ANCIENT EGYPT • YOUNG READERS BOOK AWARDS • GERM WAR • FREUD LIVES!

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TRACES OF THE BIG BANG:
ATOMS FORGED IN THE FIRST MINUTES HELP TO EXPLAIN HOW GALAXIES FORMED

Blebbing to oblivion: cells sacrifice themselves for the sake of the body

SCIENTIFIC AMERICAN

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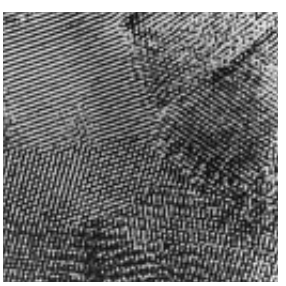
NEWS AND ANALYSIS

All atoms of deuterium, a heavy isotope of hydrogen, are cosmic leftovers from the first minutes of creation. Knowing how much of this material existed originally can guide astrophysicists in their quest for understanding of early conditions in the universe, which influenced galaxy formation and other later events. Recently they have found a way to peek back billions of years by examining the spectral lines in light from quasars that has passed through ancient interstellar clouds.

Because of their low cost and horrifying potential for harm, biological weapons could become the arms of choice for many nations and terrorists. The author of a new book on this menace describes what steps can and should be taken to discourage their proliferation.



Want to make copper five times stronger or ceramics that are not brittle? By shrinking 10,000-fold the structural grains making up these and other solids, manufacturers can now prescribe the strength, color and plasticity of new materials for applications from electronics to cosmetics.

About the Cover
When a cell "commits suicide" through the process of apoptosis, its surface seems to boil with small, rounded protrusions, or blebs, that detach from the main body. Image by Slim Films.

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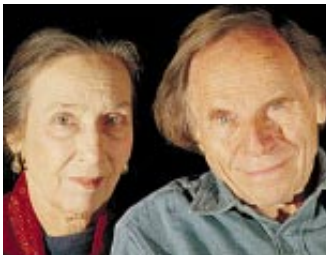
FROM THE EDITORS

Experienced Readers for Young Minds

This issue marks only the second occasion of the Scientific American Young Readers Book Awards, but it builds on a much longer tradition. Every December since 1949, this magazine has reviewed the best of the current crop of science books for children and teenagers, intended as a service to parents and teachers (not to mention the young readers themselves, who might like to choose their own books, thank you).

If reviewing children's books sounds easy, think again. James R. Newman, who began the column, wrote in 1952: "This is my third annual roundup of children's science books, an exertion which has understandably given rise to some strong opinions about this branch of literature. Of the hundreds of books I have read, few have impressed me as first-rate. The majority range from mediocre to wretched; the wretched examples are not rare." He continued, dyspeptically but not unfairly, "Science popularization for children, I am sorry to note, receives less regard from educators than it deserves, less effort from writers than it requires, less attention from publishers than its potentialities justify." Fresh to the reviewer's job in 1966, Philip and Phylis Morrison echoed those sentiments in their own way but still had the good cheer to add, "Happily there are so many admirable books that we need dwell no further on the unsuccessful ones."



THE MORRISONS, Phylis and Philip, select the Young Readers Book Awards.

If the unsatisfying average quality of children's science books is one problem, their quantity is another. The past 12 months brought 700 books for the Morrisons' consideration. Scouting out the best could be a full cottage industry.

But then, who could be better suited for the task than our own cottage industrialists, the Morrisons? Their home and office in Cambridge, Mass., was found in a recent scientific analysis to be 48 percent books by weight. They are accomplished writers, having co-authored the classic *The Powers of Ten* and other works. And—here I'm letting you in on a closely guarded secret—during his years as a physicist at M.I.T., Phil quietly invented and swallowed a perpetual-motion machine. That is why, with Phylis's assistance, he has been able to endure as a reviewer and columnist for *Scientific American* for 30 years. Fans will find him back with a new installment of "Wonders" next month.

I'm glad to report that Phil and Phylis have lowered neither their high standards nor their high spirits over three decades. They are the guiding lights of these Young Readers Book Awards. Our thanks to them and to the authors and publishers who are this year's winners. Happy reading.

JOHN RENNIE, *Editor in Chief*
editors@sciam.com

LETTERS TO THE EDITORS

AGED ANTS

In the August article "Insects of Generation X," David Schneider writes that the 17-year cicada is "perhaps the longest-lived insect in the world." These cicadas certainly do live a long time, but the Methuselah of insects is probably an ant queen. In their book *The Ants* (Harvard University Press, 1990), Bert Hölldobler and Edward O. Wilson list seven species of ants in which the reproductive females can live for more than 18 years. Queen ants from the species *Pogonomyrmex owyheei* reportedly can live for 30 years or more. I find it interesting that insects have become the most successful group of animals by virtue of their marvelous cuticle, which enables them to resist desiccation in the open air. Yet the ones that live the longest reside for most of their lives in the 100 percent humidity of a subterranean environment.

DOROTHY MAY
Park College
Parkville, Mo.

DATING SERVICE

The excellent article by Elizabeth Nesme-Ribes, Sallie L. Baliunas and Dmitry Sokoloff, entitled "The Stellar Dynamo" [August], raised a question in my mind about radiocarbon dating. The authors mentioned research by John A. Eddy, who noted that the amount of carbon 14 in tree rings varied depending on the level of sunspot activity. During periods of increased sunspot activity, the magnetic fields in solar wind shield the earth from the cosmic rays that create carbon 14 in the upper atmosphere. But don't most dating systems rely on the assumption that the ratio of carbon 14 to carbon 12 in the atmosphere is constant over time? If so, how can radiocarbon dating be used accurately?

ROBERT O. LOE, JR.
Jacksonville, Fla.

Baliunas replies:

Scientists who carry out radiocarbon dating are aware that the ratio of carbon 14 to carbon 12 in the atmosphere has not been strictly constant over time and that the radiocarbon age of an ancient object differs somewhat from its true age. Several phenomena—including changes in sunspot activity—can contribute to such errors. Fortunately, researchers can circumvent this problem by calibrating the radiocarbon dating scale using samples for which the true age is known. Counting the yearly growth rings from live and fossil trees, for example, has provided a means to correct the radiocarbon timescale over the past 8,000 years. For more remote times, radiocarbon ages can be compared with results from other dating techniques that are not affected by cosmic ray variations. Such studies have shown that differences between radiocarbon ages and true ages can be as great as a few thousand years. These large discrepancies most likely result from long-term changes in the earth's magnetic field, which also affect the production of carbon 14.

THE SANDS OF TONGA

The pictorial "Sands of the World," by Walter N. Mack and Elizabeth A. Leistikow, in your August issue was delightful. Sands seem dull until we look closely and see an infinity of wonders among the grains. The primary shells in one sample, however, were misidentified.

WALTER N. MACK

Foraminifers from Tonga

The disklike objects in the sand from Tonga, in the southwest Pacific, are not the remains of crinoids. They are instead the shells of a large type of single-celled protist called a foraminiferan. These remarkable organisms produce a complex shell (called a test) with numerous tiny compartments, some of which are visible in the photograph. Crinoid fragments do not have this type of internal structure, and their stem fragments (which these tests resemble) would uniformly have a central hole.

MARK A. WILSON
The College of Wooster
Wooster, Ohio

Editors' note:

Our apologies; an unfortunate mix-up of captions attached to the original photographs led to the surprising appearance of crinoids in Tonga.

IN DEFENSE OF DOWN UNDER

In their article "Sunlight and Skin Cancer," David J. Leffell and Douglas E. Brash [July] imply that the Australian population is predominantly made up of descendants of British and Irish criminals. Although the first European settlers on the continent were indeed convicts, their numbers were soon swamped by settlers with much the same origins and motivations as those who settled North America: namely, the new immigrants were drawn by fortune, freedom and opportunity.

LES G. THOMPSON
Bairnsdale, Australia

WHEN IN BELGIUM...

My wife and I immediately recognized the opening photograph in "The Mystery of Lambic Beer," by Jacques De Keersmaecker [August]: while in Brussels recently, we asked for a particular lambic, only to be informed that there were no clean glasses available. Generic tumblers were out of the question, as the glass must match the beer!

NORMAN M. ROLAND
Great Neck, N.Y.

Letters selected for publication may be edited for length and clarity.

ERRATUM

The quote from Donald S. Coffey, cited on page 59 of the September issue, appeared in the April 15, 1996, issue of *Cancer Research,* not the journal *Cancer.*

50, 100 AND 150 YEARS AGO

SCIENTIFIC AMERICAN

DECEMBER 1946

The first fruits of atomic 'peacefare' are already being harvested. Using the same techniques that produced the bomb, laboratories at Oak Ridge are now turning out radioactive isotopes. Much has been written about the use of radio-active materials to trace vitamins, amino acids and other fuels for the human machinery through the system, but benefits to industry have been overlooked. Many chemical products are formed by processes which are relatively mysterious. The isotopes, because they are atom-sized 'observers,' can help clear up the mysteries."

DECEMBER 1896

Dr. Shibasaburo Kitasato has collected from reliable sources information about 26,521 cases of diphtheria in Japan previous to the introduction of serotherapy, 14,996 of whom died (56 per cent). Of 353 cases treated after serotherapy was introduced in Japan, from November, 1894, to November, 1895, only 31 died (8.78 per cent). There is reason to believe that mortality can be lowered if treatment could be commenced early in the course of the disease. Thus in 110 cases in which injections were made within forty-eight hours after the invasion, all ended in recovery. On the other hand, of 33 cases treated after the eighth day of the disease (including some patients in a moribund condition), 11 were lost."

"Herr G. Kraus has investigated the purpose of the rise of temperature at the time of flowering of various species of Acaceae and Palmae. In Ceratozamia longifolia he found this elevation to take place in the daytime, the maximum attained being 11.7° C above that of the air. In the Acaceae examined, the elevation of temperature is accompanied by a rapid consumption of starch and sugar. Dr. Stahl sees in it a contrivance for attracting insects to assist in pollination."

"India rubber is becoming a prime necessity of civilization due to use in such articles as pneumatic tires and feeding bottles. But rubber producing plants seldom exist within easy distance of some export station. Hundreds of men have racked their brains to produce a substitute, but none has in the least degree succeeded. Whether our state, or any other, will enter this branch of tropical forestry remains to be seen. The Germans, with their usual thoroughness, have a strong scientific staff at the Cameroons. The English, in their usual makeshift way, content themselves with sending home to Kew for suggestions. But the government of India has at least tried an experiment upon the great scale, a nursery of Para rubber trees in Assam, extending over two hundred square miles."

DECEMBER 1846

Urbain Leverrier's new planet [Neptune] is two hundred and thirty times as large as the earth, being the largest of the system. This discovery is perhaps the greatest triumph of science upon record. A young French astronomer sets himself at work to ascertain the cause of the aberrations of the planet Herschel [Uranus] in its orbit. He finds that another planet of a certain size placed at nearly twice the distance of Herschel from the sun would produce precisely the same effects he noted. He calculates its place in the heavens, with such precision, that astronomers, by directing the telescope to the point where its place for that evening is indicated, have all succeeded in finding it."

The new type setting machine

"A novel item in a lawyer's bill. A solicitor who had been employed by a railway company in England, on making out his bill, after enumerating all other ordinary items, adds the following—'To mental anxiety, item not contained in the above, £2000,' and it was paid without any demur."

"The Clay and Rosenborg type setting machine is expressly adapted to all kinds of plain composition, poetry or prose. Power is applied by means of a revolving crank and may be driven by steam power, being in effect, a *steam type setting machine!* The machine is in the form of a cottage piano-forte, with two rows of keys. To work one of these machines it requires one man and four boys and, when the machine is in full operation, will set up as much as eight compositors."

NEWS AND ANALYSIS

IN FOCUS

DEADLY ENIGMA

The U.S. wakes up to the threat of mad cow disease and its relatives

NIGEL DICKINSON *Still Pictures*

REMAINS OF CATTLE SUSPECTED OF HARBORING BSE, or bovine spongiform encephalopathy, are tested, then burned—here, in Wrexham, U.K.

It is, in the words of one group of researchers, "a true quandary." How can an abnormal form of a protein present in all mammals cause some 15 different lethal brain diseases that affect animals as diverse as hamsters, sheep, cattle, cats and humans? Yet the dominant theory about the group of illnesses that includes scrapie in sheep, mad cow disease in cattle and Creutzfeldt-Jakob disease in humans holds just that. What is certain is that some mysterious agent that resists standard chemical disinfection as well as high temperatures can transmit these diseases between individuals and, less often, between species. What is unknown is how the agent spreads under natural conditions and how it destroys brain tissue. Because of the characteristic spongelike appearance of brain tissue from stricken animals, the diseases are called transmissible spongiform encephalopathies (TSEs).

Finding the answers is a matter of urgency. In Britain, mad cow disease, or bovine spongiform encephalopathy, has turned into a national calamity. A worldwide ban is on British beef and livestock imports. The government is slaughtering all cattle older than 30 months—some 30,000 a week—to allay fears that the disease, which causes animals to become nervous and develop an unsteady gait, will spread to people. So far British medical researchers have identified 14 unusual cases of Creutzfeldt-Jakob disease in young people that they suspect were a human manifestation of mad cow disease. New studies of the victims' brains appear to strengthen that conclusion. The biochemical properties of the suspected disease-causing protein in the brains of the victims are distinctly different from those usually found in Creutzfeldt-Jakob disease, supporting the notion that the disease came from a novel source.

Apprehensive that the U.S. cattle industry could be in line for a disaster like the one in Britain, in October the Food and Drug Administration was about to propose controls on the use of animal-derived protein and bone meal in cattle feed.

Mad cow disease is believed to have spread in Britain because of the practice of incorporating material from the rendered carcasses of cattle and other animals into cattle feed. That cannibalistic practice is also standard in the U.S.

Although only one case of the disease has been confirmed in North America—in an animal imported from Britain to Canada—other TSEs, including scrapie in sheep and comparable diseases in mink and mule deer, are well known in the U.S. Nobody has any idea whether some native scrapielike agent could transform itself into mad cow disease or something unpleasantly like it. "As long as we continue to feed cows to cows we are at risk," says Richard F. Marsh of the University of Wisconsin, who has studied TSE in mink. The cattle-rendering industry, however, is resisting blanket bans and wants to see controls only on tissues for which there is firm evidence of infectivity.

Unfortunately, the science of TSEs generally is not in a firm state. Laboratory tests show that the diseases have variable and strange characteristics. They are most easily transmitted by injecting brain tissue from an infected animal into a recipient's brain, but sometimes eating brain or other offal will do the job. (Kuru, a human TSE formerly common in Papua New Guinea, was spread because the Fore people ritually consumed the brains of their dead.) There are distinct strains of some TSEs, including scrapie and Creutzfeldt-Jakob disease, but passage through a different species can permanently alter the diseases' pathological characteristics in the original host species.

NIGEL DICKINSON *Still Pictures*

MASSIVE BRITISH CATTLE CULL means incinerators cannot keep up with demand.

The leading theory that ties these characteristics together comes from Stanley B. Prusiner of the University of California at San Francisco [see "The Prion Diseases," by Stanley B. Prusiner; Scientific American, January 1995]. The theory posits that a ubiquitous mammalian protein called prion protein can, rarely, refold itself into a toxic form that then speeds the conversion of more healthy protein in a runaway process. Some mutant forms of the protein are more likely to convert spontaneously than others, which accounts for rare sporadic cases. TSEs are thus both inherited and transmissible, and unlike those of any other known diseases, the pathogen lacks DNA or RNA.

Some of the strongest evidence for Prusiner's theory is his demonstration that mice genetically engineered to produce an abnormal prion protein develop a spongiform disease and can transmit illness to other mice via their brain tissue. Critics, such as Richard Rubenstein of the New York Institute for Basic Research, note that the mice in these experiments contain very little of the abnormal prion protein that is supposed to be the disease agent. So, Rubenstein argues, they may not be truly comparable to animals with TSEs. Perhaps, Rubenstein and others suggest, some toxin in the brains of the sick experimental mice caused the recipients of their tissue to become sick, too. Prusiner maintains, however, that no ordinary toxin is potent and slow enough to give his results.

Prusiner insists his most recent experiments, which employ elaborate tests designed to rule out possible sources of error, make his theory unassailable. And one of Prusiner's chief rivals, Byron W. Caughey of the Rocky Mountain Laboratories of the National Institutes of Health in Hamilton, Mont., has made the protein-only theory more plausible by experiments that he believes replicate the process by which TSEs propagate in the brain. Caughey and his associates have shown that under specific chemical conditions, they can convert some of the normal prion protein into the abnormal form in the test tube. Moreover, abnormal proteins from different strains of scrapie, which are chemically distinguishable, seem to produce their own strain-specific type of abnormal protein.

Caughey believes his experiments indicate that normal, healthy prion protein changes into the pathological variant when it forms aggregates of some 20 to 50 molecules. The process gets under way if it is seeded by a piece of the abnormal aggregate. Together with Peter T. Lansbury of the Massachusetts Institute of Technology, Caughey has proposed a geometric model illustrating that aggregates can form in different crystalline patterns corresponding to different TSEs.

Caughey says he is keeping an open mind on whether there might be some DNA or RNA along with the protein that might help explain the variety of TSEs. The ultimate proof of the protein-only theory would be to fabricate abnormal protein from simple chemicals and show that it caused transmissible disease in animals, but neither Caughey nor anyone else can do that. Caughey's experiments still need a seed from a sick animal, and the amount of abnormal protein the experiments produce is not enough to prove that the freshly created material can cause disease.

Prusiner, for his part, is not about to concede to Caughey. He believes aggregates are merely an artifact of Caughey's experimental procedures. "There are no ordered aggregates of polymers of prion protein in cells in the brain," he declares. Prusiner's studies lead him to think, instead, that an as yet unidentified "protein X" is responsible for converting the normal prion protein to the scrapie form. He and his co-workers have synthesized fragments of the healthy prion protein and shown that they can spontaneously form fibrils that resemble those seen in the TSE diseases.

Whether protein-only prions can explain TSEs or not, it will take more than a decade for British scientists to unravel how BSE spreads, predicts D. Carleton Gajdusek of the NIH, who first showed how kuru spreads. A test for TSEs in humans and in a few animals was announced in September, but so far it seems to perform well only when clear symptoms of illness have already developed. Although the test may be useful to confirm suspected TSEs in humans, the most important step for governments to take, Gajdusek says, is to maintain intensive surveillance for patients with unusual neurological symptoms. His pictures and descriptions of children with kuru have been distributed to neurologists in Europe to help them recognize possible victims.

—Tim Beardsley in Washington, D.C.

ENVIRONMENT

DOWN THE DRAIN

Russia continues to pump nuclear waste into the ground, despite U.S. aid

Russian officials are still injecting liquid nuclear waste directly into the earth, two years after the extremely controversial cold war practice was first disclosed in the U.S. press. Moreover, the injections are taking place—with no end in sight—despite the fact that the U.S. is now aiding the decaying weapons complex of the former Soviet Union to the tune of half a billion dollars a year. None of the U.S. money is being used to attempt to halt the massive dumping of high-level nuclear waste.

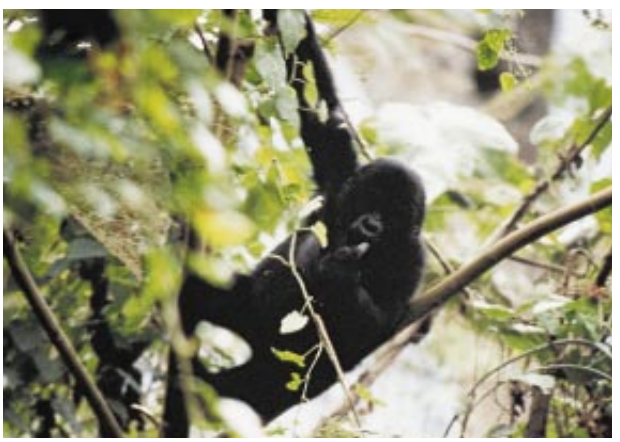
"They are still injecting at Tomsk and Krasnoyarsk," says Nils Bohmer, a nuclear scientist at the Bellona Foundation, a research institute in Oslo, Norway, that specializes in environmental and nuclear issues. Tomsk-7 and Krasnoyarsk-26 were key sites in the sprawling former Soviet weapons complex. During the cold war, both places were secret cities where plutonium and other materials for nuclear weapons were produced in special reactors and industrial plants. The plutonium produced at the sites is now as much a by-product as the liquid, high-level waste, because the Russians are no longer using this plutonium to make new nuclear weapons or reactor fuel. They continue to run the reactors because they provide heat and electricity for nearby towns.

The fact that the waste is still being injected was confirmed by an official of the Ministry of Atomic Energy of the Russian Federation (Minatom) at a recent conference in Prudonice, near Prague, according to several people who attended the conference. All asked that their names—and even the name of the conference—not be used, out of concern that the Russian attendees of the confer-

FIELD NOTES

Jungle Medicine

Deep in the Impenetrable Forest inside Uganda's Bwindi National Park, an enclave of 13 mountain gorillas has suffered years of interminable eavesdropping by primatologists trying to learn about the animals: how they fight, mate, play. Recently fresh eyes peering through the underbrush



JOHN P. BERRY

have focused instead on what humans can learn *from* the great apes—specifically, what they know about medicine.

"We call it 'zoopharmacognosy,' " says John P. Berry, a 24-year-old plant biochemist at Cornell University who has spent months in Bwindi studying mountain gorillas. "Anthropologist Richard W. Wrangham and my adviser, Eloy Rodriguez, came up with that term after several beers in an African disco" to describe their novel approach to drug hunting: analyze the plants that other animals eat when they feel ill. Chimpanzees, for example, have been seen swallowing whole leaves or chewing the spongy pith from more than a dozen bitter-tasting plants that they normally avoid. Testing the plants, researchers discovered biologically active compounds in about half. Some kill parasites and bacteria; others dispatch fungi or insects. Whether the chimps eat what they do out of acquired knowledge or sheer instinct remains an open question.

In any case, it seems likely that gorillas do the same, so Berry traveled from Ithaca to Africa in search of new drug candidates. "Gorillas eat a somewhat bizarre and very diverse diet—everything from bark and dead wood to leaves of every kind and even soil," Berry relates with the authority of one who has tasted several ape delicacies. "Their environment supplies more than enough food; it's like a big salad bowl. So every day they get up from their nest site, plop down, eat everything in sight, then move 50 meters and start all over."

Wild gorillas will charge at unfamiliar humans, so observers have to habituate apes slowly to their presence by mimicking the animals' behavior. "In the bush, the trackers smack their lips loudly, like they're eating leaves. The male silverback will grunt, and they will grunt right back." Every once in a while, thunderous flatulence comes rumbling out of the underbrush, Berry says. "And the trackers will do the same thing right back to them! They do a pretty good imitation, actually."

Berry himself concentrates more on the trail of half-eaten vegetation the apes leave in their wake. On hearing secondhand stories of sick gorillas climbing to the alpine regions to eat the leaves of lobelia plants, Berry hiked up to see them. "They look like something out of Dr. Seuss," he recalls. "Lobelia has 15-foot-tall flowers and immense rosettes of leaves."

Although Berry has yet to catch apes in the act of self-medication, researchers have observed gorillas eating the bright red fruit of wild ginger plants, which are used medicinally by local peoples in Gabon. Analysis of the fruit showed it to contain a potent, water-soluble antibiotic. "I tasted the fruit myself—it is sweet and gingery-hot," Berry says. "I like it. But you can't finish a whole fruit, because you start feeling a queasy, burning sensation in your stomach," which he speculates may indicate activity against normal gastric bacteria. "We plan to look at the dung of gorillas that eat these, to see if their microflora are resistant." Meanwhile Rodriguez is setting up another observation post, in South America, where he may find new drugs of a different kind. "There are reports of monkeys there eating hallucinogenic plants and going bananas," Berry deadpans. *—W. Wayt Gibbs in San Francisco*

IN BRIEF

And the Nobel Prize winners are ...

Chemistry. Robert F. Curl, Jr., and Richard E. Smalley of Rice University and Sir Harold W. Kroto of the University of Sussex, for their discovery of buckminsterfullerenes, or buckyballs.

Economics. James A. Mirrlees of the University of Cambridge and the late William Vickrey of Columbia University, for their contributions to the theory of incentives under asymmetric information.

Physics. David M. Lee and Robert C. Richardson of Cornell University and Douglas D. Osheroff of Stanford University for their discovery of superfluid helium 3.

Physiology or Medicine. Peter C. Doherty of the University of Tennessee and Rolf M. Zinkernagel of the University of Zurich, for their discoveries concerning the specificity of cell-mediated immunity.

Extreme Doubt

The thrill is gone over findings that a form of *DRD4*—a gene coding for dopamine receptors in the brain—leads to novelty-seeking behavior. Scientists at the National Institutes of Health compared the genes of Finnish alcoholics, clear novelty-seekers according to standard psychological tests, and more stoical control subjects. The suspect *DRD4* form, they found, appeared equally in both groups. What is more, alcoholics carrying the novelty-seeking gene were the least adventurous of their lot.

TONY STONE IMAGES

Combinatorial Support

Researchers at Merck Laboratories have simplified combinatorial chemistry—a cut-and-paste process that churns out thousands of potentially valuable compounds all at once. Chemists have always tagged these products for testing with tiny inert spheres. But dendrimers, too, can be used as labels. These large molecules are quick to assemble and dissolve more readily than the spheres do—making it easier to analyze the reaction products.

Continued on page 26

ence might be less candid in the future.

At Tomsk-7, approximately 1.1 billion curies of radioactivity have been injected into the ground so far, Bohmer says. (Exposure to tens of curies can endanger human beings.) At Krasnoyarsk-26, roughly 700 million curies are believed to have been released, Bohmer says. Tomsk and Krasnoyarsk are both in Siberia, near rivers that empty into the Arctic Ocean. The liquids are injected into the earth between 300 and 700 meters down, underneath layers of shale and clay that, Minatom officials maintain, trap the liquids.

U.S. experts, however, tend to be more disturbed by the practice. "Groundwater flows are likely to bring that waste back to the surface," says Henry W. Kendall, a Nobel Prize–winning physicist at the Massachusetts Institute of Technology who has advised the U.S. government on nuclear waste issues. "It's tomorrow's problem and therefore can easily be forgotten," he adds.

More serious may be possible dumping at a third site, Dmitrovgrad. Little information was available, but Bohmer believes the practice continues there as well. Injections at the Dmitrovgrad site are particularly worrisome because of the possibility that they could migrate into the nearby Volga River, near which great numbers of people live. Citing Russian reports, Murray Feshbach, a professor at Georgetown University and an expert on contamination in the former Soviet Union, notes that contamination from the Dmitrovgrad injections "has moved faster than they thought, so it becomes more likely to be a danger to the large population along the Volga."

Releases of radioactive waste into a lake also continue at another materials production site, known as Chelyabinsk-65. During 1995, 700,000 curies were pumped into Lake Karachai, Bohmer states. The lake's accumulation of 120 million curies already makes it one of the most contaminated on the earth.

This year the U.S. will spend approximately $530 million on a bewilderingly large number of programs and initiatives focused on the weapons complexes of the former Soviet Union. Very little of this money goes toward environmental activities, however. The biggest share—$300 million—is rigidly targeted to either eliminating or preventing the proliferation of weapons, materials and delivery systems of mass destruction.

Much of the remaining $230 million is spent under the aegis of various programs run by the U.S. Department of Energy. No formal restrictions prevent this money from being spent on environmental projects, although practically none of it is. "Any efforts to get environmental projects going have been met with yawns," says a spokesperson at one of the DOE's national laboratories. (Clyde W. Frank, the DOE's deputy assistant secretary for environmental restoration and waste management and a key figure in the department's aid programs to Russia, did not respond to a request to be interviewed for this article.)

ITAR-TASS/SOVFOTO

RADIATION LEVELS *were measured after a small tank containing radioactive solution exploded near Tomsk-7 in 1993.*

This year the bulk of the DOE money is being spent on what is known as materials protection, control and accounting—keeping bomb-grade materials out of the hands of terrorists or others who might use them against the U.S. Some of the DOE money goes toward shoring up Russian reactors; some is also spent on various pursuits aimed at keeping former weapons scientists busy and therefore less likely to sell their services to potentially hostile groups or nations.

"Even if the DOE wanted a significant program to assist the Russians in cleaning up their nuclear mess, Congress wouldn't fund it," says Thomas B. Cochran, a senior scientist at the Natural Resources Defense Council in Washington, D.C. "Unless you can see a tangible benefit for the U.S., like having fewer nuclear weapons aimed at it, funding is unlikely." —*Glenn Zorpette*

In Brief, *continued from page 24*

Critical Costs

Managed care plans, the *Journal of the American Medical Association* reports, offer no real savings to the critically ill. Researchers at the University of Pittsburgh Medical Center credit the lower costs to stronger patients, not greater efficiency. Indeed, they found that managed care patients in the intensive care unit were generally younger than those with traditional insurance and so needed less time to recover. In time, then, managed care plans may well become more expensive.

Stoking the Oldest Coal

Humans have kindled fire with coal since Paleolithic times, it now seems. At two Stone Age settlements near Nantes, France, archaeologists uncovered oddly compressed charcoal bits—some in a hearth. The specimens were deformed before they were charred and so entered the hearth as coal, not wood. The scientists speculate that wood may have been scarce during the last glacial age.

Hothouse Flowers

The lotus, often painted with its petals folded around a phallus, has long symbolized female fertility. In keeping, new research shows that these exotic blossoms embrace beetles and other pollinators at night—attracting them with heat. Botanists in Australia found that lotus petals shielded from sunlight remained between 29 and 36 degrees Celsius (85 and 96 degrees Fahrenheit)—even when the air surrounding them dropped to 10 degrees C. Only two other plant species similarly regulate their own temperature: *Philodendron selloum* and *Symplocarpus foetidus.*

PATTI MURRAY *Earth Scenes*

The Chicken **and** ***the Egg***

The earliest lineages most likely sprung forth from ribozymes, biochemists at Yale University now say. These large RNA enzymes edit genes by removing flawed code and splicing in the correction. Thus, they may have served as both chicken and egg in primitive cell reproduction. Most recently, researchers have tried to use ribozymes to erase viral genes responsible for deadly infections and to repair faulty genes causing various inherited conditions.

Continued on page 30

POLICY

BEYOND THE TEST BAN

Experts debate the need for a giant laser-fusion machine

On September 24, President Bill Clinton signed the Comprehensive Test Ban Treaty, a long-sought pact prohibiting nuclear weapons testing. Less than one week later, Clinton signed a bill authorizing a huge increase in funds for, well, nuclear weapons testing.

More specifically, the legislation provides $191 million for fiscal year 1997—up from only $18 million this year—for construction of a gigantic laser complex capable of generating miniature thermonuclear explosions. The stadium-size facility at Lawrence Livermore National Laboratory is expected to take six years to construct at a total cost of $1.1 billion. Various environmental and arms-control groups oppose the project, arguing that it is a relic of cold war thinking that should be abandoned. "It's not evil," says Tom Zamora Collina of the Institute for Science and International Security in Washington, D.C. "It's just a waste of money."

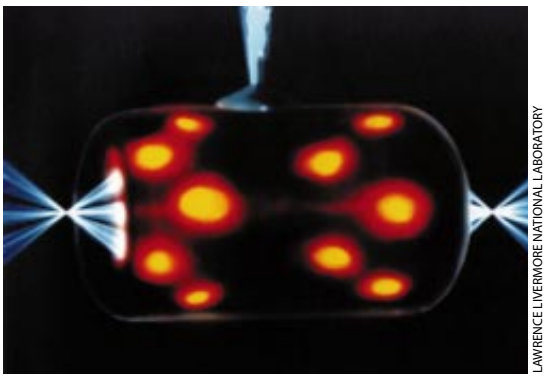
If built, the so-called National Ignition Facility (NIF) will consist of 192 lasers whose light will converge on minute pellets of heavy hydrogen and cause them to implode. Ideally, the pellets will then "ignite"—that is, achieve nuclear fusion, the same process that makes stars shine and hydrogen bombs explode.

Proponents of the NIF emphasize that it will have nonmilitary applications. The machine could establish whether the technique known as inertial confinement fusion holds any promise for commercial power generation. Experiments may also provide insights into nuclear processes that take place in the sun and other stars.

But the primary justification for the facility is to ensure that existing nuclear weapons work properly, now that the U.S. has pledged not to conduct any more nuclear tests. (The test ban treaty must still be ratified by the U.S. Senate and by legislatures of other countries before it goes into effect.) Even before Clinton signed the treaty in September, his administration had imposed a moratorium on testing; the last full-scale detonation of a warhead occurred in 1992 at the end of the Bush era.

Administration officials nonetheless agreed to support the Stockpile Stewardship Program, which is intended to ensure "the safety and reliability" of existing weapons. The NIF is only the largest and most expensive of more than half a dozen machines that the national laboratories—including Los Alamos and Sandia as well as Lawrence Livermore—will receive under the stewardship program.

Critics of the NIF and other facilities charge that they served as payments from the Clinton administration to the national laboratories for their acceptance of a test ban. "These are bribes so they'll go along with the CTBT," says Joseph Cirincione, chair of the Coalition to Reduce Nuclear Dangers.



LAWRENCE LIVERMORE NATIONAL LABORATORY

LASER BEAM
striking a millimeter-size chamber generates x-rays **(red spots)** ***in a test of inertial confinement fusion.***

That claim is corroborated by Frank von Hippel, a physicist at Princeton University who served on a panel that reviewed the security implications of the NIF for the Department of Energy. Although the panel members had concerns about the facility, they did not take a strong stance against it, von Hippel explains, because they feared their opposition might damage the prospects for a test ban.

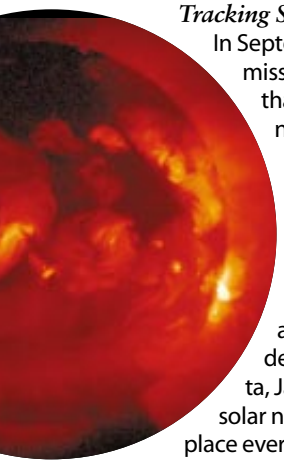
The NIF may still bog down in legal challenges. The Department of Energy is expected to release its final environmental impact statement soon. Once the statement is published, it will immediately be challenged in court by a coalition of 90 environmental and disar-

In Brief, *continued from page 26*

Cashing in on Contraceptives

Public funding for contraceptive services clearly limits the number of teenage and single mothers. In addition, these measures dramatically lower abortion rates and Medicaid expenditures. In a recent study, the Alan Guttmacher Institute calculated that were this funding cut, abortion rates would rise by 40 percent in the U.S. The estimate—which is conservative by many accounts—means that each tax dollar spent on contraceptive services saves three dollars in Medicaid costs for treating pregnant women and newborns.

NASA GODDARD SPACE FLIGHT CENTER



Tracking Solar Neutrinos

In September scientists dismissed the long-held belief that the number of neutrinos emitted by the sun follows an 11-year cycle. A few weeks later Peter Sturrock and Guenther Walther of Stanford University put forth a new periodicity: after studying data from detectors in South Dakota, Japan and Italy, they say solar neutrino changes take place every 21.3 days.

FOLLOW-UP

Fourth Rock from the Sun

Believers had a big thrill last summer when NASA announced that they had uncovered signs of Martian life in a meteor. The evidence came in the form of tiny, sausage-shaped imprints, which the scientists said were most likely left by "nanobacteria." Now, however, researchers at the Massachusetts Institute of Technology have demonstrated that purely inorganic happenings can make identical marks. The truth is out there. (See October 1996, page 20.)

Waiting to Exhale

A simple breath test can now diagnose peptic ulcers caused by *Helicobacter pylori.* To detect this bacteria in the past, physicians biopsied a patient's stomach tissue. But soon they may use the Meretek UBT Breath Test, approved by the FDA in September. Patients slosh down a urea solution, fortified with heavy carbon isotopes. Because *H. pylori* breaks urea down rapidly, the heavy carbon wafts up and out if the organisms are present. (See February 1996, page 104.)

—Kristin Leutwyler

mament groups, including the Natural Resources Defense Council (NRDC) in Washington, D.C. None of the potential applications of the NIF can justify its cost, asserts Christopher Paine of the NRDC. The safety and reliability of the stockpile can be maintained more cheaply and effectively by testing components of existing weapons than by conducting pure-fusion experiments, he says.

In addition, Paine doubts whether the NIF can establish the feasibility of inertial confinement fusion for power generation. Ion beams and gas-based lasers, he says, have shown more promise than the glass lasers that will be deployed in the NIF. Glass lasers, which use glass rather than gas for a lasing medium, generate tremendous temperatures and are susceptible to fracturing.

Indeed, the lens of an NIF prototype laser—or "beamlet"—shattered in a test firing at Livermore in September. "Here we are six months from construction, and we can't build one little beamlet," Paine says. *—John Horgan*

HUMAN BIOLOGY

SEX AND THE SPINAL CORD

A new pathway for orgasm

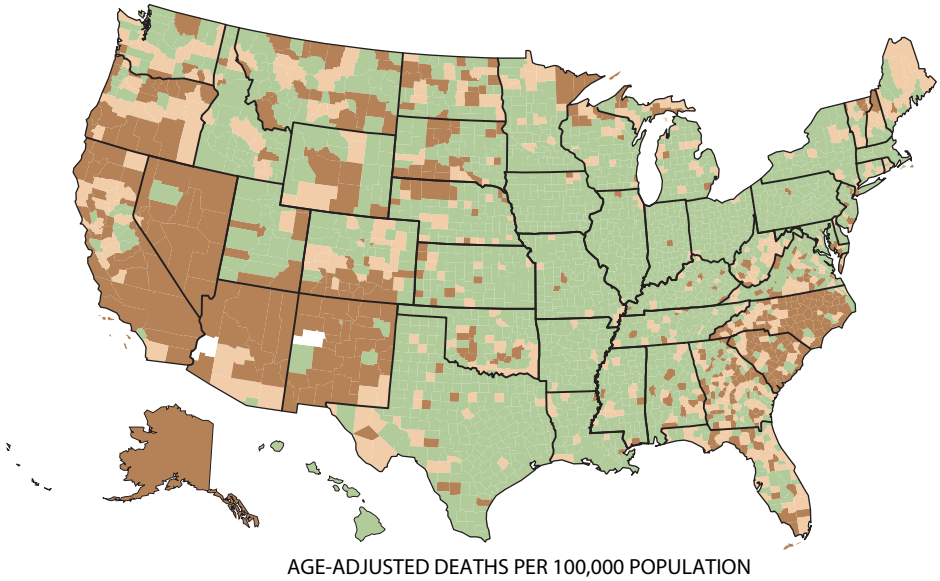
The sexiest part of the human body may never be ogled on the pages of *Playboy.* New research suggests that this distinction goes to the rather unphotogenic vagus nerve. Known to orchestrate such mundane tasks as breathing, swallowing and vomiting, this nerve wends its way through all the major organs, bypassing the spinal column and hooking directly into the base of the brain.

It is precisely because the vagus nerve does not touch the spinal column that its role in sex was recently discovered. Barry R. Komisaruk and Beverly Whipple of Rutgers University were investigating reports of orgasm in women who

BY THE NUMBERS

Deaths Caused by Alcohol

Excessive alcohol consumption leads to more than 100,000 deaths annually in the U.S. Accidents, mostly from drunken driving, made up a quarter of this number in 1992; alcohol-related homicide and suicide accounted for 11 and 8 percent, respectively. Cancers that are partly attributable to alcohol, such as those of the esophagus and larynx, contributed an additional 17 percent. About 9 percent resulted from alcohol-related stroke. Another major contributor is a group of 12 ailments wholly caused by alcohol (*see map below*), of



SOURCE: National Center for Health Statistics. Data are for 1979–1992 and are shown by county for 12 causes of death wholly attributable to excessive alcohol consumption among people 35 and over.

had spinal cord injury above the ninth thoracic vertebra. Although these women were not receiving stimuli from the nerves known to be responsible for orgasm—the pudendal, pelvic or hypogastric nerves—the two researchers documented the hallmarks of orgasm: increases in their subjects' blood pressure, heart rate, pain threshold and pupil dilation. "It was a complete surprise," Komisaruk says. "We knew there had to be another pathway at work."

Delving deeper, Komisaruk turned to rat studies. He severed all the sensory nerves that are known to serve the genitals and then stimulated the rats' cervixes. He observed pupil dilation and an increase in the animals' threshold to pain. Komisaruk next removed a section of the spinal cord at thoracic vertebra seven, just above where the pelvic and hypogastric nerves join the column. He observed the same results.

Komisaruk's findings recalled a 1990 study by Matthew J. Wayner and his colleagues at the University of Texas at San Antonio. Wayner's group injected a tracer into rat genitalia and observed that it was taken up by the vagus nerve and the nodose ganglion of the medulla—indicating that there was a pathway that circumnavigated the spinal cord. Wayner's discovery, along with his own findings, suggested to Komisaruk that he might have evidence for an undiscovered route for orgasmic sensation. So he cut the vagus nerve in his rats and repeated his experiments. There was no pupil dilation, no increased resistance to pain. "The cranial nerves, like the vagus, have been around since the early vertebrates," says William D. Willis, a neurophysiologist at the University of Texas at Galveston. "Komisaruk's research suggests that this may be a primitive and more commonly found pathway for orgasm."

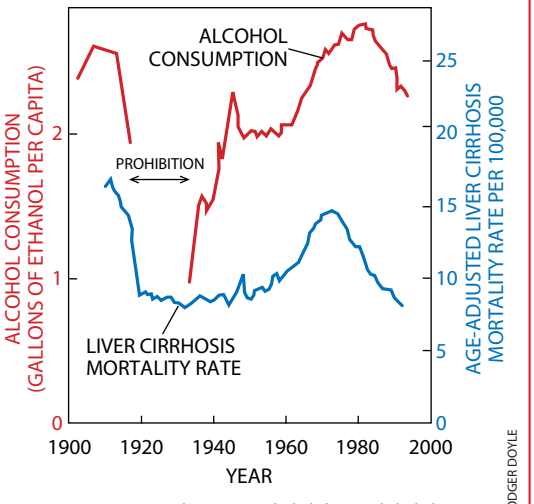
Komisaruk and Whipple then turned back to their human subjects. They injected women who had complete spinal cord injury with a tracer. Although the hypogastric and pelvic nerves were useless, positron emission tomographic

which alcoholic cirrhosis of the liver and alcohol dependence syndrome are the most important. These 12 ailments represented 18 percent of all alcohol-related deaths in 1992.

The most reliable data are for the 12 alcohol-induced conditions. Mortality from these conditions rises steeply into late middle age and then declines markedly, with those age 85 or older being at less than one sixth the risk of 55- to 64-year-olds. Men are at three times the risk of women; blacks are at two and half times the risk of whites.

The geographical pattern of mortality from these 12 conditions is partly explained by the amount of alcohol consumed by those who drink, which is above average in the Southeast and in areas of the West. In New Mexico, Arizona, Alaska and in many counties in the Plains and Mountain states, the mortality rates are high, in part, because of heavy drinking among Native Americans. In the South Atlantic states, blacks contribute substantially to the high mortality rates, although white rates there are above average as well. One unexplained anomaly is the comparatively low mortality rates in Kentucky, Tennessee, Alabama, Mississippi and Louisiana, a region where alcohol consumption is high among drinkers.

During the past 150 years, there were at least four peaks of alcohol consumption: about 1840; the 1860s; the first decade of the 20th century; and between 1979 and 1981. Each peak was probably accompanied by an increase in alcohol-related deaths, as suggested by the rate of liver cirrhosis mortality, which, since the early 20th century, has paralleled the consumption of alcoholic beverages. (Up to 95 percent of liver cirrhosis deaths are the result of alcohol.) Among western nations, the U.S. is now somewhat below average in both alcohol consumption and liver cirrhosis mortality. *—Rodger Doyle*



SOURCE: National Institute on Alcohol Abuse and Alcoholism

Editors' note: The legend title for the map that appeared in the October 1996 column was misprinted. It should have read, "Change in Topsoil Erosion."

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scans revealed that the nodose ganglion of the medulla was taking up the tracer.

The existence of this pathway explains long-standing anecdotal reports of nongenital orgasms in women with damaged spinal cords. Such women have reported orgasm after stimulating a hypersensitive area just above the level of the injury; in these cases, orgasm would take place on the shoulder, chest or chin. (Similar studies on men are being planned.) Komisaruk has hypothesized that any part of the body is capable of excitation, tension and sudden release—indeed, the cycle may be a function of the nervous system that manifests itself in reflexes as nonsexual as sneezes and yawns.

"The eventual goal of all this work," Whipple sums up, "is to tap into and amplify this pathway so we can help women who've had neurological problems. These women could have normal, healthy sex lives." *—Brenda DeKoker*

ANTI GRAVITY

The Victors Go Despoiled

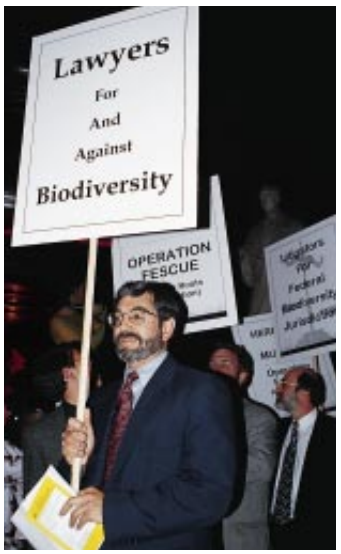
Fool me once, shame on you; fool me twice, shame on me," *Star Trek*'s Mr. Scott once wisely noted. Unfortunately, Scotty never revealed who should carry the shame for foolings greater than two. Considering that the Ig Nobel Prizes were awarded in October for the sixth year in a row, one can only assume there is plenty of shame to go around.

Harvard University's Sanders Theater accommodated this year's Ig Nobels, a good-natured spoofing of those other awards that scientists, writers and peaceable folks get. The Igs go to "individuals whose achievements cannot or should not be reproduced," according to the official program.

Real Nobel laureates attended, namely, Dudley Herschbach (Chemistry, 1986) and William Lipscomb (Chemistry, 1976). But Richard Roberts, winner of the 1993 Nobel Prize for Physiology or Medicine, did not. "He planned to join us," alleged Marc Abrahams, the producer and host of the Igs, "but, for some reason, instead chose to attend his daughter's wedding in California. Happily we have a plaster cast of his left foot." The cast was later auctioned, fetching $30.

With biodiversity the theme, 13-year-old Kate Eppers, reputedly the spokesperson for the Committee for Bacterial Rights, struggled to open multicellulocentric minds. "Every time you wash your hands," she entreated, "you wipe out billions and billions of bacteria, and that's not fair. Bacteria have rights, too. When your mom asks you to wash your hands, just say no."

After this counsel came shocking revelations concerning the taxonomic classification of Barney the television dinosaur, offered by Earle Spamer of Philadelphia's Academy of Natural Sciences. Primarily because of the purple fuzz on his dermal covering, Barney is actually more closely related to a dead salmon than he is to any saurian, according to Spamer. "How is he on a bagel?" cried out one not quite fed-up attendee.



STEVE MIRSKY

IG DELEGATES take a stand on biodiversity.

Finally, Abrahams announced the Igs. Harald Moi of Oslo took home the Public Health award for his groundbreaking discovery of a gonorrhea infection transmitted via an inflatable doll. The victim was a seaman, which merely confuses the issue. (Moi's finding was published in the journal *Genitourinary Medicine* in 1993.) In a perverse reversal of the usual Nobel itinerary, Moi traveled *from* Scandinavia *to* Harvard to pick up his prize. "The biggest problem in this case was how to perform the mandatory partner notification and treatment," he noted in his acceptance speech. "I think on a ship, if the crew is there for several months, perhaps they need dolls," he said afterward. "But they shouldn't share them."

