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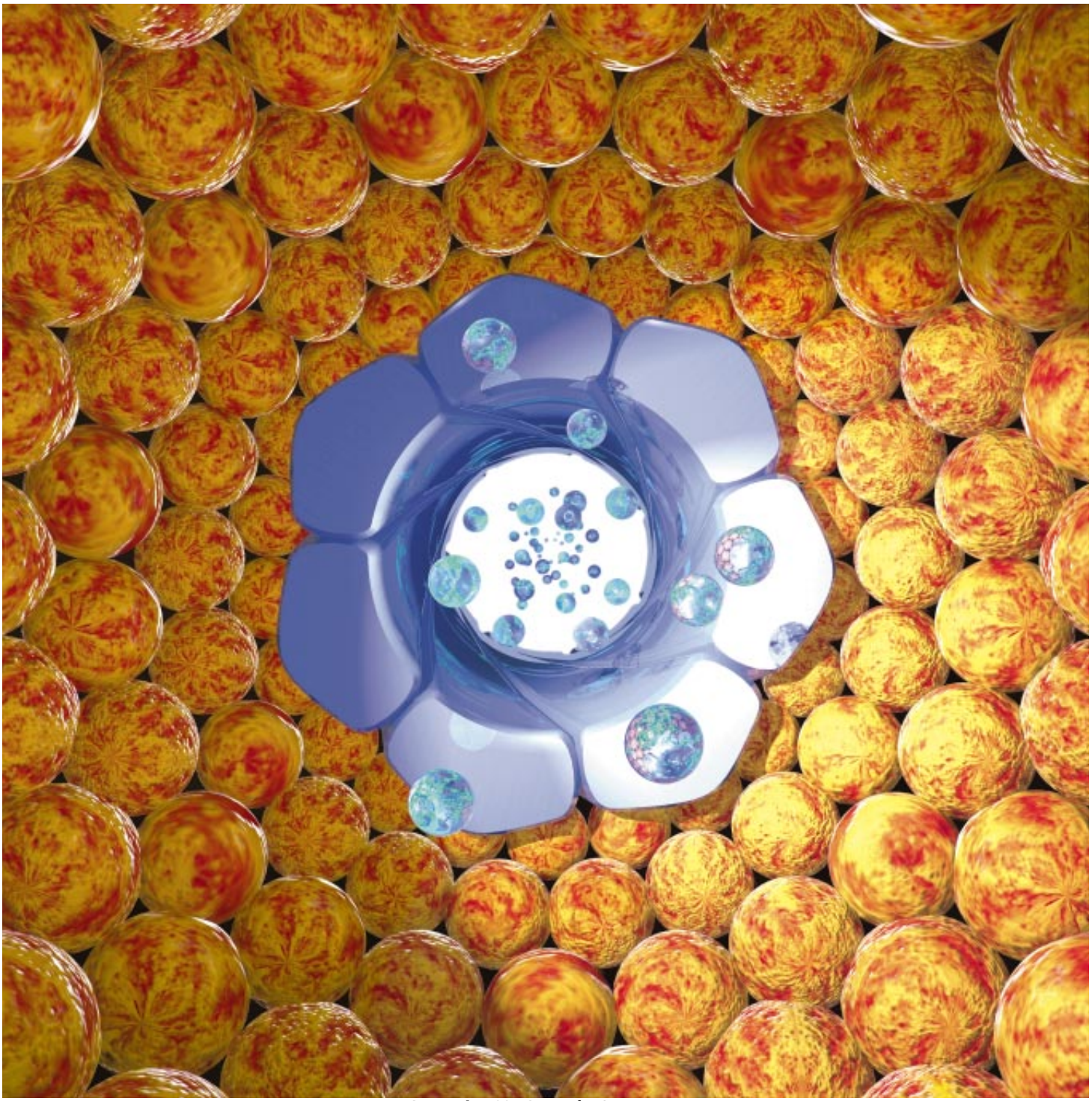
THE TRUTH ABOUT FALSE MEMORIES

WHY WE CAN REMEMBER EVENTS THAT NEVER HAPPENED

Building doors into cells



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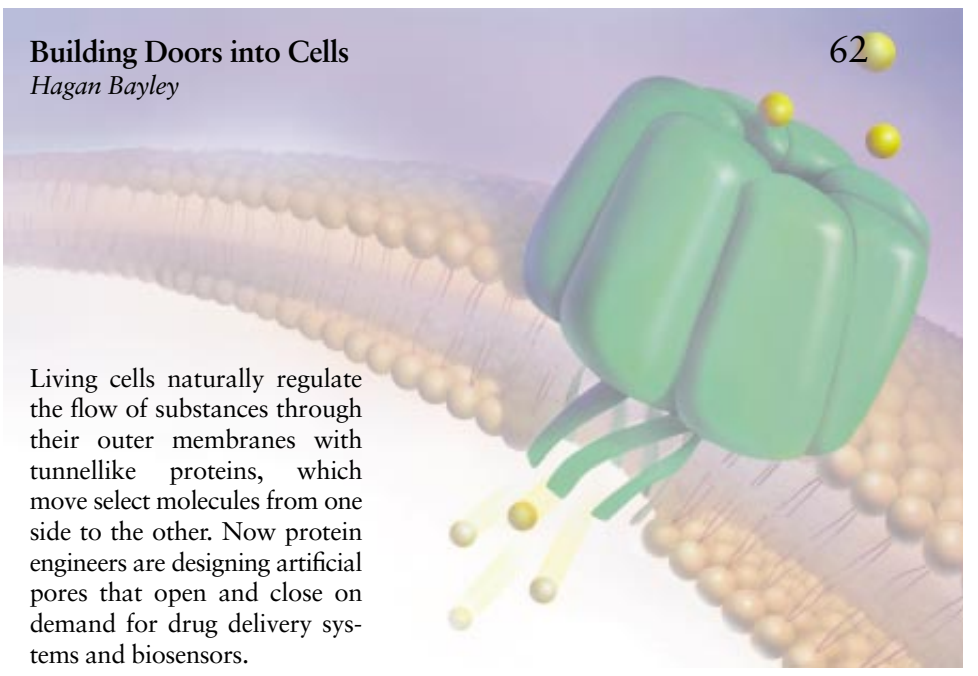
NEWS AND ANALYSIS



About the Cover

Seen from inside a cell, this artificial pore in the outer membrane allows drug molecules to enter. Controllable pores can be made by modifying the natural bacterial protein alpha-hemolysin. Image by Keith Kasnot.

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Making (Up) History

God cannot alter the past," Samuel Butler wrote, "but historians can." Even in the absence of revisionist impulses—remember the better known maxim that history is written by the winners—anyone reconstructing past events will almost inevitably get parts wrong, either through errors of commission or omission. Strict deduction can go only so far at making sense of spotty physical clues and personal accounts (of whatever dubious reliability) before at least a measure of imaginative inference creeps in. Also, like the apocryphal blind men who felt parts of an elephant and assumed the whole animal was either like a snake or a tree or a wall, historians may unintentionally overgeneralize from the relatively few details that they understand best.

For archaeology, as an extension of history, the problem grows worse because time wipes away so much of the evidence. As Michael E. Smith points out in "Life in the Provinces of the Aztec Empire," the records most studied by archaeologists in Central America have generally been biased to reflect pre-Columbian Lifestyles of the Rich and Famous. Researchers made assumptions about how the other half lived, but they might as well have been guessing the habits of middle America by surveying the mansions of Bel Air.

MICHAEL E. SMITH

CLUES to everyday Aztec life are in these figurines.

Real data to the rescue. After digging more extensively at sites outside the Aztec capitals, Smith and other archaeologists have started piecing together a more well informed view of the average Aztec's life and have learned that it was a richer, more cosmopolitan existence than had been supposed. You will find a description of their findings, beginning on page 76.

A people's history is vulnerable to distortion, but perhaps a more disturbing finding is that personal histories are, too. We all know that memory is unreliable: we forget appointments, we misremember addresses, we're mistakenly sure that we've picked up our keys. We would probably like to think these lapses are confined to minutiae. But a growing body of psychological study demonstrates that with a bit of prompting, people can be convinced that they "remember" in detail totally fictitious events of major consequence. To paraphrase George Santayana, those who cannot remember the past are condemned to invent it.

Psychologist Elizabeth F. Loftus reviews some of the research on "Creating False Memories," beginning on page 70. Obviously, these findings do not mean that every remembrance is untrustworthy, but they should be of concern to anyone involved in law enforcement, psychotherapy, journalism and other activities that depend on memory to get at the truth.

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LETTERS TO THE EDITORS

CLONING COMMOTION

I do not, quite frankly, understand all the fuss over the ethics of cloning humans or, for that matter, livestock ["The Start of Something Big?" by Tim Beardsley, News and Analysis, May]. How is cloning humans fundamentally different, ethically, from in vitro fertilization? It's not as if we could start growing clones to keep a handy supply of compatible body parts in case the need for a transplant arises. The same laws, rights and freedoms would apply to a clone as would apply to anyone else.

The thought of vast herds of genetically identical livestock brings to mind the vast orchards of genetically identical apple trees over the mountains from me in eastern Washington. True, the risk is that any disease or parasite that infects one member of the herd (or one tree in the orchard) will infect them all, and the farmer could be financially wiped out in one fell swoop. It may be unwise to put all one's eggs in one genetic basket; that's a choice each farmer must make. But is it unethical? Hardly.

KEVIN MOUNTS
Seattle, Wash.

SUZANNE MURPHY TSW/Click/Chicago Ltd.

HUMAN CLONES, alias identical twins, have full rights.

TALKING ABOUT THE WEATHER

I read with considerable interest the article "The Coming Climate," by Thomas R. Karl, Neville Nicholls and Jonathan Gregory, in the May issue. It clearly and forthrightly discussed the limitations and inconsistencies among various climate models based on the record of the past 100 years. But the keys to climate change do not lie in the recent past, where most choose to look, but in the gloom of the global record. That record indicates that current models are unable to predict the climatic extremes in, for example, the Miocene (24 million to five million years ago), parts of the Eocene (56 million to 34 million years ago), when alligators inhabited Arctic regions, or even the (relatively) recent ice ages.

It is no wonder that arguments about the consequences of global warming leave most citizens and politicians confused. For all we know, that warming may save us from a long-term descent into another ice age. Given the uncertainties, there is really only one good reason to try to reduce greenhouse gas emissions: to improve the energy efficiency of the global economy. That alone will liberate resources that will be needed to cope with the inevitable changes the future will bring.

ANDREW V. OKULITCH
Geological Survey of Canada

PORTRAIT OF THE PLAGUE

The caption for the painting that accompanied the review of Christopher Wills's book *Yellow Fever Black Goddess* ["Portrait of a Pathogen," by Paul Ewald, Reviews and Commentaries, May] states that "malaria devastated Marseilles in 1720." The year 1720 is a famous date for Marseilles and nearby Provence because that very year plague cast a tragic shadow over the country. Some reports indicate that the black death claimed 30,000 lives in Marseilles and killed 85,000 in Provence within a few months. The painting also shows a street covered with corpses and assistants who protected themselves with linen masks. This image fits better with historical reports about the plague than with descriptions of malaria.

MICHEL GUILLOTON
University of Limoges, France

Editors' note:

The copy of the painting we received was mislabeled; we regret the error.

NUCLEAR POWER

David A. Schwarzbach's enthusiasm for the "rational" course of consuming all of Iran's natural gas within 50 to 100 years ["Iran's Nuclear Puzzle," June] for everyone's short-term profit is Western and conventional. Iran may have another agenda, in a larger time frame. The late Shah of Iran was a pioneer in decrying the folly of burning our planet's irreplaceable petrochemicals as mere fuel. Perhaps Iranian commitment to nuclear power is a legacy of the Shah's concerns about the uses of his country's natural wealth.

BILL DURHAM
Seattle, Wash.

ASSISTED SUICIDE

John Horgan, in his excellent review of current options for care of the terminally ill ["Trends in Health Care: Seeking a Better Way to Die," May], correctly points out that because the desire for suicide is uncommon among the terminally ill when control of their symptoms is adequate, our attention should focus more on quality of remaining life. But the difficult issue of assisted suicide will persist. Some dying patients will seek assistance if unable to accomplish this alone; furthermore, some physicians may feel ethically compelled to provide such assistance if it is otherwise unavailable. Because of legitimate concerns about potential conflicts of interest, the ethical dilemma of assisted suicide is hopelessly complicated by physician participation. If society's consensus were that assisted suicide—stringently scrutinized and regulated—is acceptable, it need not and should not be physicians who provide it.

PAUL DRUCK
Minneapolis, Minn.

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50, 100 AND 150 YEARS AGO

SCIENTIFIC AMERICAN

SEPTEMBER 1947

A BETTER INSULATOR—"Reported to have a lower thermal conductivity than still air, heretofore theoretically considered the most efficient thermal insulator, a new material is 6 percent silica and 94 percent air. Chemically known as an aerogel, this new insulator is so efficient that it will make possible an increase in refrigerator and freezer capacity of up to 60 percent."

OIL DEODORIZED—"Decades ago, highly malodorous petroleum from certain fields was found to contain certain types of sulfur compounds, and these proved responsible for the 'skunk' which drove away possible buyers. When Herman Frasch discovered the effectiveness of metallic oxides in removing this sulfur by chemical action, he not only 'sweetened' the oil by destroying its odorous constituents, but he also brought into the market vast new supplies of oil from Canada, Ohio, and subsequently from other fields."

The new electrical cab

SEPTEMBER 1897

SEARCH FOR ELEMENTS—"At the British Association for the Advancement of Science meeting, Prof. William Ramsay showed why he expected still another element would in time be found resembling both helium and argon in some respects. Based on the difference in the atomic weights of helium and argon, he was led to believe that another member would be found for this group to fill a vacancy. Such discoveries, based on Mendeleef's 'Periodic Law,' have been predicted and made before this. The speaker expressed his own confidence in the soundness of Mendeleef's law, in spite of some discrepancies between the actual and theoretical atomic weights of many elements." [*Editors' note: Ramsay and Morris W. Travers isolated the new element the next year and named it neon.*]

TRUFFLE BIOLOGY—"The manner in which the truffle is reproduced has been a puzzle to botanists. A recent communication to the Academie des Sciences by M. Grimblot throws an interesting light upon the subject. It would seem that the diffusion of the spores is effected by wood mice. M. Grimblot's researches are in a line with other experiments to ascertain whether the diffusion of the spores is not effected by cattle. It is also thought that the moist heat in the intestines of these animals is necessary for the development of the spores of this valuable edible fungus."

ELECTRICAL CABS IN LONDON—"On August 19, electrical cabs began to ply for hire in the streets of London in competition with the ordinary hackney carriages. As our engraving shows, the new vehicle resembles very closely a horseless and shaftless coupé, carried on four wooden solid rubber-tired wheels. A three-horsepower motor is supplied with current by 1,400 pounds of storage batteries. The cabs can travel up to thirty-five miles per charge and at speeds up to nine miles per hour. It is intended to have electric supply stations at other parts of London besides that at Juxon Street, Lambeth."

SEPTEMBER 1847

ELECTRO-AGRICULTURE—"High expectations were once raised, relative to accelerating the growth of vegetables by electricity. Accurate scientific experiments have been lately made under the supervision of the London Horticultural Society, which set the matter finally at rest. A large and powerful electric machine was used, and the plants, in pots, were kept heavily charged, four hours each day, for four weeks, and not the slightest influence could in any case be perceived, either favorable or detrimental, to vegetable growth between those electrified and those not."

CUCA—"Prescott, in his 'Conquest of Peru,' says the cuca is a shrub which grows to the height of a man. The leaves, when gathered, are dried in the sun, and being mixed with a little lime, form a preparation for chewing, much like the betel leaf of the East. With a small supply of this cuca in his pouch, and a handful of roasted maize, the Peruvian Indian in our time performs his wearisome journeys day after day, without fatigue or at least without complaint. Yet, with the soothing charms of an opiate, this weed, so much vaunted by the natives, when used to excess, is said to be attended with all the mischievous effects of habitual intoxication."

NEWS AND ANALYSIS

IN FOCUS

EVOLUTION EVOLVING

New findings suggest mutation is more complicated than anyone thought

GOPAL MURTI SPL/Photo Researchers, Inc.

ASEXUAL POPULATIONS OF* E. COLI *BACTERIA seem to increase their rate of "good" mutations depending on the environment.

Nine years ago John Cairns and his colleagues at the Harvard School of Public Health reported in the influential journal *Nature* sensational experiments "suggesting that cells may have mechanisms for choosing which mutations will occur"—specifically, in ways that give those cells an advantage in stressful conditions. This radical proposal collided head-on with the sacrosanct principle of genetics that mutations occur at a rate that is completely unrelated to whatever consequences they might have. Cairns's suggestion thus conjured the ghost of Jean-Baptiste Lamarck, who argued in the 19th century that species evolve through the inheritance of "acquired" characteristics—ones that individuals develop in response to environmental challenges.

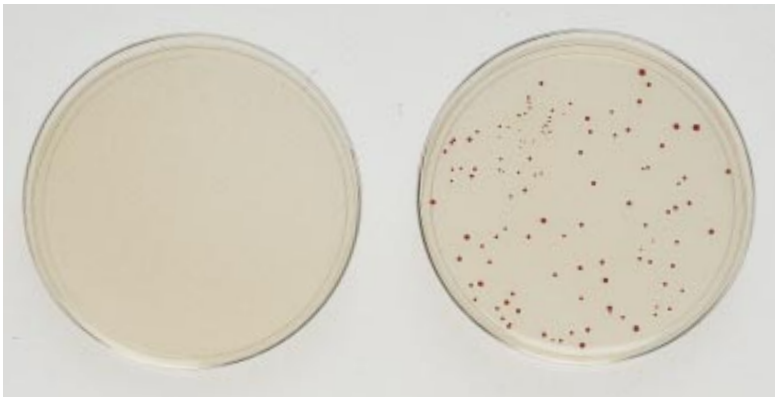
Cairns postulated that bacterial cells, in effect, mysteriously know in advance which mutations are likely to benefit them. Then, when investigators stress the cells by starving them, the bacteria tip fate's scales so that rare beneficial mutations happen more often than chance would allow.

This incendiary idea, known as directed mutation, ignited a firestorm of debate. Almost a decade later the dust has still not settled. Investigators around the world have immersed themselves in complex experiments to learn whether the apparent surplus of beneficial mutations in Cairns's studies—confirmed by other researchers—might have a less explosive alternative explanation. Potentially far-reaching discoveries are now emerging.

Most biologists now believe—and Cairns has acknowledged—that the seeming excess of beneficial mutations found in many directed-mutation studies might arise because researchers are more likely to spot and so count beneficial events than they are harmful ones. Various theories have been advanced to explain why, although none has gained universal acceptance. Recent experiments, however, provide important evidence for one effect that could produce such a counting bias. The effect, hypermutation, thus might make true directed mutation unnecessary. But hypermutation itself opens the door to some intriguing possibilities.

Hypermutation was first proposed as an explanation for Cairns's results in 1990, by Barry G. Hall of the University of Rochester. Hall conjectured that when starving, a few bacterial cells might enter an unusual state in which they generate multiple mutations. Cells that by random chance produced favorable mutations in extremis would survive to be counted, but others would probably die and leave no trace. So investigators would see more beneficial mutations than harmful or neutral ones.

For some years, technical obstacles made it hard to confirm or refute this explanation. Now Patricia L. Foster of Boston University and, separately, Susan Rosenberg of the University of Alberta have performed experiments that give it a boost. Like Cairns, the researchers studied bacteria that lack the ability to feed on the sugar lactose. When Foster and Rosenberg deprived the bacteria of all sugars except lactose, excess mutations arose not only in a gene that allowed the bacteria to use the lactose but in other genes, too. The two sets of results "together show the generality of hypermutation under lactose selection," commented Bryn A. Bridges of the University of Sussex in *Nature* on June 5. The results suggest, as Hall had proposed, that hypermutation occurs in some cells that are under physiological stress, possibly because DNA is more likely to break under such conditions.



NAJLAH FEANNY *SABA*

ECHOES OF LAMARCK?
***Normal bacteria are wiped out in an antibiotic-coated petri dish* (left), *whereas their descendants, which have defective genes that cannot repair mutations, thrive* (right).**

Bridges reserved judgment on whether bacteria evolved the capacity for hypermutation as an adaptation to overcome nutritional stress or whether the effect is merely a mechanical response to starvation. But studies reported in the same journal a week later suggest—to some, at least—a possible way that hypermutation may indeed have evolved as an adaptation.

These latest findings show that in natural populations of bacteria, "mutator genes," which increase the mutation rate, can spread through a population by allowing the bacteria to evolve faster. Paradoxically, this happens even though mutations produced by the mutator genes, like others, are on average harmful. The seemingly impossible occurs because mutators occasionally arise in individuals that also carry an advantageous gene. In an asexual population, the mutator may then spread with the advantageous gene, a phenomenon called the hitchhiking effect.

François Taddei of the CNRS in Paris and an Anglo-French team showed in a theoretical study that in a changing environment, the faster evolution made possible by mutator genes often outweighs their disadvantage to the individual. And Paul D. Sniegowski of the University of Pennsylvania and his colleagues showed that mutators can get ahead in real populations as well. In three out of 12 bacterial colonies evolving in a new environment, mutator genes swept through the population and became ubiquitous.

Researchers have found evidence that mutator genes are especially common in tumors and pathogens. By allowing faster evolution, they might help the villains evade hosts' immune systems, Sniegowski suggests. And although he emphasizes that his finding has no immediate bearing on the notion of directed mutation, the new crop of results leads some biologists to suspect that mutation might play a more complicated role in evolution than they had believed.

In a *Nature* commentary on June 12, E. Richard Moxon of John Radcliffe Hospital in Oxford, England, and David S. Thaler of the Rockefeller University note that many pathogens have some collections of genes that are excessively prone to mutation. Mutation frequently varies the combinations of these hypermutable genes that are in active service by making individual genes functional or not. Because the genes affect how the pathogen interacts with its host, hypermutation within such special sets of genes allows the microbe to confound immune defenses.

Other hypermutable gene sets might assist in solving different challenges, Moxon and Thaler conjecture. If, for example, the genes' rate of mutation is affected by a microbe's physiological state, like the mutation rates Rosenberg and Foster studied, hypermutable genes could generate mutations when a cell was starving and so help mimic directed mutation. The mutations would still be random, but the most beneficial ones would remain long enough to be counted. The appearance of directed mutation might thus arise "with no requirement for new molecular mechanisms," Moxon and Thaler surmise.

The scientists suggest further that if physiological factors can influence hypermutable genes, perhaps separate mutator genes can also switch on and off hypermutable genes. Mutation rates would then be subject to fine-grained genetic control. Thaler says that "the mechanisms for the generation of variants are themselves subject to evolution."

It might take another decade to learn whether evolution routinely plays such a sophisticated game with mutation rates. But one piece of unpublished work lends support to the notion that mutator genes might have a part in how hypermutation simulates directed mutation. Hall has recently isolated five bacterial genes that make excess favorable mutations seem to appear elsewhere in the bacterial DNA. Hall thinks his newly isolated genes somehow stimulate hypermutation and so generate the illusion of overabundant advantageous mutations. "In my gut I feel it's an evolved phenomenon," he says. Pure directed mutation, with its spooky foreknowledge, may be dead. But real mechanisms that produce the ghost of directed mutation could yet shake up biology.

"In evolutionary theory there has been an overemphasis on the power of selection as opposed to the generation of diversity," Thaler goes on to reflect. "Maybe this will take it to another level." —*Tim Beardsley in Washington, D.C.*

LABORATORY SAFETY

LOOKING FOR ALTERNATIVES

A scientist's death raises questions about a toxic mercury compound

Chemists and biologists across the country were shocked this summer by the death of their colleague, Dartmouth College professor Karen E. Wetterhahn. A highly esteemed researcher, the 48-year-old chemist was seeking to understand how high doses of heavy metals can disrupt the normal functions of molecules and cells. Ironically, Wetterhahn herself became the victim of heavy metal poisoning when, in the course of her experiments, she accidentally exposed herself to dimethylmercury, a rarely used and extremely toxic compound.

Wetterhahn was using nuclear magnetic resonance (NMR) spectroscopy to investigate the binding of mercury ions to a protein involved in DNA repair, says Dartmouth chemistry department chairman John S. Winn. By measuring the resonance of bound mercury nuclei, Winn explains, Wetterhahn could determine the nearby molecular structure and figure out what part of the protein was being attacked by the metal. The resonance of each element studied in NMR spectroscopy is measured in reference to a standard compound that contains that element, just as the height of mountains is measured against sea level, Winn says. Following a tradition set in the published literature, Wetterhahn chose dimethylmercury as a standard for her mercury measurements.

By all accounts a meticulous experimentalist, Wetterhahn spilled a tiny amount of the colorless liquid compound on her latex gloves in August 1996 while transferring it to an NMR tube, according to Michael B. Blayney, director of environmental health and safety at Dartmouth. Although she was most likely unaware of it at the time, the toxic material apparently permeated her gloves and seeped into her skin in a matter of seconds, Blayney says. Wetterhahn became ill a few months later and died of mercury poisoning less than a year after the exposure.

In the wake of her death, Wetterhahn's Dartmouth colleagues are trying to get word out to the chemistry community that disposable latex and PVC gloves do not offer sufficient protection against this and other hazardous materials. In a May 12 letter to *Chemical and Engineering News,* Blayney and two other Dartmouth scientists reported the poisoning incident and related an independent laboratory's finding that dimethylmercury penetrates disposable gloves in 15 seconds or less. Blayney has also contacted the chemical's distributors, who are in turn updating the safety information that is sent to those who purchase dimethylmercury.

JON GILBERT FOX

CHEMIST KAREN E. WETTERHAHN was accidentally poisoned in her own lab.

The letter's authors further urged the mercury-NMR community to consider using a less dangerous benchmark. Paul D. Ellis, one of the scientists who helped to define the dimethylmercury standard in the 1970s, explains that the compound was chosen for the chemical properties that allow it to give a clear, reproducible NMR signal. Yet Ellis, an associate director at the Pacific Northwest National Laboratory in Richland, Wash., says chemicals such as dimethylmercury must be treated "as if they're death on wheels." In light of the compound's devastating toxicity, Ellis believes an inorganic mercury salt, a much safer substance, could serve as a secondary reference to dimethylmercury—NMR researchers need never actually handle the more hazardous material.

Inorganic mercury salts are generally less volatile and less lipid-soluble than dimethylmercury, so scientists face a smaller risk of inhaling or absorbing mercury when working with them, says Northwestern University chemist Thomas V. O'Halloran. But using these salts as NMR benchmarks can be tricky because they are sensitive to their environment in solution—concentration, solvent type and temperature can all affect the NMR signal of the mercury. (A liquid at room temperature, dimethylmercury can be used neat.)

Still, a carefully prepared salt solution should make an acceptable alternative standard, according to O'Halloran, an expert in the use of mercury NMR to probe protein structure and function. Several members of the mercury-NMR community already use salt standards, and researchers in O'Halloran's laboratory are conducting experiments to characterize a variety of mercury compounds fully. (Their data, along with comments, are to be posted at http://www.chem.nwu.edu/~ohallo/HgNMRStandards on the World Wide Web.)

Although only a handful of labs currently utilize mercury NMR, O'Halloran and others believe the number will grow in the next few years because the approach provides a powerful tool for investigating biological systems. Because mercury can be substituted for metals such as zinc and copper, which do not give NMR signals, mercury NMR can be used to examine the metal-ion binding sites of proteins crucial to biological processes.

At the time of her death, O'Halloran says, Wetterhahn was using these and a variety of other techniques to lead her field to a deeper understanding of the toxicology of metal-containing compounds. "Her scientific accomplishments, her enthusiasm and her courage," O'Halloran remarks, "will continue to inspire further studies, conducted with appropriate caution, into the influence of these potentially dangerous substances on life." —*Rebecca Zacks*

ASTRONOMY

CRASH AND BURN

Radio "eyes" witness the mass births and deaths of stars

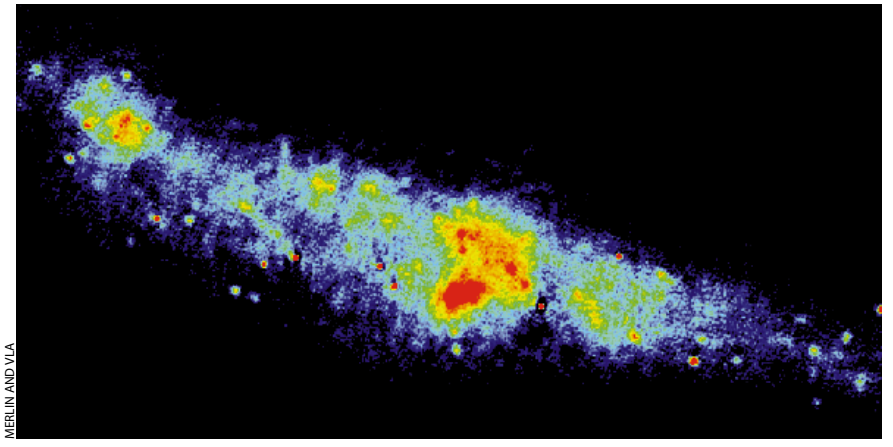
Much like Shiva in Hindu mythology, the universe often destroys with one hand while creating with the other. The peculiar galaxy known as M82 is a prime case in point. For years, textbooks described M82 as an exploding galaxy based on its jagged, agitated appearance. Astronomers have since come to realize that what they were witnessing was not death alone but also violent birth. An unsettling interaction with its huge neighbor M81 seems to have disrupted M82 so that gas and dust are rapidly being converted into stars. As these stars age, some explode as supernovas, compressing the surrounding gas and triggering still more star formation.

This "starburst" process has been understood in principle and yet never observed in detail. The same gaseous material that gives rise to new stars obscures any light coming from where the action is. Radio waves, however, can penetrate freely through the murk. Knowing that, a team including Tom W. B. Muxlow, Alan Pedlar and Karen A. Wills of the University of Manchester used the Multi-Element Radio-Linked Interferometer Network (MERLIN), a group of radio telescopes scattered across the U.K., to scrutinize the inner regions of M82. The result (*below*) offers an in-depth look at the galactic upheaval that creates stars en masse.

To generate the image, the Manchester team combined its MERLIN observations with data collected by the Very Large Array (VLA) radio telescope in Socorro, N.M. The composite result covers an area roughly 3,000 by 2,000 light-years across (M82 as a whole is about 40,000 light-years wide) with a resolution comparable to that of the best ground-based optical telescopes. Each of the spherical shapes is a supernova remnant, debris from the thermonuclear detonation of a short-lived, massive star. Some 50 supernovas have occurred in this region just within the past 1,000 years, more than 10 times the rate in our own, much larger galaxy. "M82 is like a vast lab for understanding the birth and death of high-mass stars," Wills says. As the supernova remnants expand, they gradually blur into the more diffuse radio glow of M82, a cumulative relic of older explosions that took place as long as 10 million years ago.

The kind of galactic encounters that produce starbursts are rare in our cosmic neighborhood. At 10 million light-years distant—about five times as far as the Andromeda galaxy—M82 is the nearest major starburst galaxy. But collisions were far more common in the early universe, and starbursts probably were critical episodes in the evolution of many galaxies, including the Milky Way. So "studying M82 is just the start," Wills notes: Astronomers look to the galaxy as a Rosetta Stone to help them understand how amorphous blobs of gas transformed into the star-studded, organized systems that we see today.

To that end, Muxlow and others are teaming up again with their counterparts at the VLA to study the extremely remote objects spotted by the Hubble Space Telescope in what is known as the Hubble Deep Field (actually a spot of the sky located near the handle of the Big Dipper). Although it will not be possible to study these faint glimmers with anything like the precision of the M82 image, these radio observations should demonstrate whether, as many researchers suspect, the irregular shapes seen by the space telescope are indeed young galaxies experiencing early hiccups of star formation. Such a finding would establish a crucial developmental link between our modern world and the near-formless era of the big bang—the greatest, most violent creator of them all. —*Corey S. Powell*



MERLIN AND VLA

STARBURST GALAXY M82 ***is studded with supernova remnants*** **(round shapes),** ***as seen in this radio image.***

FIELD NOTES

FLYING AND THE BENDS

"Getting narked" for science

Richard D. Vann is addressing the guinea pigs, including me. "For this study to be successful," he says, "somebody's got to get some decompression sickness. We don't know if it's going to be today, or if it will be any of you, but someone is going to get it."

