbon dioxide. Each winter, for example, a blizzard of frozen carbon dioxide rages over one pole, and a few meters of this dry-ice snow accumulate as previously frozen carbon dioxide evaporates from the opposite polar cap. Yet even on the summer pole, where the sun remains in the sky all day long, temperatures never warm enough to melt frozen water.

Despite the abundant evidence for cold, dry conditions, the impression of Mars as a perpetually freeze-dried world has been steadily giving way since the *Mariner* probes first reported their findings. Planetary scientists, who continue to examine the voluminous data from both the Mariner and the later Viking missions of the 1970s, now realize that Mars has had a complex climatic history—one that was perhaps punctuated with many relatively warm episodes. At certain times, huge volumes of water flowed freely across the surface of the planet. Before considering what this as-

MARS IN THE PAST experienced episodes during which a thick greenhouse atmosphere may have warmed the planet and created conditions that caused frozen ground to melt. Such a shifting climate would have allowed water to flow across the surface and, perhaps, to accumulate in large lakes or seas (*below*). Some of these bodies of water may have been covered by sea ice (*white areas*) or darkened by suspended sediment (*red plumes*). The same landscape shown on the opposite page may have appeared wholly different (*right*), with liquid water resting on the surface.



MARS VISTAS BY SUSAN KITCHENS; MARS GLOBAL MOSAIC COURTESY OF ALFRED MCEWEN AND NASA; DIGITAL EFFECTS TO GLOBE BY SLIM FILMS

tonishing fact means for the possibility of life evolving on Mars or the strategy for the next round of Martian exploration (which is just now getting under way; see box on page 86), it is instructive to review how this reversal in the way Mars is perceived came about.

Muddy Recollections

Scrutinizing the *Mariner* and *Viking* images obtained from orbit, planetary scientists soon noticed that most old Martian craters (unlike lunar ones) are eroded and that features resembling mudflows occur around almost every large, young crater on Mars. Such muddy "ejecta" probably represent the frozen remnants of a cataclysmic moment in the past when an asteroid or comet collided with the Martian surface, melting a patch of icy permafrost (where water-saturated ground had been frozen) and excavating a large hole that tapped a zone containing liquid water deep underground. By the late 1970s planetologists concluded that a considerable amount of underground ice and water has been present below the Martian surface throughout much of the history of the planet.

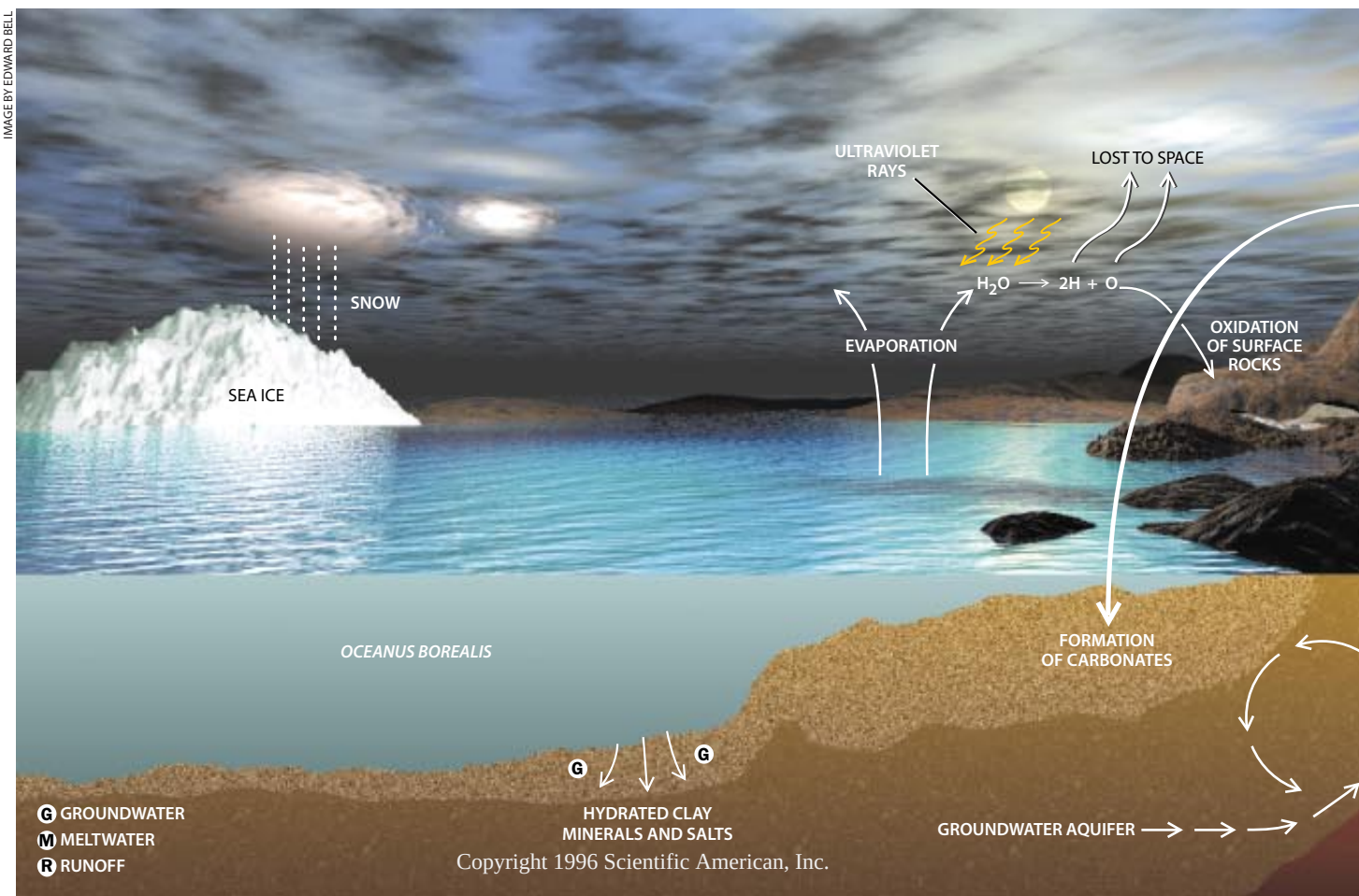
Yet not all Martian craters have these muddy flows surrounding them. Smaller craters appear more like their counterparts on the moon, with just streaks of dry ejecta scattered around them. Near the equator of Mars, only craters greater than about four kilometers in diameter display muddy ejecta, but closer to the Martian poles, craters as small as one kilometer across also have relic mudflows. This dependence on latitude arises because the ice-free, surficial layer varies in thickness. This layer extends deeper near the equator (to about 800 meters) than near the poles because the relative warmth of the Martian tropics purges much of the subsurface of frozen water. Hence, near the equator only the impact of bigger objects (that is, those that leave relatively large craters) will burrow down through the upper layer to heat the underlying icy permafrost and release a torrent of mud.

Researchers have since found other indications that a thick substratum of frozen ground exists on Mars. They have also identified evidence that ice once formed on the surface, where it appears to have created characteristic glacial landscapes. These features include bouldery ridges of sediment left by melting glaciers at their margins and meandering lines of sand and gravel deposited beneath glaciers by streams running under the ice (so-called eskers).

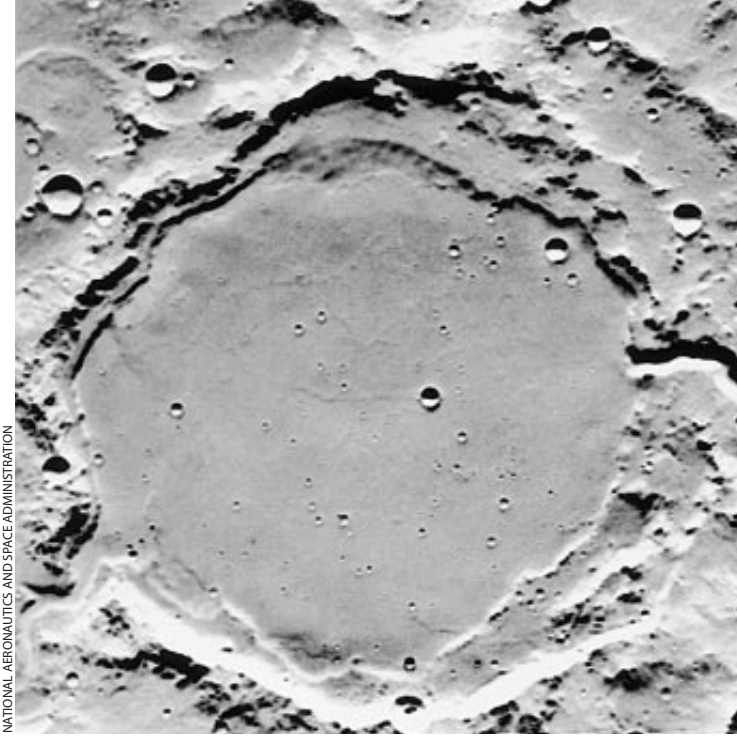
Many telltale landforms on Mars resemble frosty sites on Earth. For example, the pitted terrain on Mars corresponds to an earthly equivalent called thermokarst, which forms when the ice contained at shallow levels melts and the ground collapses. The apron-shaped lobes of rocky debris seen on the flanks of some Martian mountains might be rubble-covered glaciers. Or, more likely, they represent "rock glaciers," like the ones that form within the Alaska Range and in the Antarctic Dry Valleys on

WATER CYCLING during past wet episodes on Mars would have had many components. A thick atmosphere most likely carried a substantial amount of water evaporated from lakes and seas. That water vapor would, in turn, condense into clouds and eventually precipitate. Rain formed in this way would have created surface runoff, and much of this water would have percolated into the ground. Snowfalls might have accumulated to form glaciers, which in turn would have discharged their meltwaters into glacial lakes. Hydrothermal circulation, associated perhaps with sites of volcanism, could also have brought water to the surface from reservoirs deep underground.

IMAGE BY EDWARD BELL



BLYTH ROBERTSON *Geological Survey of Canada*



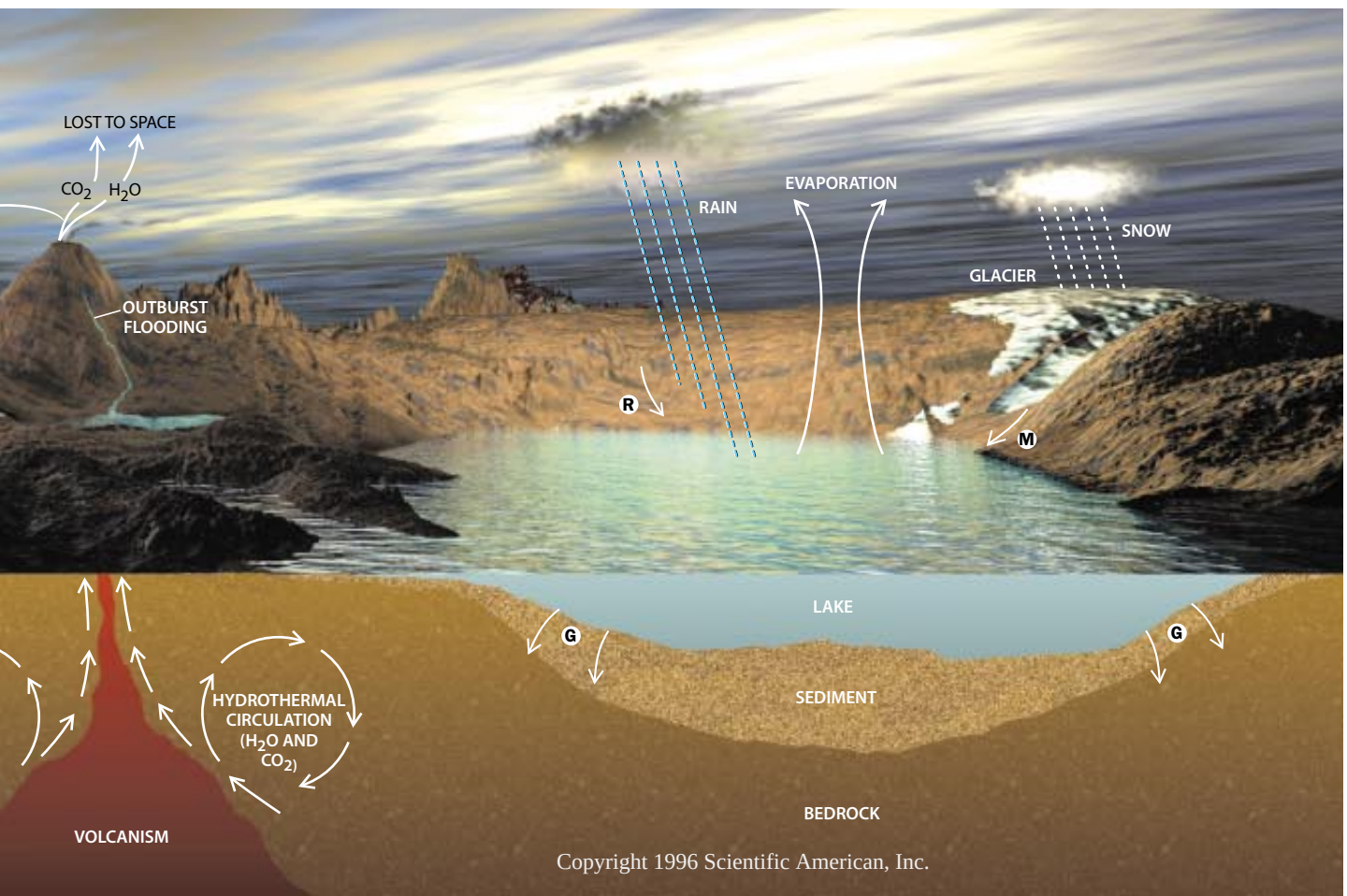
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

CRATER LAKES can be found on Earth in the depressions left after an impact of an asteroid or comet. The New Quebec Crater (*above*) is a prime example of the formation of such a lake. A similar body may have once occupied a smooth-floored crater of the Martian highlands (*right*), which shows both a terraced inlet (*8 o'clock position*) and a deeply incised outlet channel (*3 o'clock position*).

Earth. These distinctive sloping surfaces result after thousands of freeze-thaw cycles cause the top meter or so of water-soaked ground to creep slowly downhill.

Glacial features and muddy ejecta around craters are not the only examples of water shaping the Martian surface. In some places, sinuous valleys one kilometer wide and many hundreds of kilometers long form large branching networks. Carl Sagan of Cornell University, Victor R. Baker of the University of Arizona and their colleagues suggested in the 1970s that such troughs were created by running water. Other Martian valleys have blunt starting points and short tributaries, characteristics that are typical of erosion by groundwater "sapping." That process, common on Earth, results from the seepage of water from underground springs, which causes the overlying rock and soil to wash away.

Images of Mars also reveal enormous outflow channels etched on the surface. Some of these structures are more than 200 kilometers wide and can stretch for



ROCK GLACIER near McCarthy, Alaska (*right*), flows from a semicircular embayment that is typical of mountains carved by glaciers. The scene looks remarkably similar at certain sites on Mars (*far right*), where longitudinal flow lines emanate from curved mountain ridges.

JEFFREY S. KARGEL

2,000 kilometers or more. These channels emanate from what is called chaotic terrain, regions of fractured, jumbled rocks that apparently collapsed when groundwater suddenly surged outward. The ensuing floods carved the vast channels, leaving streamlined islands more than 100 kilometers long and gouging cavernous potholes several hundred meters deep. Baker compared the Martian outflow channels to similar, albeit smaller, flood features found on Earth in parts of Oregon and Washington State. Those so-called channeled scablands of the Pacific Northwest formed after a glacier that had dammed a large lake broke open suddenly and caused a catastrophic flood.

The geometry of the Martian outflow channels indicates that water could have flowed along the surface as rapidly as 75 meters per second (170 miles per hour). Michael H. Carr of the U.S. Geological Survey estimates that the vast quantity of water necessary to create these many enormous channels would have been enough to fill a global Martian ocean that was 500 meters deep, although not all this liquid flowed at one time. One source for that great quantity of water may have been a deep lake in Valles Marineris, a region on Mars partly covered with sedimentary layers that appear to be ancient lake deposits. Water could also have gushed from a large reservoir under ice-impregnated permafrost that had been warmed by heat from the interior of the planet.

Why should such an underground accumulation of water suddenly inundate the surface? Scientists are unsure of the exact cause, but this groundwater might have started to flow after the icy permafrost capping it thinned and weakened, perhaps because of a sudden climate warming, volcanism or tectonic uplift. Perhaps a large meteor impact or quake triggered the cataclysmic dousing. Once water broke through to the surface, carbon dioxide from saturated groundwater—a Martian seltzer of sorts—may have erupted in tremendous geysers, further undermining the stability of the saturated underground layers. The result was to produce chaotic terrain and to unleash floods and mudflows of a magnitude that has rarely, if ever, been matched by any earthly deluge.

An Ocean Away

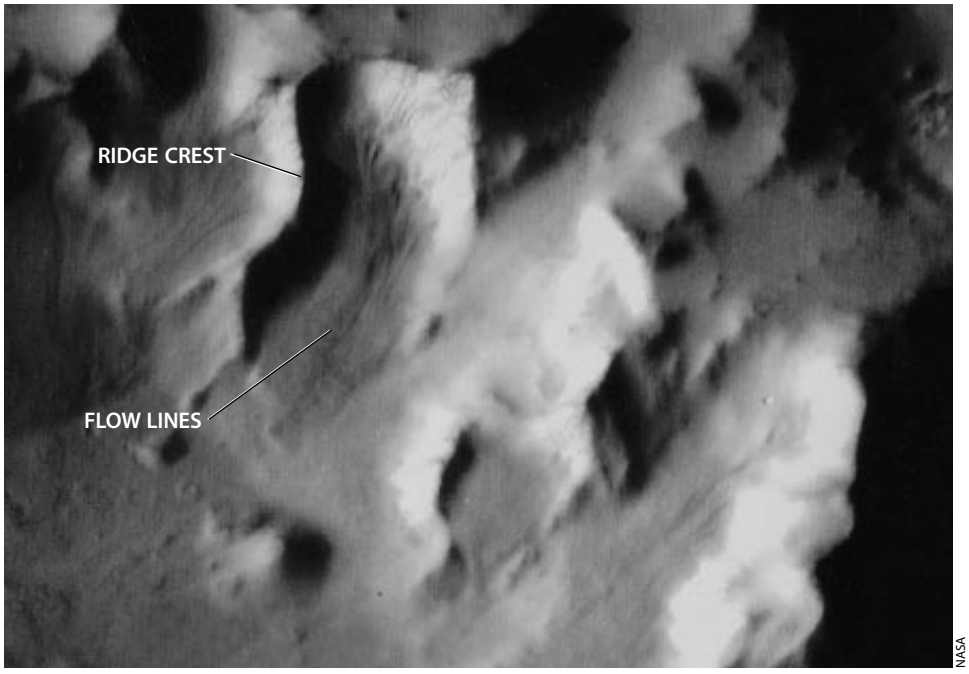
Some highland areas on Mars contain extensive systems of valleys that drained into sediment-floored depressions. These lowlands were at one time full of water. The largest of these Martian lakes filled two gigantic impact basins called Hellas and Argyre.

But these lakes may not have been the largest bodies of water on the planet. Research groups led by David H. Scott and Kenneth L. Tanaka of the U.S. Geological Survey and by Jeffrey M. Moore of the National Aeronautics and Space Administration Ames Research Center independently concluded that repeated floods from the outflow channels emptied to the north and formed a succession of transient lakes and seas. We have interpreted many features bordering these ancient basins as marking where glaciers once emptied into these deep bodies of water. Tanaka and Moore believe that thick layers of sediment deposited in these seas now stretch across much of the extensive northern plains. According to several estimates, one of the larger of the northern seas on Mars could have displaced the combined volume of the Gulf of Mexico and the Mediterranean Sea.

Yet even that great body of water may not have been the supreme example: there may have been a Mars ocean. As early as 1973 the late Henry Faul of the University of Pennsylvania raised this intriguing possibility in a paper he romantically entitled "The Cliff of Nix Olympica." Understandably, given the paucity of observations then available, the paper was never accepted for publication. But during the past decade, other researchers, working with information acquired during the Viking missions, have revived Faul's idea.

For instance, in 1989 Timothy J. Parker and his colleagues at the Jet Propulsion Laboratory in Pasadena, Calif., again proposed a northern ocean (arguing that many features in the northern plains looked as if they had resulted from coastal erosion). To enhance prospects for publication, however, they deliberately obscured the provocative thrust of their work with the mundane title "Transitional Morphology in the West Deuteronilus Mensae Region of Mars: Implications for Modification of the Lowland/Upland Boundary." In a subsequent paper, these researchers ventured a more direct title to convey their ideas: "Coastal Geomorphology of the Martian Northern Plains." Motivated in part by such work, Baker and several colleagues (including us) named this hypothetical northern ocean Oceanus Borealis. We calculated that it was possibly four times as large as the Arctic Ocean on Earth, and we proposed a scenario for the actions of the water cycle on Mars that could have accounted for it.

Whereas most planetary scientists now agree that large bodies of water formed



NASA

repeatedly in the northern plains on Mars, many do not accept that there was ever a true ocean there. Some envision that only a vast, muddy slurry, or mud ocean, existed. In any case, it is clear that huge amounts of water once flowed over the surface of Mars. Yet the fate of that water remains unknown. Some of it may have percolated into the subsurface and frozen in permafrost. Some may have frozen in place and might now stretch across much of the floor of the northern plains, hidden by a mantle of dust and sand. Some water may simply have evaporated, to be later lost to space or deposited as snow at the poles.

Trust the Old Salts

Although images of the landforms left by ancient glaciers, river valleys, lakes and seas are strong testament that Mars was once rich in water, evidence comes from other sources as well. Earth-based spectroscopic measurements of Mars reveal the presence of clay minerals. Even more directly, the two landers that set down on the surface during the Viking program analyzed Martian soil and found that it probably contains 10 to 20 percent salts. Martian rocks, like those on Earth, react to form salt and clay minerals when exposed to water. But such chemical weathering probably cannot occur under the cold and dry conditions that now reign on Mars.

Some scientists have also studied Martian rocks found here on Earth. These rare samples of the Martian surface were blasted into space by the impact of an asteroid or comet and later fell to Earth as meteorites. Allan H. Treiman of the Lunar and Planetary Institute in Houston and James L. Gooding of the NASA Johnson Space Center have shown in the past several years that minerals in some of these so-called SNC meteorites were chemically altered by cool, salty water, whereas others were affected by warmer hydrothermal solutions. Their conclusions imply that Mars once had a relatively warm, wet climate and may have had hot springs. Just perhaps, conditions were right for life.

That possibility inspired David S. McKay of the NASA Johnson Space Center and his colleagues to examine an SNC meteorite for signs of ancient Martian life. Although their conclusion that fossil microbes are present is open to debate (and a vigorous one is indeed going on), the composition of the rock they studied—with fractures filled by minerals that probably precipitated from an aqueous solution—indicated that conditions on Mars a few billion years ago would have been compatible with the existence of life.

In agreement with this assessment, many atmospheric physicists had already concluded that Mars has lost immense quantities of water vapor to space over time. Their theoretical calculations are in good accord with measurements made by various Soviet space probes that showed oxygen and hydrogen atoms (derived from breakdown of atmospheric water exposed to sunlight) streaming away from Mars. The continuous loss of these elements implies that Mars must once have had all the water needed to fill an Oceanus Borealis.