Don Featherstone traveled all the way from Fitchburg, Mass., to receive the Art Ig. Featherstone is the creator of the pink flamingo lawn ornament. "Let's keep [future] archaeologists guessing," he suggested. "Get out and buy as many of these lawn ornaments as possible."

Not all the winners made it to the festivities. Missing were five tobacco executives, who garnered the Ig for Medicine, for "their unshakable discovery, as testified to the U.S. Congress, that nicotine is not addictive." Also absent was Robert Matthews of England's Aston University, who captured the Ig for Physics with his 1995 paper in the *European Journal of Physics* explaining that toast does indeed fall buttered-side down.

The evening featured much cavorting by Herschbach and Lipscomb, who appeared in key roles in the opera *Lament del Cockroach,* "an epic tale of punctuated equilibrium." They portrayed non-*Blattidaen* insects trying to mate with female roaches so as to hybridize their own species into hardier stock before an asteroid could wipe them out. Somehow the opera was listed as having three acts, rather than major segments.

Abrahams wrapped up the ceremony by offering encouragement to the entire scientific community: "If you didn't win an Ig Nobel Prize this year, and especially if you did, better luck next year." *—Steve Mirsky*

Other Ig Winners

Biology. Anders Baerheim and Hogne Sandvik of the University of Bergen in Norway, for their report "Effect of Ale, Garlic, and Soured Cream on the Appetite of Leeches."

Peace. Jacques Chirac, president of France, for commemorating the 50th anniversary of Hiroshima with atomic bomb tests in the Pacific.

Chemistry. George Goble of Purdue University, for using liquid oxygen and charcoal to ignite a barbecue in three seconds.

Biodiversity. Chonosuke Okamura of the Okamura Fossil Laboratory in Nagoya, Japan, for finding what he claims to be fossils, less than 0.01 inch across, of horses, dragons, princesses and more than 1,000 other extinct "minispecies."

Literature. The editors of the journal *Social Text,* for publishing New York University physicist Alan Sokal's now infamous spoof of postmodern science criticism.

Economics. Robert Genco of the University of Buffalo, for his discovery that "financial strain is a risk indicator for destructive periodontal disease."

A list of the real Nobel Prize winners in science is on page 24.

PHYSICS

HARD TO MELT

Ice cubes that take the heat

Ice melts when removed from its subzero confines, right? Not certain kinds. Researchers have found that ordinary ice can remain solid at five degrees Celsius and, possibly, up to 18 degrees C.

Laura A. Stern and Stephen H. Kirby of the U.S. Geological Survey, along with William B. Durham of Lawrence Livermore National Laboratory, made the serendipitous discovery. They were trying to study a substance found on moons of the outer solar system and in cold ocean-floor sediments—methane clathrate, to be specific. This material has a cagelike structure of water molecules that traps methane within its cavities. To make a rock of clathrate, the scientists ground ice into a powder, mixed it with methane in a cylinder, then gently warmed it.

Because ice is less dense than liquid water, it occupies more volume, and so the researchers expected the pressure to drop as the ice melted, thereby making more space available. (The water's reaction with methane should have reduced the pressure even further.) But they saw no sudden pressure drop. Nor could they detect any absorption of heat, indicative of melting.

"I was raising my eyebrows at this point," Stern recounts. "I thought it was an artifact of the system." Repeating the procedure with neon instead of methane, she found the pressure dropped rapidly at the melting point of ice. Methane, though, permitted the ice to be superheated—that is, warmed beyond its melting point without melting.

The investigators think each ice grain was able to acquire a rind of methane clathrate. During warming, ice at the surface begins to melt first; these incipient droplets of water were being instantly transformed into clathrate. The rind thus acted as a shield, preventing any water from touching the ice within—which would have initiated the grain's change to water.

"The melting temperature is the temperature at which the liquid and solid are at equilibrium," Durham explains—if no liquid, no melting. Another reason these ice grains can be superheated is that they apparently have few defects: flaws in the crystalline structure of ice can initiate the changeover to liquid droplets.

A similar phenomenon was observed

JOHN PINKSTON AND LAURA A. STERN

FIRE AND ICE:
an icelike substance called methane clathrate hydrate can burn.

in 1986 with gold-coated crystals of silver. And water frozen under pressure into different crystalline configurations—namely, ice II through ice X—can withstand rather toasty conditions (up to 70 degrees C). But the high temperatures for ordinary ice, or ice I, are a first. "Others have found superheating of a couple of degrees," Stern points out. "We're looking at perhaps 18 degrees." The researchers plan to repeat the experiment with larger ice grains, to see if the effect is enhanced. Meanwhile they are boning up on classical thermodynamics, which never seems to run out of surprises. —*Madhusree Mukerjee*

EVOLUTIONARY BIOLOGY

FEAR AND FECUNDITY

Death-defying guppy stunts—just to dazzle the females

Knights in days of yore would embark on dangerous adventures simply to impress their intended ladies, and it's a fair bet that much modern machismo still stems from the same motivation. The idea that male animals perform risky stunts or evolve encumbering decorations simply to show off their cool has divided biologists. A recent study of what turns on females suggests, however, that the notion may be more than a theoretical possibility, at least for a small fish.

Jean-Guy J. Godin of Mount Allison University in New Brunswick and Lee Alan Dugatkin of the University of Louisville studied first how male Trinidadian guppies that vary in the amount of orange coloration on their bellies respond to a predator fish, both when possible mates were present and when they were absent. The researchers then looked at what kind of male behavior tempted the females to get acquainted later. The results, reported in the *Proceedings of the National Academy of Sciences,* leave some room for biologists to debate their interpretation but have an uncomfortably familiar ring to anyone who has gone through puberty.

Flashily colored males were far more likely to make close approaches to inspect a model predator than were drab males. Not too surprising, given that the dandies might be more vigorous and better able to look after themselves. More intriguing was that the flashy males maintained their bravado when females were around, thus apparently losing out on the chance to strike up a relationship. Drab males, in contrast, would keep their distance from a predator in order to stay close to an appealing female. That might suggest the gaudy individuals were making a mistake, but their payoff came later. Females that had watched displays of derring-do preferred to spend time subsequently with studs that fearlessly approached the predator than with milquetoasts.

The authors suggest female guppies bestow their charms mainly on males who live dangerously because boldness and colorfulness are honest signals of genetic quality. The signals are honest because for weak specimens, checking out predators and being brightly colored are genuinely risky—both mean an increased chance of being swallowed. A show-off male really must be healthy to survive, and so the impressed females demonstrate their interest.

Many theorists now agree that evolution can in principle produce handicaps, as biologists call displays that impress because they are dangerous to their owner. This paradoxical idea was proposed by Amotz Zahavi of Tel Aviv University in 1975, but nobody has yet found an unassailable instance. Some biologists wonder whether Godin and Dugatkin's fast-lane male guppies were really putting themselves in harm's way, because they were also more quick to turn and flee. But Godin and Dugatkin hope to show that male guppies' romantic extravagances can qualify as handicaps, by investigating whether the male and female roles in their courtship drama are inherited. If the scientists succeed, academic prizes—and who knows what other rewards—may be theirs.

—*Tim Beardsley in Washington, D.C.*

GÉRARD LACZ *Animals Animals*

TRINIDADIAN GUPPIES ***court extravagantly: males risk death to show off to females.***

CYBER VIEW

Snap, Crunch or GigaPOP?

The Internet, warn some éminences grises, is staggering chaotically toward massive outages, perhaps even a total collapse. Nonsense, retort others: the future has never looked brighter for the global network. Both sides are correct. True, the explosive growth of the World Wide Web is pushing Internet standards and switches near their breaking points, while floods of information regularly back up the network plumbing. But for more than a decade, congestion has hung over the Net like the sword over Damocles, poised to sever its connections. Last-minute additions of more and bigger pipes have always averted crisis. This time, however, the problems run deeper, and although technical solutions are in hand, they will exact a price—and not just in the figurative sense. The resulting economic tremors may well topple some of the Web's shakier business plans, but they should also reshape the Internet into a more efficient and reliable medium.

The source of doomsayers' angst is the Net's geometric growth: by most measurements, it doubles in size every nine months or so. Such rapid expansion creates three major threats to the system. The first jeopardizes its ability to connect any two computers on the network. The Internet does so in much the same way as an automated postal system: computers wrap data into packages, stamp the packets with addresses and hand them to automated postal clerks (called routers) to deliver.

But the Internet's numerical address system has nothing to do with location. The Net equivalent of 10 Main St. may be in Maine, whereas 11 Main St. is in Ohio. So each automated clerk has to look up delivery instructions in a table for every packet it handles. Because packets often pass through 10 or more routers before reaching their destination, the time spent poring over large tables can jam up traffic considerably. More alarming, routers' tables are growing twice as fast as their ability to search them. Within two years, that could leave the Net's postmasters with just two unpleasant options: either toss some packets into the trash or refuse to add new addresses (especially those for competing network companies) to their tables.

Two recent innovations will postpone that Faustian choice. The first was a stopgap measure: the agency that hands out Net addresses has been pressuring network managers to organize addresses into sensible groups—much like zip codes. That strategy bought enough time to start using the second improvement, a scheme called tag switching, which

DAVID SUTER

was introduced in September by Cisco, the company that built most of the routers on the Internet. Here the first clerk to examine a package writes down explicit instructions for all the other clerks that will handle it, saving them the time and trouble of consulting their tables.

The second threat to the Net is that it may run out of numerical addresses altogether, bringing its geometric growth to a crashing halt. Although the current addressing format theoretically supports about 4.3 billion computers, large swaths of the numbers have been given away but never used. By recycling old addresses and dipping into reserves, the existing supply can probably be stretched into the next decade—long enough to switch to new software, playfully named "Internet Protocol, the Next Generation." IPng will allow every human on the planet to have something like 100 network devices. That should suffice for a while.

The final danger to the stability of the burgeoning Internet is that congestion will slow data to a crawl, ruining plans for fancy interactive games, cheap long-distance calls and grainy video on demand. Because bottlenecks often occur at the switches deep inside the Internet cloud rather than at the periphery where workers and consumers connect, the problem will only grow worse as more people buy PCs and fast modems. Slick routing tricks such as tag switching will help for a time. And many of the companies who own parts of the Internet's backbone are scrambling to expand it; MCI tripled the capacity of its segment this past summer. But demand will outstrip supply as long as Internet access remains so inexpensive; MCI has also seen the flow over its network swell 56-fold in less than two years.

As Microsoft Network, America Online and Prodigy get ready to join companies offering unbeatable, all-you-can-surf pricing, some schools and corporations with high hopes for the Internet are preparing to jump ship. In October a group of universities announced plans to build Internet II, a high-speed national network linking perhaps 50 research institutions. The private network would connect to the Internet at "GigaPOPs" scattered throughout the country. (A POP, or point of presence, is the Internet equivalent of a post office.) But it would close its gates to outside users in order to preserve enough bandwidth to work on high-tech projects—such as telemedicine, distance learning, scientific visualization and broadcast video of undergrads' dorm parties—without the hassle of Internet congestion. Companies such as Chrysler are rumored to be toying with similar options to link factories with dealers and material suppliers. (Private "intranets" exist, but they generally link their far-flung locations using the Internet and are thus at the mercy of Net-wide congestion.)

Internet II will not ease the pressure on Internet I directly by more than a few percent, but it may have a lasting indirect influence. University officials involved say they want to try out new pricing policies and special delivery software designed to help guarantee rapid responses and clear channels to those willing to pay for them.

These good ideas have been around for years. One, called resource reservation protocol, or RSVP, is even scheduled to appear this fall in Cisco routers and Intel videoconferencing software. The hang-up has been billing: if the urgent data are delivered partly by MCI, partly by Sprint and partly by Pacific

Bell, all three need to agree on systems to split the fees. Internet II, because it would have just one backbone and one bill to pay, could test whether RSVP and other priority schemes work at large scales, while punting on the billing issue.

In the meantime, some networking companies, chafing at the thin margins of their commodity business, will soon start offering higher-quality Internet access for higher prices. No one knows how the market will react when, inevitably, basic services slow as premium customers are ushered to the head of the queue. If, as some insiders predict, the companies that run the Internet's backbone soon begin charging those on its limbs according to the amount of data they send or receive, they will have little choice but to pass the costs along. Forced to decide what is worth paying for, many customers will first tune out images—thus destroying the fledgling Internet advertising business—and will then search more, browse less. Although this may rob the Net of much of its charm, it would almost certainly prod it toward greater utility.

—W. Wayt Gibbs in San Francisco

TECHNOLOGY AND BUSINESS

SUPERCOMPUTING

THE SALE OF A NEW MACHINE

Can a new scientific computer revive a moribund industry?

A scant four years ago the supercomputing market seemed poised to move beyond its government and academic roots and make a grand entrance into the much larger worlds of commerce and industry. In the U.S. alone, more than a dozen companies planned for this shift by marketing or developing ultrahigh-performance computers. But the big move into the mainstream never occurred to the extent that many analysts had predicted.

Instead the organizations that were designing or promoting these machines withered or folded altogether (some even before they managed to complete their machines). Today only two viable domestic producers of high-end supercomputers remain in the U.S.: Cray Research—which was recently bought by Silicon Graphics—and IBM.

Now a new entrant, Tera Computer Company in Seattle, is preparing to wade into these treacherous waters. Tera's long-overdue computer has been in development for almost a decade—throughout the entire boom and bust cycle that eventually left the supercomputer market in its present dormancy. The company is expected to deliver its first machine to the San Diego Supercomputer Center, part of the University of California system, early next year.

Why do Tera's founders think they can succeed where many of the industry's brightest minds have recently failed? "We're different," says Burton J. Smith, Tera's chairman and chief scientist. "Whether that translates into success in the market, we'll see. But certainly, the same old approach won't work."

The Tera machine is billed as the world's first shared-memory computer that can be scaled up to include hundreds of processors (the ability to accommodate so many processors puts the machine in a category known as massively parallel). In a shared-memory machine, all the processors have access to a common memory; in the alternative design, called distributed memory, each processor has its own memory. The chief advantage of shared memory is ease of use. The model it presents to programmers is relatively straightforward, because they need not keep track of which memory harbors individual data elements.

One significant difficulty in building a highly parallel shared-memory machine is that various techniques are necessary to ensure that multiple processors do not waste too much of their time inhibiting one another by trying to access the same data at the same time. These techniques, in turn, can easily lead to inefficiencies that seriously degrade the machine's overall performance.

Tera hopes to get around this problem with a unique design, in which each of the machine's processors can act as though it were as many as 128 different "virtual" processors. Each virtual processor runs a different programming job or a different piece of a larger job. On each clock cycle the machine can switch from one virtual processor to another; in so doing, it executes with every tick of the clock an instruction from a different program. This same scheme is employed to keep the machine's processors from competing for data.

The Tera machine's processors are custom-designed; this fact is significant because the power and economy of mass-produced processors are often cited as factors in the collapse of the supercomputing market. As much cheaper and easier-to-use workstations based on off-the-shelf processors increased in power, fewer buyers were willing to pay for relatively complex supercomputers based on custom

SILICON GRAPHICS AND LIVERMORE SOFTWARE TECHNOLOGY CORP.

AIR-BAG SIMULATION
and other crash analyses are common supercomputer uses.

processors, especially when these machines were much harder to program.

On the other hand, computer scientists agree that custom design of processors provides the only means for a shared-memory computer to include as many processors as Tera's (eventually, up to 256).

To avoid the fate of so many of its predecessors, the Tera machine—which is expected to cost about $10 million for a configuration with 16 processors—will have to enable users consistently to achieve a reasonable fraction of its theoretical peak processing rate of about one billion floating-point operations per second (one "gigaflop") for each processor. "They'll need to get very high efficiency out of those processors," says Wayne Pfeiffer, associate director of the San Diego center. The Tera machine's projected peak rate of one gigaflop per processor is about half that of the Cray T90, a state-of-the-art vector supercomputer. The T90, however, can include no more than 32 processors.

Regardless of whether Tera succeeds, the future of ultrahigh-performance computing belongs to scalable machines, according to Malvin H. Kalos, director of the Cornell Theory Center, a supercomputer facility located at Cornell University. Only this type of machine, he asserts, has a chance of achieving the trillion floating-point operations per second (a "teraflop") that many scientists and engineers are seeking to help them meet a series of "Grand Challenges" first identified years ago by the Nobel Prize–winning physicist Kenneth Wilson. These challenges include so-called rational drug design, which would let biochemists design entire drug molecules on a computer, and the forecasting, on a fine scale, of global shifts in rainfall, temperature and other climate factors over periods ranging from decades to centuries. *—Glenn Zorpette*

METEOROLOGY

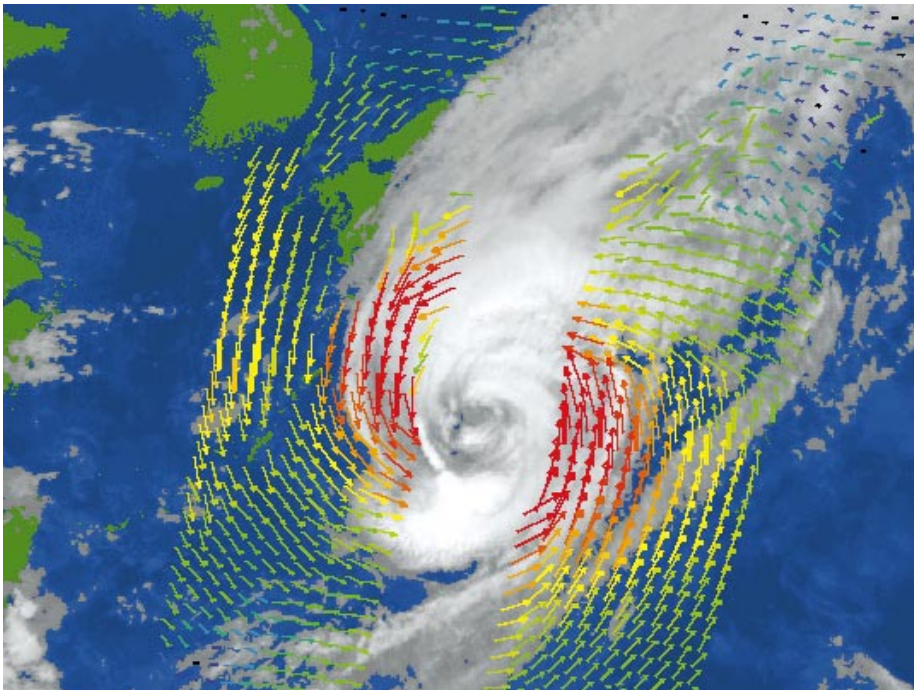
Where the Wind Blows

Ancient mariners cursed the capricious wind for the ships it stranded and sunk. Gyroscopic stabilizers and diesel engines now pacify tempests and plow through calms, but a shift in the trade winds can still add days, and dollars, to a sea crossing. And for much of the world, oceanic winds drive the weather. The climate models scientists have built inside computers to predict the path and fury of storms, to speculate on the effects of a rise in global sea temperatures and to understand exactly what causes weather-disrupting El Niño conditions are only as good as the knowledge they contain of where, and how strongly, the wind blows over the water.

Such data have been at best a patchwork of infrequent and sometimes inaccurate readings assembled from buoy and ship reports. Forecasters and sea captains should thus have been heartened in late September to see the first measurements sent back from the National Aeronautics and Space Administration's scatterometer, a NASA instrument launched on Japan's Advanced Earth Observing Satellite. Every two days the device passes over at least 90 percent of Earth's ice-free oceans and returns data that, when churned through computers on the ground, yield a detailed wind map.

Peering through clouds and rain to gauge the direction and speed of invisible pockets of air demands a few technological tricks. The first is to focus not on the wind itself but on its effects. Gusting over the surface of the deep, winds create ripples known as cat's-paws. To most radar operators, the chop appears as noise; fighter jets and missiles sometimes exploit the effect, flying low over the water to sneak up on their targets. But hidden within the clutter are nuggets of information. NASA's scatterometer gathers them by beaming seaward radio pulses at a frequency that is reflected best by centimeter-size waves. When each pulse hits the water, it is altered very slightly by the ripple that scatters and reflects it. With six antennae, each three meters (almost 10 feet) long, the satellite records reflected pulses precisely enough that the subtle changes can be used to calculate the direction and speed of the ripples and thus of the gales that produced them.

Back on Earth, computers plot the data as oceans of arrows indicating the direction and speed of the breeze at 190,000 points. Superimposed over satellite photographs of clouds, the maps can reveal the strength and extent of storms even before they form. In September NASA used the scatterometer to clock 60-mile-per-hour winds inside typhoon Violet off the coast of Japan (*below*). The agency plans to send wind data every two hours to U.S. forecasters, who will relay advisories to coastal communities and all the ships at sea, arming them better against inclement weather. *—W. Wayt Gibbs in San Francisco*



NASA/JET PROPULSION LABORATORY

MATERIALS SCIENCE

WELDING WITH A MATCH

Foils less than 100 microns thick bond with a mere spark

Lugging around a torch and tanks of oxygen and fuel for welding is hardly convenient for a soldier on the battlefield, a diver off an oil rig or an astronaut on a spacewalk. Under such extreme circumstances, the welder's trademark tools may soon give way to hair-thin foils that can fuse two pieces of metal together without oxygen.

The ability to engineer these multilayer foils was patented by Troy Barbee, Jr., of Lawrence Livermore National Laboratory and Timothy Weihs, now at Johns Hopkins University. When exposed to a match flame or a spark from a battery, the foil releases a momentary wave of energy and heat sufficient to melt the filler metal used to form a welded joint.

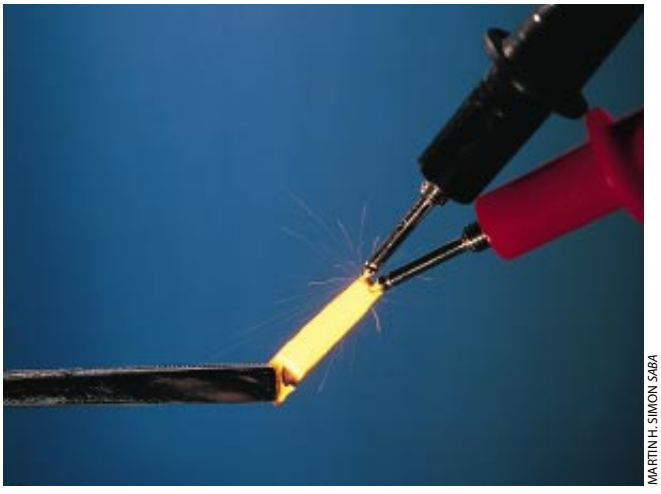
The foil's hot flash comes about because of the rapid combination of its constituent atoms. The foils consist of boron, carbon, silica or aluminum added to a transition metal, such as nickel. "Nickel would much rather go with aluminum than itself," Weihs explains. The strong affinity that the different components have for one another leads to a self-propagating, exothermic reaction that raises the foil's temperature to 1,600 degrees Celsius in about a millisecond, depending on the composition and thickness of the layers.

Because the atoms are so close to one another and because of the speed of the reaction, there is little time for oxygen molecules to mingle with the metals, resulting in a weak or brittle joint. The strength of the foil (and hence the quality of the weld) can be manipulated by changing the thickness of the layers, each of which are typically five to 2,000 nanometers thick. The thinner the layer, the stronger the foil, where a "thin" layer is 20 to 25 atoms in thickness.

Although the idea of using exothermic reactions to join metal is not new, other techniques have drawbacks. In the thermite process of welding, for example, aluminum and iron oxide powders must be ignited with the intense heat from a magnesium torch, and the resulting bond may be compromised because of the presence of oxygen.

The main drawback to the new foils, however, is the time it takes to manufacture them. Building a typical one, which would have about 1,000 layers, could take anywhere from eight to 24 hours, Weihs says. That's because the production involves a costly process called magnetron sputtering, by which atoms are ejected onto a substrate.

The high cost and the slow rate of production may limit the foils' use to such low-oxygen environments as underwater or space. But it's conceivable that someday there will be no more hauling bulky canisters or hiding behind a mask to safeguard against flying sparks. Welders may simply need to pack a pair of tweezers. —*Erica Garcia*



MARTIN H. SIMON *SABA*

***THIN FOIL** glows with heat when given a spark.*

CHEMICAL ENGINEERING

PLASTIC POWER

Polymers take a step forward as photovoltaic cells and lasers

For nearly 20 years, scientists have expected great things from semiconducting polymers—chimerical chemicals that can be as pliable as plastic wrap and as conductive as copper wiring. Indeed, these organic compounds have conjured dreams of novel optoelectronic devices, ranging from transparent transistors to flexible light-emitting diodes. Few of these ideas have made it out of the laboratory. But in the past year, researchers have added two promising candidates to the wish list: solar cells and solid-state lasers.

The lasting appeal of these materials—also called synthetic metals—is that they are more durable and less expensive than their inorganic doubles. Furthermore, they are easy to make. Like all plastics, they are long, carbon-based chains strung from simple repeating units called monomers. To make them conductive, they need only be doped with atoms that donate negative or positive charges to each unit. These charges clear a path through the chain for traveling currents.

Scientists at Advanced Research Development in Athol, Mass., have made plastic solar cells using two different polymers, polyvinyl alcohol (PVA) and polyacetylene (PA). Films of this copolymer, patented as Lumeloid, polarize light and, in theory at least, change nearly three quarters of it into electricity—a remarkable gain over the 20 percent maximum conversion rate predicted for present-day photovoltaic cells. Lumeloid also promises to be cheaper and safer. Alvin M. Marks, inventor and company president, estimates that whereas solar cells now cost some $3 to $4 per watt of electricity produced, Lumeloid will not exceed 50 cents.

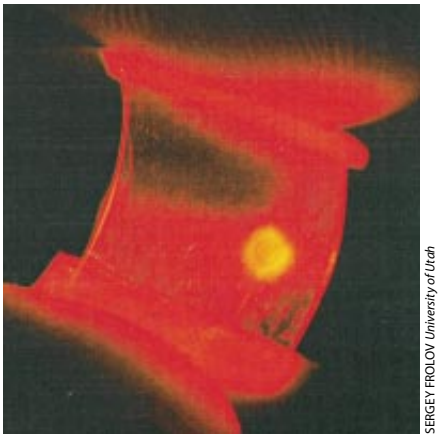
The process by which these films work resembles photosynthesis, Marks explains. Plants rely on diode structures in their leaves, called diads, that act as positive and negative terminals and channel electrons energized by sunlight. Similarly, Lumeloid contains molecular diads. Electrodes extract current from the film's surface. To go the next step, Marks is developing a complementary polymer capable of storing electricity. "If photovoltaics are going to be competitive, they must work day and night," he adds. His two-film package, to be sold in a roll like tinfoil, would allow just that.

Plastics that swap electricity for laser light are less well developed, but progress is coming fast. Only four years ago Daniel Moses of the University of California at Santa Barbara announced that

semiconducting polymers in a dilute solution could produce laser light, characterized by a coherent beam of photons emitted at a single wavelength. This past July, at a conference in Snowbird, Utah, three research teams presented results showing that newer polymer solids could do the same. "I'm a physicist. I can't do anything with my hands," says Z. Valy Vardeny of the University of Utah, who chaired the meeting. "But the chemists who have created these new materials are geniuses."

Earlier generations of semiconducting polymers could not lase for two main reasons. First, when bombarded with electricity or photons, they would convert most of that energy into heat instead of light—a problem called poor luminescence efficiency. Second, the films usually absorbed the photons that were produced, rather than emitting them, so that the polymers lacked optical gain—a measure of a laser medium's ability to snowball photons into an intense pulse.

Because the newer materials have fewer impurities, they offer much higher luminescence efficiencies and show greater lasing potential, Vardeny states. In the *Japanese Journal of Applied Physics*, his group described a derivative of poly (*p*-phenylenevinylene), or PPV, with a luminescence efficiency of 25 percent. The red light was composed of photons having the same wavelength, but it did not travel in a single beam. In *Nature*, another group from the Snowbird meeting offered a way around this shortcoming. Richard H. Friend and his colleagues at the University of Cambridge placed a PPV film inside a device called a microcavity. Mirrors in the structure bounced the emitted light back and forth, amplifying it into a focused laser beam.



SERGEY FROLOV *University of Utah*

***HIGH LUMINESCENCE** from this thin film of a PPV derivative shows the promise of plastic lasers.*

The third group from Snowbird, led by Alan J. Heeger of U.C.S.B., tested more than a dozen polymers and blends as well. Their results, which appeared in the September 27 issue of *Science*, show that these materials can emit laserlike light across the full visible spectrum—even in such rare laser hues as blue and green. In place of a microcavity, Heeger set up his samples so that the surrounding air confined the emitted photons to the polymer, where they could stimulate further emissions. "We wanted to show that a whole class of materials do this and that they definitely provide optical gain," Heeger says.

The challenge now will be finding a way to power these polymers electrically. All three groups energized their samples using another laser, but practical devices will need to run off current delivered from electrodes. It is no small problem. Vardeny notes that electrical charges generate destructive levels of heat and that electrodes can react chemically with the film, lowering the polymer's luminescence efficiency. "It's going to be hard," Heeger concurs, "but I'm optimistic." *—Kristin Leutwyler*

COMPUTING

Recently Netted...

Easy Electronic Charging. By spring, virtual-credit-card-swiping machines are going to become as ubiquitous as the real ones that now sit on checkout counters. The dominant player in Internet credit-card authorization will most likely be VeriFone (http://www.verifone.com/), the company that owns about three quarters of the domestic market for swipe terminals. VeriFone is now offering software that is SET-compliant (from "secure electronic transactions," the protocol worked out by MasterCard, Visa, IBM, Microsoft and others). The program sends the buyer's encrypted, digitally signed payment via the Internet to the financial institution, which then sends the approval codes back to the merchant. Because the software also verifies the digital signature and safeguards against tampering, it is the equivalent of the magnetic strip on a real credit card. The system should reduce the expense of electronic transactions (credit-card purchases by telephone cost the merchants more, to cover the possibility of fraud). According to Fred Kost of VeriFone, Wells Fargo Bank will offer the company's point-of-sale software to its merchant customers by year's end. The cost will be about $1,500, which is $700 more than the outlay for a physical processor, but banks are expected to discount the devices as they seek to galvanize electronic commerce.

Cryptolopes to Go. IBM's Cryptolope containers are digital wrappers for text and multimedia files sent on the Net; the cryptolope (for "cryptographic envelope") keeps track of who opens, saves, forwards or prints the file—and then charges a fee for these operations. The container presents a summary of its contents—for instance, an abstract of a magazine article, a music video or Picasso sketch—followed by the costs and conditions for opening the envelope. If the user agrees to the terms, a digital key unlocks the encrypted material. The containers provide a tracking and payment mechanism for publishers worried about unauthorized distribution of their products on the Net. "I think of them as digital Styrofoam," says David Holtzman of IBM infoMarket (the IBM that markets the containers). "They're a simple encapsulating tool that developers can use to build complicated commercial systems."

Prices for the containers are set by the owners of the content; IBM gets a fraction of this fee—what Holtzman calls "a piece of the click." IBM is showcasing the new technology at its infoMarket site (http://www.infomarket.ibm.com/). So far cryptolope activity is business to business—for instance, financial analysts buying company profiles—but by licensing the technology, IBM expects to break into the consumer market. (America Online will use the envelopes to deliver software and other digital material.) The technology may also become the latest incursion of Big Brother into the office: the containers can provide definitive proof of delivery of memos that one could have once claimed never to have received. *—Anne Eisenberg (aeisen@poly.edu)*

PROFILE: MANUEL ELKIN PATARROYO

The Man Who Would Conquer Malaria

The turn-of-the-century stone building is rotting inside, floorboards dusty and dilapidated, pigeons roosting in the eaves. There are no windows in the moldy sills, and weeds are thriving—even this structure in the middle of Bogotá, Colombia, suggests the jungle is not so very far away. "This is how my buildings always come," says Manuel Elkin Patarroyo, proud of the efforts that have transformed other nearby structures into a charming enclave, complete with gardens, that recall the Pasteur Institute in Paris—a similarity that delights Patarroyo, because he says that it irritates his rivals there.

Once restored, this addition to the Institute of Immunology at the San Juan de Dios Hospital will permit Patarroyo to expand his research empire and to begin mass-producing the source of his fame and his controversy: the malaria vaccine SPf66. But the immunologist does not want to dally in the ruined building and talk about whether the world is going to want such vast quantities of the compound. The day is slipping away, it's already 10 o'clock in the morning, and there are labs to dash through and years of work to review.

Patarroyo has a talent for transforming more than architecture. In the decade since he appeared on the international immunology scene, he has ridden innumerable highs and lows. Currently, in the eyes of many researchers, he is down again—this time for good. The most recent trial of SPf66 (published in the *Lancet* in September) failed: Thai children given several inoculations were no more protected than those given placebo. This finding follows a 1995 study of young children in the Gambia that also found the vaccine ineffective.

But Patarroyo has rebounded before. And anyway, to his mind no such thing as a down period exists—no matter what the studies find. His spirit is irrepressible, as is his belief that he does not have to answer his critics, that all will be made clear eventually. "I don't care. They cannot touch me. It is their problem," he states emphatically. "My enthusiasm will not leave me for a minute. The opposite! They don't know what a favor they do me."

STEPHEN FERRY *Gamma Liaison*

Then he is off again, dashing through another lab and sliding down the length of a hall to answer a telephone. In rapid succession, he gives a tour of the molecular modeling room, the place where work on tuberculosis and on leishmaniasis is being conducted, and the "*peptideria,*" where the synthesized peptides that form the basis of the malaria vaccine are stored. He also points out myriad other labs and the entrance to the restricted area where SPf66 is made. "I usually arrive at eight in the morning, and I leave at 10 P.M., Saturdays included. It is not unusual for me, because it is as I want it to be," he says, pausing in front of a mural, one of the many works given to the institute by famous Latin American artists. "If you are doing what you want and what you like, you do not feel a tension. My wife and my family are used to that."

A group of his colleagues passes at that moment, and Patarroyo ruffles their hair, slaps them on the back, teases them. They laugh and joke with him. He explains—still for a moment against the swirling, colorful backdrop of "A Sense of Immunology," by Colombian painter Gustavo Zalamea—that he sets up competitions in order to get work done more quickly. He has promised trips to Cartagena, a beautiful city on the coast, or seats at one of the Nobel ceremony dinners if his researchers finish projects ahead of schedule. "But I tell them, 'You son of a gun, if you want to go the Nobel, you have to buy a tuxedo, because we are not going to be underdeveloped,' " he laughs.

Patarroyo refers often to his position as a Third World scientist in the First World research community. Yet he is in a very privileged situation. In Colombia, Patarroyo is a national hero; according to a magazine poll, his popularity exceeds that of his good friend, author Gabriel García Márquez. His funding is guaranteed by the government, as is his access to a large population of owl monkeys, some of the only animals that can serve as hosts for the malaria parasites that plague humans. Unlike many researchers whose finances are linked to their results and to being politic, Patarroyo really is free to ignore his critics.

He is not free, however, to ignore the realities of life in Colombia—where numerous guerrilla groups vie for power, where the drug trade bleeds into every

activity and where the magic realism of García Márquez can seem prosaic. This summer one of Patarroyo's shipments of white powder—that would be SPf66—was replaced with vials of a quite different white powder. And a few years ago Patarroyo and his family encountered guerrillas on a drive home to Bogotá from some pre-Columbian ruins. "I was captured for five hours because they wanted to talk to me," Patarroyo says, making light of the experience, his voice perhaps more quiet than he realizes.

But what makes him most happy about his notoriety, Patarroyo continues quickly, is that young Colombians are becoming interested in science. Another poll pronounced that 67 percent of the nation's kids want to be scientists. "What other success could I claim better than that one? To have brought into this country a consciousness," Patarroyo exclaims. "So for the children, rather than being Maradonas [the Argentine soccer great] or rock stars, no! They want to be scientists, and I think that is very important in our country."

Patarroyo himself had a very particular vision as a youth, as he tells it: "It was when I was 11, really, that I liked chemistry so much. And my dream was always to make chemically synthesized vaccines." His parents were both business people and wanted their children to be the same; they ended up with five physicians, one nurse and one child psychologist among their progeny. Although Patarroyo opposed his parents' business values, he acknowledges that his father gave him a firm sense that whatever he did, he must be useful to humankind.

He left his hometown of Ataco, in the Tolima region, to attend medical school in Bogotá. He says that he was a mediocre medical student and that it was not until his internship at San Juan de Dios that he understood what science was about. "It was so beautiful to me to save lives," he muses. "I wanted to make vaccines because I wanted to be useful."

In the late 1960s Patarroyo went abroad—something he encourages his researchers to do. After a short stint in virology at Yale University in 1968, Patarroyo worked in immunology at the Rockefeller University for several years. He then returned to Colombia, where he studied various infectious diseases until a colleague urged him to change his focus. "He said I was an idiot, that I was working on a problem that was not as important as malaria. Then he gave me the statistics," Patarroyo recounts as he drives carefully but quickly through the Bogotá traffic to a traditional Colombian restaurant. Every year as many as 500 million people contract malaria; between 1.5 and three million of them, mostly children, die. Treatment of the disease is tricky, because strains of the parasite in many regions have become resistant to the principal drug, chloroquine, and the alternative, Lariam, increasingly appears to be highly toxic.

Patarroyo's approach to developing a malaria vaccine was unusual. Instead of creating it from dead or weakened strains of the malaria parasite, he synthesized peptides identical to those used by the most virulent strain, *Plasmodium falciparum*. At the time of Patarroyo's initial experiments, few immunologists thought manufactured peptides could produce a strong immune response. Patarroyo nonetheless tested various peptides for their ability to produce antibodies in monkeys and settled on four: one used by the parasite during its larval stage and three used by the mature parasite to bind to and infect red blood cells. In 1987 he reported that vaccination protected 50 percent of the monkeys. Controversy subsequently flared up when investigators could not replicate the results; Patarroyo claims they used a different compound.

"We are really privileged, scientists," Patarroyo says. "It was so beautiful to save lives."

Pausing in the middle of his lunch, Patarroyo starts to sketch a timeline on a yellow pad, marking the dates of his papers. Right after his first success, he fell into his first quagmire. "I made a mistake because of my ignorance in epidemiology," he explains. He decided to vaccinate Colombians but did not set up a double-blind study. He was roasted by the scientific community for his methodology and for the ethics of moving so quickly to human trials.

As other results were reported over the years—the vaccine was consistently safe but proved inconsistently protective—the community continued to divide. "He has always been a very intense personality, provoking strong emotions," notes Hans Wigzell, head of the Karolinska Institute in Stockholm. "I have been very impressed by his capacity to press on. His science is like brute force." Wigzell cautions that even early on Patarroyo "had the feeling that people didn't understand him. So this is not something that has just popped up. Personally, I like him."

Even though most studies found the vaccine benefited only about 30 to 40 percent of patients, many in public health were delighted: 30 percent of 500 million is still a great deal. SPf66 was held to a different standard than other vaccines because of the peculiarities of malaria: even people who have developed natural immunity to the parasite often lose it. As major trials in Colombia and then in Tanzania bolstered the 30 percent or so figure, it seemed as though Patarroyo was vindicated. In 1995 he donated the rights to the vaccine to the World Health Organization.

Then came the Gambia and Thailand. Although some immunologists maintain they are not ready to give up on SPf66, they are frustrated by the variability of the results. "There has got to be some way of evaluating why it is or it is not working," comments Louis Miller of the U.S. National Institutes of Health.

Patarroyo notes that there may be reasons for the inconsistencies: very young children's immune systems, such as those of the six- to 11-month-olds inoculated in the Gambia, are different from those of adults; the vaccine used in Thailand may not have been identical to SPf66; genetic variability determines immune responses. But, he adds, he is uninterested in point-counterpoint. He just wants to keep going, studying ways of improving the vaccine and of developing others. That is the credo of the institute, he insists: "It is the search for the essence of things. It is not that we are going to develop a malaria vaccine. It is that we want to develop a methodology. Really to make vaccines." Then Patarroyo hints that his new research will illuminate why SPf66 seems so mercurial.

Whatever he may have in the wings, SPf66 remains the only malaria vaccine in trials, and his work, confounding and controversial, has enlivened the field. As for Patarroyo, he seems thrilled as always to be a scientist, thrilled to be directing his laboratory and thrilled to be free to think and transform. "We are really privileged, scientists," he says, skipping up the stairs to his office a little more slowly than usual because of lunch. "We get to have intellectual development! How many get to have that? Most people have to do things they don't like." —*Marguerite Holloway*

The Specter of Biological Weapons

States and terrorists alike have shown a growing interest in germ warfare. More stringent arms-control efforts are needed to discourage attacks

by Leonard A. Cole

In 1995, on a whim, I asked a friend: Which would worry you more, being attacked with a biological weapon or a chemical weapon? He looked quizzical. "Frankly, I'm afraid of Alzheimer's," he replied, and we shared a laugh. He had elegantly dismissed my question as an irrelevancy. In civilized society, people do not think about such things.

The next day, on March 20, the nerve agent sarin was unleashed in the Tokyo subway system, killing 12 people and injuring 5,500. In Japan, no less, one of the safest countries in the world. I called my friend, and we lingered over the coincidental timing of my question. A seemingly frivolous speculation one day, a deadly serious matter the next.

That thousands did not die from the Tokyo attack was attributed to an impure mixture of the agent. A tiny drop of sarin, which was originally developed in Germany in the 1930s, can kill within minutes after skin contact or inhalation of its vapor. Like all other nerve agents, sarin blocks the action of acetylcholinesterase, an enzyme necessary for the transmission of nerve impulses.

The cult responsible for the sarin attack, Aum Shinrikyo ("Supreme Truth"), was developing biological agents as well. If a chemical attack is frightening, a biological weapon poses a worse nightmare. Chemical agents are inanimate, but bacteria, viruses and other live agents may be contagious and reproductive. If they become established in the environment, they may multiply. Unlike any other weapon, they can become more dangerous over time.

Certain biological agents incapacitate, whereas others kill. The Ebola virus, for example, kills as many as 90 percent of its victims in little more than a week. Connective tissue liquefies; every orifice bleeds. In the final stages, Ebola victims become convulsive, splashing contaminated blood around them as they twitch, shake and thrash to their deaths.

For Ebola, there is no cure, no treatment. Even the manner in which it spreads is unclear, by close contact with victims and their blood, bodily fluids or remains or by just breathing the surrounding air. Recent outbreaks in Zaire prompted the quarantine of sections of the country until the disease had run its course.

The horror is only magnified by the thought that individuals and nations would consider attacking others with such viruses. In October 1992 Shoko Asahara, head of the Aum Shinrikyo cult, and 40 followers traveled to Zaire, ostensibly to help treat Ebola victims. But the group's real intention, according to an October 31, 1995, report by the U.S. Senate's Permanent Subcommittee on Investigations, was probably to obtain virus samples, culture them and use them in biological attacks.

Interest in acquiring killer organisms for sinister purposes is not limited to groups outside the U.S. On May 5, 1995, six weeks after the Tokyo subway incident, Larry Harris, a laboratory technician in Ohio, ordered the bacterium that causes bubonic plague from a Maryland biomedical supply firm. The company, the American Type Culture Collection in Rockville, Md., mailed him three vials of *Yersinia pestis*.

Harris drew suspicion only when he called the firm four days after placing his order to find out why it had not arrived. Company officials wondered about his impatience and his apparent unfamiliar-

M. MILNER *Sygma*

ity with laboratory techniques, so they contacted federal authorities. He was later found to be a member of a white supremacist organization. In November 1995 he pled guilty in federal court to mail fraud.

To get the plague bacteria, Harris needed no more than a credit card and a false letterhead. Partially in response to this incident, an antiterrorism law enacted this past April required the Centers for Disease Control and Prevention to monitor more closely shipments of infectious agents.

What would Harris have done with the bacteria? He claimed he wanted to conduct research to counteract Iraqi rats carrying "supergerms." But if he had cared to grow a biological arsenal, the task would have been frighteningly simple. By dividing every 20 minutes, a single bacterium gives rise to more than a billion copies in 10 hours. A small vial of microorganisms can yield a huge number in less than a week. For some diseases, such as anthrax, inhaling a few thousand bacteria—which would cover an area smaller than the period at the end of this sentence—can be fatal.

Kathleen C. Bailey, a former assistant director of the U.S. Arms Control and Disarmament Agency, has visited several biotechnology and pharmaceutical firms. She is "absolutely convinced" that a major biological arsenal could be built with $10,000 worth of equipment in a room 15 feet by 15. After all, one can cultivate trillions of bacteria at relatively little risk to one's self with gear no more sophisticated than a beer fermenter and a protein-based culture, a gas mask and a plastic overgarment.

Fortunately, biological terrorism has thus far been limited to very few cases. One incident occurred in September

FEARFUL of Iraqi biological and chemical weapons, travelers donned gas masks in Tel Aviv Airport during the 1991 Persian Gulf War.

PATRIC ROBERT *Sygma*

EBOLA VIRUS, victims of which were buried in a mass grave in Kikwit, Zaire, in 1995, was reportedly considered as a potential biological weapon by Japan's Aum Shinrikyo cult.

1984, when about 750 people became sick after eating in restaurants in an Oregon town called The Dalles. In 1986 Ma Anand Sheela confessed at a federal trial that she and other members of a nearby cult that had clashed with local Oregonians had spread salmonella bacteria on salad bars in four restaurants; the bacteria had been grown in laboratories on the cult's ranch. After serving two and a half years in prison, Sheela, who had been the chief of staff for the cult leader, Bhagwan Shree Rajneesh, was released and deported to Europe.

But as a 1992 report by the Office of Technology Assessment indicated, both biological and chemical terrorism have been rare. Also rare has been the use of biological agents as weapons of war. Perhaps the first recorded incident occurred in the 14th century, when an army besieging Kaffa, a seaport on the Black Sea in the Crimea in Russia, catapulted plague-infected cadavers over the city walls. In colonial America a British officer reportedly gave germ-infested blankets from a smallpox infirmary to Indians in order to start an epidemic among the tribes. The only confirmed instance in this century was Japan's use of plague and other bacteria against China in the 1930s and 1940s.

As the 20th century draws to a close, however, an unpleasant paradox has emerged. More states than ever are signing international agreements to eliminate chemical and biological arms. Yet more are also suspected of developing these weapons despite the treaties. In 1980 only one country, the Soviet Union, had been named by the U.S. for violating the 1972 Biological Weapons Convention, a treaty that prohibits the development or possession of biological weapons.

Since then, the number has ballooned. In 1989 Central Intelligence Agency director William Webster reported that "at least 10 countries" were developing biological weapons. By 1995, 17 countries had been named as biological weapons suspects, according to sources cited by the Office of Technology Assessment and at U.S. Senate committee hearings. They include Iran, Iraq, Libya, Syria, North Korea, Taiwan, Israel, Egypt, Vietnam, Laos, Cuba, Bulgaria, India, South Korea, South Africa, China and Russia. (Russian leaders insist that they have terminated their biological program, but U.S. officials doubt that claim.)

Grim Reality

The first five of these countries—Iran, Iraq, Libya, Syria and North Korea—are especially worrisome in view of their histories of militant behavior. Iraq, for example, has acknowledged the claims of U.N. inspectors that during the 1991 Persian Gulf War it possessed Scud missiles tipped with biological warheads. A 1994 Pentagon report to Congress cited instability in eastern Europe, the Middle East and Southwest Asia as likely to encourage even more nations to develop biological and chemical arms.

Reversing this trend should be of paramount concern to the community of nations. Indeed, the elimination of biological as well as chemical weaponry is a worthy, if difficult, goal. The failure of this effort may increase the likelihood of the development of a man-made plague from Ebola or some other gruesome agent.

Dedication to biological disarmament in particular should be enhanced by another grim truth: in many scenarios, a large population cannot be protected against a biological attack. Vaccines can prevent some diseases, but unless the causative agent is known in advance, such a safeguard may be worthless. Antibiotics are effective against specific bacteria or classes of biological agents, but not against all. Moreover, the incidence of infectious disease around the world has been rising from newly resistant strains of bacteria that defy treatment. In this era of biotechnology, especially, novel organisms can be engineered against which vaccines or antibiotics are useless.