Well, actually, in the four years the study has been going on at the Hyperbaric Center at Duke University Medical Center, 22 people have been "bent" during some 580 trials. But if you are going to get bent, this is the place to do it; the Duke center is one of the best for both clinical treatment of, and research into, the illnesses caused by decompression, which can cause nitrogen to bubble out of solution in the blood. And besides, only mild bends are expected.

I met Vann several years ago and, ordinarily, like and appreciate his unflinching candor. After graduating from Columbia University in the 1960s, he voluntarily subjected himself to experimental, 207-meter (650-foot) dives in a chamber. A fit, wiry man, he's been bent about 10 times, once during these experiments.

The point of our study is to find out how long divers should wait before flying. Because the cabins of commercial airliners are pressurized to only about two thirds or three quarters of an atmosphere, flying too soon after a dive can bring on the bends. But official recommendations on how long to wait range

BUTCH USERY *Duke University School of Medicine*

TRYING TO GET BENT *are volunteers in a pressure chamber at Duke University.*

from two hours (the U.S. Navy) to 24 hours (the U.S. Air Force), with hardly any data to support either of them.

Twelve of us have volunteered to be compressed in a hyperbaric chamber to four atmospheres, the pressure at a depth of 30 meters (100 feet) for 15 minutes. After an hour at surface pressure we are to be compressed again, this time, to roughly three atmospheres (19 meters) for half an hour. After a 15-hour surface interval, we are to go back into the chamber for a four-hour "flight," at a simulated altitude of 2,440 meters.

My chamber mates and I turn out to be more of a cross section than might be expected. Yes, rugged males are fairly well represented, but so are petite women. There is a physician from Munich, a married couple from North Carolina, a millwright from Virginia, a government bureaucrat from Maryland and three people from Tennessee, a factory worker and a foundry worker/diving instructor who brought along his 18-year-old daughter. We have all signed an informed consent statement indicating we understand the risks of the study. Reassuringly, Duke Medical Center's committee on the protection of human subjects approved the study.

If there are no cases of the bends during our run and during another with the 15-hour interval, Vann will move on to a 14-hour interval. The intervals will keep getting shorter until there are two mild cases in 10 trials, or three in 35. Testing also stops if there are four mild cases or if any case is more than mild.

After a checkup and a pizza lunch, we are sealed in the chamber. There is a loud hissing as the pressure builds. The "descent" rate of nine meters per minute soon turns out to be too rapid for my left ear, and I have to interrupt the descent a few times to let it equilibrate. The rising pressure sends the temperature shooting to about 43 degrees Celsius (110 degrees Fahrenheit). When we get to 30 meters, I feel a kind of vague exhilaration and realize I am at last experiencing the narcotic effects of breathing nitrogen at high pressure. We had been told that "getting narked" was more likely in the chamber because of the heat and lack of distractions. The next thing I notice is that my own voice sounds high-pitched and strange to me, although everyone else's voice sounds fine. William Moore, the millwright, tells a joke about a toothbrush salesman. I laugh. I'm definitely narked.

The tipsy feeling soon disappears as the pressure is reduced and we begin "surfacing." By the time we get to one atmosphere, the temperature has dropped to around 10 degrees C, and the chamber is full of fog.

After we surface, Bruce Cohen, the study's physician, examines my left eardrum. He pronounces it "pink and angry" but not so much so that I can't continue. Following both the dives, and every 30 minutes during the flight the next day, a medical technician uses an acoustic device to listen for bubbles in the blood flowing in our hearts. Bubbles had been detected in one of the subjects the day before, after the first dive. The bubbles never turned into an actual case of the bends, however. In the end, none of us comes down with the bends.

At home, I had a difficult time convincing my friends that I'd had rather a lot of fun. After all, I helped advance diving physiology, however incrementally, and I bonded with a bunch of other divers, in this mysterious way that seems to require dissolved nitrogen in your blood.

A month after our trials, the 14-hour surface interval was tested, and still no one was bent. Vann is undeterred. "My guess is that we'll start picking up some symptoms at 13 hours. But my predictions have been wrong so often that I've stopped trusting them. That's why," he adds with a laugh, "we need you laboratory rats to tell us." —*Glenn Zorpette*

Jacques-Yves Cousteau, 1910–1997

Jacques Cousteau's love for water began when, as an anemic four-year-old, he learned to swim at a French resort well north of his hometown of St.-André-de-Cubzac, near Bordeaux. He began more formal training in the ways of the seas after entering the French naval academy in 1930. A few years later Cousteau, who held no science degree, started experimenting with snorkel hoses, portable breathing devices and other diving equipment. Those efforts reached a pinnacle in 1943, when Cousteau and engineer Émile Gagnan produced the Aqua-Lung—known now as scuba, an acronym for *s*elf-contained *u*nderwater *b*reathing *a*pparatus.

WIDE WORLD PHOTOS

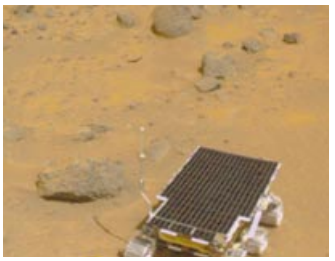
With a movie camera in a watertight housing, Cousteau went on to capture and describe spectacular vistas of the undersea world, starting with *The Silent World,* a book and documentary that garnered prestigious awards. That and subsequent projects, especially in the 1960s and 1970s, solidified Cousteau's reputation as explorer and popularizer. The projects—among them a documentary about experimental habitats on the continental shelves and a television series, *The Undersea World of Jacques Cousteau*—inspired a generation of oceanographers and environmentalists.

During the 1990s, Cousteau faced several, more personal challenges, including the death of his first wife, Simone Melchior, and alienating disputes with his first son, Jean-Michel. Moreover, his famed vessel, the *Calypso,* sank in Singapore Harbor in 1996. Ill for months, he died on June 25, 1997, from heart and lung problems. —*The Editors*

IN BRIEF

Martian Chronicles

Pathfinder and its tiny rover, Sojourner, continue to reveal new facts about the red planet's rocks. The Viking probes launched in 1975 offered limited insight, because most rocks surrounding their landing spots had a similar makeup. But Pathfinder put down in the middle of an ancient floodplain. Scientists guess that there, long ago, flowing water ferried in a wide variety of rocks from afar. In fact, recent data on Barnacle Bill and a larger boulder nearby, dubbed Yogi, demonstrate that the two are quite different. Analyses of other rocks such as Scooby Doo should reveal more details about Mars's history. Images and updated information are available at http://www.jpl.nasa.gov/mpfmir/ on the World Wide Web.



NASA

Putting Seaborgium in Its Place

Some heavy elements prove hard to position on the periodic chart. It's not as simple as counting electrons. Relativistic effects between these particles make recent finds such as rutherfordium, which has 104 electrons, behave in unexpected ways. But Matthias Schädel of GSI in Darmstadt, Germany, and his colleagues have now shown that 106-electron seaborgium in fact does resemble lighter group VI chemicals in its same column, such as molybdenum and tungsten.

AMA on Abortion

For only the second time in its 150 years, the American Medical Association has called for laws against a medical procedure. Last year the organization, which represents nearly half of all doctors in the U.S., asked Congress to condemn female genital mutilation. And in June this year, they endorsed federal legislation that would ban late-term abortions. The group, which is otherwise pro-choice, also voted to work with lawmakers to ensure that doctors performing late-term abortions would be spared criminal charges. Under the current federal proposal, physicians would face fines and up to two years in prison. Many states have established more severe penalties.

More "In Brief" on page 28

ANTI GRAVITY

An Axis to Grind

Any man will tell you that the mammalian penis is pretty special, but such commentary is usually worthless. Now comes independent confirmation from a female scientist that the penis is indeed one of evolution's exceptional accomplishments.

Diane Kelly, a postdoctoral associate at the College of Veterinary Medicine at Cornell University, has a long interest in how organisms solve life's engineering challenges. At Duke University, Kelly studied the relation between form and function in the mammalian penis, work that appears in the August issue of the *Journal of Morphology*.

As hydrostatic organs, penises have to fill with fluid to adopt a reproducible, typical shape with structural integrity. Kelly had seen passing comments in the literature describing the human and dog penises as having collagen fibers apparently running perpendicular to one another. To extend those findings, she turned to the nine-banded armadillo, or peba.

"They're not endangered," Kelly says of her study subject, "and they're easy to get." As easy as collecting them from the roads near Tallahassee, where their horny coverings are no match for Florida drivers. What pebas really have going for them, however, is bang for the buck. "Their penis is about one third of their body length when it's erect," Kelly notes. "So you can work with this nice big piece of tissue."

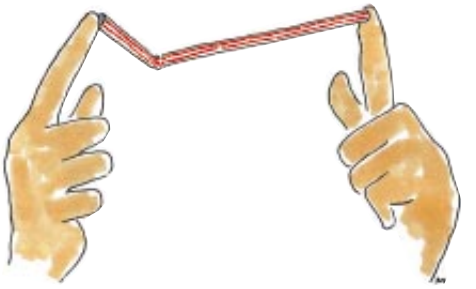
Doing those tests, however, meant giving dead armadillos erections, no mean accomplishment. "All the tissue I used had already been separated from the animals," Kelly explains. "So what you end up with is a little sock, with one open end." Tie off the opening, inject some saline, and voilà.

On erection, two crimped layers of collagen fibers straighten. An inner layer of collagen forms rings around the long axis while the outer layer makes for parallel lines along the axis. Kelly's careful measurements of the fiber angles, the first in the literature, showed that the angle between them was exactly 90 degrees, or orthogonal. The mammalian penis is thus the only hydrostatic organ reinforced by collagen fibers in this way.

Now, other biological systems have orthogonal fiber arrays—for example, worm bodies. In worms, however, the entire crosshatched array runs diagonally to the long axis, not along it, as in the penis. "Worms can bend" thanks to the alignment of the array, Kelly says: "The whole idea behind the penis is that you don't want it to bend."

Kelly also did quick takes on other mammalian species to make sure that the fiber array was similarly oriented. "I used tissue that people gave me," she confides. "It was amazing. At meetings I started talking to people about what I was doing, and then people started giving me things."

The fiber orthogonality and relation to the long axis give the mammalian penis qualities that are more sophisticated than those of other vertebrate penises. Although very good at withstanding head-on forces, the erect mammalian penis does have an Achilles' heel. "If the bending force is very large," Kelly elaborates, "the side in compression will tend to fail. And the kind of failure you get is a very sharp kink, like when you take a soda straw and you push on both ends. It'll bend for a little while in a curve, but then one end of it just goes. In engineering terms, it's called local buckling. And local buckling is often considered a sort of catastrophic failure." To be sure.



MICHAEL CRAWFORD

The medical literature does mention cases of "penile fracture," which appear to be unfortunate instances of the above scenario. "Subjects aren't very forthcoming about how they did it. So it's kind of hard to get hard data on that," Kelly says. At least one known veterinary example involves a very unhappy rhinoceros, whose charging days are very likely over. Those poor souls learned that the laws of nature, unlike some of its products, are strictly unbendable. —*Steve Mirsky*

In Brief, *continued from page 26*

A Touch of DNA

Forensic scientists down under have demonstrated that it is possible to take DNA fingerprints from, well, fingerprints. No blood, no hair, no bone. Roland A.H. van Oorschot and Maxwell K. Jones of the Victoria Forensic Science Center simply swabbed objects—briefcase handles, pens and telephone handsets—that specific individuals had touched. In each case, the team found genetic typings that matched the user. The catch? Objects held by many people offer many profiles, and the most dominant is not always significant. Also, a handshake can be sufficient for transferring telltale DNA between palms.

Taking Heart

Some 70 percent of all infants born with severe heart defects die before their first birthday, but imaging techniques until now used only in adults may well improve the odds. Indeed, a recent study by cardiologist Paul T. Pitlick and his colleagues at Stanford University found that contrast-enhanced electron-beam CT scanning, a noninvasive procedure that enables a computer to generate a three-dimensional model, is as effective as traditional angiography in diagnosing congenital heart defects. And the resulting 3-D models, which can be rotated and disassembled, should help pediatric cardiologists do delicate surgery on walnut-size hearts.

IMATRON

Death of a Salesman

Sudden changes in climate and environment understandably make globetrotters more susceptible to sundry illnesses. In addition, a new study of 10,884 employees at the World Bank has found that serious travelers are more prone to psychological maladies as well. The researchers, led by Bernhard Liese, director of the bank's health services department, discovered that men on the go filed 80 percent more insurance claims than their deskbound colleagues. Female frequent flyers filed 18 percent more claims. To explain why men who take one trip a year submit twice as many claims for psychological treatment, the authors cite the stress of culture differences, shifting time zones and separation from family. They do not speculate as to why women are less likely to file. *—Kristin Leutwyler*

SA

ANTHROPOLOGY

NEANDERTHAL NOTES

Did ancient humans play modern scales?

Julie Andrews made the do-re-mi scale famous by cleverly teaching it to her spoiled young charges, but Neanderthals may have been better students. A recent analysis of what may be the world's oldest known musical instrument, a flutelike piece of bone found at a Neanderthal hunting camp, suggests that more than 43,000 years ago the foothills of the Slovenian Alps may have been alive with the sound of music based on that very same scale.

The "flute" was discovered in 1995 by Slovenian Academy of Sciences paleontologist Ivan Turk, who was leading excavations of the Divje Babe I cave in northwestern Slovenia. Found near an ancient hearth and Mousterian tools (those associated with Neanderthals of this period), the fragment of cave bear thigh bone preserves two complete holes and perhaps remnants of two others. The holes in this bone, between 43,000 and 82,000 years old, are "really well rounded and just about the right separation for humans to put their fingers on," according to team member Bonnie Blackwell, a Queens College geologist.

When Bob Fink, a musicologist in Saskatoon, Saskatchewan, saw a photograph in a newspaper report announcing the discovery last year, the spacing of the holes caught his eye. The distance between the second and third holes was twice that between the third and fourth holes. This indicated to Fink that the flute could produce whole tones and half tones, the fundamental elements of the diatonic, or do-re-mi, scale. The notes are "inescapably diatonic," Fink writes in his analysis (on the World Wide Web at http://www.webster.sk.ca/greenwich/fl-compl.htm). Based on the widespread use of this scale throughout many cultures over time, the odds are, says Fink, that the complete flute would have produced the entire scale. He thus suspects that the flute had at least six holes and was some 37 centimeters long.

Not everyone agrees with Fink. Cleveland State University ethnomusicologist T. Temple Tuttle points out that for the observed hole spacings, "there are a number of scales for which this is a prototype," citing the South Indian system as a more likely match.

Others wonder whether this piece of bone is indeed a flute. The holes may simply be the result of carnivore gnawing. Blackwell maintains that nothing on the micrographs indicates that this bone has been chewed on, but other researchers want to judge for themselves. "I haven't seen it," admits New York University anthropologist Randall K. White, "but my tendency for this kind of Mousterian stuff is to be hyperskeptical."

David W. Frayer, an anthropologist at the University of Kansas, attributes a lot of skepticism to preconceived notions about Neanderthals and their capabilities. He points to a strikingly similar flute from Hungary attributed to later Europeans. "No one doubted that it was a flute, and it's more fragmentary than the Divje Babe flute," Frayer says. "That this is found in the Mousterian causes people to question it."

Flute playing would fit neatly into the growing body of evidence that supports a view of a more sophisticated Neanderthal: they buried their dead, made symbolic objects and adorned their bodies. And if they were playing musical instru-

NEANDERTHAL FLUTE
reconstructed from a bear bone could have played do-re-mi.

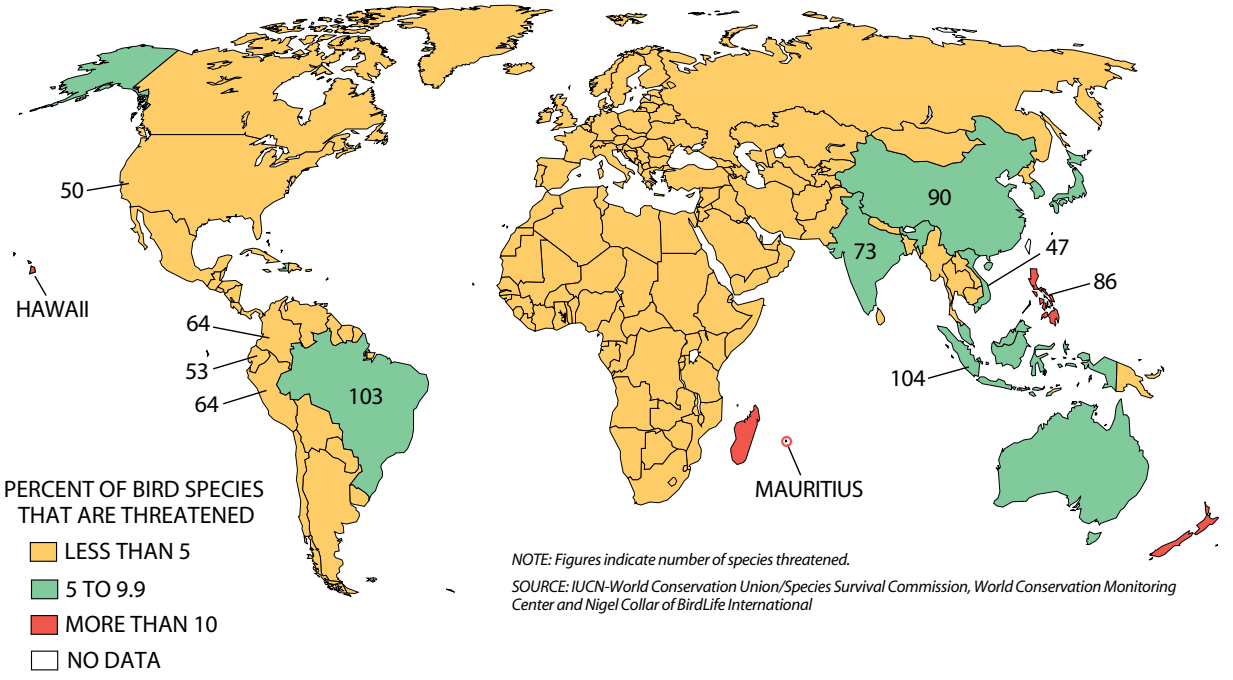
PHOTOGRAPH COURTESY OF BONNIE BLACKWELL; DRAWING BY PORTIA ROLLINGS

ments, opines University of Michigan paleoanthropologist Milford H. Wolpoff, "it would be a key to arguing that they were capable of language as well."

But such advanced practices may not have seeded the modern human inclination for them. Researchers analyzing DNA that was extracted from Neanderthal bone found no trace of genetic intermixing with moderns and therefore concluded that Neanderthals are not our ancestors. Critics, however, point out that these findings are based on a very small sequence of DNA from a single individual and that the data are still compatible with Neanderthal ancestry. Yet even if Neanderthals were an evolutionary dead end, it is clear that they had more in common with Julie Andrews and other modern humans than anyone would have predicted. *—Kate Wong*

BY THE NUMBERS

Threatened Birds



NOTE: Figures indicate number of species threatened.

SOURCE: IUCN-World Conservation Union/Species Survival Commission, World Conservation Monitoring Center and Nigel Collar of BirdLife International

There are many reasons for protecting birds, not the least of which is the delight we take in watching them. It's sad, then, to note that 1,107 bird species—11 percent of the globe's total—are at risk of dying out. This report comes from a major new study by IUCN (also known as the World Conservation Union) and BirdLife International, the world's chief organization concerned with threatened birds. Their data show that 168 bird species are "critically endangered"—meaning they face an extremely high risk of extinction in the wild in the immediate future. (The other two IUCN risk categories are "endangered," or very high risk of extinction in the near future, and "vulnerable," or high risk in the medium-term future.)

Birds, like other animal groups, are most threatened in island habitats, and indeed, of the 104 bird species that became extinct in the past 400 years, about 90 percent lived on islands. Island species, particularly in the tropics, are often found nowhere else on the planet and therefore cannot be replenished from outside. Such species have few defenses against such introduced predators as cats and dogs, and their habitats may be constricted by nonindigenous herbivores such as goats. Furthermore, they are vulnerable to introduced diseases. It is no wonder, then, that the two countries with the highest risk for birds are the Philippines and New Zealand. In both places, 15 percent of species are threatened. But of all islands with sizable populations, Hawaii, at 33 percent, has the highest proportion of threatened bird species.

Significant threats to bird life exist in continental areas as well, such as South America, because of exploitation of the tropical forest. Although the proportion of avian species threatened is moderately low, this region supports a huge variety of birds, and so the absolute number of species at risk is quite large, as shown by the numbers on the map. The comparatively high rates in China and India probably result in part from population pressure.

The risk on other continents is low, but that does not necessarily indicate an absence of major problems. In Europe, for example, where only 1 to 2 percent of species are threatened, a quarter of all species classified as not threatened have suffered significant declines in the past 20 years. In the continental U.S., where the threat to birds is also low, several once widespread species have vanished altogether, including the passenger pigeon and the colorful Carolina parakeet. Among several bird orders, more than 20 percent of species are threatened. They include pheasants, quails, parrots and macaws, all of which are threatened by habitat loss and exploitation by hunters and traders. Also of concern are albatross and petrels, which breed on small oceanic islands. Many species of rails, cranes and kagus are also at high risk because they are very slow-breeding animals, making them extremely vulnerable to disturbance of nesting grounds and wintering areas. Songbirds, which account for almost 60 percent of all bird species, have a slightly below-average risk of extinction, but some species, including those in American grasslands, are in serious decline. *—Rodger Doyle (rdoyle2@aol.com)*

RODGER DOYLE

PROFILE: JAN MOOR-JANKOWSKI

A Whistle-Blower's Wars

MARK HAVEN

OLD-WORLD HONOR *led animal experimenter Jan Moor-Jankowski into conflict with his former employer.*

At the bus stop in Greenport, N.Y., the village where he has retired to tend his wounds, Jan Moor-Jankowski is waiting. He holds out a hand, towering over me with a straight-backed, military posture softened by a slight stoop of politeness. Tired folds of skin hang around his eyes, giving him the sad look of a basset hound. His old war injuries have become inflamed, Moor-Jankowski tells me, walking with a slight limp: "It's probably stress-related." His voice, too, sounds tired and halting. He has nightmares, these days, of being forever barred from the laboratory he created.

Moor-Jankowski co-founded and for 30 years directed the Laboratory for Experimental Medicine and Surgery in Primates (LEMSIP), a facility affiliated with New York University. In 1995 Moor-Jankowski and M. Louis Dinetz, the assistant director of LEMSIP, were dismissed, and N.Y.U. made plans to sell the facility. Moor-Jankowski says he was harassed, and ultimately fired, by N.Y.U. Medical Center for protesting violations of federal rules at another animal experimentation lab at N.Y.U.

Peter L. Ferrara, senior director of public affairs at N.Y.U. Medical Center, says that LEMSIP had become a financial liability, and its management was transferred to the Coulston Foundation, which dismissed Moor-Jankowski. But the foundation states that it started managing LEMSIP only in 1996 and had nothing to do with the firing.

Moor-Jankowski and Dinetz are suing N.Y.U., as well as the U.S. Department of Agriculture, which administers the Animal Welfare Act. Although the USDA fined N.Y.U. $450,000 for violations of the act—the largest such fine ever levied—Moor-Jankowski charges that it failed to respond to his pleas for whistleblower protection. The USDA declined to comment, citing the litigation.

The case of Moor-Jankowski provides the extraordinary spectacle of a scientist who experiments on chimpanzees, no less, receiving succor from antivivisectionists. "At times I hate him, for what he does [to animals]," says Geza Teleki, a primate conservator in Washington, D.C. "At times I like him, because he stands by what he says." LEMSIP was exceptional among American animal laboratories in that its doors were open to animal-rights activists and the media. "It is not necessary to hide [animal research]," Moor-Jankowski declares. "I find that open discussion in a democracy is a basis for formulating judgment."

A breeze rustles through the shady garden of his summer home; we settle down on the porch, on either side of a crystal vase filled with roses from a bush gone wild. His wife, Deborah, arranges a lunch of patés, cheeses and strawberries and bids Moor-Jankowski to tell me some war stories: "Your sense of honor and integrity begins young," she says with startling conviction.

Born in Poland, Moor-Jankowski was 15 when World War II arrived. In 1942 his parents died, and Moor-Jankowski was incarcerated by the Nazis in a Warsaw prison. He emerged one day under guard to find the surroundings burned down after a Jewish uprising. Someone started shooting, the guards fell to the ground, and Moor-Jankowski dashed into the ruins. The young man was later to be captured by, and to run from, German and Soviet soldiers innumerable times. "I always knew I had to run," he says, fixing me with his large eyes. "I never believed in waiting. All my life, I was always for going forward."

In 1944 Moor-Jankowski found himself in Berlin in the uniform of a German officer, participating in an elaborate scheme run by the Polish underground. He ferried arms from Italian partisans to Polish ones and transported Jewish and other deportees between Warsaw and Berlin so they could escape persecution. Later that year an explosive bullet burst in his knee, and Moor-Jankowski was shifted from hospital to hospital—apparently speaking German even under anesthesia—until in April 1945 he escaped to Switzerland.

Soon the war was over. Moor-Jankowski earned a medical degree; his

thesis described the flexible leg brace he invented and wears to this day. But his primary interest involved blood types, then the only known genetic marker. Moor-Jankowski found that an isolated Alpine population had an exceptionally high frequency of blood group O, carried by a recessive gene, and Rh negative. The discovery offered proof of the theory of genetic drift, by which random genes can become lost over time.

In 1959, at the University of Cambridge in England, Moor-Jankowski began to study primates as models for human immunology. He discovered that serum proteins could initiate an immune reaction and described the serum allotypes, or groupings, in mice, monkeys and humans. Soon after, Moor-Jankowski moved with his animals to the U.S. Along with Edward Goldsmith, a prominent surgeon, he was invited by a group of medical schools in the New York City area to set up a primate laboratory. LEMSIP was born, moving in 1967 to Sterling Forest, a suburb north of the city.

LEMSIP became a center of research on hepatitis, blood diseases such as sickle cell anemia and later, AIDS. The laboratory, designated a World Health Organization Collaborating Center for Hematology in Primate Animals, served as a model for primate facilities around the globe. In 1983 scientists from the Pasteur Institute in Paris announced the first vaccine for hepatitis B, developed on LEMSIP's chimpanzees. Moor-Jankowski organized conferences, launched a series of monographs and in 1971 founded a journal, all on animal experimentation. For his scientific and wartime achievements, he received numerous awards. And meanwhile, LEMSIP enjoyed good relations with animal-rights groups because of its open-door policy.

Even so, Moor-Jankowski always seemed to be in trouble of some kind. LEMSIP had a successful breeding colony of chimpanzees, funded by the National Institutes of Health; however, in 1979 the NIH shifted its contract—and the entire colony—to another facility that offered cheaper rates. LEMSIP sued. Although not pursued, the suit damaged Moor-Jankowski's relations with the NIH. (And the colony failed to breed in its new location.) In 1981 monkeys in a laboratory in Silver Spring, Md., were discovered chewing on their own arms and legs, the nerves to which had been cut for studies on nerve growth. Although some researchers testified that the animals had received adequate veterinary care, Moor-Jankowski said that was not possible on the 55 cents a day that the laboratory charged the NIH per primate. LEMSIP charged $2.50, and the monkeys it used in similar experiments did not self-mutilate.

That public statement won Moor-Jankowski no friends in the medical community. "He has his own ethics," Teleki notes. "And it certainly does not involve towing the line." And soon he was in real trouble. In 1983, as chief editor of the *Journal of Medical Primatology,* he published a letter by chairwoman Shirley MacGreal of the International Primate Protection League. She was criticizing a plan by an Austrian pharmaceutical company, Immuno, to establish a hepatitis research station in Sierra Leone using wild-caught chimpanzees. Immuno sued Moor-Jankowski and several other parties for libel. Ultimately, everyone settled but him. Seven years later the New York Court of Appeals threw out the suit in a landmark ruling that extended First Amendment protections to letters to the editor.

This scientist who experiments on chimps has received succor from antivivisectionists.

Still, the triumph was bitter. Moor-Jankowski received no support from scientific or medical groups; rather the National Association for Biomedical Research filed a brief in support of Immuno, arguing that a scientific journal should not offer a forum to an animal advocate. Those who did come to his aid were television companies, newspapers, New York–area universities—and animal-protection groups.

Meanwhile trouble was brewing at N.Y.U. Medical Center. Moor-Jankowski served on its animal care committee, a body required by law to oversee animal research. It transpired that Ronald Woods, a researcher at another N.Y.U. facility, was depriving his monkeys of water in an unapproved procedure.

Moor-Jankowski protested the water deprivation. "I'm not an animal lover," he explains. "But they are sentient beings, and they deserve their fair share." He was also convinced that Woods's studies were scientifically questionable. In 1993 three of the monkeys died after undergoing botched surgery. The USDA came in to investigate, and Moor-Jankowski cooperated.

It was at this time, Moor-Jankowski recalls, that LEMSIP started having bureaucratic problems. He had raised $1.2 million for improving cage sizes and primate care at the facility. But, he says, N.Y.U. Medical Center "didn't allow me to spend the money," so that LEMSIP ended up violating the new animal welfare regulations. Ferrara denies these claims and adds that updating LEMSIP would have required "three or four" million dollars. Moor-Jankowski and Dinetz also claim they were asked by N.Y.U. Medical Center to inflate overheads on a grant proposal. "It's clearly not something we would ask him to do," Ferrara responds. (But earlier this year N.Y.U. Medical Center paid a $15.5-million settlement for overbilling the federal government, the largest such payment by a university.)

In early 1995 N.Y.U. started to make plans to sell LEMSIP. Claiming he was being harassed for having helped USDA investigators, Moor-Jankowski sought whistle-blower protection from the agency. On August 8 the USDA informed David Scotch, associate dean of N.Y.U. Medical Center, of the complaint. "The day after, Scotch came into my office and fired me," Moor-Jankowski recounts.

Moor-Jankowski also charges that he was not allowed to collect his blood-grouping reagents and personal papers and that a guard was appointed to bar his entrance to LEMSIP. Mail was not forwarded, so he had to relinquish his editorship of the journal. His life's work, he says, remains locked inside LEMSIP. All of this, Ferrara says, is "clearly untrue." Meanwhile the fate of the institution is in limbo.

It is getting late in the afternoon, and Moor-Jankowski is exhausted. He goes inside to lie down, while I walk to the seaside with Deborah. She is worrying about his health; the case, which has barely progressed, is taking a toll. Although the USDA initially stated that N.Y.U. Medical Center "did in fact bring reprisals" against Moor-Jankowski, it later claimed there was not enough evidence. The defendants have asked for the case to be dismissed, which Moor-Jankowski's lawyer has vigorously opposed. For Moor-Jankowski, the larger goal is to force the USDA to protect the whistle-blowers who help it to uphold the law: "If it is so difficult for me, with all my awards and recognition, a young man who sees fraud has no chance."

This battle may turn out to be his longest one yet. —*Madhusree Mukerjee*

SPACE VENTURES

BUCK ROGERS, CEO

Trying to make money from the moon and asteroids

Not so long ago the idea of mining the moon or asteroids belonged strictly to science fiction. Then more visionary thinkers began seriously considering how tapping the wealth of materials in space might open the solar system to commerce sometime in the 21st century. Now a few real-life entrepreneurs are planning ventures to exploit Earth's near neighbors over just the next few years. Curiously, the makeup of some current scientific missions suggests that a shift toward commercialization of space exploration is already quietly under way.

The Near-Earth Asteroid Rendezvous (NEAR) probe recently raced past the asteroid Mathilde, on its way to the asteroid Eros. NEAR is one of the so-called Discovery missions sponsored by the National Aeronautics and Space Administration. Discovery programs must cost less than $150 million (in 1992 dollars) and require no more than three years to develop. But there is a more subtle aspect. Rather than being a NASA mission per se, NEAR is being run by a set of academic and industry partners; NASA essentially just buys the scientific data.