But water was not the only substance lost. Recently David M. Kass and Yuk L. Yung of the California Institute of Technology examined the evolution of carbon dioxide—a potent greenhouse gas—in the atmosphere of Mars. They found that over time an enormous quantity of carbon dioxide has escaped to space. That amount of gaseous carbon dioxide would have constituted a thick Martian atmosphere with three times the pressure found at the surface of Earth. The greenhouse effect from that gas would have been sufficient to warm most of the surface of Mars above the freezing point of water. Thus, from this perspective, too, it seems quite plausible that the climate on Mars once was much warmer and wetter than it is today.

Yet many questions remain about how water might have arranged itself on the surface of Mars: Was there actually an ocean? Did water shift rapidly between different reservoirs? When and for how long was Mars wet? Although the absolute timing of these events remains unknown, most researchers believe that water sculpted the surface of Mars at many intervals throughout the history of the planet. The constant loss of water and carbon dioxide from the atmosphere suggests that early epochs on Mars (that is, billions of years ago) may have been especially warm and wet. But some balmy periods may also have been relatively recent: Timothy D. Swindle of the University of Arizona and his colleagues studied minerals in an SNC meteorite created by aqueous alteration and determined that they formed 300 million years ago—a long time by human standards but only a few percent of the age of the 4.6-billion-year-old solar system. Their result was, however, accompanied by a considerable degree of uncertainty.

The duration of the wet periods on Mars is also difficult to gauge exactly. If the eroded Martian landscapes formed under conditions typical of terrestrial glacial environments, more than a few thousand but less than about a million years of warm, wet climate were required. Had these conditions endured substantially longer, erosion would have presumably erased all but traces of a few impact craters, just as it does on Earth.

This limitation does not apply to the

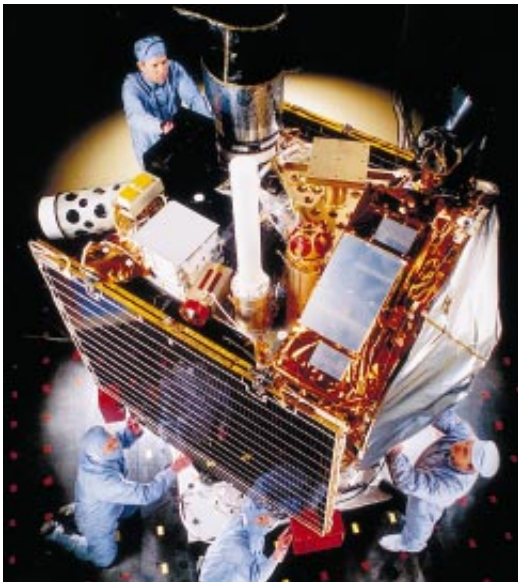
A Mars Probe Parade

There are nine scientific programs to explore Mars now in preparation or on the drawing board, and three of these unmanned missions will be launched this month and next. The first probe—*Mars Global Surveyor*—is scheduled to blast off on November 5. During the summer of 1997 the *Surveyor* craft (*top photograph below*) will go into orbit around Mars, a vantage from which it will be able to map the surface in fine detail.

Less than two weeks after the launch of *Surveyor*, the international Mars '96 mission will commence. Russia, in collaboration with Germany, France, Finland and several other nations, is sending a small scientific armada: one spacecraft will enter into orbit around Mars, two landing craft will gently touch down, and two "penetrators" will bury themselves deeply in the Martian soil.

Early in December the National Aeronautics and Space Administration will launch its second probe of this year, *Mars Pathfinder*. Seven months later *Pathfinder* will set down on the surface within the mouth of an ancient outwash channel. This event will occur on July 4, which will be 21 years to the day after *Viking 1* settled onto the surface of the red planet. Once safely perched on the Martian surface, *Pathfinder* will release a small six-wheeled vehicle (*bottom photograph below*) to explore the terrain immediately around the touchdown point.

Within a decade, scientists will send at least four additional orbiting spacecraft and five more surface probes to examine Mars (*timeline at right*). Although the U.S. strategy for the exploration originally called for a sample return mission to be carried out in 2005, the recent discovery of evidence that microscopic life-forms may have existed on Mars has prompted NASA to consider accelerating that schedule.



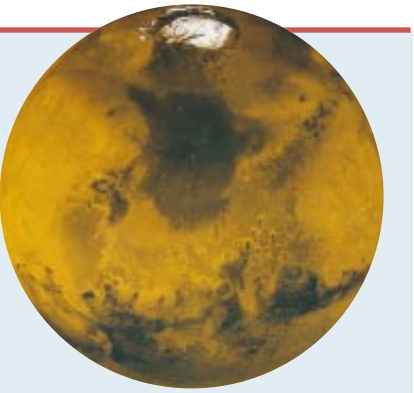
SURVEYOR orbiter is readied for flight.

Such a mission to bring Martian rocks back to Earth, though the most scientifically exciting, is also the most technically daunting of all the programs yet planned. The probe will be able to carry sufficient quantities of hydrogen (a conveniently light element) to fuel the return trip, but the spacecraft might have to restock with the heavier oxygen that it needs to burn this hydrogen during the ride home. To solve that problem, the spacecraft may have to generate a supply of oxygen on the surface of Mars by breaking down carbon dioxide, a substance that is, fortunately, available in copious amounts in the Martian atmosphere.

—J.S.K. and R.G.S.

MOBILE ROBOT will explore the Martian surface.

PHOTOGRAPHS COURTESY OF JET PROPULSION LABORATORY



A TIMELINE OF MARS MISSIONS

November 5, 1996 (U.S.) *Mars Global Surveyor*

NASA sends a space probe to Mars to conduct an orbital survey of the planet's surface. The craft will arrive in the summer of 1997.

November 16, 1996 (International) *Mars '96*

Russia and collaborating European nations send a collection of spacecraft to Mars. An orbiter and four separate surface probes will arrive in September 1997.

December 5, 1996 (U.S.) *Mars Pathfinder*

This probe will land in an ancient outflow channel on July 4, 1997, and release a mobile robot to explore the site.

1998–1999 (U.S.) *1988 Mars Surveyor* (orbiter and lander)

One probe will continue orbital surveys with emphasis on locating isolated carbon dioxide deposits on the surface. Meanwhile a landing craft will touch down and explore the southern polar region.

1998–1999 (Japan) *Planet B*

An orbiting probe will investigate the upper atmosphere of Mars.

2001 (U.S.) *Mars '01* (orbiter and lander)

An orbiting satellite and a surface landing craft will continue to conduct surveys of the surface of Mars.

2001 (Russia) *Mars '01*

One or several landing craft, perhaps with mobile vehicles, will explore the surface.

2003 (U.S.) *Mars '03* (orbiter and lander)

While one satellite conducts surveys from orbit, a probe will land and explore regions that may have once harbored life.

2005 (U.S.) *Mars Surveyor '05*

A spacecraft will land, collect samples and return them to Earth, perhaps by using fuel made on the surface.

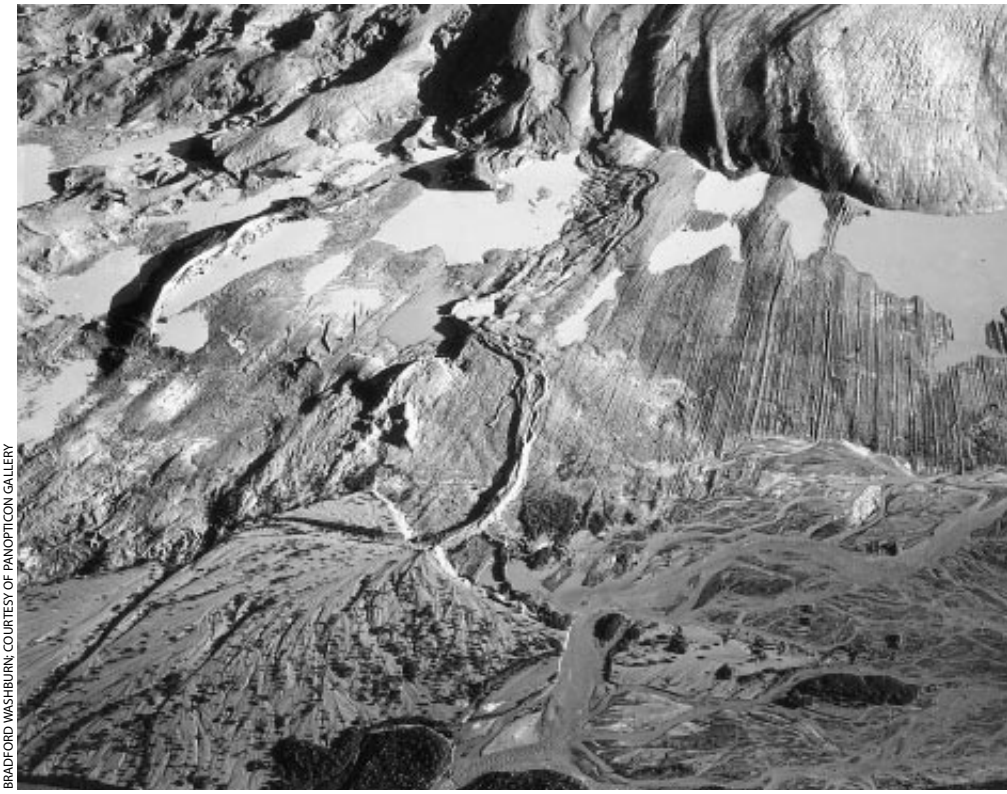
earliest history of the planet, billions of years ago, before the craters now visible had formed. A young Mars may well have had vigorous erosion smoothing its face. But eventually, as the planet slipped toward middle age, its visage became cold, dry and pockmarked. Only scattered intervals of warmth have since rejuvenated the surface of the planet in certain regions. Yet the mechanism that causes Mars to switch between mild and frigid regimes remains largely mysterious. Scientists can now venture only crude explanations for how these climate changes might have occurred.

Turning on the Heat

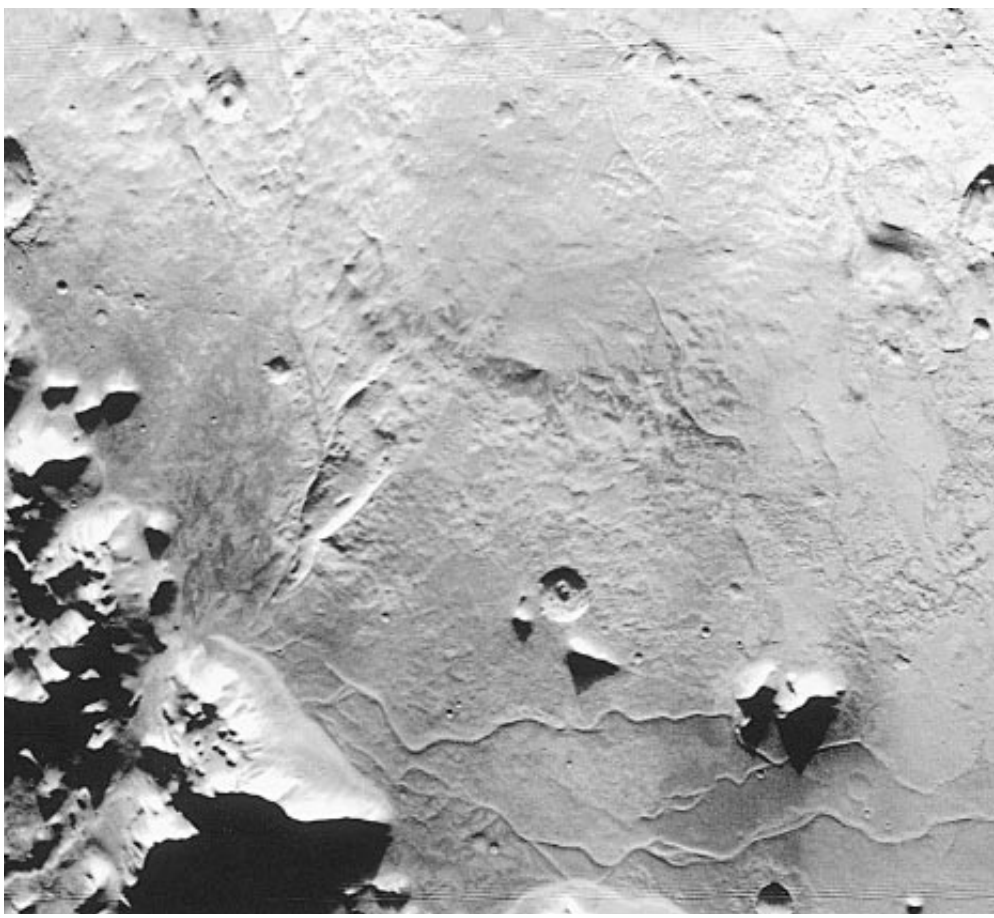
One hypothesis involves shifts in obliquity, the tilt of the spin axis from its ideal position, perpendicular to the orbital plane. Mars, like Earth, is now canted by about 24 degrees, and that tilt changes regularly over time. Jihad Touma and Jack L. Wisdom of the Massachusetts Institute of Technology discovered in 1993 that, for Mars, the tilt can also change abruptly. Excursions of the tilt axis through a range of as much as 60 degrees may recur sporadically every 10 million years or so. In addition, the orientation of the tilt axis and the shape of the orbit that Mars follows both change cyclically with time.

These celestial machinations, particularly the tendency of the spin axis to tilt far over, can cause seasonal temperature extremes. Even with a thin atmosphere such as the one that exists today, summer temperatures at middle and high Martian latitudes during periods with large obliquity could have climbed above freezing for weeks on end, and Martian winters would have been even harsher than they are currently.

But with sufficient summer warming of one pole, the atmosphere may have changed drastically. Releases of gas from the warmed polar cap, from seltzer groundwater or from carbon dioxide–rich permafrost may have thickened the atmosphere sufficiently to create a temporary greenhouse climate. Water could then have existed on the surface. Aqueous chemical reactions during such warm periods would in turn form salts and carbonate rocks. That process would slowly draw carbon dioxide from the atmosphere, thereby reducing the greenhouse effect. A return to moderate levels of obliquity might further cool the planet and precipitate dry-ice snow, thinning the atmosphere even more and re-



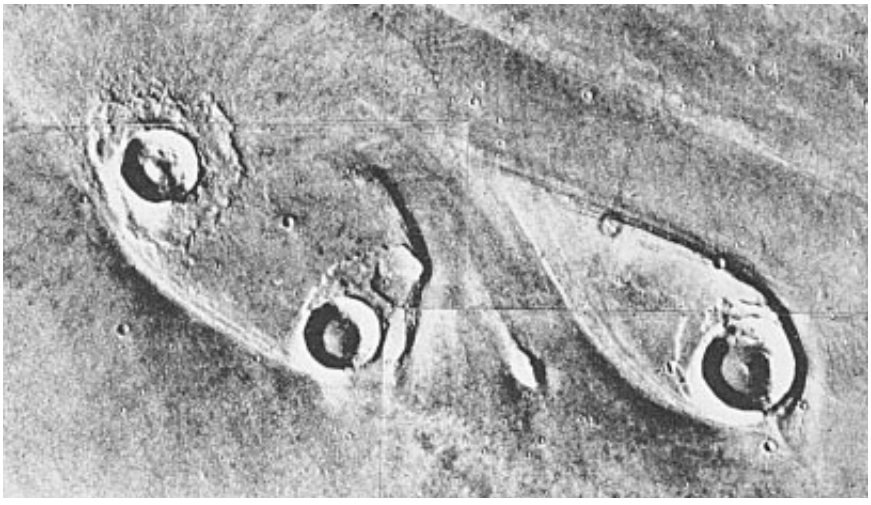
BRADFORD WASHBURN, COURTESY OF PANOPTICON GALLERY



NASA

ESKERS are sinuous ridges made up of sand and gravel deposited by streams that formerly ran underneath a sheet of ice. They decorate the landscape near the toe of a glacier in Tasnuna Valley, Alaska (*top*). Eskers appear also to exist on the floor of the Argyre basin on Mars (*bottom*), indicating that melting glaciers once covered the area.

COURTESY OF VICTOR R. BAKER



NASA

TEARDROP-SHAPED HILLS, sculpted by floodwaters of glacial Lake Missoula, are found in the channeled scablands of eastern Washington State (*top*). Similar streamlined hills dot the floor of outflow channels on Mars, commonly forming behind raised crater rims (*bottom*).

turning Mars to its normal, frigid state.

This theory of climatic change needs to be tested, but new observations and fresh insights will undoubtedly come from a decade-long series of unpiloted spacecraft that will next visit Mars. The expeditions begin this month with the launch of American and Russian probes. This program of exploration had been slated to conclude in 2005 with the return of Martian rocks. But the discovery of what may be fossil microbes in an SNC meteorite has sparked thoughts of obtaining Martian samples sooner so that scientists can better evaluate whether microorganisms existed on Mars several billion years ago—or even more recently.

The American spacecraft soon to be under way include *Mars Pathfinder* and *Mars Global Surveyor*. *Pathfinder* will land on a bouldery plain of an outflow channel that once fed an ancient sea. Although not equipped to test directly for signs of life, this lander will release a small roving vehicle to explore the local environs. *Surveyor* will take pictures from orbit that can resolve features that are just a few meters across. Measurements from this orbiter will also allow scientists to make detailed topographic maps and to search for icy deposits as well as new evidence of ancient glaciers, lakes and rivers. Information gathered by these next missions should give scientists a clearer picture of what Mars looked like during its last episode of warmer climate, perhaps 300 million years in the past.

By 300 million years ago on Earth, amphibians evolved from fish had crawled out of the sea and inhabited swampy coastlines. Might other complex creatures have flourished simultaneously along Martian shores? The basic conditions for life may have existed for a million years late in Martian history—perhaps much longer during an earlier period. Were these intervals conducive for organisms to evolve into forms that could survive the dramatic changes in climate? Could Martian organisms still survive today in underground hot springs? The next decade of concentrated exploration may provide the definitive answers, which, if positive, would mark an intellectual leap as great as any in human history. SA

The Authors

JEFFREY S. KARGEL and ROBERT G. STROM have worked together on various projects in planetary science for over a decade. Kargel met Strom soon after beginning graduate studies at the University of Arizona, where he received a doctorate in planetary sciences in 1990. Kargel remained at the University of Arizona's Lunar and Planetary Science Laboratory for two years doing postdoctoral research on the icy moons of the outer solar system and then joined the U.S. Geological Survey's astrogeology group in Flagstaff. Strom began his career working as a petroleum geologist, but he became involved in lunar exploration efforts during the 1960s and joined the faculty of the University of Arizona, where he continues to teach and conduct research. He has participated on National Aeronautics and Space Administration science teams assembled for the Apollo program, for the Mariner missions to Venus and Mercury, and for the Voyager missions to the outer solar system.

Further Reading

Ancient Oceans, Ice Sheets and the Hydrological Cycle on Mars. V. R. Baker, R. G. Strom, V. C. Gulick, J. S. Kargel, G. Komatsu and V. S. Kale in *Nature,* Vol. 352, pages 589–594; August 15, 1991.

Ancient Glaciation on Mars. J. S. Kargel and R. G. Strom in *Geology,* Vol. 20, No. 1, pages 3–7; January 1992.

The Ice Ages of Mars. J. S. Kargel and R. G. Strom in *Astronomy,* Vol. 20, No. 12, pages 40–45; December 1992.

Coastal Geomorphology of the Martian Northern Plains. T. J. Parker, D. S. Gorsline, R. S. Saunders, D. C. Pieri and D. M. Schneeberger in *Journal of Geophysical Research E (Planets),* Vol. 98, No. 6, pages 11061–11078; June 25, 1993.

See the World Wide Web site for the Center for Mars Exploration at http://cmex-www.arc.nasa.gov

Can China Feed Itself?

Some surprisingly reasonable policy changes would enable the world's largest nation to produce more food for its 1.2 billion citizens

by Roy L. Prosterman, Tim Hanstad and Li Ping

When the Venetian explorer Marco Polo brought back wheat noodles from China, he introduced Europeans to a new and popular dish that was also a product of the era's most sophisticated agricultural system. In the 13th century Chinese farmers relied on advanced irrigation systems and innovative double-cropping techniques to provide food for more than 100 million people. Rice and wheat were abundant.

Today China is faced with the daunting challenge of feeding 1.2 billion people—22 percent of the global population—on only 9 percent of the world's arable land. (Despite the country's geographic expanse, much of the western part is desert and unfit for agriculture.) The most recent estimates suggest that China's fertile land covers 130 million hectares—only 0.11 hectare for each person in China, compared with 0.73 hectare for every American. Moreover, in the past few years, China's population has been increasing by about 14 million every year. As the steadily expanding urban population encroaches on rural areas, the amount of land available for agriculture has decreased annually by about 400,000 hectares.

In light of these factors, as well as the news that during the past 10 years China's grain production per person has reached a plateau, some observers have painted a gloomy picture for the future of China's agricultural system and the country's ability to feed its citizens without buying massive quantities of foreign grain. In 1995, for the first time in decades, China began importing more grain than it exported. Although the country can afford to purchase large quantities of food from abroad thanks to its healthy economy, escalating demand on world markets could raise prices to such a level that other developing countries might not be able to procure the food they need.

Not surprisingly, many economists and policymakers around the world have recognized the importance of improving China's agricultural system. Chinese leaders have publicly stated that the country must become self-sufficient in its production of grain, for reasons of both social stability and national security. But can China feed itself? With this question in mind, we have, over the past nine years, traveled approximately 35,000 kilometers across the Chinese countryside, through most of the main agricultural regions, interviewing more than 500 families. At each stop, we wanted to hear from the farmers themselves about what might help them generate more and better crops to feed China.

In particular, we wanted to learn how the farmers might be able to achieve three goals we believe must be met if China is to become self-sufficient. First, the farmers must augment their current output per hectare. Second, they need to develop unused land into farmland. And finally, they must slow or stop the destruction of existing farmland. Fortunately, as our research shows, these three goals

are intertwined and can be addressed with a common solution: policy changes that grant farmers more secure rights to their land.

A History of Turmoil

Since 1949, when the Communists took power, China's agricultural practices and system of property ownership have undergone several turbulent changes. Before the revolution, many Chinese farmers were poor tenants who tilled fields owned by wealthy landlords. Soon after Mao Tse-tung's peasant army conquered China, however, the government confiscated the holdings of landlords and wealthy farmers and distributed the property among all farming households on an egalitarian basis. The new landowning families operated small, independent farms and sold their harvest on an open market. For the first time in recent Chinese history, the dream of "land to the tillers" was a reality. Farmers responded to the new system with extraordinary zeal: grain production went up by about 15 kilograms per person each year between 1949 and 1955.

In the 1950s, under the influence of the Soviet system, Mao became imbued with the ambition to build a powerful nation under a planned economic system. As a result, China gradually began to collectivize its agriculture. The government encouraged farmers to form groups known as mutual aid teams in the early 1950s; these teams consisted of no more than 10 households and served to coordinate the farming practices of the members. Property rights did not change, however—each family retained ownership of its plot. Later, during 1956 and 1957, the government further consolidated farms into agricultural collectives, each one with as many as 300 households. In this case, members actually had to surrender most of their land to the collective, although they could keep small private plots for growing food for the family.