Nor do physical barriers against infection offer great comfort. Fortunately, most biological agents have no effect on or through intact skin, so respiratory masks and clothing would provide adequate protection for most people. After a short while, the danger could recede as sunlight and ambient temperatures destroyed the agents. But certain microorganisms can persist indefinitely in an environment. Gruinard Island, off the coast of Scotland, remained infected with anthrax spores for 40 years after biological warfare tests were carried out there in the 1940s. And in 1981 Rex Watson, then head of Britain's Chemical and Biological Defense Establishment, asserted that if Berlin had been bombarded with anthrax bacteria during World War II, the city would still be contaminated.

Although many Israelis did become accustomed to wearing gas masks during the 1991 Persian Gulf War, it seems unrealistic to expect large populations of civilians to wear such gear for months or years, especially in warm regions. U.N. inspectors in Iraq report that in hot weather they can scarcely tolerate wearing a mask for more than 15 minutes at a time.

Calls for more robust biological defense programs have grown, particularly after the Persian Gulf War. Proponents of increased funding for biological defense research often imply that vaccines and special gear developed through such work can protect the public as well as troops. But the same truths hold for both the military and civilians: unless an attack organism is known in advance and is vulnerable to medical interventions, defense can be illusory.

Indeed, the Gulf War experience was in certain respects misleading. Iraq's biological weapons were understood to be anthrax bacilli and botulinum toxin. (Although toxins are inanimate products of microorganisms, they are treated as biological agents under the terms of the 1972 Biological Weapons Convention.) Both are susceptible to existing vaccines and treatments, and protection of military forces therefore seemed possible. Research that would lead to enhanced defense against these agents is thus generally warranted.

But the improbabilities of warding off attacks from less traditional agents deserve full appreciation. Anticipating that research can come up with defenses against attack organisms whose nature is not known in advance seems fanciful. Moreover, even with all its limitations, the cost of building a national civil defense system against biological and chemical weapons would be substantial. A 1969 United Nations report indicated that the expense of stockpiling gas masks, antibiotics, vaccines and other defensive measures for civilians could exceed $20 billion. That figure, when adjusted for inflation, would now be about $80 billion.

Vaccines and protective gear are not the only challenges to biological defense. Identifying an organism quickly in a battlefield situation, too, is problematic. Even determining whether a biological attack has been launched can be uncertain. Consequently, the Pentagon has begun to focus more on detection.

In May 1994 Deputy Secretary of Defense John Deutch produced an interagency report on counterproliferation activities concerning weapons of mass destruction. Biological agent detectors in particular, he wrote, were "not being pursued adequately." To the annual $110 million budgeted for the development of biological and chemical weapons detection, the report recommended adding $75 million. Already under way were Pentagon-sponsored programs involving such technologies as ion-trap mass spectrometry and laser-induced breakdown spectroscopy, approaches that look for characteristic chemical signatures of dangerous agents in the air. The army's hope, which its spokespersons admit is a long way from being realized, is to find a "generic" detector that can identify classes of pathogens.

Meanwhile the military is also advancing a more limited approach that identifies specific agents through antibody-antigen combinations. The Biological Integrated Detection System (BIDS) exposes suspected air samples to antibodies that react with a particular biological agent. A reaction of the antibody would signify the agent is present, a process that takes about 30 minutes.

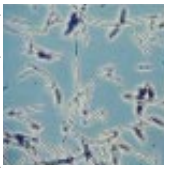
BIDS can now identify four agents through antibody-antigen reactions: *Bacillus anthracis* (anthrax bacterium), *Y. pestis* (bubonic plague), botulinum toxin (the poison released by botulism organisms) and staphylococcus enterotoxin B (released by certain staph bacteria). Laboratory investigations to identify additional agents through antibody-antigen reactions are in progress. But scores of organisms and toxins are viewed as potential warfare agents. Whether the full range, or even most, will be detectable by BIDS remains uncertain.

The most effective safeguard against biological warfare and biological terrorism is, and will be, prevention. To this end, enhanced intelligence and regulation of commercial orders for pathogens are important. Both approaches have been strengthened by provisions in the antiterrorism bill enacted earlier this year. At the same time, attempts to identify and control emerging diseases are gaining attention. One such effort is ProMED (Program to Monitor Emerging Diseases), which was proposed in 1993 by the 3,000-member Federation of American Scientists.

Although focusing on disease outbreaks in general, supporters of ProMED are sensitive to the possibility of man-made epidemics. The ProMED surveillance system would include developing baseline data on endemic diseases throughout the world, rapid reporting of unusual outbreaks, and responses aimed at containing disease, such as providing advice on trade and travel. Such a program could probably distinguish disease outbreaks from hostile sources more effectively than is currently possible.

In addition, steps to strengthen the 1972 Biological Weapons Convention through verification arrangements—including on-site inspections—should be encouraged. The 139 countries that are parties to the convention are expected to discuss incorporating verification measures at a review conference in December of this year. After the last review conference, in 1991, a committee to explore such measures was established. VEREX, as the group was called, has listed various possibilities ranging from surveillance of the scientific literature to on-site inspections of potential production areas, such as laboratories, brew-

Potential Biological Agents



M. WALKER Photo Researchers (top); CNRI Science Photo Library/Photo Researchers (middle two); Photo Researchers (bottom)

Bacillus anthracis. Causes anthrax. If bacteria are inhaled, symptoms may develop in two to three days. Initial symptoms resembling common respiratory infection are followed by high fever, vomiting, joint ache and labored breathing, and internal and external bleeding lesions. Exposure may be fatal. Vaccine and antibiotics provide protection unless exposure is very high.

Botulinum toxin. Cause of botulism, produced by *Clostridium botulinum* bacteria. Symptoms appear 12 to 72 hours after ingestion or inhalation. Initial symptoms are nausea and diarrhea, followed by weakness, dizziness and respiratory paralysis, often leading to death. Antitoxin can sometimes arrest the process.

Yersinia pestis. Causes bubonic plague, the Black Death of the Middle Ages. If bacteria reach the lungs, symptoms—including fever and delirium—may appear in three or four days. Untreated cases are nearly always fatal. Vaccines can offer immunity, and antibiotics are usually effective if administered promptly.

Ebola virus. Highly contagious and lethal. May not be desirable as a biological agent because of uncertain stability outside of animal host. Symptoms, appearing two or three days after exposure, include high fever, delirium, severe joint pain, bleeding from body orifices, and convulsions, followed by death. No known treatment.

eries and pharmaceutical companies.

Given the ease with which bioweapons can be produced, individuals will always be able to circumvent international agreements. But the absence of such agents from national arsenals—and tightened regulations on the acquisition and transfer of pathogens—will make them more difficult to obtain for hostile purposes. Verification can never be foolproof, and therefore some critics argue that verification efforts are a waste of time. Proponents nonetheless assert that sanctions following a detected violation would provide at least some disincentive to cheaters and are thus preferable to no sanctions at all. Furthermore, a strengthened global treaty underscores a commitment by the nations of the world not to traffic in these weapons.

The infrequent use of biological weapons to date might be explained in many ways. Some potential users have probably lacked familiarity with how to develop pathogens as weapons; moreover, they may have been afraid of infecting themselves. Nations and terrorists alike might furthermore be disinclined to use bioagents because they are by nature unpredictable. Through mutations, a bacterium or virus can gain or lose virulence over time, which may be contrary to the strategic desires of the people who released it. And once introduced into the environment, a pathogen may pose a threat to anybody who goes there, making it difficult to occupy territory.

But beneath all these pragmatic concerns lies another dimension that deserves more emphasis than it generally receives: the moral repugnance of these weapons. Their ability to cause great suffering, coupled with their indiscriminate character, no doubt contributes to the deep-seated aversion most people have for them. And that aversion seems central to explaining why bioweapons have so rarely been used in the past. Contrary to analyses that commonly ignore or belittle the phenomenon, this natural antipathy should be appreciated and exploited. Even some terrorists could be reluctant to use a weapon so fearsome that it would permanently alienate the public from their cause.

The Poison Taboo

In recognition of these sentiments, the 1972 Biological Weapons Convention describes germ weaponry as "repugnant to the conscience of mankind." Such descriptions have roots that reach back thousands of years. (Not until the 19th century were microorganisms understood to be the cause of infection; before then, poison and disease were commonly seen as the same. Indeed, the Latin word for "poison" is "virus.")

Among prohibitions in many civilizations were the poisoning of food and wells and the use of poison weapons. The Greeks and Romans condemned the use of poison in war as a violation of *ius gentium*—the law of nations. Poisons and other weapons considered inhumane were forbidden by the Manu Law of India around 500 B.C. and among the Saracens 1,000 years later. The prohibitions were reiterated by Dutch statesman Hugo Grotius in his 1625 opus *The Law of War and Peace,* and they were, for the most part, maintained during the harsh European religious conflicts of the time.

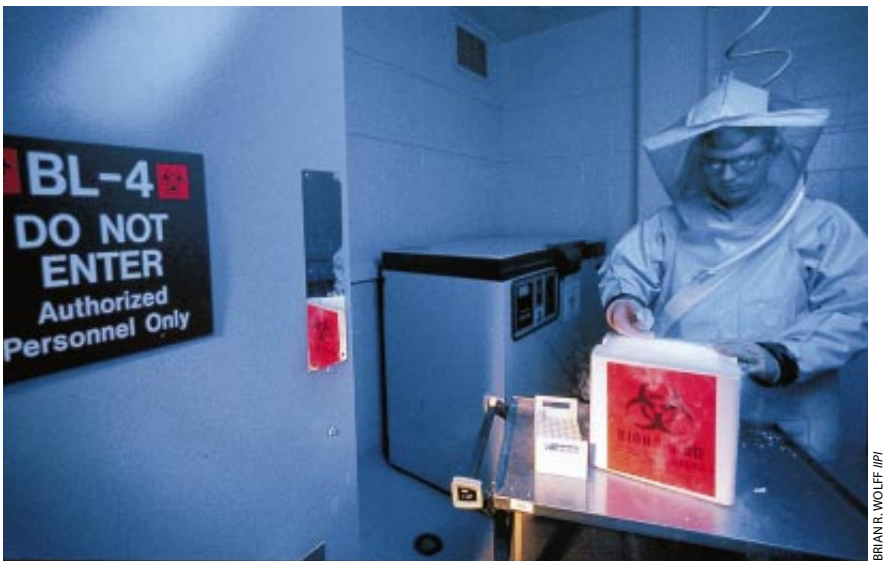
Like the taboos against incest, cannibalism and other widely reviled acts, the taboo against poison weapons was sometimes violated. But the frequency of such violations may have been minimized because of their castigation as a "defalcation of proper principles," in the words of the 18th- and 19th-century English jurist Robert P. Ward. Under the law of nations, Ward wrote, "Nothing is more expressly forbidden than the use of *poisoned* arms" (emphasis in original).

Historian John Ellis van Courtland Moon, now professor emeritus at Fitchburg State College in Massachusetts, contends that growing nationalism in the 18th century weakened the disinclinations about poison weapons. As a result of what Moon calls "the nationalization of ethics," military necessity began to displace moral considerations in state policies; nations were more likely to employ any means possible to attain their aims in warfare.

In the mid-19th century, a few military leaders proposed that toxic weapons be employed, although none actually were. Nevertheless, gas was used in World War I. The experience of large-scale chemical warfare was so horrifying that it led to the 1925 Geneva Protocol, which forbids the use of chemical and bacteriological agents in war. Images of victims gasping, frothing and choking to death had a profound impact. The text of the protocol reflects the global sense of abhorrence. It affirmed that these weapons had been "justly condemned by the general opinion of the civilized world."

Chemical and biological weapons were used in almost none of the hundreds of wars and skirmishes in subsequent decades—until Iraq's extensive chemical attacks during the Iran-Iraq war. Regrettably, the international response to Iraqi behavior was muted or ineffective. From 1983 until the war ended in 1988, Iraq was permitted to get away with chemical murder. Fear of an Iranian victory stifled serious outcries against a form of weaponry that had been universally condemned.

The consequences of silence about Iraq's behavior, though unfortunate, were not surprising. Iraqi ability to use chemical weapons with impunity, and



BRIAN R. WOLFF *IIPI*

POTENTIAL GERM AGENTS and defenses are studied in a maximum-security laboratory at the U.S. Army Medical Research Institute of Infectious Diseases in Maryland.

their apparent effectiveness against Iran, prompted more countries to arm themselves with chemical and biological weapons. Ironically, in 1991 many of the countries that had been silent about the Iraqi chemical attacks had to face a chemically and biologically equipped Iraq on the battlefield.

To its credit, since the Persian Gulf War, much of the international community has pressed Iraq about its unconventional weapons programs by maintaining sanctions through the U.N. Security Council. Council resolutions require elimination of Iraq's biological weapons (and other weapons of mass destruction), as well as information about past programs to develop them. Iraq has been only partially forthcoming, and U.N. inspectors continue to seek full disclosure.

But even now, U.N. reports are commonly dry recitations. Expressions of outrage are rare. Any country or group that develops these weapons deserves forceful condemnation. We need continuing reminders that civilized people do not traffic in, or use, such weaponry. The agreement by the U.S. and Russia to destroy their chemical stockpiles within a decade should help.

Words of outrage alone, obviously, are not enough. Intelligence is important, as are controls over domestic and international shipments of pathogens and enhanced global surveillance of disease outbreaks. Moreover, institutions that reinforce positive behavior and values are essential.

The highest priority of the moment in this regard is implementation of the Chemical Weapons Convention, which outlaws the possession of chemical weapons. It lists chemicals that signatory nations must declare to have in their possession. Unlike the Biological Weapons Convention, the chemical treaty has extensive provisions to verify compliance, including short-notice inspections of suspected violations. It also provides added inducements to join through information exchanges and commercial privileges among the signatories.

In 1993 the chemical treaty was opened for signature. By October 1996, the pact had been signed by 160 countries and ratified by 64, one less than the number required for the agreement to enter into force. One disappointing holdout is the U.S. In part because of disagreements over the treaty's verification provisions, the U.S. Senate recently delayed a vote on the pact.

Implementing this chemical weapons treaty should add momentum to the current negotiations over strengthening the Biological Weapons Convention. Conversely, failure of the Chemical Weapons Convention to fulfill expectations will dampen prospects for a verification regime for the biological treaty. The most likely consequence would be the continued proliferation of chemical and biological arsenals around the world. The longer these weapons persist, the more their sense of illegitimacy erodes, and the more likely they will be used—by armies and by terrorists.

As analysts have noted, subnational groups commonly use the types of weapons that are in national arsenals. The absence of biological and chemical weapons from national military inventories may diminish their attractiveness to terrorists. According to terrorism expert Brian M. Jenkins, leaders of Aum Shinrikyo indicated that their interest in chemical weapons was inspired by Iraq's use of chemicals during its war with Iran.

Treaties, verification regimes, global surveillance, controlled exchanges of pathogens—all are the muscle of arms control. Their effectiveness ultimately depends on the moral backbone that supports them and the will to enforce them rigorously. By underscoring the moral sense behind the formal exclusion of biological weapons, sustaining their prohibition becomes more likely. SA

Defenses against Biological Weapons

Respirator or gas mask. Filters, usually made of activated charcoal, must block particles larger than one micron. Overgarments are also advisable to protect against contact with open wounds or otherwise broken skin.

Protective shelter. Best if a closed room, ideally insulated with plastic or some other nonpermeable material and ventilated with filtered air.

Decontamination. Such traditional disinfectants as formaldehyde are effective for sterilizing surfaces.

Vaccination. Must be for specific agent. Some agents require several inoculations over an extended period before immunity is conferred. For many agents, no vaccine is available.

Antibiotics. Effective against some but not all bacterial agents (and not effective against viruses). For some susceptible bacteria, antibiotic therapy must begin within a few hours of exposure—before symptoms appear.

Detection systems. Only rudimentary field units currently available for a few specific agents. Research is under way to expand the number of agents that can be detected in battlefield situations or elsewhere.

The Author

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Primordial Deuterium and the Big Bang

Nuclei of this hydrogen isotope formed in the first moments of the big bang. Their abundance offers clues to the early evolution of the universe and the nature of cosmic dark matter

by Craig J. Hogan

The big bang model of the early universe is extraordinarily simple: it has no structure of any kind on scales larger than individual elementary particles. Even though the behavior it predicts is governed only by general relativity, the Standard Model of elementary particle physics and the energy distribution rules of basic thermodynamics, it appears to describe the primordial fireball almost perfectly.

Atomic nuclei that formed during the first seconds and minutes of the universe provide additional clues to events in the early universe and to its composition and structure today. The big bang produced a universe made almost entirely of hydrogen and helium. Deuterium, the heavy isotope of hydrogen, was made only at the beginning of the universe; thus, it serves as a particularly important marker. The ratio of deuterium to ordinary hydrogen atoms depends strongly on both the uniformity of matter and the total amount of matter formed in the big bang. During the past few years, astronomers have for the first time begun to make reliable, direct measurements of deuterium in ancient gas clouds. Their results promise to provide a precise test of the big bang cosmogony.

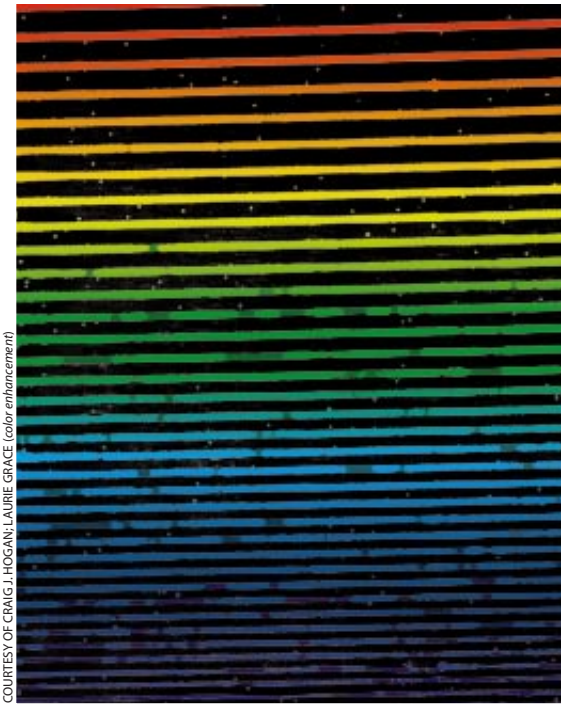
The expansion of the universe appears to have started between 10 and 20 billion years ago. Everything was much closer together and much denser and hotter than it is now. When the universe was only one second old, its temperature was more than 10 billion degrees, 1,000 times hotter than the center of the sun. At that temperature, the distinctions between different kinds of matter and energy were not as definite as they are under current conditions: subatomic particles such as neutrons and protons constantly changed back and forth into one another, "cooked" by interactions with plentiful and energetic electrons, positrons and neutrinos. Neutrons are slightly heavier than protons, however; as things cooled, most of the matter settled into the more stable form of protons. As a result, when the temperature fell below 10 billion degrees and the intertransmutation stopped, there were about seven times as many protons as neutrons.

Out of the Primordial Furnace

When the universe was a few minutes old (at a temperature of about one billion degrees), the protons and neutrons cooled down enough to stick together into nuclei. Each neutron found a proton partner, creating a pair called a deuteron, and almost all the deuterons in turn stuck together into helium nuclei, which contain two protons and two neutrons. By the time primordial helium had formed, the density of the universe was too low to permit further fusion to form heavier elements in the time available; consequently, almost all the neutrons were incorporated into helium.

Without neutrons to hold them together, protons cannot bind into nuclei because of their electrical repulsion. Because of the limited neutron supply in the primordial fireball, six of every seven protons must therefore remain as isolated hydrogen nuclei. Consequently, the big bang model predicts that about one quarter of the mass of the normal matter of the universe is made of helium and the other three quarters of hydrogen. This simple prediction accords remarkably well with observations. Because hydrogen is the principal fuel of the stars of the universe, its predominance is the basic reason for starlight and sunlight.

During the formation of helium nuclei, perhaps only one in 10,000 deuterons remained unpaired. An even smaller fraction fused into nuclei heavier than



COURTESY OF CRAIG J. HOGAN; LAURIE GRACE (*color enhancement*)

KECK TELESCOPE (*right*) on Mauna Kea, Hawaii, gathered light from a distant quasar and concentrated it on the photodetector of a high-resolution spectroscope. The resulting bands of color (*above*) are marked by dark lines where intervening gases have absorbed light of specific wavelengths. Analysis of the characteristic line patterns for hydrogen gas can reveal the presence of the heavy isotope of the element deuterium.

ROGER RESSMEYER *Corbis*

helium, such as lithium. (All the other familiar elements, such as carbon and oxygen, were produced much later inside stars.) The exact percentages of helium, deuterium and lithium depend on only one parameter: the ratio of protons and neutrons—particles jointly categorized as baryons—to photons. The value of this ratio, known as η (the Greek letter eta), remains essentially constant as the universe expands; because we can measure the number of photons, knowing η tells us how much matter there is. This number is important for understanding the later evolution of the universe, because it can be compared with the actual amount of matter seen in stars and gas in galaxies, as well as the larger amount of unseen dark matter.

For the big bang to make the observed mix of light elements, η must be very small. The universe contains fewer than one baryon per billion photons. The temperature of the cosmic background radiation tells us directly the number of photons left over from the big bang; at present, there are about 411 photons per cubic centimeter of space. Hence, baryons should occur at a density of somewhat less than 0.4 per cubic meter. Although cosmologists know that η is small, estimates of its exact value currently vary by a factor of almost 10. The most precise and reliable indicators of η are the concentrations of primordial light elements, in particular deuterium. A fivefold increase in η, for example, would lead to a telltale 13-fold decrease in the amount of deuterium created.

The mere presence of deuterium sets an upper limit on η because the big bang is probably the primary source of deuterium in the universe, and later processing in stars gradually destroys it. One can think of deuterium as a kind of partially spent fuel like charcoal, left over because there was originally not time for all of it to burn completely to ash before the fire cooled. Nucleosynthesis in the big bang lasted only a few minutes, but the nuclear burning in stars lasts for millions or billions of years; as a result, any deuterium there is converted to helium or heavier elements. All the deuterium that we find must therefore be a

COURTESY OF CRAIG J. HOGAN (*inset*); ALFRED T. KAMAJIAN (*painting*)

MEASURING THE EARLY MAKEUP of the universe is complicated because so much matter has been transmuted inside stars. Nevertheless, radiation from quasars several billions of light-years distant, at the edge of the observable universe, offers one method. Long ago this light passed through clouds of fairly pure primordial gas, possibly in the outskirts of a forming galaxy (a computer model of one primordial gas cloud is shown in the inset at the left). Hydrogen and deuterium in such clouds remove characteristic wavelengths of this light; these changes can be detected and measured on the earth.

remnant of the big bang—even the one molecule in 10,000 of seawater that contains a deuterium atom in place of a hydrogen atom.

Quasars and Gas Clouds

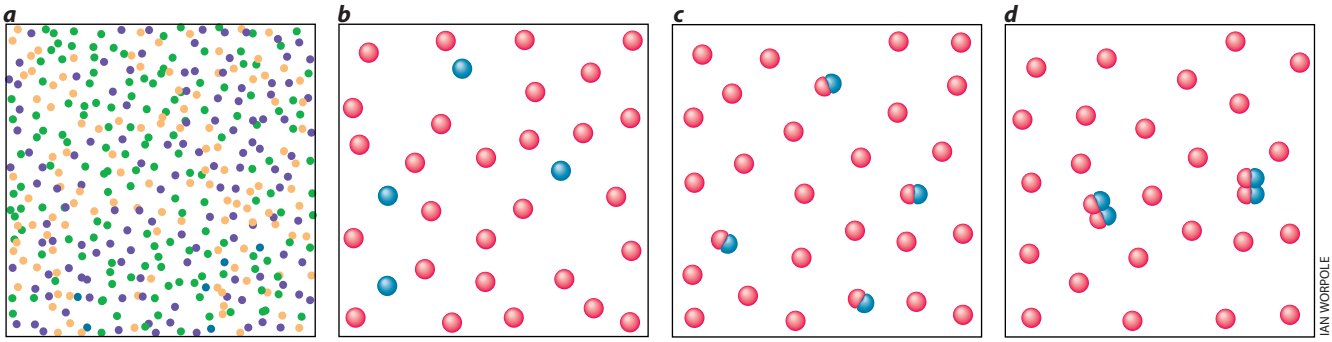
Determining the primordial ratio of deuterium to ordinary hydrogen should be highly informative, but it is not easy, because the universe is not as simple as it used to be. Astronomers can measure deuterium in clouds of atomic hydrogen gas between the stars of our galaxy, but the element's fragility renders the results suspect. We live in a polluted, dissipated, middle-aged galaxy whose gases have undergone a great deal of chemical processing over its 10-billion-year history. Deuterium is very readily destroyed in stars, even in their outer layers and their early prestellar evolution. Stars eject their envelopes when they die, and the gas in our galaxy has been in and out of stars many times. As a result, looking at nearby gas clouds can suggest only a lower limit to primordial deuterium abundance.

It would be much better if one could get hold of some truly pristine primordial material that had never undergone chemical evolution. Although we cannot bring such matter into the laboratory, we can look at its composition by its effect on the spectrum of light from distant sources. Bright quasars, the most luminous objects in the universe, are so far away that the light we see now left them when the universe was only one sixth to one quarter of its present size and perhaps only a tenth of its present age. On its way to us, the light from these quasars passes through clouds of gas that have not yet condensed into mature galaxies, and the light absorbed by these clouds gives clues to their composition. Some of the clouds that have been detected contain less than one thousandth the proportion of carbon and silicon (both stellar fusion products) seen in nearby space, a good sign that they retain very nearly the composition they had immediately after the big bang.

There is another advantage to looking so far away. The main component of these clouds, atomic hydrogen, absorbs light at a sharply defined set of ultraviolet wavelengths known as the Lyman series. Each of these absorption lines (so called because of the dark line it leaves in a spectrum) corresponds to the wavelength of a photon exactly energetic enough to excite the electron in a hydrogen atom to a particular energy level. These lines have colors that lie deep in the ultraviolet and cannot usually be seen from the ground because of atmospheric absorption; even the reddest (and most prominent) line, Lyman alpha, appears at a wavelength of 1,215 angstroms. Luckily, the expansion of the universe causes a "cosmological redshift" that lengthens the wavelengths of photons that reach the earth to the point where hydrogen absorption lines from sufficiently distant gas clouds reside comfortably within the visible range.

Lyman alpha appears in light from a typical quasar hundreds of times, each time from a different cloud along the line of sight at a different redshift and therefore at a different wavelength. The resulting spectrum is a slice of cosmic history, like a tree-ring sample or a Greenland ice core: these quasar absorption spectra record the history of the conversion of uniform gas from the early big bang into the discrete galaxies we see today over an enormous volume of space. This multiplicity of spectra offers another way to test the primordial character of the absorbing material: the big bang model predicts that all gas clouds from the early universe should have more or less the same composition. Measuring the abundances of different clouds at vast distances from us and from one another in both time and space will directly test cosmic uniformity.

In some of these clouds, we can determine from the quasar spectra both how much ordinary hydrogen there is



NUCLEOSYNTHESIS, the formation of atomic nuclei, started instants after the big bang, as the universe cooled, when the fundamental particles called free quarks (*a*) condensed into protons and neutrons (*b*). Protons (*red*) and neutrons (*blue*) paired off to form deuterons, but because the former outnumber the latter, most of the protons remained alone and became hydrogen nuclei (*c*). Almost all the deuterons in turn combined to form helium nuclei (*d*), leaving a tiny remnant to be detected today.

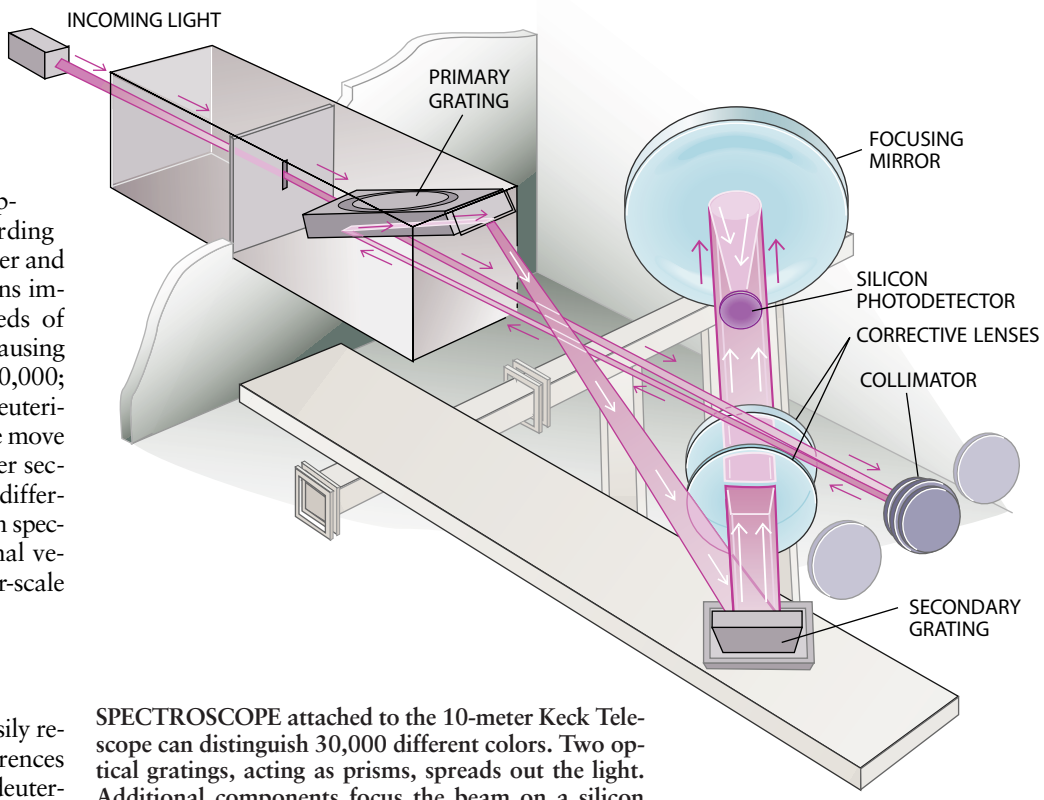
and how much deuterium. We can separate the signal from deuterium because the added mass in the deuterium nucleus increases the energy required for atomic transitions by about one part in 4,000 (twice the ratio of a proton's mass to an electron's mass). As a result, the absorption spectrum of deuterium is similar to that of single-nucleon hydrogen, but all the lines show a shift toward the blue end of the spectrum equivalent to that arising from a motion of 82 kilometers per second toward the observer. In spectrographic measurements of a hydrogen cloud, deuterium registers as a faint blue-shifted "echo" of the hydrogen.

These spectra also record the velocity and temperature distribution of the atoms. Atoms traveling at different velocities absorb light at slightly different wavelengths because of the Doppler effect, which alters the apparent wavelength of light according to the relative motion of transmitter and receiver. Random thermal motions impel the hydrogen atoms at speeds of about 10 kilometers per second, causing a wavelength shift of one part in 30,000; because they are twice as heavy, deuterium atoms at the same temperature move at only about seven kilometers per second and therefore have a slightly different velocity distribution. A modern spectrograph can resolve these thermal velocity differences, as well as larger-scale collective flows.

Waiting for the Light

Although spectrographs can easily resolve the wavelength differences between ordinary hydrogen and deuterium, splitting the light of a distant quasar into 30,000 colors leaves very little intensity in each color. For more than 20 years, these observations proved too difficult. Many of us have spent long nights waiting for photons to drip one by one onto the detectors of the world's largest telescopes, only to find that the weather, instrument problems and, ultimately, just lack of time had prevented the accumulation of enough light for a convincing result. The technique is now practical only because of improved, more efficient detectors, the 10-meter Keck telescope in Hawaii and advanced high-resolution, high-throughput spectrographs such as the Keck HIRES.

After many unsuccessful attempts on smaller telescopes, my colleagues Antoinette Songaila and Lennox L. Cowie of the University of Hawaii were allocated their university's first science night on the Keck Telescope for this project in November 1993. They trained the telescope on a quasar known as 0014+813, famous among astronomers for its brightness—indeed, it was for some years the brightest single object known in the universe. From earlier studies by Ray J. Weymann of the Observatories of the Carnegie Institution of Washington and Frederic Chaffee, Craig B. Foltz and Jill Bechtold of the University of Arizona



SPECTROSCOPE attached to the 10-meter Keck Telescope can distinguish 30,000 different colors. Two optical gratings, acting as prisms, spreads out the light. Additional components focus the beam on a silicon wafer a few centimeters square to produce an image like that on page 68. The wafer contains four million tiny photodetectors, each only 20 microns on a side.

and their collaborators, we knew that a fairly pristine gas cloud lay in front of this quasar.

The first Keck spectrum, obtained in only a few hours, was already of sufficiently high quality to show plausible signs of cosmic deuterium. That spectrum showed the absorption pattern for hydrogen gas moving at various velocities, and it showed an almost perfect echo of the Lyman alpha line with the characteristic blueshift of deuterium. The amount of absorption in this second signal would be caused by about two atoms of deuterium per 10,000 atoms of hydrogen. The result has since been independently confirmed by Robert F. Carswell of the University of Cambridge and his colleagues, using data from the four-meter Mayall Telescope at the Kitt Peak National Observatory in Arizona. Subsequent analysis has revealed that the deuterium absorption indeed displays an unusually narrow thermal spread of velocities, as expected.

It is possible that some of the absorption we saw was caused by a chance interposition of a small hydrogen cloud that just happens to be receding from us at 82 fewer kilometers per second than the main cloud we observed. In that case, the deuterium abundance would be less than we think. Although the a priori chance of such a coincidence on the first try is small, we ought to regard this estimate as only preliminary. Nevertheless, the effectiveness of the technique is clear. Absorbing clouds in front of many other quasars can be studied with the new technology; we will soon have a statistical sampling of deuterium in primordial material. In fact, our group and others have now published measurements and limits for eight different clouds.

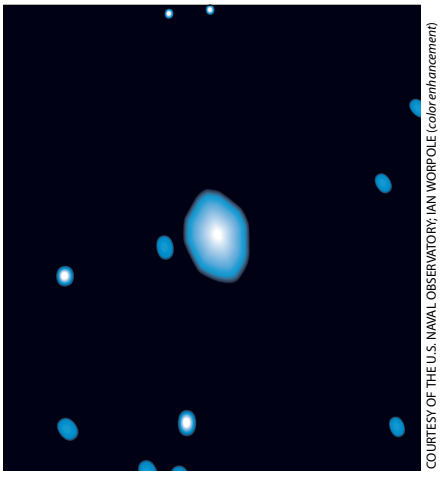
One of the most intriguing results is a measurement by David Tytler and Scott Burles of the University of California at San Diego and Xiao-Ming Fan of Columbia University, who have found a ratio that is apparently almost a factor of 10 lower than our estimate. It remains to be seen whether their result represents the true primordial value. The lower abundance might be a result of deuterium burning in early stars or a sign that the production of deuterium was perhaps not as uniform as the big bang model predicts.

Clues to Dark Matter

If our higher value is correct, the amount of primordial deuterium would fit very well with the standard predictions of the big bang model for a value of η around two baryons per 10 billion photons. With this value of η, the big bang predictions are also consistent with the amounts of lithium in the oldest stars and estimates of primordial helium seen in nearby metal-poor galaxies. Confirmation of this result would be fabulous news. It would verify that cosmologists understand what happened only one second after the beginning of the expansion of the universe. In addition it would indicate that the history of matter at great distances is like that of nearby matter, as assumed in the simplest possible model of the universe.

This estimate of η fits reasonably well with the number of baryons we actually see in the universe today. The observed density of photons calls for about one atom for every 10 cubic meters of space. This is about the same as the number of atoms counted directly by adding up all the matter in the known gas, stars, planets and dust, including the quasar absorbers themselves; there is not a huge reservoir of unseen baryons. At the same time, observations suggest that an enormous quantity of dark matter is necessary to explain the gravitational behavior of galaxies and their halos—at least 10 times the mean density of the visible baryons. Thus, our high deuterium abundance indicates that this mass is not made of ordinary atomic matter.

Cosmologists have proposed many candidates for such nonbaryonic forms of dark matter. For example, the big bang predicts that the universe has almost as many neutrinos left over as photons. If each one had even a few billionths as much mass as a proton (equivalent to a few electron volts), neutrinos would contribute to the universe roughly as much mass as all the baryons put together. It is also possible that the early universe created some kind of leftover particle that we have not been able to produce in the laboratory. Either way, the big bang model, anchored by observation, provides a framework for predicting the astrophysical consequences of such new physical ideas. SA



COURTESY OF THE U.S. NAVAL OBSERVATORY; IAN WORPOLE (*color enhancement*)

QUASAR, or quasistellar object, 0014+813 is one of the brightest objects known to exist in the cosmos. It appears here in a radiotelescope image. The light from this supermassive black hole at the center of a very young galaxy near the edge of the observable universe provided the first measurements of primordial deuterium.

The Author

CRAIG J. HOGAN studies the edge of the visible universe. He is chair of the astronomy department and professor in the departments of physics and astronomy at the University of Washington. Hogan grew up in Los Angeles and received his A.B. from Harvard College in 1976 and his Ph.D. from the University of Cambridge in 1980. After postdoctoral fellowships at the University of Chicago and the California Institute of Technology, he joined the faculty of Steward Observatory at the University of Arizona for five years. He moved to Seattle in 1990.

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Creating Nanophase Materials

The properties of these ultrafine-grained substances, now found in a range of commercial products, can be custom-engineered

by Richard W. Siegel

In September 1989 a silver-haired gentleman with money to invest walked into my office at Argonne National Laboratory, prepared to start a company. My visitor, Steven Lazarus of ARCH Development Corporation, his colleague Keith Crandall and I had long discussed the possibility of forming a company to manufacture a new breed of materials. Now, after nine months of careful consideration, Lazarus was convinced of the potential commercial value.

My colleagues and I had been studying these substances since 1985, when, in need of a title for a research proposal late one evening, I dubbed them "nanophase materials." The name reflected the essential way in which they differed from ordinary materials. Nanophase metals, ceramics and other solids are made of the same atoms as their more common forms, but the atoms are arranged in nanometer-size clusters, which become the constituent grains, or building blocks, of these new materials. And whereas the grains in conventional materials range from microns to millimeters in diameter and contain several billion atoms, those in nanophase materials are less than 100 nanometers in diameter and contain fewer than tens of thousands of atoms. To put these sizes in perspective, a three-nanometer-diameter cluster contains about 900 atoms and is almost one million times smaller than the period at the end of this sentence—or about as small as a 40-foot sailboat is compared with the size of the earth.

By 1989 we had learned that because their tiny grains responded to light, mechanical stress and electricity quite differently from micron- or millimeter-size grains, nanophase materials on the whole displayed an array of novel attributes. For example, nanophase copper is five times stronger than the ordinary metal. And nanophase ceramics, in contrast to their large-grained cousins, resist breaking. Of perhaps the greatest commercial value, we could customize the strength, color or plasticity of a nanophase material simply by controlling the exact size of its constituent grains.

Based on such promise, Lazarus and I founded Nanophase Technologies Corporation in November 1989. My world has never again been quite the same. Forming a company to manufacture

REMI BENALI *Gamma Liaison*

these substances helped to spur both industrial and academic interest. And since then, our scientists and others have markedly advanced the understanding of these unique materials and their useful characteristics. As a result, nanophase materials are now found in a variety of products—from cosmetics to electronics. They will undoubtedly find applications in countless other areas as well. The growth of our corporation is a telltale sign of the progress: we are now making tons of substances that just a few years ago were made only in milligram batches for laboratory experiments.

Building Better Materials

The history of nanophase materials began with the cooldown after the big bang, when primordial condensed matter formed nanostructures in early meteorites. Nature later evolved many nanostructures, such as seashells and skeletons, that make up the earth's living creatures. When early humans discovered fire, they created nanophase smoke particles. The scientific story of nanophase materials, however, began much later, at a meeting of the American Physical Society in 1959.

There physicist Richard Feynman of the California Institute of Technology—later a Nobel laureate—first speculated in public about the effects of manipulating minuscule bits of condensed matter. "I can hardly doubt that when we have some control of the arrangement of things on a small scale," he said presciently, "we will get an enormously greater range of possible properties that substances can have." Theoretical support for Feynman's musings soon emerged. During the early 1960s, Ryogo Kubo of Tokyo University formed a model to predict how tiny clusters of atoms would behave quantum-mechanically in their confined volumes.

This work did not predict the effects of spatial confinement on more classical behavior. But it did foreshadow these effects, which we later discovered in nanophase materials. Thus, when the sizes of the building blocks for these materials become smaller than the critical length scale associated with any property, the property changes and can be engineered through size control.

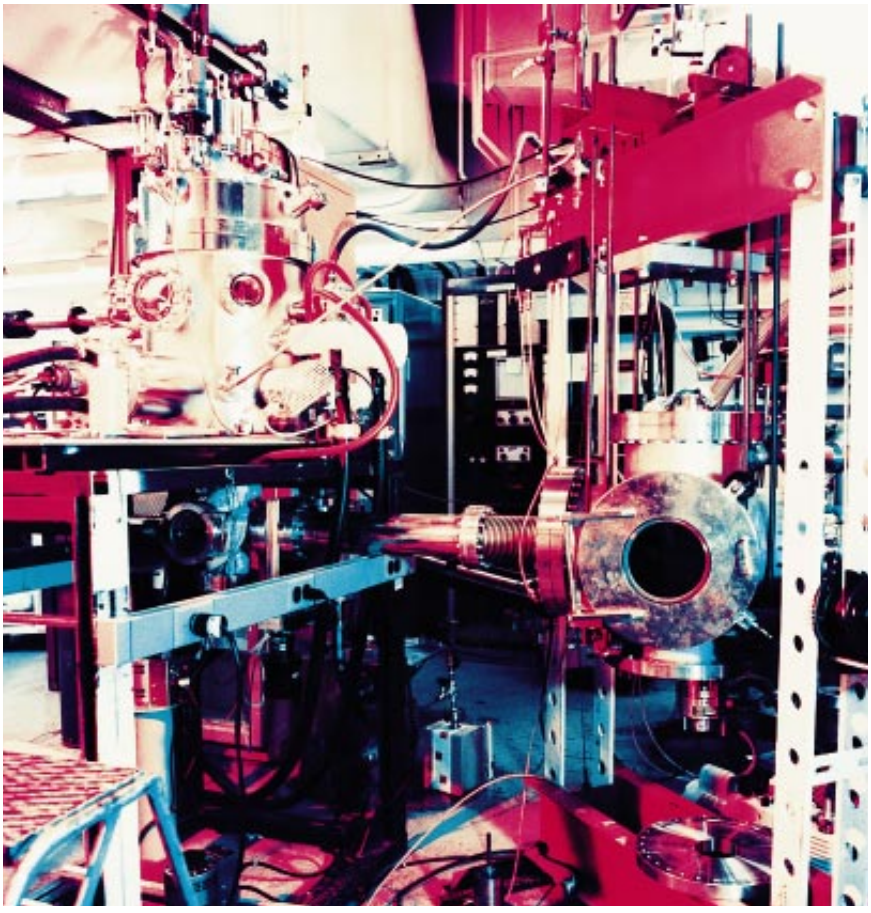
Research on atom clusters proceeded deliberately for the next 20 years. Much work on ultrafine particles took place in Japan. And similar investigations were secretly under way within the military establishment of the Soviet Union. It is probable that these scientists were examining consolidated materials made from ultrafine powders, but this research was not widely known. In 1981, though, a watershed event occurred. At a conference at Risø National Laboratory in Denmark, German physicist Herbert Gleiter, then at the University of the Saarland, suggested to his audience that materials made by consolidating ultrafine particles would themselves have radically different characteristics. Following this talk, Gleiter's laboratory published several provocative studies of nanocrystalline metals, which stirred much excitement in the materials research communities both in Europe and in the U.S.

My own involvement with nanostructuring began quite serendipitously at a conference in India four years later. There I met Gleiter's former student Horst Hahn. Hahn, who is now at the University of Darmstadt, was then about to begin a postdoctoral appointment at Argonne, and I helped to set him up, giving him the vacuum equipment he needed to build a chamber for synthesizing atom clusters. He and I soon began to discuss whether ultrafine powders might be used in making materials other than metals—the task he had initially planned to pursue. Within a few months, we had succeeded in producing a ceramic, nanophase titania, made from 10-nanometer clusters of titanium that were reacted with oxygen. (In its conventional form, titania is the whitener of choice in many applications, from paints to paper.)

To synthesize nanophase titania (TiO_2), we adopted a method similar to that used by most other researchers in Japan, the Soviet Union, Germany and elsewhere. The strategy can be likened to boiling water on a stove near a cold window in winter. During boiling, water molecules evaporate from the surface, collide with the colder room air and condense into steam, made of small water droplets suspended in air. Natural convection ferries the air—and the droplets with it—from the hot stove toward the cold window. There the steam collects as ice crystals, which can be scraped from the window and made into a snowball—a fun material, if not particularly useful.

So, too, when a metal reaches temperatures at or above its melting point, atoms evaporate from the surface of this

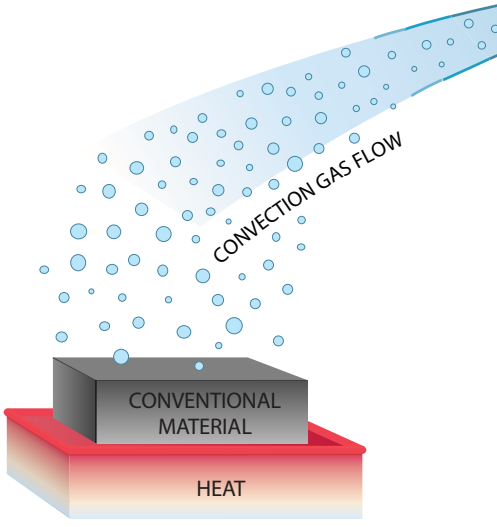
COLOR and other characteristics of nanophase materials vary according to the size of their constituent grains, or clusters. For instance, all four vials at the left contain cadmium selenide. But because these otherwise identical samples all have different-size clusters, each takes on a different hue under white light (*left*) and ultraviolet light (*above*).



SILVIA OTTE

MAKING NANOPHASE MATERIALS requires special apparatus, including a synthesis chamber (*upper left*) and a consolidation press (*lower right*).

INSIDE THE SYNTHESIS CHAMBER, a metal is heated above its melting point so that atoms evaporate from its surface. These atoms condense into clusters that convection carries to the cooled collection tube. The agglomerated clusters are removed from the tube and consolidated into dense solids.



so-called precursor material. For the purposes of making nanophase materials, these evaporated atoms are then exposed to an inert gas such as helium, which will not chemically react with them but will cool them down. In so doing, the colder helium atoms sap the evaporated atoms of energy, causing them to condense into small, nearly spherical solid clusters. The diameters of these clusters can be prescribed—anywhere from one to 100 nanometers—by controlling the evaporation rate of the precursor atoms and the type and the pressure of the inert gas.

If a nanophase metal is desired, the precursor is simply that metal in its conventional form and the clusters are prevented from reacting with any other elements in the synthesis chamber before they are consolidated. If, on the other hand, a ceramic is wanted, the metal clusters must react with an appropriate gas—oxygen in the case of nanophase titania—before they are consolidated. Because this method is relatively simple, it became the basis for much of our work. It was evident that, using the condensation approach, one could create nanophase forms of most materials—including metals, ceramics, semiconductors, polymers and composites of those substances. Even so, we needed to concentrate on making ceramics and metals at first, until we could find out exactly what was going on.