This change in the way NASA is doing business may be creating opportunities for more obviously commercial efforts. For example, James W. Benson, a retired software entrepreneur, founded Space Development Corporation this past January with the intention of launching a private probe to another near-Earth asteroid. His interest in space was sparked in 1991 by an article in the *Washington Post,* which referred to a metallic asteroid as "an astronomical El Dorado." Initially Benson planned to have his private craft fly to an asteroid and stake a mining claim, but he soon realized that the space probe could also carry scientific instruments and that he could sell the data. "We're going to be the first private exploration company," Benson asserts.

Benson has assembled a cadre of volunteer aerospace engineers to design his craft, Near-Earth Asteroid Prospector. In many ways, this group effort resembles the early stages of Lunar Prospector, a Discovery mission that will be sent to the moon at the end of October.

Alan B. Binder, the principal investigator, explains that Lunar Prospector was originally "meant to be a demonstration of commercial viability." Binder and his colleagues tried to raise funds from private sources in the early 1990s. At the time, the project was estimated to require only $10 million in addition to launch costs, which were to be picked up by the Soviets using their powerful Proton rocket. But when a $4-million contract with Pepsico (for advertising rights) failed, the venture foundered. Yet Lunar Prospector was positioned perfectly to win the competition when NASA announced the Discovery program of economy space exploration. "I had a cheap mission that was ready to go," Binder recalls.

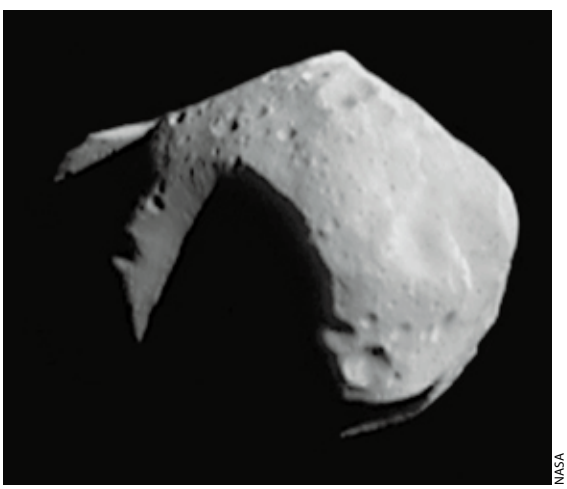
Binder, who is now retiring from Lockheed Martin, intends to mount privately sponsored lunar missions in the future and to sell the data obtained to NASA. Other lunar businesses hope to profit without depending on the space agency as their primary client. For example, LunaCorp in Arlington, Va., has teamed up with the Robotics Institute of Carnegie Mellon University in an effort to place at least two small roving vehicles on the moon, which would then serve as the central attraction for a theme park. A dress rehearsal of the concept took place this summer: the Robotics Institute sent a small "rover" to roam Chile's Atacama Desert. Paying visitors to the Carnegie Science Center in Pittsburgh had the opportunity to drive the robotic vehicle remotely.

It is remarkable to think such ticket sales might be sufficient to fund a sophisticated mission to the moon, but some in the business community are close to being convinced. According to William L. Whittaker, director of the Field Robotics Center at the Robotics Institute, his joint effort with LunaCorp almost achieved financial liftoff last year. They were negotiating with Walt Disney Company, among others, and nearly persuaded their would-be backers of the reliability of their chosen launch vehicle, the Russian Proton rocket, when the Proton carrying the Mars '96 probe sent its payload tumbling into the Pacific Ocean. That failure, Whittaker believes, gave the potential corporate backers cold feet.

David P. Gump, president of LunaCorp, is still hopeful about getting to the moon before 2001 by looking outside the U.S. for support: "For the rest of the world, going to the moon is a new thing." His company is now negotiating with a Japanese television network.

Perhaps it should not be surprising that people are seeking to make money through various entertainment schemes. After all, the current Discovery missions cost only about as much as some major motion pictures. But one business hopeful is also examining the possibility of "mining" the moon for profit. Brad R. Blair, a geologist and mining engineer, created a company called Harvest Moon to establish just how profitable moon rocks might be if sold more widely.

The idea came to Blair after discussions with David S. McKay, a NASA scientist whose former work on space resources has been eclipsed by his recent notoriety in claiming to have found evidence for ancient life on Mars. Blair was talking to McKay shortly after Sotheby's auctioned one carat of moon rock for $442,500 in 1993 and realized that, extrapolating crudely, a kilogram of



NASA

ASTEROIDS, SUCH AS MATHILDE, beckon explorers, public or private.

moon rock would be worth $2.2 billion—far in excess of the cost of retrieval. The price of moon rocks would surely drop if the supply grew, but overall revenue could still be enormous.

A properly authenticated moon rock could become like "a rare mineral or a rare gemstone," according to Blair, who notes that a piece of lunar rubble brought to Earth several months ago in the form of a meteorite was offered for $200,000 per gram. At that rate, maybe a spaceborne El Dorado is really not so far away. *—David Schneider*

OPTOELECTRONICS

TRUE BLUE

On the verge of realizing the quest for a blue laser

For roughly three decades, while countless new semiconductor marvels were developed, one of the most sought-after devices of all remained out of reach. Despite expenditures of hundreds of millions of dollars, researchers were unable to produce semiconductor diodes that could emit blue light, especially blue laser light, continuously and at room temperature.

These blue-light-emitting semiconductors were so actively pursued for several reasons. Most alluringly, they could be substituted for the infrared lasers used in compact-disc players, permitting a fourfold increase in the amount of data that could be stored on a CD. The short-wavelength blue lasers could also be used in higher-resolution displays and laser printers and in underwater communications systems. All told, billions of dollars are at stake, analysts say.

Now a charismatic researcher in Japan appears to be on the verge of achieving this semiconductor milestone. Shuji Nakamura of Nichia Chemical Industries in Tokushima, Japan, is something of a larger than life figure among his peers. "Listen, this [semiconductor laser research] is the only science I've been doing since 1964, and I have never seen anything important that wasn't reproduced within a week or two," says James S. Harris, an electrical engineer at Stanford University. "And people are still having trouble reproducing what he did years ago. He is just miles ahead of everybody else." The situation is highly anomalous in semiconductor research—where, typically, an advance with commercial promise is quickly duplicated and improved on in other laboratories.

In 1992 Nakamura demonstrated a blue-light-emitting diode, which Nichia commercialized within two years. As of this writing, Nichia's is still the highest-efficiency blue LED on the market. "No one's been able to duplicate their LED achievements in five years—and we're talking about the top epitaxial semiconductor groups in universities and in industry," says a U.S. researcher, who asked not to be identified. "It's not one or two universities screwing around."

Nakamura's latest coup, first announced at a December meeting of the Materials Research Society in Boston, is a blue-light semiconductor laser that can operate continuously and at room temperature. At a subsequent meeting, Nakamura used one of his blue lasers as a pointer during a talk.

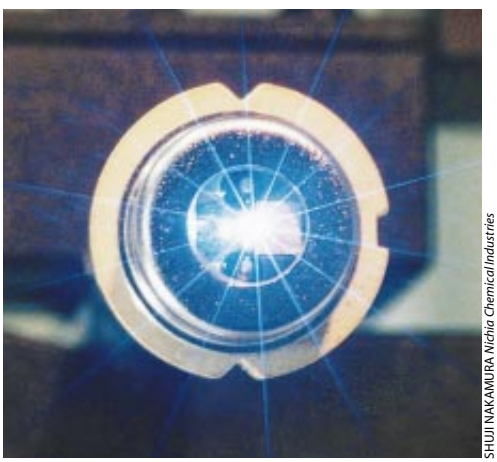
The development appears likely to turn the tide in the intense competition between two competing technologies. Researchers have invested heavily in two types of compounds, known as II-VI and III-V semiconductors after the columns on the periodic table from which their constituents come. It appeared that a II-VI type, based on the compound zinc selenide, would triumph. In January 1996 researchers at the Sony Corporation Research Center in Yokohama achieved room-temperature, continuous operation of a zinc selenide laser diode for 101 hours.

In recent months, however, Nakamura has far surpassed that with his lasers, which, like his LEDs, are based on the III-V compound gallium nitride. (Nakamura asked Scientific American not to publish the exact duration, because details of the work have not yet been peer-reviewed.) Nakamura expects to reach 10,000 hours—the lifetime believed necessary for commercial success—before the end of 1998. "This is a very big development, because these materials were written off several years ago as junk," says Theodore Moustakas, an electrical engineer at Boston University.

To fabricate his LEDs and laser diodes, Nakamura uses a radical modification of a standard technology known as metal-organic chemical vapor deposition (MOCVD). In conventional MOCVD, semiconductors are created as reactant gases flow over a substrate, parallel to its surface. Nakamura has invented a novel MOCVD system in which the gases flow in two directions, rather than one. According to Nakamura, this configuration suppresses a "large thermal convection on the substrate and cools the temperature of the reactant gases on the substrate just before reaction." This cooler temperature leads to more stable reactions and much higher-quality films, he insists. The real trick, of course, is using the system to mass-produce devices, which, at least for LEDs, Nichia has managed to do.

Blue-light gallium nitride semiconductor lasers are the subject of intensive research and development in many U.S. laboratories. At press time, only Cree Research, a small LED company in Durham, N.C., had managed to make a working laser. This past June, Cree, which is collaborating with researchers from North Carolina State University and Brown University, got pulsed operation for the first time at room temperature for several minutes before the device stopped working. More recently, the company achieved pulsed operation for several hours. The largest U.S. effort is a consortium consisting of Hewlett-Packard, Xerox, SDL and several universities. It has been working on gallium nitride laser diodes for only about 14 months, however, and has not yet made a working device.

Despite Nakamura's long-held lead, some are convinced that Goliath will eventually triumph. "It's a matter of time before U.S. companies catch up," Moustakas says. "It will be a piece of cake." *—Glenn Zorpette*



SHUJI NAKAMURA *Nichia Chemical Industries*

***BLUE-LIGHT SEMICONDUCTOR LASER** made by a Japanese researcher could revolutionize information technology.*

WOMEN'S HEALTH

HOLD THE HORMONES?

The good and the bad about postmenopausal estrogen therapy

So many issues in women's health seem mired in controversy. Consider mammograms: different recommendations abound as to who should have one and when. So it came as somewhat of a relief that a near-consensus emerged regarding estrogen therapy for menopausal and postmenopausal women. For most of these women, doctors have had two words: take it. Yet that advice could be premature. The latest studies suggest a more complicated connection between health, sickness and hormones.

Short-term hormonal treatment can help relieve hot flashes and other symptoms of menopause; long-term therapy protects against osteoporosis and appears to lower the risk of heart disease and possibly Alzheimer's. Women often begin taking estrogen at menopause, which occurs on average at age 51, and stay on it for the rest of their lives.

So the news was both good and bad when, in June, researchers from Harvard University published results from the ongoing Nurses' Health Study in the *New England Journal of Medicine*. The investigators described how hormonal therapy cut mortality rates dramatically among hormone users in the group of 50,000 postmenopausal nurses who were first questioned about their health in 1976 and have been sent follow-up surveys every two years since. The findings once again affirmed doctors' respect for estrogen. During the first 10 years of hormone use, the risk of death was 40 to 45 percent lower among hormone users than among those who had never taken the medication. The risk of dying from heart attacks dropped by 53 percent.

But after 10 years, the picture changed: the rate of mortality among hormone users was only 20 percent lower than among nonusers. The researchers, led by Francine Grodstein of Brigham and Women's Hospital, wrote that this drop-off in benefits "was primarily attributable to a 43 percent increase in death [over nonusers] due to breast cancer." For many women, that connection stirs a worry bolstered recently by a new book from breast cancer specialist Susan Love of the University of California at Los Angeles. In *Dr. Susan Love's Hormone Book,* she argues that scientists simply do not know enough about the risks and benefits of estrogen to be prescribing it so widely.

An editorial accompanying the Harvard report echoes some of these concerns. Louise A. Brinton and Catherine Schairer of the National Cancer Institute questioned whether "hormone-replacement therapy should be prescribed for life or whether for some women, it should be restricted in duration and combined with other effective disease-prevention techniques." According to Brinton, "the latest evidence certainly makes us more cautious than we were."

The solution may be to balance the risks by starting women on hormones later in life. Earlier this year researchers at the University of California at San Diego found that women who began taking estrogen on a long-term basis after age 60 and stayed on it for an average of nine years had the same bone mineral density (a good measure of a woman's risk for osteoporosis) as women who took estrogen for an average of 20 years beginning right after menopause.

In addition, Grodstein explains, although the overall risk of heart disease is about 10 times higher than that of breast cancer for all women between 50 and 80, "most of that increase comes when you are older." Grodstein and her colleagues have found that among the nurses they studied, the mortality rate from heart disease did not overtake the death rate from breast cancer until around age 60. Grodstein says that because the latest evidence indicates that hormones are relatively safe when used for up to 10 years, women might consider taking hormones for a couple of years at menopause but then "saving long-term use until their sixties or seventies when the risks are greater for heart disease or osteoporosis."

Clearer guidelines as to who should be taking estrogen when and for how long will come from the Women's Health Initiative, a program established in 1991 by the National Institutes of Health to address cardiovascular disease, cancer and osteoporosis among postmenopausal women. The nationwide study is conducting randomized trials comparing hormonal therapy with a placebo. The results—not due until at least 2005—should provide women and their doctors with much needed additional analysis of the risks and benefits of hormonal therapy. The trials will address a major criticism of the Nurses' Health Study: it involves women who were not selected randomly and are on average healthier than the general population.

Until more definitive results become available, women concerned about the

MARTHA TABOR *Impact Visuals*

EXERCISE IN POSTMENOPAUSAL WOMEN is important for preventing cardiovascular disease and osteoporosis.

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risks of estrogen can choose from a number of other drugs to fight osteoporosis and heart disease. And, of course, there is one other option. JoAnn E. Manson, one of the researchers on the Nurses' Health Study and principal investigator of the Women's Health Initiative at Harvard, points out that prevention could be worth a pound of hormones. "We know a great deal about how to prevent heart disease," she states—watching diet, getting exercise, stopping smoking, controlling blood pressure. Grodstein concurs: such lifestyle changes "only have benefits" for preventing heart disease, osteoporosis and possibly breast cancer. She adds that "estrogen is one of many options, and women are recognizing that they have other choices." —*Sasha Nemecek*

MICROMECHANICS

BEAM IT UP

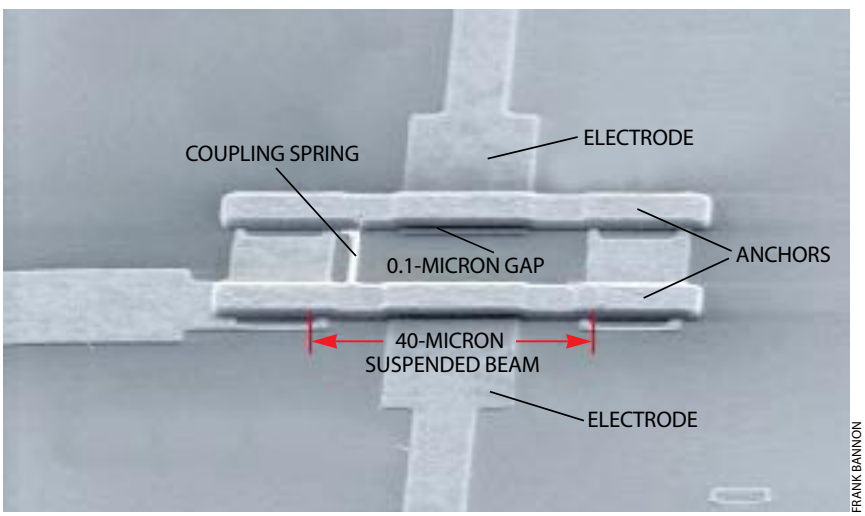
Micromechanical beams may enable a radio-on-a-chip

Making a telephone or two-way radio the size of a Dick Tracy wristwatch or a Star Trek communicator remains a nettlesome engineering design challenge. Building the transistor-based processor to the requisite size is routine. But the various discrete components needed to tweak the incoming radio signal—the filters and oscillators that select the desired frequencies—complicate greatly the fabrication of truly miniaturized radio devices.

A series of recent research papers from the University of Michigan have described microscopic resonating-beam structures that can serve as radio-frequency-filtering and oscillator elements. Coupled with a signal processor on the same chip, they may help make possible two-way radios, telephones and modems as small and inexpensive as anyone might desire. Tiny, low-power transmitter-receivers might even be dispersed widely around a building. "I don't want to mention *Star Trek,* but this could get us closer to that," says Clark T.-C. Nguyen, a professor of electrical engineering at the University of Michigan.

Nguyen's work, along with that of a few other researchers, presages a new set of applications for microelectromechanical systems (MEMS)—diminutive mechanical structures that generate or respond to electrical signals. MEMS devices are already widely used as sensors to trigger air bags and to determine blood pressure, and researchers have targeted them for everything from making laboratory instruments on a chip to fabricating switches for optical fibers.

The incorporation of microscopic mechanical components in a radio yields many of the benefits that the devices' cousin, the transistor, brings to electronics. "You get advantages of size, lower cost, ease of assembly and lower power," comments Kaigham Gabriel, director of the electronics technology office at the Defense Advanced Research Proj-



MICROMECHANICAL FILTER
consists of beams coupled by a spring. The 40-micron beams can vibrate millions of times a second when voltages are applied to the electrodes.

ects Agency (DARPA). Today's mobile radios and cellular telephones use filters and oscillators that resonate at a range of frequencies that correspond to a desired band of communications channels. Just one of these components—a surface-acoustic wave resonator, for instance—might measure up to a square centimeter, and many may be needed for a given communications system.

In a preliminary design, Nguyen and his colleagues have demonstrated resonating devices that occupy a 420-square-micron area, from 1/35,000 to 1/240,000 the size of conventional filters. The MEMS resonating structures consist of beams as small as 30 microns long and eight microns wide that are anchored at each end to a silicon chip. Their midsection is suspended some 0.1 micron above the chip surface. When the requisite radio-frequency signal voltage is applied to an electrode under the beam, the resulting electrostatic forces make the hanging section of the structure vibrate up and down at frequencies of nearly 15 million times a second—and much higher frequencies are anticipated as the research progresses and new design concepts are applied.

To construct a filter, at least two adjacent beams, both of which vibrate at the same frequency, are connected by a spring. This arrangement allows a range of frequencies to be selected with precision. The minute devices may let a two-way radio consume significantly less power than if it used ordinary filters.

Conventional semiconductor lithographic techniques would permit the patterning of a multitude of these devices alongside a processor on a single chip. The simplified design could translate into a unit significantly less expensive than existing radio-transceiver technology and one that could select widely disparate frequency bands.

In April, DARPA granted a $2.6-million contract for three years to the University of Michigan, to demonstrate resonator technology at frequencies ranging to more than a gigahertz, encompassing the spectrum used for some cellular telephones. DARPA has also let separate contracts for other radio MEMS technologies: switches that would allow a radio to change from one filter to another and capacitors that can tune a radio to different frequencies. These varied projects mean that shortly after the year 2000, the notion of a two-way radio on a chip may indeed become a commonplace reality. —*Gary Stix*

CYBER VIEW

Not So Fast

On August 7, if all went as planned, eight high-tech Buicks drove themselves and their idle passengers down a short stretch of San Diego freeway. The second part of the plan was for the media and public to ooh and aah at the feat, intended, according to the consortium of transportation agencies and carmakers that organized it, to "show that the vision of an automated highway system can be made a practical reality."

Technically, "smart" cars are indeed practical—or soon will be. Sensors can read magnets, nailed into the pavement, that indicate the direction of the road. Radars can spot obstacles ahead (at least those made of metal). Digital radios can converse with surrounding vehicles and the road itself to avoid surprises. And computers, digesting all this information, can calculate where to go and how fast.

But in the real world, automated highways are still just a vision and a muddled one at that. Self-steering cars may be able to slalom orange cones with ease. Negotiating legal, economic and political hazards will be far harder, for two reasons.

First, they will inevitably crash into humans' warped perception of risk. Smart cars may in fact be safer as they tailgate one another at 70 miles per hour, but they will not seem that way at first. Train and airplane guidance systems collapse all the time. Computer-controlled autos and roads will be even more complicated, more software-intensive and tremendously more exposed—to the weather, to stray animals and falling cargo, to saboteurs. They will fail frequently, causing dramatic collisions, some lethal. Most people overestimate the dangers of air travel because every accident makes the nightly news. Glitches in a new technology will get even more intense scrutiny.

Reporters' first question will be: Who's to blame? Current laws would hold those who build the cars and roads liable for damages whenever system failures cause a crash, whether they had been negligent or not. In theory, Congress could limit their liability, as it did for the airline industry. In practice, tort reform is a political minefield. Who is responsible, after all, for a 10-car pileup caused by a software bug or radio interference? Certainly not the nondrivers.

News anchors will then ask: Are automated highways safe enough to entrust with the lives of your children? Even if smart cars cut traffic fatalities in half, they will still kill thousands every year. Multiply the furor over a few dozen air bag–related deaths 100-fold, and the public relations problem is clear. Despite the many mortal risks we accept voluntarily, we abhor those we cannot control—especially those in systems that claim to make us safer.

It might be possible to make intelligent vehicles reliable enough to win public acceptance and overcome manufacturers' liability qualms, but only at enormous expense. Which raises the second reason that smart cars face a rocky road: their costs will almost certainly outweigh the benefits to the consumers and politicians who must endorse them.

DAVID SUTER

In 1994 the U.S. Department of Transportation paid a team of contractors and highway agencies to report on the economic sense in automating sections of several jammed corridors, including I-93 around Boston, I-495 near Washington, D.C., and two sections of the New York State Thruway. The analysts made some wildly optimistic assumptions. They spread the construction costs over 50 years. They figured that the day the new lanes opened, half the morning commuters would already have smart cars ready to pull onto it. (More sober analysts have estimated that self-driving cars will need a decade or so of sales to top 20 percent of the fleet.) They assumed that accident losses would immediately fall by 57 percent. And they reckoned that the superreliable electronics in these cars would cost only $1,800 yet would last eight years.

Their analysis did not include the price of a new bureaucracy to certify automated vehicle designs safe, nor the money needed to hire high-tech highway engineers, nor the expense of ensuring that routine roadwork doesn't send Buicks hurtling into the guardrail. Even so, the team concluded that the costs of automation for all four roads overwhelmed the savings from fewer accidents and lower congestion by huge amounts, ranging from $334 million to $681 million.

Of course, governments have paid billions before for pork-barrel projects of dubious value. But intelligent highways will come at a steep political price as well. To save money, most states will have to convert existing lanes—two or three of them, to provide adequate safety margins—on their busiest interstates. Commuters howl when high-occupancy restrictions take lanes from their route. How will voters respond when their daily jam is made that much thicker so that people richer than they can zip along at twice the speed? Don't forget that it will take years, perhaps a decade, before there are enough automated cars to fill all that empty space.

Even if robotic roadsters are not infeasible, they are certainly unwise, grumbles John Pucher, a transportation researcher at Rutgers University: "It is the biggest waste of research funds I have ever encountered." As a solution for congestion, he says, "it's pie in the sky: as average speeds improve, people don't spend less time in the car—they travel longer distances."

The automated highway consortium has explored all these obstacles and come up with more questions than answers. Its stated strategy is to add intelligence to cars bit by bit: a proximity alarm here, adaptive cruise control there, perhaps customized directions and traffic reports later. That much is smart and practical. But to demonstrate machines driving humans and call it the future is to presume naively that technology can change the culture of an entire society in years rather than generations.

—W. Wayt Gibbs in San Francisco

In Search of AIDS-Resistance Genes

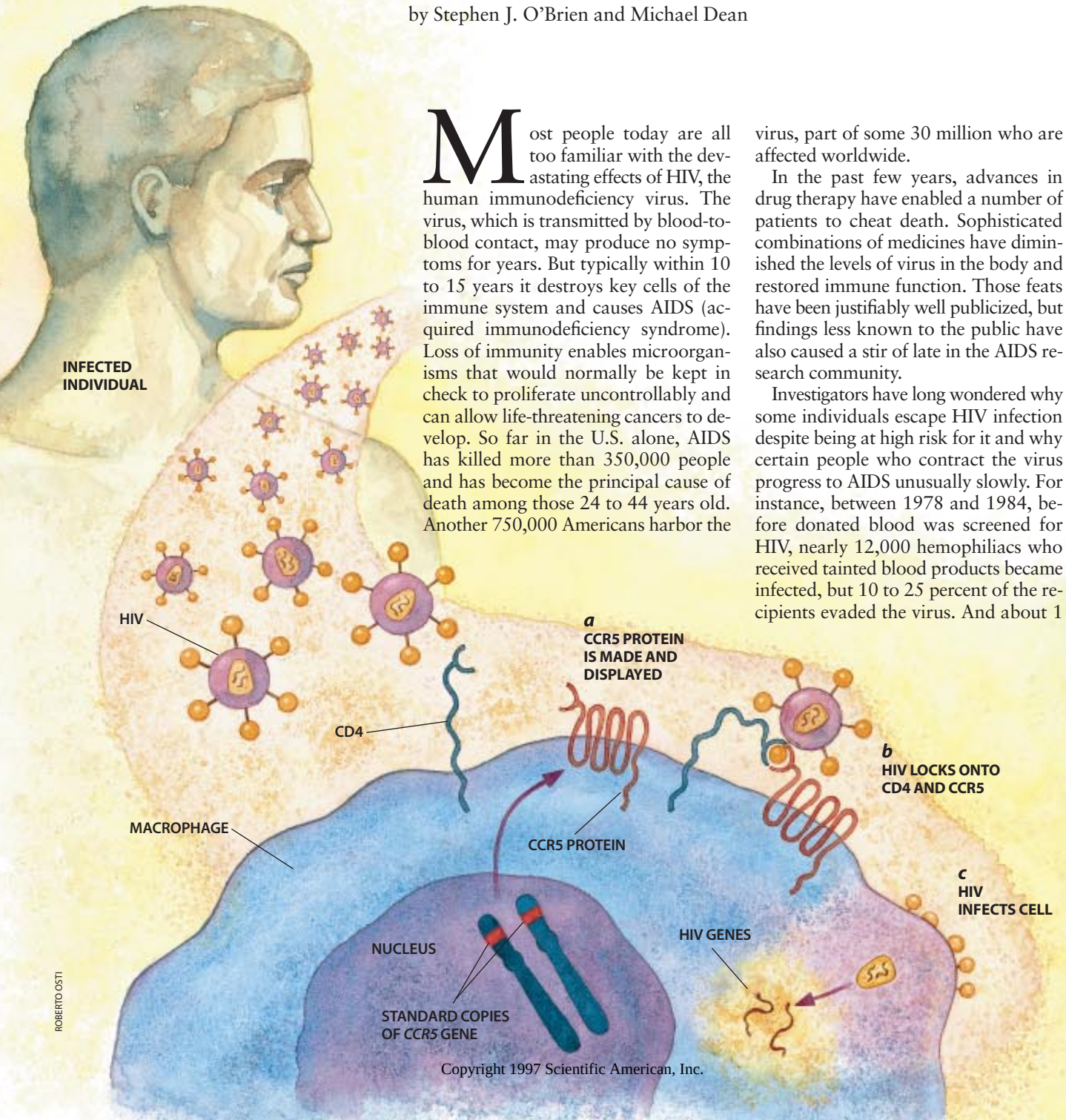
A genetic trait that protects against AIDS has now been uncovered, and others are emerging. The findings open entirely new avenues for developing preventives and therapies

by Stephen J. O'Brien and Michael Dean

Most people today are all too familiar with the devastating effects of HIV, the human immunodeficiency virus. The virus, which is transmitted by blood-to-blood contact, may produce no symptoms for years. But typically within 10 to 15 years it destroys key cells of the immune system and causes AIDS (acquired immunodeficiency syndrome). Loss of immunity enables microorganisms that would normally be kept in check to proliferate uncontrollably and can allow life-threatening cancers to develop. So far in the U.S. alone, AIDS has killed more than 350,000 people and has become the principal cause of death among those 24 to 44 years old. Another 750,000 Americans harbor the virus, part of some 30 million who are affected worldwide.

In the past few years, advances in drug therapy have enabled a number of patients to cheat death. Sophisticated combinations of medicines have diminished the levels of virus in the body and restored immune function. Those feats have been justifiably well publicized, but findings less known to the public have also caused a stir of late in the AIDS research community.

Investigators have long wondered why some individuals escape HIV infection despite being at high risk for it and why certain people who contract the virus progress to AIDS unusually slowly. For instance, between 1978 and 1984, before donated blood was screened for HIV, nearly 12,000 hemophiliacs who received tainted blood products became infected, but 10 to 25 percent of the recipients evaded the virus. And about 1



ROBERTO OSTI

percent of individuals who carry HIV remain relatively healthy, with few or no symptoms and with adequate immune functioning, for atypically long spans of 15 years or more.

The recent findings reveal that some people who are partly or fully resistant to HIV infection owe their good fortune to their genes—or, more precisely, to possession of a particular variant of a gene involved in immunologic function. This discovery has already sparked intensive efforts to translate the new genetic understanding into innovative strategies for preventing and controlling HIV infection. (We should note that we are using the term "HIV" to mean HIV-1, the virus responsible for most AIDS worldwide. Another form, HIV-2, causes AIDS more slowly and is restricted to certain parts of Africa; genetic resistance to HIV-2 has not yet been studied.)

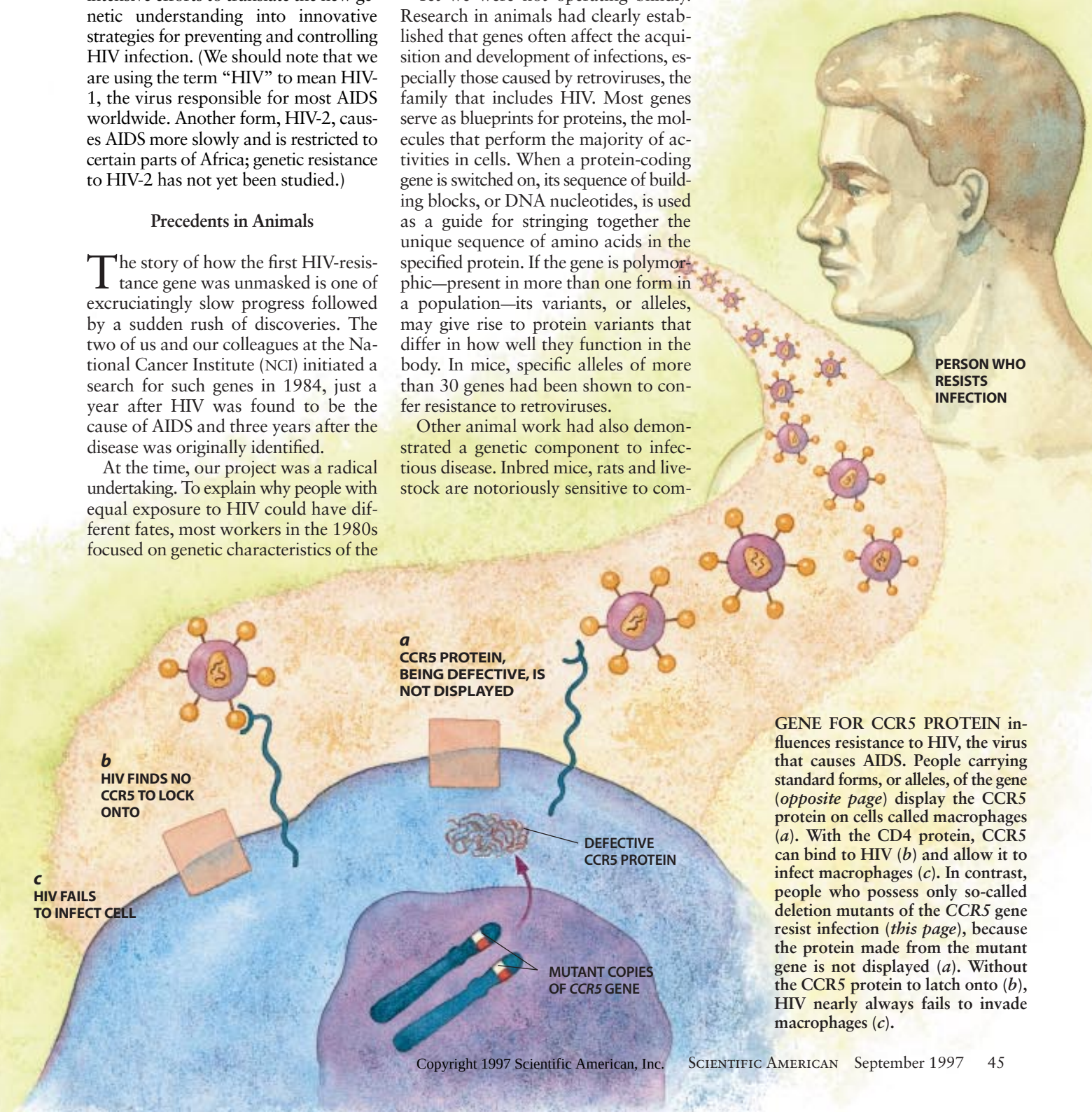
Precedents in Animals

The story of how the first HIV-resistance gene was unmasked is one of excruciatingly slow progress followed by a sudden rush of discoveries. The two of us and our colleagues at the National Cancer Institute (NCI) initiated a search for such genes in 1984, just a year after HIV was found to be the cause of AIDS and three years after the disease was originally identified.