The process of collectivization culminated in 1958, when the agricultural collectives merged into huge communes. These communes, each with an average size of about 4,000 families, took sole ownership of all property, including the private plots. All the farmers worked together on the land, receiving pay for time spent in the field, no matter how little they accomplished. And everyone shared the excess harvest. Under this system, none of the farmers had an individual stake in the land, so few cared about making improvements—in effect, the communes severed farmers from their land.

The result of collective farming was disastrous: in perhaps the world's worst famine, an estimated 30 million Chinese died between 1959 and 1962. The communal farms simply did not generate enough food for the country. In the 1960s the government broke up the communes into more manageable units. But collective farming continued on a smaller scale through the late 1970s, when some Chinese leaders started to rethink its viability.

The brainchild born of this rethinking was the policy known as the Household Responsibility System. This policy divided the collective land among individual households, creating a nation of small family farmers. The collective, however, maintained official ownership of the property. Initially, the farmers' rights to the land were to be valid for up to three years, but in 1984 the Communist Party ordered local officials to extend contracts to 15 years. In return for the right to work the land, farmers had to sell a small portion of their crops to the state at a fixed price. But they could keep the rest of their harvest, either to consume or to sell for a profit. The system clearly encouraged farmers to become more efficient: between 1980 and 1984, grain production increased by 16.2 kilograms per person each year, up from an annual average increase of 1.3 kilograms per person between 1955 and 1980.

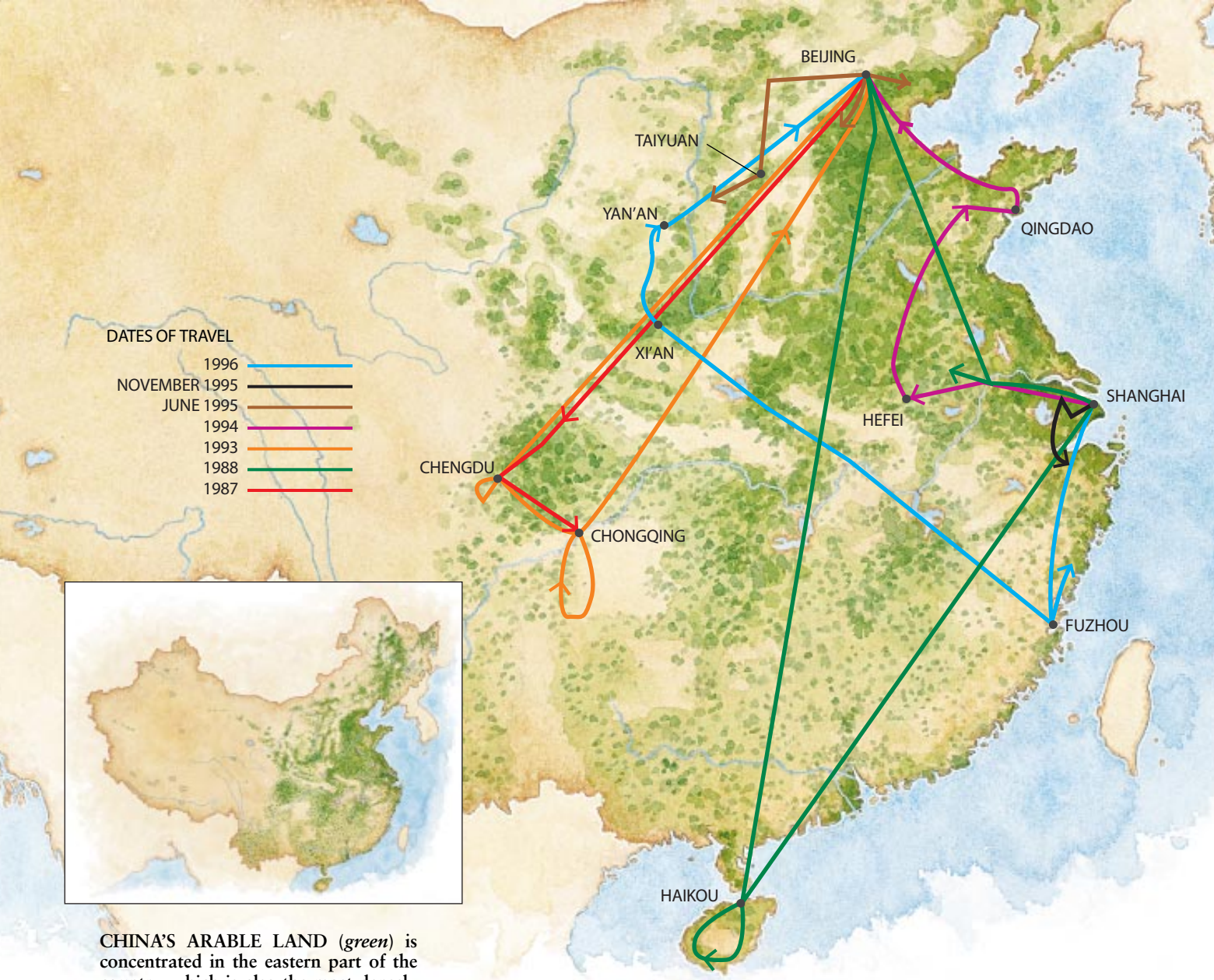
Unfortunately, the momentum behind agricultural expansion has slowed considerably since then. Between 1984 and 1993, grain production increased by only 2.9 kilograms per person each year. Although the basic guidelines of the Household Responsibility System have not changed in the past few years, farmers appear to be less motivated than they were only a decade ago.

ROBB KENDRICK *Aurora*; TIM HANSTAD *Rural Development Institute (inset)*

FARMERS in China, such as this man from Shaanxi Province, have traditionally supplied food for the entire nation, much of which is sold at local markets (*background*). In the past decade, however, China has had to import large quantities of staples such as wheat and rice. Chinese officials would like to move the country toward agricultural self-sufficiency.

An Uncertain Future

To generate more food for China, farmers must once again boost their output. Exploring possible ways that they might raise their efficiency, we surveyed hundreds of farmers throughout China. We visited farms away from large population centers and primary roads, randomly selecting people to interview. We typically visited one household at each stop, although our inter-



CHINA'S ARABLE LAND (*green*) is concentrated in the eastern part of the country, which is also the most densely inhabited. As the population has grown, the amount of land available for farming has declined. Over the past nine years, the authors traveled through most of the agricultural regions of China (*arrows*) to investigate how farmers might be able to protect their land, improve productivity on existing farms and begin to cultivate unused regions.

ROBERTO OSTI (*maps*); arable land data from *The National Economic Atlas of China*, 1994

views often attracted people from nearby farms. To ensure spontaneity, we did not give farmers advance notice of our visit. We also took extra measures to avoid the company of local officials so that we could obtain candid responses to our questions. Typical interviews were relatively informal and lasted from one to two hours; we usually conducted four or five interviews with different farmers each day, talking with them out in their fields or in their houses and courtyards [*see box on pages 94 and 95*].

The people we interviewed confirmed that they do indeed appreciate the innovations of the Household Responsibility System. Families now produce much more per hectare on their small, intensively worked farms than residents of the former collectives ever did—and they are living much better as a result. Even on these small plots (the average farm is just slightly larger than an American football field), the typical household enjoys a new brick home, consumes an adequate diet and can afford amenities such as a television.

The families also have more leisure time to enjoy these benefits. Farmers now spend far less time in the field than members of the collective did. Workers were in the collective fields for 250 to 320 days a year; in contrast, the same family members now spend between 60 and 90 days a year on their individual share of the same land. Many farmers told us that in the past, much of their time was spent, as one man put it, "leaning on my hoe." Such featherbedding has disappeared on today's farms. The families we talked to unanimously agreed that the policies implemented by the Household Responsibility System have improved their standard of living.

Chinese farmers achieved this efficiency under the new system by making relatively small but crucial modifications to their techniques. For instance, they became more assiduous in weeding, used better seed, applied fertilizer more carefully and timed more precisely such activities as sowing, transplanting, irrigating and harvesting. These practices delivered better crops almost immediately. But further gains in crop yields—one of three goals to be met to ensure China's self-sufficiency—will be far more

difficult to achieve. Farmers must start making extensive long-term investments in the land, such as better irrigation facilities, more effective drainage systems, improved land terracing and leveling, as well as significant soil upgrades.

There is considerable room for improvement: some two thirds of China's current farmland is underutilized, offering low crop yields as a result of poor land quality and insufficient irrigation. Many agricultural scientists in China have concluded that farmers could obtain crops two to three times larger than what they currently harvest. The farmers we talked to also acknowledged that the land could afford much larger yields. Yet few of them had made any major alterations to their plots, even though they all knew that such changes would boost their output.

The farmers' reluctance to sink money and labor into any extensive modifications can be directly attributed to their underlying fear that they may not be able to hold on to their property long enough to realize a return on their investment. (In contrast to the changes already made, the costs of which were recovered quickly, the next phase of improvements will take many years to pay for themselves.) Back in 1984 the central government ordered that land contracts be extended for 15 years, but local officials have not implemented this policy to any significant degree. Indeed, very few farmers even possess written contracts granting them the right to tend a specific plot. And when they do obtain a contract, the expiration date is often left blank, so the term may change without warning, or the contract may be terminated far short of what was originally promised.

Dismantling the Family Farm

A farmer's landholdings may be broken up for a variety of reasons. For example, in many villages, representatives from the collective take back all the land in the village every three to six years and reallocate the plots. Households in which someone has recently moved away or died receive a smaller portion of land, and families that have increased in size acquire a larger share. This procedure, a remnant of the absolute egalitarianism emphasized during the collective period, not only discourages farmers from making long-term investments in their land, it also undermines China's family-planning policy by encouraging farmers to have more children. Most of the farming families we interviewed favored a different approach to redistributing land among farmers: voluntary sale and purchase of perpetual-use rights to a parcel of land. Although current law does allow farmers to transfer their land rights, few are

DENNIS COX *ChinaStock*

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THREE GOALS must be achieved, the authors argue, if China is to become self-sufficient. Productivity per hectare must increase; long-term investments such as the extensive terracing constructed by workers in Guangxi Province (*top*) can help meet this goal. Unused land must be brought under cultivation, as farmers have done in Shaanxi Province (*middle*). And urban and industrial expansion into farmland—such as this factory encroaching on pasture in Shanxi Province, east of Shaanxi (*bottom*)—must be slowed.

willing to purchase rights that are so tenuous. As a result, the market in rural land rights is essentially inactive.

The government can also readily reclaim land for such nonagricultural purposes as urban or industrial development. Farmers are rarely if ever consulted in such events, known as takings, and they generally feel powerless to prevent them from happening. Furthermore, farmers are almost never adequately compensated for the land, let alone for any improvements they might have made. For instance, when a state-owned factory wants additional property to expand its operation, the factory manager negotiates with a representative of the collective. This representative has only a limited concern for the land, and the farmer—who does have a substantial interest in the transaction—is left entirely out of the loop.

Such land takings contribute to farmers' insecurity regarding their rights and at the same time eliminate valuable expanses of fertile soil. China must protect its existing farmland from industrial and urban encroachment if it is to achieve agricultural self-sufficiency. Senior government officials have recently issued a number of appeals against the taking of arable land for other uses. But because local officials can secure great sums of money by selling land rights, they often ignore or circumvent the central government's instructions. And, according to the households we talked to, once property has been reallocated to other families or reclaimed by the government, farmers have no effective means of legal redress.

The situation can be remedied, however. For instance, companies that wish to acquire land for commercial purposes could be required to seek the farmers' consent and to pay full market value for the land. Farmers could also negotiate directly with local officials for standard levels of compensation when property is reclaimed for other public purposes. (And of course, the bulk of the compensation should be given to farmers; today the money almost always goes to the collective.) Increasing farmers' participation in the taking process, together with more effective planning for the use of land, would help protect against further loss of agricultural land.

Fundamentally, though, China's farmers want more than just improved rules for land takings. They want longer and more secure rights to manage their small plots. Theoretically, current land-use rights extend for at least 15 years; most farmers favor land rights that are perpetual, can be inherited and cannot be reallocated when the household's size changes. More than 80 percent of the farmers we interviewed indicated that they would be willing to invest in their land if they were assured of having permanent access to it. Notably, perpetual land-use rights can be granted even if the collective maintains formal ownership of the land.

With longer and more secure rights in place, farmers would also begin to cultivate undeveloped land—another important step toward achieving agricultural self-sufficiency. China's Ministry of Agriculture estimates that the country has at least 33 million hectares of wasteland that could be converted into grain-growing farmland, as well as vast acres that could be transformed for growing fruit trees, medicinal herbs and other cash crops. Such a change, of course, would require significant investment—investment that farmers would make if they felt their property rights were secure. The central government has begun to make efforts in this direction.

Several years ago officials auctioned off land-use rights with terms of up to 100 years to noncultivated land in Shan-

Talking to the Farmers

During trips to China from 1987 through 1996, we surveyed hundreds of farmers throughout the countryside. In these informal interviews, we questioned the farmers about such basic matters as how much land they worked and what crops they grew. We also asked about life during and after the collective period (the years between 1955 and 1980, when families lived on large communal farms) as well as what the farmers thought about current policies and regulations regarding land use. And we solicited their opinions on new policies under consideration to reform land-use rights. The notes from our interviews are voluminous, more than 3,000 pages; we offer a few highlights. *—R.L.P., T.H. and L.P.*

(*1*) Li Ping (*center*) and Roy Prosterman (*right*) interview a group of farmers in Hebei Province and (*2*) discuss agricultural policy with a farmer in the province of Shaanxi. (*3*) In neighboring Shanxi Province, Tim Hanstad (*far left*) and Li (*far right*) meet with two farm-

TIM HANSTAD

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A Sampling of Responses

"I will only make improvements that provide results the same year."

"Why should I invest in land when it could be taken from me tomorrow?"

"If I had perpetual-use rights, I would level the land, apply more organic fertilizer and dig a well."

"We have improved yields since the collective period, but they still could be higher."

"Everyone owns land except the farmer."

How long are your land rights?

63 percent did not know
10 percent said 3 to 5 years
8 percent said 6 to 10 years
19 percent said more than 10 years

Would you favor a policy of perpetual land-use rights that could not be taken away and reallocated?

79 percent were in favor of such changes

Have you made any long-term improvements to your land, such as terracing?

61 percent had not

Would you make any long-term improvements to your land under a policy of perpetual land-use rights?

84 percent said they would

TIM HANSTAD

ers who had recently dug a well on their land (*background*). (*4*) A Shanxi farmer transports organic fertilizer in buckets, while (*5*) a man on a different farm applies a more modern chemical fertilizer to his rice crop. (*6*) Also in Shanxi, two men pose in front of their onion field. (*7*) Farmers in Fujian Province tend to their rice paddies; workers often use water buffalo to help plow the fields.

xi Province; 17 other provinces have since followed this lead. We have interviewed farmers in Shanxi Province who purchased 50- to 100-year rights to noncultivated land, guaranteed by a detailed written contract. These farmers have made substantial investments of both cash and labor to develop this land. But in contrast, the same people described to us their unwillingness to make similar expenditures on their other plots because their rights to that land were so tenuous.

Continued efforts to strengthen farmers' land rights must go beyond mere policy pronouncements from Beijing. And the experience in Shanxi Province demonstrates that this goal can be achieved. To enforce new procedures, the government will have to establish the rule of law in rural land transactions as a countermeasure to widespread abuse of power and repeated violations of contracts by local cadres. We recommend, for instance, that the government at the county level or above issue uniform land-use certificates and written contracts specifying the length of time covered and all the rights and obligations of both individual land users and the collective owners. It should also conduct a massive public education campaign to inform farmers of their rights and obligations. In addition, the government should institute a better system at the local level for resolving disputes over land rights.

The government has tentative plans for a pilot project, encompassing two counties in Fujian Province and Shaanxi Province, that would test the practicality and effects of changes similar to those recommended above. Although the final details have yet to be agreed on, we expect the project to begin within the next few months. The proposal would extend land-use rights for up to 75 years for existing farmland and 100 years for usable wasteland, end land

TIM HANSTAD

INSPECTING CONTRACTS for their land, farmers in Shanxi Province describe how more secure land-use rights have encouraged them to invest money to convert wasteland into farmland. Officials in Shanxi recently auctioned off use rights for noncultivated land with terms of up to 100 years. Pilot projects under consideration in both Fujian and Shaanxi provinces should offer farmers extended land-use rights for arable land as well as wasteland.

readjustments for changes in household size and provide written land contracts to all farm households. The plan would also implement new rules for land takings, land-use planning and the resolution of disputes.

Hope for the Future

Are there other remedies that could encourage investment in China's farmland or otherwise increase agricultural production? Some policymakers have argued that improved seed and fertilizer would boost efficiency, as would higher grain prices. Although such ideas could help, our fieldwork suggests that such steps would be peripheral at best.

Novel fertilizer and seed would most likely provide few benefits in the absence of other improvements, such as better irrigation, that farmers are unwilling to pay for right now. Higher prices would increase farmers' profits, conceivably enabling them to invest more aggressively in their land. But without secure land-use rights, farmers would still base their financial decisions on whether they would have time to recover the costs of their investments. Moreover, increasing grain prices will require substantial government outlays.

Another widely discussed strategy for enhancing agricultural output in China could in fact have the opposite effect. Some Chinese officials have proposed a return to large-scale farming based on the assumption that bigger farms would have a stronger financial position and better access to current technology than small family farms. Proponents also assert that productivity would rise if property were consolidated and managed by a few very proficient farmers. Although large farms exist in other countries—notably the U.S., where the average farm encompasses about 190 hectares—their prospects in China appear to be quite different.

Evidence from around the world demonstrates that smaller farms are typically more productive than larger farms. The expansive plots in the U.S. have led to agricultural prosperity not because of their size but rather because of the unique land, labor and capital resources available. Large farms generally employ less labor and utilize more capital per hectare than small farms do. China's countryside, however, has abundant labor and little capital. Thus, employing large numbers of workers to manage limited hectares of fertile ground makes sense given the circumstances in China. If agriculture is modernized so that one person with high-tech machinery can manage land previously farmed by 10 people, the other nine must find a job elsewhere. China already has a serious problem of rural unemployment and cannot afford even more surplus labor. In any case, as history indicates, farm size should not depend on administrative fiat but should evolve voluntarily as less interested or less capable farmers, with widening prospects away from the family farm, sell their land rights to those who want to work the land.

Fortunately, the Chinese government seems intent on continuing what has been, since 1980, a fairly sensible reform of the country's agricultural system. In 1995, for instance, the Chinese State Council announced that land rights would be extended for another 30 years. More important, the council's ruling should help put an end to the practice of reallocating land for changes in household size. The council also reiterated that land-use rights may be transferred for compensation and are inheritable. In addition, it called for strict punishment of officials who wrongfully attempt to terminate new contracts. But practical measures for enforcement of the council's directive must be tested and put in place. The Chinese government appears willing to give people greater control over the land they farm; only if it succeeds in implementing these reforms will China be assured of its ability to feed itself in the next century. SA

The Authors

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Further Reading

FROM BRIGADE TO VILLAGE COMMUNITY: THE LAND TENURE SYSTEM AND RURAL DEVELOPMENT IN CHINA. Zhu Ling and Jiang Zhongyi in *Cambridge Journal of Economics,* Vol. 17, No. 4, pages 441–461; December 1993.

WHO WILL FEED CHINA? Vaclav Smil in *China Quarterly,* No. 143, pages 801–813; September 1995.

WHO WILL FEED CHINA? WAKE-UP CALL FOR A SMALL PLANET. Lester R. Brown. W. W. Norton, 1995.

RICE BOWLS AND DUST BOWLS. Robert L. Paarlberg in *Foreign Affairs,* Vol. 75, No. 3, pages 127–132; May/June 1996.

Dyslexia

A new model of this reading disorder emphasizes defects in the language-processing rather than the visual system. It explains why some very smart people have trouble learning to read

by Sally E. Shaywitz

One hundred years ago, in November 1896, a doctor in Sussex, England, published the first description of the learning disorder that would come to be known as developmental dyslexia. "Percy F.,… aged 14,… has always been a bright and intelligent boy," wrote W. Pringle Morgan in the *British Medical Journal,* "quick at games, and in no way inferior to others of his age. His great difficulty has been—and is now—his inability to learn to read."

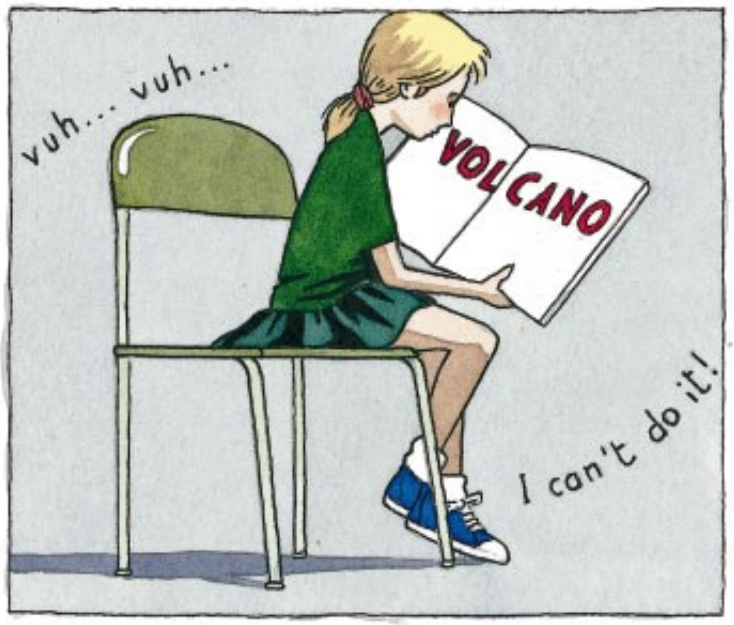
In that brief introduction, Morgan captured the paradox that has intrigued and frustrated scientists for a century since: the profound and persistent difficulties some very bright people face in learning to read. In 1996 as in 1896, reading ability is taken as a proxy for intelligence; most people assume that if someone is smart, motivated and schooled, he or she will learn to read. But the experience of millions of dyslexics like Percy F. has shown that assumption to be false. In dyslexia, the seemingly invariant relation between intelligence and reading ability breaks down.

Early explanations of dyslexia, put forth in the 1920s, held that defects in the visual system were to blame for the reversals of letters and words thought to typify dyslexic reading. Eye training was often prescribed to overcome these alleged visual defects. Subsequent research has shown, however, that children with dyslexia are not unusually prone to reversing letters or words and that the cognitive deficit responsible for the disorder is related to the language system. In particular, dyslexia reflects a deficiency in the processing of the distinctive linguistic units, called phonemes, that make up all spoken and written words. Current linguistic models of reading and dyslexia now provide an explanation of why some very intelligent people have trouble learning to read and performing other language-related tasks.

In the course of our work, my colleagues and I at the Yale Center for the Study of Learning and Attention have evaluated hundreds of children and scores of men and women for reading disabilities. Many are students and faculty at our university's undergraduate, graduate and professional schools. One of these, a medical student named Gregory, came to see us after undergoing a series of problems in his first-year courses. He was quite discouraged.