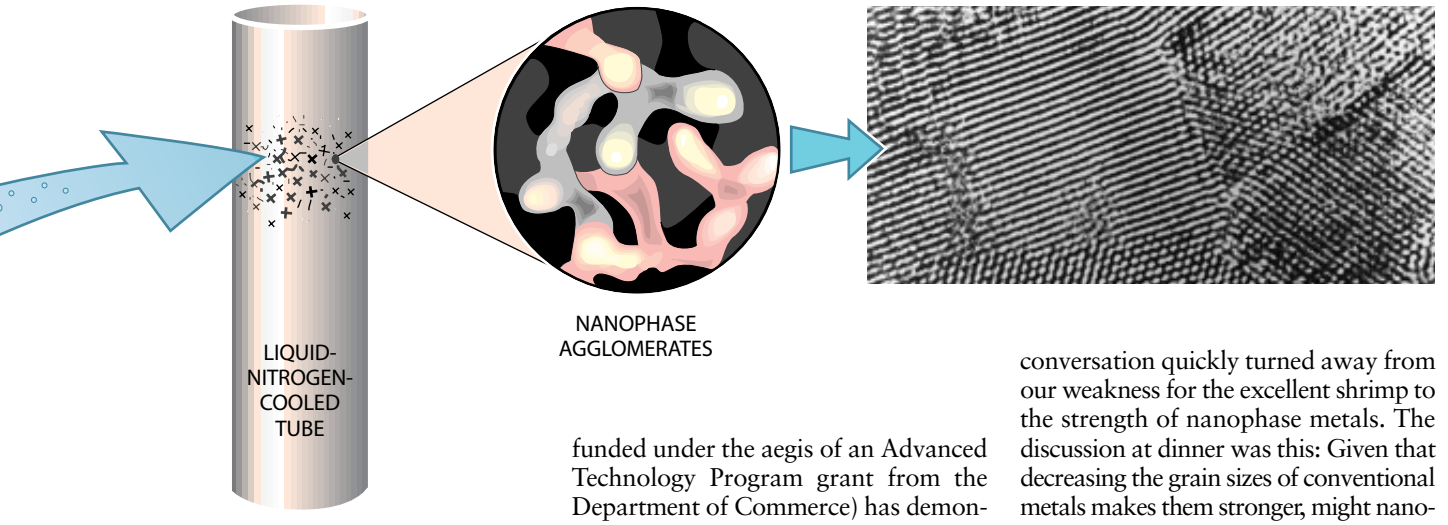
Nanophase Ceramics

In our initial experiments with nanophase titania, we became particularly interested in how this material might respond to sintering—a common manufacturing process by which compacted powders are transformed into solids. (Sintering takes place at temperatures high enough to allow the individual grains in a powder to exchange atoms so that they join completely.) It had long been thought that if you could sinter ceramic powders having ultrafine, closely packed particles, the process might occur at lower temperatures and yield a more compact solid. But there had been one frustrating problem.

Before the advent of our method, ceramic powders having very small grains had to be made using wet-chemistry techniques, the products of which were usually strongly agglomerated. These agglomerated powders would not fully consolidate, and so the sintered solids made from them were often not entirely dense. The nanophase titania powders we built from the atom up were also agglomerated, as have been all other nanophase ceramics investigated so far. But we were lucky. The agglomerates were weak and fragile enough that the grains readily consolidated or dispersed anyway. An additional advantage was that our ultrafine-grained powders also had excellent rheological, or flow, and handling properties.

Working with our Argonne colleagues Sinnanadar Ramasamy, Zongquan Li and Ting Lu under funding from the Basic Energy Sciences program of the Department of Energy, we demonstrated that the new material could be sintered at temperatures that were some 600 degrees Celsius lower than the temperature required to sinter conventional titania (1,400 degrees C). In addition, our sintered nanoscale titania showed greater hardness and resistance to fracture.

Remarkably, we found that the nanophase titania was also relatively malleable (a trait called ductility): it readily formed into small disks at room temperature, conforming to the dies in which



JENNIFER C. CHRISTIANSEN (*drawing*); GEORGE THOMAS (*micrograph*)

the consolidation process took place. These effects in titania were found to be common in a variety of other nanophase ceramics studied in subsequent collaborations with Argonne colleagues Jeffrey Eastman, Alwar Narayanasamy, Youxin Liao and Uthamalingham Balachandran.

In 1988 William Nix of Stanford University, his recently graduated student Merrilea Mayo, then at Sandia National Laboratories, and I undertook more quantitative deformation measurements. These investigations demonstrated that at room temperature nanophase titania became dramatically more ductile as the grain size decreased below about 30 nanometers. This discovery opened the window to a great commercial opportunity called net-shape forming. For the first time, it would be possible to mold mass quantities of nanophase ceramics into a variety of final shapes—say, those of car parts—in very little time and at relatively little cost. What was more, these parts would be better able than conventional metal parts to sustain high temperatures and corrosive atmospheres, such as those generated by a car's engine.

Hahn, then at the University of Illinois, and his colleagues subsequently found that fully dense nanophase titania could be deformed in compression at temperatures as high as 800 degrees C; the material was deformed by as much as 60 percent without breaking. Such conditions typically lead to catastrophic fracture in conventional ceramic parts. Recently a team at Nanophase Technologies Corporation headed by John Parker (in collaboration with partners at Caterpillar and Lockheed and funded under the aegis of an Advanced Technology Program grant from the Department of Commerce) has demonstrated true net-shape forming of nanophase ceramics—work that brings the earlier results much closer to market.

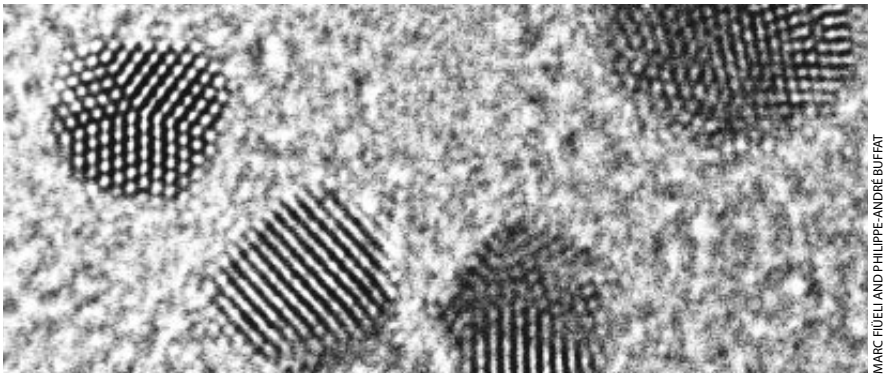
How is it possible for such brittle materials as ceramics to undergo extensive deformation in their nanophase form without fracturing into many pieces? The answer is that under pressure, nanometer-size grains are far more likely to slide over one another than millimeter-size ones are. The process—known as grain boundary sliding—is the fundamental way in which nanophase ceramics are deformed, and it resembles what happens when you step into a mound of sand. In the case of solids, though, the grains are bound to one another. A fracture occurs when too many of these bonds break. If a small incipient crack or fracture opens, atoms from nearby in the material will begin to move to fill it in. The smaller the grain size, the shorter the distances the atoms must travel and, hence, the quicker the repair can be made. Ordinary ceramics such as minerals may actually deform in this way over geologic timescales extending for millions of years. Of course, commercial manufacturers often must be able to deform a material into a particular shape in minutes or less, in which case only nanophase ceramics will suffice.

Nanophase Metals

My earliest foray into the properties of nanophase metals began about a year after our first studies of nanophase titania. While attending a conference in New Orleans in 1986, my wife, Pam, and I visited a well-known barbecue shrimp restaurant with Julia Weertman and Johannes Weertman, both from Northwestern University. The conversation quickly turned away from our weakness for the excellent shrimp to the strength of nanophase metals. The discussion at dinner was this: Given that decreasing the grain sizes of conventional metals makes them stronger, might nanophase metals, with their exceptionally small grains, be exceptionally strong?

We were keen to find out. Julia and I and Northwestern graduate student G. William Nieman set out to make nanophase palladium and copper and to study their strength as a function of grain size. To gauge the strength of the metals, we measured their hardness, testing how easily they could be deformed. As expected, the strength of pure copper increased as its average grain size decreased. When the grains were 50 nanometers in diameter, the copper was twice as hard as usual. Six-nanometer grains—the smallest size we could readily make in our synthesis chamber—yielded copper that was five times harder than normal. Further work in our own laboratory with Northwestern graduate students Gretchen Fougere and Paul Sanders, and in other laboratories around the world, confirmed our findings in many nanophase metals made by various methods.

What was going on in these nanophase metals? To find out, we needed to consider how metals are normally deformed. Here the analogy of moving a rug over a hardwood floor proves helpful. A metal is deformed when its crystalline atom planes—imagine one plane is the rug and the other is the floor—slide over each other. If you simply pull on the rug, it is very difficult to move; friction works against you over the full area of the rug. But if you make a transverse bump in the rug at one end and push that bump along to the other end and then repeat the process, the task becomes much easier. So it is with metals, where a dislocation in a plane of atoms can essentially be thought of as a bump in a rug. In conventional metals, placing

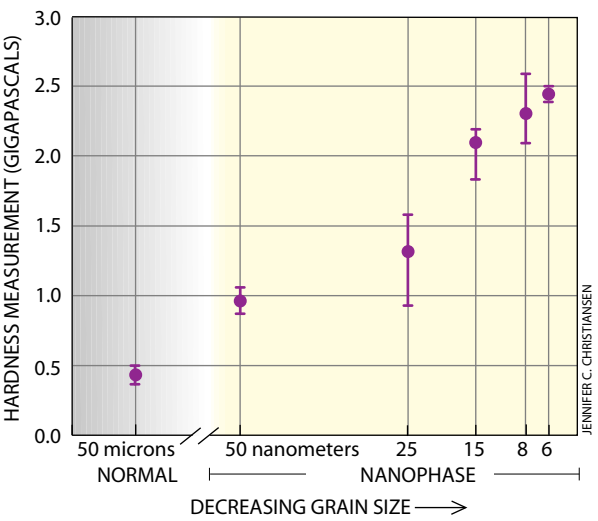


MARC FIÜELI AND PHILIPPE-ANDRÉ BUFFAT

GOLD CLUSTERS, about three nanometers in diameter on a glasslike carbon film, are shown by transmission electron microscopy.

barriers in the path of the moving dislocation—such as an interface between differently oriented grains (a grain boundary)—can impede its progress.

At first, we had thought that the nanophase metals might be stronger because they possessed many grains and thus numerous grain boundaries, all of which could stop or impede any moving dislocations as they do in conventional metals. In fact, the explanation was quite different: the nanometer-size grains were simply too small to support dislocations; they were neither present in significant numbers, nor could they easily be created. By directly observing metal clusters and nanophase samples made from them using transmission electron microscopy, we found, as did other groups later, that the clusters and grains in nanophase materials were mostly dislocation-free. (We made our observations in collaboration with Ronald Gronsky of Lawrence Berkeley Laboratory and George Thomas of Sandia National Laboratory.) Lacking large numbers of moving dislocations, these nanophase metals became much stronger than their conventional counterparts.



JENNIFER C. CHRISTIANSEN

STRENGTH OF NANOPHASE COPPER increases with decreasing grain size, as the chart above shows. Nanometer-size grains cannot support many dislocations—features that, in large numbers, enable metals to deform easily.

Other Custom Properties

Mechanical properties aside, the optical, chemical and electrical nature of nanophase materials can also be tailored to meet specific needs. Again, the size and arrangement of the constituent clusters or grains are paramount in controlling these properties. For example, particles ranging from one to 50 nanometers in diameter are too small to scatter visible light waves, which are about 380 to 765 nanometers in length. Indeed, the tiny particles are as ineffective at disrupting the longer light waves as would be a tiny boat bobbing atop large ocean swells. Thus, a consolidated nanophase material can be effectively transparent, if care is taken to remove during consolidation any pores larger than the constituent clusters. Parker and Hahn, when the latter was at Rutgers University, made just such a transparent nanophase form of yttria, a ceramic that is ordinarily opaque.

In contrast, radiation having shorter wavelengths, such as damaging ultraviolet light, cannot pass easily through dispersed nanophase ceramic particles, such as titania, zinc oxide and iron oxide. In this case, the tiny grains readily absorb or scatter the short ultraviolet rays. Consequently, nanophase powders are being tested for use in sunscreens. Also, because of quantum confinement effects, the observed color of certain nanophase clusters can vary depending on their sizes. Louis Brus, formerly at AT&T Bell Laboratories and now at Columbia University, has produced in solution several nanophase versions of cadmium selenide, each of which appears to be a different color. In fact, cadmium selenide can be made almost any color in the spectrum simply by changing its cluster size. As such, nanophase powders are making rapid inroads into the cosmetics industry.

The chemical uses for nanophase materials are also promising. In 1989 Donald Beck of General Motors and I started to explore the catalytic potential of our new materials. Nanometer-size metal particles of platinum and rhodium had long been used as catalysts, albeit with other support materials. Beck had previously studied the ability of conventional titania to remove sulfur from simulated car exhaust—a gas stream containing hydrogen sulfide. Because of the high surface-to-volume ratio of small clusters, lightly compacted nanophase samples with their high porosity have very large surface areas per unit of volume. Therefore, we guessed that they would be quite effective catalysts—and we were right. Our nanophase titania produced dramatic results. The total amount of sulfur removed from a simulated exhaust after seven hours at 500 degrees C was about five times greater than that removed by all other forms of titania we tested. More important, after seven hours of exposure, the rate at which the nanophase titania removed sulfur was still quite high; all the other samples had become useless.

The explanation for this success rested on several aspects of nanophase titania. Its nanometer-size grains and large surface area were beneficial, as expected. But, of particular value, throughout the titania grains, oxygen ions were missing. Sulfur atoms from the gas stream readily filled these empty sites. It was these vacant oxygen sites that resulted in the titania's long catalytic life. These vacancies were continually replenished as atoms diffused from the surface to the grain interiors, leaving surface vacancies available for sulfur removal. These oxygen vacancies had been well characterized in our earlier experiments on

nanophase titania using Raman spectroscopy at Argonne, where I collaborated with Carlos Melendres, Victor Maroni and Parker. When Parker later joined Nanophase Technologies, it was to lead the successful scale-up of our manufacturing effort.

Looking toward the Future

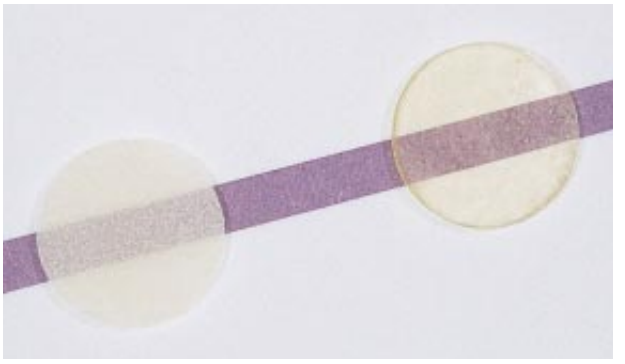
The electrical and magnetic properties of nanophase materials are also novel and controllable—as the widespread use of ultrafine magnetic powders in recording media testifies. There is much excitement at the moment over the observation that an applied magnetic field can significantly lower the electrical resistance in unique ways in a variety of nanostructures. This property, called giant magnetoresistance, will have a considerable impact on magnetic storage media applications. For this article, however, I will focus on a newly found, interesting and important electrical property of the ceramic semiconductor zinc oxide.

Zinc oxide, in its conventional polycrystalline form and doped with a number of selected impurities, is the basic material from which voltage-dependent resistors, or varistors, are made. In these simple and widely used devices, the electrical resistance effectively drops as the current through them rises over very wide ranges, keeping the voltage across them constant at some value, called a threshold voltage. This nonlinear behavior of these varistors arises from the electrical properties of their grain boundaries. Hence, I conjectured that nanophase zinc oxide—having a much larger number of grain boundaries than the normal variety—might prove to be an even better varistor material, if we could make it. With the help of my Argonne colleagues, we were able to produce pure nanophase zinc oxide.

In collaboration with University of Notre Dame student Jongtae Lee, Thomas Mason of Northwestern and others, we recently demonstrated that even pure nanophase zinc oxide exhibits varistor behavior. Its threshold voltage is small—about 40 times smaller than that for conventional, heavily doped varistor material—but usable just the same. And investigations led by our former colleague Ramasamy, now back at the University of Madras, show that if nanophase zinc oxide is doped similarly to commercial varistors, it may be even more useful. Indeed, it should be possible to produce zinc oxide varistors with threshold voltages that range over a factor of more than 300. The key engineering parameter will be the grain size and hence the number of grain boundaries loaded into the material, as well as the amount and type of dopants loaded into those grain boundaries. Much work is needed to turn these results into final products, but the potential is enormous.

Although this article has concentrated on the unusual properties of nanophase materials, we and other researchers have also devoted extensive work to characterizing the structure of these substances—crucial information for understanding their properties. Many groups worldwide are also developing various new synthesis methods. They include synthesis from atomic or molecular precursors by chemical or physical means, the latter being our preferred approach, and from processing of bulk precursors, typically by mechanical grain refinement processes or by crystallizing glasslike substances.

In general, it is preferable to make nanophase materials from atomic or molecular precursors, because the manufacturer retains the most control over the many microscopic aspects of the material. But the other methods can often yield valuable results and sometimes with greater ease. It seems clear today that nanophase materials will have an increasingly important role in the future of materials technology. A revolution has begun, and it will only grow as we learn to manipulate matter at the atomic scale in ever more clever and efficient ways. SA



ADAM LICHT

TRANSPARENT CERAMICS, such as the yttria on the right, contain pores and clusters no more than 50 nanometers in diameter. Larger particles and pores scatter visible light waves and so render a consolidated material, such as the yttria on the left, opaque.

The Author

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Further Reading

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Cell Suicide in Health and Disease

Cells can—and often do—kill themselves, in a process known as apoptosis. This capacity is essential to the proper functioning of the body; flawed regulation may lie behind many diseases

by Richard C. Duke, David M. Ojcius and John Ding-E Young

As you read this article, millions of your cells are dying. Relax. Most are sacrificing themselves to ensure your survival. Burgeoning research indicates that the health of all multicellular organisms, including humans, depends not only on the body's ability to produce new cells but on the ability of individual cells to self-destruct when they become superfluous or disordered. This critical process, today called apoptosis, or programmed cell death, was overlooked for decades. But biologists have recently made rapid strides in understanding how cellular suicide is enacted and controlled.

Many investigators are motivated both by scientific curiosity and by a desire to combat some of the world's most frightening diseases. It turns out that aberrant regulation of apoptosis—leading to too much or too little cell suicide—probably contributes to such varied disorders as cancer, AIDS, Alzheimer's disease and rheumatoid arthritis.

Researchers who studied embryonic development in the first half of the 20th century were the earliest to realize that cell death is not, as had long been assumed, invariably bad for the body; in fact, it is necessary. By the 1950s, they had shown that multicellular creatures obtain their final form by predictably eliminating selected cells. The tadpole deletes its tail during transformation into a frog; mammals erase countless neurons as the nervous system takes shape. Microscopists had also identified major signposts distinguishing this physiological cell death from accidental destruction, or necrosis.

Necrotic death occurs when a cell is severely injured, by a physical blow or by oxygen deprivation, for example. Swelling is a defining feature. Internal organelles—most obviously the mitochondria (the cell's power plants)—and the entire cell balloon and rupture. These effects occur because injury prevents the cell from controlling its fluid and ion balance; water and charged particles (especially sodium and calcium ions) that are normally pumped out now stream in. Another hallmark is inflammation: circulating macrophages and other white blood cells of the immune system converge on the necrotic cells and ingest them. Inflammation helps to limit infection and clear away debris, but the activities and secretions of the white cells can also damage normal tissue in the vicinity, sometimes extensively.

Scientists viewing the cell undergoing apoptosis see very different changes. They find no swelling. Instead the dying cell shrinks and pulls away from its neighbors. Soon it appears to boil: blebs form on the surface and disappear, immediately replaced by others. Internal organelles retain their structure, but the nucleus, which is altered little during necrosis, invariably changes dramatically during apoptosis. Most prominently, its usually dispersed chromatin (chromosomal DNA with its associated proteins) condenses into one or more distinct blobs near the nuclear envelope.

At this point, apoptotic cells are often ingested by neighboring cells—including by scavenger cells that reside in all tissues—without inciting an inflammatory response. Dying cells that are not consumed may undergo further changes: typically the nucleus comes apart, and the cells divide into a number of "apoptotic bodies" that can contain a piece or two of the nucleus. As before, these bodies are removed quietly. (Biochemical studies contributed another signature of apoptosis in the late 1970s—the chromatin frequently breaks into fragments that produce a ladderlike pattern when the pieces are sorted by size on laboratory gels.)

Interestingly, certain cells that undergo programmed death are not gobbled up; today we know they persist for a long time or even indefinitely. The lens of the eye, for instance, is made up of the carcasses of cells that replaced most of their cytoplasm with the protein crystallin as they died. In the skin, cells called keratinocytes are generated by precursors in a deep layer; they then migrate to the surface, dying along the way. Instead of crystallin, they replace their contents with a tough protein called keratin and acquire a water-repellent coating. These dead cells constitute the protective outer layer of the skin until they are sloughed off and replaced by other keratinocytes.

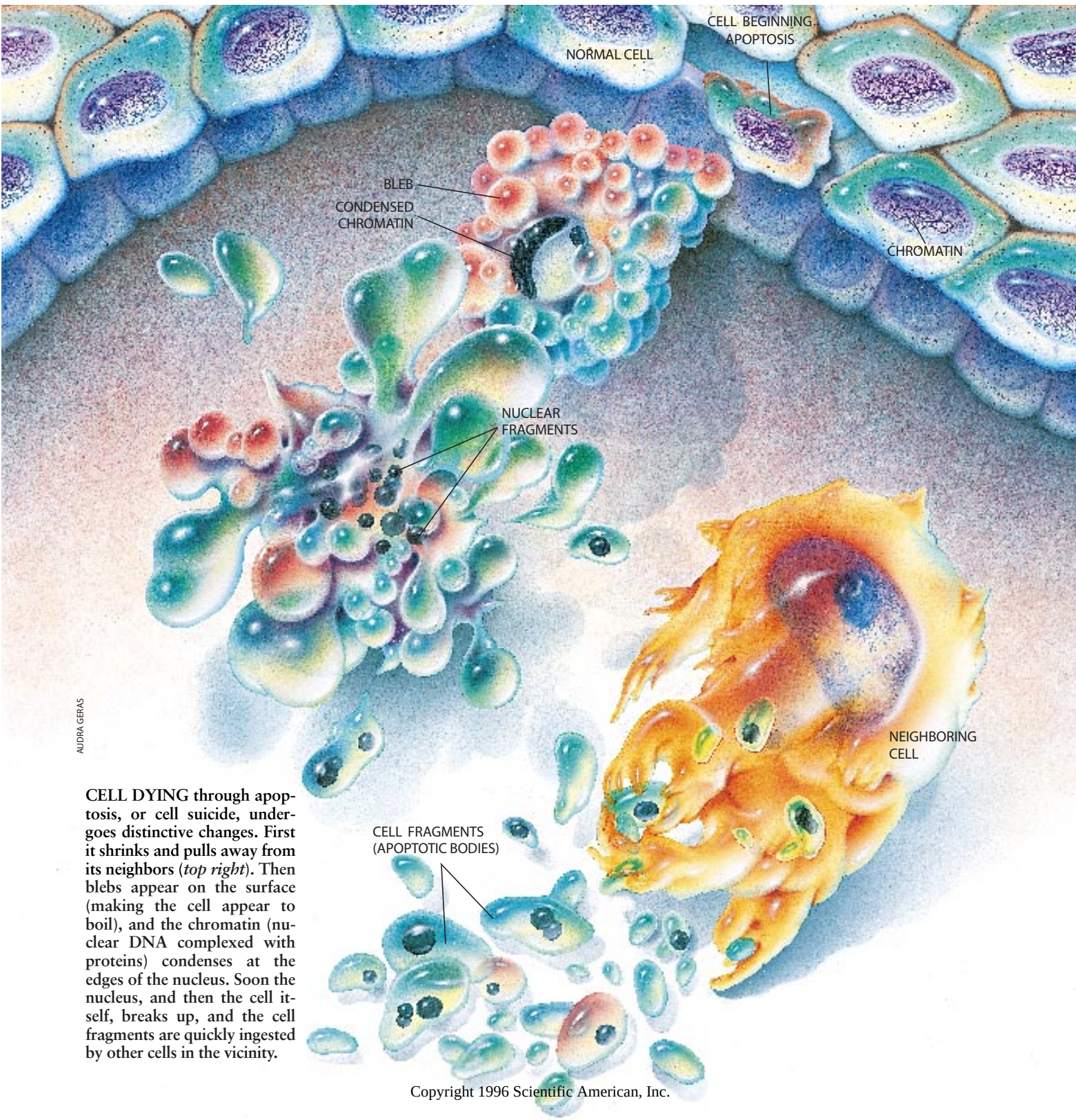
Suicide by Slicing

Although most of the observable events that define apoptosis were well documented as early as the 1950s, and its role in embryonic development was understood, the importance of apoptosis to the daily maintenance of the fully formed organism would not gain recognition for another 20 years. The Australian pathologist John F. R. Kerr and his Scottish colleagues Andrew H. Wyllie and Alastair R. Currie broke the ground in a paper published in 1972.

In their report, they contended that the same type of cell death evident during development also happens in mature organisms and continues throughout life. They suggested that unlike nec-

rosis, in which a cell is a passive victim, this form of death is active, requiring the cell to expend energy toward its own demise. The researchers further proposed that inappropriate initiation or inhibition of cell suicide could contribute to many diseases, including cancer. And it was they who, on the counsel of a coworker, adopted the Greek word *apoptosis* to distinguish this kind of cell demise from *necrosis* (Greek for "make dead"). In classical Greek, apoptosis means "dropping off," as in the dropping off of flower petals or falling leaves. (The word is usually pronounced "APP-oh-TOE-sis," with the second "p" remaining silent.)

Despite the profound insights in the 1972 publication, its observations went largely unnoticed for more than a decade, until the few groups then pursuing apoptosis began to confirm the paper's predictions. For example, they indeed found signs that apoptosis is ongoing and that its failure can contribute to cancer. The researchers also began to pinpoint some of the molecules



AUDRA GERAS

CELL DYING through apoptosis, or cell suicide, undergoes distinctive changes. First it shrinks and pulls away from its neighbors (*top right*). Then blebs appear on the surface (making the cell appear to boil), and the chromatin (nuclear DNA complexed with proteins) condenses at the edges of the nucleus. Soon the nucleus, and then the cell itself, breaks up, and the cell fragments are quickly ingested by other cells in the vicinity.

that carry out and regulate the process.

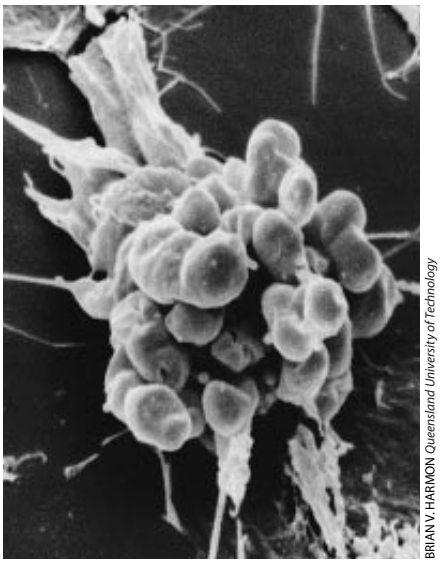
Countless scientists are now involved in deciphering exactly how and when cells kill themselves. We still have many unanswered questions but have uncovered some core principles. Most, if not all, cells manufacture a set of proteins that can serve as weapons of self-destruction. As long as a cell is useful to the body, it will restrain its death machinery. If, however, the cell becomes infected or malignant or otherwise threatens the health of the organism, the lethal proteins will be unleashed.

Apoptosis may be set in motion by various triggers, including withdrawal from a cell of the chemical signals (known as growth, or survival, factors) through which cells reassure one another of their importance. Death can also be triggered by a cell's receipt of external or internal messages that override the reassuring ones or by the cell's receipt of conflicting directives as to whether it should divide.

In some cell types, apoptosis will be triggered predictably; keratinocytes that migrate to the skin surface are dead and gone approximately 21 days after they begin their journey. Yet those same cells, as well as cells that are meant to last a lifetime (such as neurons and skeletal muscle cells), can be convinced to die prematurely if they become problematic. Sunburn, for example, will lead to apoptosis in keratinocytes that have not yet ascended very far through the skin.

In all cell types and in all multicellular organisms studied so far, the suicide weapons consist of various protein-cleaving enzymes known as ICE-like proteases. They are called "ICE-like" because they structurally resemble the first member of the group discovered—interleukin-1 converting enzyme (ICE). The ICE-like proteases that destroy the cell might be thought of as a collection of sharp knives that are normally kept under wraps. When the enzymes are activated (the blades are unsheathed and wielded), they chop various other proteins in ways that lead to destruction of the cell. Some of the cleaving destroys essential structural components of the cell. And some of the cutting leads directly or indirectly to destruction of the cell's genetic material, thereby preventing the cell from maintaining itself.

In spite of their shared death machinery, cells can differ in the specific signals that induce them to eliminate themselves. The ease and speed with which the death program is activated can also vary from one type of cell to another and from one stage of development to another in a single cell. And a given cell may be sensitive to several different triggers. A major focus of current apoptosis research is specifying the full range of apoptotic inducers and deciphering how they lead to activation of the destructive ICE-like proteases. Scientists know that instructions delivered by the inducers are conveyed to the proteases by a series of intermediaries and that different triggers may use separate intermediaries. But, for the most part, the chains of interactions, or signaling pathways, await full characterization. Investigators have been especially stymied in finding the molecules that directly activate the proteases.



BRIAN V. HARMON *Queensland University of Technology*

SURFACE BLEBS are dramatically evident in this scanning electron micrograph of a cell undergoing apoptosis.

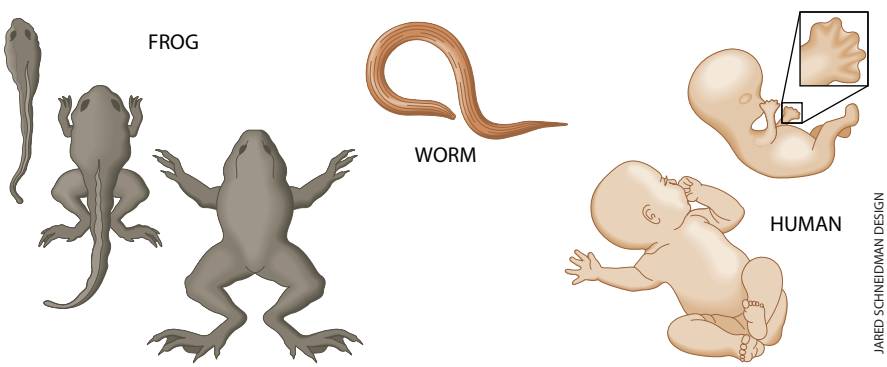
No Shortage of Triggers

A sense of the progress made so far can be obtained from a brief survey of some ways that cells known as *T* lymphocytes are persuaded to commit suicide at different stages in their life cycle. *T* cells are central players in the immune response against invading viruses and other microbes.

T cells arise from precursors in the bone marrow. The immature cells migrate to the thymus, where, as so-called thymocytes, they become more specialized. In particular, they begin to display the receptor molecules that later enable mature *T* cells to detect infection. To be beneficial, *T* cells must be able to attach through their receptors to microbial antigens (protein markers signaling an invader's presence). At the same time, they must be blind to substances made by the body itself, because self-reactive *T* cells can destroy normal tissues. Only those thymocytes that make useful receptors will mature fully and enter the bloodstream to patrol the body.

While still in the thymus, thymocytes that fail to make functional receptors undergo apoptosis, as they are of no use. Thymocytes also kill themselves if their receptors bind strongly to molecules displayed in the thymus. Tight binding is a sign the cells might later target healthy tissue for autoimmune destruction.

Mature *T* cells that finally enter the circulation remain at rest unless they encounter the antigens their receptors can recognize. The resting cells, in common with thymocytes and many other cells, are susceptible to additional inducers of suicide: x-rays (such as those delivered during radiation therapy for cancer) and other agents that damage DNA. The damage spurs cells to produce a protein



JARED SCHNEIDMAN DESIGN

PROPER DEVELOPMENT of multicellular organisms depends on the elimination of selected cells through apoptosis. The roundworm *Caenorhabditis elegans* (*top*), which is just a millimeter long, eliminates precisely 131 of its initial 1,090 cells as its hermaphroditic form matures into an adult. As a tadpole becomes a frog, it deletes its tail cells. Human embryos are thought to use apoptosis to remove webbing between digits.

called p53, which can, in turn, prompt activation of the suicide program. At one time, we and others thought that all cells had to synthesize p53 or other proteins in order to self-destruct. Protein synthesis is indeed required in many instances, but not always.

Circulating *T* cells become active—that is, they proliferate and produce proteins that promote inflammation—when their receptors bind tightly to foreign antigens. Such activity is valuable when an infectious agent is still present, but when the infection is gone, the cells must die. Otherwise they might accumulate, giving rise to chronic inflammation (with its attendant swelling and fever) and possibly to autoimmunity.

Apoptosis in the unneeded cells is induced in at least two ways. One mechanism involves deprivation of survival factors—in this case, disappearance of a *T* cell factor called interleukin-2 as the infectious agent is cleared. The second mechanism depends on a molecule called Fas that has recently garnered a lot of attention.

Resting *T* cells produce low levels of Fas, which spans the cell membrane; it projects into the extracellular space at one end and into the cell's interior at the other end, where it can convey signals deeper into the cell. When *T* cells first encounter an antigen and become activated, they make extra but initially nonfunctional Fas. They also temporarily make another surface molecule called Fas ligand. After a few days, Fas becomes operational. Then Fas ligand on activated *T* cells binds to Fas on the same cell or on other activated *T* cells at the site of infection, and the binding instructs the Fas-bearing cell to undergo apoptosis [*see top part of illustration beginning on page 86*]. Hence, activated *T* cells are given a few days to do their job (namely, eradicating an infection) and are programmed to then die.

As we implied earlier, the sensitivity of *T* lymphocytes and other cells to various inducers of apoptosis can depend on the cell's state at the time. Resting *T* cells will die rapidly in response to irradiation with x-rays, but activated *T* cells will not. Tight binding of a thymocyte's receptor to proteins in the thymus results in death, but binding to antigens by mature circulating *T* cells results in activation. What is more, some cell types are inherently more susceptible to apoptosis than others. What controls these differences?

We are beginning to think that evolution has arranged for irreplaceable cells, such as neurons and skeletal muscle cells, to be most resistant, because the loss of these cells could have dire consequences for the organism. Conversely, the cells most easily replaced, such as those of the blood, seem to be the most prone to dying with the least provocation.

A growing body of work suggests that sensitivity is modulated to a great extent by the protein Bcl-2 and its family of related molecules. The relatives go by such names as Bax and Bad. Some of these molecules block apoptosis, whereas others promote it. The proportion of blockers to promoters helps to determine how readily apoptosis can proceed. Precisely how these molecules interact with the death machinery remains uncertain.

Apoptosis and Viral Disease

Just as apoptosis is essential for an organism's survival, disturbance of its regulation appears to participate in an astonishing variety of human diseases. Viral illnesses are among them.

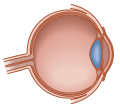
After entering a cell, viruses attempt to shut down that cell's ability to make any proteins except those needed to produce more virus. Problematically for the virus, the mere act of stalling host protein synthesis is enough to induce many kinds of cells to commit suicide. If the host cell dies, the virus is eliminated, too. Therefore, certain viruses have evolved ways to inhibit apoptosis in the cells they infect.

Epstein-Barr virus, which causes mononucleosis and has been linked to lymphomas in humans, uses a mechanism that has been seen in other viruses as well. It produces substances that resemble Bcl-2, the apoptosis inhibitor. It can also produce molecules that cause the host cell to increase its own manufacture of Bcl-2. Other viruses inactivate or degrade the apoptosis inducer p53; papillomavirus, a major cause of cervical cancer, is one example. And cowpox virus, a relative of which is used as the smallpox vaccine, elaborates a protein that prevents ICE-like proteases from carrying out the apoptotic program, suggesting that some human viruses may do the same. Investigators interested in antiviral therapy are now exploring ways to block the activity of the antiapoptotic molecules manufactured by viruses.

Luckily for humans and other animals, the immune system has its own strategies for counteracting such viral trick-

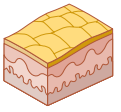
Apoptotic Cells in the Adult

Virtually all tissues harbor apoptotic cells at one time or another. The cells usually commit suicide for the greater good of the body. The list of examples here is far from exhaustive.

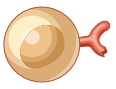


Eye. The lens of the eye, which forms during embryonic development, consists of apoptotic cells that have replaced their innards with the clear protein crystallin.

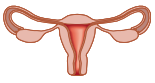
Intestine. Cells composing the fingerlike projections of the intestinal wall arise at the base of the "fingers" and, over several days, travel to the tip. They die there and are sloughed off.



Skin. Skin cells begin life in the deepest layers and then migrate to the surface, undergoing apoptosis along the way. The dead cells form the skin's protective outer layer.



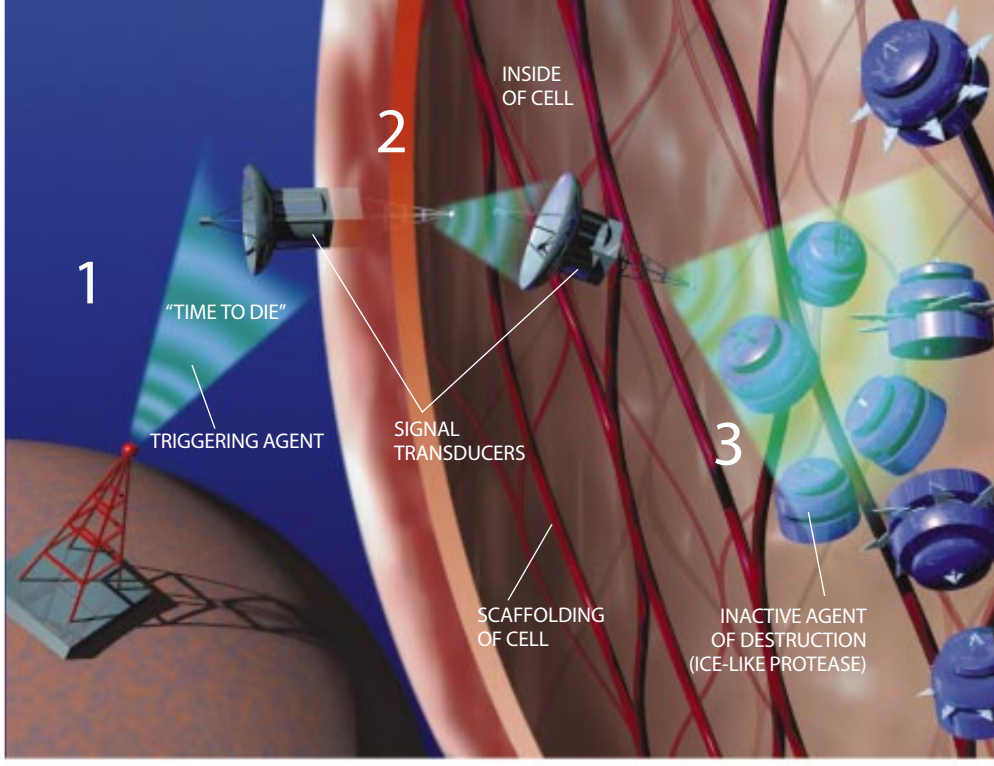
Thymus. *T* lymphocytes—white blood cells that are critical components of the immune system—mature in the thymus. Those that would be ineffectual or would attack the body's own tissues commit suicide before they have the chance to enter the bloodstream.



Uterus. When the cells of the uterine wall die and are sloughed off during menstruation, they perish by apoptosis.

Other. Cells that become infected by a virus or sustain irreparable genetic mutations often kill themselves. Failure of a genetically altered cell to commit suicide can contribute to cancer.

JARED SCHNEIDMAN DESIGN



SLIM FILMS

CELL IS INITIATING SUICIDE in this artist's conception. The process starts after a triggering signal is issued from without (*1*) or within the cell and then conveyed through a series of intermediaries, or transducers (*2*), to the agents of destruction. These agents, which belong to a family of proteins called ICE-like proteases, are activated by the signal (*3*). The proteases damage the cell in many ways, including by attacking its structural scaffolding (*4*) and by activating enzymes that disrupt the nuclear chromatin (*5*).

ery. A major tactic calls on the subset of *T* lymphocytes known as cytotoxic, or killer, *T* cells to eradicate infected cells. After killer cells bind to target cells, they bombard the cells with two kinds of proteins that together inflict a deadly one-two punch. One of the proteins (perforin) inserts itself into the membrane of the infected cell; there it forms a porelike structure that allows uptake of the other proteins—enzymes called granzymes [see "How Killer Cells Kill," by John Ding-E Young and Zanvil A. Cohn; SCIENTIFIC AMERICAN, January 1988]. Granzymes can activate ICE-like proteases and thus induce apoptosis. But if that approach to killing fails, calcium ions that pass in through the new pores can collaborate with the granzymes to produce a necrotic death.

Less fortunately, the ability of *T* cells to induce apoptosis in one another and in infected cells can inadvertently doom healthy cells residing near infected tissue. This bystander damage occurs because many cells in the body display Fas, especially when they or their neighbors are infected. When killer cells home to infected cells, the Fas ligand protruding from the *T* cell surface can dock with Fas on the diseased cells, switching on the apoptotic machinery in the infected cells. That activity is useful and augments other immune tactics for combating infection. But Fas ligand on the *T* cells can dock with Fas on healthy cells in the vicinity and trigger their suicide as well. Medical researchers have suggested that this bystander effect may explain why hepatitis viruses can cause extensive liver damage even though the viruses infect relatively few liver cells.

T Cells Die Too Easily in AIDS

Induction of apoptosis in healthy cells is also believed to contribute to the immune deficiency that plagues AIDS patients. In people who contract the human immunodeficiency virus (HIV), the cause of AIDS, the *T* lymphocytes known as helper *T* cells die. As those cells disappear, cytotoxic *T* cells perish as well, because the cytotoxic cells need growth signals from helper cells in order to forestall apoptosis. When the *T* cells dwindle, so does the body's ability to fight disease, especially viral and parasitic infections. Researchers know that many more helper cells succumb than are infected with HIV. It is also evident that a large number of the cells probably die through apoptosis. But no one knows what prompts this self-destruction.

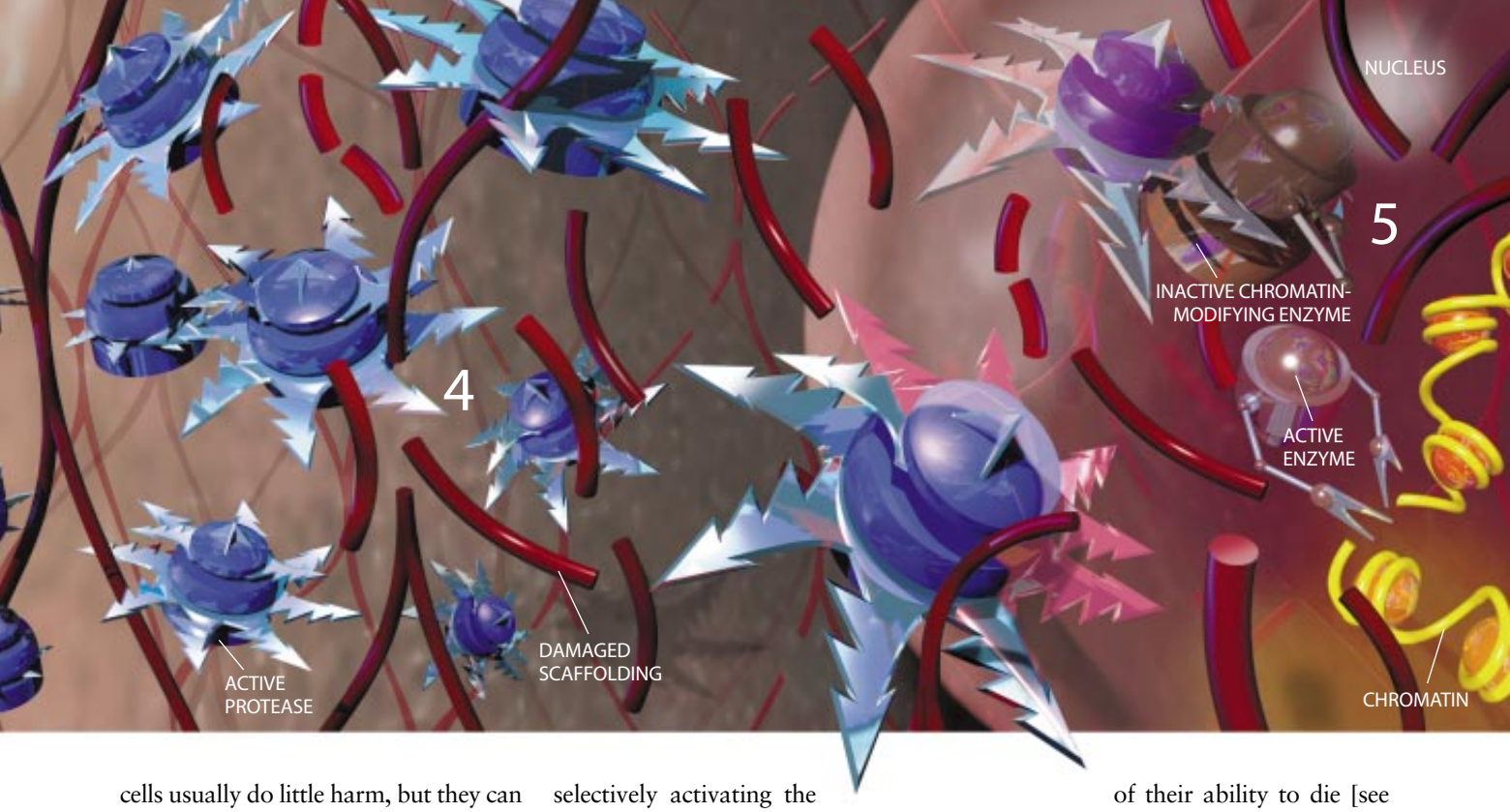
One plausible answer invokes display of too much Fas. Recall that *T* cells normally make functional Fas only after they have been active for a few days and are ready to die. But helper cells from AIDS patients may display high amounts of functional Fas even before the cells have encountered antigen. This display of Fas would be expected to cause them to undergo apoptosis prematurely, whenever they encounter Fas ligand on other cells (such as on *T* cells already activated against HIV or other microbes). The primed cells may also trigger their own death, without receiving signals from activated cells, if they encounter the antigen recognized by their receptors. As we mentioned, antigen recognition leads *T* cells to produce Fas ligand. Ligand on the primed cell can contact the cell's own Fas molecules and thereby activate the death program. Even worse, such primed, antigen-stimulated *T* cells, bearing both Fas and Fas ligand, can amplify the premature cell death by inducing suicide in one another [*see bottom part of illustration on page 86*].

It is also possible that molecules called oxygen free radicals trigger the suicide of virus-free *T* cells; these highly reactive substances are produced by inflammatory cells that are drawn to infected lymph nodes in HIV patients. Free radicals can damage DNA and membranes in cells. They will cause necrosis if they do extensive damage but can induce apoptosis if the damage is more subtle. In support of the free radical theory, researchers have found that molecules able to neutralize free radicals will prevent apoptosis in *T* cells obtained from AIDS patients. Antiapoptotic AIDS therapies are now under study.