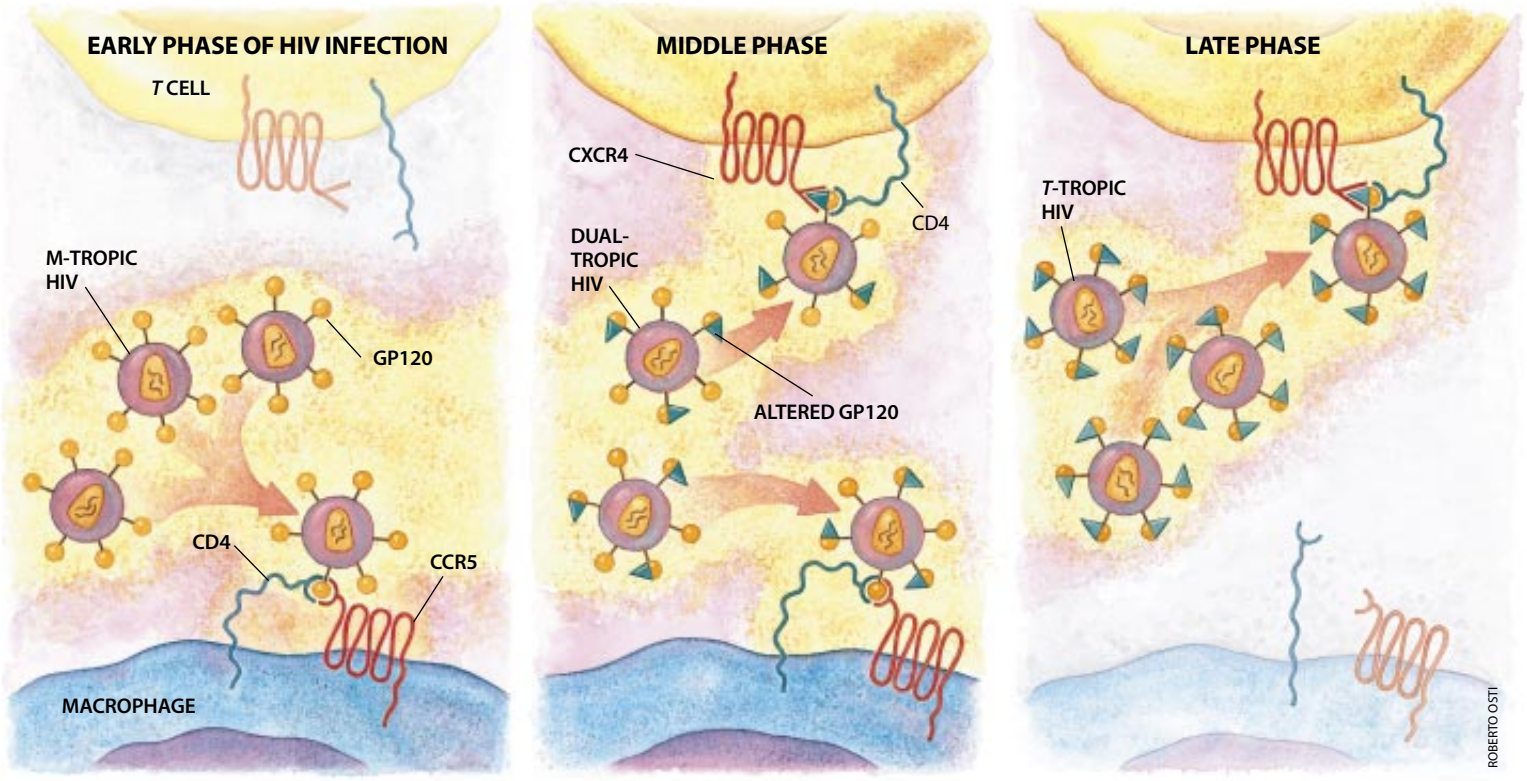
At the time, our project was a radical undertaking. To explain why people with equal exposure to HIV could have different fates, most workers in the 1980s focused on genetic characteristics of the virus (such as variations in the virulence of different strains) or on nongenetic "co-factors" that might influence the disease-causing power of the virus (such as infection of the host by another microbe). And we had little solid evidence that humans could possess genetic protection from AIDS. Indeed, certain of our colleagues doubted we would find anything on our genetic "fishing" expedition, a hunt on which we were wagering considerable time and resources.

Yet we were not operating blindly. Research in animals had clearly established that genes often affect the acquisition and development of infections, especially those caused by retroviruses, the family that includes HIV. Most genes serve as blueprints for proteins, the molecules that perform the majority of activities in cells. When a protein-coding gene is switched on, its sequence of building blocks, or DNA nucleotides, is used as a guide for stringing together the unique sequence of amino acids in the specified protein. If the gene is polymorphic—present in more than one form in a population—its variants, or alleles, may give rise to protein variants that differ in how well they function in the body. In mice, specific alleles of more than 30 genes had been shown to confer resistance to retroviruses.

Other animal work had also demonstrated a genetic component to infectious disease. Inbred mice, rats and livestock are notoriously sensitive to communicable disorders, mainly because inbreeding leaves them with a limited repertoire of disease-resistance alleles. In outbred groups, some fraction of a population is likely to have an allele that protects against a given pathogen; that allele will enable its owners to survive an epidemic and perpetuate the group. Because human populations are genetically diverse, we suspected that they, like other outbred species, possessed many powerful disease-resistance alleles.



GENE FOR CCR5 PROTEIN influences resistance to HIV, the virus that causes AIDS. People carrying standard forms, or alleles, of the gene (*opposite page*) display the CCR5 protein on cells called macrophages (*a*). With the CD4 protein, CCR5 can bind to HIV (*b*) and allow it to infect macrophages (*c*). In contrast, people who possess only so-called deletion mutants of the *CCR5* gene resist infection (*this page*), because the protein made from the mutant gene is not displayed (*a*). Without the CCR5 protein to latch onto (*b*), HIV nearly always fails to invade macrophages (*c*).



HIV'S AFFINITY FOR IMMUNE CELLS changes over time inside infected patients. Initially the virus is "M-tropic" (*left*): it favors macrophages, which it invades by binding (through its gp120 protein) to the molecules CD4 and CCR5 on the macrophage surface. Eventually, however, HIV can become "dual-tropic" (*center*). Such strains produce gp120 molecules able to recognize the CXCR4 protein on CD4-bearing *T* cells and may infect both macrophages and *T* cells. Still later, the bulk of the viral population can switch its preference to the CXCR4 receptor and become "*T*-tropic" (*right*). *T*-tropic viruses readily destroy infected *T* cells and thereby contribute to the collapse of the immune system and the onset of AIDS.

Those alleles, perhaps including defenses against HIV, simply remained to be discovered.

Further, although few pathogen-resisting alleles had been defined convincingly in humans, several epidemiological studies had noted a strong genetic influence on disease susceptibility. For instance, one analysis showed that if a biological parent of an adoptee died of an infectious disease before age 50, the adoptee had a markedly increased risk of also dying from an infection.

Unfortunately, science had provided no simple blueprint for finding HIV-resistance alleles in humans. We therefore combined knowledge and techniques from three disparate disciplines: AIDS epidemiology, human molecular genetics and population genetics theory.

High-Tech Gene Prospecting

First, we needed a source of genes from the populations of interest to us, such as individuals at high risk for HIV infection who did or did not become infected after exposure to the virus. If the two groups differed in their genetic makeup—in their alleles for specific genes—we would suspect that the genes displaying the variation influenced susceptibility to HIV infection.

To obtain human DNA for study, we joined forces with public health epidemiologists who were trying to track the pattern of the still new epidemic. As part of that effort, the epidemiologists were enlisting cohorts, or groups of several hundred individuals, at high risk for HIV infection—notably, homosexual men, users of intravenous drugs and hemophiliacs who had received contaminated blood products. These cohorts were to be monitored for years by physicians, who (with the patients' permission) would supply blood, tissue samples and case reports to researchers. As blood was collected, our cell biology team, led by Cheryl Winkler, carefully produced immortal lines of cultured cells that would provide an unlimited supply of DNA for genetic testing.

To determine which genes to compare, we took advantage of recent advances in gene mapping, a set of procedures that pinpoints the location of genes on chromosomes and determines their nucleotide sequences. More than 6,000 of the approximately 50,000 to 100,000 genes in human chromosomes have now been mapped. Back in 1984 fewer than 1,000 had been found. Nevertheless, to test even 1,000 genes in our AIDS cohorts was an impossible task.

We narrowed the choice by drawing on established knowledge of how retroviruses behave in their hosts. The host is always an unsuspecting collaborator in establishing infection and enabling pathogens to spread through tissues. To enter cells, all viruses must recognize (bind to) certain proteins encoded by host genes and displayed on the cell. These proteins normally act as receptors for other host molecules, but viruses can co-opt the receptors, using them as springboards for entry into a cell.

Once in a cell, retroviruses insidiously insert their genes into a host's chromosomes. They thereby ensure that viral genes—which can direct the synthesis of an endless supply of viral particles—are passed to each new generation of cells whenever the initial host cell replicates. Here, again, the viruses require help from the host. They must recruit several cellular enzymes to splice viral genes into chromosomes, to produce fresh viral particles and even to evade the host's immune defenses.

With such understanding to guide us, we originally decided to concentrate on

about 50 genes whose proteins could potentially influence HIV's life cycle. We also examined 250 polymorphic (variable) DNA segments that had been identified in chromosomal sites between genes. If our subjects differed in these segments, those differences would indicate that alleles of nearby genes might also vary systematically between the groups. We could then perform a fairly narrow search for those genes and try to determine their function in cells and their role in HIV infection.

Finally, to pinpoint genetic traits that confer resistance to HIV, we borrowed strategies from human population genetics. We divided each cohort into two groups, according to selected aspects of their health—for example, those infected with HIV versus those who remained free of it after extensive exposure; infected patients who progressed to AIDS rapidly versus those who progressed slowly if at all; or infected patients who acquired a specific AIDS-related disease (such as *Pneumocystis carinii* pneumonia or Kaposi's sarcoma) versus those who did not.

Having made these divisions, we compared how often each known allele or polymorphic segment appeared in the groups. We also compared what are called genotypes. An individual inherits two copies of all genes outside the sex chromosomes (one copy from the mother and one from the father). The pair of alleles at a particular chromosomal locus, or gene address, constitutes the genotype. Someone who inherits two identical alleles of a given gene is said to be a homozygote; someone who inherits two distinct alleles is said to be a heterozygote. In our screening tests, we noted the percentage of patients in each group who were homozygous for a known allele and the percentage of patients that were heterozygous. Appreciable differences in allele or genotype frequencies, or both, in two subject groups would indicate that the gene under study probably accounted for the divergent fates of the subject groups.

For years we continued to add more patients, more genes, more polymorphic segments and more sophisticated computer programs to analyze the data. Periodically, we thought we noted genetic differences, but they nearly always evaporated under close inspection. Meanwhile we monitored the many advances in understanding of human immunology and in the behavior of HIV in the body, always seeking ideas for other genes to study. Late in 1995 and early in 1996—more than a decade after we began this massive and tedious effort—cracks finally appeared in the dike.

Good Clues, at Last

Those cracks were created by other research teams who resolved two long-standing mysteries relating to HIV's molecular interaction with host cells. With those solutions came clues to genes involved in resistance to HIV.

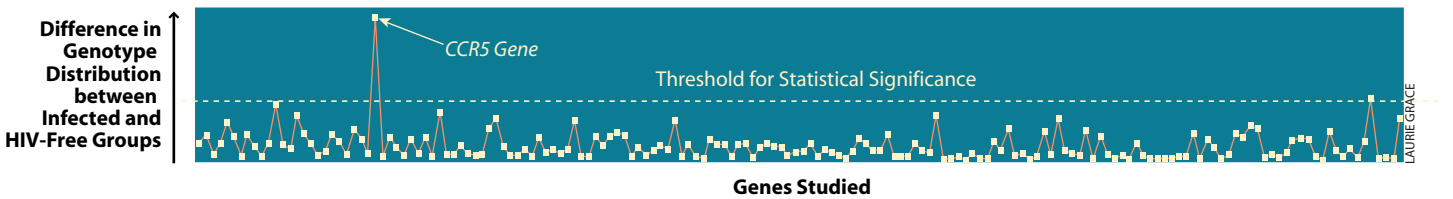
By the mid-1990s scientists and nonscientists alike were well aware that HIV caused immune deficiency mainly by depleting white blood cells known as *T* lymphocytes that displayed a protein called CD4 on their surface. These *T* cells normally orchestrate many aspects of the immune response to viruses. It was also known, albeit less widely, that HIV can infect and persist for years in another class of CD4-carrying immune cells called macrophages. HIV does not destroy macrophages and finds a safe haven in them.

The CD4 molecules on *T* lymphocytes and on macrophages usually participate in signaling between immune cells. But when HIV enters the picture, CD4 molecules bind to a sugary protein (gp120) protruding from HIV's outer envelope and, in so doing, help the virus to gain entry into the bound cells. Yet experiments had shown that CD4, though necessary for HIV infiltration of cells, was not sufficient; the cells also had to display at least one more protein to which the virus could bind. More than 10 years after the discovery of HIV, however, scientists still had no clue to the nature of that second receptor.

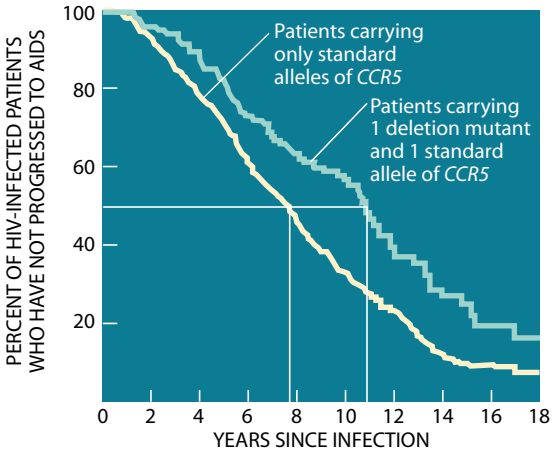
The other puzzle related to a discovery reported in 1986 by Jay A. Levy of the University of California at San Francisco. He found that a class of *T* lymphocytes displaying a different protein—CD8—secreted molecules, termed suppressive factors, that blocked HIV from invading normally susceptible cells in culture. Suppressive factors that limited virus infection had also been shown to exist in African monkeys that harbored SIV (the simian form of HIV) yet did not advance to AIDS, as well as in people who survive HIV infection for an unusually long time. The identity of these sundry suppressive factors remained to be determined, however.

In December 1995 Robert C. Gallo, then at the NCI, and other collaborators announced that they had identified three related suppressive factors that could block infection by HIV variants that prefer to colonize macrophages (so-called M-tropic strains). All three factors turned out to be known chemokines: short strings of amino acids responsible for luring immune cells to injured or diseased tissues.

	2 Copies of Standard *CCR5* Allele	2 Copies of Mutant *CCR5* Allele	1 Standard and 1 Mutant *CCR5* Allele
HIV-Infected Individuals	85 percent	0 percent	15 percent
Uninfected Individuals	83 percent	3 percent	14 percent



DIFFERENCES IN THE GENETIC PROFILE of two populations (*graph*) implicated the *CCR5* gene in resistance to HIV infection. The authors first identified the genotypes, or combinations of alleles, for each of 170 genes in a group of HIV-infected patients and, separately, in a group of uninfected individuals. For instance, they measured the percentages of people having two copies of the normal *CCR5* allele, two copies of the truncated, deletion mutant, or one copy of each (*table*). Then, for every gene, they plotted the statistical difference (*dots*) in the genotype distribution between the two populations under study. Of all the genes that were examined, only the difference for the *CCR5* gene turned out to be highly significant.



LAURIE GRACE

COMPARISON of how long HIV-infected individuals lived without progressing to AIDS revealed that patients harboring one deletion mutant of the *CCR5* gene (*green line*) avoided AIDS longer than patients carrying only standard *CCR5* alleles (*yellow line*). For instance, it took about 11 years for 50 percent of the first group to advance to AIDS but about eight years for half of the second group to reach that point.

Many investigators still grappling with the first puzzle—the search for HIV's second receptor—understood that chemokines work their effects on defensive cells by binding to surface proteins. It seemed possible that the chemokines isolated by Gallo's group—named RANTES, MIP-1α and MIP-1β—might interfere with HIV entry into immune cells by binding to and blocking some cell surface protein that HIV required for access to the interior. In other words, the cell-surface receptor (or receptors) for Gallo's chemokines could well lead a double life as the second receptor for HIV on macrophages and perhaps on other CD4-bearing cells.

The notion defied immediate testing because the cellular receptor for RANTES and its cousins had not yet been isolated. But discoveries reported early in 1996 made such tests possible and provided us, and others, with new genes to screen as resistance factors.

First, Edward A. Berger and his colleagues at the National Institute of Allergy and Infectious Diseases isolated the second receptor for HIV variants that prefer to colonize *T* lymphocytes (*T*-tropic strains). It was a chemokine receptor, albeit one (now called CXCR4) that bound a chemokine distinct from RANTES, MIP-1α and MIP-1β. If Gallo's findings had not convinced AIDS researchers that chemokine receptors played a part in HIV infectivity, Berger's results drove the point home.

Almost simultaneously, Michael Samson and Marc Parmentier of the Free University of Brussels and their collaborators isolated the gene for a receptor onto which RANTES, MIP-1α and MIP-1β all hook when they draw defensive cells to damaged tissue. Within two months, five separate groups proved that the encoded protein, now known as CCR5, was also the elusive second receptor for M-tropic strains of HIV.

Combined with observations from other studies, the new chemokine receptor findings critically refined understanding of how HIV infections become established and progress. HIV initiates infection by setting up residence primarily in macrophages. It enters these cells by linking its gp120 protein with two receptors on macrophages: CD4 and CCR5. Once inside the macrophages, HIV synthesizes large quantities of virus and challenges the immune system to its limits.

Years later the constantly mutating virus can alter the gene for gp120 in a way that causes the gp120 protein to change its second-receptor allegiance. The genetic change causes the region that recognizes CCR5 to bind more effectively to CXCR4 on *T* lymphocytes. Now the HIV population becomes dominated by *T*-tropic variants—those preferring to infect *T* cells.

This shift in attraction soon becomes deadly, because *T*-tropic viruses kill the cells they infect. Not surprisingly, the shift is often followed swiftly by an overall drop in CD4 *T* cell concentrations in patients and, simultaneously, by the onset of the opportunistic infections and cancers that for many years defined progression to AIDS. Today the Centers for Disease Control and Prevention formally defines AIDS by the presence of AIDS-defining illnesses or by a drop in CD4 *T* cells to fewer than 200 per cubic millimeter of blood; normal levels are about 1,000 per cubic millimeter.

The Expedition Succeeds

As soon as we knew that CCR5 and CXCR4 were co-receptors for HIV, we immediately decided to see whether the genes for those proteins affected resistance to HIV in our cohorts. To pursue this idea, we had to determine whether the *CCR5* and *CXCR4* genes were polymorphic. If everyone had identical versions of those genes, the genes could not account for differences in susceptibility to HIV.

All copies of the *CXCR4* gene we examined were the same. But in July 1996 Mary Carrington of our group discovered that a major variant of the normal *CCR5* gene occurred in about one in five individuals. Comparisons of the nucleotide sequences of the two *CCR5* alleles revealed that the less common one was missing 32 nucleotides. Because of the way the genetic code works, we knew that the loss would result in the premature creation of a "stop" code in the gene and would, in turn, cause the cells to manufacture a severely foreshortened version of the CCR5 protein.

When we divided nearly 2,000 high-risk patients into infected and noninfected groups and compared their *CCR5* genotypes, we found dramatic differences. Some 3 percent of the noninfected individuals carried only the deletion mutant of *CCR5* in their cells (that is, were homozygous for the mutant). In contrast, not one patient out of 1,343 in the infected group was homozygous for the deletion mutant. The difference—which indicated homozygosity for the deletion mutant was protective against HIV—was highly significant statistically and was certainly no coincidence.

Moreover, the apparent protection provided by having solely mutant *CCR5* alleles did not depend on the route of infection: no hemophiliacs, homosexuals or drug users who were homozygous contracted HIV. We suspected that homozygosity for the deletion mutant shielded patients because they manufactured only truncated CCR5 proteins that either failed to reach the cell surface or were so deformed that they could not dock with HIV.

Within a few weeks after submitting a paper on these remarkable findings to the journal *Science*, we learned we were not alone in searching for polymorphisms in chemokine receptors. Nathaniel R. Landau and Richard A. Koup of the Aaron Diamond AIDS Research Center in New York City and their co-workers had independently discovered the same 32-base-pair deletion allele. They had been studying a group of homosexual men who had many high-risk sexual exposures to HIV but had never become infected. Examination of white

The Mysterious Natural History of the Resistance Allele

The HIV-resistance allele, or deletion mutant, of the *CCR5* gene is not distributed equally among the world's peoples. It is virtually absent in African and eastern Asian populations and in Native Americans and is rare in African-Americans [*see second column in table below*]. It is, however, fairly prevalent among Caucasians (descendants of the early settlers of Europe and western Asia).

Yet even among Caucasians the distribution varies. A plot of the allele's frequency among Caucasians in Eurasia [*see map below*] reveals a gradient, or cline, that is highest in the north and drops to an undetectable level in Saudi Arabia. The frequency is calculated by counting the number of mutant copies in a population and dividing by the total of all *CCR5* copies—the sum of mutant and standard copies combined.

These patterns answer some questions and raise others about the origin and prevalence of the mutant, which codes for a defective CCR5 protein. The apparent absence of the mutant in Africa indicates that it arose some time after humans left Africa—a split widely believed to have taken place 130,000 to 200,000 years ago. But what caused the deletion mutant to reach such a high frequency in Caucasians, and when did that event occur?

The surprisingly high frequency of the allele in parts of Europe and Asia suggests that some devastating event in these locales gave originally rare individuals who harbored the mutant a dramatic survival advantage. Those individuals then lived to reproduce, causing the fraction of the population bearing the allele to become larger than before. As survivors of this historic cataclysm procreated, their *CCR5* mutation persisted and accumulated to higher levels.

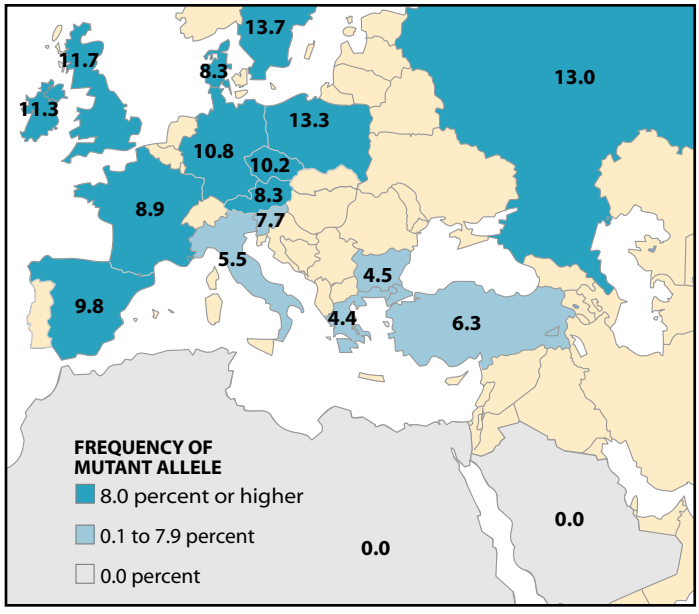
We suspect that the catastrophic event was a major epidemic caused by an agent that, like HIV, makes use of the normal CCR5 protein, but not the defective form, to infect cells. This hypothesis makes sense to us because rare alleles often become more common in animals after they provide resistance against a newly encountered pathogen. And the longer the epidemic lasts, the higher the allele frequency rises.

We also think the Eurasian epidemic occurred very long ago. Indeed, using genetic dating methods, we have estimated that the catastrophic challenge struck about 4,300 years ago and certainly no more recently than 1,200 years ago. The mutant is less common in southern Eurasia than in the north, perhaps because the eye of the epidemic was concentrated in the north.

The European and western Asian heritage of many Americans would explain why a relatively high fraction of American Caucasians harbor the allele: their ancestors brought it with them as part of their genetic endowment. And some African-Americans possess the allele, even though most Africans do not, probably because of recent intermarriage between Africans and Caucasians in the Americas.

We can only wonder, however, at that pathogen's identity. An agent like HIV, which kills more than 90 percent of its victims, could have been responsible. Today's HIV was not the culprit—it exploded in human populations within the past 20 years—although an ancient, undocumented HIV outbreak might have occurred. Other possibilities include organisms responsible for cholera, tuberculosis or the flu. The microbe that caused the bubonic plague of the 14th century, once considered a reasonable contender, probably was not at fault, though. It did not attack Europe until about 600 years ago. *—S.J.O'B. and M.D.*

Population	Frequency of Mutant Allele (percent)	Frequency of Genotypes (percent)		
	Mutant Allele	2 Copies of Standard Allele	2 Copies of Mutant Allele	1 Standard and 1 Mutant Allele
Caucasian-European	10.0	81.0	1.0	18.0
Caucasian-American	11.1	79.0	1.2	19.7
African-American	1.7	96.6	0.0	3.3
Native American; African; East Asian	0.0	100.0	0.0	0.0



blood cells from two of these men indicated that the CCR5 protein was absent from the cell surface. A look at the nucleotide sequence of the *CCR5* genes revealed that both men were homozygous for the deletion mutant. Further, in other work, Samson and Parmentier's team had searched for and failed to turn up any homozygotes for the deletion allele in a group of 743 HIV-infected people. (Those two reports appeared in August 1996, ours in September.)

Subsequent studies uncovered no homozygotes among Africans, Asians or African-Americans but indicated that 1 to 2 percent of Caucasian-Americans—those descended from Europeans or western Asians—are homozygous for the mutation. Further, when we looked at the genotypes of uninfected people known to have had extremely high exposure to HIV (through engaging in unsafe sex repeatedly or receiving high doses of HIV-contaminated clotting factors during treatment for hemophilia), we saw that as many as 20 percent of these individuals were homozygous for the deletion mutant. Resistance to infection in the other 80 percent must have come from other genetic or nongenetic sources.

It stood to reason that if two mutant *CCR5* genes provided complete protection from HIV, possession of one mu-

tant and one normal allele might provide partial protection, by halving the number of functional CCR5 proteins made by a cell. When we analyzed the time between infection and the appearance of AIDS-defining diseases, we found that the onset of overt AIDS was postponed for two to three years in HIV-infected individuals who carried one deletion allele. This delay was apparent both in homosexual men and in hemophiliacs. This heterozygous genotype (which occurs in approximately 20 percent of Caucasian-Americans) also delayed the time at which CD4 *T* cell levels fell below 200 per cubic millimeter of blood.

The excitement was overwhelming. The deletion mutant, when inherited from both parents, did indeed appear to provide powerful genetic protection against HIV even after repeated exposures. And inheritance of a single deletion mutant could slow progression to AIDS in infected individuals. These results implied that treatments able to block the interaction of HIV with the normal CCR5 protein might help protect healthy people from HIV infection or delay the advance to AIDS in people who have already contracted the virus.

For years, pharmaceutical companies had focused their anti-HIV therapeutic efforts on the virus alone, giving little attention to how the host's cellular machinery collaborates in establishing chronic disease. The drugs used in combination therapy, for example, interfere directly with the activities of HIV itself, such as by preventing certain of its enzymes from functioning. The new genetic results suggested that targeting the host's complicity in the progression to AIDS could open previously unimagined avenues for controlling HIV replication in infected patients or for preventing HIV infection in the first place.

Implications for Treatment

Not surprisingly, many investigators quickly began considering ways to keep HIV and the CCR5 protein from interacting. In theory, such strategies could involve substances that sheathe gp120. In practice, however, most efforts are searching for ways to plug the HIV binding site on CCR5.

An initial concern was that blocking CCR5 would be dangerous—that it might impair immunity by making macrophages deaf to the call of RANTES and related chemokines. But that worry was soon allayed. Individuals who possess two mutant alleles have no obvious immune dysfunction or tissue pathology and appear to be quite healthy. Evidently, other chemokine receptors can compensate for the lack of CCR5. Two of them (CCR2B and CCR3) can also serve as co-receptors for HIV, although they generally do not perform that nefarious job nearly as effectively as CCR5.

Among the therapeutic strategies under consideration is direct delivery of molecules that would obstruct CCR5's binding site for HIV. Such molecules could include chemokines or synthetic derivatives of chemokines. For instance, an international team of investigators has developed a modified chemical derivative of RANTES that shows promise in test-tube studies. Other molecular "plugs" could include synthetic antibodies—larger immune molecules that would specifically home to CCR5 and bar attachment by HIV.

Additional approaches involve vaccinating people with fragments of CCR5 that could induce the recipient's immune system to produce its own CCR5-binding antibodies. Alternatively, researchers could use genetic engineering to provide macrophages with new genes whose products would prevent CCR5 from being made or would stop CCR5 from serving as a docking site for HIV.

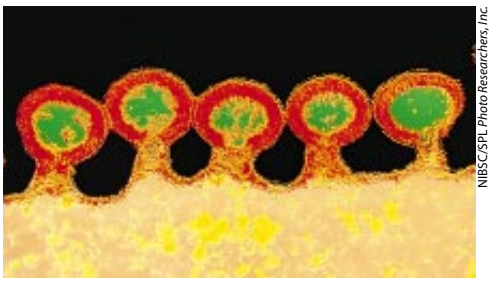
For some patients facing imminent death—such as those in the final stage of AIDS who also have lymphoma—our group is considering modifying a radical treatment increasingly applied to advanced cases of blood or breast cancers. When curing these cancers is the aim, patients are given extremely high doses of chemotherapy or radiation to eradicate all cancer cells. Because that therapy destroys the blood-producing cells of the bone marrow (including the ones that give rise to the immune system), physicians then reconstitute the patient's immune system by delivering healthy, tissue-compatible marrow.

In the case of AIDS patients, we would aim to destroy all HIV-infected blood cells and then to rescue the patient with bone marrow from donors who are homozygous for the deletion mutant of the *CCR5* gene. This last step would, we hope, help protect the patient from new HIV infection and also help prevent the cell-to-cell spread of any HIV particles that somehow survived the HIV-destroying therapy.

The idea of simultaneously curing pa-

Other Influences on HIV Progression

As we have shown, genes can certainly influence whether someone who is exposed to HIV becomes infected and progresses rapidly to AIDS. But other factors—including properties of the host and of the virus—can play a role as well.



NIBSC/SPL *Photo Researchers, Inc.*

HIV PARTICLES bud from an infected cell. Some strains are more aggressive than others.

Some people mount a stronger immune attack on HIV right from the start, perhaps because they have previously been exposed to a virus that structurally resembles HIV. A powerful early response that sharply limits HIV levels in the host could conceivably eliminate the virus in some cases. The strength of the immune response can also influence the rate at which people who do become infected advance to AIDS.

Whether an individual is contending with other viruses may also affect susceptibility to HIV and the speed of AIDS onset. The presence of concomitant infections in the body leads to the production of substances called cytokines, some of which are thought to promote HIV entry into cells and HIV replication.