Although he had been diagnosed as dyslexic in grade school, Gregory had also been placed in a program for gifted students. His native intelligence, together with extensive support and tutoring, had allowed him to graduate from high school with honors and gain admission to an Ivy League college. In college,

The Paradox of Dyslexia



Gregory had worked extremely hard and eventually received offers from several top medical schools. Now, however, he was beginning to doubt his own competence. He had no trouble comprehending the intricate relations among physiological systems or the complex mechanisms of disease; indeed, he excelled in those areas requiring reasoning skills. More problematic for him was the simple act of pronouncing long words or novel terms (such as labels used in anatomic descriptions); perhaps his least well-developed skill was rote memorization.

Both Gregory and his professors were perplexed by the inconsistencies in his performance. How could someone who understood difficult concepts so well have trouble with the smaller and simpler details? Could Gregory's dyslexia—he was still a slow reader—account for his inability to name body parts and tissue types in the face of his excellent reasoning skills?

It could, I explained. Gregory's history fit the clinical picture of dyslexia as it has been traditionally defined: an unexpected difficulty learning to read despite intelligence, motivation and education. Furthermore, I was able to reassure Gregory that scientists now understand the basic nature of dyslexia.

Over the past two decades, a coherent model of dyslexia has emerged that is based on phonological processing. The phonological model is consistent both with the clinical symptoms of dyslexia and with what neuroscientists know about brain organization and function. Investigators from many laboratories, including my colleagues and I at the Yale Center, have had the opportunity to test and refine this model through 10 years of cognitive and, more recently, neurobiological studies.

The Phonological Model

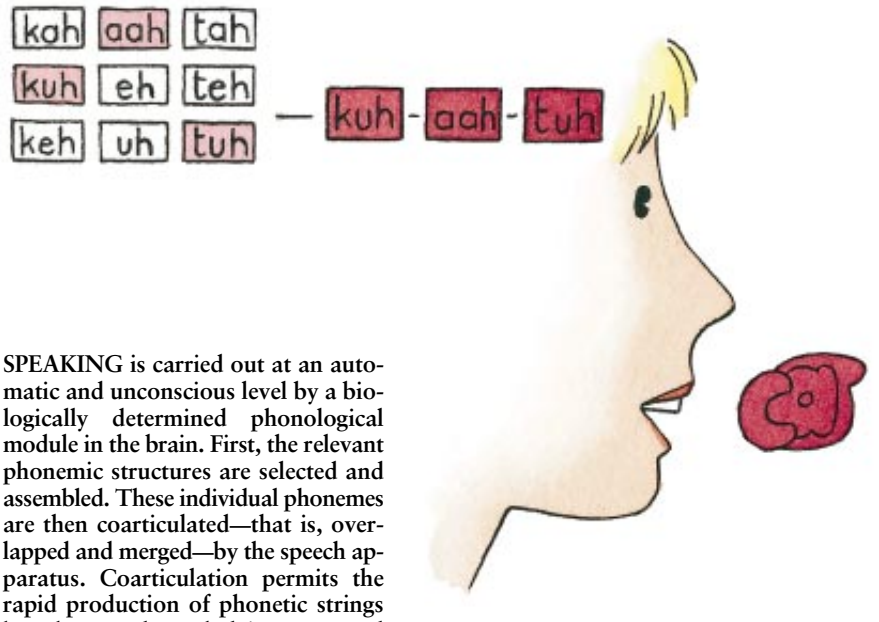
To understand how the phonological model works, one has first to consider the way in which language is processed in the brain. Researchers conceptualize the language system as a hierarchical series of modules or components, each devoted to a particular aspect of language. At the upper levels of the hierarchy are components involved with semantics (vocabulary or word meaning), syntax (grammatical structure) and discourse (connected sentences). At the lowest level of the hierarchy is the phonological module, which is dedicated to processing the distinctive sound elements that constitute language.

The phoneme, defined as the smallest meaningful segment of language, is the fundamental element of the linguistic system. Different combinations of just 44 phonemes produce every word in the English language. The word "cat," for example, consists of three phonemes: "kuh," "aah," and "tuh." (Linguists indicate these sounds as |k|, |æ| and |t|.) Before words can be identified, understood, stored in memory or retrieved from it, they must first be broken down, or parsed, into their phonetic units by the phonological module of the brain.

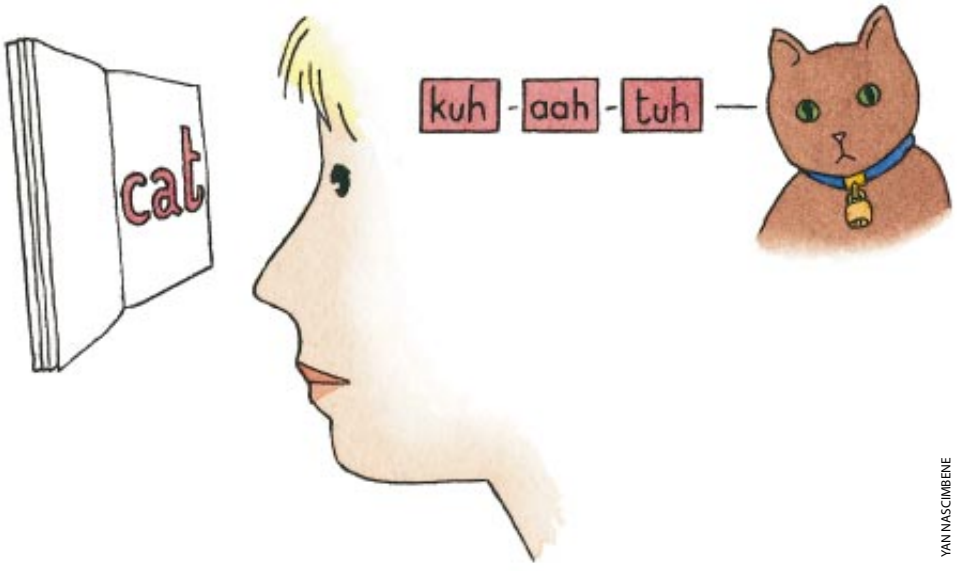
In spoken language, this process occurs automatically, at a preconscious level. As Noam Chomsky and, more recently, Steven Pinker of the Massachusetts Institute of Technology have convincingly argued, language is instinctive—all that is necessary is for humans to be exposed to it. A genetically determined phonological module automatically assembles the phonemes into words for the speaker and parses the spoken word back into its underlying phonological components for the listener.

In producing a word, the human speech apparatus—the larynx, palate, tongue and lips—automatically compresses and merges the phonemes. As a result, information from several phonemes is folded into a single unit of sound. Because there is no overt clue to the underlying segmental nature of speech, spoken language appears to be seamless. Hence, an oscilloscope would register the word "cat" as a single burst of sound; only the human language system is capable of distinguishing the three phonemes embedded in the word.

Reading reflects spoken language, as my colleague Alvin M. Liberman of Haskins Laboratories in New Haven, Conn., points out, but it is a much harder skill to master. Why? Although both speaking and reading rely on phonological processing, there is a significant difference: speaking is natural, and reading is not. Reading is an invention and must be learned at a conscious level. The task of the reader is to transform the visual



SPEAKING is carried out at an automatic and unconscious level by a biologically determined phonological module in the brain. First, the relevant phonemic structures are selected and assembled. These individual phonemes are then coarticulated—that is, overlapped and merged—by the speech apparatus. Coarticulation permits the rapid production of phonetic strings but obscures the underlying segmental nature of speech.



YAN NASCIMBENE

READING is not automatic but must be learned. The reader must develop a conscious awareness that the letters on the page represent the sounds of the spoken word. To read the word "cat," the reader must parse, or segment, the word into its underlying phonological elements. Once the word is in its phonological form, it can be identified and understood. In dyslexia, an inefficient phonological module produces representations that are less clear and hence more difficult to bring to awareness.

percepts of alphabetic script into linguistic ones—that is, to recode graphemes (letters) into their corresponding phonemes. To accomplish this, the beginning reader must first come to a conscious awareness of the internal phonological structure of spoken words. Then he or she must realize that the orthography—the sequence of letters on the page—represents this phonology. That is precisely what happens when a child learns to read.

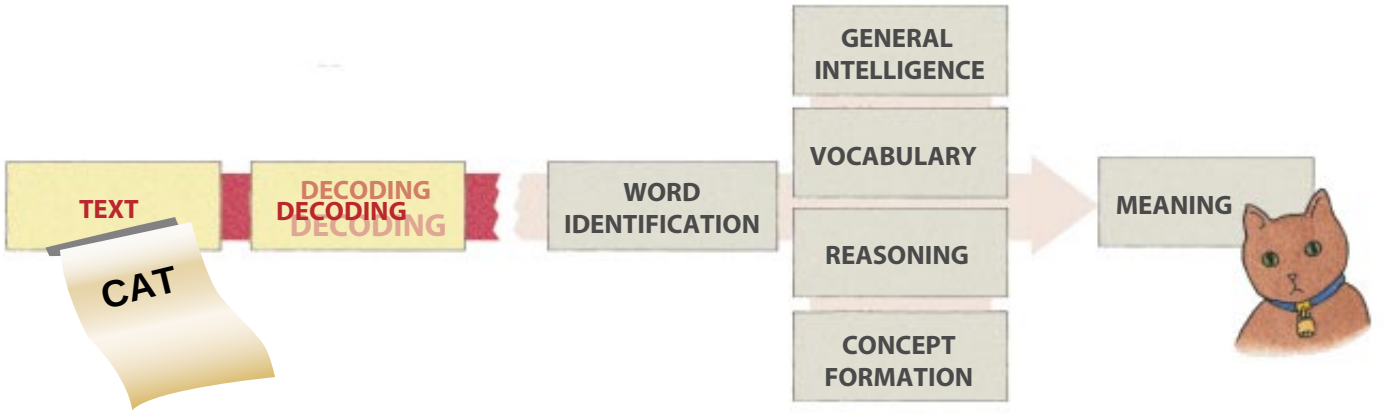
In contrast, when a child is dyslexic, a deficit within the language system at the level of the phonological module impairs his or her ability to segment the written word into its underlying phonological components. This explanation of dyslexia is referred to as the phonological model, or sometimes as the phonological deficit hypothesis.

According to this hypothesis, a circumscribed deficit in phonological processing impairs decoding, preventing word identification. This basic deficit in what is essentially a lower-order linguistic function blocks access to higher-order linguistic processes and to gaining meaning from text. Thus, although the language processes involved in comprehension and meaning are intact, they cannot be called into play, because they can be accessed only after a word has been identified. The impact of the phonological deficit is most obvious in reading, but it can also affect speech in predictable ways. Gregory's dilemma with long or novel words, for example, is entirely consistent with the body of evidence that supports a phonological model of dyslexia.

That evidence began accumulating more than two decades ago. One of the earliest experiments, carried out by the late Isabelle Y. Liberman of Haskins Laboratories, showed that young children become aware between four and six years of age of the phonological structure of spoken words. In the experiment, children were asked how many sounds they heard in a series of words. None of the four-year-olds could correctly identify the number of phonemes, but 17 percent of the five-year-olds did, and by age six, 70 percent of the children demonstrated phonological awareness.

By age six, most children have also had at least one full year of schooling, including instruction in reading. The development of phonological awareness, then, parallels the acquisition of reading skills. This correspondence suggested that the two processes are related. These findings also converge with data from the Connecticut Longitudinal Study, a project my colleagues and I began in 1983 with 445 randomly selected kindergartners; the study continues in 1996 when these children are age 19 and out of high school. Testing the youngsters yearly, we found that dyslexia affects a full 20 percent of schoolchildren—a figure that agrees roughly with the proportion of Liberman's six-year-olds who could not identify the phonological structure of words. These data further support a connection between phonological awareness and reading.

During the 1980s, researchers began to address that connection explicitly. The groundbreaking work of Lynette Bradley and Peter E. Bryant of the University of Oxford indicated that a pre-



YAN NASCIMBENE (*cat*); JANA BRENNING

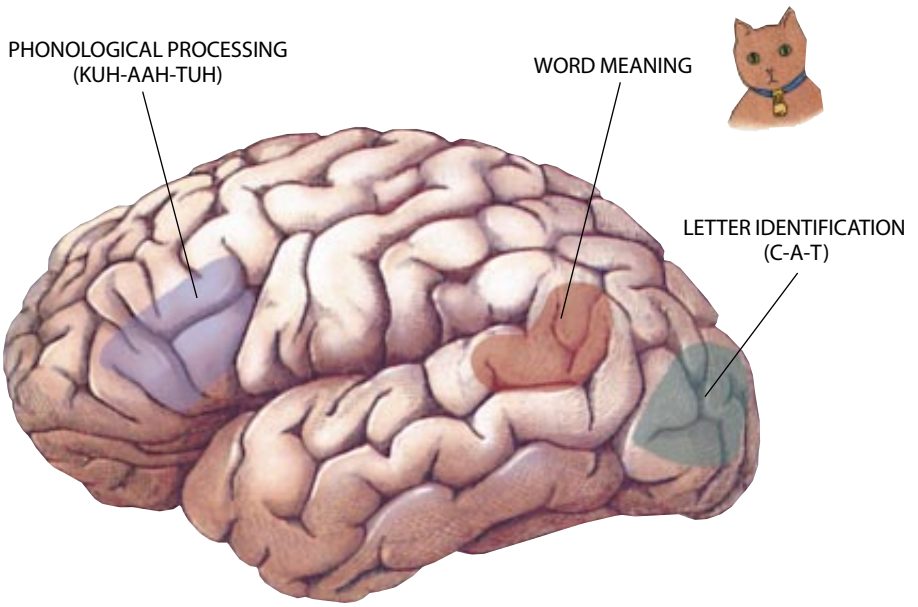
IN READING, the word (here, "cat") is first decoded into its phonological form ("kuh, aah, tuh") and identified. Once it is identified, higher-level cognitive functions such as intelligence and vocabulary are applied to understand the word's meaning ("small furry mammal that purrs"). In people who have dyslexia, a phonological deficit impairs decoding, thus preventing the reader from using his or her intelligence and vocabulary to get to the word's meaning.

schooler's phonological aptitude predicts future skill at reading. Bradley and Bryant also found that training in phonological awareness significantly improves a child's ability to read. In these studies, one group of children received training in phonological processing, while another received language training that did not emphasize the sound structure of words. For example, the first group might work on categorizing words by their sound, and the second group would focus on categorizing words according to their meaning. These studies, together with more recent work by Benita A. Blachman of Syracuse University, Joseph E. Torgesen of Florida State University and Barbara Foorman of the University of Houston, clearly demonstrate that phonological training in particular—rather than general language instruction—is responsible for the improvements in reading.

Such findings set the stage for our own study, in the early 1990s, of the cognitive skills of dyslexic and nondyslexic children. Along with Jack M. Fletcher of the University of Texas–Houston and Donald P. Shankweiler and Leonard Katz of Haskins Laboratories, I examined 378 children from seven to nine years old on a battery of tests that assessed both linguistic and nonlinguistic abilities. Our results as well as those of Keith E. Stanovich and Linda S. Siegel of the Ontario Institute for Studies in Education made it clear that phonological deficits are the most significant and consistent cognitive marker of dyslexic children.

One test in particular seemed quite sensitive to dyslexia: the Auditory Analysis Test, which asks a child to segment words into their underlying phonological units and then to delete specific phonemes from the words. For example, the child must say the word "block" without the "buh" sound or say the word "sour" without the "s" sound. This measure was most related to a child's ability to decode single words in standardized tests and was independent of his or her intelligence, vocabulary and reasoning skills. When we gave this and other tests of phonemic awareness to a group of 15-year-olds in our Connecticut Longitudinal Study, the results were the same: even in high school students, phonological awareness was the best predictor of reading ability.

If dyslexia is the result of an insufficiently developed phonological specialization, other consequences of impaired phonological functioning should also be apparent—and they are. Ten years ago the work of Robert B. Katz of Haskins Laboratories documented the problems



YAN NASCIMBENE (*cat*); CAROL DONNER (*brain*); from *Brain, Mind and Behavior,* by F. E. Bloom and A. Lazerson, W. H. Freeman, 1988

NEURAL ARCHITECTURE for reading has been suggested by functional magnetic resonance imaging. Letter identification activates the extrastriate cortex in the occipital lobe; phonological processing activates the inferior frontal gyrus (Broca's area); and accessing meaning activates primarily the superior temporal gyrus and parts of the middle temporal and supramarginal gyri.

poor readers have in naming objects shown in pictures. Katz showed that when dyslexics misname objects, the incorrect responses tend to share phonological characteristics with the correct response. Furthermore, the misnaming is not the result of a lack of knowledge. For example, a girl shown a picture of a volcano calls it a tornado. When given the opportunity to elaborate, she demonstrates that she knows what the pictured object is—she can describe the attributes and activities of a volcano in great detail and point to other pictures related to volcanoes. She simply cannot summon the word "volcano."

This finding converges with other evidence in suggesting that whereas the phonological component of the language system is impaired in dyslexia, the higher-level components remain intact. Linguistic processes involved in word meaning, grammar and discourse—what, collectively, underlies comprehension—seem to be fully operational, but their activity is blocked by the deficit in the lower-order function of phonological processing. In one of our studies, Jennifer, a very bright young woman with a reading disability, told us all about the word "apocalypse." She knew its meaning, its connotations and its correct usage; she could not, however, recognize the word on a printed page. Because she could not decode and identify the written word, she could not access her fund of knowledge about its meaning when she came across it in reading.

Of course, many dyslexics, like Gregory, do learn to read and even to excel in academics despite their disability. These so-called compensated dyslexics perform as well as nondyslexics on tests of word accuracy—they have learned how to decode or identify words, thereby gaining entry to the higher levels of the language system. But they do so at a cost. Timed tests reveal that decoding remains very laborious for compensated dyslexics; they are neither automatic nor fluent in their ability to identify

Playing Past Learning Disabilities

Dyslexia is the most common of the learning disorders, conditions that interfere with a normally intelligent child's ability to acquire speech, reading or other cognitive skills. Children with learning disabilities have become the basis of a thriving industry since 1968, when federal education officials first earmarked funds to help them. The number of children identified as having learning disabilities soared from 780,000 in 1976 to 2.3 million in 1993. An estimated $15 billion is spent annually on the diagnosis, treatment and study of such disorders.

The definitions and diagnostic criteria for learning disorders are often subjective or ambiguous; their causes are typically obscure or controversial. For example, psychologist Gerald Coles of the University of Rochester challenges the claim that 20 percent of children are dyslexic, and not all researchers and educators accept a phonological (or even biological) explanation for dyslexia. Treatment is another area that has been fraught with controversy and, often, disappointment. Over the years, educators and parents have subscribed to many techniques that promised to help children overcome their learning disabilities, despite the absence of independent research to back up those claims. Nevertheless, ongoing research holds out prospects for some real progress.

FIVE-YEAR-OLD KEILLAN LECKY interacts with a language-learning program at Rutgers University in Newark, N.J.

NINA BERMAN *Sipa Press*

One of the most lauded treatments for learning disabilities to emerge in recent years has been developed by a group led by Paula Tallal, co-director of the Center for Molecular and Behavioral Neuroscience at Rutgers University in Newark, N.J., and Michael M. Merzenich of the Keck Center for Integrative Neuroscience at the University of California at San Francisco. Their research has not focused on dyslexics per se but on "language-impaired" children who have difficulty understanding speech. Not all language-impaired children are dyslexic, Tallal notes, and not all dyslexics are language-impaired, but there is nonetheless broad overlap between the two groups. Studies have suggested that as many as 8 percent of all children may be language-impaired; of this group, more than 85 percent also exhibit dyslexia.

Tallal, who began studying language impairment in the late 1970s, has long suspected that this problem stems from an inability to process auditory information rapidly enough. Whereas most children can process phonemes lasting less than 40 milliseconds, the language-impaired may require as much as 500 milliseconds. To them, the word "bat" may be indistinguishable from "pat." This hypothesis, Tallal says, is "compatible" with the phonological-deficit model of dyslexia but places more emphasis on the role of timing in neural processing.

Language impairment, Tallal believes, usually stems from an organic deficit rather than from environmental factors. Magnetic resonance scans and other imaging studies, she states, have turned up distinct neural differences between people with normal language skills and the language-impaired. "But just because something is biologically based doesn't mean it's irremediable," Tallal adds.

Two years ago she teamed up with Merzenich and several other scientists to develop a computer-based therapy—an animated video game, essentially—for training language-impaired children. The core of the therapy is a speech-processing program that enables the researchers to alter the amplitude and duration of recorded sounds.

In one of the programs, which has a circus motif, a clown utters two closely related phonemes, such as "pa" and "da," that have been "stretched out" to a length that the children can easily comprehend. When the children correctly distinguish between the sounds, the clown congratulates them; progress is also represented by a bear moving along a tightrope.

words. Many dyslexics have told us how tiring reading is for them, reflecting the enormous resources and energy they must expend on the task. In fact, extreme slowness in making phonologically based decisions is typical of the group of compensated dyslexics we have assembled as part of a new approach to understanding dyslexia: our neuroimaging program.

The Neurobiology of Reading

The phonological model incorporates a modular scheme of cognitive processing in which each of the component processes used in word identification is carried out by a specific network of brain cells. Until recently, however, researchers have had no firm indication of how that scheme maps onto the actual functional organization of the human brain. Unlike many other functions, reading cannot be studied in animals; indeed, for many years the cerebral localization of all higher cognitive processes could be inferred only from the effects of brain injuries on the people who survived them. Such an approach offered little to illuminate the phenomena my colleagues and I were interested in. What we needed was a way to identify the regions of the brain that are engaged when healthy subjects are reading or trying to read.

Our group became quite excited, then, with the advent in the late 1980s of functional magnetic resonance imaging (fMRI). Using the same scanning machine that has revolutionized clinical imaging, fMRI can measure changes in the metabolic activity of the brain while an individual performs a cognitive task. Hence, it is ideally suited to mapping the brain's response to stimuli such as reading. Because it is noninvasive and uses no radioisotopes, fMRI is also excellent for work involving children.

Since 1994, I have worked with several Yale colleagues to use fMRI in studying the neurobiology of reading. Bennett A. Shaywitz, Kenneth R. Pugh, R. Todd Constable, Robert K. Fulbright, John C. Gore and I have used the technique with more than 200 dyslexic and nondyslexic children and adults. As a result of this program, we can now suggest a tentative neural architecture for reading a printed word. In particular, the identification of letters activates sites in the extrastriate cortex within the occipital lobe; phonological processing takes place within the inferior frontal gyrus; and access to meaning calls on areas within the middle and superior temporal gyri of the brain.

Our investigation has already revealed a surprising difference between men and women in the locus of phonological representation for reading. It turns out that in men phonological processing engages the left inferior frontal gyrus, whereas in women it activates not only the left but the right inferior frontal gyrus as well. These differences in lateralization had been suggested by behavioral studies, but they had never before been demonstrated unequivocally. Indeed, our findings constitute the first concrete proof of gender differences in brain organization for any cognitive function. The fact that women's brains tend to have bilateral representation for phonological processing explains several formerly puzzling observations: why, for example, after a stroke involving the left side of the brain, women are less likely than men to have significant decrements in their language skills, and why women tend more often than men to compensate for dyslexia.

As investigators who have spent our entire professional lives trying to understand dyslexia, we find the identification of brain sites dedicated to phonological processing in reading very exciting—it means that we now have a possible neurobiological "signature" for read-

Once the children have mastered phonemes of a given duration—say, 400 milliseconds—they can move on to more rapid, realistic phonemes. The youngsters also listen to stretched recordings of whole words, sentences and stories, such as *The Cat in the Hat*. Tallal and Merzenich reported in *Science* this past January that 11 children trained with these methods had acquired two years' worth of language skills in only one month. A control group given identical therapy, but without the stretched speech, progressed only one quarter as much.