A Role in Autoimmunity

Although normal helper *T* cells may be induced to commit suicide by other immune cells in HIV patients, the healthy cells are not technically dying from an autoimmune process. Autoimmunity is said to occur when the antigen receptors on immune cells recognize specific antigens on healthy cells and cause the cells bearing those particular substances to die. But true autoimmune diseases that involve apoptosis do exist.

If the body routinely eliminates self-reactive lymphocytes, how can autoimmunity occur at all? It turns out that the body actually allows some mildly self-reactive lymphocytes to circulate. These



cells usually do little harm, but they can become overactive through several processes. For instance, if the lymphocytes also recognize some foreign antigen (say, on a microbe or in a food), exposure to that antigen can cause them to become unusually excited; they will then expand their numbers and may attack healthy tissue with gusto.

Autoimmune reactions usually are self-limited; they disappear when the antigens that originally set them off are cleared away. In some instances, however, the autoreactive lymphocytes survive longer than they should and continue to induce apoptosis in normal cells. Some evidence in animals and humans indicates that extended survival of autoreactive cells is implicated in at least two chronic autoimmune syndromes—systemic lupus erythematosus and rheumatoid arthritis. In other words, the lymphocytes undergo too little apoptosis, with the result that normal cells undergo too much.

Medical researchers are looking into the possibility that the autoreactive lymphocytes live too long because they produce molecules that block Fas ligand (protruding from other cells) from docking with Fas on their surface, thereby preventing the ligand from sending a death message into the lymphocytes. Other proposals suggest that the lymphocytes avoid apoptosis by underproducing Fas or overproducing the suicide inhibitor Bcl-2. In any case, increased understanding of how *T* cells live and die should provide clues to strategies for selectively activating the death program in the specific lymphocytes responsible for autoimmune conditions. For instance, it might be possible to deliver a Fas-activating molecule (perhaps Fas ligand itself) directly into an arthritic joint and thus to prompt the self-annihilation of the overactive immune cells.

Several tissues in the body appear to use Fas ligand to avoid becoming targets of autoimmunity. By displaying Fas ligand, certain cells in the testis, the eye and possibly the brain induce rapid apoptosis in any Fas-bearing activated *T* cells that come their way. Researchers are hoping to use this discovery to expand organ transplantation. At the moment, the only organs and tissues that can serve as grafts are those whose so-called tissue-typing antigens closely match those on a recipient's tissues. Matches must be close because a poor fit results in immune destruction of the graft. But if donor organs and tissues could be made to display Fas ligand, they might resist immunologic attacks by the host and so become suitable for transplantation.

Cancer Cells Forget to Die

In autoimmunity, immune cells fail to die when they are supposed to; in cancer, it is tumor cells that neglect to sacrifice themselves on cue. Indeed, scientists are increasingly describing cancer as a disease involving both excessive proliferation of cells and abandonment of their ability to die [see "How Cancer Arises," by Robert A. Weinberg; Scientific American, September].

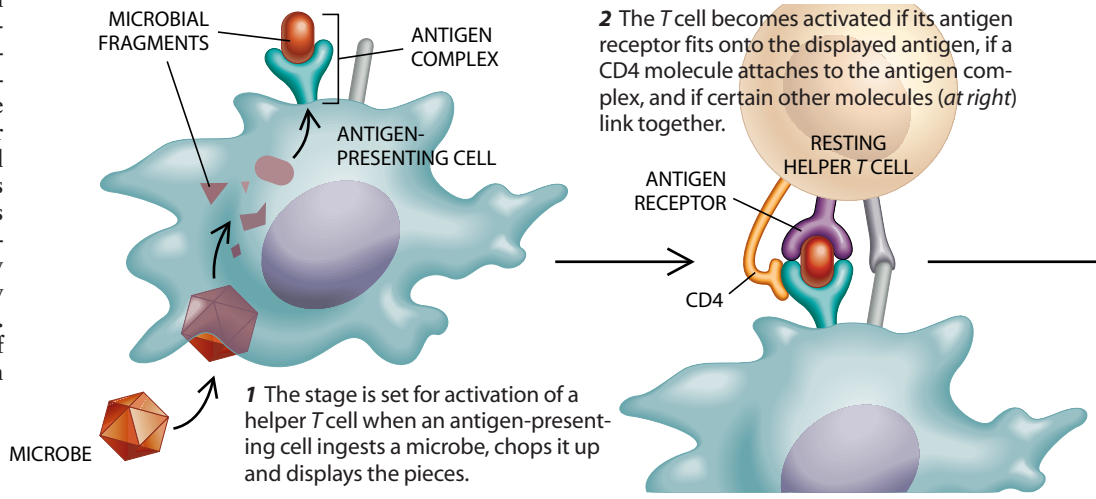
Cancer develops after a cell accumulates mutations in several genes that control cell growth and survival. When a mutation seems irreparable, the affected cell usually kills itself rather than risk becoming deranged and potentially dangerous. But if the cell does not die, it or its progeny may live long enough to accumulate mutations that make it possible to divide uncontrollably and to metastasize—to break away from the original tumor and establish masses at distant sites.

In many tumors, genetic damage apparently fails to induce apoptosis because the constituent cells have inactivated the gene that codes for the p53 protein. This protein, it will be recalled, can lead to activation of the cell's apoptotic machinery when DNA is injured. More than half of all solid tumors, including lung, colon and breast, are missing the p53 protein or manufacture a useless version.

Cells that become cancerous might still be disarmed by other apoptotic triggers. The tendency of normal cells to commit suicide when they are deprived of their usual growth factors or of physical contact with their neighbors is probably a built-in defense against metastasis; prompt activation of apoptosis in tumor cells that leave their native tissue presumably eradicates many metastatic cells before they have a chance to grow.

T CELLS IN AIDS patients undergo apoptosis prematurely even when they are not themselves diseased. When viruses invade tissues, helper *T* cells usually proliferate and orchestrate an immune response against the infiltrator (*top left*). The *T* cells die several days later, when their work is done (*top right*). But in patients infected with HIV, the virus responsible for AIDS, many healthy *T* cells commit suicide before they can proliferate and fight infection. Why they do so is unclear; one of several possibilities is shown (*bottom*).

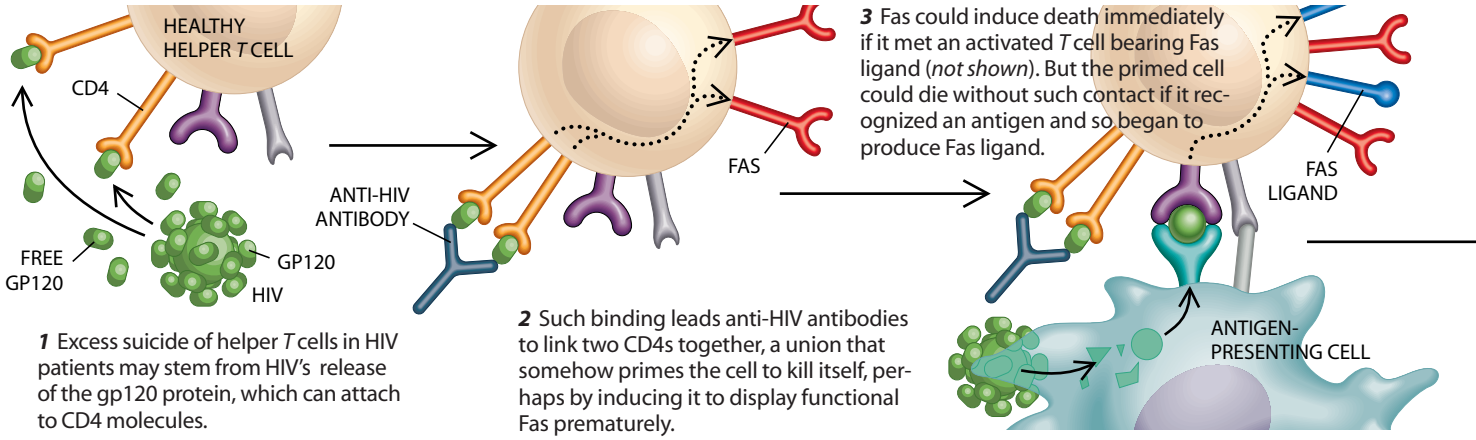
How Helper *T* Cells Normally Become Activated...



1 The stage is set for activation of a helper *T* cell when an antigen-presenting cell ingests a microbe, chops it up and displays the pieces.

2 The *T* cell becomes activated if its antigen receptor fits onto the displayed antigen, if a CD4 molecule attaches to the antigen complex, and if certain other molecules (*at right*) link together.

How Excessive Apoptosis Might Be Triggered in *T* Cells of HIV Patients



1 Excess suicide of helper *T* cells in HIV patients may stem from HIV's release of the gp120 protein, which can attach to CD4 molecules.

2 Such binding leads anti-HIV antibodies to link two CD4s together, a union that somehow primes the cell to kill itself, perhaps by inducing it to display functional Fas prematurely.

3 Fas could induce death immediately if it met an activated *T* cell bearing Fas ligand (*not shown*). But the primed cell could die without such contact if it recognized an antigen and so began to produce Fas ligand.

JARED SCHNEIDMAN DESIGN

Unfortunately, cancer cells manage at times to become impervious to the apoptotic effects of growth factor deprivation and loss of cell-to-cell contacts.

Other apoptosis-related proteins have been implicated in malignancy. In several cancers, especially certain lymphomas, cell death is blocked by excessive production of the suicide-inhibiting Bcl-2 protein. And there is reason to suspect that some tumors prevent Fas from relaying signals to the death machinery or produce Fas ligand to avoid immune-mediated apoptosis.

Oddly enough, certain normal cells make relatively high levels of Bcl-2. This Bcl-2 presumably preserves cells whose loss would be devastating to the body, but the protection comes at a price. Those same cells can be expected to give rise to aggressive tumors when they become cancerous. Protected by Bcl-2, they are less likely than other tumor cells to die; consequently, they may be more able to thrive as metastases in tissues that do not provide the survival factors made by their tissues of origin.

Consider melanocytes. These cells produce the pigment melanin, which darkens other skin cells and thereby helps to prevent them from absorbing lethal, burning doses of sunlight. If the melanocytes perished easily, the other cells would be put at risk. Melanocytes therefore manufacture large amounts of Bcl-2. Yet when melanocytes themselves become genetically damaged, they are less likely to commit suicide than other skin cells and are more likely, when malignant, to form aggressive tumors that spread readily.

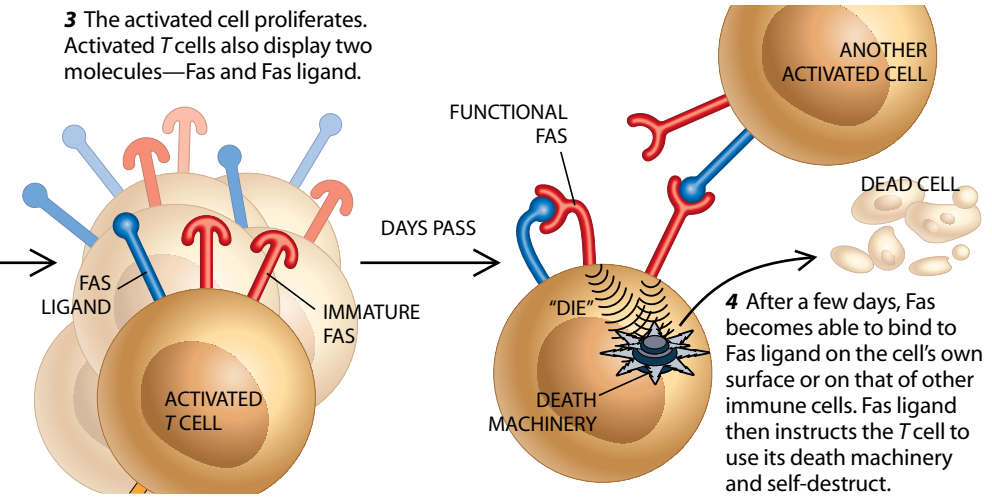
Study of apoptosis has also begun to clarify why many tumors are resistant to the killing effects of radiation and chemotherapy. These therapies were once thought to destroy cancers directly, with the malignant cells dying by necrosis. Scientists now know that the cells generally die by apoptosis, often through activation of p53. Cells that lack p53 or that produce high levels of the Bcl-2 inhibitory protein can thus become inured to the effects of anticancer treatments.

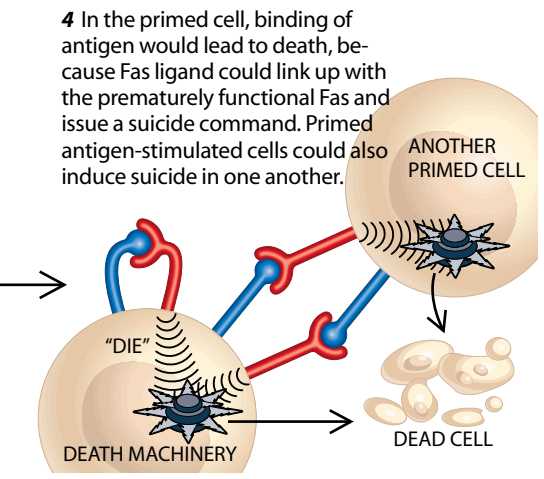
Researchers are exploring genetic therapies for overcoming resistance to apoptosis. They are introducing a normal *p53* gene into cancers that have damaged forms, with the aim of restoring production of the normal p53 protein. They are also investigating ways to prevent overactive *Bcl-2* genes from giving rise to the Bcl-2 protein. Other anticancer approaches aim to block cells from receiving specific growth factors that promote their survival.

Apoptosis in the Heart and Brain

In contrast to cancer, where too little apoptosis occurs, excessive cell suicide accounts for much of the cell death that follows so-called ischemic heart attacks and strokes—those caused by blockage of a blood vessel feeding a segment of the heart muscle or brain. In

. . . And How They Die





the heart the blockage decimates cells that were fully dependent on the now occluded vessel. Those cells die by necrosis, partly because they are catastrophically starved of the oxygen and glucose they need to maintain themselves and partly because calcium ions, which are normally pumped out of the cell, flood in and rise to toxic levels. But that is not the end of the destruction.

Over the course of a few days, cells surrounding the dead zone—which initially survive because they continue to receive nourishment from other blood vessels—can die as well. Many die by necrosis after being overwhelmed by the destructive free radicals that are released when inflammatory cells swarm into the dead zone to remove necrotic tissue. But many, less severely injured cells commit suicide. If the patient is treated by restoring blood flow (an often necessary step), still more cells may die by necrosis or apoptosis, because reperfusion leads to an increase in the production of free radicals.

A similar scenario seems to occur in stroke. Necrosis claims the most acutely affected cells. Then, over several days, inflammation and chemicals that escape from the dying cells (in particular, the neurotransmitter glutamate) lead to more necrosis and to apoptosis in neighboring cells. Sadly, because neither heart muscle cells nor neurons divide in the adult body, the cells that vanish are gone for good. Understanding of the factors that lead to the tissue death accompanying heart attack, stroke and reperfusion has led to new ideas for treatment. Notably, cell death might be limited by drugs that block free radical production or inhibit ICE-like proteases.

Apoptosis probably also accounts for much cell death in diseases marked by the progressive loss of brain neurons, such as Alzheimer's disease, Parkinson's disease, Huntington's disease and amyotrophic lateral sclerosis (Lou Gehrig's disease). The exact cause of this apoptosis is not known. Investigators have proposed various culprits, among them free radicals, insufficient levels of nerve growth factors and excessive levels of neurotransmitters. The suggestions may all be correct; it seems likely that a combination of such factors could gradually cause many cells to destroy themselves. Studies of animals imply that long-term delivery of nerve growth factors could well protect against apoptosis in these conditions.

Faulty control of apoptosis may contribute to a number of other disorders, among them retinitis pigmentosa (a cause of blindness) and osteoporosis. These are still early days in the study of cell suicide, and so efforts aimed at treating disease by manipulating the process are also at relatively early stages. Nevertheless, many biotechnology and pharmaceutical companies are already involved in the enterprise, designing new drugs and reviewing old ones for any influence on cell survival. The growing understanding of apoptosis should greatly enhance those important efforts. SA

The Authors

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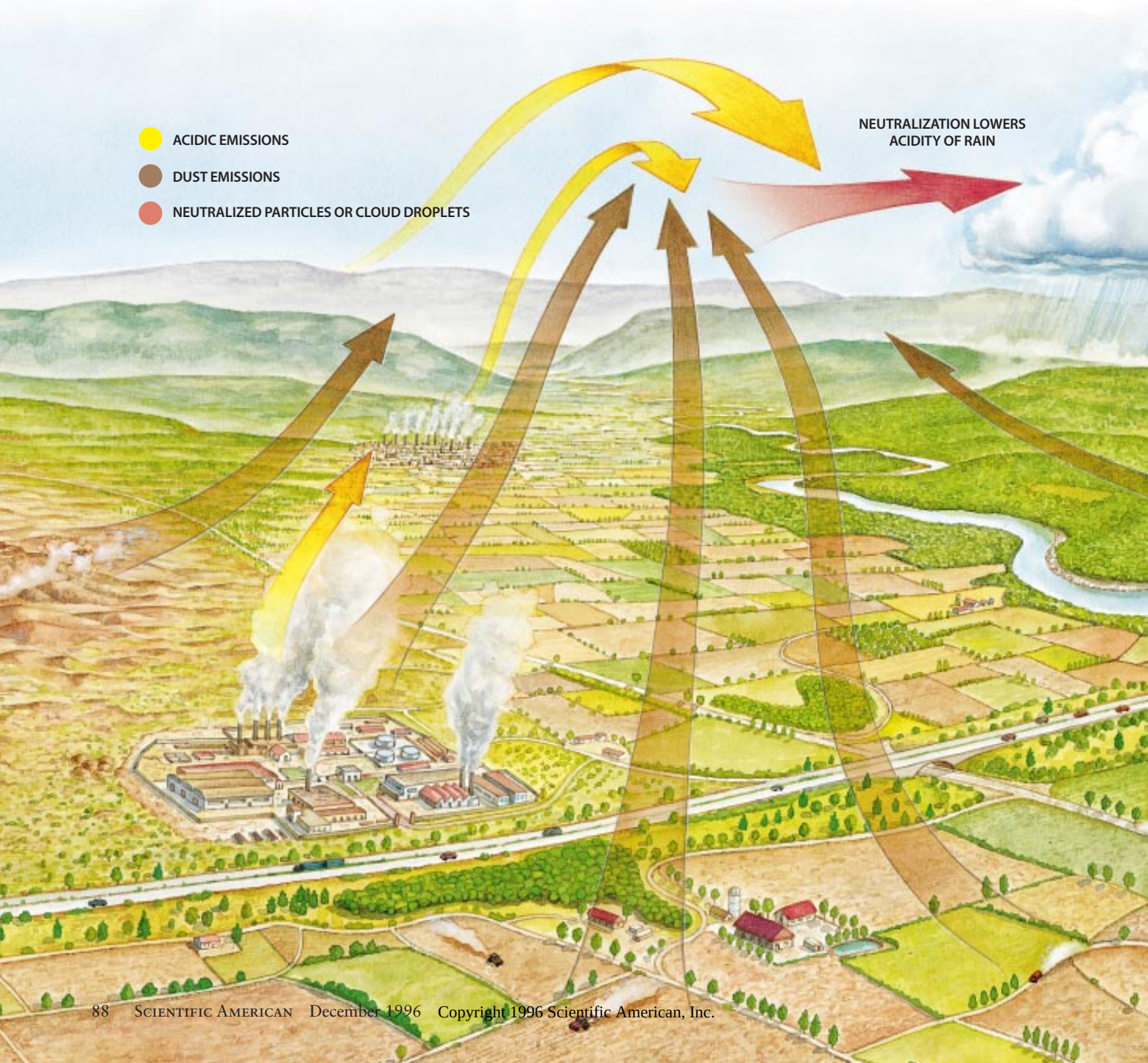
Atmospheric Dust and Acid Rain

Emissions of acidic air pollutants have fallen dramatically. Why is acid rain still a problem? Atmospheric dust may be part of the answer

by Lars O. Hedin and Gene E. Likens

For the past several decades, scientists have been studying acid rain and how it affects the environment. As the harmful consequences of acidic air pollutants became increasingly clear, governments in North America and Europe began to regulate emissions of these compounds. Countries in the European Union enacted a variety of laws to control the release of sulfur dioxide and nitrogen oxides; the Clean Air Act imposed similar regulations in the U.S. Policymakers expected these reductions to rejuvenate forests, lakes and streams in many regions. In some respects, the issue seemed wrapped up.

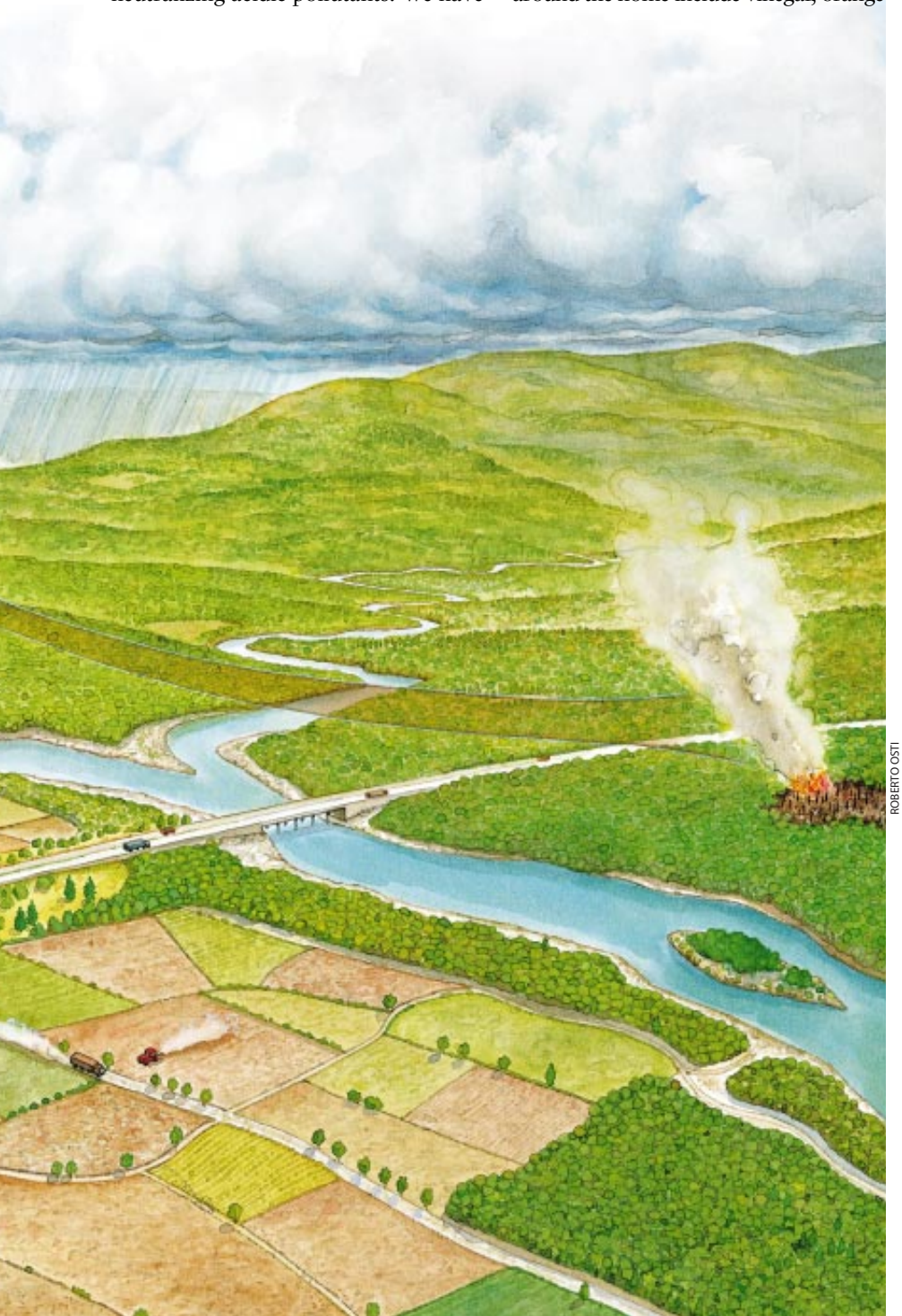


But the problem of acid rain has not gone away. Why is the rain falling on parts of Europe and North America still acidic, despite tighter controls on pollution? And why do some natural ecosystems—in particular, forests—show levels of damage from acid rain greater than scientists originally predicted?

Recent findings suggest that acid rain is a much more complex phenomenon than previously thought. Results from several studies point to the unexpected but critical role of chemicals in the atmosphere known as bases, which can counteract the effects of acid rain by neutralizing acidic pollutants. We have found that all the attention given to acidic compounds in the atmosphere has obscured the fact that emissions of bases have also decreased. A number of factors seem to be diminishing the level of these atmospheric bases and in the process aggravating the ecological effects of acid rain. Ironically, among these factors are some of the very steps that governments have taken to improve air quality.

Acids and bases are measured by what is known as the pH scale: solutions with a pH of less than 7 are acidic; those with a pH greater than 7 are basic; those with a pH of 7 are neutral. Common acids around the home include vinegar, orange juice and beer; ammonia, baking soda and antacid tablets are all bases. Most of the bases in the atmosphere can be found in airborne particles referred to as atmospheric dust. These dust particles are rich in minerals such as calcium carbonate and magnesium carbonate, which act as bases when they dissolve in water.

Atmospheric dust particles originate from a combination of sources. Fossil-fuel combustion and industrial activities, such as cement manufacturing, mining operations and metal processing, generate particles that contain bases. Construction sites, farms and traffic on unpaved roads also contribute. Sources such as forest fires and erosion caused by wind blowing over arid soils with little vegetation are considered natural yet can still be linked to human activity.



ROBERTO OSTI

ATMOSPHERIC DUST (*brown arrows*) **contains chemicals known as bases, which neutralize the acidic air pollutants (*yellow arrows*) that cause acid rain. Industrial emissions, agricultural processes, such as plowing, and traffic on unpaved roads contribute to atmospheric dust. Natural sources include forest fires and erosion by wind. Acidic pollutants derive primarily from the burning of fossil fuels in factories, cars and homes. An additional benefit of dust particles is that they deliver nutrients to forests; unfortunately, dust can cause health and environmental problems.**

A Natural Antacid

In the air, dust particles can neutralize acid rain in a manner similar to the way antacids counteract excess acid in an upset stomach. In a sense, when an acid and a base combine, they cancel each other out, producing a more neutral substance. Neutralization in the atmosphere takes place as dust particles dissolve into acidic cloud-water droplets or combine directly with acidic gases such as sulfur dioxide or nitrogen oxides. These reactions also generate so-called base cations—a term used to describe the positively charged atoms of elements such as calcium and magnesium that arise when mineral bases dissolve in water.

In addition to lowering the acidity of precipitation, atmospheric base cations also neutralize acid rain once they reach the ground—although the chemistry is a bit different than in the atmosphere. Small particles of clay and humus (decayed organic matter) in soil bear nega-

tive charges and thus attract positively charged cations, such as calcium and magnesium; as a result, soils contain a natural store of base cations attached to these particles. As acidic rainwater drains into the ground, the base cations give up their places to the positively charged hydrogen ions found in acids, which bind more tightly to the soil particles. Because these particles sequester hydrogen ions, the acidity of the water that flows through the soil stays low. In some soils the process becomes more complex: acid rain triggers the dissolution of toxic aluminum ions that also displace the base cations.

As long as the soil has an abundant supply of base cations, this buffering system, known as cation exchange, protects forests from the harmful effects of acid rain. But the natural reserves of base cations can become depleted if soils that are naturally poor in bases are exposed to acid rain over decades, as has been the case in regions of Europe and North America. In these areas, hydrogen ions and aluminum ions have displaced a large part of the available base cations in soils, allowing levels of aluminum to rise and leaving the soil highly acidic. Furthermore, such acidified soils can no longer protect downstream ecosystems from acid rain: waters that drain these forests carry both acids and aluminum into streams, lakes and rivers.

Dust particles may serve one other important role. Elements such as calcium and magnesium, as well as sodium and potassium—all of which can be found in mineral dust—are essential nutrients for most plants. Acid rain not only dislodges these elements from clay and humus particles, from which plants get most of their nutrients, it also washes them into rivers and streams, depleting the ecosystem of its store of minerals. With the exception of early work in the 1950s by Hans Egnér of Uppsala Agricultural University in Sweden and Eville Gorham of the Freshwater Biological Association laboratory in England, scientists have not paid much attention to the idea that the atmosphere can be a major source of base cations found in soils. Scientists have traditionally thought that the slow dissolution of minerals and rocks in deeper parts of the soil replenished base cations, in a natural process called chemical weathering.

But recent findings, including our own studies, are now revising the general view of how bases enter soils and how forests depend on atmospheric inputs of minerals and nutrients. In some forests the atmosphere actually appears to be the main source of base cations. These new results suggest that many forests are more sensitive to changes in atmospheric chemistry than scientists once believed.

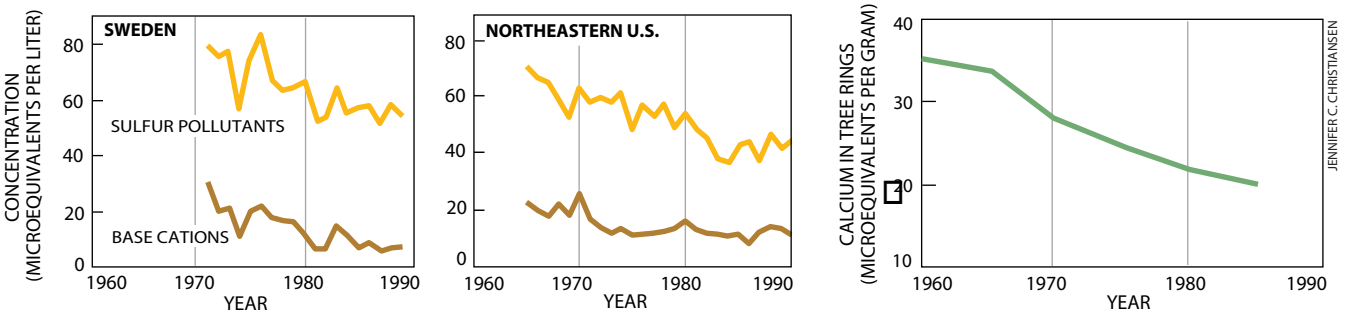
Less Dust, More Damage

Efforts to reduce emissions of acidic air pollutants offered encouraging results at first: levels of atmospheric sulfur, for instance, have dropped dramatically over the past three decades in much of Europe and eastern North America. The two of us became concerned, however, that policymakers and scientists alike might be neglecting the role of atmospheric bases in their attempts to evaluate whether these reductions in sulfur compounds have benefited the environment. Considering the significance of basic chemicals to both forest growth and the prevention of acid rain, we decided to investigate whether levels of atmospheric dust have also changed over time in response to lower emissions imposed by new regulations.

Regulations to limit emissions of dust were enacted because, as scientists have known for some time, microscopic particles suspended in the air can cause a range of health problems when inhaled; they also degrade visibility and contribute to a host of other environmental problems. Governments in North America and Europe have for over 20 years designated acceptable air-quality standards for particulate matter; these regulations were quite distinct from those focusing on acidic pollution. (Atmospheric dust from other sources appears to have dropped off as well: Gary J. Stensland and Donald F. Gatz of the Illinois State Water Survey have found that emissions of particles containing bases have fallen in response to less traffic on unpaved roads.)

Working together with European scientists, we began by evaluating the longest records of precipitation chemistry that can be found in eastern North America and western Europe. By measuring base cations dissolved in snow and rainwater, we can keep track of the levels of mineral bases in the atmosphere and monitor the input of these base cations into forest ecosystems. Our findings were startling: we discovered that atmospheric bases have declined at unexpectedly steep rates during the past 10 to 30 years. The longest existing North American record, collected at the Hubbard Brook Experimental Forest in New Hampshire, showed a 49 percent drop in atmospheric base cations since 1965.

On the other side of the Atlantic we found that the longest-running high-quality European record, from the forested area of Sjöängen in southern Sweden, showed a 74 percent decrease in base cations since 1971. Our analyses of several other records confirmed with few exceptions that atmospheric bases have declined precipitously across extend-



Note: microequivalents are used to measure quantities of acids and bases.

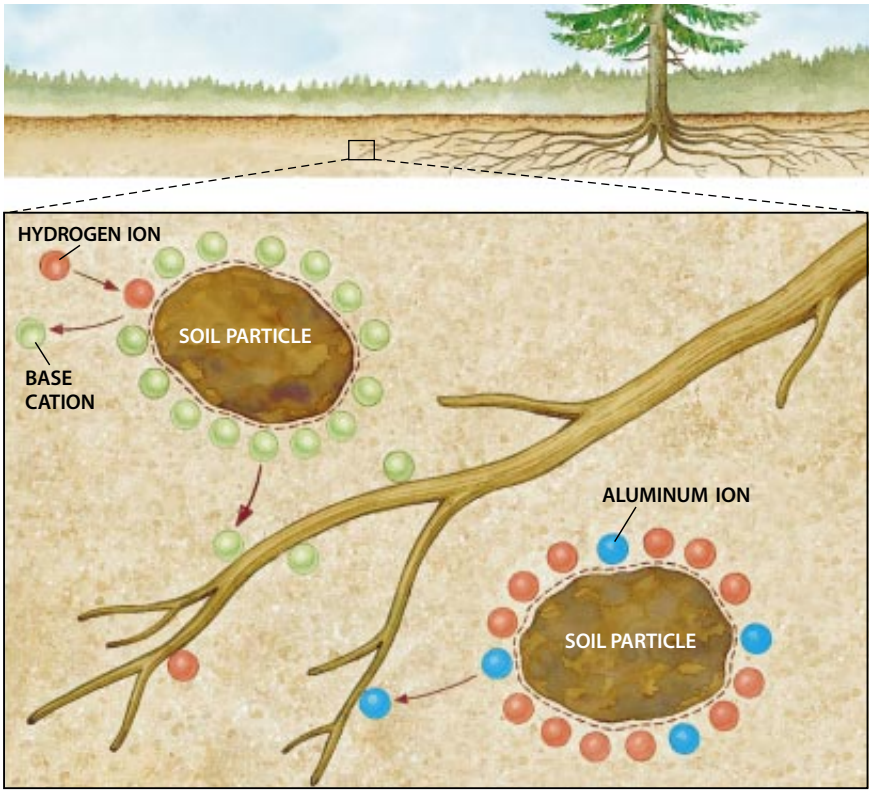
SOURCE: E. A. Bondietti et al., 1990

PARALLEL DECREASES in acidic sulfur pollutants and the base cations that neutralize them cancel out much of the expected benefit from reducing acidic pollutants. The authors' studies in Sweden and the U.S. provide evidence for these trends. In addition, other studies have shown that levels of the base cation calcium have decreased in the trees of a New Hampshire forest over the past several decades; such decreases in essential nutrients further weaken forests.

ed areas of Europe and North America.

But have these cuts in atmospheric bases been strong enough to counteract—or even nullify—the expected environmental benefits of reductions in acidic emissions? Our research indicates that this indeed has been the case. We found that the decline in bases has often mirrored the downturn in atmospheric sulfur, at rates sharp enough to offset a large part of the drop in sulfur compounds. For example, we found that the decrease in base cations canceled out between 54 and 68 percent of the reductions in atmospheric sulfur in Sweden and up to 100 percent at some locations in eastern North America [*see illustration on opposite page*]. These trends mean that declines in bases have kept the atmosphere sensitive to acidic compounds despite reduced emissions of these chemicals. When we began this work, we certainly did not anticipate that reductions in one form of pollutants—dust particles—would be found to decrease the success of reductions of another pollutant, sulfur dioxide.

The numerous sources of dust particles and the often sketchy information on emissions of particulates make it difficult to determine why these sharp reductions in atmospheric bases have occurred. We do know that new and cleaner industrial techniques, developed in accordance with regulations on the release of particulate matter, have been an important factor. For example, improved combustion efficiency and the practice of scrubbing particles from smokestacks have curtailed particulate pollution associated with the burning of fossil fuels. Evaluating the contribution of more diffuse sources of dust—traffic, agricultural methods and wind erosion, for instance—has been more difficult. But our studies suggest that the decline in dust particles mainly reflects changes in human behavior as opposed to natural variations.



BASE CATIONS (*green*) in soil provide nutrients for plants, which absorb the chemicals through their roots. Typically, base cations attach themselves to particles of humus or clay (*left*). But when acid rain falls on the soil, hydrogen ions (*red*) from the rain displace the base cations, which are then washed away. Over time, the hydrogen ions, together with aluminum ions (*blue*) released from the soil as a result of acid rain, can build up on particles (*right*). Not only do hydrogen and aluminum displace essential nutrients, but they interfere with the plant's biochemistry; aluminum in particular can be toxic.

A Major Source of Nutrients

Scientists have watched for years as calcium, magnesium and potassium levels have dropped in forest soils around the world. For example, Leif Hallbäcken and Carl Olof Tamm, both at Uppsala Agricultural University in Sweden, have documented losses of 56 to 74 percent of the available cations in Norway spruce forests over the past 60 years. Other reports show similarly dramatic losses of base cations in England, Germany and the U.S. Several recent studies of ailing forests show that the precipitous loss of base cations can be a key factor in the phenomenon of forest decline. Ernst-Detlef Schulze and his colleagues at the University of Bayreuth have argued that depletion of magnesium in soils has played a significant role in the dwindling of spruce forests in the Fichtelgebirge of Germany. Although their evidence is less clear, researchers at Oak Ridge National Laboratory in Tennessee, led by Samuel B. McLaughlin, have found that the slowdown in growth of red spruce trees in the southern Appalachian Mountains correlates with lower availability of calcium in soils. Interestingly, small-scale experiments involving fertilization of some forests with base cations, particularly calcium and magnesium, have ameliorated damage—in the sugar maple forests of Quebec, for instance, and in Norway spruce and silver fir forests of Germany and France.

Reports such as these made us wonder whether certain soils are suffering not only because of continued exposure to acid rain but also because they do not receive enough base cations from the atmosphere. Scientists can now pinpoint the origin of base cations and trace their movements through forest ecosystems by looking at the natural isotopes of the element strontium (determined by evaluating the number of neutrons in the nucleus of a strontium atom), which can be used as a tracer for calcium. Strontium atoms that derive from the bedrock and those that come from the atmosphere tend to exist as different mixtures of isotopes. This technique has illustrated that atmospheric dust is in fact a critical source of mineral ions in many forest ecosystems.

Moreover, in certain regions, where soils tend to be damaged by acid rain or naturally low in base cations, most of the calcium appears to come from the atmosphere rather than the bedrock. For instance, we have determined that in unpolluted forests of Chile, the dominant tree species, the southern beech, feeds on calcium that originates almost exclusively in the atmosphere.

These observations suggest that many forests depend quite heavily on the atmosphere for a supply of mineral bases; the drops in atmospheric base cations have therefore led to a slower replenishment of critical bases and nutrients in forest soils. Of course, natural levels of atmospheric dust have always varied, but usually across centuries or millennia. Studies conducted by Paul A. Mayewski and his co-workers at the University of New Hampshire on ice cores from Greenland indicate that the amounts of dust and calcium in the atmosphere have been strongly affected by climate variations over the past 20,000 years. In the coldest and driest global climates, high levels of calcium and dust prevailed, whereas wetter and warmer periods saw low concentrations. Analysis of modern trends, from around 700 A.D. to the present, suggests that current quantities of dust are relatively low compared with conditions during the past 20,000 years. One notable exception was the Dust Bowl, the extended drought of the mid-1930s in the western U.S.

JOHN BEATTY *Tony Stone Worldwide*

SANDSTORM in the Sahara Desert can scatter dust particles around the globe. Studies in Amazon forests have turned up dust that originated in the Sahara, more than 3,000 miles away.

Remaining Questions

As scientists have discovered the importance of bases in the atmosphere and, more recently, the link between emissions of atmospheric dust and nutrients in the soil, they have begun to paint a new picture of how forests respond to atmospheric pollution. This emerging view suggests that the effects of acid rain are more complex than expected and that the damage caused by the pollution is more serious than predicted. For instance, the widely quoted conclusion from the 1990 National Acid Precipitation Assessment Program (the most recent evaluation of the problem of acid rain by the U.S. government), that there was no clear evidence linking acid rain to forest damage, no longer seems tenable.

It is entirely feasible that continuing acid rain, in combination with limited supplies of base cations, could produce environmental conditions to which many plant species, particularly in sensitive ecosystems, have never been exposed in the course of their evolution. Consequently, predicting how they will respond over the next several decades will be extremely difficult. And effects may not be limited to plants. Jaap Graveland and his colleagues at the University of Groningen, have noted that certain birds, such as the great tits of the Netherlands produce thinner, more fragile eggs in forests that have been heavily damaged by acid rain and have low stores of calcium in the soil.

What can we do about acid rain and atmospheric dust? Suggestions range from the improbable to the feasible. After the publication of one of our recent papers, a reader wrote proposing that forests might be saved by a hot-air balloon campaign to drop calcium-rich particles from the skies—a costly and impractical solution. Deliberate increases in the release of particulates are also unrealistic and would set back progress in air-pollution control by decades. One reasonable suggestion, however, is to reduce emissions of acidic pollutants to levels that can be buffered by natural quantities of basic compounds in the atmosphere; such a goal would mean continued reductions in sulfur dioxide and nitrogen oxides, perhaps even greater than those prescribed in the 1990 Amendments to the Clean Air Act in the U.S.

The ecological dilemma of atmospheric dust will very likely be with us for some time: base cations take years to build up in soils, and it may take decades or more for forests to recover their depleted pools of nutrients, even if levels of acidic air pollution continue to fall. In the meantime, researchers and governments must develop careful strategies not only for monitoring the current health of forests but also for predicting their stability in the next century and beyond. Simple solutions do not always work in complex ecosystems. SA

The Authors

LARS O. HEDIN and GENE E. LIKENS have worked together for more than a decade, examining how acid rain affects forest and aquatic ecosystems. Hedin is an assistant professor in terrestrial biogeochemistry in the section of ecology and systematics at Cornell University. In addition to his research on base cations, Hedin studies nutrient cycles in unpolluted temperate and tropical forests. Likens is director of the Institute of Ecosystem Studies in Millbrook, N.Y. He has published extensively on the topic of acid rain and on how human activities impact the environment.

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A Cricket Robot

Can a simple electromechanical system perform a complex behavior of a living creature? There was one sure way to find out

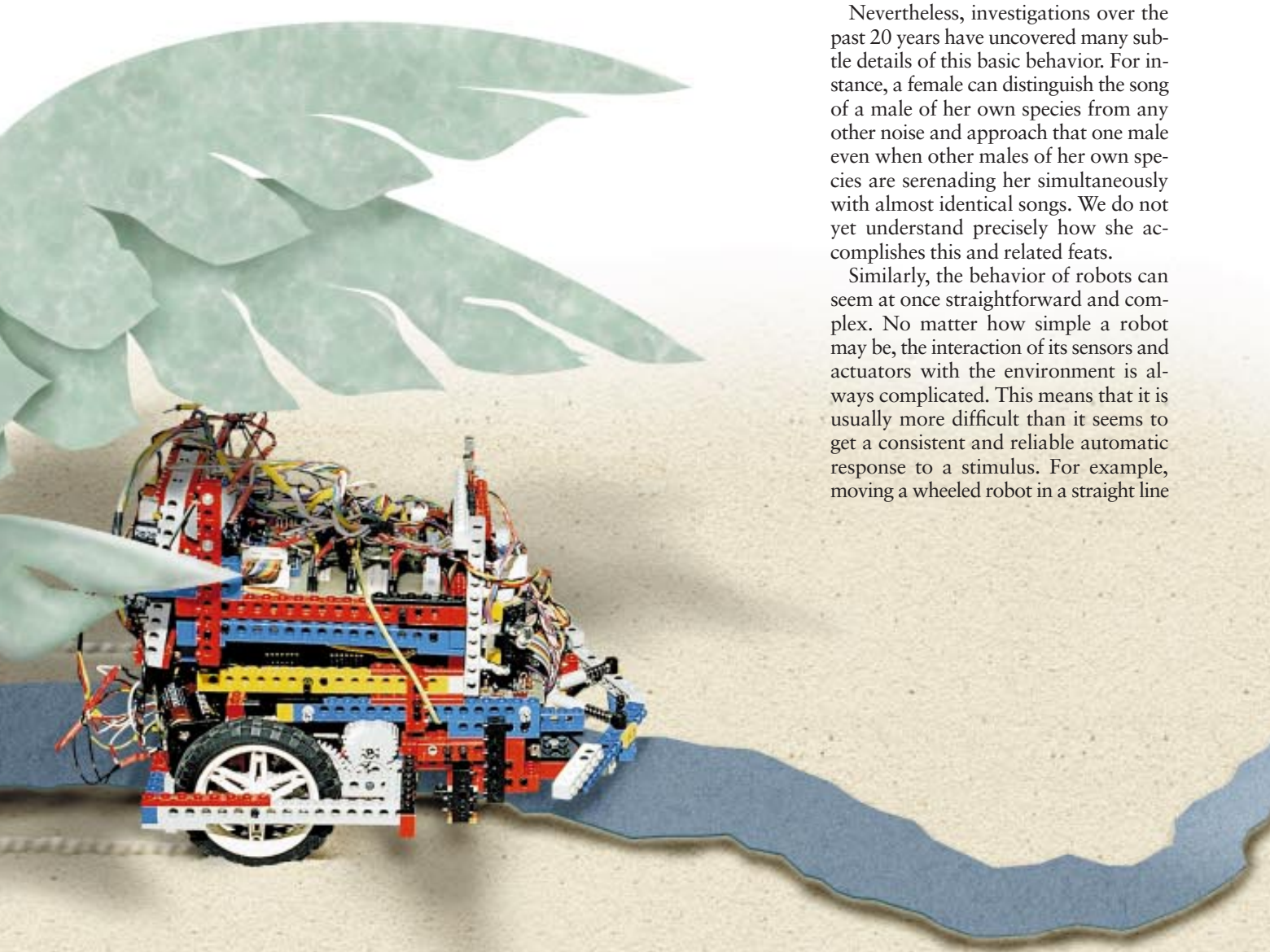
by Barbara Webb

When we describe a behavior as robotic, it is usually to call attention to its predictability. Whether the subject is a bored supermarket cashier or an acquaintance not known for spontaneity, robotic behavior might be characterized as a series of seemingly automatic reactions in response to interactions or events.

Insect behavior, too, might be considered to be robotic or automatic. Detailed research into the specific actions of some insects, however, has revealed a great deal more variety than this characterization suggests. The female cricket attempting to locate a mate from the male's calling song is a good example. In some respects, this activity seems very simple: when she hears the appropriate song, the insect may continue to walk toward it for hours, even if placed on a treadmill.

Nevertheless, investigations over the past 20 years have uncovered many subtle details of this basic behavior. For instance, a female can distinguish the song of a male of her own species from any other noise and approach that one male even when other males of her own species are serenading her simultaneously with almost identical songs. We do not yet understand precisely how she accomplishes this and related feats.

Similarly, the behavior of robots can seem at once straightforward and complex. No matter how simple a robot may be, the interaction of its sensors and actuators with the environment is always complicated. This means that it is usually more difficult than it seems to get a consistent and reliable automatic response to a stimulus. For example, moving a wheeled robot in a straight line



is not just a matter of supplying motors on each side with the same power. Mechanical inaccuracies of motors, gears and wheels will require a slightly different power to get the same turn rate from the wheels. Friction and inertial forces will vary, and the power will have to be adjusted constantly from measurements of the turning rate and feedback of the error. Even when the wheels turn at the same rate, unevenness in the ground and slipperiness will move the robot off a true straight line unless it has some compass sense that allows it to change wheel speeds to compensate.