Finally, the viral strain itself can make a big difference in the rate at which HIV infection advances. Strains that are quite choosy about the cell types they will infect, that replicate and mutate relatively slowly and that do not kill host cells are likely to be least destructive to the immune system—at least at first. Even initially mild strains, however, may later mutate into more aggressive forms. *—S.J.O'B. and M.D.*

tients and giving them protection from residual or sequestered HIV holds great appeal, but we are approaching bone marrow therapy cautiously because of a few important concerns. For one thing, bone marrow transplants are inherently risky: immunologic differences between the donor and the recipient can cause rejection of the transplant or, worse, can cause the immune cells in the donor marrow to attack the tissues of the host and kill the patient.

In addition, in recent months, a few individuals have surfaced who are homozygous for the deletion mutant but who have nonetheless become infected with HIV. We do not yet know how the infection became established, but some signs indicate that these rare patients met with an unusual "hot," or highly virulent, *T*-tropic strain of the type that typically emerges only in the late stages of HIV infection.

Until now, conventional wisdom held that *T*-tropic viruses were unable to spread infection from one person to another. They seemed to be recognized and destroyed by the healthy immune system of newly exposed individuals. Successful infection was thought to require M-tropic viruses, which quietly multiplied to high levels in macrophages without eliciting destruction of those cells. Some evidence suggests that the patients who became infected even though they were homozygous for the deletion mutant were merely unlucky and simply encountered odd *T*-tropic strains that were able to circumvent immune defenses and establish infection without needing M-tropic strains to lay the groundwork. It is also possible, however, that the patients' innate resistance to M-tropic strains somehow sped up the transition of M-tropic strains to hot *T*-tropic types able to establish infection on their own.

If CCR5-mediated resistance to M-tropic strains actually encouraged HIV to turn hot, the finding would mean that bone marrow transplants—and, in fact, any preventives or therapies aimed at blocking HIV's access to CCR5—could backfire and encourage, instead of forestall, infection and advancement to AIDS. The fact that most people who are homozygous for the deletion allele avoid HIV infection instead of succumbing to severe *T*-tropic viruses is reassuring. Nevertheless, before physicians can routinely treat patients with antagonists of CCR5, investigators need to show that such drugs improve, rather than diminish, the likelihood of survival.

As scientists explore safe, effective ways to capitalize on the recent genetic findings, they also continue to look for other genetic factors that could suggest additional ways to shield people from AIDS. Indeed, our group has recently identified a variant of the *CCR2B* gene that even in a single copy delays the onset of AIDS by two or three years, just as heterozygosity for *CCR5* does. And earlier this year Jianglin He of the Dana-Farber Cancer Institute and his colleagues reported that the CCR3 protein promotes HIV entry into microglia (immune cells in the brain) and that blockade of the receptor prevents HIV infection of microglia in the laboratory.

BERND AUERS

STEVE CROHN possesses only deletion mutants of the *CCR5* gene. Like most others with that same genetic profile who have had high exposure to HIV, he remains free of the virus. Investigators are working to develop treatments that will confer similar protection to people who carry standard copies of the *CCR5* gene.

After more than a decade of searching for genetic traits that provide protection from AIDS, we are indeed pleased by the quickening pace of discovery. But the main goal must be transforming genetic insights into novel ways to evade or attack HIV, a virus clever enough to destroy the very cells meant to eradicate it. Although therapeutic applications remain speculative for now, we are hopeful that the combined talents of researchers from many fields will provide a scientific recipe for reversing the deliberate progression of the AIDS epidemic. SA

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The Authors

STEPHEN J. O'BRIEN and MICHAEL DEAN have collaborated for more than a decade. O'Brien has been chief of the Laboratory of Genomic Diversity at the National Cancer Institute since 1986. He is internationally recognized for his contributions in human and animal genetics, evolutionary biology, retrovirology and species conservation. With two other colleagues, O'Brien also founded and co-directs NOAHS, a Smithsonian Institution consortium of scientists and apprentices who apply biotechnology on behalf of species conservation. Dean is chief of the human genetics section of the Laboratory of Genomic Diversity, where he applies new genetic techniques to the study of complex human diseases. The authors dedicate this article to the memory of Daniel O'Brien, Stephen O'Brien's brother, who died from AIDS in 1994.

Further Reading

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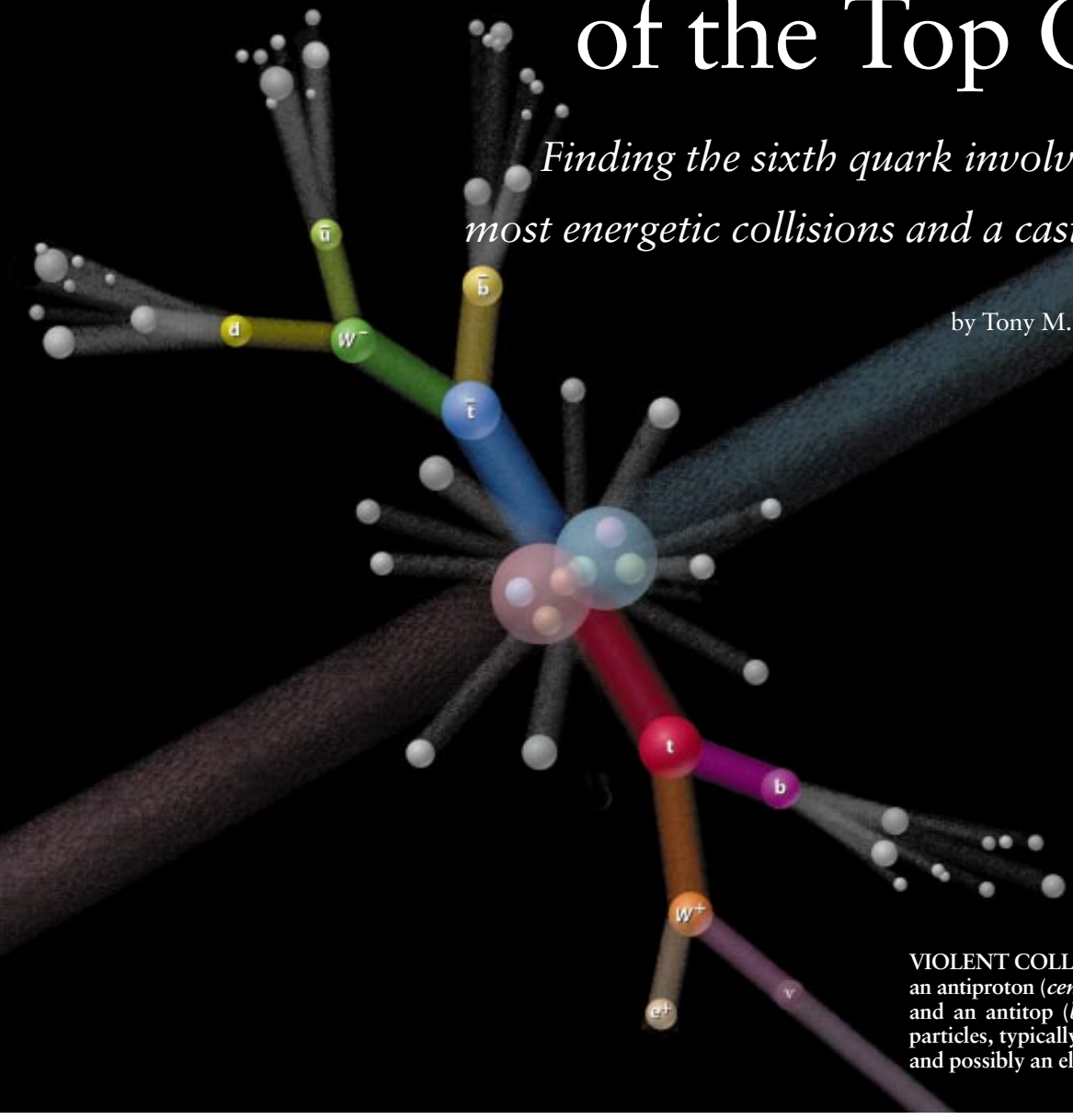
The Discovery of the Top Quark

Finding the sixth quark involved the world's most energetic collisions and a cast of thousands

by Tony M. Liss and Paul L. Tipton



VIOLENT COLLISION between a proton and an antiproton (*center*) creates a top quark (*red*) and an antitop (*blue*). These decay to other particles, typically producing a number of jets and possibly an electron or positron.

MICHAEL GOODMAN

In March 1995 scientists gathered at a hastily called meeting at Fermilab—the Fermi National Accelerator Laboratory in Batavia, Ill., near Chicago—to witness a historic event. In back-to-back seminars, physicists from rival experiments within the lab announced the discovery of a new particle, the top quark. A decades-long search for one of the last missing pieces in the Standard Model of particle physics had come to an end.

The top quark is the sixth, and quite possibly the last, quark. Along with leptons—the electron and its relatives—quarks are the building blocks of matter. The lightest quarks, designated "up" and "down," make up the familiar protons and neutrons. Along with the electrons, these make up the entire periodic table. Heavier quarks (such as the charm, strange, top and bottom quarks) and leptons, though abundant in the early moments after the big bang, are now commonly produced only in accelerators. The Standard Model describes the interactions among these building blocks. It requires that leptons and quarks each come in pairs, often called generations.

Physicists had known that the top must exist since 1977, when its partner, the bottom, was discovered. But the top proved exasperatingly hard to find. Although a fundamental particle with no discernible structure, the top quark turns out to have a mass of 175 billion electron volts (GeV)—as much as an atom of gold and far greater than most theorists had anticipated. The proton, made of two ups and one down, has a mass of just under 1 GeV. (The electron volt is a unit of energy, related to mass via $E = mc^2$.)

Creating a top quark thus required concentrating immense amounts of en-

ergy into a minute region of space. Physicists do this by accelerating two particles and having them smash into each other. Out of a few trillion collisions at least a handful, experimenters hoped, would cause a top quark to be created out of energy from the impact. What we did not know was how much energy it would take. Although many properties of the top, such as its charge and spin (intrinsic angular momentum), were predicted by the Standard Model, the mass was unconstrained.

Although particles can be created from nothing but energy, certain features, such as electrical charge, cannot—these are "conserved." A top quark cannot be born all by itself. The easiest way to make a top is along with an antitop—identical in mass but with opposite signs for other properties, so that conserved quantities cancel out.

In 1985, when the Fermilab collider was first activated, the search for the top had already been going on for eight years. Early forays at the Stanford Linear Accelerator Center in Palo Alto, Calif., and at DESY in Hamburg, Germany, turned up nothing. Over the years the hunt moved on to different accelerators as they came into operation with ever more energetic particle beams. In the early 1980s at CERN, the European laboratory for particle physics near Geneva, beams of protons and antiprotons hitting one another at energies up to 315 GeV generated two new particles, the *W* and the *Z*.

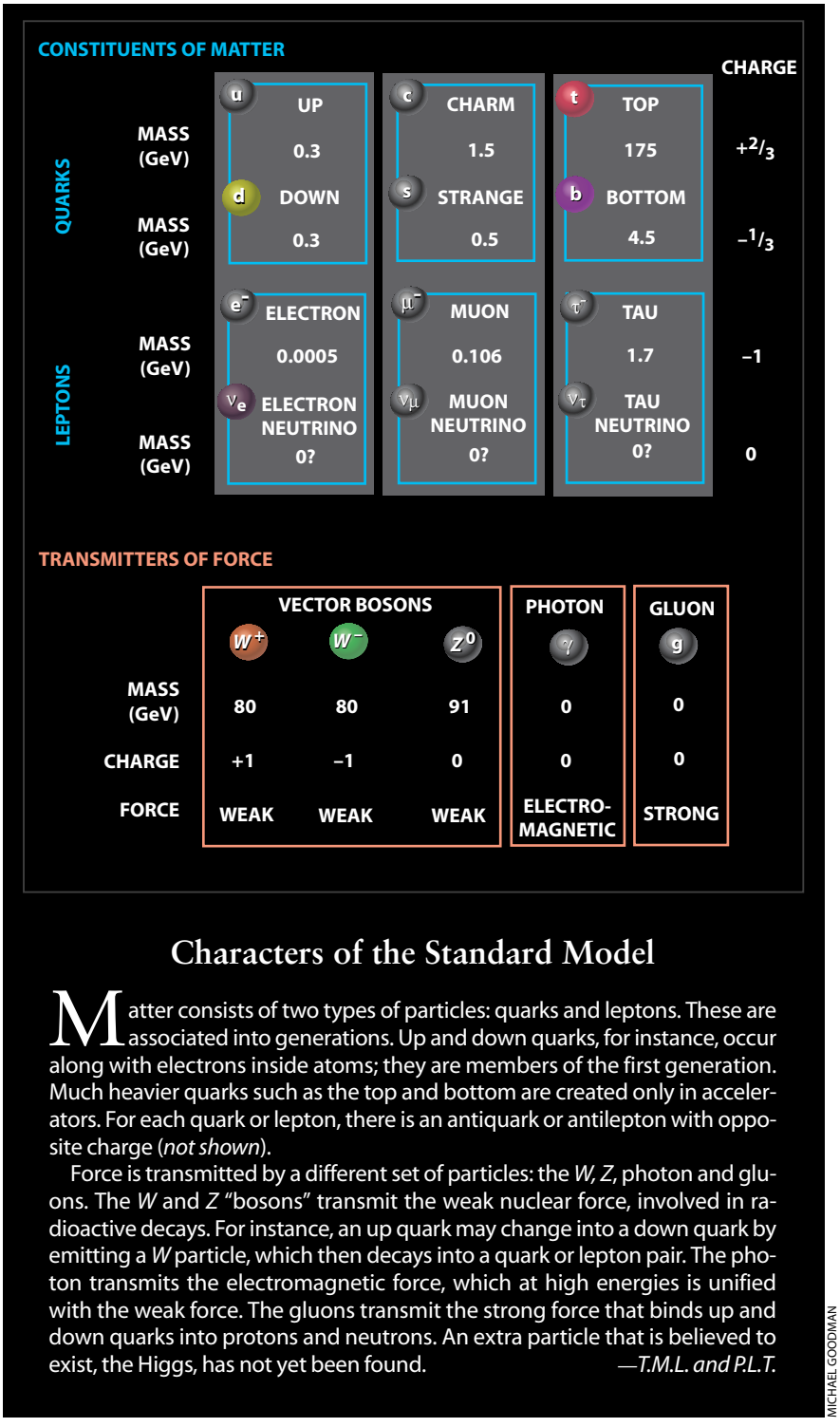
Whereas quarks and leptons constitute matter, these particles transmit force—in particular the weak force, responsible for some types of radioactive decay. Their discovery provided further confirmation of the Standard Model, which had accurately predicted their masses. It was widely believed that the discovery of the top quark at CERN was imminent.

Finding it would still be a difficult feat. When protons and antiprotons hit one another at high energies, the actual collision is between their internal quarks and gluons. Each quark or gluon carries just a modest fraction of the total energy of its host proton or antiproton, yet the collision must be energetic enough to generate top quarks. Such collisions are rare, and the higher the required energy—that is, the higher the top mass—the rarer they are.

By 1988 the top had not yet been observed at CERN; the experimenters concluded its mass must be greater than 41 GeV. Meanwhile the collider at Fermilab was just coming into its own with our young CDF (Collider Detector at Fermilab). A brief flurry of intense competition between us and a group at CERN brought the decade to a close without a top but with the knowledge that its mass could be no lower than 77 GeV.

By this time CERN had reached its limit. With its comparatively lower beam energies, its collisions would be unlikely to create top quarks heavier than 77 GeV. The competition was now between CDF and a new experiment across the accelerator ring at Fermilab, called DØ (pronounced "dee zero," after its location on the ring).

In the early 1980s Leon M. Lederman, then director of Fermilab, decided that CDF needed some local competi-

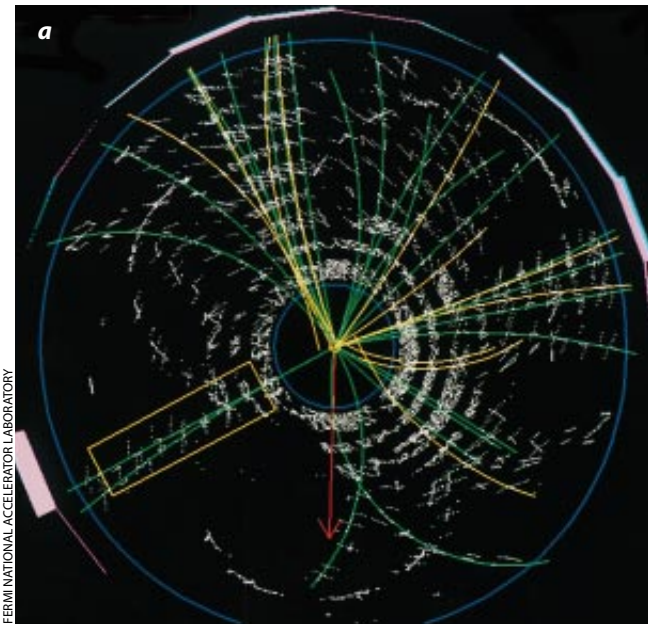


Characters of the Standard Model

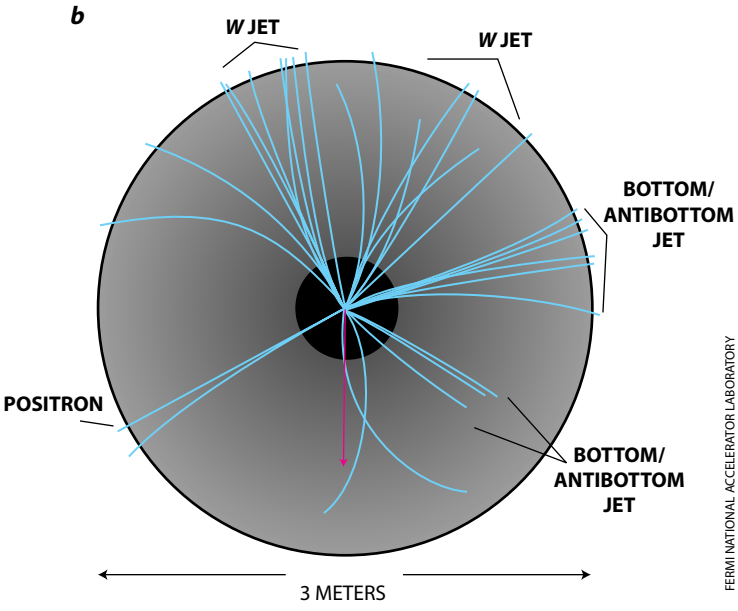
Matter consists of two types of particles: quarks and leptons. These are associated into generations. Up and down quarks, for instance, occur along with electrons inside atoms; they are members of the first generation. Much heavier quarks such as the top and bottom are created only in accelerators. For each quark or lepton, there is an antiquark or antilepton with opposite charge (*not shown*).

Force is transmitted by a different set of particles: the *W*, *Z*, photon and gluons. The *W* and *Z* "bosons" transmit the weak nuclear force, involved in radioactive decays. For instance, an up quark may change into a down quark by emitting a *W* particle, which then decays into a quark or lepton pair. The photon transmits the electromagnetic force, which at high energies is unified with the weak force. The gluons transmit the strong force that binds up and down quarks into protons and neutrons. An extra particle that is believed to exist, the Higgs, has not yet been found. *—T.M.L. and P.L.T.*

MICHAEL GOODMAN



FERMI NATIONAL ACCELERATOR LABORATORY



FERMI NATIONAL ACCELERATOR LABORATORY

tion. So we acquired in-house rivals: beginning in 1992 the DØ collaboration began to take data. In addition to spurring on our efforts, which it certainly did, having two complementary experiments studying the same physics was healthy in another way. Despite the best efforts of experimenters, spurious results can occur. Having a second experiment provides a cross-check.

Both CDF and DØ are international collaborations of more than 400 physicists. There are also numerous engineers, technicians and support personnel. The rival teams are independent of each other and never collaborate on their analyses. Each tries to beat the other to the punch. But it is friendly competition, and we regularly share tables in the cafeteria and enjoy both serious scientific conversation and a considerable amount of needling.

It is part of the unwritten code of both experiments that the results of any physics analysis are not discussed outside the collaboration until the analysis is finished. It was clear, however, that keeping any secrets in the top search was going to be tricky. Among other things, there are at least three physicists with a spouse on the rival team. To prevent the rumor mill from spinning out of control, we agreed with DØ that if one of the experimental groups was about to make a newsworthy announcement, it would give the other a week's notice.

The critical part of a high-energy experiment is the detector, which records the debris from a collision. Based on the best theoretical calculations, we expected that about one out of every 10 billion collisions would produce a top quark. The rest, though interesting for a host of other projects, would be a complicated backdrop from which the top would have to be extracted.

Over the course of a decade, both the CDF and DØ collaborations constructed enormous, complicated instruments, with hundreds of thousands of channels of electronics, in order to isolate the top's "signature"—the trace it would leave in the detectors. Whereas the CDF detector emphasizes the ability to track accurately the paths of individual particles in a magnetic field (in order to measure their momenta), the DØ device relies on an extremely precise segmented calorimeter, which measures the energy from each collision.

The top and antitop, once produced, decay almost instantly. Unlike the up and down quarks, which are stable, the top quark has a lifetime of only about 10^{-24} second. The Standard Model predicts that if heavy enough, the top quark will decay nearly all the time into a *W* and a bottom quark. So a top and antitop, if created, should generate two *W*s, a bottom and an antibottom.

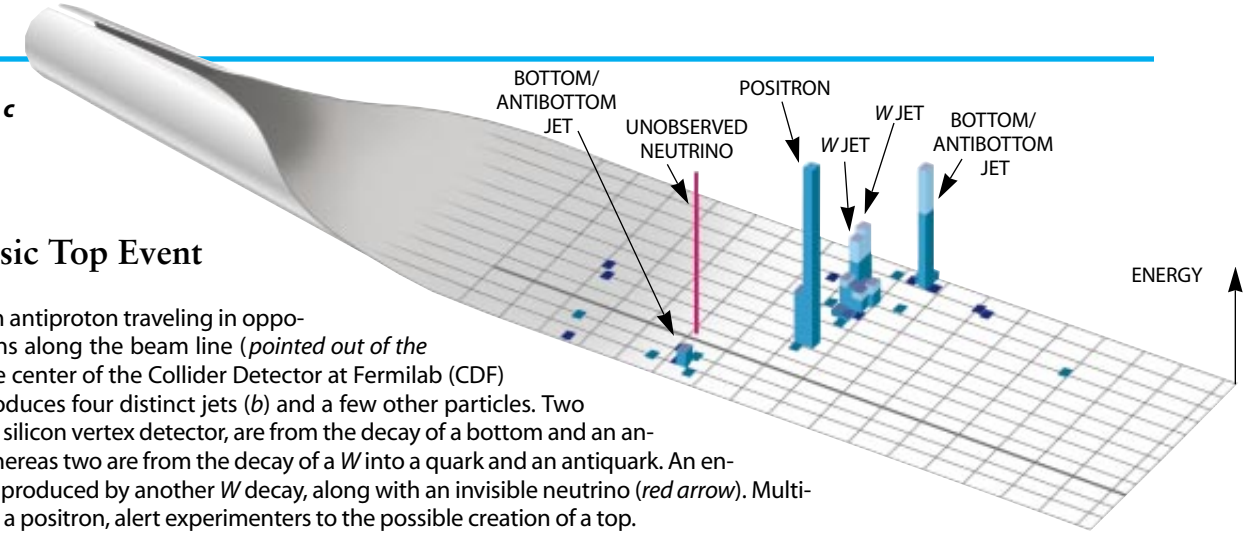
Unfortunately, neither the *W*s nor the bottom quarks can be directly observed. The *W*'s lifetime is about the same as the top's. The bottom, too, is unstable, though much longer lived than the top. Moreover, individual—or "bare"—quarks are never seen. The strong force, which binds the quarks together, ensures that quarks always appear stuck together with other quarks and antiquarks—in pairs called mesons or in triplets called baryons. (Protons and neutrons are examples of baryons.) When a quark emerges from a collision, it gets "dressed up" by a cloud of other quarks and antiquarks. What is observed is a jet, a directed beam of particles that have roughly the same direction of motion as the original quark.

A Barrage of Jets

The *W* can decay into a quark and an antiquark from the same generation, such as an up and an antidown. In this case, the quark and antiquark show up in a particle detector as two jets. But the *W* can also decay "leptonically"—into a charged and a neutral lepton from the same generation, such as an electron and a neutrino.

If the charged lepton is an electron or muon (a heavier copy of the electron), that particle can be directly observed in the detector. But if it is a tau (an even heavier copy of the electron), it decays quite rapidly, making it hard to identify. The neutrino (which has little or no mass) passes through a detector completely unobserved. Fortunately, its presence can be indirectly deduced because it carries away momentum. When the momenta of all the particles seen in the detector are added up, and a significant amount is missing, a neutrino is assumed to have carried it off.

By the time we started taking data in



JENNIFER C. CHRISTIANSEN

A Classic Top Event

A proton and an antiproton traveling in opposite directions along the beam line (*pointed out of the page*) collide at the center of the Collider Detector at Fermilab (CDF) (*a*). The impact produces four distinct jets (*b*) and a few other particles. Two jets, identified by a silicon vertex detector, are from the decay of a bottom and an antibottom quark, whereas two are from the decay of a *W* into a quark and an antiquark. An energetic positron is produced by another *W* decay, along with an invisible neutrino (*red arrow*). Multiple jets, along with a positron, alert experimenters to the possible creation of a top.

A magnetic field directed along the beam line curves the paths of the charged particles. The direction of curvature shows the sign of a particle's charge, and the extent reveals its momentum. Further, a calorimeter wraps around the beam line; it measures the energies of the emerging particles. It is shown unrolled (*c*). The height of a bar indicates the energy released by particles in the corresponding segment. The combination of devices allows experimenters to reconstruct the original event (*depicted on page 54*) with a high degree of confidence. —*T.M.L. and P.L.T.*

August 1992, we had pushed the top mass limit up to 91 GeV. This represented a milestone. The *W* mediates interactions between quarks in the same generation—and so between the top and the bottom. If the top were light enough—below about 75 GeV—a *W* might have produced a top by decaying to it, along with an antibottom. But now we knew that the only way we could find a top was by creating a top-antitop pair.

Among the most striking features of a top "event" are the jets produced by bottom quarks. The bottom quark travels in a jet as part of a meson or baryon, then decays roughly half a millimeter from where it was generated. In 1992 we started to track the particles in jets very precisely using a special instrument placed right on top of the region where the beams collide [see "The Silicon Microstrip Detector," by Alan M. Litke and Andreas S. Schwarz; SCIENTIFIC AMERICAN, May 1995]. This silicon vertex detector could locate the path of a particle to within 15 microns. By finding most of the tracks in a jet and extrapolating them backward, we hoped to find the point where the bottom quark decayed—and thereby identify it as a bottom jet.

The silicon technology was new, and we were concerned about the effects of trillions of particles passing through it. We knew that the entire detector could be fried in a fraction of a second if an accelerator glitch spilled the beams into it. We developed a special protection scheme, which would kick the beam safely away from the silicon if a problem was detected. Even as we were learning how to use the new vertex detector, the DØ collaboration was commissioning its own new detector on the opposite side of the accelerator ring.

In October 1992, just three months later, we saw our first hint of the top—an event characterized by a highly energetic muon and electron, lots of missing momentum and at least two jets. We analyzed that one event in excruciating detail, finally concluding that it was probably the real thing. DØ had also observed a similar event, the most likely interpretation of which involved a top. But a single event was not enough; we needed to observe the top in several different ways to make sure we were not being fooled by "background," events randomly mimicking the top signature. We began to analyze the data even more avidly than before, but when nothing particularly spectacular showed up, we knew we were in for a long haul.

Three groups were involved in analyzing the CDF results. Our first candidate for a top was found by a group searching among events with two leptons (from two *W* decays) and at least two jets (presumably from the bottom quarks). The two other groups were looking at events with a lepton (from one *W* decay) plus jets (from the other *W* decay and the bottom quarks). These two teams used different strategies to discern top events. One used the signals from the silicon vertex chamber, which was functioning very well, to identify bottom jets. The other looked for low-energy leptons, a telltale sign of a bottom-quark decay.

Nearly a year into the run, the mass limit was pushed to 108 GeV by CDF and later to 131 GeV by DØ, and we were still searching. Then, in July 1993, at a meeting of the entire CDF collaboration, the three groups presented the results of their ongoing analyses. Independently they were ambiguous, but together they offered persuasive evidence of a top. One of us (Tipton) was soon to go to a conference and present our latest results. After the meeting, we began to realize that if these results were presented, the audience would conclude that we had strong indications of a top. Our work was not yet ready for such intense scrutiny. So Tipton gave a talk focusing on our methods and the various difficulties in finding the top, but without the latest results. Soon rumors began to fly, some very accurate and others wildly off. We did not help matters when in the spring of 1994 we canceled a scheduled talk at a major conference.

Of the trillion or so collisions created within CDF, we had isolated 12 events that seemed to involve the creation of a top-antitop pair. Other physical processes can imitate the signature of such an event, and we had to estimate their likelihood. After months of effort, we estimated that roughly 5.7 of these background events were to be expected. The probability that background alone was responsible for these 12 events was about one in 400, leaving a small

chance that no tops had been observed.

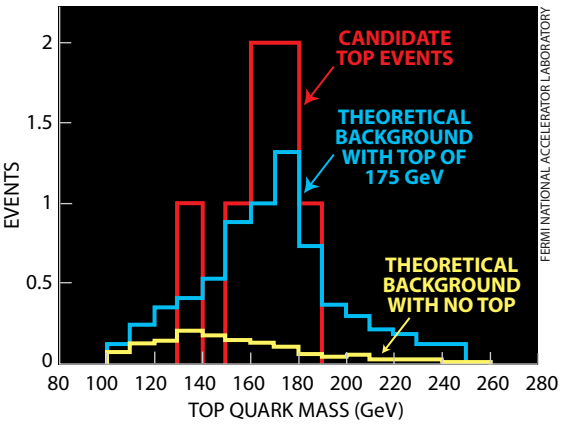
We subjected the 12 events to exhaustive analysis. One crucial study involved an attempt to "reconstruct" the top mass. By adding up the energies in the jets and leptons emitted by a (presumed) top-antitop pair, we could arrive at a value for the mass of the top. If the events were indeed from such a pair, the derived masses should fall close to some one value—the true top mass. In contrast, background events should give a much broader distribution. The mass indeed clustered in a narrow range, implying a top mass of about 175 GeV. To many of us, this was convincing evidence that we were not being fooled by background.

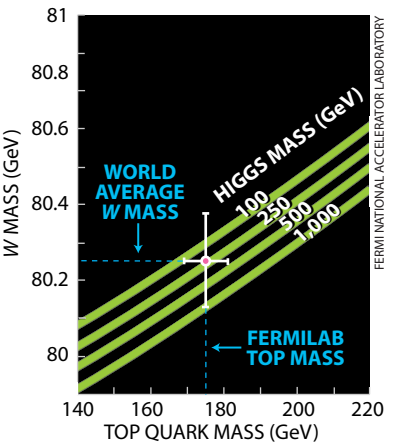
We initially planned to write four papers, one for each kind of analysis and one summarizing the results. At the next meeting of the entire collaboration, which we privately refer to as the October Massacre, the four groups writing the papers presented them to the rest of the collaboration. We were loudly and appropriately criticized because the papers were incomplete and did not paint a coherent picture. We abandoned the four-paper idea, and a small group (including the two of us) started instead to work on one.

The process was excruciating. Each person in the collaboration had a different view as to the strength of the claim we should make. It is hard to satisfy 400 editors. Moreover, as the effort finally drew to a close months later, we were even receiving corrections from physicists outside the collaboration, who were not supposed to have the drafts at all. After much debate, the collaboration decided to report the result not as a discovery but more tentatively as evidence for the existence of a top quark. On April 22, 1994, when we finally submitted the paper for publication, most of us thought it was a very good paper, the result of an excellent, democratic process we hoped never to have to repeat.

We hid all the drafts and documentation in a subdirectory of our secretary's computer, under the name of "pot." As might be expected, this feeble attempt at encryption did little to safeguard our secrets. Just before the announcement, two postdoctoral fellows posted a tongue-in-cheek theoretical paper on an electronic bulletin board. On the basis of a wild theory, they "predicted" the top mass—the CDF value to the last decimal place—and noted they were available for job offers.