This year Tallal, Merzenich and two colleagues founded a company called Scientific Learning Principles, based in San Francisco, to develop and market an interactive CD-ROM containing their learning program. They plan to test prototypes in 25 or more special education schools and clinics in the U.S. and Canada over the next year. As many as 500 children are expected to participate.

The studies will include not only language-impaired children but also those diagnosed with dyslexia, attention-deficit disorder and other common learning disabilities. "We want to determine the generalizability of this technique," Tallal notes. If all goes well, she says, the CD-ROMs will be made available to certified learning centers beginning next year.

Since the media first reported on this research a year ago, Tallal and her colleagues have been inundated with queries from the press and parents. In part to satisfy these demands, they have created a World Wide Web site (http://www.scilearn.com).

Tallal emphasizes that the questions raised by Coles and other skeptics about the causes and frequency of learning disabilities are important. She nonetheless thinks "it is a mistake to focus on all these differences in definition." Real progress, she says, will come about only through empirical research.

—John Horgan, staff writer

The Myths of Dyslexia

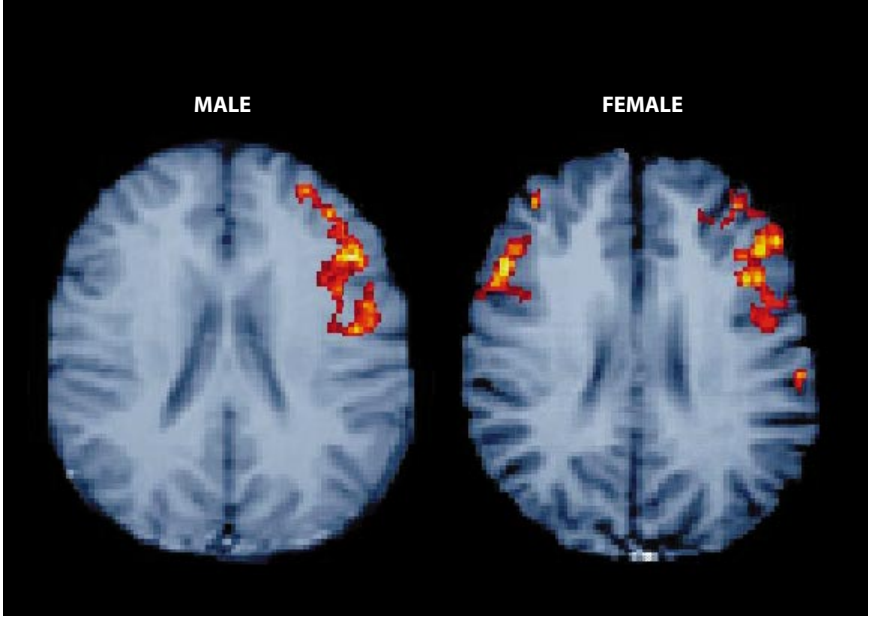
Mirror writing is a symptom of dyslexia.
In fact, backwards writing and reversals of letters and words are common in the early stages of writing development among dyslexic and nondyslexic children alike. Dyslexic children have problems in naming letters but not in copying letters.

Eye training is a treatment for dyslexia.
More than two decades of research have shown that dyslexia reflects a linguistic deficit. There is no evidence that eye training alleviates the disorder.

More boys than girls are dyslexic.
Boys' reading disabilities are indeed identified more often than girls', but studies indicate that such identification is biased. The actual prevalence of the disorder is nearly identical in the two sexes.

Dyslexia can be outgrown.
Yearly monitoring of phonological skills from first through 12th grade shows that the disability persists into adulthood. Even though many dyslexics learn to read accurately, they continue to read slowly and not automatically.

Smart people cannot be dyslexic.
Intelligence is in no way related to phonological processing, as scores of brilliant and accomplished dyslexics—among them William Butler Yeats, Albert Einstein, George Patton, John Irving, Charles Schwab and Nicholas Negroponte—attest.



BENNETT A. SHAYWITZ ET AL. *Yale NMR Research*

BRAIN ACTIVATION PATTERNS during reading, as revealed in these functional magnetic resonance images, differ in men and women. During phonological processing, men show primarily unilateral activation, in the left inferior frontal gyrus. In women, phonological processing activates both the left and the right inferior frontal gyri.

ing. The isolation of such a signature brings with it the future promise of more precise diagnosis of dyslexia. It is possible, for example, that the neural signature for phonological processing may provide the most sensitive measure of the disorder. Furthermore, the discovery of a biological signature for reading offers an unprecedented opportunity to assess the effects of interventions on the neuroanatomic systems serving the reading process itself.

Putting It in Context

The phonological model crystallizes exactly what we mean by dyslexia: an encapsulated deficit often surrounded by significant strengths in reasoning, problem solving, concept formation, critical thinking and vocabulary. Indeed, compensated dyslexics such as Gregory may use the "big picture" of theories, models and ideas to help them remember specific details. It is true that when details are not unified by associated ideas or theoretical frameworks—when, for example, Gregory must commit to memory long lists of unfamiliar names—dyslexics can be at a real disadvantage. Even if Gregory succeeds in memorizing such lists, he has trouble producing the names on demand, as he must when he is questioned on rounds by an attending physician. The phonological model predicts, and experimentation has shown, that rote memorization and rapid word retrieval are particularly difficult for dyslexics.

Even when the individual knows the information, needing to retrieve it rapidly and present it orally often results in calling up a related phoneme or incorrectly ordering the retrieved phonemes. Under such circumstances, dyslexics will pepper their speech with many um's, ah's and other hesitations. On the other hand, when not pressured to provide instant responses, the dyslexic can deliver an excellent oral presentation. Similarly, in reading, whereas nonimpaired readers can decode words automatically, individuals such as Gregory frequently need to resort to the use of context to help them identify specific words. This strategy slows them further and is another reason that the provision of extra time is necessary if dyslexics are to show what they actually know. Multiple-choice examinations, too, by their lack of sufficient context, as well as by their wording and response format, excessively penalize dyslexics.

But our experience at the Yale Center suggests that many compensated dyslexics have a distinct advantage over nondyslexics in their ability to reason and conceptualize and that the phonological deficit masks what are often excellent comprehension skills. Many schools and universities now appreciate the circumscribed nature of dyslexia and offer to evaluate the achievement of their dyslexic students with essays and prepared oral presentations rather than tests of rote memorization or multiple choices. Just as researchers have begun to understand the neural substrate of dyslexia, educators are beginning to recognize the practical implications of the disorder. A century after W. Pringle Morgan first described dyslexia in Percy F., society may at last understand the paradox of the disorder. SA

The Author

SALLY E. SHAYWITZ is, along with Bennett A. Shaywitz, co-director of the Yale Center for the Study of Learning and Attention and professor of pediatrics at the Yale University School of Medicine. She received her M.D. from the Albert Einstein College of Medicine in Bronx, N.Y., and has spent her entire professional career at Yale, where, since 1983, she has directed the Connecticut Longitudinal Study. Currently she is using functional magnetic resonance imaging to study the neurobiology of dyslexia in children and young adults. A pediatrician and neuroscientist, she received the impetus to study dyslexia from the many very bright dyslexics she came to know as patients, students and, often, colleagues. She acknowledges the helpful comments of the Shaywitz tribe—Adam, Jon and David—in preparing this article.

Further Reading

THE ALPHABETIC PRINCIPLE AND LEARNING TO READ. Isabelle Y. Liberman, Donald P. Shankweiler and Alvin M. Liberman in *Phonology and Reading Disability.* Edited by D. P. Shankweiler and I. Y. Liberman. University of Michigan Press, 1989.

LEARNING TO READ. Edited by Laurence Rieben and Charles A. Perfetti. Lawrence Erlbaum Associates, Hillsdale, N.J., 1991.

EVIDENCE THAT DYSLEXIA MAY REPRESENT THE LOWER TAIL OF A NORMAL DISTRIBUTION OF READING ABILITY. Sally E. Shaywitz, Michael D. Escobar, Bennett A. Shaywitz, Jack M. Fletcher and Robert Makuch in *New England Journal of Medicine,* Vol. 326, No. 3, pages 145–150; January 16, 1992.

SEX DIFFERENCES IN THE FUNCTIONAL ORGANIZATION OF THE BRAIN FOR LANGUAGE. Bennett A. Shaywitz, Sally E. Shaywitz, Kenneth R. Pugh, R. Todd Constable, Pawel Skudlarski, Robert K. Fulbright, Richard A. Bronen, Jack M. Fletcher, Donald P. Shankweiler, Leonard Katz and John C. Gore in *Nature,* Vol. 373, pages 607–609; February 16, 1995.

TOWARD A DEFINITION OF DYSLEXIA. G. Reid Lyon in *Annals of Dyslexia,* Vol. 45, pages 3–27; 1995.

Rock Art in Southern Africa

Paintings and engravings made by ancestors of the San peoples encode the history and culture of a society thousands of years old

by Anne Solomon

For more than three hours, Aron D. Mazel of the Natal Museum and I walked through the grassy foothills of the Drakensberg Mountains in KwaZulu-Natal, meeting not a soul on the way. Ultimately, we came to a wide cave half-screened by bushes and a splashing waterfall. Behind this watery veil are some of the finest specimens of ancient San, or Bushman, rock painting in South Africa. The water has not damaged them, although vandals have. We gazed at walls covered with more than 1,600 images of humans and animals engaged in myriad activities. That night, we slept in the cave, continuing our expedition the next day. At nearby sites, we collected tiny flakes of paint from 10 different works of art and then returned to Cape Town.

The pigment from a painting of an eland (the biggest local antelope) turned out to contain microscopic plant fibers. Mazel and Alan L. Watchman, who owns the laboratory Data-Roche Watchman, dated these strands at about 400 years old. Such a direct measurement is rare. Most pieces of rock art, painted in red, brown or yellow ocher—a hydrous iron oxide—contain no organic carbon. So radiocarbon dating, which measures the steady decline of the isotope carbon 14 in organic materials, cannot be used. The earliest date comes from a Namibian cave, where excavated floors contained painted slabs from between 19,000 and 26,000 years ago. But the remainder of the work seems to fall into the Holocene period—approximately the past 10,000 years.

The artists were among the earliest inhabitants of southern Africa, the ancestors of the modern-day San peoples. The term "San" is a linguistic label: the San and Khoi—formerly Hottentot—languages make up the Khoisan group of several dozen related languages and dialects, characterized by click sounds. The plant-gathering and hunting economy of the San has been extensively studied as a model of how early humans may have lived. In contrast, the Khoi were herders. About 1,500 to 2,000 years ago, the Khoi herders and groups of Iron Age farmers moved southward into San territories. Traces of that contact are evident in paintings of the fat-tailed sheep the Khoi brought with them, as well as those of cattle, assegais (spears) and shields, part of the culture of the Iron Age farmers.

Although inklings of this history can be gleaned from the paintings, the lack of reliable dates makes any detailed reconstruction difficult. It is only after the 15th century, when Europeans "discovered" southern Afri-

JENNIFER C. CHRISTIANSEN

ROGER DE LA HARPE *Anthony Bannister Photo Library*

ROCK ART, such as this painting of elands and humans (*right*) in Kamberg Nature Reserve in KwaZulu-Natal, is found all over southern Africa (*above*). Its range attests to the vast areas once occupied by the ancient San. (Except for those noted, all the paintings that follow are from KwaZulu-Natal.)

ca, that we begin to have a clearer picture of the historical conditions. In 1652 the Dutch established the first permanent settlement in Cape Town. As the newcomers expanded their domain, they frequently clashed with indigenous peoples, and the San way of life rapidly eroded. Thefts of cattle and horses by the San led to retaliatory raids by European farmers. Episodes are recorded in which entire San groups were massacred. The surviving communities were eventually absorbed into indigenous herding and farming societies or became laborers around European settlements.

The painting tradition is now long dead. Today relatively few San speakers live in the old ways, except in parts of Botswana and Namibia. Even in these remote areas, their ancestral lands and traditions are under pressure. In the past few years, nationalist movements have emerged, in response to the dispossession to which the Khoisan have frequently been subjected—by other Africans as well as by colonial orders. Only the wide distribution of archaeological sites, place-names and rock art alerts us to the vast areas once occupied by these peoples.

In studying the art, the archaeologist is forced to seek all imaginable clues. There are two overlapping classes of work: the paintings, which usually occur in caves and shallow shelters, and engraved boulders found in drier areas. The engravings, which are more often abstract, have until recently attracted scant attention from scholars. The style and subject matter of the paintings vary distinctly between regions. Sometimes a

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single site combines several styles, so that it is impossible to tell whether it is the work of different contemporary artists or art from different historical periods. Early researchers suggested that simpler or less delicate images, in one color only, are the oldest, with color range and stylistic intricacy evolving through time. Today we know there is no such straightforward correlation. Some of the roughest work is probably the most recent—perhaps the art of shepherds and children.

By far the most common subjects are humans, usually naked and in profile. Most seem to be male, but quantitative studies conducted by Patricia Vinnicombe (now at the Aboriginal Affairs Department of the government of Western Australia), the late Harald Pager and others show that the sex of at least half the figures cannot be identified. Also favored were large herbivores. Throughout South Africa, paintings of eland (*Tragelephus oryx*) predominate. In Zimbabwe, the eland is seldom painted; instead kudu (*T. strepsiceros*) is preferred.

ANNE SOLOMON

ANTHONY BANNISTER *ABPL*

DANCING, accompanied by clapping and singing in melodic overtones, is an integral part of San life. Women may dance alone, as in the painting at the left; a few are depicted with leather "aprons" that are still occasionally worn. The detail (*right*) from another painting of a dance probably depicts a

ANNE SOLOMON

PROBABLE RAIN CEREMONY, showing an animal being captured by rainmakers or shamans (*left*), is painted in red ocher. The man hanging onto the tail of an eland (*above*) is most likely also a shaman. In San mythology the eland is God's favorite animal—and, along with other large herbivores, is associated with rain.

Elephant paintings are found frequently in southwestern Cape Province but seldom in the Drakensberg Mountains to the northeast.

As excavations have shown, the emphasis given to particular animals does not simply reflect the local fauna, nor does it correspond with the most important food animals. With the exception of snakes, the San rarely painted reptiles and insects. To add to the mystery, they showed almost no interest in portraying the landscape.

In interpreting the rock art, researchers are lucky to have an enormous collection of testimony by San speakers. By far the richest body of material was collected a century ago, from people speaking a San language known as !Xam (the initial character is a click sound). In 1870 a group of !Xam San men from northern Cape Province were imprisoned in Cape Town for offenses ranging from stock theft to murder. Wilhelm H. I. Bleek, a German philologist, acquired custody of the men. They built huts at the bottom of his garden and worked as domestic servants, but mainly they supplied accounts of their traditions. While Bleek focused on the language, his sister-in-law Lucy C. Lloyd recorded most of the more than 10,000 pages of !Xam lore in *Specimens of Bushman Folklore,* written by W.H.I. Bleek, L. C. Lloyd and G. M. Theal (George Allen, London, 1911).

Rainmakers

The !Xam, unfortunately, no longer painted or engraved and could not comment directly on the art. Only one account detailing the process of painting is available. In the 1930s a Mrs. How located an old Sotho man named Mapote, who had had half-San stepbrothers. Mapote told Mrs. How that as a young man he and his stepbrothers "used to paint at one end of a cave whilst the true Bushmen painted at the other." In recreating that activity, Mapote used brushes made from feathers inserted into reeds and demanded the blood of a freshly killed eland to mix with his pigments. The subjects he chose to portray were eland, hartebeest (*Alcelaphus bu-*

female initiation ceremony. The !Kung San family above is celebrating a successful hunt in the Kalahari by dancing into the night. Note the white ostrich-eggshell knee bracelets on the woman at the bottom left; they resemble the white-dot decorations on the painted figures (*left*).

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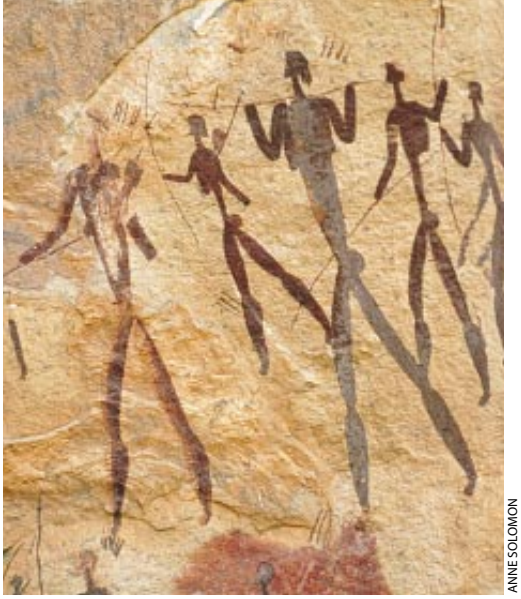

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HUMANS are represented in varying styles. The women shown here (*above, left*) are voluptuous, whereas the men carrying quivers full of arrows on their backs (*center*) are exceedingly tall and thin. The clothed figures (*right*), wearing leather cloaks known as karosses, have strange concave faces.

selaphus), lions and humans. Although we cannot be sure that his methods were the same as in the more distant past, Mapote provided a tantalizing glimpse into the making of rock art.

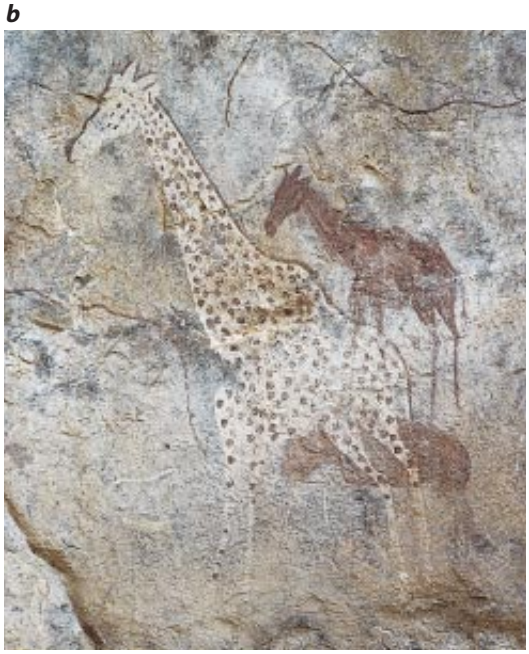
The !Xam testimony showed that hunting scenes were not as prominent as early researchers had believed. Some paintings originally thought to depict hunts almost certainly portray an important rainmaking ritual. The !Xam saw the rain cloud as an animal walking the countryside on "legs" of streaming rain. Rainmakers had to entice a large mythical herbivore from its home in a water hole, take it to a high place and slaughter it; where its blood ran, rain would fall. The depicted rain animals resemble such large herbivores as antelope or hippopotamus, but often with strange features and proportions. Both Khoi and San peoples still hold very similar beliefs about rain. Early in this century, an anthropologist recorded a Khoi ceremony involving animal sacrifice, which incorporated many features described by the !Xam.

How literally such connections should be interpreted is controversial. Since the late 1970s, J. David Lewis-Williams of the University of the Witwatersrand has argued that many paintings refer to occasions of ritual healing. These ceremonies are still practiced by communities in Botswana and Namibia. During a ritual dance that may last all night, sha-

a

ROGER DE LA HARPE *ABPL*

b



ANTHONY BANNISTER *ABPL*

DIVERSE ANIMALS occur in San art. The aardvark (*a*), overlaid with human figures, is from the Giant's Castle Game Reserve in South Africa. The giraffes (*b*) are from the Erongo Mountains in Namibia. Some rain animals resemble a hippopotamus (*c*); this one is from Zimbabwe. The delicate rhebok (*d*) is a game animal. The painting actually contains two rhe-

mans enter an altered state of consciousness induced by rhythmic movement, singing and clapping. In this hallucinatory state, they gain access to the spirit world, acquiring supernatural powers that allow problems besetting the community, including illness, to be resolved.

Various features of the rock art can be interpreted as references to shamanism. Some human figures are shown with red streaks under the nose; a shaman in a trance may indeed bleed from the nose. Lewis-Williams and his colleagues have proposed that shamanic hallucinations may have prompted the first making of art. They hypothesize that because humans all share the same neurological circuitry, visual hallucinatory forms should be the same throughout time—and that geometric designs drawn in the European Paleolithic and Bronze ages, as well as North American Indian art, may also be understood in terms of hallucinatory experiences.

Window on Culture

My own feeling is that the diversity of the art is better explained by multiple derivations and motivations. Several scholars have noted the extraordinary similarities between the mythology of San groups far distant from one another in time and space. All San peoples tell of a primeval time when animals were people; after an initial creation event, they differentiated. But these first people were often stupid, lacking customs and manners, and only after a second creation did they become the San of today. (According to one account, it took a single creation for men to become fully human, but two for women.)

Many stories recount the doings of these animal people. Some explain the origins of fire, heavenly bodies and other physical phenomena. We hear why the baboon has a hairless rump, why people marry and why death is inevitable. Other narrative themes include encounters with warlike neighbors or dangerous carnivores. Food is a constant preoccupation, with a surprising number of stories featuring autophagy—the eating of one's own body. (This theme may relate to the high symbolic value placed on meat; otherwise little is known about its significance.) The stories dramatize the dilemmas of existence that faced San hunter-gatherers and emphasize themes of death and regeneration.

The belief that animals were once people allows an interpretation of therianthropes—figures both human and animal. These paintings, and others of fantastic creatures, may portray beings from the primordial world. Alternatively, some may depict the shaman's experience of physical transformation during a trance—when shamans enter the realm of the spirits of the dead. But because the mythical world would have been known to all, nonshamans were probably also among the artists.

Notably, many creatures that occur in the mythology are not reflected in the art. To Lewis-Williams, this is because

ANNE SOLOMON

THERIANTHROPE (a half-animal, half-human figure) derives from San religious tradition. In the beginning, animals were humans; only after a creation event were they differentiated. This creature seems to be carrying a smaller antelope on its back.

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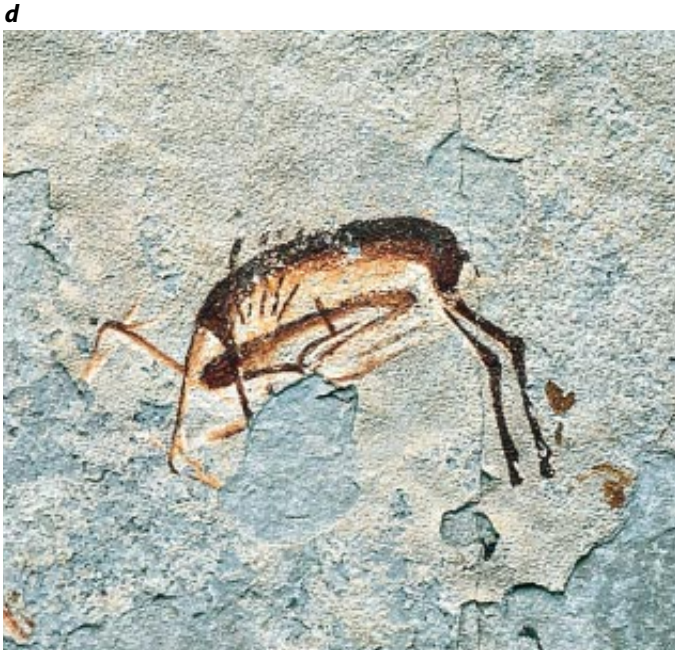
ANNE SOLOMON

d



ANNE SOLOMON

boks, superposed. (The second rhebok has its head downward.) Humans and large herbivores are believed to possess *n!ow,* a quality linked to birth, death and weather: good *n!ow* brings rain, whereas bad *n!ow* is associated with harsh conditions. The San's preference for portraying humans and large herbivores may have to do with their possessing *n!ow.*

ANNE SOLOMON

the art is more closely linked with ritual than with mythology. But a number of the stories deal with the relation between our world and that of the spirits and describe how the San perceived the universe. Although the art does not illustrate the myths, it draws on the same stock of religious beliefs. The mythology thus provides a context for both art and ritual. It seems likely that many sites were painted during, or in connection with, rituals or other such occasions.