Counteracting the complex effects of the environment thus seems to require control algorithms of a matching sophistication. But does it really? An alternative, increasingly popular approach in robotics is to design the robot so that its interaction with the environment is exploited rather than resisted. For example, instead of attempting to force the robot to travel a straight-line course, it could be programmed to follow contours of the terrain that lead to its destination—circumventing rather than conquering hills in its path. Through this type of approach, what seems like complex behavior in a robot can come from a surprisingly uncomplicated control algorithm.

To investigate these issues, I designed and built a cricket robot based on relatively simple hardware, principles and algorithms. The behavior of this robot, I hoped, would have much of the complexity of the insect itself when confronted with a similar environment. I also hoped to cast some light on the neurobiology that may underlie cricket behavior.

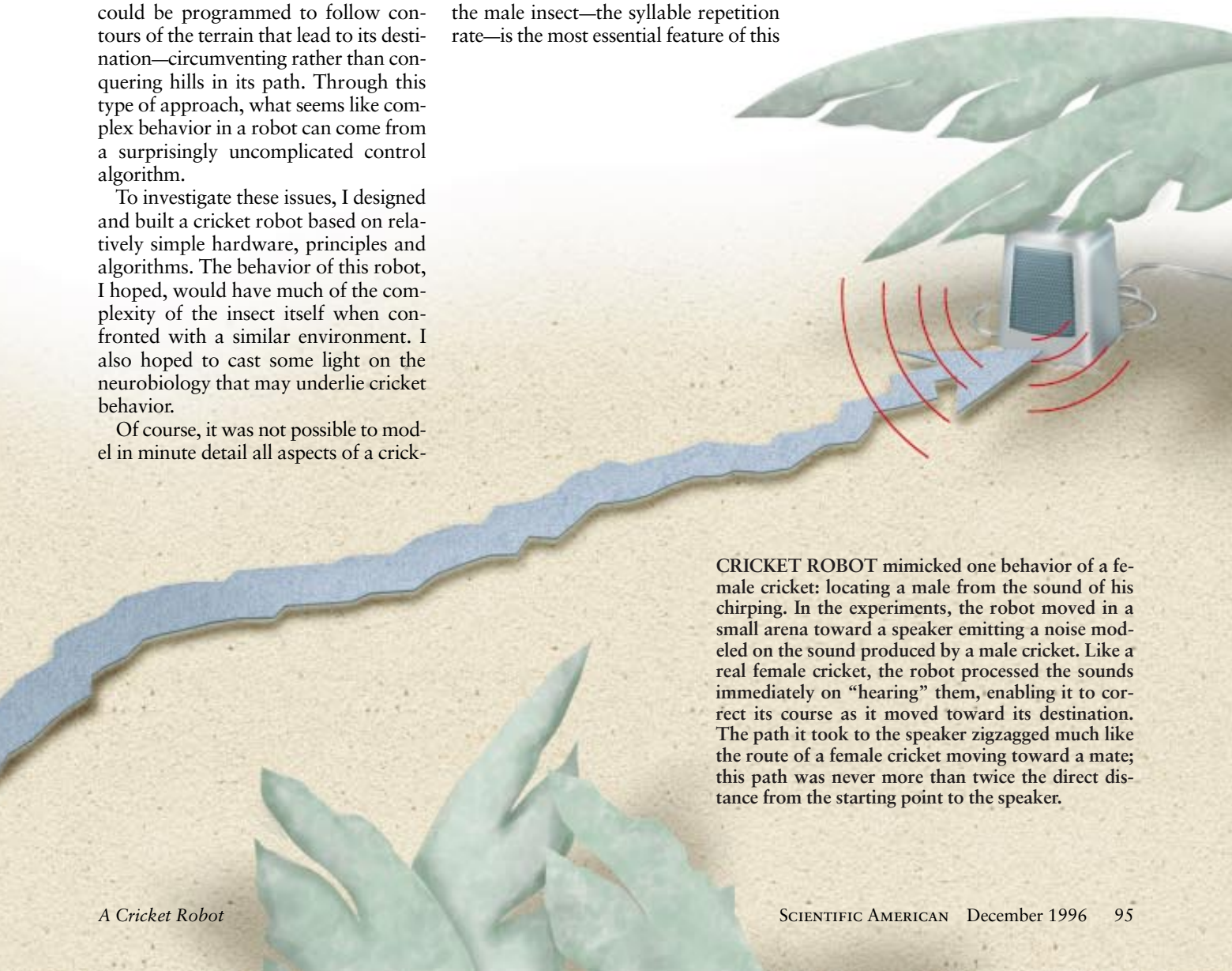
Of course, it was not possible to model in minute detail all aspects of a cricket's behavior, so I chose the specific but significant activity mentioned above: the ability of the female to identify and locate a singing male of her species. (This process of moving to a specific sound, along with all the sensory and locomotive requirements that it entails, is known as phonotaxis.)

Female crickets are quite selective with regard to the sounds that attract them. First, the song's underlying, or carrier, frequency is its most distinctive feature. Males can produce an almost pure tone by rubbing one wing against the other, and females of the same species respond best to that tone and not to sounds of lower or higher frequency than the carrier, which is generally around 4.5 kilohertz. Second, the rhythm of the song as the male opens and closes its wings is also distinctive and species-specific. Each rub of the wings creates the characteristic burst of sound known as a syllable; experiments have established that the rate with which syllables are repeated by the male insect—the syllable repetition rate—is the most essential feature of this pattern for eliciting a female response.

Although in many species the noise is more extensively patterned—for example, syllables are repeated three to five times in a group known as a chirp, followed by a period of silence before the next chirp—many females will respond to syllables that are repeated over and over again, separated by an unvarying interval. Not only must the female cricket distinguish the correct rhythm and sound of a male of her species, but she must also often do so when a number of potential partners are simultaneously serenading her. Somehow she manages to direct herself toward only one of these suitors, ignoring the rest.

In the laboratory the main preference shown is for louder songs; presented with two songs that both have the correct syllable repetition rate, the female will move toward the louder of the two. A louder song may indicate a male who

LAURIE GRACE (*digital composition*); BARBARA WEBB (*photograph*)



CRICKET ROBOT mimicked one behavior of a female cricket: locating a male from the sound of his chirping. In the experiments, the robot moved in a small arena toward a speaker emitting a noise modeled on the sound produced by a male cricket. Like a real female cricket, the robot processed the sounds immediately on "hearing" them, enabling it to correct its course as it moved toward its destination. The path it took to the speaker zigzagged much like the route of a female cricket moving toward a mate; this path was never more than twice the direct distance from the starting point to the speaker.

JEFF FOOTT *Bruce Coleman Inc.*

is larger or simply closer. Other than loudness, however, researchers have not clearly established any other specific characteristics of naturally occurring songs that females prefer.

After choosing the correct sound and, if necessary, selecting from among several examples of it, the female cricket must actually locate the source of the sound—that is, move toward and find it. The only evidence that the cricket has recognized or chosen the sound is the fact that she moves toward it. Therefore, a single process—one that could locate only certain kinds of sound—might suffice to produce the observed behavior. If this were the case, the apparently selective behavior of the female cricket could be replicated by building a robot in which the mechanism that enables it to locate sound works only for the right kind of sound.

Through a Cricket's Ear

A cricket has a rather ingenious sensory mechanism that enables it to detect the direction of sound sources. Its ears are on its forelegs, and because the cricket's body is a poor shield for low-frequency sounds, there is little difference in the strength, or amplitude, of the sound received at each of its two ears. There is a difference in the times at which the sound arrives, but this difference is measured in microseconds and cannot be timed by the cricket's auditory neurons.

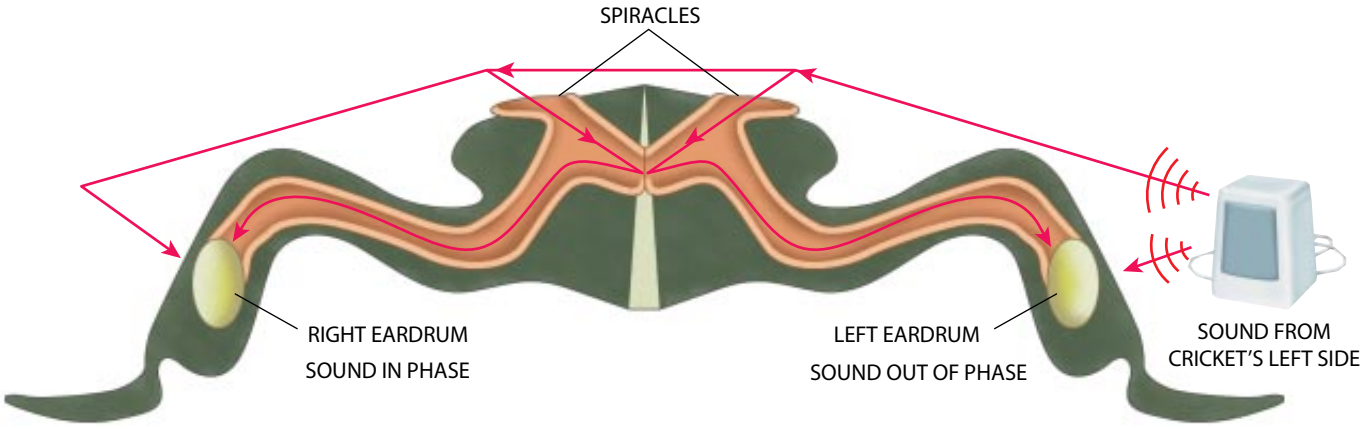
Sound passes along a tracheal tube that connects the ears to each other and to further openings, called spiracles, on the cricket's body. Hence, sound arrives at the ear both externally and internally through the tube, having traveled different distances. The time that it takes for sound to travel through the tube shifts its phase. At the eardrum, the waves reinforce or cancel one another according to their relative phase, which also depends on the direction of the sound. Therefore, the amplitude of the resulting eardrum vibration represents the direction of the sound source [*see bottom illustration on opposite page*]. Conveniently, the amplitude is larger on the side closer to the sound.

The "ears" of the robot I built were miniature microphones. With a great deal of help, I designed an electronic circuit that processed the signals in a way that mimicked the basic functions of a cricket's auditory system. One of the fundamental principles of this system is that the cricket's tracheal tube best transmits sounds of the desired calling song frequency, and the phase shifts in this transmission are suited to that particular wavelength. The mechanism does not reliably detect the direction of sounds at other frequencies. In other words, by relying on phase shifts tuned only to the right wavelength, the auditory system inherently ignores sounds of the wrong wavelength, because they do not produce a directional response.

The robot was a small vehicle, cubic in shape and about 20 centimeters on a side. Built with Lego bricks, the robot had two drive wheels and a caster on the front. As it was rather larger than a cricket, its ears were farther apart, and so I chose a lower frequency (two kilohertz) for the song that would attract it. The output from the microphone circuit provided a signal every 30 milliseconds. This signal corresponded to the eardrum vibration. Mimicking what occurs in a real cricket auditory system, the signal from the circuit had a higher amplitude on the side of the sound source, for sound of the right frequency. In practice, however, the robot's ears signaled the correct direction at best 90 percent of the time because of unwanted noise—in the speaker, in the room and from the robot's own motors.

The difference in vibration amplitude at the eardrums has to be neurally encoded if it is to be compared and used to drive the motor response. In the cricket, approximately 50 sensory neurons per ear converge on a small number of interneurons in the insect's central nervous system. Two of these interneurons—one connected to the left ear and the other to the right—form a pair that appears to be critical to phonotaxis. Neurophysiologists can measure and manipulate the firing of this neuron pair while the animal is walking in response to sound. By doing so, they have shown that the animal always turns to the side on which one member of this neuron pair is responding more strongly.

When a burst of sound occurs, each member of the neuron pair sums the input from the sensory neurons in the cor-



LAURIE GRACE

CRICKET'S BODY channels sounds through an internal tracheal tube that connects the insect's ears to each other and to two openings, called spiracles, at the top of the body (*above*). Each ear is near a knee on a front leg (*photograph, left*). Because of the tube, sound reaches each ear in two ways: directly from the sound source, and indirectly, via the tube, from the spiracles and other ear. At the ear closer to the sound source, the sound that has traveled directly to the outside of the eardrum has traveled a shorter distance than the sound arriving through the tube at the inside of the eardrum. Because of this difference in distance, the sound arriving at one side of this eardrum is out of phase with respect to the sound arriving at the other side. At this eardrum the out-of-phase waves are summed, causing a vibration of greater amplitude, sensed as a louder sound.

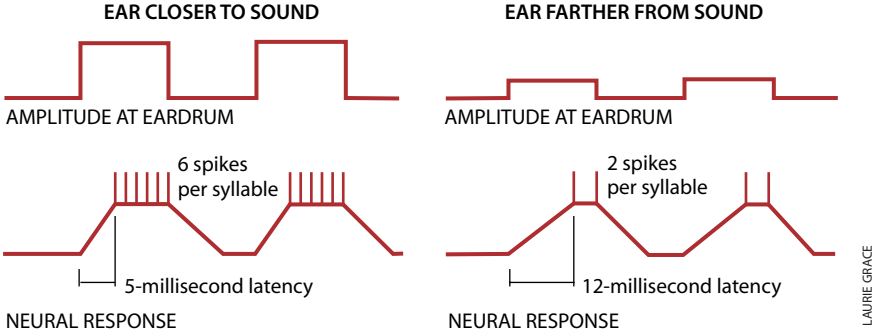
responding ear and, after a threshold is reached, starts firing. How quickly the firing starts depends on the strength of the input; how frequently the firing occurs also closely correlates with the strength of the input. Therefore, there are two ways that the eardrum vibration is encoded by the activity of neurons: the latency (the time that passes before the neurons start firing) and the rate of neural firing during the burst of sound. After a burst of sound ends, the neuron takes a short while to return to its resting state. If another sound begins during this recovery time, the firing recommences more rapidly because the neuron is already close to its threshold.

The most straightforward way the female cricket's nervous system might use this response to locate the sound is, at each sound burst, to turn to the side on which the firing begins first. (This way, she would be turning toward the side on which the sound is closer.) A significant consequence of this scenario is that a response occurs only at the beginning of a sound burst. This notion fits neatly with the fact that syllable repetition is the most important factor in determining whether a female responds to a song. If the sound is continuous or repeats more rapidly than the neuron's recovery time, the neuronal firing will be continuous. In this case, the side on which the neurons began firing first will be unclear. If, on the other hand, the sound repeats too slowly, the information about which way to turn will arrive less frequently and may not be enough to steer the female toward the male. A particular repetition rate between these two extremes would of course be ideal.

Song of the Cricket Robot

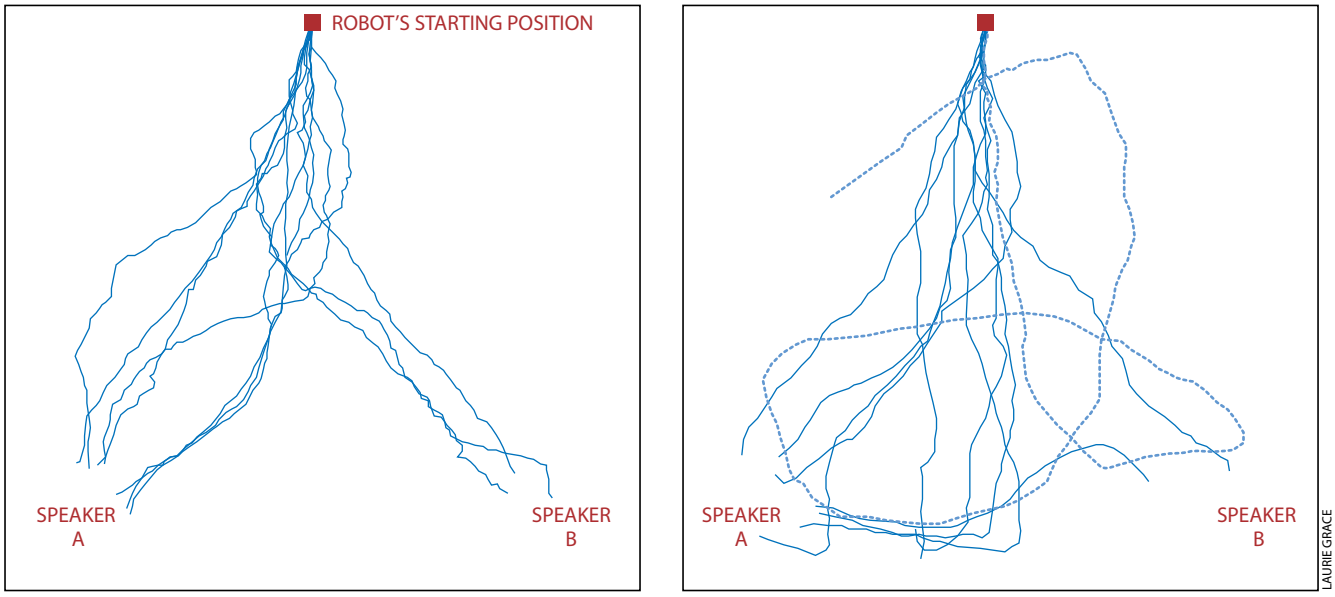
The alternative to comparing onset times is comparing firing rates, which seems to cause the cricket to turn to the side that is firing more frequently. (This response also corresponds to an insect's turning toward the side on which the sound is closer.) This mechanism is the more popular hypothesis among neurophysiologists, although no definitive evidence exists for either possibility. Because firing rate will signal direction for any sound pattern—continuous sound, fast or slow syllable repetition—this hypothesis requires that the cricket have some additional neural processes by which it picks out songs of the right rhythm. Indeed, certain neurons have been found in the cricket brain that appear to have this property.

These facts notwithstanding, for my robot I used an algorithm based on comparing the onset time and ignoring the firing rate. I wanted to test whether such a mechanism can explain the observed selectivity of the female for certain songs, without further neural processes. Because my robot's sensory system depended on having a particular wavelength of sound, and its "neural" comparator depended on having a particu-



LAURIE GRACE

RESPONSE OF AUDITORY INTERNEURON depends on the direction of the sound source. The mechanical amplitude of the eardrum vibration (*top waveforms*) is greater at the eardrum closer to the sound source (*top left*). Each "square" in the waveform is in response to one sound, or syllable, from a male cricket. The interneuron that corresponds to the closer ear responds to the higher-amplitude vibration by rising in potential relatively quickly and by peaking, or "spiking," in potential six times (*lower left*). For the farther ear, the rise in potential is slower and the spikes fewer (*lower right*).



PATHS TO SOUND SOURCE taken by the robot were essentially indistinguishable from those taken by a cricket. The trials were all run in an arena four meters long by 3.3 meters wide. When sounds, known as syllables, were emitted by two speakers simultaneously, the robot simply traveled to one or the other (*left*). Female crickets also move toward a single chirping male when a number are chirping. When the syllables alternated between the two speakers, the robot's paths became more aimless, with the vehicle often winding up between the speakers (*right*). Again, females displayed similar behavior in this situation.

lar rhythm, it did not need to select the right song actively—it simply did not work for the wrong song. If my robot performed well in locating appropriate songs, this would lend credence to the hypothesis that the location mechanism of real crickets could also function in this way.

Programming the robot to function in this manner was relatively easy. Its "brain" was a 68000-type microprocessor, programmed to take various sensor inputs and to send start and stop commands to the right and left motors. In addition to the microphones and the circuit that modeled the phase delay and canceling in the cricket's auditory system, the robot had infrared and bump switches that could detect obstacles. The control program itself consisted of just 100 or so lines of code.

The readings from the ear circuit were summed over time. If one side reached a preset threshold first, the wheel on that side was briefly stopped, causing a small change in direction. If the sound continued, the sum would stay above the threshold and no further response would occur. If the sound stopped, the sum fell back toward zero, mimicking the recovery time of the cricket neuron. Thus, only discontinuous sound that repeated frequently would cause the robot to respond often enough to turn toward the sound.

Because the robot processed sound more slowly than a cricket, the syllable pattern of the song had to be slowed by a factor of about 10, to 300 milliseconds per syllable. Despite this slower sound pattern, the robot still turned and moved forward quite rapidly, with something like the speed of a real cricket. In other words, the robot changed direction at the speed of a cricket while receiving information at only one tenth the speed. Effectively, the robot had a more difficult task. The bright side was that I could be sure that if the robot was able to find the sound, it was certainly not beyond the capacity of the cricket to do so in the same way.

I put the robot through a series of trials. In each trial, I started the robot at one side of an arena and recorded the track it took toward a speaker producing the sound. When the syllables had the ideal length (300 milliseconds) and pitch (two kilohertz), the robot headed toward the speaker in a zigzag path very similar to the meandering observed in actual cricket phonotaxis. This path never covered more than twice the direct distance from start to finish [*see illustration above*]. When I placed obstacles between the starting point and the sound source, the robot found its way around them to the speaker.

To find out how the robot would react to sounds differing from the ideal, I carried out a series of trials with different syllable rates. When I increased the syllable rate (with syllables and gaps lasting less than 200 milliseconds), the robot's program could no longer distinguish the gaps in the sound. It would send very few turn signals to the motors, driving the robot in straight lines around the arena. If it found the speaker at all, it was mostly by chance. When I decreased the rate (syllables and gaps lasting more than 500 milliseconds), the behavior was also less successful. The turns became less frequent, and the robot ended up taking a curved path in the general direction of the speaker, which it often failed to reach. Although I expected that the robot would succeed only within a certain range of syllable rates, I discovered afterward that real crickets, too, tend to take curved paths at slower rates while failing more completely for faster rates. So the robot not only succeeds like a cricket but tends to fail like one, too.

The fact that a male cricket's song is actually a series of chirps—three or so syllables separated by periods of silence—has been more or less disregarded in the above discussion. During our trials, however, I thought it might be interesting to see how well the robot navigated when the syllable train was broken up into chirps. The results were mixed. The robot could move quite a long way in the arena during the silences between chirps, so it tended to overshoot the speaker and then take a while to recover its bearings. On the other hand, when it did reach the speaker, it got there more rapidly than it had with

the continuous song of evenly spaced syllables. This was because when all went well for the machine, during the chirps it would assume the correct heading and during the silent periods move quickly toward the speaker without further time-wasting adjustments.

Again, it was only subsequently that I discovered a correspondence in crickets: their tracking behavior is more direct when chirps are present, but the turning behavior of a cricket constrained to one location, as measured by the movement of legs (or abdomen, if flying), is stronger with continuous syllables. The evidence from the robot suggests that situational factors, rather than additional neural processing mechanisms, may explain the effects of chirp structure on the female's movement toward a potential mate.

Surprising Similarities

So far the results had shown that the robot could mimic the cricket's recognition and location of the correct song. But could this simple vehicle, like a female cricket, choose one calling male from among several? I didn't think so, but it was easy to answer this question by adding a second speaker to the arena and playing the sound through both. To my surprise, the robot seemed to have no problem making up its mind (so to speak) and went almost directly to one speaker or the other.

Because I programmed the robot, I knew it was not capable of distinguishing or deciding between the sounds. Yet again it appears that it is the interaction of the robot's uncomplicated mechanisms with particular sound fields that produces this interesting—and useful—behavior. It might even be enough to explain how the female cricket selects a mate. Unfortunately, in these experiments I did not have enough control over the properties of the stimulus to test whether the robot would prefer certain songs over others.

One variation on two sound sources was possible, however: I could test the behavior when the song was split between the speakers, with syllables coming alternately from either side. Obviously, this situation does not occur in nature, and it is just as well. A female cricket presented with this scenario becomes confused and moves between the two sounds. The robot did more or less the same.

These results as a whole are encouraging, although of course the robot's success does not in itself prove that real crickets work this way. Nevertheless, it does suggest some alternative interpretations of neurophysiological and behavioral results. More generally, it shows that a rather competent and complex performance can come from a simple control mechanism, provided it interacts in the right way with its environment. My colleagues and I are now reimplementing this mechanism on a smaller robot that can process sound more rapidly; we should then be able to test it with recordings of real cricket songs to see if it makes the same choices that female crickets appear to make. If this experiment succeeds, we may have to change our understanding of what it means to behave robotically. SA

ROBERT P. CARR *Bruce Coleman Inc. (animal)*; BARBARA WEBB *(model)*

ROBOTIC AND REAL CRICKETS differ in many physical attributes, including size. In the author's experiments, characteristics of the sounds and environment were scaled to the robot. In future experiments, however, cricket-size robots will be tested with the recorded songs of real male crickets.

The Author

BARBARA WEBB received a B.S. (and a University Medal) in psychology from the University of Sydney in 1987 and a Ph.D. in artificial intelligence from the University of Edinburgh in 1993. She is currently a lecturer in the department of psychology at the University of Nottingham, where she teaches artificial intelligence. Her main research interest is in perceptual systems for the control of behavior in robots and lower animals. Her other professional interests include cricket escape behavior and the modeling of the use by insects of polarized light in navigation.

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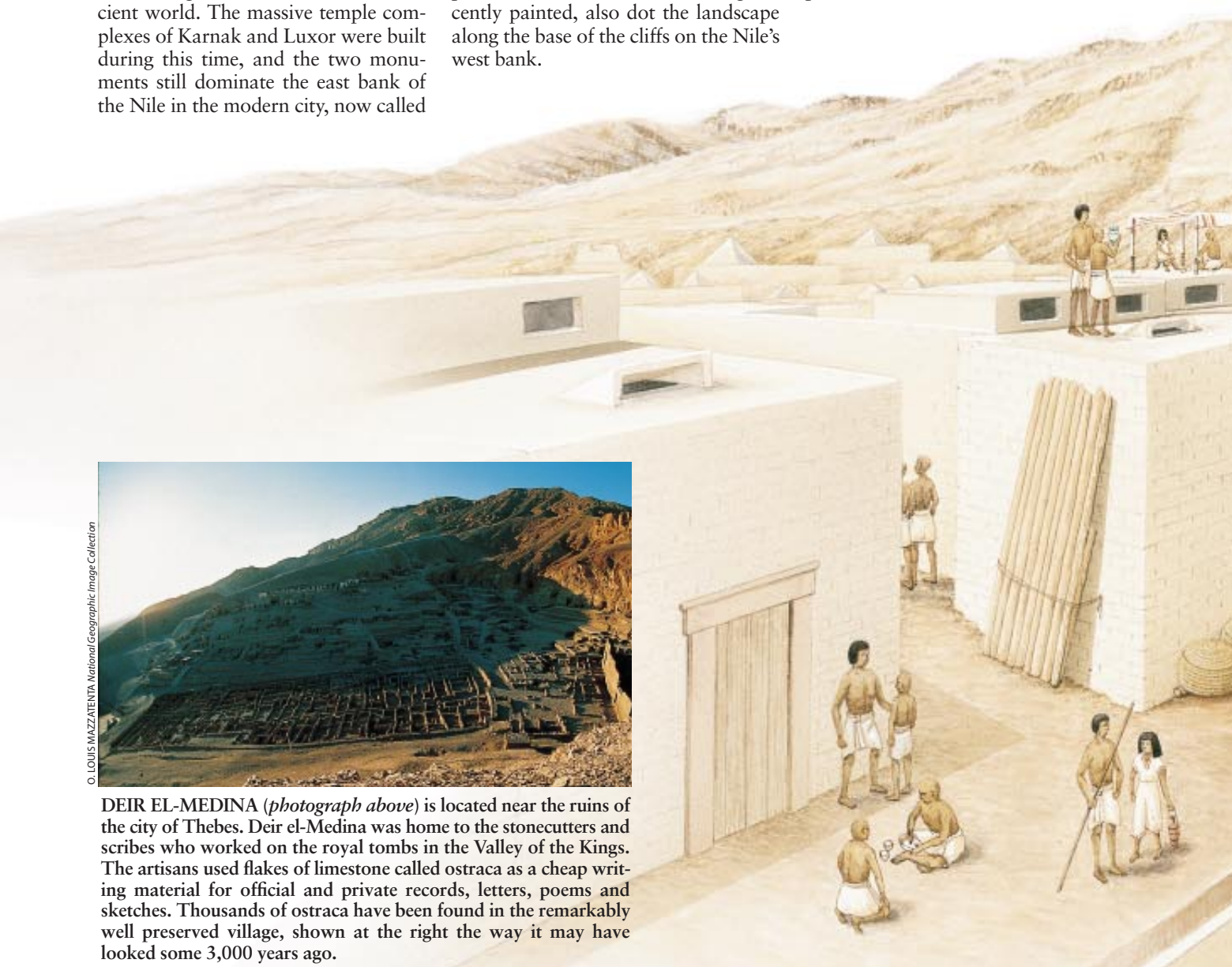
Daily Life in Ancient Egypt

Workmen and their families lived some 3,000 years ago in the village now known as Deir el-Medina. Written records from the unusually well educated community offer fascinating descriptions of everyday activities

by Andrea G. McDowell

During the period known as the New Kingdom (1539–1075 B.C.), Egypt's southern capital city of Thebes developed into one of the great urban centers of the ancient world. The massive temple complexes of Karnak and Luxor were built during this time, and the two monuments still dominate the east bank of the Nile in the modern city, now called Luxor. The nearby Valley of the Kings, on the west bank of the Nile, contains some 60 tombs, including that of the pharaoh Tutankhamen. Hundreds of private tombs, some of them magnificently painted, also dot the landscape along the base of the cliffs on the Nile's west bank.

Although some of the paintings in the private monuments preserve tantalizing pictures of the luxurious life of the nobility, on the whole, the remaining temples and tombs tell us more about reli-



O. LOUIS MAZZATENTA *National Geographic Image Collection*

DEIR EL-MEDINA (*photograph above*) is located near the ruins of the city of Thebes. Deir el-Medina was home to the stonecutters and scribes who worked on the royal tombs in the Valley of the Kings. The artisans used flakes of limestone called ostraca as a cheap writing material for official and private records, letters, poems and sketches. Thousands of ostraca have been found in the remarkably well preserved village, shown at the right the way it may have looked some 3,000 years ago.

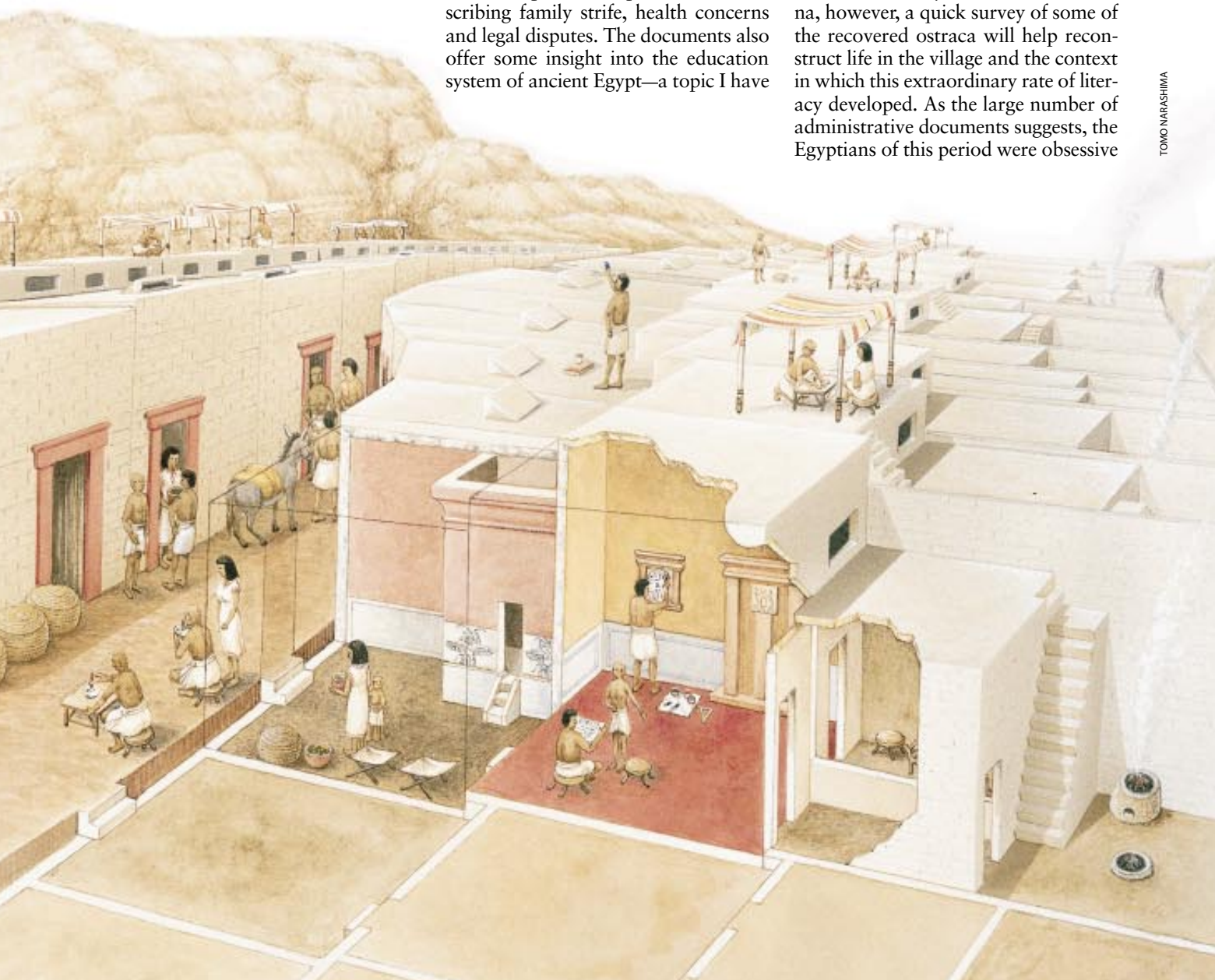
gious experience and beliefs concerning the afterworld than about the experiences of the living. Daily life is less well documented because, unlike the stone monuments we see today, the majority of homes, which were made of sun-dried brick, have succumbed to the damp of the floodplain, along with the furnishings and any written material that would have documented the lives of the literate few. On the westernmost edge of the sprawling ancient city, however, the remains of one small community escaped the general disintegration. This is the village now called Deir el-Medina, the home of the craftsmen who cut and decorated the royal tombs in the Valley of the Kings.

Lying in an arid and relatively isolated region, the site remains remarkably well preserved: houses and chapels are still standing to a height of up to two meters in some places. Archaeologists in the first half of this century found a wealth of religious monuments and household possessions among the effects, as well as intact tombs containing coffins, furniture and clothing. And across the entire site but especially in the town's garbage dumps, researchers recovered tens of thousands of written documents, most of them dating from the period between 1275 and 1075 B.C. Some of the texts are on sheets of papyrus, but most are on shards of pottery or smooth, white flakes of limestone, known as ostraca, that served as a sort of scrap paper for the community.

These writings bring the villagers to life. In them, one finds government records, love poems and private letters describing family strife, health concerns and legal disputes. The documents also offer some insight into the education system of ancient Egypt—a topic I have been investigating for some time. The wealth of texts from the site suggests that in some periods of its history, most men in the town could read and write. (Scholars do not know whether many women in Deir el-Medina were literate. Women in the village did exchange letters, but they may have dictated their thoughts to men.) This high literacy rate stands in stark contrast to the situation throughout the rest of ancient Egyptian society, which during the New Kingdom period had a total literacy rate hovering around only 1 or 2 percent. The ostraca illuminate how the villagers achieved such an impressive level of education.

"Bring Some Honey for My Eyes"

Before we look more closely at the educational system in Deir el-Medina, however, a quick survey of some of the recovered ostraca will help reconstruct life in the village and the context in which this extraordinary rate of literacy developed. As the large number of administrative documents suggests, the Egyptians of this period were obsessive



TOMO NARASHIMA

FITZWILLIAM MUSEUM, UNIVERSITY OF CAMBRIDGE

EGYPTIAN MUSEUM, CAIRO

PORTRAITS of a stonecutter (*left*) and a scribe (*right*) demonstrate two distinct styles of drawing found on ostraca in Deir el-Medina. The rather informal sketch of the stonecutter with his chisel and mallet shows a bulbous nose, stubbled chin and open mouth, no doubt exaggerated for comic effect. The self-portrait of the scribe Amenhotep adoring the god Thoth adheres to the formal canons of Egyptian art.

bureaucrats, keeping careful records of the tools issued to the men laboring on the tombs, the rations delivered to the gang, the overall progress of the work and almost every other detail that could be quantified.

The residents' private jottings are even more varied. Many are purely practical: receipts for purchases or records of legal battles (the villagers were avid litigators). The most intriguing texts are perhaps the personal letters, which take the reader straight into the world of New Kingdom Egypt. In one such missive, a father, Pay, writes to his son about his eye disease—apparently one of the hazards of tomb building because of the dust, bad lighting and flying splinters of stone associated with the task:

> The draftsman Pay says to his son the draftsman Pre[emhab?]: Do not turn your back on me; I am not well. Do not c[ease] weeping for me, because I am in the [darkness(?) since] my lord Amon [has turned] his back on me.
>
> May you bring me some honey for my eyes, and also some ocher which is made into bricks again, and real black eye paint. [Hurry!] Look to it! Am I not your father? Now, I am wretched; I am searching for my sight and it is not there.

Pay's lament is not surprising: blindness would have completely incapacitated a draftsman, who painted the figures and hieroglyphs inside the tombs. Descriptions of the mixture of honey, ocher and black eye-paint that Pay requested appear in specialized medical papyri, suggesting that it was a common remedy. Indeed, honey does have antiseptic properties, and ocher, an ingredient in many other prescriptions of the day, feels cool on the eyelids and was thought to reduce swelling. Because

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TOOLS OF THE TRADE included brushes of all sizes, a pot of red pigment and raw minerals. Scribes used these tools to paint the figures and hieroglyphs that decorated the royal tombs.

so many workmen suffered from this type of eye disease, this treatment may have been well known, and Pay was ordering it for himself. Alternatively, Pay could have been asking his son to fill a doctor's prescription.

Roughly half the texts found at Deir el-Medina are religious or literary pieces. Copies of most of the "classics" from ancient Egyptian literature have been found at the site; in some cases, ostraca from the village provide the only surviving example of a work. These classics were a fundamental part of a student's education: thousands of school texts bear extracts from the masterpieces of Middle Kingdom (roughly 2000–1640 B.C.) literature, composed in a language as remote from the vernacular of the students as the English of Chaucer is from ours. Furthermore, many of the villagers were authors in their own right, composing instruction texts, hymns and letters. For example, the scribe Amennakhte wrote a poem in praise of the cosmopolitan city of Thebes, located just across the Nile:

What do they say to themselves
in their hearts every day,
those who are far from Thebes?
They spend the day
dreaming [?] of its name, [saying]
"If only its light were ours!"…
The bread which is in it is more tasty
than cakes made of goose fat.
Its [water] is sweeter than honey;
one drinks of it to drunkenness.
Behold, this is how one lives
in Thebes!
The heaven has doubled [fresh] wind
for it.

The villagers held knowledge of and ability in the literary arts in high esteem, as indicated on a papyrus found in the archives of a resident scribe. In this extract, the writer presents an unusual tribute to learning: whereas other documents tend to emphasize primarily writing skills and familiarity with classical literature, this description of the profession of scribe emphasizes authorship, the creation of texts and the fame that can come after death. In short, the writer appeals to the great Egyptian aspiration for immortality:

As for the learned scribes from the time that came after the gods—those who foretold the things to come—their names endure forever, although they have gone, having completed their lifetimes, and their relatives are forgotten.

They did not make for themselves pyramids of copper with tombstones of iron. They were unable to leave an heir in the form of children [who would] pronounce their name, but they made for themselves an heir of the writings and instructions they had made.

The Importance of Being Educated

The exceptional rate of literacy among the workmen at Deir el-Medina no doubt developed because the many skilled artisans needed an understanding of hieroglyphs for their job in the royal tombs. Early in the history of the village, the pharaohs' tombs contained only simple copies of the guides to the afterworld, written in cursive script with accompanying vignettes drawn in stick figures. But at the end of the 14th century B.C., elaborately carved and painted scenes began to appear in tombs. At the same time, the literacy rate in the town rose sharply, as evidenced by the increase in the number of texts written after this period.

The king Horemheb, who ruled from 1319 to 1292 B.C., introduced these painted reliefs to the Valley of the Kings. The more elaborate projects of Horemheb and later kings required a team of draftsmen to do the initial drawings and the final paint job; because the tomb paintings included large amounts of hieroglyphic texts, these workers had to be literate.

Perhaps more surprising was that at least some of the men responsible for

A Lesson in Egyptian Literature

The ostracon shown here bears an excerpt from the poem "Satire on the Trades," a classic of Middle Egyptian literature. The poem describes a variety of occupations, such as weaver, arrow maker and courier, that the author considered inferior to the laudable profession of scribe. The student who made this copy was apparently unfamiliar with the archaic language of the poem—written more than 700 years earlier—and garbled the original text. At the end of the lesson, the student wrote the date in red ink. —*A.G.McD.*

Original excerpt

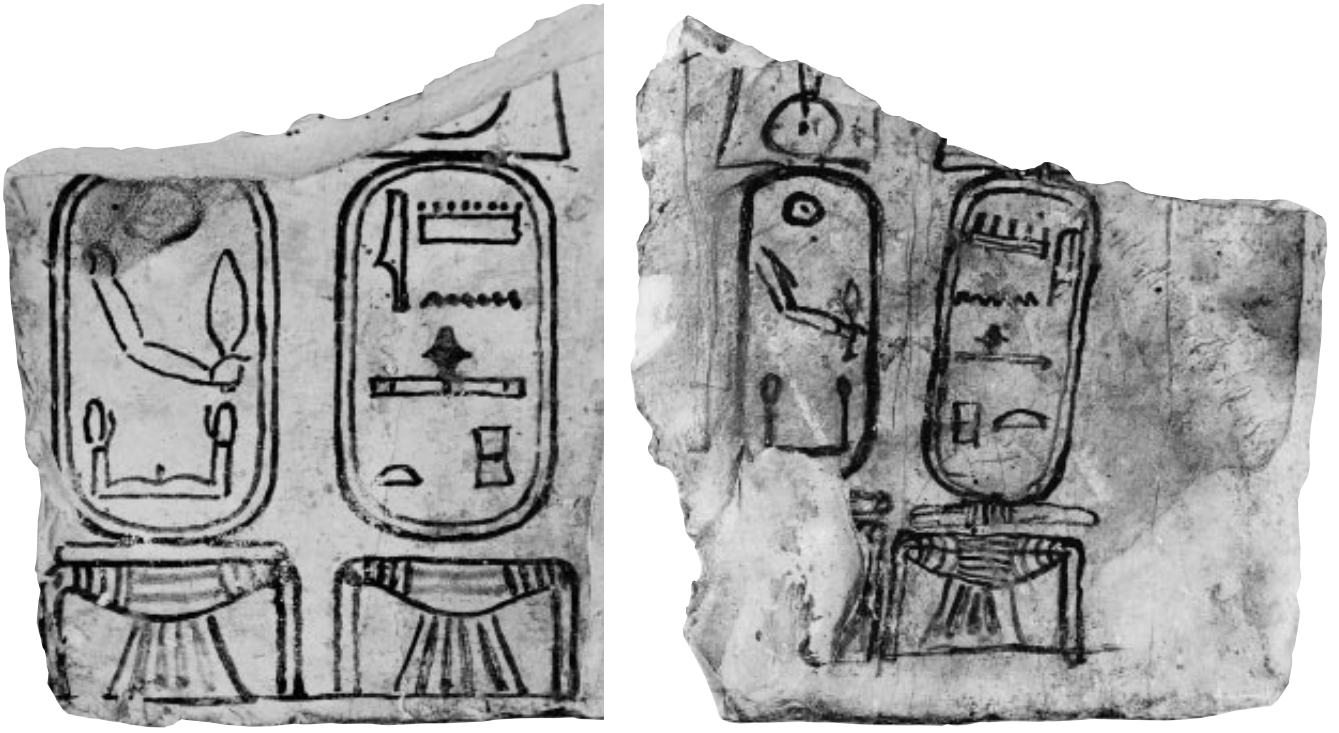
The courier goes into the desert,
Leaving his goods to his children;
Fearful of lions and Asiatics,
He knows himself [only] when
he's in Egypt.
When he reaches home at night,
The march has worn him out;
Be his home of cloth or brick,
His return is joyless.

Translation by Miriam Lichtheim, from *Ancient Egyptian Literature I* (University of California Press, 1973)

Student's copy of excerpt

The courier goes into the desert,
Leaving his goods to his children;
Fearful [of] lions and Asiatics,
What is it when he's in Egypt?
When he reaches home distressed,
The journey has divided him.
While he comes forth [from] his
cloth [or] brick,
He will not come it in joy.

—Third month of winter season, day 1



MEDELHAVSMUSEET, MUSEUM OF MEDITERRANEAN AND NEAR EASTERN ANTIQUITIES, STOCKHOLM

TEACHER'S EXAMPLE of the cartouches of King Amenhotep I was drawn with a confident hand on one side of this ostracon (*left*). A student then turned over the ostracon and made a copy (*right*), in the process reversing some of the signs.

the grueling task of carving the tomb out of the mountainside were also literate, even though their job did not call on such skills. Ambition may have motivated these laborers: education and literacy offered the keys to a good career in Egypt, separating the artisan class from the peasants, and the skills would have stood the workers in good stead had there been no job for them among the tomb builders. In addition, the culture of learning in the village may have also been a powerful stimulus, encouraging young people to study to keep up with their peers.

Egyptologists can glean numerous details from the ostraca found in Deir el-Medina, but unfortunately, we still know little of how the residents actually learned to read and write. Egyptian texts of the New Kingdom refer to schools only incidentally, indicating that they existed and that relatively young children attended them. For example, a short story found in the village describes the experiences at school of its young hero, a boy whose mother is not married:

> He was sent to school and learned to write very well. He practiced all the arts of war and he surpassed his older companions who were at school with him. Then his companions said to him: "Whose son are you? You don't have a father!" And they reviled him and mocked him: "Hey, you don't have a father!"

But scholars have no evidence for an actual school at Deir el-Medina—no textual references to a school building, no structure that looks like a schoolroom,

EGYPTIAN MUSEUM, LEIPZIG UNIVERSITY

OVENS for baking stood in the kitchen areas behind the houses in Deir el-Medina. In this sketch, the words "blowing into the oven" can be seen in the text to the left of the woman.

and no concentrations of student exercises that might signify a teaching area. In fact, we have no clues about how the workmen's children learned their primary skills of reading and writing.

Some of the ostraca left behind do give a somewhat more complete picture of what could be called secondary education—additional training in reading, writing and culture. Many of the documents found in the village are obviously exercises for advanced students, occasionally signed with the names of the student and teacher. Some of the writings bear a date marking the end of a day's lesson; some texts include several such dates, suggesting that a student used a single ostracon for several lessons.

From the various signatures on the ostraca, it is clear that fathers or grandfathers often supervised their sons' or grandsons' education, although on some occasions, fathers—even literate ones—might send their sons to someone of a higher rank for advanced training. (One signature, unfortunately badly preserved, may be a female student's, so at least one woman might have received her education in this fashion.) Pupils would have been from any station in life, including not only the future leaders of the community but also some boys who would never rise above the rank of stonecutter. Teachers consistently came from higher classes, however: the instructors mentioned in the ostraca were primarily scribes, draftsmen or chief workmen.

The students seem to have fit their lessons around their jobs at the tomb, as indicated by the dates in the ostraca—for example, texts often contain multiple dates separated by several days, indicating that there was usually time between lessons when both the instructor and pupil were presumably at work. Nevertheless, there was plenty of time for learning. Workers had many days off, especially as the tomb neared completion toward the end of a pharaoh's reign. During the final stages of construction, they might spend no more than one day out of four in the Valley of the Kings.

FRENCH INSTITUTE OF EASTERN ARCHAEOLOGY, CAIRO

STUDENT'S DRAWING of a royal portrait on this ostracon has been corrected in white by his teacher. In Deir el-Medina, young men had individual tutors who educated them in reading, writing and culture.