A few days after the submission of the CDF paper, we held a seminar and press conference at Fermilab to announce the findings. The DØ collaboration presented its results as well. Although consistent with CDF's, the DØ data showed little compelling evidence for top quarks except for the one exceptional event recorded early in their run. The group had, however, assumed a low value for the top mass and as a consequence had not designed its search optimally.





TOP MASS reconstructed (*above*) from 12 initial events at the CDF cluster around the value of 175 GeV. But the accuracy with which the top and *W* masses are known is not enough (*below*) to predict the mass of the Higgs particle. It may vary from 100 to 1,000 GeV.

Within weeks DØ had finished its reanalysis (for a heavier top) and were observing some signs of it as well. Meanwhile both teams set to collecting more data. To confirm the finding, we would need at least twice as many top events. CDF put in a new silicon vertex detector; the old one had been damaged by radiation. Once again we had to learn its particular quirks, but in the end this device worked even better than the first. We wrote a new algorithm for using the vertex detector to detect top candidates, putting to good use our previous experience. Once we had enough data, we processed them with the completed algorithm. It was almost immediately obvious that we indeed had the top.

The final presentations, made on March 2, 1995, showed overwhelming evidence for the top quark from both CDF and DØ. Both teams reported a probability of less than one in 500,000 that their top quark candidates could be explained by background alone.

Since then, we have acquired more than 100 top events. We have also made preliminary searches for phenomena beyond the Standard Model. The extremely large mass of the top—the current value is 175.6 GeV—suggests that it may be fundamentally different from the other quarks, and therein lies the hope that it may lead us past the Standard Model. Although successful, this model leaves many questions unanswered.

Within the Standard Model the weak interaction, mediated by the *W* and *Z* particles, and the electromagnetic interaction, transmitted by photons, are unified into a single "electroweak" interaction at very high energies. Such energies existed in the very early universe. In the low-energy world in which we live, the electromagnetic and weak interactions behave very differently. The mechanism behind the "breaking" of their initial symmetry is not known, but in the simplest model it is caused by a new particle called the Higgs.

At high energies, when the symmetry exists, the *W*, *Z*, photon, leptons and quarks are all massless. At lower energies, when the symmetry breaks, the *W* and the *Z* interact with the Higgs and become massive. The quarks and leptons also acquire masses in the process. But whereas the *W* and *Z* masses can be calculated from the Standard Model, the quark and lepton masses have to be inserted by means of adjustable parameters that describe how strongly each type of quark or lepton interacts, or "couples," with the Higgs.

For an electron, which is very light, the interaction strength is 3×10^{-6}. For a top quark, it is almost exactly unity.

This relatively strong coupling with the Higgs, and to some extent the mystique associated with a value of unity, suggests that the top quark may have a special role. We do not yet know what it is. Certainly the top's great mass makes it the most influential quark, in terms of its interactions with other particles. A very precise measurement of the top's mass, for example, along with that of a *W,* would lead to a prediction for the Higgs's mass.

There are ways of breaking the symmetry of electroweak theory that do not invoke an elementary Higgs particle. In one candidate theory the Higgs is replaced by a top-antitop pair. This theory predicts the existence of new, heavy particles that decay into top-antitop pairs. Such an effect would enhance the rate of production of top quarks.

Over the Top

The sheer enormousness of the top's mass makes its decays fertile ground for new particle searches. Some theorists have speculated that a few of the events collected by CDF may contain supersymmetric particles [see "Is Nature Supersymmetric?" by Howard E. Haber and Gordon L. Kane; SCIENTIFIC AMERICAN, June 1986]. Supersymmetry is a postulated symmetry that assigns as yet undiscovered partners to every particle in the Standard Model. If such partners exist and are lighter than the top, they might show up in top events. For instance, a top may decay to its own supersymmetric partner (the "stop"). Or supersymmetry could allow a gluino (hypothetical partner to a gluon) to decay into a top-antitop pair. Such effects might even cancel each other out, leading to no net change in the observed production of tops and antitops.

Supersymmetry predicts not just one Higgs but a family of four or more. If they exist and are lighter than the top, some of these particles could be found in top decays. CDF and DØ have both mounted searches for these hypothetical particles, so far with null results.

Another critical question is whether quarks, especially the massive top, are really fundamental particles with no substructure. Recently the CDF collaboration measured the rate at which high-energy jets are produced at Fermilab's collider, finding that it is higher than expected. Very energetic scattering at wide angles (reminiscent of Rutherford scattering, which revealed that the atom has a nucleus) offers insights into the structure of the colliding objects. One possible interpretation of our results is that the excess jets are caused by collisions of even smaller objects within quarks—something not observed by any other experiment.

So radical a conclusion, which would completely change the theory of quarks, can be reached only if we can rule out all other possibilities. An "excessive" production of jets could be coming from subtle inaccuracies in the predictions. We are in the process of exploring the possibilities; the data currently favor one of these more boring explanations. For now we must conclude that the top quark, though massive, is indeed fundamental; it has no parts.

At present, the Fermilab accelerator is being revamped, and both CDF and DØ collaborations are dramatically improving their detectors. We will resume taking data in 1999. The accelerator upgrades will allow top quarks to be produced at 20 times the previous rate, and the detector upgrades will improve the efficiency of identifying top quarks. The net result is that both groups will find tops 30 times faster than before, allowing a more detailed look at the top's characteristics. By 2006 the Large Hadron Collider at CERN will begin operation. It will produce two proton beams colliding at 14 TeV (tera, or 10^{12}, electron volts)—seven times the energy at Fermilab—generating almost one top-antitop pair per second.

In a few years, physicists will start using the top to try to answer the many questions that still remain about matter and the forces that govern the physical world. What new tenets of physics may arise beyond what we now know is a matter of active speculation that will end only when measurements start to unravel the workings of nature. SA

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ABOUT 1,000 PHYSICISTS and uncounted technicians contributed to the CDF and DØ collaborations' efforts to find the top quark. The first pages of their respective papers reporting the discovery consist entirely of names.

The Authors

TONY M. LISS and PAUL L. TIPTON helped to build key elements of the Collider Detector at Fermilab (CDF) and have both served as conveners of the search group for the top quark. For his Ph.D. at the University of California, Berkeley, Liss participated in a search for monopoles. In 1988 he joined the faculty at the University of Illinois at Urbana-Champaign and in 1990 was awarded an Alfred P. Sloan Fellowship. Tipton received his Ph.D. from the University of Rochester in 1987 studying bottom quarks and is now on the faculty there. He is a recipient of the U.S. Department of Energy's Outstanding Junior Investigator Award and the National Science Foundation's Young Investigator Award. Tipton is an avid Chicago Bulls fan; Liss is a lifelong sufferer with the New York Knicks. The authors would like to thank Lynne Orr and Scott Willenbrock for helpful discussions as well as all their colleagues at CDF and DØ.

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Building Doors into Cells

With the help of recombinant DNA technology, researchers have learned how to create artificial pores that might be used to deliver drugs or act as biosensors to detect toxic chemicals

by Hagan Bayley

The outer membrane of a cell does more than just contain what is inside—it serves as a molecular gatekeeper, carefully regulating what passes in and out. Nutrients and other desired compounds enter; unwanted molecules remain outside; and waste products pass out of the cell. But in the perpetual warfare between species, pathogenic bacteria have developed the ability quite literally to penetrate the cell's defenses and disrupt the balance of entry and exit.

The weapons used in battle consist of protein molecules released by the pathogen to bore holes into the cell membrane, allowing foreign material to rush in and some of the cell's contents to leak out. Interestingly, humans ward off many of these attacks with a similar armory: the immune system also exploits the properties of its own so-called pore-forming proteins to destroy foreign cells.

In my group, we are examining not only the basic science of how these proteins work but also their potential applications in biotechnology and medicine. Ideally, we would like to dispatch molecular gatekeepers of our own design. That way, we could bombard cancer cells with proteins that would damage the cells' outer membranes, making them more susceptible to chemotherapy. Or we could create synthetic membranes with artificial pores embedded in them to serve as biosensors or drug delivery agents.

Bacterial pore-forming proteins exhibit a range of characteristics. The protein alpha-hemolysin, which I shall discuss in this article, is secreted by the common bacterium *Staphylococcus aureus,* which causes staph infections. The protein assaults target cells by forming pores approximately two nanometers in diameter—sufficiently large to permit small molecules such as the sugar sucrose to pass through but too small for larger molecules, including most proteins. In contrast, streptolysin-O, from the bacterium *Streptococcus,* can make pores exceeding 30 nanometers in diameter. Like alpha-hemolysin, streptolysin-O causes cell damage or death by piercing the cell membrane.

Another kind of protein, known as an S-layer protein, provides a defensive envelope for bacteria; it forms flat sheets with numerous openings of roughly uniform size, between two to six nanometers across, depending on the type of bacterium. The pores in these sheets allow selected nutrients to reach the cell membrane for transport into the cell.

ARTIFICIAL PORE can penetrate a cell membrane or an artificial membrane made of a double layer of fats, or lipids. Such channels, formed from modified versions of the bacterial protein alpha-hemolysin, can be designed to control the passage of drugs or other molecules.

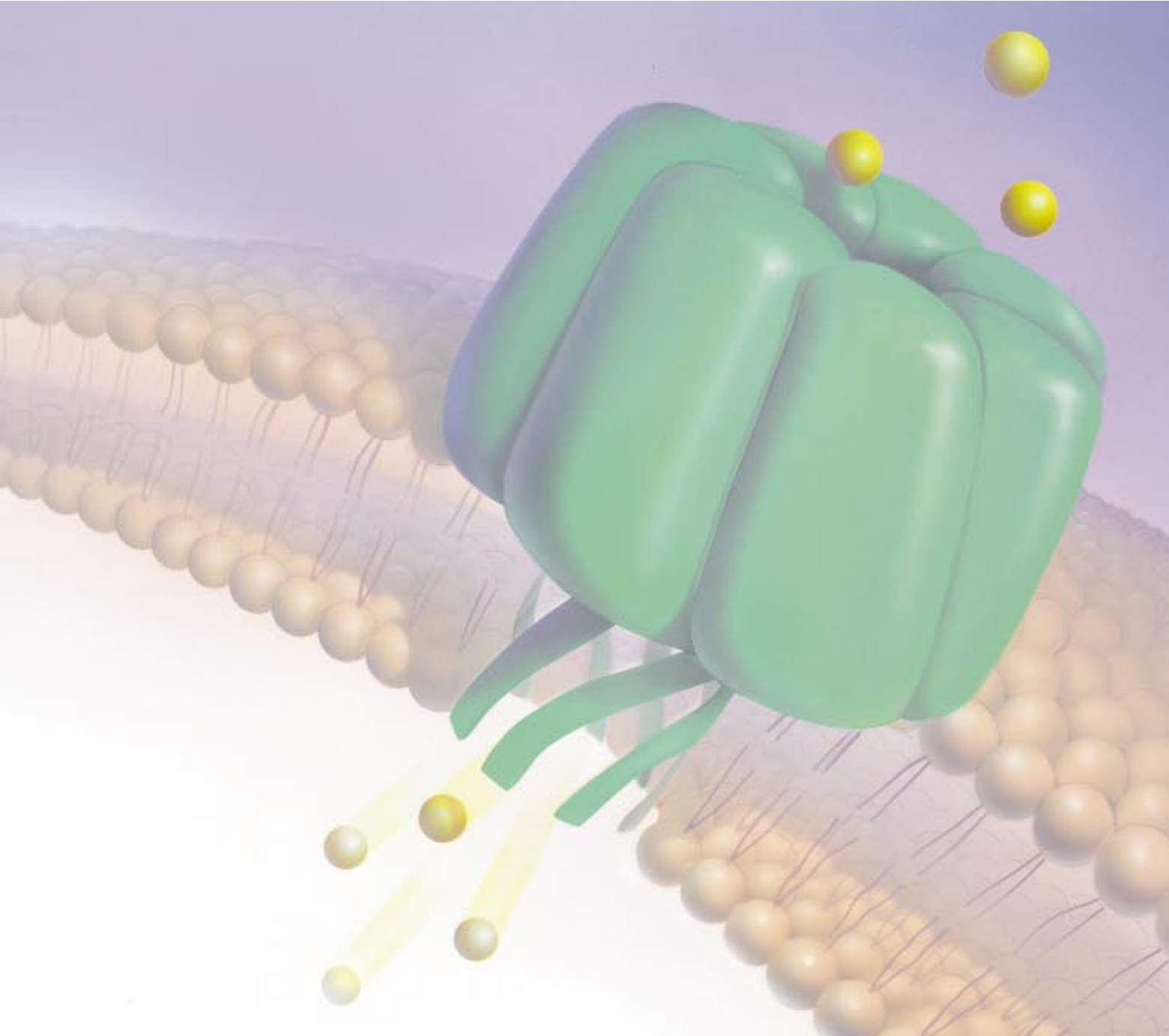
Mushroom-Shaped Pore

In my work, I have chosen to study the protein alpha-hemolysin for several reasons. It can be produced in large amounts (a few grams if necessary) from bacterial cultures; the structure is fairly small, with only 293 amino acid building blocks, making it simple to alter by recombinant DNA technology; and the molecule is extremely stable compared with other proteins. The structure of the gene that encodes the protein was published in 1984 by Gary S. Gray, then at Biogen, and Michael Kehoe, then at the University of Geneva. Just last year J. Eric Gouaux, now at Columbia University, and his research group determined the three-dimensional structure of the alpha-hemolysin pore, demonstrating that it exists as a mushroom-shaped complex of seven alpha-hemolysin molecules [*see upper left illustration on page 64*].

Research by Sucharit Bhakdi's team at the University of Mainz in Germany suggests that alpha-hemolysin can assemble into a pore in two ways. Certain cells, such as rabbit red blood cells, have on their surface special receptors that bind to alpha-hemolysin; these receptors may either trigger pore formation or help to orient the hemolysin structure correctly on the cell membrane. But conveniently, even in the absence of such receptors, alpha-hemolysin molecules can still function; on artificial membranes (made from a double layer of molecules known as lipids), the proteins organize themselves, or self-assemble, into pores. The proteins will also spontaneously assemble when mixed with certain laboratory chemicals related to common detergents. Self-assembly offers real advantages to biotechnologists seeking to manufacture products based on alpha-hemolysin, because otherwise troublesome aspects of the production process will take care of themselves.

Recent work on alpha-hemolysin by my lab and by Bhakdi's and Gouaux's groups has also helped clarify many details concerning how the opening actually forms. Once individual alpha-hemolysin molecules bind to a cell membrane or an artificial lipid membrane, they consolidate into groups of seven in what

ALFRED T. KAMAJIAN



is known as a prepore complex. The center of each monomer consists of a long strand of approximately 40 amino acids; investigators have now determined that this strand burrows into the cell membrane to become part of the lining of the channel [*see upper illustrations on pages 64 and 65*].

Open Sesame

My goal on starting this research was to use the techniques of protein engineering to manipulate three essential properties of the alpha-hemolysin pore: the size of the opening, the selectivity of the channel for letting different molecules pass through, and the pore's ability to open and close.

Under normal circumstances, the alpha-hemolysin pore is open. It displays only a slight preference for allowing negatively charged molecules to pass through (rather than positively charged or neutral molecules), but this bias is quite minimal. For the purposes of my work, the opening turns out to be just the right size—a bigger or smaller channel would be more difficult to remodel. Therefore, I consider the alpha-hemolysin pore to be a blank slate, ready to be modified by protein engineering.

Nevertheless, when I began, I had little idea how opening and closing the channel, seemingly the most difficult of the three tasks, might be achieved. But researchers in my laboratory have been able to place molecular triggers and switches into the protein that prompt the pore to open or close on command. Our attention has focused on this aspect of the work because of its considerable practical implications.

Protein engineering has been our technique of choice because it permits the amino acids in a protein to be replaced with other naturally occurring amino acids or even with "unnatural" amino acids made in the laboratory. We can therefore put a variety of potential triggers and switches into alpha-hemolysin and explore which ones will work.

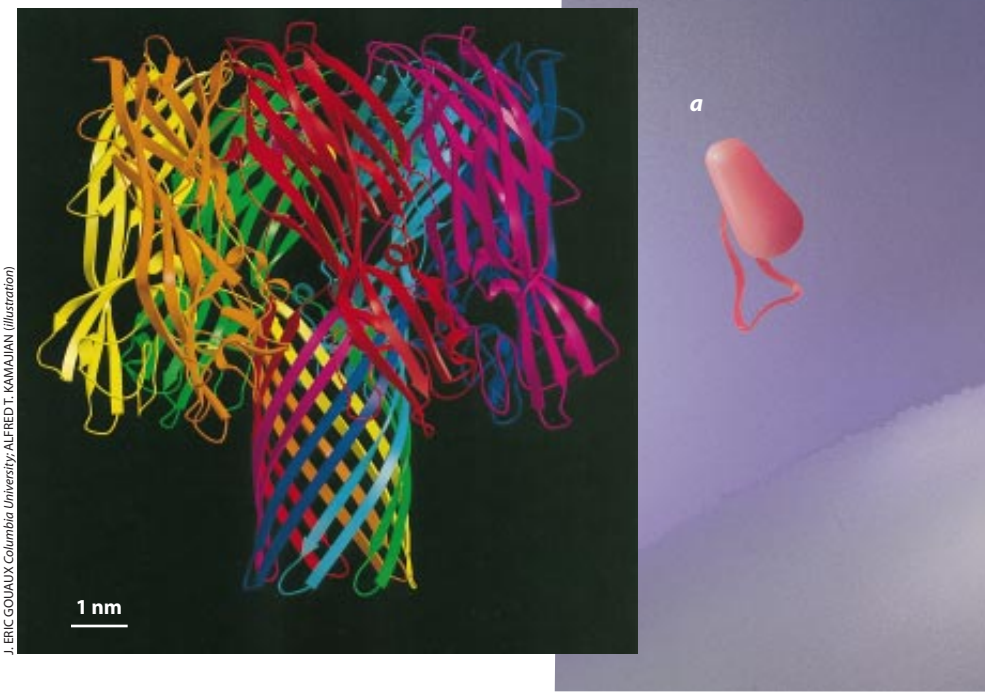
In principle, molecular switches might be biochemical (activated by enzymes) or chemical (activated by the binding of small molecules to the protein). Activation by a physical stimulus, such as heat

or light, is another possibility. As it turns out, all three approaches have been successful with alpha-hemolysin.

With the help of Barbara J. Walker of the Worcester Foundation for Experimental Biology in Shrewsbury, Massachusetts, where I began this research, I have introduced a biochemical trigger into alpha-hemolysin by first adding a small polypeptide chain—between 11 and 53 amino acids—to the central strand of the protein that ordinarily breaks through the cell membrane. This additional segment blocks the opening of the pores; subsequent treatment of the protein with an enzyme known as a protease clips off this extra piece, allowing pore formation to proceed.

Biochemical triggers might be used to make alpha-hemolysins that penetrate only selected cells. For example, specially modified hemolysins could be guided to a tumor with the aid of antibody fragments (chosen to recognize cancer cells) built into the protein's structure by genetic engineering. When these hybrid proteins reach the cancer cells, pore formation could be activated by the proteases released by the cancer cells. (Metastatic cancer cells secrete enzymes known as tumor proteases that assist the cells both in their escape from primary tumors and in their colonization of new sites.) The altered hemolysins would begin drilling holes into the cancer cells, thereby enhancing their permeability and hence susceptibility to various cytotoxic drugs. As a step in this direction, Rekha G. Panchal in my group created mutant alpha-hemolysins that are activated by tumor proteases.

Eventually, it may be possible to insert a biochemical switch that could turn pore-forming activity both on and off, rather than just turn it on. Dan W. Urry of the University of Alabama at Birmingham has modified the shape of a synthetic protein and then returned it to its original configuration with the help of enzymes by exploiting what is called a phosphorylation reaction. We have begun to adapt Urry's methods to create biochemical switches that would enable us to open and close the alpha-hemolysin pore repeatedly.

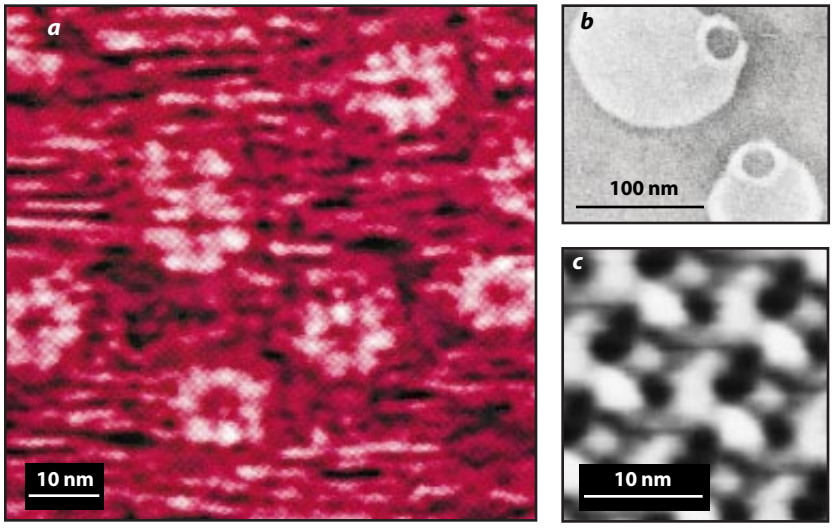


J. ERIC GOUAUX *Columbia University*; ALFRED T. KAMAJIAN (*illustration*)

Chemical Triggers

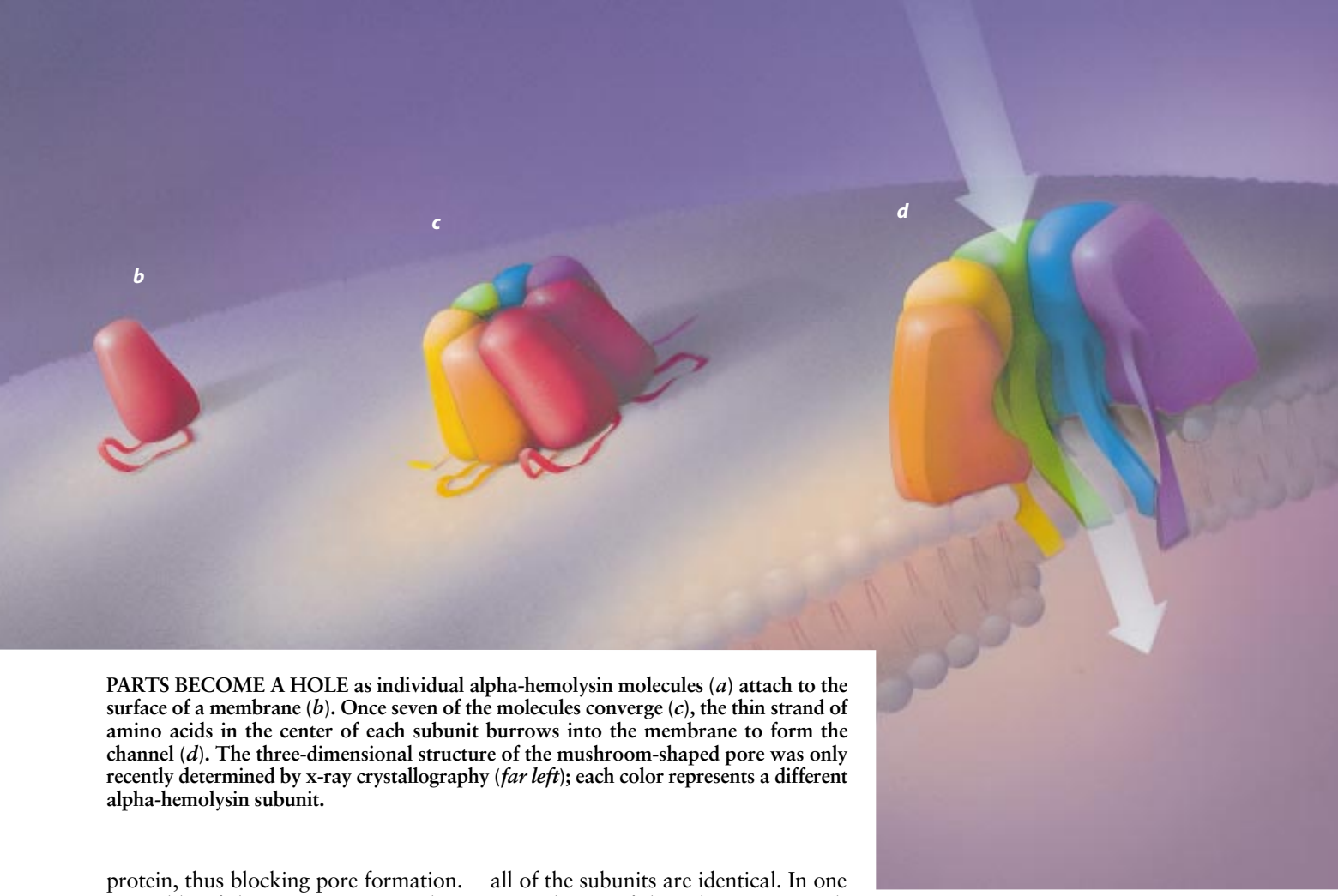
We have also introduced a second type of trigger into the structure of alpha-hemolysin that is activated by certain small, highly reactive molecules. We believe this technology can be adapted to produce sensitive artificial membranes for use in biosensors that detect toxic molecules, including pesticides and nerve gases. Investigators in my laboratory have designed a mutant version of alpha-hemolysin that is embedded in the surface of a liposome (a microscopic sac made of a lipid bilayer membrane) and assembles into an open pore when a highly reactive organic compound attaches permanently to a genetically engineered region of the structure. The opening of the channel can be detected by the release through the pores of fluorescent dye put inside the liposome when it is assembled.

We have also developed a chemical switch that can be turned on and off repeatedly by the binding of metal ions to the protein. Such a switch would be useful for taking repeated measurements with biosensors. Replacing five assorted amino acids on the central strand of the protein with five copies of the amino acid histidine creates a site where zinc and other metal ions can bind to the



JIE YANG *University of Vermont* (*a*); SUCHARIT BHAKDI *University of Mainz* (*b*); UWE SLEYTR *University of Agricultural Sciences Vienna* (*c*)

MICROSCOPIC PORES are made by a variety of proteins. The author has studied derivatives of alpha-hemolysin that generally form openings roughly two nanometers in diameter. Certain versions can be larger, though, up to six nanometers in diameter (*a*). The protein streptolysin-O can make pores exceeding 30 nanometers across (*b*). A third type of protein, an S-layer protein, forms sheets of pores of uniform size; the pores shown in *c* are about three nanometers in diameter.



PARTS BECOME A HOLE as individual alpha-hemolysin molecules (*a*) attach to the surface of a membrane (*b*). Once seven of the molecules converge (*c*), the thin strand of amino acids in the center of each subunit burrows into the membrane to form the channel (*d*). The three-dimensional structure of the mushroom-shaped pore was only recently determined by x-ray crystallography (*far left*); each color represents a different alpha-hemolysin subunit.

protein, thus blocking pore formation. Assembly of the pore continues when the metal ion is removed. Once the hole opens, the ion can seal the pore again by binding to the central channel and obstructing the passage of other molecules. The sealing and resealing process can be repeated numerous times.

This so-called H5 structure (shorthand for five histidines), as well as other, related hemolysins constructed by Walker and Stephen Cheley in my Worcester group, could be effective as highly responsive biosensors for monitoring metal pollutants. Indeed, we have been developing such devices in collaboration with John J. Kasianowicz of the National Institute of Standards and Technology. The U.S. Navy is also very interested in the rapid and continuous measurement of metal ions in seawater—it would like to devise tracking systems that can detect trace amounts of metals leached from enemy ships—and so the Office of Naval Research has sponsored this aspect of our work.

Recent advances in protein-engineering techniques and the new information on the structure of alpha-hemolysin have enabled Orit Braha and her colleagues in my lab to improve on the H5 molecule by making pores in which not all of the subunits are identical. In one example, six of the subunits are unaltered, but one contains a site where a metal ion can bind. When the metal ion binds, an electric current (sent through the pore by an applied potential field) changes. The fluctuation in this current gives both the concentration and the identity of the ion present. Notably, the oscillating signal from one pore can be used to measure several metals at once; an array of sensors could handle a complex mixture of substances. Another advantage of these sensors is their size: because binding at just one pore is sufficient to obtain a current reading, these sensors can be extremely small.

Thousands if not millions of different modifications can be made to pore-forming proteins, resulting in an extraordinary array of potential biosensors. We are currently developing sensors for nonmetallic substances as well. Kasianowicz and his colleagues have shown recently that single strands of large molecules such as DNA can also be detected as they move through the pore.

The findings with H5 offer an illustration of the interplay between biotechnology and basic science. The structure provided not only a prototypical component for a sensor but also revealed information about how the pore functions: the work with H5 helped to demonstrate that the central strand of the natural protein lines the interior of the pore.

Light Switches

In thinking about designing an alpha-hemolysin that would be activated by a third type of switch—a physical stimulus—I noted that there are naturally occurring membrane channels that can be physically activated by either mechanical impulses or voltage applied across the cell membrane. In most circumstances, however, activation by light is a more attractive option: light does not interfere with many natural processes, and it can be applied with exquisite spatial and temporal control.

Besides, I had spent from 1974 to 1979 as a graduate student in the lab of Jeremy R. Knowles at Harvard University developing light-sensitive chemicals for investigating the structure of membrane proteins. Therefore, I was not surprised when after an interval of many years, photochemistry and membrane proteins were reunited in my research

group, but with quite a different focus.

Our approach relied on the light-sensitive structure of nitrobenzyl compounds, which were first used in organic synthesis in the 1960s by Jack A. Barltrop, then at the University of Oxford, and later adapted for small biological molecules by Jack H. Kaplan and his colleagues, then at Yale University. We developed a nitrobenzyl derivative, called bromonitrophenylacetic acid (BNPA), that after binding to the protein will switch off the pore formation process.

To accomplish this, workers in my group first introduced a single cysteine amino acid at a key site in the protein. When the cysteine reacts with the BNPA, the protein becomes inactive. The protein's activity could be regenerated by exposing it to ultraviolet radiation—at wavelengths that do little damage to most cells. Eventually, researchers may be able to make pore-forming molecules that can be turned on with light of one wavelength and off with light of another wavelength. They might also build hybrid switches in which a protein is, say, turned on with light and off with metal ions.

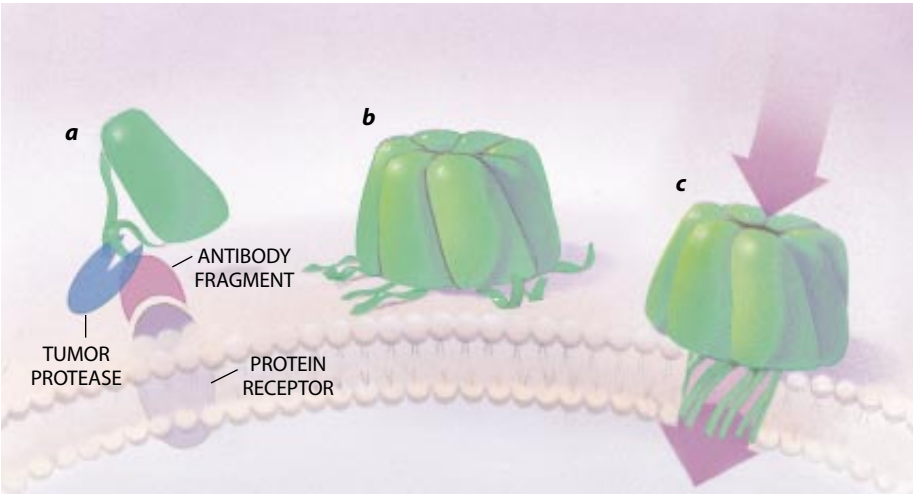
The present technology, however, has immediate applications in the laboratory: researchers often need to make selected cells in a tissue sample porous without altering any of the other cells. In this way, small molecules that probe the activity of the cell can be introduced, while crucial proteins remain inside. In my laboratory, we have been able to make single neurons in a collection of neurons permeable by shining light on the chosen cell. Engineered hemolysins exposed to the light penetrated the selected neuron; the rest of the neurons remained intact. By using sophisticated optical devices, it will be possible to make just one region of a neuron permeable by shining light on that area of the cell.