One of my research sites in southwestern Cape consists overwhelmingly of images of women. This unusual prevalence, here and elsewhere, suggests that some locations may have been ritual sites used only by women, perhaps in connection with female initiation—a well-documented ceremony conducted when girls attained adulthood. One cannot necessarily assume, as many have, that the art was a male preserve.

Much of San gender ideology seems to center on the threat that sexually mature women were believed to pose to men and to the community. The !Xam believed that the female initiate could with a glance turn men into stone or into a tree. Yet, despite fear of her dangerous powers, a young woman's attainment of adulthood was a cause for celebration. (Male initiation seems to have been a far less important rite.)

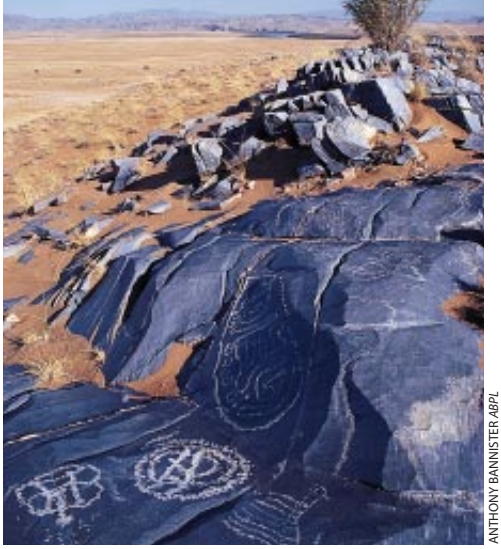
San societies are egalitarian, in the sense that all share access to resources, but in groups studied by anthropologists men have some advantages. Their status is enhanced by their being providers of meat—women are the gatherers of roots and fruits. It seems that only men were rainmakers, and in modern San groups, substantially more men than women are shamans. In fact, most of the very large and densely painted sites are peculiarly deficient of images of women. Possibly, sites with images primarily of one sex were painted during rituals conducted only by that sex.

Of course, paintings and engravings depicting European colonists may well be records of real events rather than ritual occasions. In addition, the art ap-

ARON D. MAZEL *Natal Museum*

ENCOUNTER with Europeans, and their guns and horses, is depicted in Beersheba Shelter in KwaZulu-Natal. Many San were killed in such episodes. Today the San, who once roamed across all of southern Africa, are confined to a few diminishing pockets.

ROGER DE LA HARPE *ABPL*



ANTHONY BANNISTER *ABPL*

ENGRAVINGS are found in arid areas, and the choice of subjects is puzzling. The boulder (*far left*), from northern Cape Province in South Africa, depicts antelopes. (Near its top left are sticklike figures of a European couple, probably added later.) Assorted animals are also chiseled into this cliffside in Khorixas, Namibia. But many engravings, such as these in the desert of southern Namibia (*above*), show abstract figures. Such patterns are now believed to have been inspired by hallucinatory experiences.

pears to reflect interactions between the San and other groups. John H. Parkington and members of the Spatial Archaeology Research Unit at the University of Cape Town have suggested that handprints found along the southwest coast, usually overlying earlier art, may have been the work of Khoi herders. Depictions of cattle introduced by the migrating herders and farmers, as well as iron artifacts, maize cobs and glass beads found in excavations, all testify to San involvement in other African economies.

Out of Date

In some ways, however, the art's full story remains tantalizingly outside the historian's reach. The main problem is that of dates. Mass spectrometry sometimes allows radiocarbon dating of trace amounts of organic materials contained in the binder that was mixed with the pigment. The possibility that a paint sample has been contaminated remains a snag, and it also seems that San artists did not always use binders. Our best information comes from material that has fallen from a cave wall into layered archaeological deposits on the floor. Charcoal or other organic substances in the deposits can be carbon-dated, providing an approximate age.

Although such finds are rare, Royden Yates and Antonieta Jerardino of the University of Cape Town have recently unearthed, in a west coast cave, painted slabs that are securely dated to about 3,500 years ago. And in addition to the cave that Mazel and I visited in KwaZulu-Natal, one other site has yielded a precise date. In southwestern Cape Province, archaeologists from the University of Cape Town have sampled a painting of a human figure in black. Because the paint was probably charcoal-based, it contained enough carbon for radioactive dating and proved to be about 500 (plus or minus 140) years old.

Apart from the pressing problem of dating, much else remains to be done. Unexplored areas remain: new discoveries and interpretations endlessly prompt new questions and debates. As an extraordinary and evocative record of the past, San rock art is becoming part of the culture of postapartheid South Africa. Yet paintings are slowly fading, flaking off the rock or being obliterated by graffiti, and engraved boulders are vanishing. Through the combined efforts of a spectrum of specialists, we hope to ensure that the rock art will endure as a testament to an ancient African culture, tragically displaced. SA

See "Science Safari," a Scientific American Frontiers *look at South Africa, airing on PBS November 20.*

The Author

ANNE SOLOMON is a research associate at the University of Cape Town in South Africa, where she also obtained her Ph.D. She has studied extensively the connections of San rock art and gender ideology. Solomon is a committee member of the South African Archaeological Society and serves on the editorial board of the *South African Journal of Field Archaeology.* Her current research focuses on the technology of painting and the problem of dating.

Further Reading

NDEDEMA. Harald Pager. Akademische Druck-u Verlagsanstalt, Graz, 1971.

PEOPLE OF THE ELAND. Patricia Vinnicombe. University of Natal Press, 1976.

BELIEVING AND SEEING: SYMBOLIC MEANINGS IN SOUTHERN SAN ROCK PAINTINGS. J. David Lewis-Williams. Academic Press, 1981.

HUNTERS AND HERDERS OF SOUTHERN AFRICA. Alan Barnard. Cambridge University Press, 1992.

MISCAST: NEGOTIATING THE PRESENCE OF THE BUSHMEN. Edited by Pippa Skotnes. University of Cape Town Press, 1996.

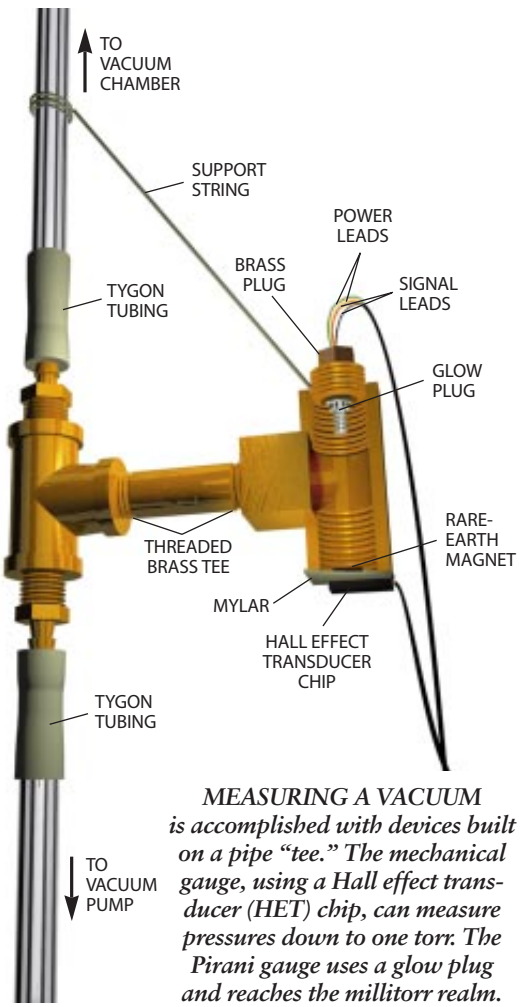
by Shawn Carlson

Much Ado about Nothing

I am convinced that all successful scientists, professional or amateur, start off as discovery junkies. The experience of making an original find, of knowing that no one else has ever had your particular insight, is utterly addictive. There is no better way to feed this addiction than by expanding your laboratory's capacity for discovery. Last month's column focused on how to create a vacuum—a process that opens up many marvelous opportunities for exploring nature. This column completes the discussion by describing how to measure very low pressures.

To cover the range of pressures obtainable by the vacuum system described in October's column, you'll need two different gauges. One is a mechanical gauge that responds directly to the force that gas molecules apply to a diaphragm; it can record pressures down to about one torr. (A torr is the pressure required to elevate a column of mercury to a height of one millimeter. One atmosphere is about 760 torr.) Below this level one needs to resort to more sensitive devices, such as a so-called Pirani gauge, which can infer the pressure from other, related properties of a gas. Some such gauges can work above one torr, but they are much less convenient than the mechanical gauges. In addition to the gauges, you'll need an assembly that connects them to the vacuum.

The mechanical gauge is an adaptation of the technique to detect such micromovements as insect heartbeats that I described in the August column. It relies on the motion of a magnet and a Hall effect transducer (HET), an inexpensive chip that can be used to sense tiny changes in magnetic fields. You can purchase one from Honeywell Micro Switch in Freeport, Ill.: call (800) 537-6945 or (815) 235-6847; ask for model number SS94A1F.



BRYAN CHRISTIE

MEASURING A VACUUM is accomplished with devices built on a pipe "tee." The mechanical gauge, using a Hall effect transducer (HET) chip, can measure pressures down to one torr. The Pirani gauge uses a glow plug and reaches the millitorr realm.

First, place a bead of epoxy all around the rim of an old mayonnaise jar's mouth and stretch over it a thin sheet of Mylar. Once set, epoxy a rare-earth magnet (Radio Shack; part number 64-1895; $2) to the center of the sheet. Next, thoroughly coat one rim of a 1/4-inch-diameter brass pipe "tee" with epoxy. Affix the coated rim to the Mylar, making sure that the rim is centered over the magnet. After the epoxy has set, with an X-Acto knife gently cut the Mylar at the rim of the jar and carefully trim the excess Mylar from the pipe fitting. Finally, affix the HET to the pipe so that its sensitive area is centered on the Mylar membrane. Epoxy a 1/4-inch-wide plastic washer over the rim and then glue the HET to the washer. Make sure the HET's sensor is directly over the magnet.

As the pressure inside the tee falls, the Mylar will flex inward and move the magnet away from the HET. Use the "slowly varying signal" circuit described in the August column to register the displacement. You'll need to experiment to find the right gain. If set too high, the instrumentation amplifier will quickly saturate and thereby become ineffective; too low, the measurement won't be as sensitive as it could be.

You can build the rest of the vacuum assembly from a few dollars' worth of brass plumbing parts, all with 1/4-inch diameters. Completely coat with epoxy the threads of two devices known as hose-barb adapters. Tightly screw them into a brass pipe tee and epoxy a short length of pipe into the tee's center. To the other end of this pipe, connect the tee that has your mechanical gauge. Tygon tubing (check your local hardware store) links the adapters to the 1/4-inch-wide pipe of your vacuum system.

My simple gauge, which I slapped together in about an hour, bottoms out at about a couple of torr. There are plenty of ways to improve the performance of the instrument, and I invite you to experiment with variables such as the thickness of the Mylar, the area of the membrane, electronics, construction techniques and so on. I'll happily post your innovations to the Society for Amateur Scientists's World Wide Web site.

Even the most refined mechanical gauges, however, will not be able to detect pressures below about one torr. Getting to that range requires a clever alternative. It turns out that the ability of a gas to conduct heat is nearly independent of pressure over an amazingly wide range of pressures. Near one torr, however, the gas becomes so tenuous that its thermal conductivity begins to drop. This drop continues until the thermal conductivity reaches essentially zero at about one millitorr. You can exploit

the relation to measure pressures between one torr and one millitorr.

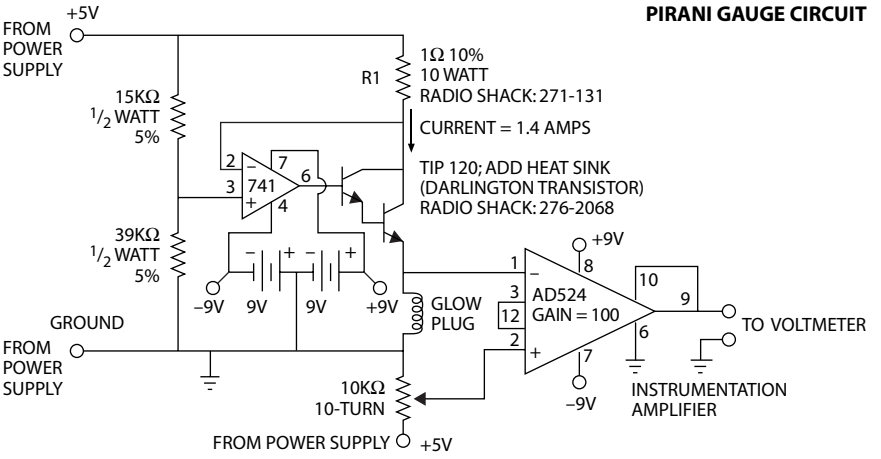
The simplest gauge that measures thermal conductivity is the Pirani gauge. I tip my inventor's hat to Bruce R. Kendall, a physicist at Pennsylvania State University, for developing a wonderfully straightforward, robust and inexpensive type of Pirani gauge. The heart of Kendall's sensor is a glow plug: a platinum-alloy filament used to fire the cylinders in some types of engines, for example, diesel. But the Pirani gauge requires a smaller version of the glow plug, such as those used in model airplanes. They are available at hobby shops and cost less than $10. I've achieved satisfactory results with the O. S. Engine model A5, which retails for about $8.

Kendall's device takes advantage of the fact that a metal's electrical resistance changes with temperature. Kendall connects his glow plug to a source of constant current and then measures the voltage difference between the leads. The pressure sets the rate at which heat is conducted from the wire, which in turn changes the wire's final temperature and therefore its resistance. Because resistance is simply the voltage across the wire divided by the current flowing through it, this changing resistance produces a shift of a few millivolts that you can easily measure.

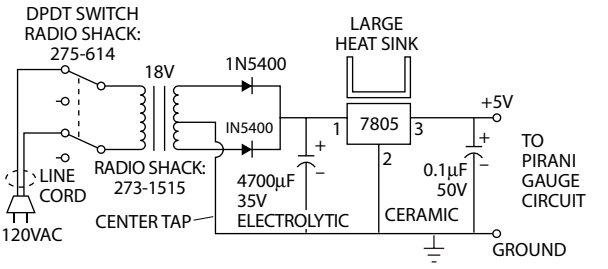
You'll need a source of constant current that can produce about 1.4 amperes. The circuit shown at the right is easy to construct and does the trick. The circuit relies on the AD524 chip, an outstanding instrumentation amplifier available from Analog Devices in Norwood, Mass.; call (800) 262-5643, ext. 3, for a local distributor. You can also construct an instrumentation amplifier from three type 741 operational amplifiers (see August's column for details).

Warning: A few coiled snakes lurk within the power supply. For protection from the line voltage, encase the circuit inside a project box. The first time I built this circuit the 4,700 microfarad capacitor blew apart because I installed it backwards (it could not handle the current flow). Young experimenters should not build this circuit without adult supervision. Also, because this circuit generates a respectable amount of heat, you must drill a few arrays of 1/8-inch-wide vent holes in the back of the box. The heat from the 7805 power supply

PIRANI GAUGE CIRCUIT



5-VOLT POWER SUPPLY



BRYAN CHRISTIE

***CIRCUITS** supply a constant current to the Pirani gauge and convert household current to five volts of direct current.*

chip must be drawn away, or the chip will overheat and shut down. Radio Shack sells an inexpensive heat sink (no. 276-1363, $1) as well as a heat-sink compound to ensure a good connection (no. 276-1372, $2).

The power supply circuit can deliver at most a continuous current of 1.5 amperes. The Pirani gauge will draw a nominal 1.4 amperes, but the exact current depends quite sensitively on the value of the power resistor (labeled "R1" in the schematic). The one-ohm Radio Shack model has a 10 percent tolerance, which means that its actual value could vary between 0.9 and 1.1 ohms. If it is less than 0.95 ohm, you risk drawing too much current from the power supply. Use a digital multimeter to ensure that the resistance is above 0.95 ohm.

To secure your Pirani gauge inside the vacuum housing, drill a small hole through a 1/4-inch-wide brass plug and thread two insulated contact wires through it. Connect one wire to the glow plug's housing and the other to the terminal at the bottom so that the glow plug rests as closely as possible to the brass plug. Next, coat the body of the gauge (but not the filament!) with enamel-based paint to insulate it electrically from the vacuum housing. Thoroughly fill the hole with epoxy, then screw the plug into the brass tee. You may be able to keep the plug from leaking air by wrapping Teflon tape around its threads before screwing it in, but I had to resort to epoxy. (Teflon tape will enable you to remove the plug for maintenance—when my glow plug burns out, I'll have to rebuild the whole assembly).

I have never needed to calibrate a vacuum gauge, and you probably won't either. That's because many applications require only a rough estimate of the pressure. And that's a lucky thing because calibrating a low-pressure gauge can be nightmarish. Its response is often not a linear function of pressure. Pirani gauges are even worse because their response depends on the particular gas being evacuated.

But if you're set on calibrating your gauges, you'll have to compare them with calibrated instruments. I suggest you call on local scientists, who are often happy to open their laboratory doors for such projects. But no matter how carefully calibrated your gauge, in real working conditions you'll be lucky if you can determine the pressure to within a factor of two. SA

For more information about amateur science projects, visit the Society for Amateur Scientists's World Wide Web site at http://www.thesphere.com/SAS/ or call (800) 873-8767 or (619) 239-8807.

by Ian Stewart

A Guide to Computer Dating

In 46 B.C. the Roman calendar was getting out of sync with the seasons. On the advice of the Alexandrian astronomer Sosigenes, Julius Caesar introduced an extra day into every fourth, or "leap," year to make the average length of the year 365 1/4 days. Misunderstanding the rule, his priests counted the fourth year of one cycle as the first in the next, so every third year became a leap year. The mistake wasn't fully sorted out for 50 years.

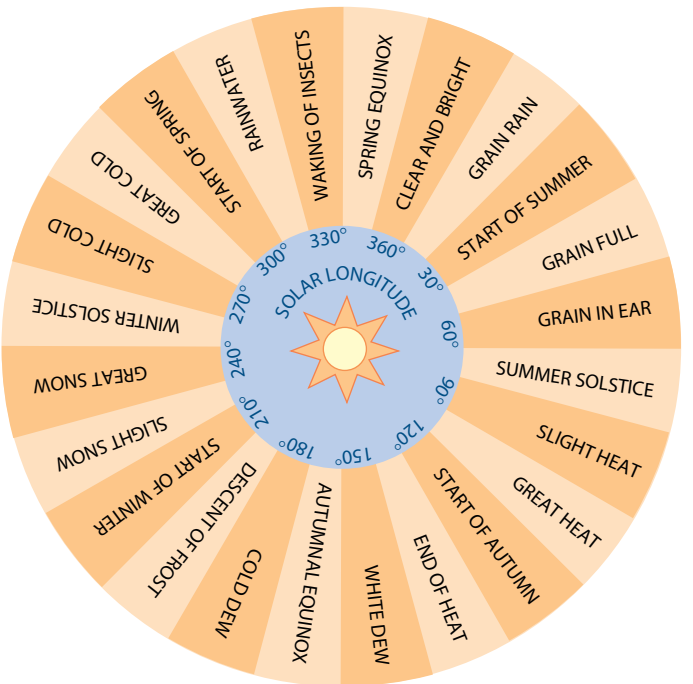
We need not make such dating errors again. About 10 years ago Nachum Dershowitz and Edward M. Reingold of the University of Illinois decided to develop calendar and diary features for the Unix-based editor GNU Emacs. Out of this project grew a computer code for converting dates from one calendric system to another. The 14 calendars included are the Gregorian, International Organization for Standardization (ISO), Julian, Coptic, Ethiopic, Islamic, Persian, Baha'i, Hebrew, Mayan, French Revolutionary, Chinese, old Hindu and modern Hindu.

Calendars vary from culture to culture because they are all attempts to perform the impossible: to rationalize the irrational. Our units for time are based on three astronomical cycles—the day, month and year. A 24-hour mean solar day is the period between successive occasions when the sun is overhead. The period between successive new moons is the mean synodic month, which lasts 29.530588853 days. The time required for the sun to return to the same position in its apparent path is the mean tropical year of 365.242199 days. If the lunar period were 29.5 days and the solar period 365.25, then the moon would repeat its motion exactly every 59 days (2×29.5) and the sun every 1,461 days (4×365.25). So every 86,199 days ($59 \times 1{,}461$), the system of earth, moon and sun would return to precisely the same relative position. A calendar with an 86,199-day cycle would remain in step forever (ignoring slow changes caused by tidal friction).

Unfortunately for calendar designers, the ratios between days, months and years behave like irrational numbers: they are not expressible as exact fractions (at least, using relatively small numbers). So the lunar and solar cycles never actually return to precisely the same state.

In practice most cultures decide either on a solar calendar and fudge the months or on a lunar calendar and ignore problems with the seasons. Whatever the choice, the calendar designer must find practical ways to deal with small cumulative errors. Hence, the complicated paraphernalia of leap days, months of variable length and so on. To find out just how complex it can get, consult a copy of Reingold's *Calendrical Calculations* (Cambridge University Press, 1996) or visit the book's home page on the World Wide Web (http://emr.cs.uiuc.edu/home/reingold/calendar-book/index.html).

The simplest calendric system would just number consecutive days, choosing some convenient "epoch," or starting day. Astronomers use the Julian day, but Dershowitz and Reingold prefer an invention of their own: the "fixed date" or *rata die,* abbreviated to R.D. Thus, day 1 of the R.D. system is January 1 in year 1 of the Gregorian calendar, the calendar we now use. There was no actual year 1 in the Gregorian calendar, because it was introduced in 1582 by Pope Gregory XIII, so we extrapolate backwards. The "first" day was a Monday, which allows us to take day 0 as the previous Sunday and number the days of the week from 0 to 6. *Calendrical Calculations* uses the R.D. value as a common reference system.



JENNIFER C. CHRISTIANSEN

CHINESE CALENDAR
contains a solar year divided into 24 terms.

Here are two simple warm-up problems that exemplify the type of mathematics required:

1. What day of the week will 1,000,000 R.D. be?

2. How many complete mean tropical years will elapse between 0 and 1,000,000 R.D.?

To answer the first question, observe that the days of the week form a repeat-

ing cycle of length 7. Therefore, any R.D. that is a multiple of 7 must be a Sunday, any that leaves a remainder of 1 on division by 7 is a Monday, and so on. We say that the day number is the R.D. number modulo 7. In general, x modulo 7 means to find the remainder on dividing x by 7. Because $1{,}000{,}000 = 7 \times 142{,}857 + 1$, this remainder is 1 when $x = 1{,}000{,}000$. So 1,000,000 R.D. is a Monday.