The education system in Deir el-Medina differed from that in other cities and towns around Egypt, most notably in who learned to read and write. Furthermore, the writing materials used and the time available for instruction also stand in contrast to practices elsewhere. Student exercises found in other locations were composed on reused papyrus—readily available to those in official positions—and appear to be the handiwork of young apprentices who were being groomed for government service. These students pursued their studies daily and managed to complete several pages of papyrus a day.

Although some aspects of the schooling system in Deir el-Medina diverged from the typical approach to education, the residents of the village apparently agreed with widespread notions about what should be taught and why. Teachers in this workmen's village might train stonecutters in between days on the job, writing on flakes of limestone (the material most available to them), but they still instructed their students in the great classics of Egyptian literature, with the goals of passing on wisdom and ensuring a successful career. As one village scribe wrote to a young pupil: "Set your heart very firmly on writing, a useful profession for the one who does it. Your father had hieroglyphs, and he was honored in the streets." SA

The Author

ANDREA G. McDOWELL began her study of Deir el-Medina while working on her Ph.D. in ancient history at the University of Pennsylvania. She was a lecturer at Leiden University, junior research fellow at Somerville College at the University of Oxford and an assistant professor of Egyptology at Johns Hopkins University before moving to Yale University, where she is now a student in the law school. McDowell is also working on a book about Deir el-Medina, tentatively scheduled for release next fall.

Further Reading

A Community of Workmen at Thebes in the Ramesside Period. Jaroslav Černý. French Institute of Eastern Archaeology, Cairo, 1973.

Commodity Prices from the Ramessid Period: An Economic Study of the Village of Necropolis Workmen at Thebes. Jac. J. Janssen. E. J. Brill, Leiden, 1975.

The Tomb-Builders of the Pharaohs. Morris Bierbrier. British Museum Publications, London, 1982.

Letters from Ancient Egypt. Translated by Edward F. Wente. Edited by Edmund S. Meltzer. Scholars Press, 1990.

Why Freud Isn't Dead

by John Horgan, *senior writer*

The anxiety is palpable. Fifty or so psychoanalysts have gathered in a ballroom at New York City's Waldorf-Astoria Hotel to discuss what one of them calls "the survival issue," meaning their rapidly declining status in the mental-health field and in the culture at large. One analyst complains that his daughter's college catalogue does not list a single course on Sigmund Freud, who founded psychoanalysis a century ago. Another expresses amazement that psychoanalysis "has managed to get so many people so angry and to get itself so marginalized in such a short period of time." "Maybe it's time for me to retire," sighs a therapist from southern California having trouble enlisting new patients.

Some paranoiacs, the old joke goes, really do have enemies. Freud's ideas have been challenged since their inception, but in the 1990s the criticism has reached a crescendo. Every year yields more books, such as *Why Freud Was Wrong* and *Freudian Fraud*. Last year the Library of Congress postponed an exhibit on Freud until at least 1998 after protesters—including Freud's own granddaughter—complained that it was too hagiographic.

Market forces are also threatening psychoanalysis. Of the roughly 15 million people in therapy in the U.S., few have the time or money for a treatment that typically lasts years and calls for as many as five one-hour, $100 sessions a week. Many patients—and all health insurers—favor short-term psychotherapies that target specific problems rather than delving deeply into a patient's past. Two popular approaches are cognitive-behavioral therapy, which seeks to alter unwanted habits of thought and behavior, and interpersonal therapy, which focuses on patients' current relationships with others.

Meanwhile psychiatrists and other M.D.'s are increasingly prescribing medication rather than "talk therapy"—a term that embraces both analysis and all other psychotherapies—for such common ailments as depression and anxiety. Sales of the antidepressant fluoxetine hydrochloride, whose brand name is Prozac, have more than doubled in the past two years, and more than 20 million people worldwide are now taking the drug, according to its manufacturer, Eli Lilly.

Given all these trends, it seems fair to ask, as *Time* magazine did on its cover three years ago, "Is Freud Dead?" Not quite. The meeting at the Waldorf-Astoria provided evidence of that. Some 400 members of the American Psychological Association's psychoanalysis division assembled this past April to trade insights about incest, alcoholism, obesity, obsessive-compulsive disorder and other afflictions. Relatively few of the 75,000 social workers, 60,000 psychologists and 40,000 psychiatrists in the U.S. call themselves psychoanalysts. Still, membership of the American Psychoanalytic Association, which is based in New York City and is the largest society for analysts, has remained surprisingly steady over the past decade at about 3,000. Moreover, the vehement attacks on Freud—which are met with equally vigorous defenses—demonstrate the astonishing vitality of the Viennese neurologist's ideas.

The Phlogiston Era

So the real question is this: Why is Freudian theory still alive? One explanation may be that his oeuvre, in spite of its flaws, still represents a compelling framework within which to ponder our mysterious selves. Freud's view of human nature "hasn't been matched by any other theory," asserts Peter Gay of Yale University, author of the admiring biography *Freud: A Life for Our Time* (W. W. Norton, 1988). Even such prominent critics as Adolf Grünbaum, a philosopher at the University of Pittsburgh, acknowledge the continuing allure of Freud's ideas. "I wouldn't work hard on a critique of psychoanalysis if I didn't think there was anything in it," he says.

To be sure, specific Freudian hypotheses, such as the Oedipal complex and female penis envy, have fallen out of favor even among psychoanalysts. "There are very few analysts who follow all of Freud's formulations," notes Morris Eagle, president of the psychoanalysis division of the American Psychological Association and a professor at Adelphi University in Garden City, N.Y. Nevertheless, psychotherapists of all stripes still tend to share two of Freud's core beliefs: One is that our behavior, thoughts and emotions stem from unconscious fears and desires, often rooted in childhood experiences. The other is that with the help of a trained therapist, we can understand the source of our troubles and thereby obtain some relief.

But there is an even more important reason for the persistence of Freud's legacy, and psychoanalysis in particular. Freudians cannot point to unambiguous evidence that psychoanalysis works, but neither can proponents of more modern treatments, whether Jungian analysis, cognitive-behavioral therapy or even medications. Indeed, claims about the "wonder drug" Prozac notwithstanding, numerous independent studies have found that drugs are not significantly more effective than "talking cures" at treating the most common ailments for which people seek treatment, including depression, obsessive-compulsive disorder and panic attacks.

The anti-Freudians argue, in effect, that psychoanalysis has no more scientific standing than phlogiston, the ethereal substance that 18th-century scien-

THE FATHER OF PSYCHOANALYSIS endures in spite of challenges from purveyors of alternative therapies.

Skeptics continue to challenge Sigmund Freud's ideas about the mind. Yet no unquestionably superior theory or therapy has rendered psychoanalysis completely obsolete

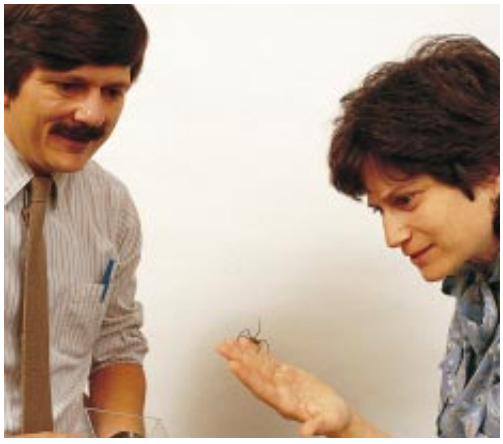
COMPUTER COMPOSITION BY SLIM FILMS; CORBIS-BETTMANN (*photograph*)

Treatments for the Mind: A Lack-of-Progress Report

STEPHEN FERRY *Gamma Liaison*

PSYCHOANALYSIS, which delves into childhood experiences, generally requires three or more sessions a week. No controlled studies of its effectiveness have been conducted.

COGNITIVE-BEHAVIORAL therapy seeks to alleviate specific disorders, such as phobias, through modification of thought and behavior. Although it is increasingly popular, controlled studies have not conclusively demonstrated its superiority to other treatments.



SHAHN KERMANI *Gamma Liaison*

tists thought gave rise to heat and fire. But the reason scientists do not still debate the phlogiston hypothesis is that advances in chemistry and thermodynamics have rendered it utterly obsolete. A century's worth of research in psychology, neuroscience, pharmacology and other mind-related fields has not yielded a medical paradigm powerful enough to obviate Freud once and for all.

Will scientists ever get past the phlogiston era and create a truly effective treatment for the mind? Jerome D. Frank has his doubts. In his seminal 1961 book *Persuasion and Healing,* the psychiatrist contended that the theoretical framework within which therapists work has little or nothing to do with their ability to "heal" patients. That power stems, rather, from the therapist's ability to make patients believe they will improve. In other words, Frank explains, the placebo effect is the primary active ingredient underlying all psychotherapies and even most drug treatments.

"I do think my views have been borne out," says Frank, now a professor emeritus at the Johns Hopkins University School of Medicine. Frank questions whether science can demonstrate the efficacy—or lack thereof—of psychotherapy, because science cannot pinpoint or measure the qualities that enable a particular therapist to induce the placebo effect in a particular patient. He is therefore bemused by the persistence of the attacks on Freud. "People have been attacking Freud because he wasn't a scientist, but that misses the point. He was a great mythmaker."

Freud-bashing is hardly a novel pastime. The eminent philosopher Karl Popper carped more than 60 years ago that psychoanalysis—derided by one wag as "the treatment of the id by the odd"—was unfalsifiable and therefore unscientific. But Freud was such a dominant figure during the first half of this century, not only within the mental-health community but throughout Western culture, that he and his followers could shrug off such complaints. "Freud turned his back on the whole problem" of empirical testing, says Frederick Crews, a professor emeritus of English at the University of California at Berkeley who has excoriated Freud and his modern descendants in a series of articles in the *New York Review of Books*.

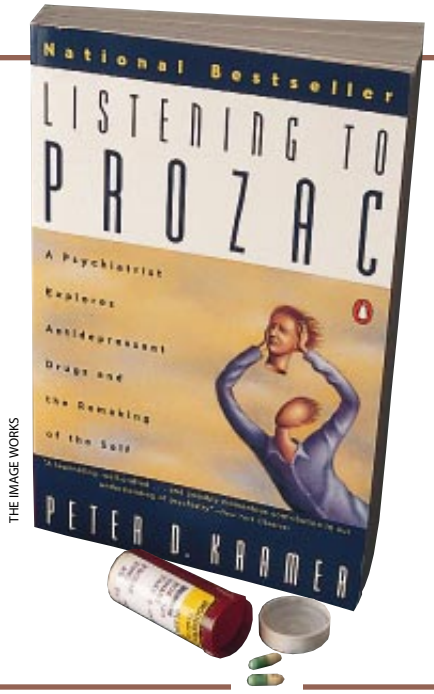
All Must Have Prizes

Only in the 1950s did half a dozen prominent psychoanalytic institutes in New York, Chicago, Boston and elsewhere begin gathering data on patient outcomes. The results, which involved more than 600 patients, were reviewed in an article in the 1991 *Journal of the American Psychoanalytic Association* (Vol. 39, No. 4) by a group led by Henry Bachrach, a clinical professor of psychiatry at the New York Medical College at Saint Vincents Hospital.

The authors concluded that from 60 to 90 percent of the patients studied had showed "significant" improvement as a result of psychoanalysis. Bachrach and his colleagues acknowledged that the studies were not ideal: investigators admitted only those patients thought likely to benefit from psychoanalysis, a common practice; the assessments of patients' responses were made by their therapists, who might be inclined toward reporting positive outcomes; and there was no control group. But these weaknesses "were no greater than in comparable research about other forms of psychotherapy," Bachrach's team asserted at the 1992 meeting of the American Association for the Advancement of Science.

Indeed, most "outcome" studies supporting alternative talk therapies have also been flawed, according to Robyn M. Dawes, a psychologist at Carnegie Mellon University. In his 1994 book *House of Cards: Psychology and Psychotherapy Built on Myth* (Free Press), Dawes presents a scathing critique not just of psychoanalysis but of all talk therapies. The methods that therapists employ for diagnosing patients and assessing their progress are highly subjective and variable, Dawes charges. He also maintains that therapists' training and mode of therapy have no correlation with patients' outcomes.

Dawes still thinks psychotherapy can work, especially when directed toward specific problems. For example, some reports have indicated that cognitive-behavioral therapy is the best available treatment for panic disorder, a condition marked by extreme, unwarranted fear. But this claim is not corroborated by a rigorous, controlled study carried out recently by M. Katherine Shear, a psychiatrist at the University of Pittsburgh, and three colleagues.



THE IMAGE WORKS

MEDICATIONS such as Prozac have become the most common treatment for depression and other emotional disorders, but they have not been shown to be more effective than talk therapies.

W&D McINTYRE *Photo Researchers*

ELECTROCONVULSIVE therapy is increasingly prescribed for intractable depression, although it can cause memory loss. Moreover, relapse rates reportedly run as high as 85 percent.

For one group of patients, Shear's team provided 12 sessions of standard cognitive-behavioral therapy, which called for physical and mental exercises designed to help patients control their panic. In the sessions of the control patients, therapists provided only "reflective listening." Both sets of patients responded equally well. These data, Shear and her colleagues concluded in the May 1994 *Archives of General Psychiatry,* "raise questions about the specificity of cognitive-behavioral treatment."

The investigations of Shear, Dawes and others corroborate the so-called Dodo hypothesis, first set forth in a classic 1975 paper by the psychologist Lester B. Luborsky and two colleagues. The status of all psychotherapies, Luborsky and his co-authors proposed in the *Archives of General Psychiatry,* could be summed up by the proclamation of the Dodo overseeing a footrace in *Alice's Adventures in Wonderland:* "*Everyone* has won, and *all* must have prizes!"

Luborsky, a professor of psychiatry at the University of Pennsylvania, says he has just completed a review of more recent efficacy studies, and he is more convinced than ever that the Dodo hypothesis is correct. "There is a huge amount of evidence that psychotherapy works," he emphasizes, but no evidence "across a broad range of samples" that any one mode is superior. Luborsky has also found evidence for what he calls the "allegiance effect," the tendency of researchers to find evidence favoring the therapy that they practice.

Of course, another interpretation of the Dodo hypothesis is that everyone has *lost,* and *none* must have prizes. That is the conclusion of E. Fuller Torrey, a psychiatrist associated with the National Institute of Mental Health in Washington, D.C. In *Freudian Fraud* (HarperCollins, 1992), Torrey blasted psychoanalysis and all other talk therapies as pseudoscience. Freud's ideas took hold not because of their scientific merits, he contends, but because they meshed with the notion—popular among many left-leaning intellectuals—that human nature is highly malleable.

Torrey disputes the underlying assumption of all talk therapies—that the human psyche is shaped by childhood experiences and can be reshaped through psychotherapy. The evidence is overwhelming, he says, that an individual's personality is determined primarily by genes and other physiological factors. Torrey is confident that sooner or later, drugs, gene therapy and other biological remedies will render talking cures obsolete. In the meantime, he argues, psychotherapy should be excluded from health care coverage.

Torrey's outlook is merely an extreme version of what has become the dominant paradigm within the mental-health community. That was apparent at the annual conference of the American Psychiatric Association held this past May. The contrast between this gathering and the relatively tiny psychoanalysis meeting held at the Waldorf-Astoria Hotel was dramatic: more than 15,000 psychiatrists and other mental-health workers assembled in New York City's gigantic Jacob K. Javits Convention Center.

By far the best-attended sessions were breakfasts and dinners sponsored by the drug companies, during which hundreds of psychiatrists heard talks about the benefits of Prozac for obsessive-compulsive disorder and of Zoloft, another so-called selective serotonin reuptake inhibitor, for depression. Sessions on talk therapy were, in comparison, sparsely attended. One entitled "The Future of Psychotherapy" drew only about 20 people. "At this point, I don't think the future of psychotherapy is very good," lamented Gene L. Usdin, a psychiatrist from the Ochsner Clinic in New Orleans.

Drug Trials on Trial

But in an indication that drugs are not the panacea they are sometimes perceived to be, several sessions of the psychiatry meeting were also dedicated to electroconvulsive "shock" therapy. The practice declined in popularity over the past few decades, especially after being depicted as a form of torture in the 1975 movie *One Flew over the Cuckoo's Nest.* But technical improvements have reportedly reduced its major side effect—severe memory loss—and it is now quietly making a comeback as a treatment for patients who suffer from severe depression, schizophrenia and other disorders and who do not respond to drugs.

Indeed, some researchers have challenged the notion that medications represent a great step forward in the treatment of mental illness. The only drug treatments "unambiguously" proved to

be superior to talk therapy, contends Martin E. P. Seligman of the University of Pennsylvania, president-elect of the American Psychological Association and an authority on efficacy research, are lithium for manic-depression and tranquilizers such as clozapine for schizophrenia. There is "simply no evidence," he remarks, that Prozac and other drugs are superior to talk therapies for more common disorders, such as depression and obsessive-compulsive disorder.

Seligman's view has been corroborated by three other psychologists, David O. Antonuccio and William G. Danton of the University of Nevada School of Medicine and Garland Y. DeNelsky of the Cleveland Clinic Foundation. In the December 1995 issue of *Professional Psychology,* they presented the results of a meta-analysis of dozens of studies of drugs and psychotherapy. The group concluded that "psychological interventions, particularly cognitive-behavioral therapy, are at least as effective as medication in the treatment of depression, even if severe."

Two vociferous critics of the growing use of antidepressants are Seymour Fisher and Roger P. Greenberg, both psychologists at the State University of New York Health Science Center at Syracuse. Fisher and Greenberg have written extensively on Freud's theories, most recently in *Freud Scientifically Reappraised,* published this year by John Wiley & Sons. But they are best known for contending in their 1989 book *The Limits of Biological Treatments for Psychological Distress* (Lawrence Erlbaum) and in numerous articles that antidepressants are not nearly as effective as advertised.

After analyzing studies of antidepressants conducted over the past 30 years, they concluded that two thirds of the patients placed on medication either showed no improvement or responded equally well to a placebo as to the antidepressant; drugs produced significantly superior outcomes in only one third of patients. The studies also showed that the effects of medication wane for many patients after the first several months, and those who discontinue treatment have high relapse rates.

Depressing Results

The most serious claim Fisher and Greenberg make is that many ostensibly controlled, double-blind studies of antidepressants are actually biased in favor of showing positive effects. Such studies usually provide the control group with an inert placebo. But because all antidepressants usually cause side effects—such as dry mouth, sweating, constipation and sexual dysfunction—both patients and physicians can often determine who has received the drug, thus triggering an expectation of improvement that becomes self-fulfilling.

To avoid this problem, some drug trials have employed placebos that produce side effects resembling those of the antidepressant, such as dry mouth or sweating. (Atropine, which is often prescribed for motion sickness, is a common substitute.) These studies generally find much less difference between the antidepressant and the placebo than do studies in which the placebo is inert, Fisher and Greenberg note.

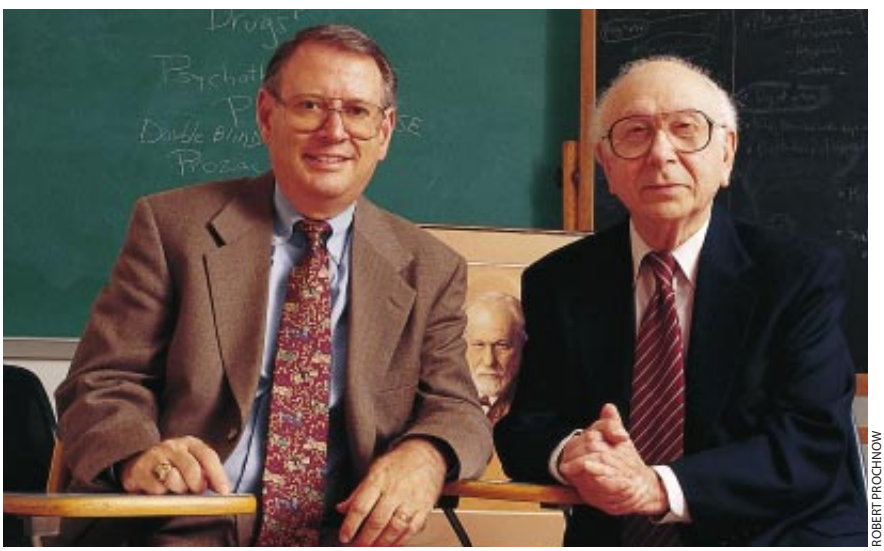
Other effects may also skew results, the authors argue. For example, during the course of a study many patients drop out because of unpleasant side effects, an unwillingness to conform to the protocol of the study or other problems. Moreover, investigators seeking subjects for a study often exclude those who seem too inarticulate or disorganized or whose depression is accompanied by other physical or mental ailments. In an overview of their findings in the September/October 1995 issue of *Psychology Today,* Fisher and Greenberg concluded that "most past studies of the efficacy of psychotropic drugs are, to unknown degrees, scientifically untrustworthy."

The findings of Fisher and Greenberg have been roundly faulted by psychiatrists, who contend that as psychologists—who cannot prescribe drugs—they are biased in favor of psychotherapy and against medication. But the assertion that the placebo effect might explain much of the effectiveness of medications for emotional disorders has been supported by Walter A. Brown, a psychiatrist at Brown University and an authority on the placebo effect.

It is a tenet of medical lore, Brown elaborates, that patients respond better to new drugs than to older, more established ones. The phenomenon is summed up in a doctor's dictum that dates back to the last century: "Use new drugs quickly, while they still work." The introduction of a novel drug, Brown explains, often generates high hopes among both patients and physicians and thus induces a strong placebo effect; over time, as the drug's novelty fades and its side effects and limitations become more apparent, it becomes less effective.

Unfortunately, neither psychotherapy nor antidepressants are terribly effective at treating depression, according to an ambitious study initiated by the National Institute of Mental Health almost 20 years ago. Called the Treatment of Depression Collaborative Research Program, it involved 239 depressed patients treated at three different hospitals with one of four different methods: cognitive-behavioral therapy; interpersonal therapy; the antidepressant imipramine plus "clinical management," a brief weekly consultation with the drug-dispensing physician; and clinical management with a placebo pill.

The study, the results of which were



ROBERT PROCHNOW

DRUG CRITICS Seymour Fisher (*right*) and Roger P. Greenberg of the State University of New York Health Science Center at Syracuse charge that antidepressant drug trials may be biased toward producing positive results in patients.

released in 1989, has been subjected to second-guessing almost since its inception. Earlier this year, in the *Journal of Consulting and Clinical Psychology* (Vol. 64, No. 1), the psychologist Irene Elkin of the University of Chicago and three colleagues reviewed the data in "Science Is Not a Trial (But It Can Sometimes Be a Tribulation)." The findings were not encouraging, the researchers admitted.

Some severely depressed patients, especially those who were functionally impaired, responded better to imipramine than to the psychotherapies. But for the majority of patients, there was little or no significant difference between any of the treatments, including the placebo-plus-clinical-management approach. Only 24 percent of the patients were judged to have recovered and not relapsed for a sustained period. "Although many people improved," Elkin says, "if you look at the total picture, at the number of people who got significantly better and stayed well, that number is low."

DODO hypothesis—that all mental-health therapies are roughly equal—alludes to the Dodo in Lewis Carroll's *Alice's Adventures in Wonderland*, who tells racers, "*Everyone* has won, and *all* must have prizes!"

One increasingly popular view in mental-health circles is that psychotherapy and drugs can work best in tandem. A notable advocate of this idea is Peter D. Kramer, a psychiatrist at Brown and author of the 1993 best-seller *Listening to Prozac* (Penguin). Although the book is often described as a prodrug, antipsychotherapy tract, Kramer calls himself "a psychotherapist at heart" who thinks drugs can enhance the effects of talk therapy, and vice versa. In the future, he says, "there will be something called psychotherapy that will subsume psychotherapy as it is currently practiced and psychopharmacology."

But the view that psychotherapy-plus-drugs can be more effective than psychotherapy alone was undermined by a survey carried out recently by *Consumer Reports*. The magazine—published by the Consumers Union, a nonprofit group based in Yonkers, N.Y.—asked readers about their experiences seeking help for emotional difficulties. The magazine released the results of its survey, to which 4,000 readers responded, in the November 1995 issue.

The survey had much to comfort talk therapists. Most readers said they had been helped by psychotherapy; in addition, the longer they remained in therapy, the more they felt they had improved. Some observers worried that this finding might reflect the tendency of certain patients to become "therapy addicts." Nevertheless, the American Psychological Association immediately began using the finding to criticize the practice of health insurers to place strict limits on the duration of talk therapy.

A Unified Science of Mind

Psychologists were also delighted that readers who received psychotherapy alone seemed to fare as well as those getting talk therapy in conjunction with drugs such as Prozac. The *Consumer Reports* survey "has provided empirical validation of the effectiveness of psychotherapy," declared Seligman, president-elect of the psychology association, in the December 1995 issue of *American Psychologist*. He acknowledged that the survey had some methodological weaknesses. But these flaws were no more severe than those of more formal comparison studies, he asserted.

On the other hand, the survey also lent support to the Dodo hypothesis. All the therapies seemed to be equally effective—or ineffective. Respondents reported the same degree of satisfaction whether they were treated by social workers, who require only a master's degree; psychologists, who need a doctorate; or psychiatrists, who must complete medical school. Only marriage counselors scored lower than the norm. But readers reported more satisfaction with Alcoholics Anonymous than with any of the mental-health professionals or medications.

Optimists hope that in years to come, the sciences of the mind will coalesce around a new, more powerful paradigm, one that will transcend the schisms—nature versus nurture, drugs versus talk therapy—now rending the mental-health community. One proponent of such a shift is Steven Hyman, a psychiatrist and neuroscientist at Harvard University who was appointed director of the National Institute of Mental Health this past spring. "From the point of view of people who think about the brain and mental health, the traditional dichotomies are simply false," he declares.

Research has shown that traumatic experiences can change the way the brain works, as can talk therapy, Hyman notes. As evidence, he cites an article in the February 1996 *Archives of General Psychiatry* about patients who received cognitive-behavioral therapy for obsessive-compulsive disorder; positron-emission tomography showed that their brains had undergone changes similar to those induced by medication in other obsessive-compulsive patients.

Hyman is confident that genetics, brain imaging and other fields will generate new insights into and treatments for mental illness. Yet he describes himself as an "equal opportunity skeptic," who views not only Freudian theory but also some of the new biological explanations of mental illness as merely "good stories" still lacking empirical substantiation. "We are not going to clone the next serotonin receptor and say we understand the brain," he remarks.

That scholars still debate Freud's ideas, Hyman adds, suggests that science's grasp of the mind is still rather tenuous; after all, experts on infectious diseases do not debate the validity of Louis Pasteur's ideas. "In mature scientific fields," he notes, "one usually doesn't look at writings more than three or four years old." Freud, it seems, may be with us for some time to come. SA

To obtain a poster of "Freud Endures" (page 107), please see page 36.

by Shawn Carlson

Dissecting the Brain with Sound

In the summer of 1893 Arthur Nikisch, then Europe's premiere conductor, popped in on the legendary composer Pyotr Ilich Tchaikovsky to talk a little shop. According to Nikisch's assistant, Richard Lert, we know only one thing for sure about their get-together: Nikisch didn't like the way Tchaikovsky had scored the finale of his Sixth Symphony (the *Pathétique*), and he adamantly wanted the maestro to change it.

The contentious passages were certainly unorthodox. Tchaikovsky alternated the main theme and accompaniment between the first and second violin sections; as a result, each section played every other note of each theme. Nikisch wanted Tchaikovsky, who was preparing the piece for public debut, to rescore the movement so that the first violins would play the main theme alone, and the second violins would play only the accompaniment.

No one knows why Nikisch opposed Tchaikovsky's score so intensely. He may have rehearsed the *Pathétique*, and it's tempting to believe that he did. If so, Nikisch's musical ire might have been aroused by a peculiar and newly discovered facet of human perception.

The odd score hardly affects a listener today, because the first and second violins sections sit together; the listener hears both themes coming from the same region of the orchestra. But 100 years ago orchestras were arranged differently. The first violins sat on the conductor's left, and the second violins on the conductor's right. Standing in the center, Nikisch may have felt as if he were being battered from both sides by two disjointed sets of sounds that did not integrate into a harmonious whole.

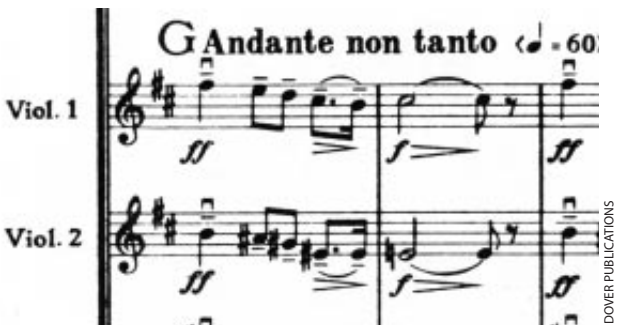
I say "may have felt" because (here's that peculiar facet of perception) people don't all hear music in precisely the same way. In fact, according to Diana Deutsch, a professor of psychology at the University of California at San Diego, how we perceive certain sound patterns depends on our native language and whether we are right- or left-handed. Even our dialect matters: people brought up in California tend to hear certain sound patterns quite differently from those reared in England, for example.

The *Pathétique*'s contentious measures are an example of this kind of pattern. Most people's brains blend the violins' voices into Tchaikovsky's intended melodies. Nikisch's singular genius for conducting, however, suggests an extraordinary precision at discerning patterns in sound. He may have objected to the score because his ear was not fooled by the illusion.

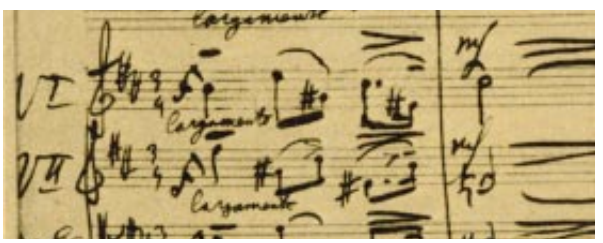
Today these mysterious illusions can serve as sonic scalpels for dissecting the brain and discerning some of its inner workings. Until now, only a handful of professional scientists have been able to wield them. But no longer. Deutsch has just created the first collection of audio illusions on compact disc. Skillfully narrated by Deutsch herself, "Musical Illusions and Paradoxes" will let you experience some striking sonic chicanery (Philomel Records, Box 12189, La Jolla, CA 92039-2189; telephone: 800-225-1228; fax: 619-453-4763; Web site http://www.philomel.com; $14.95 plus $4.95 shipping). What is more, armed with this CD, any amateur scientist can conduct original research on how the brain processes sound.

I recently visited Deutsch's laboratory and got to experi-

CORBIS-BETTMANN



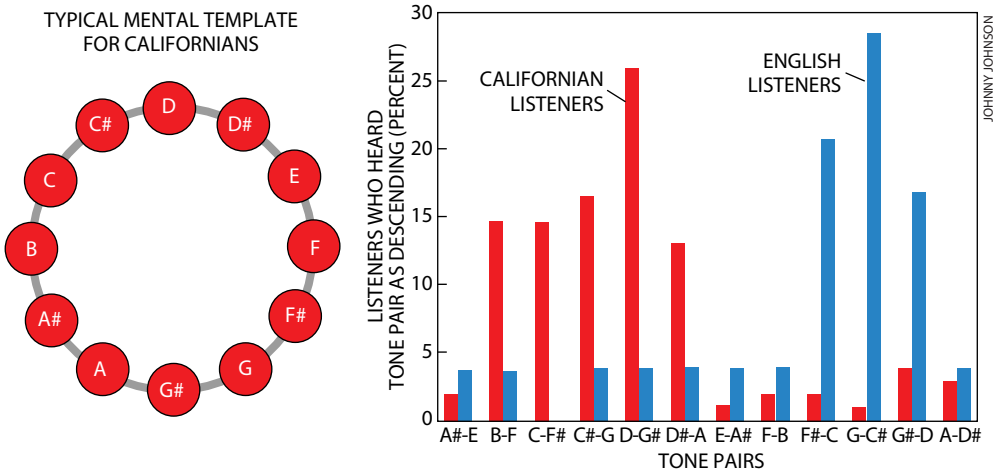
DOVER PUBLICATIONS



GLINKA MUSEUM, MOSCOW

CORBIS-BETTMANN

CONDUCTOR VERSUS COMPOSER: conductor Arthur Nikisch (top) *rescored part of the* Pathétique *so that the first violin plays F, E, D, C, B and the second plays B, A#, G#, E#, E. The original, by Tchaikovsky* (right), *shown in his own hand, has the first violin playing B, E, G#, C, E# and the second F, A#, D, E#, B. Nikisch's objection may have resulted from a peculiar aspect of the human perception of tones.*



RESULTS OF THE TRITONE PARADOX

suggest that people form a fixed mental template that places ambiguous musical tones (those without any octave information) in a circle. For Californians, ambiguous tones constructed from B, C, C#, D, D# tend to fall in the upper half of the circle, so that tone pairs B-F, C-F#, C#-G, D-G# and D#-A are heard as descending. For Britons, the opposite tends to be true.

ence these illusions firsthand. My initiation began with the octave illusion. Through stereo headphones, she played me a simple pattern: two notes one octave apart alternating from ear to ear so that when the higher note was played in my right earphone, the lower note appeared in my left, and vice versa. But that's not at all what I heard. Rather I perceived a pattern that alternated between a single high note and a single low note with the high note always appearing in my right ear and the low note always appearing in my left.

This, Deutsch insists, makes me a typical right-hander. We righties tend to be dominated by the left hemispheres of our brain. Most of the signals from my right ear shoot over to my left hemisphere, where neurons decipher their pitch, and my weaker right hemisphere predominately processes signals from my left ear. Then, a separate bunch of neurons deciphers where sounds originate in space. These neurons tend to rely on frequency to localize sound and thus assign the source to whichever ear receives the higher pitch. That, coupled with my left hemisphere's dominance, creates the paradox: when the high pitch enters my left ear, I can't hear it at all, and I localize the pitch I do hear (the low pitch) in the wrong ear.

People with more equally balanced hemispheres than I have (most left-handers and some right-handers) hear the illusion differently. In fact, left-handers are equally likely to hear the higher tone in either ear and are twice as likely as right-handers to hear more complex patterns in which notes change pitch or the higher tone shifts from ear to ear.

Lowering the right earphone's volume decreases the stimulation inside the left hemisphere and thereby tilts the scales toward the right hemisphere. At some point, the illusion changes for even the most left-brained right-hander. The same trick might suddenly cause a hemisphere-balanced lefty to perceive the illusion (no one has tested the possibility yet). The difference in volume between the two earphones required to change the subject's perception provides a measure of hemispheric dominance.

Volume control is in this way your first sonic scalpel. Set the level on the soft side. Adjust the balance knob on your stereo amplifier until the illusion just changes. Then using a sound meter (check your local Radio Shack store), measure the sound intensity in each earphone. Repeat the procedure several times and average the result. Plot a histogram of this average (see April's column for information about histograms) for about 30 righties (or lefties), and you will discover something fundamental about the way brains of right-handers (or left-handers) are structured.

Deutsch's so-called tritone paradox presents more research opportunities. The paradox uses computer-generated tones constructed from the same note (say, D); each tone effectively consists of all the same notes spanning five octaves played simultaneously [*see illustration on opposite page*]. The result is ambiguity: people perceive the tone as a D but disagree as to which octave it belongs. The paradox comes about when a second, similarly crafted tone is played immediately after the first. This second note lies half an octave, or one tritone, away—equivalent to a musical distance of six semitones (or six piano keys, including the black ones). So after the D tone is played, a G-sharp tone would follow. Because neither note has any octave information, there is no clear answer as to which note is higher in pitch. Some people insist that the G-sharp is lower than the D; others hear it as higher.

According to Deutsch, how people perceive this paradox depends on where they grew up. Californians tend to hear the illusion in a manner completely opposite to people from the south of England [*see illustration above*]. Further-

more, children tend to hear the paradox as their mothers do. Apparently, the dialect that one grows up hearing affects how the brain resolves these tones.

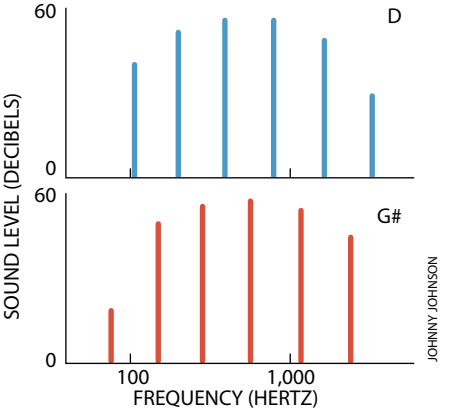
Actually, few data exist on this effect. How do folks from Maine, or Tennessee, or Nova Scotia, or South Africa respond? Do different generations show different responses? No one knows. By recording your friends' responses to the tritone paradox, you can make a real contribution to science.

My absolute favorite treat from Deutsch's CD is the high-low illusion. Deutsch first recorded the words "high" and "low." She then laid down a continuous stereo track in which the words alternate at a dizzying pace back and forth between the speakers. The result is a pattern that sounds like language, but the words are not quite recognizable.

Within a few seconds of listening to this strange cacophony, my brain started imposing a shifting order over the chaos as I began hearing distinct words and phrases. First came, "blank, blank, blank." Then "time, time, time." Then "no time," "long pine" and "any time." I was then astonished to hear a man's voice spilling out of the right speaker only. In a distinct Australian accent, it said, "Take me, take me, take me!"

This illusion suggests more avenues for exploration. See if your subjects' responses correlate with their beliefs or state of mind. That may reveal fresh insights into how attitudes affect our perceptions. Or measure how long it takes for your subjects to hear "play time" after you suggest it. Let me know what you find.

By the way, Tchaikovsky, who died a few months after the meeting, refused to give in. Nikisch rescored the contested passages anyway and thereby created a separate school of performance for this symphony. A few modern conductors still side with Nikisch and use his revision in their performances of Tchaikovsky's *Pathétique*.



***AMBIGUOUS TONE PAIRS** are made by combining several notes. Here D and G# tones that are ambiguous in octave each consist of six D and G# notes from other octaves (as measured in terms of frequency).*

The Society for Amateur Scientists, in collaboration with Diana Deutsch, has developed an experimenter's package to help amateur scientists contribute to this field. It includes the CD, a cassette tape to test perceptual ability, detailed instructions and data sheets that will enable you to conduct original experiments and even collaborate directly with Professor Deutsch. Send $24.95 plus $5 shipping to the Society for Amateur Scientists, 4951 D Clairemont Square, Suite 179, San Diego, CA 92117. Additional information can be found at http://www.thesphere.com/SAS/

by Ian Stewart

Cows in the Maze

Mazes are more common in serious mathematics than you might imagine. Any mathematical investigation, in effect, requires you to find a path through a maze of statements, with the path from each statement to the next being a valid logical deduction. A new kind of maze invented by Robert Abbott of Jupiter, Fla., called Where Are the Cows?, is both geometric and logical. It is taken from his new book *Supermazes* (Prima Publishing, Rocklin, Calif., 1996). (Some readers might recall Abbott as the inventor of the card game Eleusis, discussed by Martin Gardner in these pages in 1959 and 1977.)

Abbott's maze is based on a logical twist, that of self-reference. Self-referential statements cause headaches for logicians and philosophers. One instance is the paradox associated with Epimenides, a Cretan who declared that all Cretans are liars, which reduces to:

THIS STATEMENT IS FALSE.

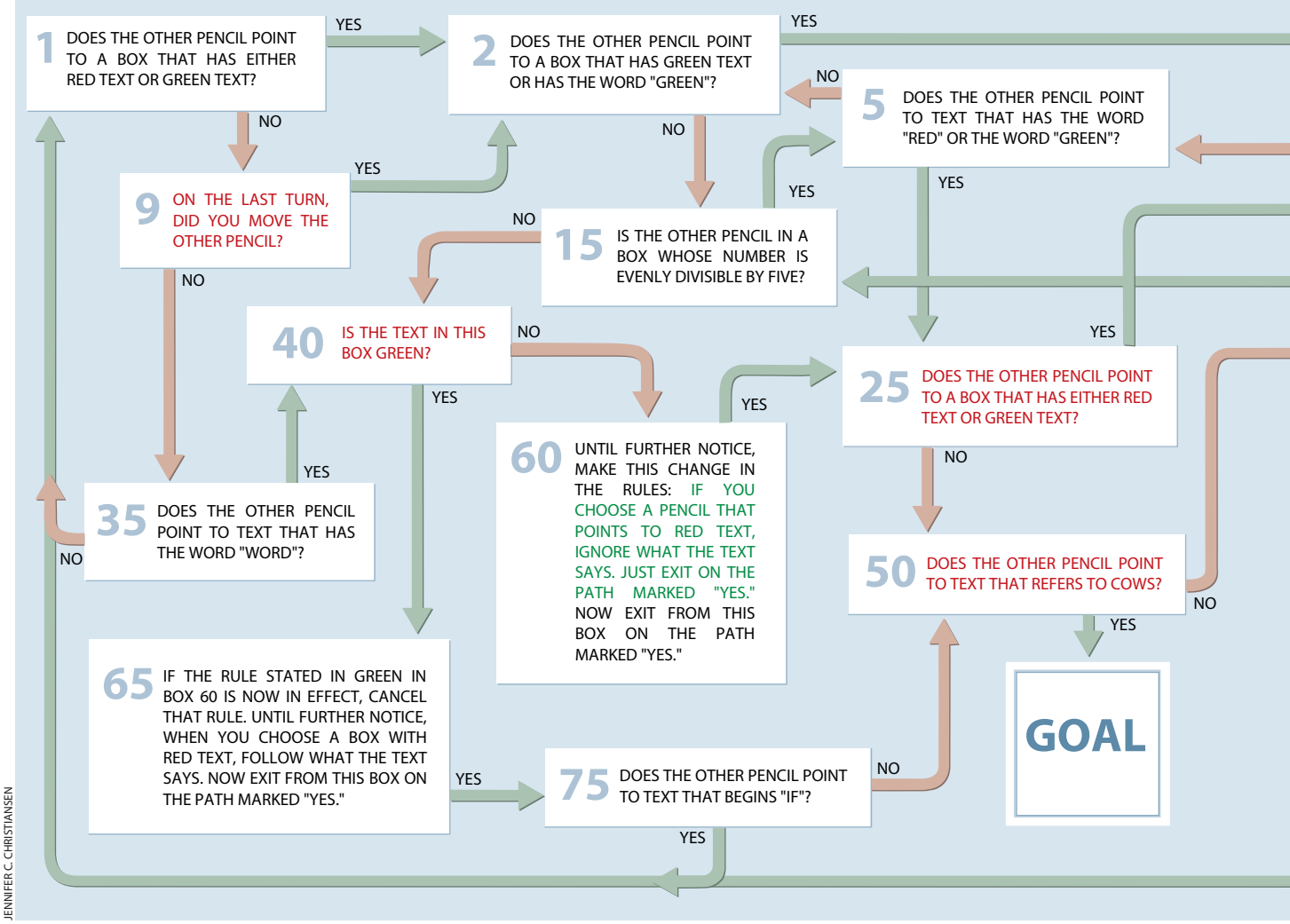
Well, is it, or isn't it? You're in trouble either way. And there are mutually referential statements like this, too:

THE NEXT SENTENCE IS TRUE.
THE PREVIOUS SENTENCE IS FALSE.

It's a logical minefield.

Self-reference is an important area of study for logicians. But the really important question (from my standpoint) is this: Can self-reference be used to bring more confusion to mazes? The answer, I am happy to report, is "yes."

Abbott's maze is shown in the figure below. Not only is the text self-referential, but the rules for the maze change according to how you move. In order to thread this maze, you need both hands, and it helps to hold a pencil or some other pointer in each to remind you where you are. To start, place one pencil on box 1 and the other on box 7. (The numbering on the boxes is not strictly sequential: that's deliberate.) Your objective is to make a series of moves so that at least one of the pencils ends up pointing to the box labeled GOAL. To make a move, choose one of



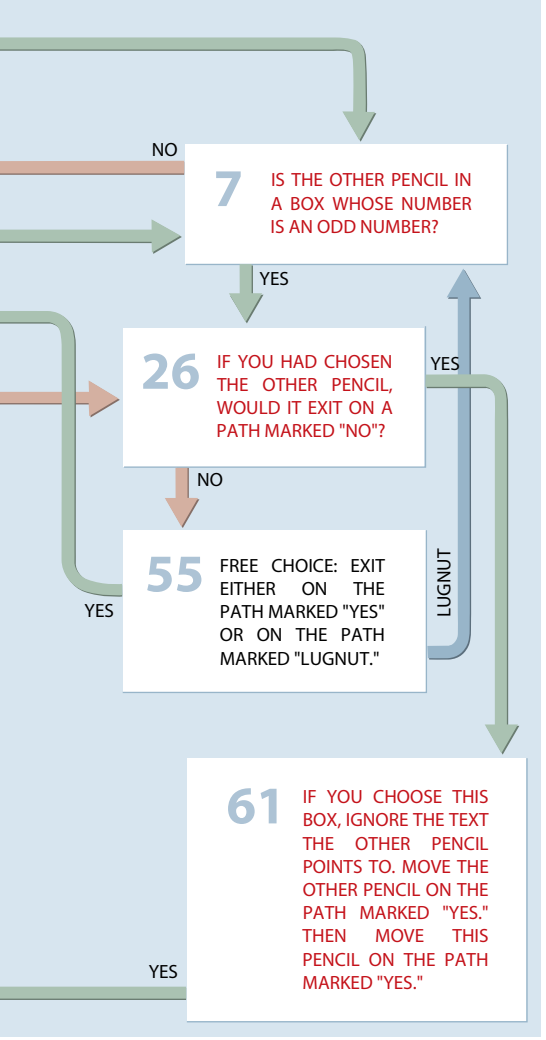
JENNIFER C. CHRISTIANSEN

the pencils, then follow the instructions in the box to which that pencil points. That's it. No other choices need be made, except when you follow the instructions in box 55.

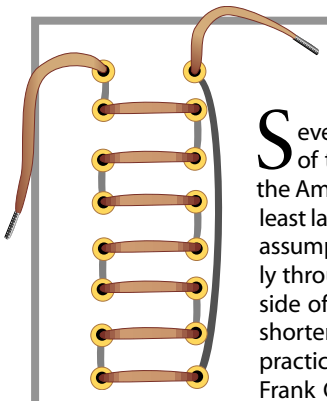
For example, suppose that your first choice is the pencil pointing to box 7. The answer to the box question ("Is the other pencil in a box whose number is an odd number?") is obviously "yes." So you must move the pencil in box 7 along the path labeled YES, which leads it to box 26.

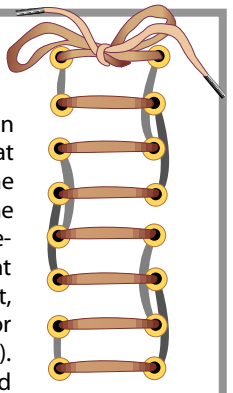
Easy? Just wait. Suppose you now choose the pencil in box 26. "If you had chosen the other pencil, would it exit on a path marked NO?" Hmm. The other pencil was (and still is) in box 1. If you had chosen that, then the question would have been "Does the other pencil point to a box that has either red

WHERE ARE THE COWS?
is a self-referential maze (having nothing to do with cows).



FEEDBACK





Several readers queried the conclusion of the July column, which stated that the American way of lacing shoes uses the least lace. Implicit in my treatment was the assumption that the lace passes alternately through the holes on the left and right side of the shoe. Without this constraint, shorter lacings are possible (although for practical reasons stronger lace is needed). Frank C. Edwards III of Dallas, Tex., found two shorter methods (*shown at left and right*) when n is even, both of length $(n-1)(g+2d)$. When $n=8$, $g=2$ and $d=1$, the length is 28, compared with 33.3 for American lacing.