One of the most exciting applications for pore-forming proteins lies in the area of drug delivery. For example, drugs could be transported inside liposomes and, with the help of any of the triggering techniques mentioned earlier, released on command through artificial pores implanted in the membrane. In addition, biomedical researchers have considerable interest in encapsulating enzymes or even entire cells, thereby protecting them from attack by a patient's immune system. Once the enzymes are shuttled to the desired location, they might be used to destroy toxic substances that build up in people with certain genetic disorders, such as phenylketonuria, in which the body cannot properly metabolize the amino acid phenylalanine. The condition can ultimately lead to nerve cell damage.

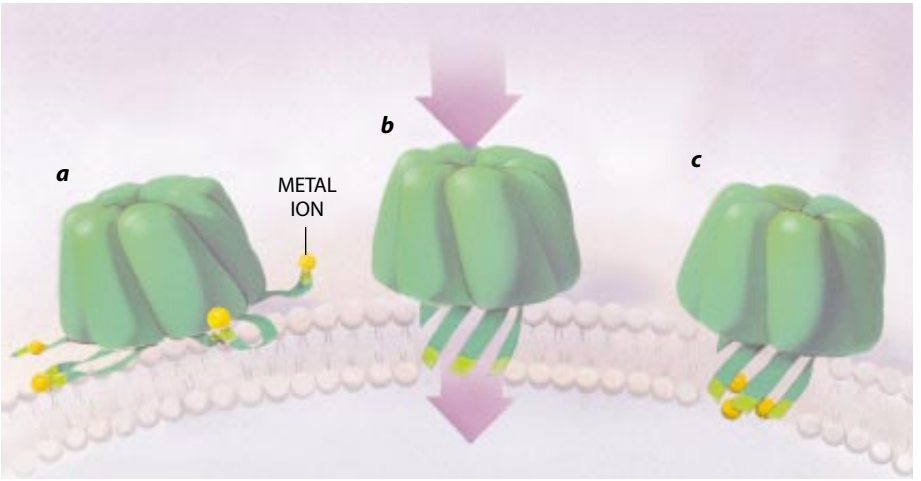
Encapsulated cells could be used to deliver hormones lacking in people with diseases such as insulin-dependent diabetes. Drugs, enzymes and cells within membranes bearing artificial pores would provide a level of control over where, when and how much of the medication is delivered that improves markedly on existing technologies.

Other bacterial pore-forming proteins with quite different properties—including the streptolysin-O and S-layer proteins—are also being reengineered in our laboratory and elsewhere. Uwe Sleytr and his colleagues at the University of Agricultural Sciences Vienna have already adapted the naturally occurring sheets of pores created by S-layer proteins for use in filtration devices. These sheets have also served as templates to form nanoscale grids by metal vapor deposition in work by Ken Douglas and Noel A. Clark of the University of Colorado in Boulder and Kenneth J. Rothschild of Boston University.

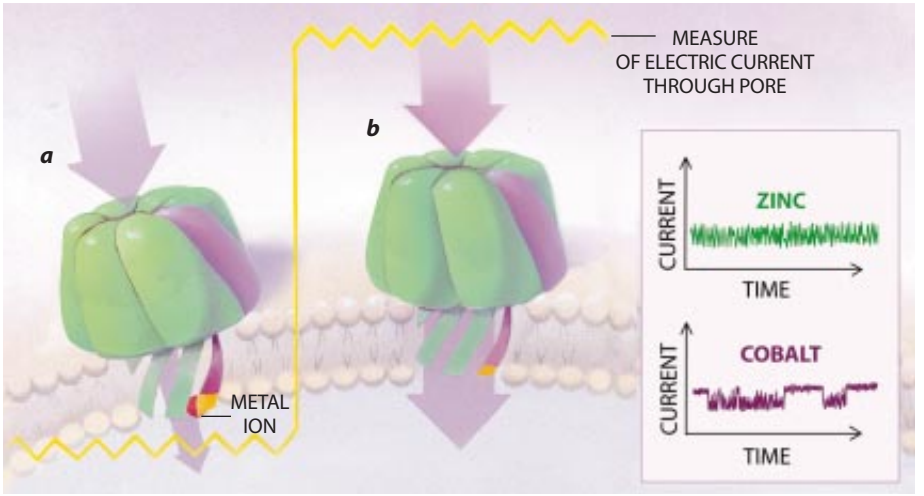
In my lab, we are attempting to build triggers and switches into designer pores—polypeptides based only loosely on natural structures—as pioneered by



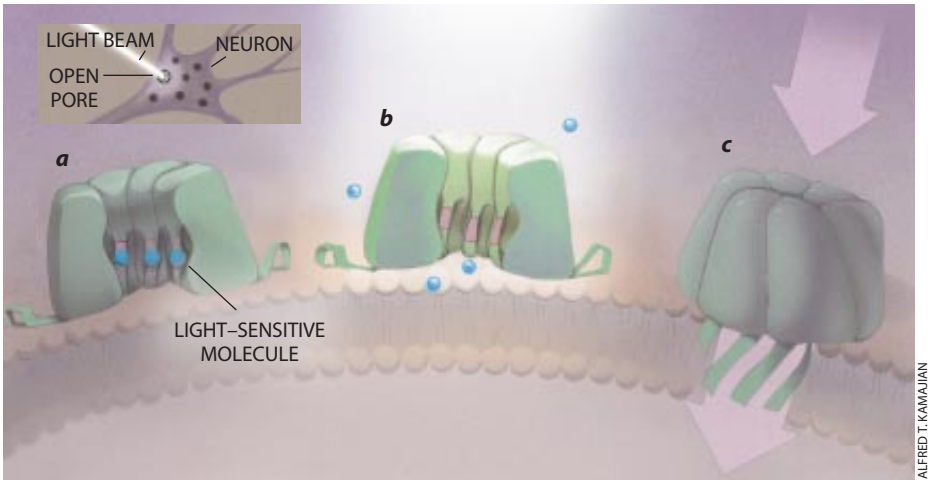
PUNCTURING CANCER CELLS will make them more permeable to cytotoxic drugs. Researchers are developing an altered version of alpha-hemolysin that includes an antibody fragment that both recognizes receptors on cancer cells and prevents pore formation. When the modified alpha-hemolysin reaches the cancer cell, tumor proteases—proteins secreted by all tumors—will snip off the antibody fragment (*a*). After seven of the protein subunits converge (*b*), the pore opens (*c*).



DOORS INTO CELLS can be opened and closed repeatedly on command. When metal ions bind to the modified protein called H5, the channel cannot form (*a*). Removing the metal opens the pore (*b*); adding the metal reseals the pore (*c*). This technique has been used by Mehmet Toner's team at Massachusetts General Hospital to introduce cryoprotectant chemicals into living cells that must be frozen for storage.



BIOSENSORS made from artificial pores can detect a variety of substances. A carefully modified alpha-hemolysin protein (only one of the seven subunits, shown in pink, has been altered to bind to metal ions) partly closes when a metal is attached (*a*) and opens when the metal is removed (*b*). The magnitude and duration of the changes in electric current sent through single pores identifies the kind of metal present (*inset*); the frequency of the current shifts reveals the concentration.



BEAM OF LIGHT can clear a pathway into cells. Light can be directed at particular cells—for example, in a neuron (*inset*)—very precisely, so researchers can use this method to control which cells they will make permeable. Light-sensitive molecules attached to the modified alpha-hemolysin protein prevent a pore from forming (*a*) until they are removed with light (*b*). Once the molecules are gone, the pore will open (*c*).

Maurice Montal and his co-workers at the University of California at San Diego. Designer proteins based on the alpha-hemolysin structure, for instance, might have additional utility as antimicrobial agents if they could be made to disrupt the outer membranes of microbes selectively.

There is still much to be done through protein engineering of alpha-hemolysin itself. For example, we are currently investigating techniques to improve the mechanical and heat stability of alpha-hemolysin pores used as components of biosensors. Workers are also examining chemical modifications to reduce immunogenicity of alpha-hemolysin—its tendency to provoke an attack by the immune system—for biotherapeutic applications; immunogenicity now stands as a major hurdle for all biotherapeutics.

If these challenges can be addressed, more futuristic possibilities may emerge for this technology. Pore-forming proteins might be used as conducting components in molecular electronic devices. Although proteins are relatively large for this role by present-day standards, they do have sophisticated properties, such as the ability to recognize other molecules, a capability that cannot be built into inorganic materials. Two-dimensional crystals that are formed readily by alpha-hemolysin and S-layer proteins might serve as templates for ordered arrays of molecules in the emerging science of nanotechnology. It might even be possible to design membranes that, by allowing only certain molecules to pass through, could be used to create highly selective filters to purify such substances as drugs, contaminated water or blood. The field of pore-forming proteins is just beginning to open up. SA

The Author

HAGAN BAYLEY is professor and head of the department of medical biochemistry and genetics at Texas A&M University, where he is also a professor of chemistry. His studies of alpha-hemolysin were initiated at the Worcester Foundation for Experimental Biology in Shrewsbury, Mass. He enjoys working at the interface of chemistry and biology, developing techniques for protein modification that have applications in both basic science and biotechnology.

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Running on Water

The secret of the basilisk lizard's strategy lies in its stroke

by James W. Glasheen and Thomas A. McMahon

The basilisk lizards of Central America are renowned for their seemingly miraculous flight across water. When startled, these green or brown reptiles scamper over ponds or lakes on their hind legs—the younger ones appearing virtually airborne, the larger ones sinking down somewhat. By videotaping seven *Basiliscus basiliscus* captured in a Costa Rican rain forest and by constructing mechanical models in order to understand the underlying physics, we have been able decipher the mystery of these lizards' magnificent movements.

It all begins with a slap of the foot. The basilisk lizard strikes the water to create upward force. This force, in turn, provides a medium-size, or 90-gram, lizard with as much as 23 percent of the support it needs to stay on the water surface. Then, a split second later, comes the stroke. As the foot crashes down, it pushes water molecules aside and creates a pothole of air. In addition to the forces generated by accelerating water out of the foot's way, the lizard obtains support from forces created by the difference in pressure between the air cavity above the foot and the hydrostatic pressure below. Together the slap and subsequent stroke can produce 111 percent of the support needed to keep an adult lizard striding along the surface. Smaller lizards, those weighing two grams or less, should be able to create 225 percent of the support they need—and consequently, their runs across the water appear freer and less cumbersome.

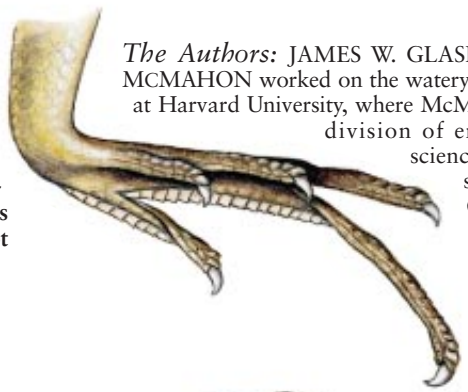
All these gains would be lost, however, if the lizard did not pull its foot out of the hole before the water closed in around it. By slanting its long-toed foot backwards and by slipping it out while it is surrounded only by air, the creature avoids the drag that would result from pulling its foot through water. A tiny fringe that surrounds the basilisk's five toes may facilitate this motion. Like a parachute, the fringe flares out as the foot is

STEPHEN DALTON *Animals Animals*

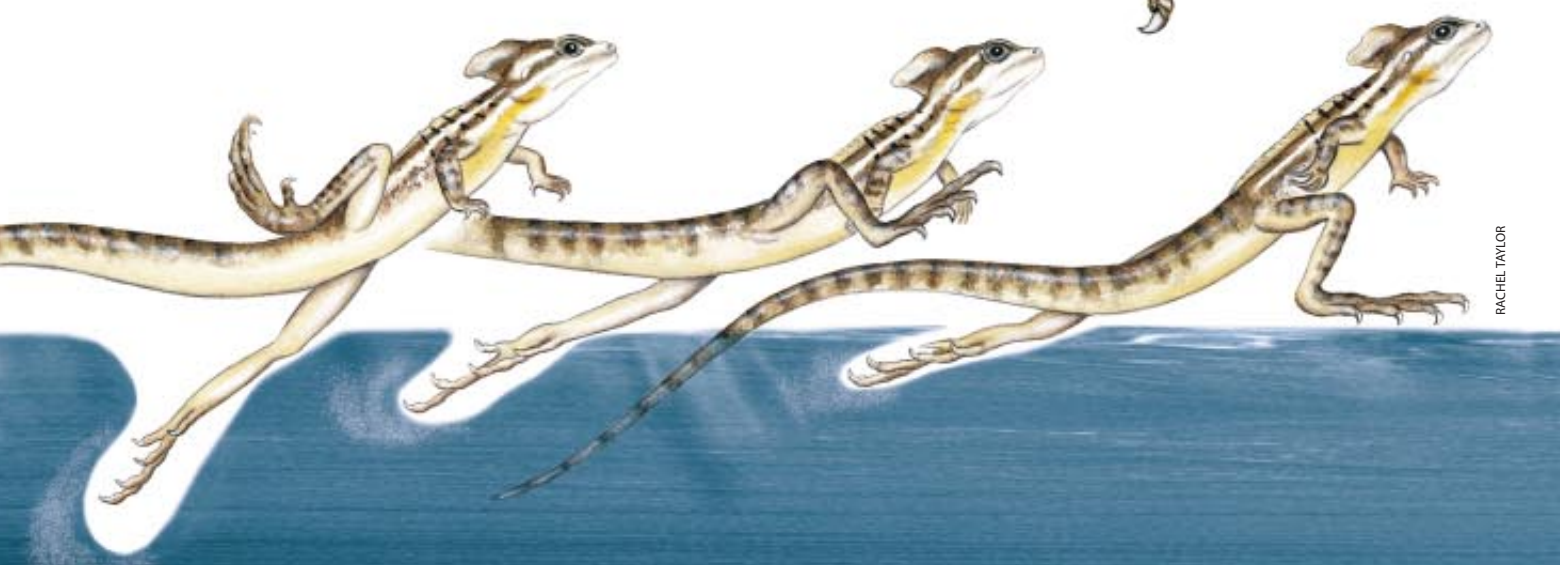
slapped down, thus creating more surface area—all the better to hit the water with. Then, as the foot is pulled up, the fringe collapses, and the long toes are withdrawn just before the hole closes.

Although their secret is now unveiled, the lizards are likely to remain alone on top of the water. Some web-footed birds can achieve similar runs on water, but their dynamics are slightly different and not well understood. As for humans, they have nothing to learn from the lizards except to stay ashore: an 80-kilogram person would have to run 30 meters per second (65 miles an hour) and expend 15 times more sustained muscular energy than a human being has the capacity to expend. The basilisks bask singularly in the liminal world between water and air. SA

BASILISK LIZARD sprints across water in the Costa Rican rain forest (*above*). Adults usually run on water only when startled; young ones, however, will do so simply to get from one place to another. A medium-size lizard takes about 20 steps a second when running (*sequence below*); with each of these steps the lizard's foot creates an air pocket from which the foot is withdrawn before water rushes back in. Tiny collapsible fringes around the basilisk's foot (*right*) may help in this process.



The Authors: JAMES W. GLASHEEN and THOMAS A. MCMAHON worked on the watery capabilities of the basilisk at Harvard University, where McMahon is a professor in the division of engineering and applied science. Glasheen, now a consultant with McKinsey and Company, was a doctoral student at the time of their collaboration.



RACHEL TAYLOR

Creating False Memories

BRYAN CHRISTIE; PHOTOGRAPH COURTESY OF JOSEFA JAKLITSCH

Researchers are showing how suggestion and imagination can create "memories" of events that did not actually occur

by Elizabeth F. Loftus

In 1986 Nadean Cool, a nurse's aide in Wisconsin, sought therapy from a psychiatrist to help her cope with her reaction to a traumatic event experienced by her daughter. During therapy, the psychiatrist used hypnosis and other suggestive techniques to dig out buried memories of abuse that Cool herself had allegedly experienced. In the process, Cool became convinced that she had repressed memories of having been in a satanic cult, of eating babies, of being raped, of having sex with animals and of being forced to watch the murder of her eight-year-old friend. She came to believe that she had more than 120 personalities—children, adults, angels and even a duck—all because, Cool was told, she had experienced severe childhood sexual and physical abuse. The psychiatrist also performed exorcisms on her, one of which lasted for five hours and included the sprinkling of holy water and screams for Satan to leave Cool's body.

When Cool finally realized that false memories had been planted, she sued the psychiatrist for malpractice. In March 1997, after five weeks of trial, her case was settled out of court for $2.4 million.

Nadean Cool is not the only patient to develop false memories as a result of questionable therapy. In Missouri in 1992 a church counselor helped Beth Rutherford to remember during therapy that her father, a clergyman, had regularly raped her between the ages of seven and 14 and that her mother sometimes helped him by holding her down. Under her therapist's guidance, Rutherford developed memories of her father twice impregnating her and forcing her to abort the fetus herself with a coat hanger. The father had to resign from his post as a clergyman when the allegations were made public. Later medical examination of the daughter revealed, however, that she was still a virgin at age 22 and had never been pregnant. The daughter sued the therapist and received a $1-million settlement in 1996.

About a year earlier two juries returned verdicts against a Minnesota psychiatrist accused of planting false memories by former patients Vynnette Hamanne and Elizabeth Carlson, who under hypnosis and sodium amytal, and after being fed misinformation about the workings of memory, had come to remember horrific abuse by family members. The juries awarded Hammane $2.67 million and Carlson $2.5 million for their ordeals.

In all four cases, the women developed memories about childhood abuse in therapy and then later denied their authenticity. How can we determine if memories of childhood abuse are true or false? Without corroboration, it is very difficult to differentiate between false memories and true ones. Also, in these cases, some memories were contrary to physical evidence, such as explicit and detailed recollections of rape and abortion when medical examination confirmed virginity. How is it possible for people to acquire elaborate and confident false memories? A growing number of investigations demonstrate that under the right circumstances false memories can be instilled rather easily in some people.

My own research into memory distortion goes back to the early 1970s, when I began studies of the "misinformation effect." These studies show that when people who witness an event are later exposed to new and misleading information about it, their recollections often become distorted. In one example, participants viewed a simulated automobile accident at an intersection with a stop sign. After the viewing, half the participants received a suggestion that the traffic sign was a yield sign. When asked later what traffic sign they remembered seeing at the intersection, those who had been given the suggestion tended to claim that they had seen a yield sign. Those who had not received the phony information were much more accurate in their recollection of the traffic sign.

My students and I have now conducted more than 200 experiments involving over 20,000 individuals that document how exposure to misinformation induces memory distortion. In these studies, people "recalled" a conspicuous barn in a bucolic scene that contained no buildings at all, broken glass and tape recorders that were not in the scenes they viewed, a white instead of a blue vehicle in a crime scene, and Minnie Mouse when they actually saw Mickey Mouse. Taken together, these studies show that misinformation can change an individual's recollection in predictable and sometimes very powerful ways.

Misinformation has the potential for invading our memories when we talk to other people, when we are suggestively interrogated or when we read or view media coverage about some event that we may have experienced ourselves. After more than two decades of exploring the power of misinformation, researchers have learned a great deal about the conditions that make people susceptible to memory modification. Memories are more easily modified, for instance, when the passage of time allows the original memory to fade.

False Childhood Memories

It is one thing to change a detail or two in an otherwise intact memory but quite another to plant a false memory of an event that never happened. To study false memory, my students and I

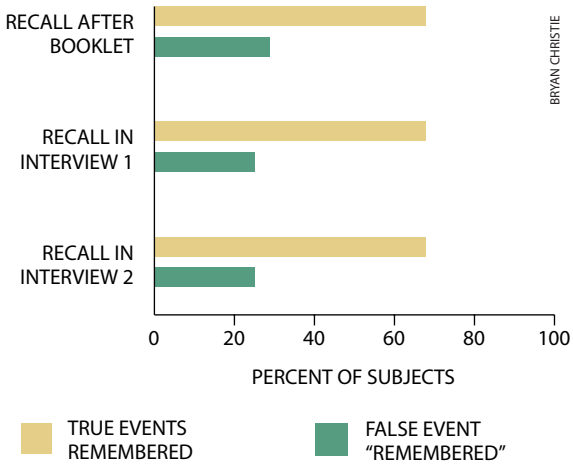
FALSE MEMORIES are often created by combining actual memories with suggestions received from others. The memory of a happy childhood outing to the beach with father and grandfather, for instance, can be distorted by a suggestion, perhaps from a relative, into a memory of being afraid or lost. False memories also can be induced when a person is encouraged to imagine experiencing specific events without worrying about whether they really happened or not.

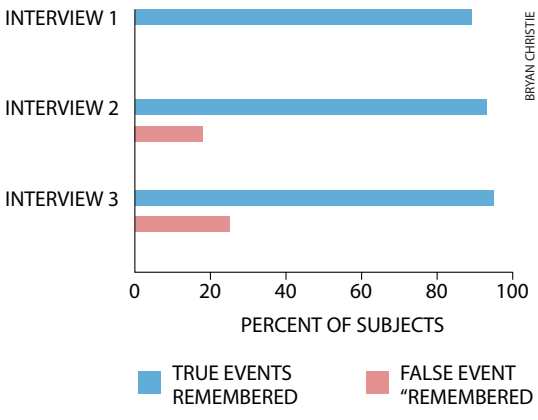
first had to find a way to plant a pseudomemory that would not cause our subjects undue emotional stress, either in the process of creating the false memory or when we revealed that they had been intentionally deceived. Yet we wanted to try to plant a memory that would be at least mildly traumatic, had the experience actually happened.

My research associate, Jacqueline E. Pickrell, and I settled on trying to plant a specific memory of being lost in a shopping mall or large department store at about the age of five. Here's how we did it. We asked our subjects, 24 individuals ranging in age from 18 to 53, to try to remember childhood events that had been recounted to us by a parent, an older sibling or another close relative. We prepared a booklet for each participant containing one-paragraph stories about three events that had actually happened to him or her and one that had not. We constructed the false event using information about a plausible shopping trip provided by a relative, who also verified that the participant had not in fact been lost at about the age of five. The lost-in-the-mall scenario included the following elements: lost for an extended period, crying, aid and comfort by an elderly woman and, finally, reunion with the family.

After reading each story in the booklet, the participants wrote what they remembered about the event. If they did not remember it, they were instructed to write, "I do not remember this." In two follow-up interviews, we told the participants that we were interested in examining how much detail they could remember and how their memories compared with those of their relative. The event paragraphs were not read to them verbatim, but rather parts were provided as retrieval cues. The participants recalled something about 49 of the 72 true events (68 percent) immediately after the initial reading of the booklet and also in each of the two follow-up interviews. After reading the booklet, seven of the 24 participants (29 percent) remembered either partially or fully the false event constructed for them, and in the two follow-up interviews six participants (25 percent) continued to claim that they remembered the fictitious event. Statistically, there were some differences between the true memories and the false ones: participants used more words to describe the true memories, and they rated the true memories as being somewhat more clear. But if an onlooker were to observe many of our participants describe an event, it would be difficult indeed to tell whether the account was of a true or a false memory.

Of course, being lost, however frightening, is not the same as being abused. But the lost-in-the-mall study is not about real experiences of being lost; it is about planting false memories of being lost. The paradigm shows a way of instilling false memories and takes a step toward allowing us to understand how this might happen in real-world settings. Moreover, the study provides evidence that people can be led to remember their past in different ways, and they can





RECALL OF PLANTED CHILDHOOD EVENTS in this study appears to increase slightly after the details become familiar to the subject and the source of the information is forgotten. Ira Hyman and his colleagues at Western Washington University presented subjects with true events provided by relatives along with a false event—such as spilling a punch bowl on the parents of the bride at a wedding. None of the participants remembered the false event when first told about it, but in two follow-up interviews, initially 18 percent and later 25 percent of the subjects said they remembered something about the incident.

FALSE MEMORY TOOK ROOT in roughly 25 percent of the subjects in this study by the author and her co-workers. The study was designed to create a false recollection of being lost at age five on a shopping trip. A booklet prepared for each participant included the false event and three events that he or she had actually experienced. After reading the scenarios, 29 percent of the subjects "recalled" something about being lost in the mall. Follow-up interviews showed there was little variation over time in recalling both the false and true events.

even be coaxed into "remembering" entire events that never happened.

Studies in other laboratories using a similar experimental procedure have produced similar results. For instance, Ira Hyman, Troy H. Husband and F. James Billing of Western Washington University asked college students to recall childhood experiences that had been recounted by their parents. The researchers told the students that the study was about how people remember shared experiences differently. In addition to actual events reported by parents, each participant was given one false event—either an overnight hospitalization for a high fever and a possible ear infection, or a birthday party with pizza and a clown—that supposedly happened at about the age of five. The parents confirmed that neither of these events actually took place.

Hyman found that students fully or partially recalled 84 percent of the true events in the first interview and 88 percent in the second interview. None of the participants recalled the false event during the first interview, but 20 percent said they remembered something about the false event in the second interview. One participant who had been exposed to the emergency hospitalization story later remembered a male doctor, a female nurse and a friend from church who came to visit at the hospital.

In another study, along with true events Hyman presented different false events, such as accidentally spilling a bowl of punch on the parents of the bride at a wedding reception or having to evacuate a grocery store when the overhead sprinkler systems erroneously activated. Again, none of the participants recalled the false event during the first interview, but 18 percent remembered something about it in the second interview and 25 percent in the third interview. For example, during the first interview, one participant, when asked about the fictitious wedding event, stated, "I have no clue. I have never heard that one before." In the second interview, the participant said, "It was an outdoor wedding, and I think we were running around and knocked something over like the punch bowl or something and made a big mess and of course got yelled at for it."

Imagination Inflation

The finding that an external suggestion can lead to the construction of false childhood memories helps us understand the process by which false memories arise. It is natural to wonder whether this research is applicable in real situations such as being interrogated by law officers or in psychotherapy. Although strong suggestion may not routinely occur in police questioning or therapy, suggestion in the form of an imagination exercise sometimes does. For instance, when trying to obtain a confession, law officers may ask a suspect to imagine having participated in a criminal act. Some mental health professionals encourage patients to imagine childhood events as a way of recovering supposedly hidden memories.

Surveys of clinical psychologists reveal that 11 percent instruct their clients to "let the imagination run wild," and 22 percent tell their clients to "give free rein to the imagination." Therapist Wendy Maltz, author of a popular book on childhood sexual abuse, advocates telling the patient: "Spend time imagin-

JASON GOLTZ

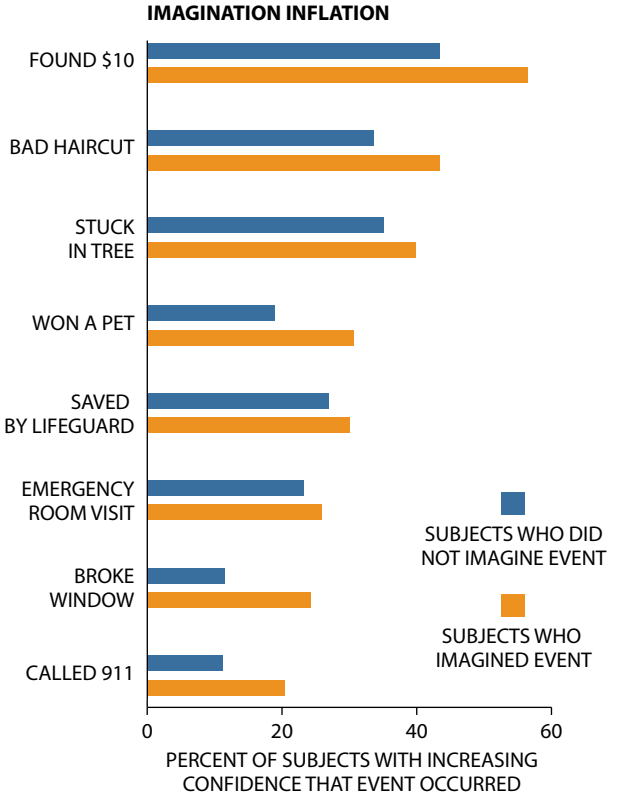
ing that you were sexually abused, without worrying about accuracy, proving anything, or having your ideas make sense.... Ask yourself...these questions: What time of day is it? Where are you? Indoors or outdoors? What kind of things are happening? Is there one or more person with you?" Maltz further recommends that therapists continue to ask questions such as "Who would have been likely perpetrators? When were you most vulnerable to sexual abuse in your life?"

The increasing use of such imagination exercises led me and several colleagues to wonder about their consequences. What happens when people imagine childhood experiences that did not happen to them? Does imagining a childhood event increase confidence that it occurred? To explore this, we designed a three-stage procedure. We first asked individuals to indicate the likelihood that certain events happened to them during their childhood. The list contains 40 events, each rated on a scale ranging from "definitely did not happen" to "definitely did happen." Two weeks later we asked the participants to imagine that they had experienced some of these events. Different subjects were asked to imagine different events. Sometime later the participants again were asked to respond to the original list of 40 childhood events, indicating how likely it was that these events actually happened to them.

Consider one of the imagination exercises. Participants are told to imagine playing inside at home after school, hearing a strange noise outside, running toward the window, tripping, falling, reaching out and breaking the window with their hand. In addition, we asked participants questions such as "What did you trip on? How did you feel?"

In one study 24 percent of the participants who imagined the broken-window scenario later reported an increase in confidence that the event had occurred, whereas only 12 percent of those who were not asked to imagine the incident reported an increase in the likelihood that it had taken place. We found this "imagination inflation" effect in each of the eight events that participants were asked to imagine. A number of possible explanations come to mind. An obvious one is that an act of imagination simply makes the event seem more familiar and that familiarity is mistakenly related to childhood memories rather than to the act of imagination. Such source confusion—when a person does not remember the source of information—can be especially acute for the distant experiences of childhood.

Studies by Lyn Goff and Henry L. Roediger III of Washington University of recent rather than childhood experiences more directly connect imagined actions to the construction of false memory. During the initial session, the researchers instructed participants to perform the stated action, imagine doing it or just listen to the statement and do nothing else. The actions were simple ones: knock on the table, lift the stapler, break the toothpick, cross your fingers, roll your eyes. During the second session, the participants were asked to imagine some of the actions that they had not previously performed. During the final session, they answered questions about what actions they actually performed during the initial session. The investigators found that the more times participants imagined an unperformed action, the more likely they were to remember having performed it.



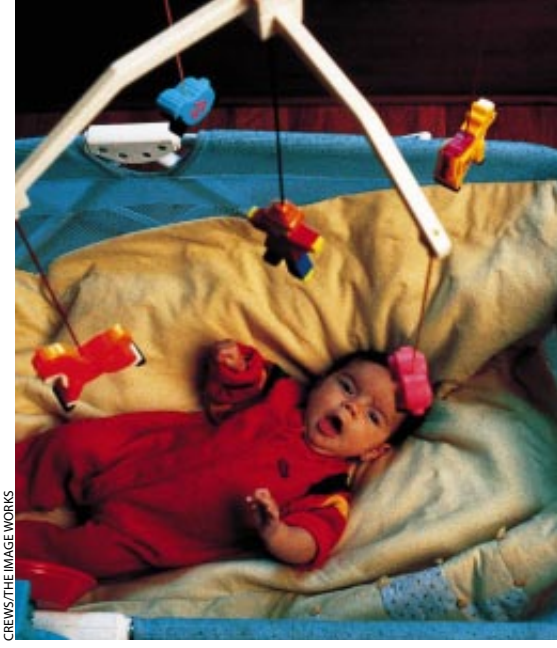
BRYAN CHRISTIE

IMAGINING AN EVENT can increase a person's belief that the fictitious event actually happened. To study the "imagination inflation" effect, the author and her colleagues asked participants to indicate on a scale the likelihood that each of 40 events occurred during their childhood. Two weeks later they were given guidance in imagining some of the events they said had not taken place and then were asked to rate the original 40 events again. Whereas all participants showed increased confidence that the events had occurred, those who took part in actively imagining the events reported an even greater increase.