To answer the second question, divide 1,000,000 by 365.242189 to get 2,737.9093. This tells us that 1,000,000 R.D. occurs 2,737 complete (mean tropical) years after 0 R.D. We find 2,737 by omitting everything after the decimal point. Mathematically, this operation is performed by the "floor function" $\lfloor x \rfloor$, which is the greatest integer less than or equal to x.

Now consider converting a Gregorian date, such as December 25, 1996, to its R.D. value. Recall Pope Gregory's leap-year rule: multiples of 4 have an extra day on February 29, unless they are multiples of 100 (but multiples of 400 are also leap years). Dershowitz and Reingold show that this rule leads to the prescription in the box above. Then with the month M = 12, the day D = 25 and the year Y = 1996, we get (a) = 728,175, (b) = 498 – 19 + 4 = 483, (c) = 336, (d) = –1 and (e) = 25. The R.D. value is 728,175 + 483 + 336 –1 + 25 = 729,018. The day of the week is therefore 729,018 modulo 7 = 3; so Christmas 1996 will happen on a Wednesday.

To see the complexity that *Calendrical Calculations* handles with ease, consider the modern Persian calendar. It was adopted in 1925, but its epoch is March 19, A.D. 622—the vernal equinox prior to the epoch of the Islamic calendar. There are 12 months: the first six have 31 days, the next five have 30, and the last—*Esfand*—has 29 in an ordinary year and 30 in a leap year. The leap-year pattern is highly intricate. It follows a cycle of 2,820 years, containing 683 leap years.

The 2,820 years are divided into 21 subcycles of 128 years, followed by one of 132. Each 128-year subcycle is divided into sub-subcycles of lengths 29 + 33 + 33 + 33, whereas the 132-year subcycle is divided as 29 + 33 + 33 + 37. Finally, in each sub-subcycle, the years 5, 9, 13 and so on—going up by fours—are leap years. The Persian calendar is

in error by 1.7 minutes at the end of one 2,820-year cycle, so it would take 2.39 million years to slip a day relative to the true astronomical cycles!

The old Hindu lunisolar calendar follows a very different pattern. The overall structure involves a cycle lasting 1,577,917,500 days. The "year" (strictly the *arya* sidereal year) is $^1/_{4,320,000}$ of this number, or 365.258 days. Each solar month is $^1/_{12}$ of a year. Each lunar month is $^1/_{53,433,336}$ of the 1,577,917,500-day cycle, equal to 29.531 days. The basic idea is to run both months simultaneously. Every so often a lunar month is completely contained in a solar month. In that case, that lunar month is considered to be a leap month; an extra lunar month is inserted following it.

Unlike the other calendars, the Chinese one is based on astronomical events, not arithmetical rules. The version implemented in *Calendrical Calculations* is the most recent, dating from 1645. Months are lunar, beginning with the new moon, and years contain either 12 or 13 months. The arrangement of the months, however, depends on the passage of the sun through the signs of the zodiac. The solar year is divided into 12 major solar terms, called *zhongqi*, and 12 minor solar terms, called *jieqi*. Each term corresponds to a 15-degree segment of solar longitude, the major ones starting at multiples of 30 degrees and the minor ones in the gaps between those.

The basic rule is that the winter solstice always occurs during the 11th month of the year. In a year that contains only 12 complete lunar months, therefore, the months are always numbered 12, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11. In a year that contains 13, however, one of the numbers is duplicated in a leap month, the first month that does not contain a major solar term. (Because there are 13 lunar months and only 12 major solar terms, at least one lunar month must fail to contain a major solar term.)

Present-day calendars are so complex—what of the future? All the various astronomical cycles are slowly changing their lengths because of gravitational tidal forces. Moreover, there is the precession of the equinoxes, which has occasional glitches related to ice ages—so a future calendar must be linked to climate.

In fact, the calendar must be interactive, adjusted according to what actually happens, not just based on preset rules, because astronomers have discovered that the motion of the solar system is chaotic. New Year's Day in A.D. 10,000,000 may still be the first of January, but nobody can predict how many days from now that will be. SA

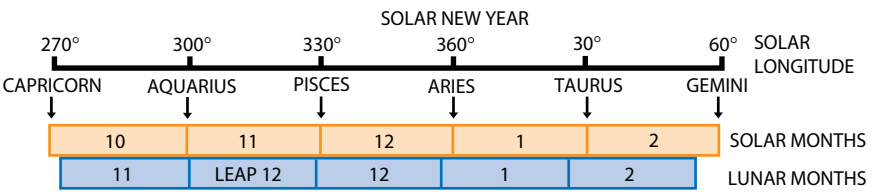
The *Rata Die*

To find the R.D. value of month M, day D and year Y in the Gregorian calendar, compute (⌊ and ⌋ are "floor" functions):

(a) 365 (Y-1)
(b) ⌊(Y–1)/4⌋–⌊(Y-1)/100⌋+⌊(Y–1)/400⌋
(c) ⌊(367M – 362)/12⌋
(d) 0 if M ≤ 2, –1 if M > 2 and Y is a leap year, and –2 otherwise
(e) D

and add them together.

Item a is the number of nonleap days in prior years; and b is the number of leap days in prior years (one every fourth year, except that every 100th year is omitted; but you put back every 400th). Item c is a cunning formula for the number of days in prior months of year Y, based on the assumption that February has 30 days, which it doesn't; hence, the correction term d. In step e the number D is of course the number of days in the current month—the only days not yet counted.



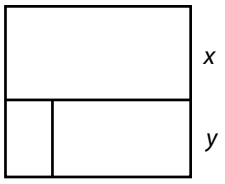
OLD HINDU LUNISOLAR CALENDAR
has solar and lunar months running concurrently, leading to leap months.

JENNIFER C. CHRISTIANSEN

FEEDBACK

The June column focused on the "plastic number" made popular by Richard Padovan and the associated sequence of "Perrin numbers." Padovan pointed out that the plastic number was invented by a French architectural student, Gérard Cordonnier, in 1924 and by a Dutch Benedictine monk-architect, Hans van der Laan, in 1928. He added that, as I had speculated, his family indeed originated in the Italian city of Padova.

Ervin Wilson of Los Angeles discovered that the Padovan sequence (which should perhaps be rechristened) is closely related to the *S'lendro* musical scale used in Javanese and Balinese music. This scale and another called *Pélog* can be elegantly derived from patterns in Pascal's triangle; these patterns are in turn related to the Padovan sequence. John H. Bonnett, Jr., of Livingston, N.J., sent me a wealth of information, and I offer one example. If a square is divided into three similar (same shape, different size) rectangles, as in the figure, then the ratio of the two pieces along the vertical edge is the plastic number.



Plastic number is the ratio **x/y**.

Jeffrey Shallit of the University of Waterloo pointed out that in 1982 he had found two "Perrin pseudoprimes," nonprime numbers n that divide the Perrin number A(n). His values are $n = 271{,}441 = 521^2$ and $n = 904{,}631 = 7 \times 13 \times 9{,}941$. (The first was published by William W. Adams and Daniel Shanks, also in 1982.) The calculation by Steven Arno that I mentioned concerns a special class of Perrin pseudoprimes, not all of them. John P. Robertson of Berwyn, Pa., added that he had found no other Perrin pseudoprimes less than 2,900,000. Can readers find further examples? —*I.S.*

ENCYCLOPAEDIA BRITANNICA; MERRIAM-WEBSTER

THE WORLD ON A PLATTER

Review by Timothy Ferris

Encyclopedia Americana on CD-ROM
Grolier Education, 1996 (Windows, Macintosh or DOS, $595)

Britannica CD 2.02
Encyclopaedia Britannica, 1996 (Windows or Macintosh, $299)

Compton's Interactive Encyclopedia
1997 edition. Compton's New Media, 1996 (Windows, $50)

Microsoft Encarta97 Encyclopedia
Deluxe edition. Microsoft Corporation, 1996 (Windows or Macintosh, $79.95)

Grolier Multimedia Encyclopedia
1997 edition. Grolier Interactive, 1996 (Windows or Macintosh, $59.95)

McGraw-Hill Multimedia Encyclopedia of Science & Technology
McGraw-Hill, 1995 (Windows, $1,300)

Encyclopedias seem ideally suited to the CD-ROM format. In this new incarnation they can offer something to everyone, from scholars short on bookshelf space to students delighted to find that their homework includes watching cartoon animations that feature digital sound. A few months spent using six leading encyclopedias indicates that most of them have indeed made a graceful transition to the brave new world of multimedia. Whereas for some works, this is simply a matter of putting old—if tasty—wine in new bottles, others are rapidly mutating into something novel. Asking which is "better" is like deciding between a screwdriver and a laser pointer: it depends on the task at hand.

Multimedia features are at a minimum in the three high-priced encyclopedias—the *Americana,* the *Britannica* and the *McGraw-Hill*—and that turns out to be both good news and bad.

Scientists and enthusiasts of science who prized the hard copy edition of the *McGraw-Hill Multimedia Encyclopedia of Science & Technology* will love the CD-ROM version. It's lean, mean and effective—a powerful resource that wears its learning lightly. It installs and boots up without making a fuss, and its user interface has the intuitive ease that has become almost essential in an age when savvy computer users would sooner be caught counting on their fingers than paging through a manual. Its search engine is efficient and free from bothersome idiosyncrasies. It can display multiple articles simultaneously, each in its own window, a handy feature. Although it calls itself a "multimedia" encyclopedia, *McGraw-Hill*'s fanciest offerings consist of a few dozen rudimentary animations. Although plain and simple, they are generally accurate and to the point.

Britannica weighs in with the assets one expects from the grande dame of general encyclopedias—long, authoritative articles that are often written well enough to keep you reading after you have answered the specific question that brought you there. Her admirable content aside, however, the old lady shows alarming signs of being caught in a precarious position, with one foot in the leatherbound, five-foot bookshelf of her distinguished past and the other in the departing digital dinghy. Installation can be cranky, the screen displays only a few hundred words of text at a time, and user support consists of leaving an answering-machine message that is returned days later if at all. But the glitches are being repaired (version 2.02 is a big improvement over version 2.0), and *Britannica*'s splendid content certainly counts for a lot.

The publisher claims that *Britannica* contains more than 2,000 illustrations, but they are kept out of the way and seem almost an afterthought in comparison with the over 40 million words of text. Nor are there any animations, video clips or sound files. *Americana* is staider still. Nothing more than line drawings and diagrams, not even any photographs, augment its 25 million words of sober text. This does lend the disk flexibility, however: because it contains little more than words, the same CD-ROM can be accessed from Windows or DOS or on a Macintosh. The scientific content of *Americana* seems sound, if sometimes a bit dated.

The three shorter, more reasonably

priced encyclopedias dwell in the realm of true multimedia, offering easy access to brief, breezy articles accompanied by plenty of sounds and moving pictures. Illustrated timelines and ample hypertext links make them attractive to students, and all three CD-ROMs include educational games to help younger users get involved.

Grolier's was the first major encyclopedia to go digital, and the company's experience shows in version 9. But its attractive package often emphasizes form over substance, leading to quick letdowns for readers who want to explore a subject in depth. The writing is at once wordy and short, and often blousy and vapid to boot: "Man-made violence was front-page news all too often," says the narrator of a recent-history slideshow, who sounds as if she has no more idea than anyone else what that is supposed to mean. An animation on nuclear fusion misses most of the important points while pelting the viewer with unnecessary jargon.

Compton's is comparably heavy on condiments and short on beef. Although a breeze to use, it is flawed by a bumptious brashness that tries to pass itself off as sophistication. Here, as in the fake-leather *Compton*'s of old, one constantly runs into sentences that sound less like a reference work than like a high school term paper cribbed from one. We are informed that "although she fancied herself a genius and published a number of books and plays, Gertrude Stein is remembered best for the talented people who visited her in Paris, France." Much more assured is *Compton*'s multimedia side, which features a superior planetarium/space exploration game and six "exploration" programs aimed at getting kids involved creatively. ShowMaker, which makes it easy for students to combine material they have gathered from the encyclopedia into a multimedia presentation, is good, creative fun, despite its bittersweet implication that pure print is being bid a hasty farewell.

Encarta is rather more literate, noting that Gertrude Stein's "experiments with prose were frequently misunderstood and erroneously construed as meaningless" and offering a palatable sound clip of an actress reading Stein's sonorous poem "Susie Asado." Its multimedia embellishments are spotty, with many lost opportunities: an article on sound recording, amazingly, includes no sound beyond a dry male voice discussing CD technology, and three seconds of poorly recorded music intended to demonstrate its capabilities. But there are some compelling film clips, from Igor Sikorsky piloting a prototype helicopter to Louis Armstrong singing a snatch of the blues, and good still photographs, too. To contemplate Aaron Copland's craggy visage while hearing an excerpt from his "Appalachian Spring" (although the caption is silent about who's conducting it) is to be reminded that sound can be more moving than moving pictures are.

Encarta's "deluxe" edition comes on not one but two CDs. This ups the mul-

ON THE SCREEN

The Island of Dr. Moreau
DIRECTED BY JOHN FRANKENHEIMER
New Line Cinema, 1996

Striking special effects and Marlon Brando are the two best reasons to see the latest film adaptation of H. G. Wells's classic science-fiction novel. The deranged Dr. Moreau—whose experiments to transform animals into humans have populated an island with hideous half-breeds—is played by Brando as an uproarious cross between Charles Laughton and Audrey Hepburn.

The film is entertaining but scientifically absurd. And don't look for any complex, or even coherent, insights into the ethics of experimenting on living beings. One of the few wise characters is an animal-human hybrid, who bears the title of "Sayer of the Law." Toward the end of the film, he bristles at the suggestion that scientists might be able to help him and his fellow creatures by finishing Moreau's work: "No. No more scientists. No more laboratories. No more experiments. I thought you would be able to understand that. We have to be what we are."

In wrapping up the movie with this platitude, director John Frankenheimer discards a chance at a nice bit of irony. The wisdom that allows the law sayer to decry the dangers of "science" (biotechnology actually, but we'll cut him some slack—he's half-beast) was made possible by that very same science: Moreau's warped handiwork. *—Glenn Zorpette*

timedia ante but also entails a lot of disk swapping.

Most of the CD-ROMs reviewed here offer on-line connections capable of freshening them beyond the dreams of the encyclopedists of old. NASA's claim to have found evidence of life on Mars, for instance, was available to be downloaded within days of its making headlines. So while they retain many of their old faults, multimedia encyclopedias also open out toward a bright future. The very audacity of the encyclopedias' charter—to encompass the totality of knowledge in a single publication—remains part of their appeal, as does their inevitable failure to attain it, even while the Net sings its siren song that all will soon be known to all.

TIMOTHY FERRIS is professor of journalism at the University of California, Berkeley. His latest book, The Whole Shebang: A State-of-the-Universe(s) Report, *will be published by Simon & Schuster in the spring.*

PETER SOREL *New Line Cinema*

HEAVY META

Review by John Polkinghorne

From Physics to Metaphysics
BY MICHAEL REDHEAD
Cambridge University Press, 1995
($29.95)

Is There a God?
BY RICHARD SWINBURNE
Oxford University Press, 1996
($19.95)

Everyone has a metaphysics—a worldview—just as all people speak prose, whether they are aware of it or not. Science can and should contribute to that worldview, but it should by no means monopolize it. Unless you are one of those biologists so flushed with the recent success of your discipline that you are moved to claim that "science is all," you will want to locate scientific understanding within a wider view of knowledge that gives equally serious consideration to other forms of human insight and experience. If for convenience we call the scientific perspective "physics," then we can fittingly call that stereoscopic view "metaphysics," for it goes beyond ("meta") the purview of science alone.

As these two very different books demonstrate, there is no unique way to go from physics to metaphysics. There are, however, conditions of consonance that place limits on the exercise. Although one view (scientifically obtained or otherwise) does not determine the full nature of a landscape, it imposes certain requirements on it: that stretch of water on which the sun is glinting amid the trees must find some place in the overall scene, whether as the beginning of a great lake or as the bend in a small river.

Most philosophers agree that metaphysical theories should be elegant, economical and coherent—even though they may disagree on the application of those criteria. We can further expect consensus that a metaphysics should explain the entire set of phenomena that are fundamental to human experience. But even more disputes arise here: some thinkers espouse a wide view; others treat only a narrow portfolio of experience as basic. I always encourage my skeptical scientific friends to adopt a more generous (and, in my view, more

BRIEFLY NOTED

LAURA SOUTHWORTH

IN SEARCH OF NATURE, *by Edward O. Wilson. Island Press, 1996 ($19.95).*
BIODIVERSITY II, *edited by Marjorie L. Reaka-Kudla, Don E. Wilson and Edward O. Wilson. Joseph Henry Press, 1996 ($34.95).*
Why should we care if other species go extinct? These books offer the short and long answer to the question. Edward O. Wilson's solo offering makes the case in a series of brief, elegant essays; he also gives a clear introduction to his controversial ideas on sociobiology. The edited anthology methodically pieces together the extent of biodiversity, the threats it faces and the practical measures needed to preserve it. Although not aimed at the lay public, these papers should not intimidate anyone with a serious interest in the subject.

THE NIGHT IS LARGE, *by Martin Gardner. St. Martin's Press, 1996 ($29.95).*
Martin Gardner was this magazine's "Mathematical Games" columnist for over a quarter of a century; the 47 essays in this volume (written between 1938 and the present) show how mathematics has informed but never limited the scope of his inquiry. Discussions of Shakespeare and God mingle with a stinging critique of supply-side economics and a rumination on the failure of the "new math." The parts are unified, in Gardner's words, by "this sense of endless, unfathomable magic that envelops almost everything I have written."

IN SMALL THINGS FORGOTTEN, *by James Deetz. Anchor Books, 1996 ($11).*
History is pretty much junk, one might conclude after finishing this breezy introduction to historical archaeology. Poring over estate listings, pottery shards, gravestones and excavated foundations, James Deetz reconstructs the changing face of American life during the colonial era, as immigrant traditions and aesthetics adapted to the New World. The book makes a powerful argument for an empirical kind of history far removed from the anonymous assertions of high school textbooks.

Continued on page 123

adequate) account of reality. Those who deny the mystery of music, for example, will regard it simply as the neurological consequence of the impact of air vibrations on the human eardrum, but nothing requires such an impoverished description. As a particle physicist and a minister, I often find myself simultaneously convinced by both exterior and interior perceptions of the underlying structure of the universe.

Michael Redhead comes at the debate with a sympathy for metaphysics but also with a strong scientific conservatism. He is a philosopher of physics at the University of Cambridge; he has a particularly expert knowledge of quantum theory; and he rightly protests against illegitimate and all too fashionable importations of consciousness into quantum phenomena. Observations, he affirms, are physical measurements, not human perceptions—and so the mystical edifices that many New Age writers have tried to build on quantum mechanics are doomed to collapse.

Indeed, what Redhead considers the most metaphysically significant aspect of quantum mechanics is not any mysticism involving Schrödinger's cat but rather the theory's fundamental nonlocality. Once two quantum entities have interacted with each other, they retain the ability instantaneously to influence each other, however widely they may subsequently separate. Albert Einstein considered this togetherness-in-separation to be so crazy that it must demonstrate that there was something missing in quantum theory. John Bell, however, cast nonlocality in testable form, and Alain Aspect and his colleagues confirmed that the property is in fact a real property of nature.

Redhead views this discovery as evidence that we should take a holistic view of physical reality. Once they have come together, the two quantum entities continue to form a single system even after their physical separation. It seems that the subatomic world cannot be treated as a collection of purely independent entities. This metaphysical conclusion causes Redhead to look quizzically at the reductionist claims made by ebullient speculative particle theorists in their "theories of everything." I do not think that philosophers in general have yet come to terms with this declaration from quantum physics: the days of Universe as Mechanism are over.

Contrary to what many of his philosophical colleagues claim, Redhead does not believe that scientists simply mold physical experience into the pleasing shapes that fit their intellectual fancy. It is refreshing to encounter a philosopher of science who does not take it on himself to lecture scientists that they are involved in a socially constructed language game or that instead of learning about the physical world they are simply finding empirically adequate ways of talking about it—using ideas that are fine for getting things done but that should not be taken as serious descriptions of the world. Redhead, like almost all scientists, is a realist; he believes that we make reliable maps of our physical environment, although, like all maps, they do not reveal absolutely every detail of the terrain. The physical world resists our attempts to twist it into the form of our prior expectations.

Past this rather limited conclusion, however, Redhead will not venture. Richard Swinburne, in contrast, takes into account a much wider range of phenomena, and his metaphysical proposal is correspondingly much more ambitious than Redhead's. Swinburne is a well-known philosopher of religion who has just written the first popular introduction to his main ideas. In his new book, he boldly suggests that the best-supported and most comprehen-

SEEN ON TV

LENNART NILSSON

Odyssey of Life: The Photographer's Secrets
Airing on PBS November 24, 25 and 26, 1996

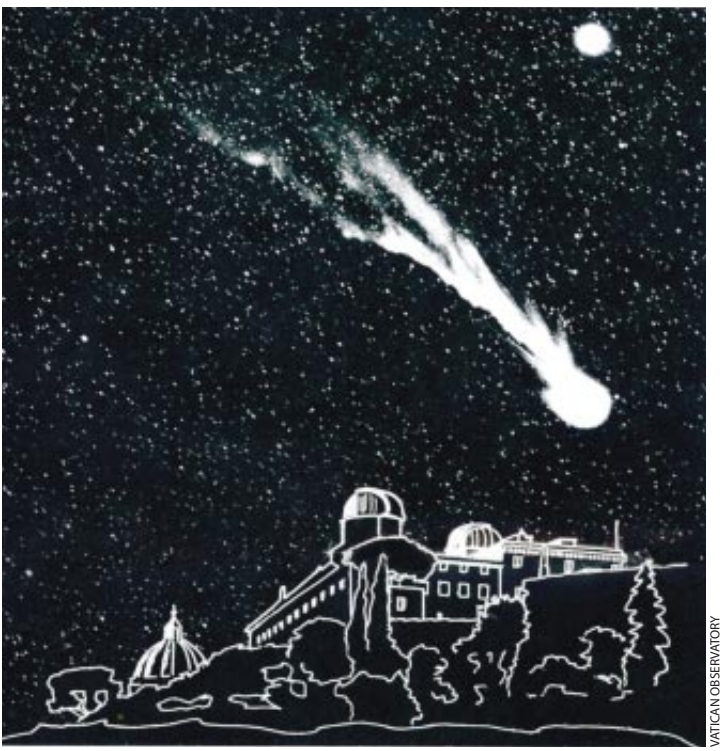
Lennart Nilsson's name may not be familiar, but you have probably seen his work: his photo essay on the development of the fetus, which appeared in *Life* magazine more than 30 years ago, has become a pop culture artifact. In this three-part television special, Nilsson updates his style with the latest technology. The first episode begins just where one would expect, at the moment of union between sperm and egg; the developmental sequences that follow are astounding, often eliciting a bemused "how did he get that shot?" reaction. Part two focuses ingeniously on the microscopic organisms that live on, in and around all of us. But gadget hounds may be most entranced by the parts of the last installment in which Nilsson allows himself to be photographed in action for the first time. Nilsson has always prized picture over word (the narration in *Odyssey of Life* is poetic but hardly groundbreaking); his on-camera scenes convey the privileged joy of a master magician revealing his secrets. —*Corey S. Powell*

sive theory of everything is in fact provided by belief in God (understood in the sense of the Judeo-Christian-Islamic tradition as "a person, omnipotent, omniscient, and perfectly free"). In so doing, he seeks to provide an explicit rejoinder to the philosophical naïveté and atheistic reductionism that he detects in writers such as Richard Dawkins and Stephen W. Hawking.