The lacing depicted at the right was also sent in by Michael Melliar-Smith of Santa Barbara, Calif., Stephen Wallet of San Diego, Calif., and several others. Neil Isenor of Waterloo, Ontario, recalled being shown this method by an officer cadet roommate in the 1950s. William R. Read of Vancouver, B.C., told me that as an "infantryman during World War II, I was required to lace my boots" in the same manner, adding that the method was known as "Canadian straitlacing."

Maurice A. Rhodes of Nelson, B.C., traced the method back to the Scots, asking whether I had mislaid my ancestry. (Despite my name, the last Scottish ancestor I can trace is a great-great-great-grandfather, a sea captain by the name of Purves, who is buried in Canterbury Cathedral.) Rhodes explained that the same method was taught to air cadets at Canada's Royal Military Colleges in the late 1940s. And Donald M. Graham of Vancouver, B.C., informed me that his 10-year-old daughter, Nicole, invented the method for herself, the first time she had to put new laces in her sneakers. —*I.S.*

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text or green text?" Box 7 does contain red text, so the answer to the question in box 1 is "yes." So the pencil would have exited along the YES path. All of which means that the answer to the question in box 26 is "no." So the pencil in box 26 now moves along the NO path and ends up in box 55.

Phew.

Most of the boxes ask questions, and your exit path depends on the answer. Some boxes, however, work differently. Box 61 tells you to move both pencils, and the move is not completed until you have done that. Box 55 has an exit marked LUGNUT instead of the usual NO. This does make a difference—for example, if your other pencil points to box 26.

The truly drastic boxes are 60 and 65. Box 60 changes the rule for exiting a box with red text, replacing it with the rule "Just exit on the path marked YES," which I shall call rule 60. Box 65 undoes rule 60. It is possible to have one pencil pointing to box 60 and the other to box 65. Each box effectively tells you to ignore the other box. But that doesn't cause self-referential problems, because you have to choose which one to obey; you don't obey both at once.

Some of the instructions may appear ambiguous. For example, box 5 asks whether the other pencil points to text that has the word "red" or "green." If the other pencil points to box 1, the answer is clearly "yes." But what if it also points to box 5, which has quotes around the words "red" and "green"? Abbott's interpretation is that the quotes are irrelevant, and thus the answer is "yes." Also, box 50 asks whether the other pencil points to text referring to cows; the word "cows," however, does not appear in any other box. Of course, both pencils may point to 50, in which case you can exit to GOAL—unless you argue that box 50 does not refer to cows as such. Avoid philosophical nitpicking of this kind, or else you'll never solve the maze.

You may by now have convinced yourself that the only possible way to reach GOAL is to have both pencils at box 50. That would be true in the absence of box 60. If you can get a pencil to box 50 when rule 60 is in force, then no matter where the other one is, you're done. In fact, there is one other imaginable way to reach GOAL; can you find it?

The weirdest situation that could occur has both pencils pointing to box 26. There is no clear way to answer the question. So what happens? Cunningly, Abbott has built his maze so that both pencils can point to box 26 only when rule 60 is in force, in which case the text in box 26 is ignored! The same holds true if both pencils are pointing to box 61.

What you really ought to do now is have a go, without any further help. If you don't want to resort to brute force, you have several strategies. One is to look for key features of the maze. For example, in order to reach GOAL, you must have a pencil on box 50 and be in a situation for which the correct exit is YES. Another trick is to work backwards from a desired position.

Enjoy! SA

HINTS

If you've tried all the above and are still stuck, here are some suggestions:

- To get to GOAL, you must reach the position (50,50), in which both pencils point to box 50 and rule 60 is not in force. The other two strategies to finish cannot actually be realized.
- To reach (50,50), you must first get to (35,35). You are then 18 steps away from GOAL.
- To reach (35,35), you have to get to (61,75) and move the pencil to box 61. Then both pencils can be moved to box 1. From there it's easy to get to (35,35).
- There are lots of ways to get from the start (1,7) to (61,75). All of them require you to activate the box 60 rule and then cancel it again at box 65.

SOLUTION

In each pair below, the number in red designates the pencil that you should choose to move. An asterisk shows that rule 60 is in force.

(1,7), (1,26), (2,26), (15,26), (26,40), (26,60), (55,60), (25,55)*, (7,55)*, (26,55)*, (55,61)*, (15,61)*, (40,61)*, (61,65)*, (61,75), (1,1), (1,9), (1,35), (9,35), (35,35), (35,40), (35,60), (25,35)*, (7,35)*, (26,35)*, (35,61)*, (1,35)*, (9,35)*, (2,35)*, (15,35)*, (5,35)*, (5,40)*, (25,40)*, (25,65)*, (25,75), (50,75), (50,50), GOAL.

The Scientific American Young Readers Book Awards

by Philip and Phylis Morrison

GÉRARD MARIÉ

This year we were impressed by the topical freshness of many of the books we saw. The winners we have chosen, on display in these pages, are from a group of about 700 contenders. They will appeal to a wide variety of tastes and needs.

ART AND ARCHITECTURE

Dawn of Art: The Chauvet Cave
BY JEAN-MARIE CHAUVET, ÉLIETTE BRUNEL DESCHAMPS AND CHRISTIAN HILLAIRE
Translated from the French by Paul G. Bahn. Illustrated. Harry N. Abrams, 1996 ($35)

Murals: Cave, Cathedral, to Street
BY MICHAEL CAPEK
Illustrated in color. Lerner Publications Company, 1996 ($21.50)

Architecture and Construction
Gatefolds, transparent and tracing paper pages. Scholastic, 1995 (spiralbound, $19.95)

In *Dawn of Art: The Chauvet Cave,* the oldest known paintings in the world are well reproduced, and they are stunning. These Cro-Magnon artists painted bison, bear, cow, horse, hyena, ibex, lion, mammoth, rhino and stag. Chauvet Cave murals were already ancient when the famous cave of Lascaux was freshly painted. Nor is the work marked by crude technique or simple style; the paintings here are as sophisticated as any, often making use of the natural bulges of the rock. A few have been securely dated at 31,000 years before the present, by direct detection of the radiocarbon in charcoal pigment from the paintings.

The first book is not for children alone, but rather for everyone. We hope it will make its splendid way into many homes, classrooms and libraries. It makes good reading, too, for most of the brief text among the nearly 100 paintings in full color tells the authors' personal story. The three friends had been combing the Ardèche Valley in southeastern France for more than six years when they found this cave on a "fine and cold winter Sunday" in December 1994. They walked up an old mule path, stopped to enjoy a wide, sunlit view and saw in denser vegetation the narrow opening "to a little cavity" six feet above the ground. They entered to find a small place with a low ceiling. Going on, removing some rocks, Éliette Deschamps wriggled her way to a chamber whose floor she could make out 30 feet below by her helmet lamp. Shouts found no quick echo; this was a really big room in the darkness. They went back to their van to get a long rope ladder, then returned to climb down to the main level of Chauvet Cave, walking carefully among what were the ancient remains of many bears until they spotted the red ocher drawing of a little mammoth. They had reopened the oldest art gallery in the world.

An epilogue by an archaeologist of the region offers an early interpretation and compares Chauvet with many other painted caves. It will take years for experts to complete detailed study. Because of its fragility, Chauvet cannot be visited by the public save in the glowing pages of a book like this one.

PHOTOGRAPH BY NANCY HOYT BELCHER; MURAL BY GLENNA BOLTUCH AVILA

Not all murals are in dark caves. The second book, by Michael Capek, is brief and lively for young readers, yet wide-ranging. You will see and read of gray whales painted nearly life-size five years back on a powerhouse wall along the coastal highway in Los Angeles. A grave and marvelous Christ painted large 900 years ago in the dome of a little Catalonian church is here and also the most celebrated of ceilings, that of the Vatican's Sistine Chapel executed by Michelangelo. A theater wall in Atlanta shows Paul Robeson heroic in the gold epaulets of Emperor Jones. But in Cincinnati a domed and pillared temple, complete with sweeping circular staircases, turns out to be only a full-size mural done across a blank wall of a big grocery warehouse!

Our third recommendation—*Architecture and Construction,* the translation of a striking French book—makes elaborate provisions for reader interaction but names no author. Its opening paintings show the construction of an ancient Egyptian pyramid and compare it with I. M. Pei's small, glassy pyramidal entrance to the Louvre Museum. From there go back to shelters of straw, snow, sticks and hides, the Greek temples of stone and the brick Coliseum.

Continue on to a castle, the Brooklyn Bridge and the cast-iron framed glass of London's Crystal Palace, its facade printed on a transparent sheet. Skyscrapers are next, followed by Fallingwater, Frank Lloyd Wright's (leaky) masterpiece, with a part of its design on tracing paper to show how well it fits its complex, hilly setting. Glossy pages and elaborate foldouts enhance the brief text; a timeline, references and addresses of architectural sites to visit and enjoy close this artful book.

LIVING CREATURES

The Naked Mole-Rat Mystery: Scientific Sleuths at Work
BY GAIL JARROW AND PAUL SHERMAN
Color photographs. Lerner Publications Company, 1996 ($23.95)

Sand and Fog: Adventures in Southern Africa
BY JIM BRANDENBURG
Edited by Joann Bren Guernsey. Color photographs. Walker and Company, paperbound edition, 1996 ($6.95)

Cricketology
BY MICHAEL ELSOHN ROSS
Color photographs by Brian Grogan. Illustrations by Darren Erickson. Carolrhoda Books, Minneapolis, 1996 ($19.95)

The farmers who live on the brick-hard soil in the semiarid lands of East Africa have always known of long burrows below ground where small, strange rodents live, eating some of the root crops, forming mounds of soil here and there, but so thoroughly hidden that they were rarely seen. Like moles they were burrow dwellers, although their teeth and tails were like those of rats. They are neither, but a distinct rodent family, related more to guinea pigs. Strangest of all was their hairlessness, so that the zoologists named them naked mole-rats.

Twenty-five years ago Jennifer Jarvis, then a graduate student in Nairobi, grew curious about how and why the little mammals managed without fur. She learned how to attract one up into a subsurface burrow and then blocked its retreat to the depths. Soon she formed new colonies of her captives and provided a home in a fish tank. At first, they fought viciously. That stopped, and one adult female grew longer and began to breed. Over the years she concluded that they were an organized society. Only one female ever bred; others "kept house," cleaning out added dirt and feeding the young, and some of the bigger animals guarded against predators, mainly snakes.

Meanwhile a theorizing zoologist, Richard Alexander of the University of Michigan, suggested in some detail how a mammalian society of the anthill or beehive variety might work. Someone who knew of Jarvis's work in Africa told Alexander. Soon it was clear that the es-

HANDS-ON SCIENCE

The Puzzle Arcade: For People Who Like Lots of Hints
BY JERRY SLOCUM
Varied inclusions and a zippered pouch of puzzle parts. Klutz, Inc., Palo Alto, 1996 (spiralbound, $19.95)

Bent wires, cut-up cards, a grand maze, colorful printing and breezy but sympathetic prose only begin to describe this book. Its real nature lies in its ingenious demonstration of the interactivity of hand, eye, language and form. The author is a renowned collector of mechanical puzzles, about 20 of which are here; they are accompanied by picture puzzles, illusions and a gaggle of word puzzles. At the simplest, a small plastic pyramid can be fitted together of two bits. Some classical puzzles are offered in new form, like Sam Loyd's famous movable drawing that shows either 12 or 13 personages. Most important is not the head-scratching puzzles alone, but the freely offered help—hints for those who gamely struggle, and then full solutions to all the puzzles. This open sharing disarms the usual unalloyed challenge that can injure the sensitive and the unlucky.

LOU BROOKS

MORE WINNERS IN BRIEF

1 IS FOR ONE, *by Nadia Wheatley. Illustrated by Darius Detwiler. Mondo Publishing, Greenvale, N.Y., 1996 (paperbound, $6.95, three volumes).*
This counting book is a diminutive eye-opener to the recursive style that math and language share in echo of the infinite. It is 1 himself, lean, tall and svelte in his blue bow tie, who opens the work by juggling a few digits. Later, 8 sits at dinner but "leaves peas on his plate." At last, we see 1 and 0, tucked in bed cozily at 10:00 P.M. A palm-size book in an envelope on the inside back cover continues the tale. But wait! A third book, the size of a postage stamp, is tucked into the smaller book. This economical, witty and subtly profound work for the early-reading audience has no match.

DARIUS DETWILER

BUILDING AN IGLOO. *Text and photographs by Ulli Steltzer. Henry Holt and Company, 1995 ($14.95).*
Tookillkee Kiguktak lives on Ellesmere Island in a house, but when he goes on a hunt for musk ox or polar bear, he builds the igloo as his father taught him. The book walks through the steps: find the right spot, pace off the circular plan, outline and cut the snow blocks. Next it is time to build. Four rows spiral upward, blocks smaller as the top is approached; rounding off with the final dome demands special skill. The photographer has made a precise and beautiful record of this day's work.

INCREDIBLE COMPARISONS. *Written by Russell Ash. Illustrated in color. DK Publishing, 1996 ($19.95).*
Russell Ash's comparisons, colorfully spread across 60 outsize pages, take us through the universe, line up plenty of speedsters in all media and seek out extremes in population and in the human body. To wit, the diplodocus was three times as long as our longest living land animal, the reticulated python, but today's blue whale outstretches diplodocus and python end to end. All the gold ever mined would make a cubical casting that could stand on a well-reinforced tennis court—and sell for $2 trillion.

Continued on page 123

sentials of naked mole-rat society were just about what Alexander had imagined.

JIM BRANDENBURG

A generation of work has opened these strange creatures to our understanding. Questions multiply: How do they manage without fur? How does the queen rule? Why don't the others breed? What fixes jobs, animal sizes, population? How do they sleep, feed, signal? How do they dispose of wastes and of their dead? How do new colonies form? What about their genes in inbred colonies of 50 or 100 mole-rat siblings or half-siblings?

Many clever experiments have given answers. Even in the half-year since this fine book was put out, exciting new results have appeared. The mystery is being unraveled, but no one expects the questions to end. Novices of all ages will appreciate the fact that experimenters who ask such questions about mole-rats use methods that young readers can understand. Gail Jarrow is a teacher and writer with a background in zoology, and her next-door neighbor, Paul Sherman, a Cornell professor, is a leading researcher on the naked mole-rat. We readers benefit from their countryside friendship.

Two thousand kilometers southwest of naked mole-rat territory lies the coastal desert of Namibia. Only fog brings moisture to this arid region. The cold Antarctic current dries out all on-shore westerlies, and the east winds from land must cross the steppe and desert of the Kalahari. Sand is everywhere, and Jim Brandenburg, a gifted photographer, shows us in *Sand and Fog* an endless rolling sea of dunes, both at the scale of one little lizard buried in the hot sands and in a heroic sweep across a treeless hillscape where a group of giraffes stands tall amid low green scrub.

People form this place, too. A glittering handful of diamonds have been harvested from the sands by low-paid gatherers. A young Himba woman poses, quietly displaying what must be the oldest fashion of our species; she is covered head to toe in smoothed red ocher, a flower in her hair. Text and image are often searching, and we face the children who have encountered unexploded weaponry—and so still bear the wounds of the lengthy war that has ended, if not yet for them.

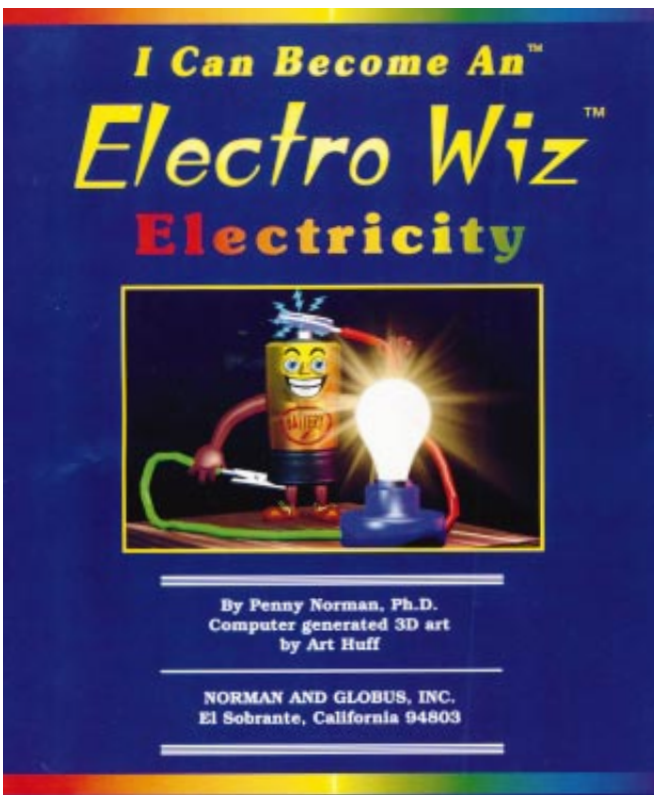
Closer to home is *Cricketology,* a book that fosters a friendly interaction between children and nature. Most of us recall lengthy free concerts on crickety summer nights, and many know that cricket houseguests have been watched and welcomed for 1,000 years in China. The kids (second to sixth graders) in El Portal Elementary (at the entrance to Yosemite National Park in California) have furthered the science of cricketology with the help of their teacher, author and naturalist Michael Ross and his cricket-wise family. Ross's book combines a gentle view of insect husbandry with a wonderfully kid-centered batch of questions to put to your crickets that you may come to know them better.

Crickets may learn, it appears, after trials of hole-finding speed, or did they follow their own footsteps somehow? They are attracted by light, or is it

HANDS-ON SCIENCE

I Can Become an Electro Wiz: Electricity
BY PENNY NORMAN
Computer art by Art Huff. Norman and Globus, 1995 (Telephone: 510-658-3453)
($19.95; D cell not included)

Good lab kits pose a tough design challenge. This one displays the essentials of success: safety, attention to learning by experience and long smoothing in the hands of many children (the audience here is grades K through 5 or so). One component is enough to suggest the welcoming spirit here. A small plastic envelope contains a large paper clip, two brass paper fasteners and a card labeled SWITCH. Two pages in the guide show how to make this switch. The hard-working battery (whimsically cartooned) needs a load—don't short it out! A red LED glows when properly connected. Alternatively, the load can be a little motor that turns a pinwheel or a satisfyingly audible buzzer. Make a test loop and see what does and does not close the circuit: choose a penny, a bottlecap or an ice cream stick, all included here. Now try a two-loop version and compare. There are word lists, a game or two and a fine page to help you troubleshoot.



DESIGN BY KATIE MEYERS AND PENNY NORMAN; ILLUSTRATION BY ART HUFF

warmth? They hop five times farther from a concrete sidewalk than from a smooth floor tile. They will tread across water if they need to escape. Plenty of questions here are left unanswered. Cricketology is a complicated and exciting study, full of fun, and kids can advance it and themselves along these lines.

We should also honor Professor A. E. Dolbear of West Virginia, who just 100 years ago published his formula for telling the temperature from the rate of tree-cricket chirping.

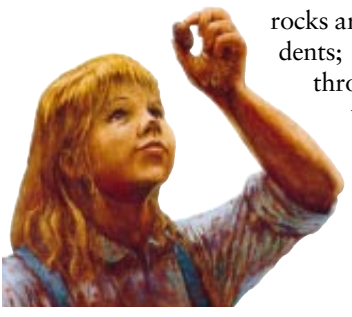
GREG MICHAELS

PLANET EARTH

The Pebble in My Pocket: A History of Our Earth
BY MEREDITH HOOPER
Illustrated by Chris Coady. Viking, Penguin Books USA, 1996 ($14.99)

Prehistoric Journey: A History of Life on Earth
BY KIRK R. JOHNSON AND RICHARD K. STUCKY
Denver Museum of Natural History and Roberts Rinehart Publishers, Boulder, Colo., 1995 ($39.95; paperbound, $19.95)

A young girl holds in front of her eyes the smooth, warm brown pebble she has picked up from the ground. Twenty pages later she puts it down among yellow flowers in a green field, the subsoil section visible below, filled with pebbles. Each page of Meredith Hooper's book bears a landscape and a few lines of text, a dramatic tale of fiery volcanoes and of mountains rising slowly, slowly, as time and the weather sculpt pebbles out of the substance of the hills themselves. A river runs to the sea, and the pebble is rounded as it rolls. Neither the living forms nor the embedded rocks are permanent residents; all are passing through, on the way to the bottom of the sea. Time passes, and life changes; rocks give way to a pebbly beach, and in turn dinosaurs, then herds of horses, gallop past. The time of ice quickly makes way for more familiar scenery until the story is brought up-to-date. "Every pebble has its own story"; pick one up, and you are a new actor in the long history of the earth.



CHRIS COADY

For all the universality of the earth's history, some times and places are privileged. The Denver Museum has organized a new set of eight dioramas, captured in *Prehistoric Journey,* to show what is found at the fortunate sites where traces of ancient creatures lie exposed. The scenes rely on the eloquent witness of photography, heightened by artists' colorful and careful conjectures.

You can see for yourself the desert scrub of the Ediacara Hills in the Australian Outback and the impressions in rock of early multicellular forms. Then comes a flashback to the really old times of all-bacterial life, with fossil mats of colonies of the unicellulars and some microscopic details. Ancient fishes and old plants are held in the perilous cliffs east of Yellowstone.

Life then essays dry land, big Devonian plants and small amphibians on Beartooth Butte near Yellowstone. Dinosaurs, of course, abound throughout the fossil sites, as they did in the inland seas that spanned the American West.

A few more pages grab attention: a 15-foot fish whose sinuous ribcage holds its final meal; a tree-climbing lemurlike cousin of ours making its way in the tropical forests of the early Tertiary Rockies, and the White River Formation of Colorado, where one day in 1994 a six-man crew from the museum recovered 1,000 mammalian jaws from a single square mile of outcrop!

There are bigger albums of fossils than this slim volume, and well-done studies of this or that ancient site, but this book nicely integrates the story of life's variety and the landscapes where traces of ancient creatures survive.

MORE WINNERS IN BRIEF

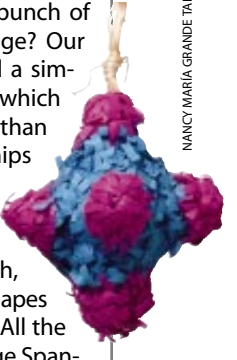
Continued from page 121

PAPER AIRPLANES AND OTHER SUPER FLYERS, *by Neil Francis. Illustrations by June Bradford. Kids Can Press (29 Birch Ave., Toronto, Ontario M4V 1E2), 1996 ($16.95; paperbound, $5.95).*
This book tells it straight a dozen times: how to make and fly gliders, twirling-wing papercraft and "strange super flyers" out of supermarket meat trays, small cans and different parachutes. Each plane is presented in step-by-step color drawings. We tested the classical dart, folded of one paper sheet, then added elevators, rudder and ailerons. It flies level and can roll all the way. This is a serious little working guide for grade school friends, clubs and classes.

JUNE BRADFORD

THE WEATHER SKY. *Photographed, illustrated and written by Bruce McMillan. Sunburst Books (Farrar, Straus and Giroux), paperbound edition, 1996 ($6.95).*
A year races by in a couple of dozen wide pages. Each day sampled is given four portions: a photograph in color of the sky, a drawing of the clouds against altitude, a thumbnail segment of a local weather map and a text paragraph describing the physical processes that molded the intricate shapes shown. Cirrus, for instance, floats high and cold, always white because it consists of tiny ice crystals. A helpful seasonal reference, the book is instructive fun for anyone beyond fifth grade.

EL GUSTO DEL MERCADO MEXICANO/A TASTE OF THE MEXICAN MARKET. *Written and illustrated by Nancy María Grande Tabor. Charlesbridge Publishing, Watertown, Mass., 1996 (paperbound, $6.95).*
How would you present a bunch of bananas on the printed page? Our author-artist has developed a simple yet engaging technique, which she uses to display more than 100 different foods. She snips out banana shapes of yellow paper and arranges them in bunches and pairs for the camera. For shiny fresh fish, she constructs streamlined shapes of crumpled aluminum foil. All the text is printed twice, one page Spanish, the facing page English.



NANCY MARÍA GRANDE TABOR

Continued on page 125

CULTURE

Jacks around the World
BY MARY D. LANKFORD
Illustrated in color by Karen Dugan.
Morrow Junior Books, 1996 ($16)

The Story of Writing: Alphabets, Hieroglyphs and Pictograms
BY ANDREW ROBINSON
Illustrated in color and in black-and-white. Thames and Hudson, 1995 ($29.95)

The first pages of *Jacks around the World* open to a spread that holds a bright world map, whereon numbers mark a surprising list of 14 countries where children play a game related to our own jackstones. The text that follows begins quite properly, with a serious two-page piece on the fundamental rules and techniques of American play. You can learn the finger game called Stone, Scissors, Paper here if you want a change from tossing a few jacks to determine the order of play. Just count "one, two, three" and show fingers, American-style, or try the Japanese chant "*ishi, hasami, kami.*"

KAREN DUGAN

Around the world, most versions use pebbles, and the rules of action differ. The Hawaiian game prepares a pile of 100 or so pebbles and claims them one at a time as your special stone is tossed. Miss once, and your turn ends—hence, no counting at all. In New Zealand and Tibet, where sheep and goat flocks are numerous, real knucklebones and their like are preferred. In Japan and Singapore deft players toss small bags of silk filled with rice, beads or other seeds. But the origin of the curious cast-metal spinners with six arms that we call jacks remains obscure.

Open in design and layout, rich in images—see Napoleon's troops awed by obelisks and a carved wall—*The Story of Writing* is a concise introduction to the vital technology we call writing. The author is not a linguist, but he is a well-informed and assured writer.

The book has three sections of increasing length: "How Writing Works," "Extinct Writing" and "Living Writing." The first makes plain that there is no "pure" system of writing, no pure pictograph or ideogram, no road signs, music or math without added words. Any language can be written, if clumsily, in any script; nontonal Japanese is about as distinct from tonal Chinese as languages go, yet every Japanese uses some Chinese script. In Malta the local form of Arabic is written in English script.

The history of decipherment is fascinating. Ten or so important written languages remain incompletely or not at all known, from the Indus Valley signs to the mysterious script of Easter Island and the stamped letters of the Phaistos clay disk of Crete. Some seem hopeless unless we find new material to analyze. The last section explains, very lightly, "the most complicated writing in the world": Japanese. Multiple scripts, both ideographic and syllabic, are in everyday use. What people cannot learn to do! And they do it very well, thank you.

IN THE LAB

Chemistry Imagined: Reflections on Science
BY ROALD HOFFMANN AND VIVIAN TORRENCE
Smithsonian Institution Press, 1993 (paperbound, $19.95)

The Cool Hot Rod and Other Electrifying Experiments on Energy and Matter
BY PAUL DOHERTY, DON RATHJEN AND THE EXPLORATORIUM TEACHER INSTITUTE
Drawings and photographs in black-and-white. John Wiley & Sons, 1996 (paperbound, $10.95)

Starry Messenger: A Book Depicting the Life of a Famous Scientist, Mathematician, Astronomer, Philosopher, Physicist Galileo Galilei
BY PETER SÍS
Frances Foster Books (Farrar, Straus and Giroux), 1996 ($16)

A collage of collages by a gifted artist and a Nobelist chemist-poet is not for every young reader. But in high school and early college years, there are many talented students of both genders drawn to the arts, delighted by literature and happy with the order they see in science. The first book is for them and their elders.

Here are nearly 40 mixtures, essays and poems on chemistry and chemists by Professor Roald Hoffmann and a similar set of apt and intricate full-page images by the artist Vivian Torrence. They challenge, instruct, surprise and move. A collage on Marie Curie centers her portrait on the page, grave as usual, and around it a sculptor's chisel carving an x-ray image (a woman's hand with a wedding ring), x-ray spectral data, hydrometric apparatus and a Niels Bohr atomic diagram of radium orbits. (The long critical essay on these collages by Lea Rosson DeLong differs a little on the collage's content.) Hoffmann's accompanying pages evoke the days when he was 10 years old, a "displaced person" in a German camp, an eager child learning his fourth language and reading two biographies, one of Marie Curie, one of the American chemist George Washington Carver. "Years have passed," he writes. "The boy is… older.… The romance is off the radium.… But Marie Curie still makes him cry."

The Danish physicist Bohr also taught that order is not the only goal of science. Let the book's diverse novelty guide happy but perplexed readers.

Confusion of a different kind may beset the young experimenter who attempts investigations into even the simplest electrostatics in our age of wall outlets. The San Francisco Exploratorium has collated a reliable hands-on guide to two dozen experiments that disclose free electrical charges and much more. All these intimate experiments were made and tested by schoolteachers who worked from the bigger, showier and much dearer exhibits of the celebrated do-it-yourself museum.

DESIGN BY HOWARD GROSSMAN; PHOTOGRAPH BY THE STOCK MARKET

Would you like an electrophorus—a long-time carrier of electrical charge at 10 or 20 sparky kilovolts of potential—easy to make in 15 minutes out of cheap stuff and tested for workability in the damp, leaky air of San Francisco Bay? It's here right on the first pages. Items: an alu-

minum-foil pie tin, a Styrofoam coffee cup, hot glue or tape. A Leyden jar? Another small piece of foil, a nail and a plastic 35-millimeter film can. Drawings along with simple, satisfying explanatory instructions follow. If you go on, you can make electroscopes in the same style, detect electrical charge transfer and show the most basic of facts within matter, the conservation of electrical charge, merely by pulling apart two pieces of tape. There are a few others of this series, called Snackbooks, out already, and more soon to come.

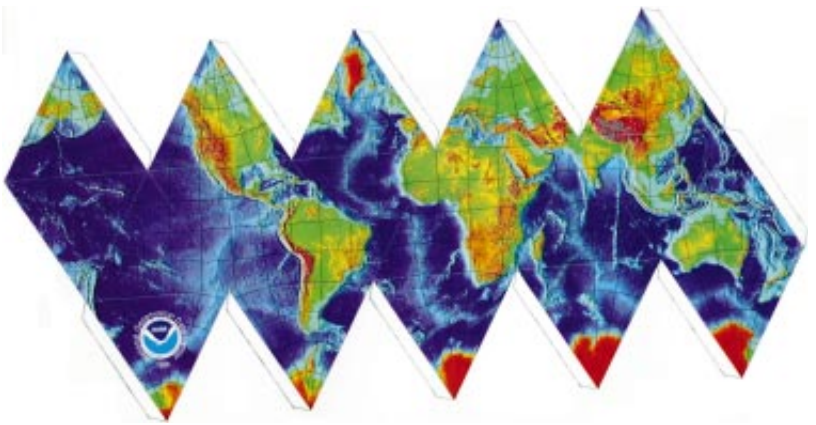

PETER SÍS

Of course, the path of science is not without its risks, perhaps greater formerly than now. Galileo is the prototype of the embattled scholar. In *Starry Messenger,* Peter Sís recounts with feeling the life of Galileo, often supported by Galileo's own words (after the translation of the late Stillman Drake), yet as much from Brecht or Kafka as from history. This large, thin book of paintings evokes an old volume in color, form and tone. It opens with the night sky over Florence and closes with a similar scene over a darkened New York, the high towers replacing the bulk of the Duomo.

The illustrations are splendid. The golden moon drawings do justice to Galileo's and yet seem more fit for a Medici prince than Galileo's own spare wash drawings in sepia. The trial painting is a stunner. A couple of hundred red-robed cardinals sit all alike in judgment, every eye of the serried ranks on the philosopher below, standing alone on a circular floor not unlike the sky that got him into trouble. News of his final pardon from Rome in 1992 is inset into a Renaissance map of the constellations. A work of art from cover to cover, this is a book of rare quality.

HANDS-ON SCIENCE

Surface of the Earth Icosahedron Globe 1995
National Geophysical Data Center,
National Oceanic and Atmospheric Administration (Mail Code E/GC,
325 Broadway, Boulder, CO 80303-3328) ($0.50 per copy; $5 handling)


DIGITAL IMAGE BY PETER W. SLOSS

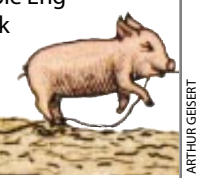
One sheet of heavy paper stock offers a colorful map of the physical world, projected onto 20 flat triangles. Two dozen straight-line scissors cuts are all that one needs to turn that sheet into an icosahedron, to be joined with rubber cement at the tabs. Then you have a bright polyhedral "globe" of the world bereft of cities or boundaries, bearing a space-age, shaded-relief map in coded color. This is not a sphere but a pretty good substitute, five inches pole to pole. The Mid-Atlantic Ridge is as clear in light blue as are the Andes in crimson, for depths and elevations are both keyed. Handling costs are the only hitch; if three or more friends each want one, the globe's a bargain.

MORE WINNERS IN BRIEF

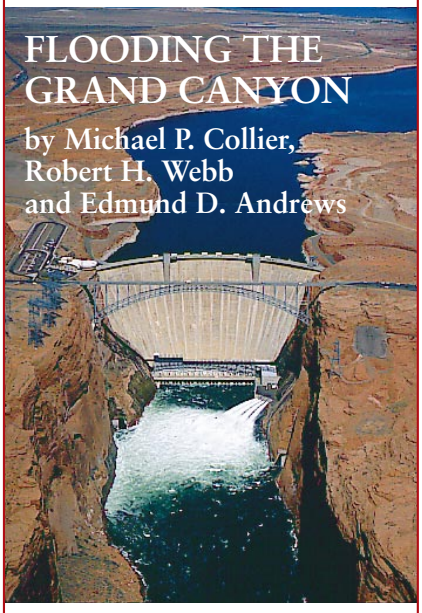
Continued from page 123

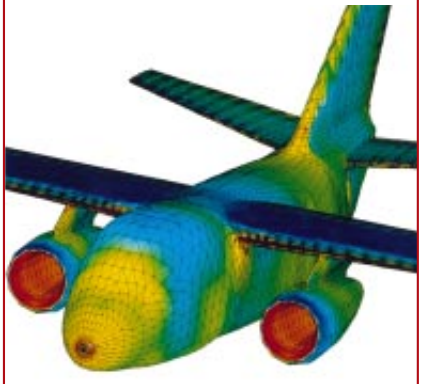
SPOT A DOG, A CHILD'S BOOK OF ART, *by Lucy Micklethwait. Illustrated in color. Dorling Kindersley, 1995 ($9.95).*
In this beautiful small book, the very knowing author has chosen a baker's dozen of fine paintings, all with canine visitors. Each text page sets one simple question in very big type: Where is the little dog? Can you see a shy dog? To answer, the child needs first to look with care at the entire painting, giving the art time to work its joys on the youngest. Picasso's *Three Musicians* hides a cubist's flat dog under a chair; the shy dog is in Degas's *Dancing Class,* just visible between the leg and tulle skirt of the nearest resting dancer.

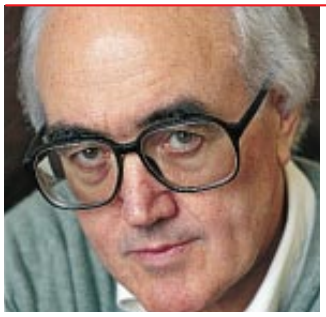
ROMAN NUMERALS I TO MM, NUMERABILIA ROMANA UNO AD DUO MILA: LIBER DE DIFFICILLIMO COMPUTANDO NUMERUM. *Written and illustrated by Arthur Geisert. Houghton Mifflin, 1996 (MCMXCVI) ($15.95).*
Make counting big numbers pain-free, even if expressed in those awkward Is, Vs, Xs, and Cs. What you see is a couple of dozen neatly etched and tinted pages crowded with energetic animals—looking at sundials, aloft in a hot-air balloon race, and touring the countryside near their large farm home. Most of the animals are cheerful pigs, MMMMDCCCLXIV of them. The text, including the rules of Roman notation, is all in simple English, so that this book amuses both readers and the read-to. Perhaps it was translated from Pig Latin?


ARTHUR GEISERT

HOW TO SPEAK CHIMPANZEE, *by Richard Brassey. Crown Publishers, 1995 ($12).*
Chimps are not built to speak, but they do communicate vividly, in body tone, gestures, hoots, grunts and kindred verbalizations. These are painted and spelled out here to make a colorful phrase book of youthful chimpanzee; the discourse is far from alien. There are four pages about the art of cooling down, a vocabulary small humans need as well. And most chimps, like their little distant cousins, go to bed quietly, with occasional grunts of contentment: "Eh mmmmmm," eyes shut, thumb in mouth.







COMMENTARY

CONNECTIONS

by James Burke

Sweet Dreams

One of the less glamorous aspects of my work is having to fly frequent transatlantic red-eyes, and any airline that gives me a sleep-inducing hot chocolate gets my money. So there I was the other night, droning up into the sky, sipping and thinking about Sir Hans Sloane. Sloane helped to establish the place where I do most of my research, when his collection of 2,500 plants, animals and assorted memorabilia became the core of what would end up as the British Museum. And it was Sloane (while spending time in 1688 as personal physician to the governor of Jamaica) who discovered the soothing effects of mixing chocolate and warm milk.

Back in England, in 1715, Sloane treated one of the great beauties and literary wits, Lady Mary Wortley Montagu, who was suffering from smallpox. (She ended up with no eyelashes and a pitted face.) A year later, when Lady Mary moved to Turkey with her incompetent ambassador husband and saw what the locals were doing for smallpox (inoculation), she carried out Turkish-style treatment on her own son. When she went home, she persuaded various royals to inoculate *their* kids. Then, with Sloane's help, everybody else got vaccinated, too.

In 1736 Lady Mary found herself fatally attracted (as were various other lords and ladies) to an androgynous Italian science type named Francesco Algarotti, half her age, who was visiting London and doing for women readers a rewrite of Isaac Newton's work. They fell hopelessly in love. Well, *she* did. Three years of one-sided passion later, Lady M. headed for Italy and a change of air, after arranging a secret rendezvous with Algarotti. Of course, he never showed, having gone off to Prussia to be court chamberlain (the Prussian crown prince Frederick had also apparently fallen for him, to judge by the fact that he went around referring to Algarotti as the "Swan of Padua").

Algarotti was a bit of a social climber (you noticed), and so he must have been tickled pink when his interest in Newton brought him a social invitation as rare as hen's teeth. It was to stay at the Château de Cirey in Lorraine, at which the extremely reclusive François-Marie Arouet Voltaire was holed up with his intellectual paramour Gabrielle Émilie, Marquise de Châtelet (the French state security cops were after Voltaire for such misdemeanors as saying England had a better political system). Each of them was also producing a version of Newton: he, a general book for lay readers; she, a rather more demanding commentary on the *Principia Mathematica*.

People used to picnic on hills next to battlefields and enjoy the carnage.

Voltaire also happened to be a big admirer of a pal of Algarotti's: the Italian priest-experimenter Lazzaro Spallanzani, who (100 years before Louis Pasteur) noticed that putrefaction did not occur in hermetically sealed vessels. He also investigated how flat stones skipped on water, climbed around volcanoes and sliced up thousands of worms, snails, salamanders and tadpoles to test their regenerative abilities. He reported the first case ever of artificial insemination of a spaniel. Above all, Spallanzani made real enemies among the scientific establishment by rubbishing the popular idea of spontaneous generation of life (that is, that maggots came from decaying meat, mice from rotting cheese, and so on).

Spallanzani became so famous that he inspired the wizard-genius character in one of a collection of creepy pseudoscientific yarns (full of maniacs, automata, ghosts and such) written around 1815

DUSAN PETRICIC

by a Berlin lawyer and known, from the author's name, as the *Tales of Hoffmann*. Apart from having his story lines snitched by such operatic biggies as Tchaikovsky and Wagner, E.T.A. Hoffmann's other main claim to fame was that he defended a pan-German liberal fanatic by the name of Friedrich Jahn.

The recent defeat by the French had brought German university student mobs into the streets, calling for a united Germany, free speech, democracy and other such dangerous lunacy, and Jahn was in court because much of this stuff was his idea. That, and gymnastics. Which Jahn saw as the only way to make German youth strong and disciplined enough for "the struggle ahead." A crackdown on Jahn's adherents followed his trial, on grounds that exercise might be detrimental to state security.

After one of Jahn's devotees carried out the spectacular 1819 stabbing of a well-known establishment figure, August von Kotzebue, freedom of the press was abolished, all universities were taken over by the state, and another disciple, the athletic liberal Karl Follen (a close friend of the Kotzebue stabber), fled to Harvard. There he opened the first college gym in America and started everybody jogging. By 1851 German-American gymnastics was so widespread that 100 gym clubs had united as the Socialist Gymnasts' League and were chosen to provide Abraham Lincoln's bodyguard at his inauguration in 1861.

German gymnastics really took off in the U.S. when the YMCA adopted physical health as one of its basic tenets and built some of the first public gyms (and eventually invented basketball to play in them). The international nature of the YMCA movement had been established as early as 1855, with a conference held in Paris to cement the charter. This gathering was the brainstorm of Swiss libertarian and evangelist Jean-Henri Dunant.

In 1859 Dunant happened to be in Italy watching the one-day battle of Solferino (people used to picnic on hills next to battlefields and enjoy the carnage). Dunant was so appalled at the condition of the 6,000 wounded that he fetched buckets of water and 300 citizens and battle-watching tourists to wash wounds all night. In 1862 the publication of his book *Memories of Solferino* led to the founding of the Swiss Red Cross in 1864. By the end of the century the Red Cross was on every battlefield, doing everything but blood transfusions (probably needed by the wounded above all else but which, when attempted, often seemed to kill rather than cure).

It took the Viennese immunologist Karl Landsteiner to make transfusions possible. In 1909 he discovered the three main blood groups—A, B and O—and in doing so revolutionized surgery at a stroke of the needle. In 1922 Landsteiner moved to the Rockefeller Institute for Medical Research in New York City and collected a Nobel in 1930.

That same year, in the same place, another Nobel winner, French-born surgeon Alexis Carrel, who had developed new suturing techniques that changed the world of blood vessel surgery, took a major step forward in organ transplantation (for which Landsteiner's blood-matching discovery was essential). The success followed Carrel's collaboration with a chap whose sister-in-law had a heart valve problem that was inoperable because at the time there was no way to maintain the patient's circulation during the operation.

So when somebody introduced this fellow to Carrel, they became a dream team. Over the next few years he perfected a new perfusion pump for Carrel that used compressed gas to keep the necessary fluids flowing in the body. In 1938 both men made the cover of *Time*.

The pump maker was used to the publicity, of course, because he was already world-famous. He was Charles Lindbergh, in 1927 the first person to fly across the Atlantic and the man who made possible flights like the one on which I nodded off at the beginning of this column. Hope you didn't. SA

ANNUAL INDEX 1996

AUTHORS

ARTICLES, BY KEY WORDS

THE AMATEUR SCIENTIST
by Shawn Carlson

MATHEMATICAL RECREATIONS
by Ian Stewart

WORKING KNOWLEDGE

POP TOPS

DRT MFG. CO.

ERMAL C. FRAZE patented the idea for a pull tab that could be attached directly to the surface of a can top.

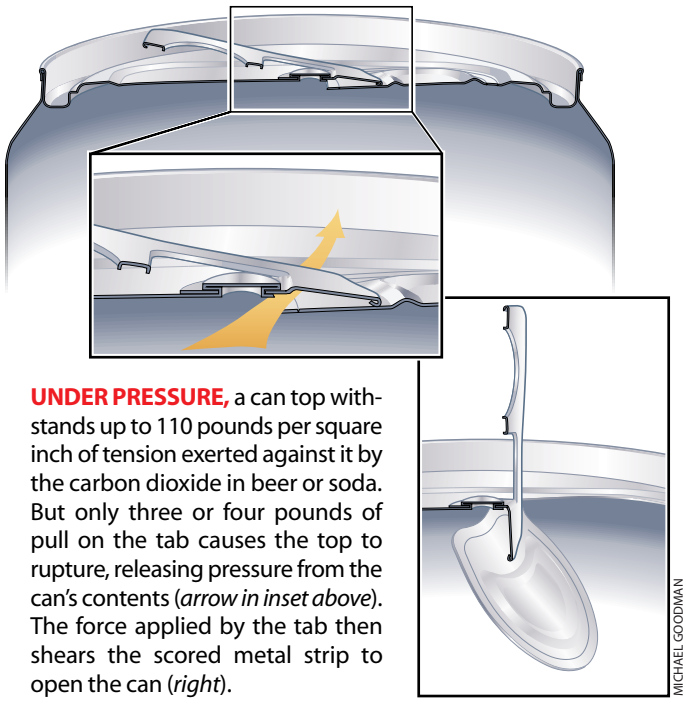
by Wesley G. Rogers

Engineers interested in the aesthetics of their profession might consider the aluminum or steel pop top, which goes by many names. "Zip," "tap," "snap" and "pop"—as well as the less sonorous "tab" and "ring"—are all adjectives that have preceded the noun "top" at one time or another in the 35-year history of the self-opening can lid.

According to engineering lore, the late Ermal C. Fraze, founder of Dayton Reliable Tool & Manufacturing Company in Ohio, came up with a practical idea for the pop-top lid after attempting with halting success to open a beer can on the bumper of his car. For decades, inventors had been trying to devise a can with a self-contained opener. Their elaborate schemes had proved unworkable because they required complex manufacturing steps for the attachment of the pull tab—the element that exerts force to open the can top. Fraze succeeded because he conceived of a simple and economical rivet to hold the tab in place. Unlike previous approaches, the rivet was formed from the surface of the can top itself.

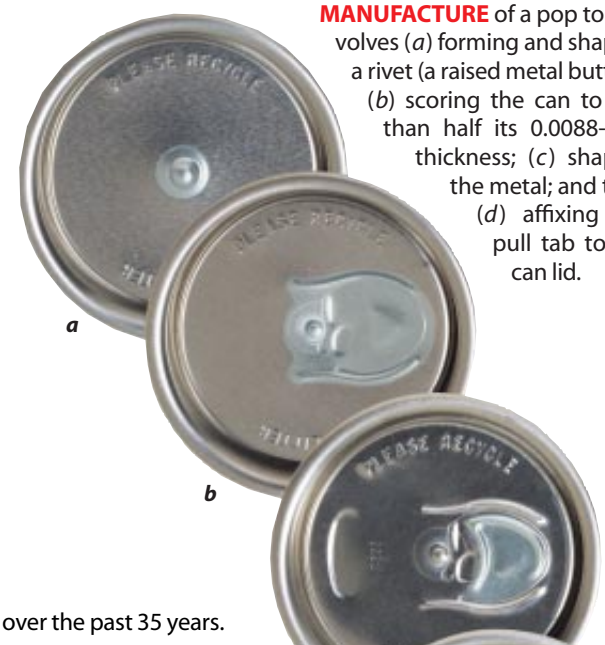
Since the mid-1960s, the pop top has experienced dozens of refinements. Sharp edges that might cut the person who drinks from the can are gone. And the tab remains fixed to the top after opening, so that park maintenance workers no longer spend hours scouring the grounds to remove the metal scraps. The development of the technology, in fact, continues. Today one pound of aluminum yields 1,000 tabs, a fourfold increase over the amount produced per pound of metal in 1965. The simple manufacture of snap, tap and pop may pose a challenge to the ingenuity of the engineering community for years to come.

WESLEY G. ROGERS is vice president of Dayton Reliable Tool & Manufacturing Company in Dayton, Ohio.



UNDER PRESSURE, a can top withstands up to 110 pounds per square inch of tension exerted against it by the carbon dioxide in beer or soda. But only three or four pounds of pull on the tab causes the top to rupture, releasing pressure from the can's contents (*arrow in inset above*). The force applied by the tab then shears the scored metal strip to open the can (*right*).

MICHAEL GOODMAN



MANUFACTURE of a pop top involves (*a*) forming and shaping a rivet (a raised metal button); (*b*) scoring the can to less than half its 0.0088-inch thickness; (*c*) shaping the metal; and then (*d*) affixing the pull tab to the can lid.

DAN WAGNER; MICHAEL GOODMAN (*color enhancement*)

EVOLUTION of the pop top has carried it through many variations over the past 35 years.

JIM CALLAWAY *SABA*