The keystone of Swinburne's argument is that the creative will of God "provides by far the simplest explanation of all phenomena." Such judgments of simplicity are always open to dispute because they depend on the criteria and viewpoint of the one making the judgment. A physical reductionist, wearing the equations of the supposed Grand Unified Theory on his or her T-shirt, would probably also claim to be starting from a simple origin. The real grounds for disagreement between such a person and Swinburne would seem to lie in the question of the adequacy of their respective hypotheses to explain the many-layered reality of human experience. (We are back to the mystery of music.) To take one example: Do we just accept science's wonderful power to describe the order of the world through beautiful mathematical equations, or do we see therein the hint of a divine mind at work? Swinburne writes, "I do not deny that science explains, but I postulate God to explain why science explains."

But once having postulated God, Swinburne finds himself caught in a conundrum that troubles many believers: how to reconcile the primacy of a creator with the existence of so much evil and suffering in the world. He is candid enough to admit that "it is inevitable that any attempt by myself or anyone else to construct a theodicy (to justify the ways of God) will sound callous, indeed totally insensitive to human suffering." There are many religious responses to the mystery of pain and evil, but they lie at deeper, more existential levels than those plumbed by mere logical argument. The nearest Swinburne gets to such depths is a discussion of the evidential value of religious experience.

These two books present telling contrasts in the ways to construct a modern metaphysics. Redhead is cautious, looking to physics but not much beyond it. He lays aside the great questions of meaning and purpose for others to answer. Swinburne is bolder and takes into account a much richer range of human experience, but he then finds himself with more problems to answer for. He is respectful of science within its proper domain, but he knows that domain to be self-limited to what is impersonal and repeatable. If we are to fulfill the ambition, so natural to the scientist, to understand fully the world in which we live, we shall have to be prepared to take the wide view.



VATICAN OBSERVATORY

THE VATICAN OBSERVATORY at Castel Gandolfo and Comet Whipple-Fedtke

JOHN POLKINGHORNE is president of Queens College, Cambridge. His books on science and religion include The Faith of a Physicist *(Princeton University Press, 1994) and* Beyond Science *(Cambridge University Press, 1996).*

BRIEFLY NOTED

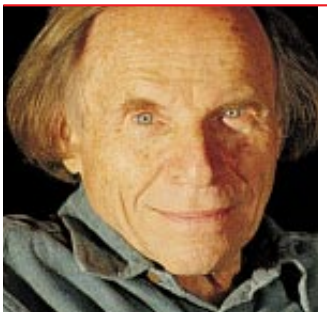
Continued from page 121

YESTERDAY'S TOMORROWS, *by Joseph J. Corn and Brian Horrigan. Johns Hopkins University Press, 1996 ($24.95).*
This paperback reissue derives from an exhibit organized by the Smithsonian Institution in 1984. On page after page of fantasy images (from films, advertisements, comic books and so on), our hopes and fears about the future are charmingly, sometimes painfully, laid bare. The accompanying essays, alas, still bear the marks of hastily assembled wall text; they are disjointed and rife with editorial errors.

THE CASE FOR MARS, *by Robert Zubrin with Richard Wagner. Free Press, 1996 ($25).*
Undaunted by the flawed visions of past prognosticators, Robert Zubrin argues that humans can—and must—establish colonies on Mars. He carries the reader along swiftly with his enthusiastic technical, financial and social arguments. The closing appeal for readers to become "space activists" brings the argument back down to Earth: spectacular ventures to Mars will occur only when the public deems such costly undertakings worthwhile.

MICROCOSMOS, *directed by Claude Nuridsany and Marie Pérennou. Miramax Films, 1996 (opens October 11).*
Biologists Claude Nuridsany and Marie Pérennou left the university to seek new ways to communicate science to the public. *Microcosmos* focuses on the daily life of the insects and other tiny creatures that inhabit a field in the south of France. Dispensing with narration, the film relies on sharp camera work, stop-motion photography and a clever soundtrack to keep the action moving. The flashes of anthropomorphism are entertaining and deliberate: the filmmakers slyly transform their buggy actors into empathetic characters.

MIRAMAX FILMS



WONDERS

by Philip Morrison

Giant against Giant in the Dark

DUSAN PETRICIC

Any seashore is an open frontier, a source of novelty as unceasing as the waves themselves. Once on a summer morning I came across a dozen blue-crested, translucent bladders the size of footballs, strewn windblown over the wetted sands. They were festooned with what I recognized as the stinging filaments of Portuguese man-of-wars, the poetic common name of this species. Organized colonies of living polyps found worldwide on warm sea surfaces, they were at once beautiful and a bit frightening. A casual beachcomber is justified in recalling such a surprise for half a lifetime, although it is by no means exceptional.

One truly exceptional sort of flotsam has been found from Norway to New Zealand. A published master list records some 200 similar verified shoreline finds over the past 350 years. A startled stroller—or an offshore fisherman emptying a net—comes on a solitary big sea animal, beached, dead or dying. That creature is hardly credible: a tentacled form fathoms long, with huge staring eyes and a parrot beak! Half-myths of folklore and print expound these tangible remains. A few real if confused encounters at sea are vividly recalled, too, dizzily extrapolated by authors and image makers from the days of epics up to Jules Verne, Arthur C. Clarke and Disney Studios. Surely all these sightings earn the arresting name of sea monster; they are in fact giant squid.

What may or may not be a single species is dubbed *Architeuthis,* naturalists' Latin for "extreme squid." Measured lengths reach up to 60 feet overall, including the tentacles, stout sucker-bearing arms and a jet-propelled torpedo body that may run up to as much as a ton or two in mass. A similar body plan can be found in plenty at your own local fish market, of course much reduced in scale: the eight-inch-long calamari.

Our own kind, the vertebrates, has included huge sharks, ancient reptiles and, more recently, fossil super-rhinos from the Gobi Desert. Indeed, the biggest animal of all time is a modern vertebrate, the blue whale; the largest known invertebrate ever is the giant squid. Dwelling today at depth, monstrous *Architeuthis* has never yet been observed in vigorous life by any zoologist.

On the alert for wonders of sky and sea, I have wandered beaches for years now with a recurrent thought. Might an unusual form appear awash in the breaking waves, delivering up—possibly this morning!—a giant squid? My dreamy hopes almost came true in 1980, when one, if only a young female 30 feet long, was cast up on a wintry beach north of Ipswich, only 30 highway miles from our Massachusetts city home. I missed seeing that find aground, but even skeptics can inspect the remains at the Smithsonian National Museum of Natural History, embalmed whole in cold, clear isopropyl alcohol but manifestly real. (A really big martini, said the wit who prepared it.)

Can we enlist some squid-stalking whale to carry camera and light under sonar control?

Squid are a populous order. Oxygen-thirsty, flesh-hungry, feeding on fish and smaller squid, they are fast-moving, wary predators in the colder waters of all the wide oceans. Curiously evolved mollusks, they have inverted their inherited clamlike body plan to present not a shell but a leathery mantle and a head-borne cluster of arms and tentacles. (Within every giant squid's mantle is stowed its vestigial heirloom, a chitinous rod a few feet long.)

So few have come ashore as corpses that we might think them rare indeed, for a 50-foot squid is hard to hide forever even in the depths of the sea. Where can such monsters live and die unseen? By a stunningly improbable indirection, we have found them as links in the food chain of other giants. *Architeuthis,* as gigantic as it is, its glassy eyes as large as pizzas, is in fact customary prey for a much more massive hunter, the toothed sperm whale. That 20-ton cousin of ours feeds mostly on squid of all sizes. The stomachs of caught sperm whale often hold 5,000 to 10,000 squid beaks, many of tremendous size. Whale foreheads bear ring marks that fit the sucker disks of struggling giant squid, and almost every dissected sperm whale yields quite fresh chunks of squid tentacles, often small, but some as thick as a robust harpooner's thigh. The estimate is a precarious one, but it is plausible that the worldwide squid fishery, long operated by the million sperm whales now alive, takes tens of millions of giant squid every year, comparable in annual tonnage to any human fishery in the salt sea.

Smithsonian zoologist Clyde F. E. Roper, seafarer since his boyhood on Ipswich Bay, has long been on the track of *Architeuthis* alive. It was he who led the collection, study and preservation of the Massachusetts specimen, and his current exhibit bears witness to the breadth of his knowledge and researcher's passion. A squid gourmet, he certifies that the whales need fear no human competition for their big catch. Carefully tasting a fresh-frozen tentacle fragment, he and his companions unanimously found its flesh bitterly ammo-

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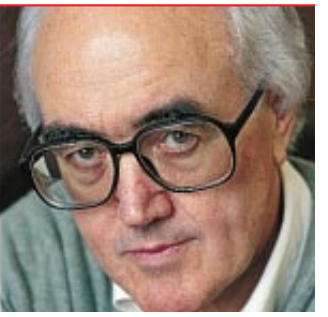

CONNECTIONS

by James Burke

What Goes Around Comes Around

Back in the dawn of time, I reported for the BBC whenever an *Apollo* lifted off. So nowadays every time a shuttle comes back for recycling, I am reminded of those great "use once and throw away" days. On one of which, in 1973, a crew went up to the orbiting *Skylab* (itself a piece of converted leftover *Apollo* hardware), where major discoveries were being made about the solar corona having dark bits in it, which meant significant things to those interested in solar wind.

When you think "Apollo," you can't help but think "Wernher von Braun"—the German-born engineer who made possible those extraordinary Saturn V launch vehicles. As he himself said, he'd had lots of earlier practice with all those wartime missiles (a.k.a. vengeance weapons) that left Peenemünde regularly and at very high speeds, heading for England (and me).

She spent most of her time in Paris, directing her energies into killing *Bernard with thought waves.*

Devilishly difficult things to hit, buzz bombs. At first it took the antiaircraft gunners an average of 2,500 rounds to bring one down. Then (and on behalf of the U.K., I thank you, Bell Labs), along came the M-9 Predictor, and the cost of bagging a doodlebug went down to 100 shells. Significant savings all around (including lives). All it took was the magic math to run a feedback loop that could update constantly the set of data you got from the radar about the incoming buzz bomb's *last* position, so as to be able to make a good guess at its *next* and to point the guns that way. Then boom.

The idea of feedback came to those involved with guns and such from those involved with gastric juices and such. Physiology had been looking at the body's internal balancing systems (you know: if hot, sweat; if thirsty, drink) ever since a mid-19th-century Beaujolais winegrower and physiologist called Claude Bernard first noticed something odd about rabbits. Simply, if they were given no food for a while, the bunnies appeared to live off themselves (off their reserves of fat, we would say today). The difference in diet showed up in their urine. Which led Bernard to further discoveries, such as how the liver secreted exactly the amount of sugar you happened to be short of (or not, if not). And after that, all the rest of those reactions that happen in order to maintain what we now call homeostasis.

Mind you, there were those who were far from happy about the rabbits—and the dogs, frogs, guinea pigs and rats—on which Bernard and others performed their diverse tests. Some of which, in all honesty, might not have been strictly unavoidable. (Bernard said, "The science of life is a superb and dazzling lighted hall which may be reached only by passing through a long and ghastly kitchen.") It was rather too much for Bernard's wife, who left him and joined the antivivisectionists, one of whom was an Englishwoman, Anna Kingsford. She spent most of her time in Paris, directing her energies into *killing* Bernard (and other high-profile physiologists, such as Paul "the Bends" Bert) with thought waves.

The antivivisection group eventually was embraced, mistakenly, by the Humane Society movement. In fact, such societies had existed since the 18th century, and they weren't there to save animals at all. Only the "apparently drowned," and human at that. Many of these unfortunates had, for various questionable reasons, simply fallen into water. But there was a less dubious motive for being considered apparently drowned. What you did to qualify was to jump overboard when your ship was on the rocks and there was nowhere else to go. Then, with a bit of luck, you would be rescued by an offshoot of the Humane Society called (in 1824) the National Institution for the Preservation of Life from Shipwreck.

The reason for the Shipwreck Institution's cork-lined boats and crews was that by this time there were simply many more ships heading for trouble rather than for port. What with the extra cargo floating across the oceans, thanks to the Industrial Revolution, with tons of manufactured goods going one way and raw materials the other, more money was being lost than ever before when people's ships didn't come in. Hence, the fuss and cork.

All the more so after mid-century, when American naval officer Matthew F. Maury (see last November's column) got hundreds of navigators to keep (and send him) logs of wind, pressure, temperature and currents. He also persuaded them to throw daily bottles into the sea (sealed) carrying bits of paper on which they had scribbled their lati-

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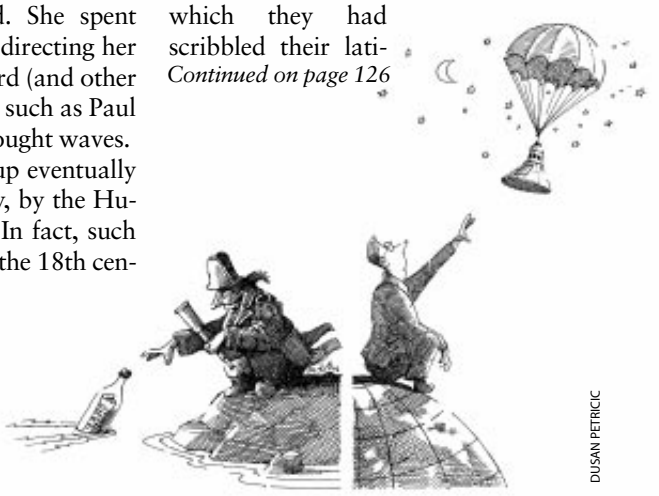


DUSAN PETRICIC

Wonders, *continued from page 124*

niacal, beyond human tolerance. Animals of the deep avoid both the surface and the bottom of the sea. The giant squid has adapted to near-neutral buoyancy by replacing the sodium chloride usual in body fluids with the much lighter ions of ammonium chloride.

Good news came this year to the hunters of *Architeuthis*. Over the past decade, the commercial fishermen of New Zealand have pioneered a deep fishery for new, tasty fish species. They often trawl eastward of Wellington where the seafloor drops sharply to the abyss. There sperm whales, too, are frequent hunters. A few astonished fishing boats have reported netting giant squid too cumbersome to carry home, and at the end of 1995 two New Zealand research ships came back with 10-yard squid brought up dead in their nets.

The search for living giant squid will begin in these game-rich depths. Roper has planned a powerful international exploration of the steep Kaikoura canyon, where a diverse fauna supports giant predators and giant prey alike. His team unites New Zealand research ships, crew-carrying submersibles (the *Johnson Sea-Links* out of Harbor Branch Oceanographic Institute in Florida), many university scientists from the U.S., Australia and New Zealand, and a seasoned deepwater video production team from the National Geographic Society. This stirring chase live on television will amaze viewers in homes and classrooms across the world.

How does a sperm whale catch giant squid? Can we enlist some squid-stalking whale to carry camera and light under sonar control? What is the wider ecological context of this combat of giants? The unprecedented expedition is fully planned and already substantially funded. Under one third of the needed $5 million remains to be found by next year's season at the end of 1997. Few readers may have that sum about them, but their articulated public enthusiasm can be a nourishing substrate for a few new major supporters of this long-ripe, hopeful adventure, a voyage as mythic, strange and penetrating as any at sea. SA

More on giant squid can be found on the World Wide Web at http://seawifs.gsfc.nasa.gov/OCEAN_PLANET/HTML/squid_Architeuthis.html

Connections, *continued from page 125*

tude, longitude and the date. Said bottles were to be picked up by others doing the same. Result: a zillion details on wind and current conditions, which led to one of Maury's famous publications, *Sailing Directions*. These illustrated, as such, oceanic expressways and indicated the fastest—read "cheapest"—route from any point A to any point B.

Another source of Maury's knowledge of wind and water was the French physicist J.B.L. Foucault, who some years earlier had invented an amazing pendulum, which hung on a very long wire and proved that the earth turned. As an inertial pendulum swings back and forth, it appears with each swing to trace a changing path (clockwise, in the Northern Hemisphere, and vice versa down South). Maury deduced from this that as the planetary surface rotates, the path of winds in the Northern Hemisphere coming up from the equator would be deflected to the east (and vice versa).

Foucault's inertial investigations led him to other matters affected by the turning planet. Life for astronomers wasn't made any easier by the fact that, because of the earth's rotation, they and their telescopes were whizzing around at a fair lick (no observational pun intended), making it hard to keep an eye on stars and stuff that, after all, were not doing the same thing. So Foucault came up with a clockwork gizmo (well, siderostat) that rotated a mirror 360 degrees, in the opposite direction to the earth's, once every 24 hours.

This technique kept the mirror constantly pointing at its heavenly target. This also made it easier for Foucault to do his next trick: use the astonishing new daguerreotype photographic apparatus to get portraits of various celestial bodies, now that they sat in the frame long enough for you to take their picture.

This nifty process went over very big with stargazers, because you can do great things with photographs of stars (like count them or overexpose them and see many more). So in Königsberg, Germany, during the 1851 eclipse, a professional named Berkowski took the first photograph of the phenomenon that the *Skylab* crew would study, from orbit, 122 years later: the solar corona.

Proof that in the world of connections (and orbits), what goes around indeed comes around. SA

WORKING KNOWLEDGE

TELEVISION RATINGS

by Edgar W. Aust

In 1936 engineer Arthur C. Nielsen, Sr., attended a demonstration at the Massachusetts Institute of Technology of a mechanical device that could keep a record of the station to which a radio was tuned at any given moment. Nielsen bought the technology practically on the spot and six years later launched the Nielsen Radio Index, which analyzed the listening habits of 800 homes. Later, he adapted the same technology to the new medium of television, creating a ratings system that nearly all American broadcasters use today to help determine the popularity of their programs.

Over the years, Nielsen Media Research has used several methods to collect viewing information, including surveys and volunteer diaries. In 1986 the company supplanted these with an electronic device called a People Meter. The meter is now connected to televisions and telephone lines in about 5,000 households throughout the U.S.

Nielsen households are selected from a sample that is statistically representative of the television-viewing population. Each household receives nominal compensation—about $50 and occasional gifts—for their cooperation. In order to keep the sample representative, viewers can participate for only two years.

As they watch TV, volunteers press buttons to indicate their presence. The People Meter records the gender and age of each viewer, as well as the time spent watching each channel frequency. Every night the device transmits that household's data by modem to Nielsen's central computer in Florida, which assembles the data into a ratings database.

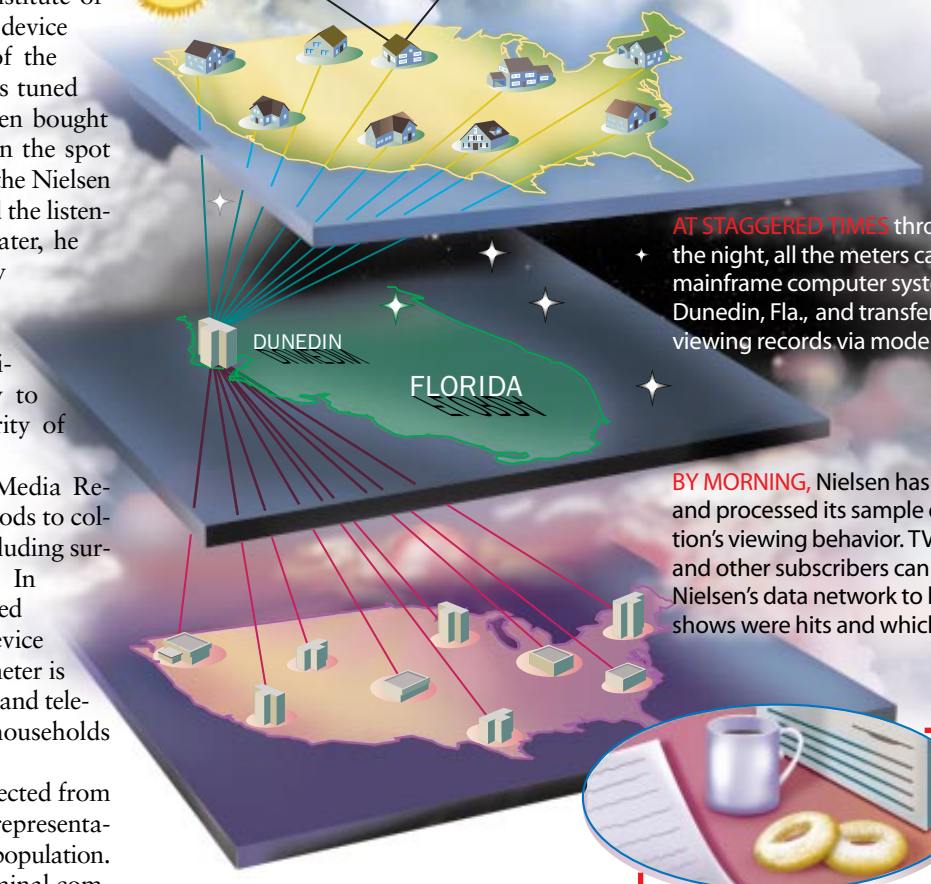
To meet the changing needs of broadcasters and sponsors, the technology continues to evolve. In 1986 Nielsen introduced a system that uses computerized pattern recognition to identify particular commercials as they are broadcast. Future versions of the People Meter now under development will monitor codes embedded into digital TV signals to verify which programs are on the air. They will also use image-recognition computers to identify viewers the moment they hit the couch.

EDGAR W. AUST is senior vice president of engineering and technology for Nielsen Media Research in Dunedin, Fla.

NIELSEN PEOPLE METER is programmed with the age and gender of each household member. Viewers enter their code when they begin watching; visitors can log their presence as well. The meter records which channels are tuned by sensing the frequencies emitted by the cable box, TV or videocassette recorder.

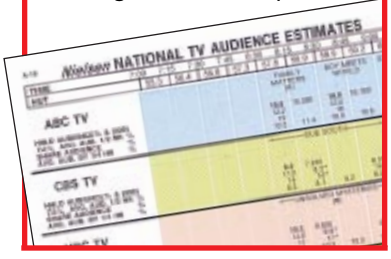
EVERY DAY, in some 5,000 homes throughout the U.S., People Meters gather data on who watched what, when and for how long.

AT STAGGERED TIMES throughout the night, all the meters call Nielsen's mainframe computer system in Dunedin, Fla., and transfer their daily viewing records via modem.



BY MORNING, Nielsen has assembled and processed its sample of the nation's viewing behavior. TV executives and other subscribers can log in to Nielsen's data network to learn which shows were hits and which flopped.

EVERY WEEK subscribers receive a detailed report chronicling how many Nielsen household viewers were watching television during any given quarter hour and how specific programs fared against their competition.



PHOTOGRAPHS BY NIELSEN MEDIA RESEARCH; ILLUSTRATIONS BY LAURIE GRACE