Impossible Memories

It is highly unlikely that an adult can recall genuine episodic memories from the first year of life, in part because the hippocampus, which plays a key role in the creation of memories, has not matured enough to form and store long-lasting memories that can be retrieved in adulthood. A procedure for planting "impossible" memories about experiences that occur shortly after birth has been developed by the late Nicholas Spanos and his collaborators at Carleton University. Individuals are led to believe that they have well-coordinated eye movements and visual exploration skills probably because they were born in hospitals that hung swinging, colored mobiles over infant cribs. To confirm whether they had such an experience, half the participants are hypnotized, age-regressed to the day after birth and asked what they remembered. The other half of the group participates in a "guided mnemonic restructuring" procedure that uses age regression as well as active encouragement to re-create the infant experiences by imagining them.

Spanos and his co-workers found that the vast majority of their subjects were susceptible to these memory-planting procedures. Both the hypnotic and guided participants reported infant memories. Surprisingly, the guided group did so somewhat more (95 versus 70 percent). Both groups remembered the colored mobile at a relatively high rate (56 percent of the guided group and 46 percent of the hypnotic subjects). Many participants who did not remember the



CREWS/THE IMAGE WORKS

MEMORIES OF INFANCY—such as a mobile hanging over a crib—can be induced even though it is highly unlikely that events from the first year of life can be recalled. In a study by the late Nicholas Spanos and his colleagues at Carleton University, "impossible" memories of the first day of life were planted using either hypnosis or a guided mnemonic restructuring procedure. The mobile was "remembered" by 46 percent of the hypnotized group and by 56 percent of the guided group.

mobile did recall other things, such as doctors, nurses, bright lights, cribs and masks. Also, in both groups, of those who reported memories of infancy, 49 percent felt that they were real memories, as opposed to 16 percent who claimed that they were merely fantasies. These findings confirm earlier studies that many individuals can be led to construct complex, vivid and detailed false memories via a rather simple procedure. Hypnosis clearly is not necessary.

How False Memories Form

In the lost-in-the-mall study, implantation of false memory occurred when another person, usually a family member, claimed that the incident happened. Corroboration of an event by another person can be a powerful technique for instilling a false memory. In fact, merely claiming to have seen a person do something can lead that person to make a false confession of wrongdoing.

This effect was demonstrated in a study by Saul M. Kassin and his colleagues at Williams College, who investigated the reactions of individuals falsely accused of damaging a computer by pressing the wrong key. The innocent participants initially denied the charge, but when a confederate said that she had seen them perform the action, many participants signed a confession, internalized guilt for the act and went on to confabulate details that were consistent with that belief. These findings show that false incriminating evidence can induce people to accept guilt for a crime they did not commit and even to develop memories to support their guilty feelings.

Research is beginning to give us an understanding of how false memories of complete, emotional and self-participatory experiences are created in adults. First, there are social demands on individuals to remember; for instance, researchers exert some pressure on participants in a study to come up with memories. Second, memory construction by imagining events can be explicitly encouraged when people are having trouble remembering. And, finally, individuals can be encouraged not to think about whether their constructions are real or not. Creation of false memories is most likely to occur when these external factors are present, whether in an experimental setting, in a therapeutic setting or during everyday activities.

False memories are constructed by combining actual memories with the content of suggestions received from others. During the process, individuals may forget the source of the information. This is a classic example of source confusion, in which the content and the source become dissociated.

Of course, because we can implant false childhood memories in some individuals in no way implies that all memories that arise after suggestion are necessarily false. Put another way, although experimental work on the creation of false memories may raise doubt about the validity of long-buried memories, such as repeated trauma, it in no way disproves them. Without corroboration, there is little that can be done to help even the most experienced evaluator to differentiate true memories from ones that were suggestively planted.

The precise mechanisms by which such false memories are constructed await further research. We still have much to learn about the degree of confidence and the characteristics of false memories created in these ways, and we need to discover what types of individuals are particularly susceptible to these forms of suggestion and who is resistant.

As we continue this work, it is important to heed the cautionary tale in the data we have already obtained: mental health professionals and others must be aware of how greatly they can influence the recollection of events and of the urgent need for maintaining restraint in situations in which imagination is used as an aid in recovering presumably lost memories. SA

The Author

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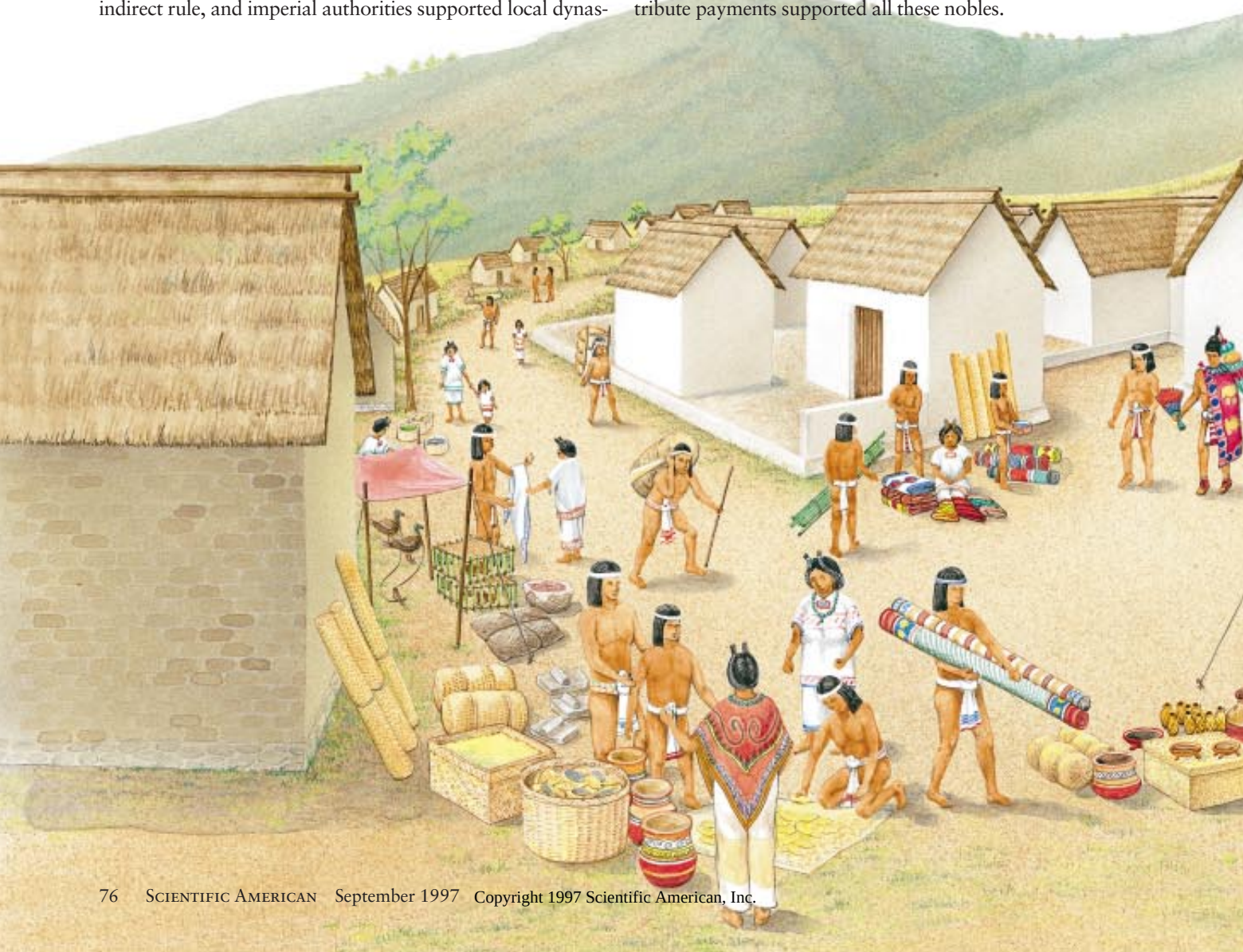
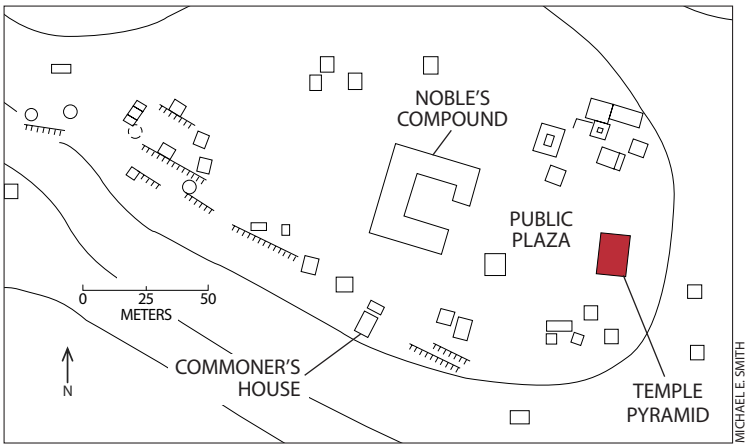
Life in the Provinces of the Aztec Empire

The lives of the Aztec common people were far richer and more complex than the official histories would have us believe

by Michael E. Smith

In 1519, when Hernán Cortés led his army into Tenochtitlan in the Valley of Mexico, that Aztec city was the capital of a far-flung tributary empire. The emperor Motecuhzoma sat atop a complex social and political hierarchy, and the Aztec populace owed allegiance and tribute to nobles at several levels. Below the emperor were the kings of subject city-states. The Aztec dominion employed a policy of indirect rule, and imperial authorities supported local dynasties so long as they delivered their quarterly tribute payments on time. Officials recorded these payments in documents such as the Codex Mendoza [see "The Codex Mendoza," by Patricia Rieff Anawalt and Frances F. Berdan; Scientific American, June 1992]. Local nobles, who lived in both urban and rural areas, were subjects of their city-state king. At the bottom of the hierarchy were the commoners, whose tribute payments supported all these nobles.





MICHAEL E. SMITH

MARKET PLAZA in the 15th-century Aztec town of Cuexcomate teemed with vendors, buyers and artisans. Here commoners could trade craft goods made in their homes—mainly textiles—for salt and painted pottery imported from the Valley of Mexico and other areas, obsidian blades from regions hundreds of kilometers away and needles and other bronze objects from western Mexico. Local produce and goods such as woven mats, baskets, corn-grinding tools and tortilla griddles were also displayed and traded. A map of the center of the modern dig site at Cuexcomate (*left*) indicates the location of the temple pyramid, a noble family's compound and commoners' dwellings, as well as other buildings and the more distant terraced fields and rural dwellings, as depicted in the reconstruction below.

TOMO NARASHIMA

HOUSE FOUNDATION

RITUAL FIGURINES

FIGURINE MOLDS

Aztec commoners must have had a heavy tribute obligation. How were they able to meet their payments? First of all, there were millions of commoners, so the tribute burden was spread over a large population. During the 1970s, surveys of patterns of settlement turned up the startling discovery that the Aztec period witnessed one of the major population explosions of antiquity. The number of people in the Valley of Mexico, the heartland of the Aztec Empire, increased from 175,000 in the early Aztec period (A.D. 1150–1350) to nearly one million in the late Aztec period (A.D. 1350–1519). Similar patterns of growth occurred in other parts of Aztec territory as well.

The Aztec population explosion placed a heavy stress on the environment of central Mexico. New villages and towns

TOMO NARASHIMA

d

FRAGMENTS OF IMPORTED POTTERY

e

BRONZE IMPLEMENTS

f

CERAMIC TOOLS FOR SPINNING COTTON

PHOTOGRAPHY BY MICHAEL E. SMITH

sprung up everywhere, and all available land was cultivated, often at considerable labor expense. Wherever possible, farmers built dams and canals to irrigate cropland; they also built terraced stone walls on hillsides to make new fields; and they drained the swamps outside Tenochtitlan to create raised fields (*chinampas*), one of the most highly productive agricultural systems of the ancient world. These intensive farming practices transformed the central Mexican countryside into a managed landscape of cultivation.

What were the effects of tribute extraction, population growth and agricultural intensification on the Aztec common people? Did these processes leave people impoverished and powerless, or did they allow commoners to prosper and thrive? Few of the available written accounts have information on conditions beyond the imperial capital, and thus it is up to archaeologists to study these questions.

Until very recently, no major archaeological excavations had been carried out at Aztec sites. Most Aztec cities and towns either were destroyed during the Spanish Conquest or were occupied and then buried under later settlements. The few surviving sites were small, unassuming peasant villages. Most archaeologists working in Mesoamerica bypassed Aztec sites on their way to the spectacular jungle ruins of classic-period Maya civilization. Aztec sites were deemed either too difficult to excavate or too small to bother with. This neglect came to an abrupt end in 1978, when the Mexican government mounted an extensive excavation of the Great Temple of Tenochtitlan. Situated in the middle of Mexico City today, the magnificence of this structure, and the richness of the offerings associated with it, awakened a new

TYPICAL PEASANT HOUSE was small (roughly 15 to 25 square meters) and probably had two doors and no windows. Many activities, such as the ubiquitous weaving, took place in patios between the dwellings. Houses were furnished with mats and baskets; a simple shrine with two or three figurines and an incense burner adorned one wall. The absence of hearths is puzzling; quite possibly cooking was done, as it is in traditional villages today, in a lean-to against the back of the house. The photographs above the drawing show artifacts unearthed in the modern Mexican state of Morelos from trash middens adjacent to Aztec dwellings of the 12th through 16th centuries.

interest in Aztec society. Unfortunately, these excavations did not provide much new information about the commoners or life in the provinces.

To address these issues, my wife, Cynthia Heath-Smith, and I embarked on archaeological projects at rural and urban sites in the modern Mexican state of Morelos. Located just south of the Valley of Mexico, this was the first area outside the valley to be conquered when the Aztecs began their military expansion in the 1430s.

We first excavated two rural sites—Capilco and Cuexcomate—southwest of the modern city of Cuernavaca. Later we turned to the Aztec city of Yautepec in north-central Morelos. By excavating the houses of both rich and poor, we have found that provincial society was far more complex than previously thought. Aztec peasants were not simple farmers whose lives were dominated by the need to pay tribute to their elite overlords. Commoners living in both rural and urban areas of the provinces made heavy use of a thriving marketing system. They exchanged craft goods produced in their homes for a variety of foreign goods, and most of this economic activity was accomplished outside imperial control and ignored by early writers on the Aztecs.

Peasant Life

Archaeologists have found that excavations of houses and associated remains often provide the best data on ancient social and economic patterns. Capilco and Cuexcomate were good examples because traces of house walls were visible above the ground, and we did not have to waste time trying to find buried structures. Capilco was a village with 21 houses, and Cuexcomate a town with more than 150 structures, including temples, storehouses and ritual dumps. Houses at these sites were small (with a mean area of 15 square meters) and built of adobe brick walls supported on stone foundations. We excavated test pits in 29 houses selected at random. We then chose 10 of these for more complete clearing of architecture and associated deposits. These excavations allowed us to refine the Aztec chronology by splitting the late Aztec period into two subperiods—late Aztec A (A.D. 1350–1440) and late Aztec B (A.D. 1440–1519)—to yield a more detailed analysis.

Capilco was founded by a few peasant families in the early Aztec period. The population explosion began in the late Aztec A period, when Cuexcomate was founded and both settlements grew rapidly. The residents of these communities could not support themselves using rainfall agriculture alone, so they had to intensify their agricultural practices. Farmers built terraces on slopes and in ravines to create additional, more productive plots in which they grew maize, beans and cotton. Houses at these sites were not packed very closely together, and open areas were probably devoted to farming.

Cotton was an important crop in this part of the Aztec Empire, and household production of cotton textiles soon became the major craft. Every excavated house yielded large quantities of ceramic artifacts used in the hand spinning of cotton. Beadlike spindle whorls provided weights for the twirling wooden spindle, and small bowls with tripod supports were designed to control the spindle. Documentary sources state that all Aztec women, from the lowest slave to the highest noblewoman, spun and wove cloth. Cotton textiles had two economic functions beyond use as clothing. First, they were the most common item of tribute demanded by both city-states and the Aztec Empire. Second, they served as a form of money in the marketplaces, where they could be used to obtain a range of goods and services.

In addition to textiles, some residents of these sites manufactured paper out of the bark of the wild fig tree, as attested to by "bark beaters" made of basalt. The Aztecs used paper to make books of picture-writing and to burn in ritual offerings.

The many ceramic vessels used and discarded at each house were probably purchased in the marketplaces. Although

The Aztec Empire

The Aztec Empire covered much of central and southern Mexico when Spanish conquerors arrived in A.D. 1519. The sites described in the article were part of the tributary provinces of Cuauhnahuac and Huaxtepec, located in what is now the Mexican state of Morelos. Four times a year the people of these provinces delivered large amounts of tribute in cotton textiles and other products to the imperial capital, Tenochtitlan. —*M.E.S.*

JONNY JOHNSON

local potters produced a full range of vessels, people often bought many decorated foreign pots. About 10 percent of all ceramic vessels excavated from these sites had been imported from the Valley of Mexico and other areas. These vessels did not have any functional superiority to the wares made locally, and people must have simply enjoyed using a variety of decorated serving bowls.

In addition to ceramic vessels, people had other foreign goods in their homes. We recovered thousands of broken obsidian blades, whose closest geologic source was 100 kilometers away. Obsidian blades, which had extremely sharp cutting edges, served in many household and craft activities. Needles and other items of bronze were imported from western Mexico. People obtained salt from the Valley of Mexico, where specialists extracted it by boiling and evaporating the saline lake water. Salt was transported in distinctive ceramic basins, and in every excavated house we found many shards of these vessels. The market system connected the inhabitants of these rural sites to the rest of the Aztec Empire and beyond.

These excavations also revealed something of the noneconomic life of Aztec peasants. For example, every house contained a variety of incense burners and small ceramic figurines in the forms of humans and deities. These artifacts played a role in domestic rituals, which focused on purification and curing. Such ceremonies complemented the more spectacular public celebrations that took place at the towering temple pyramids in the larger cities and towns. Early Spanish priests described in detail the Aztec public religion, and excavation of the Great Temple has shown where these activities occurred. Before the recent excavations of houses, however, scholars had no idea of the nature of domestic rituals.

Not surprisingly, the larger town of Cuexcomate was a more complex community than Capilco. The town was laid out around a public plaza with a small temple pyramid on its east side. Across the plaza from the temple was a distinctive residential compound that, at 540 square meters, was significantly larger than the other houses. Its rooms were elevated above ground level by stone platforms. The compound employed finer construction materials and methods than most houses, including ample use of lime plaster. These features, combined with a floor plan that corresponds to the layout of Aztec palaces, led us to conclude that the compound was the residence of a noble household.

The artifacts left by the nobles who lived in this compound differed in quantity but not in kind from the artifacts found in the dwellings of commoners. For example, this structure yielded significantly greater numbers of imported and decorated ceramics than did the commoners' houses, as one might expect. Nevertheless, nobles did not have exclusive use of any category of artifact. We uncovered the most costly imported goods, such as polychrome bowls from the religious center of Cholula, bronze objects and jade jewelry, at both common and noble residences, showing that both groups had ready access to the extensive Aztec marketing system of central Mexico.

The conquest of this region by the Aztec Empire around A.D. 1440 ushered in the late Aztec B period. Soon after, the noble's compound at Cuexcomate was abandoned, and a new, smaller elite compound was built on the north side of the plaza. Populations continued to grow; Cuexcomate expanded from 200 to 800 persons, and Capilco grew from 35 to 135 persons in the late Aztec B period. Agricultural workers constructed extensive terracing to keep up with population growth, but farming reached a point of diminishing returns as all available land was terraced.

Artifacts and architecture provide clues to ancient standards of living, and evidence at these sites points to a significant decline between periods A and B. For example, nobles as well as commoners had fewer imported goods and fewer decorated ceramic vessels in the later period. Wealth indices, which we calculated from the quantities of valuable artifacts found at each house, showed a consistent decline. Some commoners tried to compensate for their economic difficulties by increasing their production of textiles. At each site, the houses with the most cotton spinning artifacts were the ones with the lowest wealth indices. In other words, the poorest households put the greatest efforts into craft production, probably to compensate for low crop yields or a lack of land. This pattern has occurred in many parts of the world when overpopulation and land scarcity have led to declining standards of living.

Urban Life

To round out our study of provincial life, we turned to Yautepec, the capital of a powerful city-state in Aztec times. Former Aztec cities in central Mexico are still occupied today, with the ancient ruins buried under layers of historical and more modern settlement. The early Spaniards built Christian churches on top of the remains of Aztec pyramids and placed their own towns over the Aztec cities. In this respect, Yautepec is unusual. There the Spanish settlement covered only part of the city. In 1989 Hortensia de Vega led a team of archaeologists from Mexico's National Anthropology Institute in the excavation of a large mound at the edge of modern Yautepec. This mound turned out to be the ruin of the royal palace of Yautepec. It is the only Aztec palace to be extensively excavated. We were invited to join the work at Yautepec to study houses from other parts of the ancient city.

At that time, very little was known about Aztec cities except for Tenochtitlan. Although archaeologists had collected surface artifacts from cities in the Valley of Mexico, no one had excavated any urban Aztec houses. The first field season, in 1992, we devoted to a surface survey that established the size and extent of the Aztec settlement. Even within the modern town it was not difficult to trace the extent of ancient Yautepec, which covered just over two square kilometers. In 1993 we returned to excavate houses. We began by digging test pits in open fields and vacant lots and succeeded in locating and uncovering seven houses and their yard areas.

The Yautepec excavations encountered quite dense concentrations of artifacts, and in six months of fieldwork, we recovered 1.2 million potsherds and nearly 50,000 obsidian artifacts, mainly blades and other tools. The classification and study of these materials are still in progress, but preliminary results reveal some fascinating similarities and differences with respect to the earlier findings at Cuexcomate and Capilco.

Of the seven houses excavated at Yautepec, five were small dwellings of commoners, which had an average size of 26 square meters. Like their rural counterparts, the houses were built of adobe bricks placed on foundation walls of stone cobbles. We also excavated an elite residence that was much larger (430 square meters) than the common houses and made greater use of lime plaster and dressed stone masonry. Another house was a poorly preserved structure of intermediate size (80 square meters) whose class affiliation is not clear.

Yautepec commoners, like their country cousins at Capilco and Cuexcomate, had ready access to foreign goods. The same kinds of imported ceramics, obsidian, salt, jade and bronze were found in residences at Yautepec. We cannot make quantitative comparisons, however, until all artifact studies have been completed. A number of technical analyses currently under way will determine the places of origin of the raw materials used for various artifacts at Yautepec. At this point, we do know that most of the obsidian came from a source near Pachuca, a city north of the Valley of Mexico. We are applying x-ray fluorescence techniques to determine the geologic sources of the remaining obsidian artifacts. Compositional studies of ceramics, including thin-section petrography and neutron-activation analysis, will help distinguish wares manufactured in the Yautepec Valley from those imported from other parts of central Mexico.

One set of analyses recently completed illuminates the origins of the bronze artifacts. Dorothy Hosler of the Massachusetts Institute of Technology analyzed the chemical composition, design and metallurgical properties of metal artifacts from all three of the sites. These objects include sewing needles, awls, bells and tweezers, all composed of copper-tin or copper-arsenic bronze alloys. Morelos was not a metal-producing zone in ancient times, and these artifacts closely resemble the bronze artifacts made in the Tarascan Empire of western Mexico.

Hosler has completed the first application of lead isotope analysis to ancient Mesoamerican metallurgy by sampling ore sources in several areas and artifacts from a variety of sites, including Yautepec. A number of the Yautepec bronze objects match ore samples from the Tarascan territory. Although written sources report that the Aztecs and Tarascans were constantly at war, the excavations nonetheless provide clear evidence that Tarascan bronze and obsidian were traded across the border and that they made their way into the homes of provincial commoners through the Aztec marketing system.

Yautepec, unlike the rural sites, had numerous craft industries in addition to domestic textile production. Several households made obsidian blades, and a few excavations uncovered evidence of the production of lip plugs, ear plugs and other obsidian jewelry. We also recovered molds used to make ceramic spindle whorls and figurines. Although these molds are not abundant, they were found in many different excavations at Yautepec. Bark beaters for the manufacture of paper were also present. At this point, it appears that many of the common households at Yautepec produced various craft items in addition to cotton textiles.

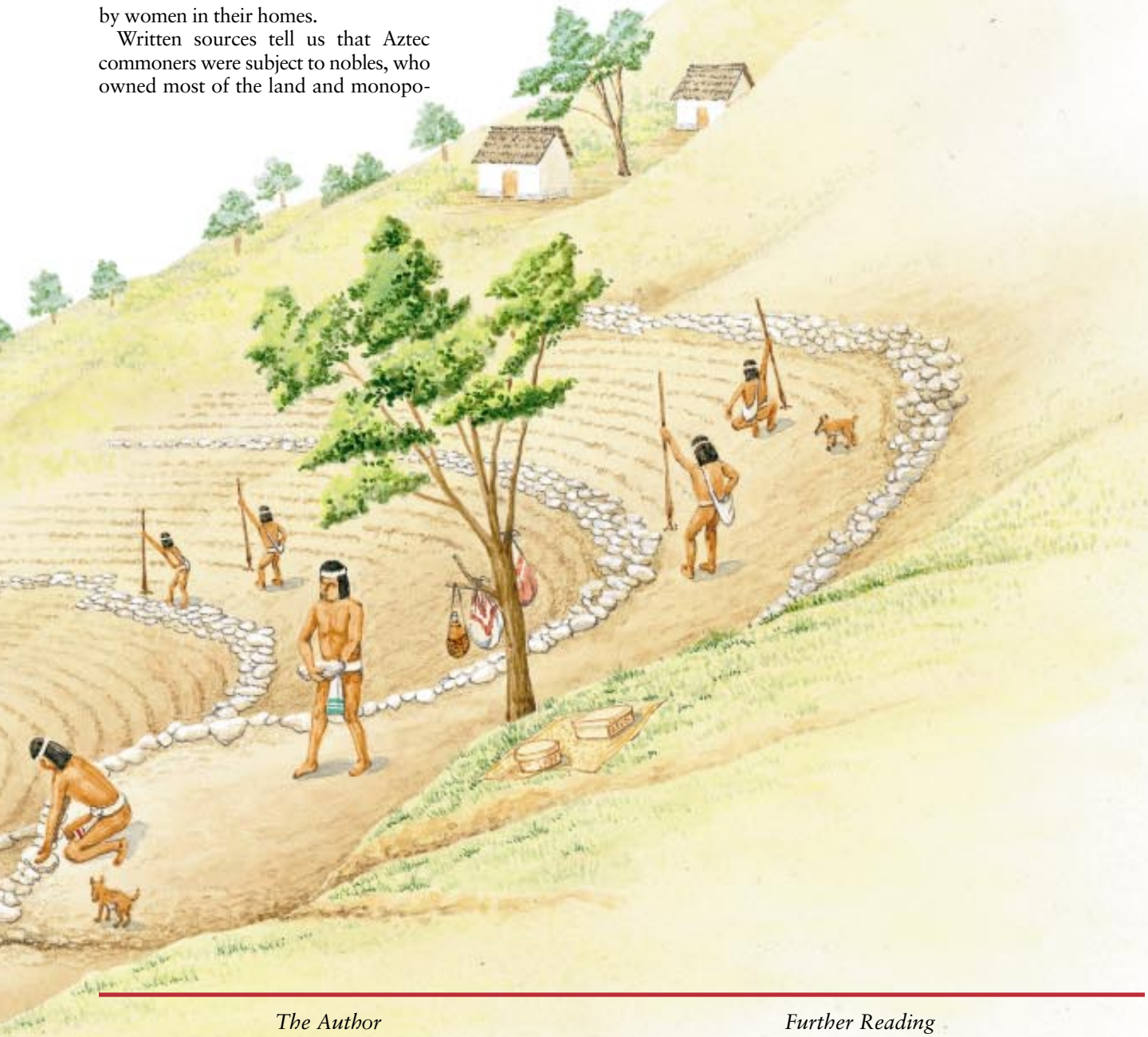
Provincial Aztecs

What do these excavations tell us about the people who lived in the provinces of the Aztec Empire? The overall impression is that provincial commoners were relatively prosperous, enterprising people. In spite of an economic decline after conquest and incorporation into the Aztec Empire, commoners in both urban and rural settings still enjoyed access to a wide range of imported goods. These goods were obtained through the markets. Both documentary and archaeological data indicate that the Aztec market system operated largely outside state control. The

INTENSIVE AGRICULTURAL PRACTICES evolved to meet the demands of the expanding Aztec population in the 15th century. Farmers built terraced fields—called check-dam terraces—in otherwise unusable ravines to trap the soil eroding in seasonal streams that arose during the heavy rains. The farmers piled up stones, one row at a time, and the terrace formed itself from the erosion as soil washed down the hillside. Each row of stones was set just behind the previous row, without the use of mortar. Thus, the terrace walls sloped rather steeply, and the heavy rains often caused breaches, such as the one being repaired at the left of the illustration. In the terraces they created in this way, the farmers grew primarily maize, beans and cotton.

markets connected people in even the smallest peasant villages with the larger informal Aztec economy of central Mexico. Family members engaged in a variety of craft activities to produce goods to sell in the markets. At sites in Morelos, the most important of these products were cotton textiles manufactured by women in their homes.

Written sources tell us that Aztec commoners were subject to nobles, who owned most of the land and monopolized power within the city-states. Archaeological excavations suggest that at least in several provincial settlements, this burden was not excessive. There is no evidence to suggest that nobles controlled craft production or exchange. The people in the provinces managed to achieve a degree of economic success through channels unconnected to the state and unreported in the official histories of the Aztecs. Illuminating the lives of these previously invisible people is one of the rewards of being an archaeologist today. SA



TOMO NARASHIMA

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Booming Sand

Though known for centuries, sound-producing sand remains one of nature's more puzzling phenomena

by Franco Nori, Paul Sholtz and Michael Bretz

For thousands of years, nomads traveling through deserts heard mysterious sounds they thought were made by ghosts or demons. Marco Polo reported that evil spirits "at times fill the air with the sounds of all kinds of musical instruments, and also of drums and the clash of arms." Today a nonoccult explanation is available: those diverse noises are all acoustic emissions produced by shifting sands.

At least 30 "booming" dunes have been found in deserts and on beaches in Africa, Asia, North America and elsewhere. Listeners have likened the sounds they make to bells, trumpets, pipe organs, foghorns, cannon fire, thunder, low-flying propeller aircraft, the buzzing of telegraph wires, even moaning or humming. Nevertheless, researchers do not agree on just how and why, in many parts of the world, under certain conditions, the sand sings.

Is it the size or shape of individual grains of sand? The way in which they interact? All these elements, among others, are at work. Very few systematic examinations of the phenomenon have been conducted, however, and no one scenario completely elucidates the mechanism that produces sound. We do not have the final answer but aim to raise questions that could point the way to a satisfactory explanation.

The sounds made by sand are not always dramatic. Walking on some beach sand, for example, elicits squeaking noises underfoot. This type of sand, called "squeaking" or "whistling," can be found at beaches, lakes, shores and riverbeds around the world. Its less common cousin, booming sand, transfixed not just Marco Polo but intrigued Charles Darwin and mystified countless others. Booming occurs almost exclusively in large, often isolated dunes deep in the desert or on "back beaches" far from water.

Listeners often compare the sounds of booming sand to those of musical instruments. In some cases, the peals occur in steady beats, sounding like drums or tambourines. In other dunes, the sand produces sounds more akin to trumpets, stringed instruments or bells. Such remarkably clear reverberations usually occur only when small quantities of sand move in response to some force, yielding just one frequency of vibration at a time. In 1994 we observed that small, induced avalanches at Sand Mountain in Nevada created sounds similar to those of a didgeridoo, an Australian aboriginal instrument characterized by a low, droning cadence.

Sounds of the Desert

Squeaking sand produces sounds with very high frequencies—between 500 and 2,500 hertz, lasting less than a quarter of a second. The peals are musically pure, often containing four or five harmonic overtones. Booming sand makes louder, low-frequency sounds of 50 to 300 hertz, which may last as long as 15 minutes in larger dunes (although typically they last for seconds or less). In addition, they are rather noisy, containing a multitude of nearby frequencies. Booms have never been observed to contain more than one harmonic of the fundamental tone.

These dramatic differences once led to a consensus that although both types of sand produce acoustic emissions, the ways in which they do so must be substantially different. In the late 1970s, however, Peter K. Haff, then at the California Institute of Technology, produced squeaks in booming sand, suggesting a closer connection between the two.

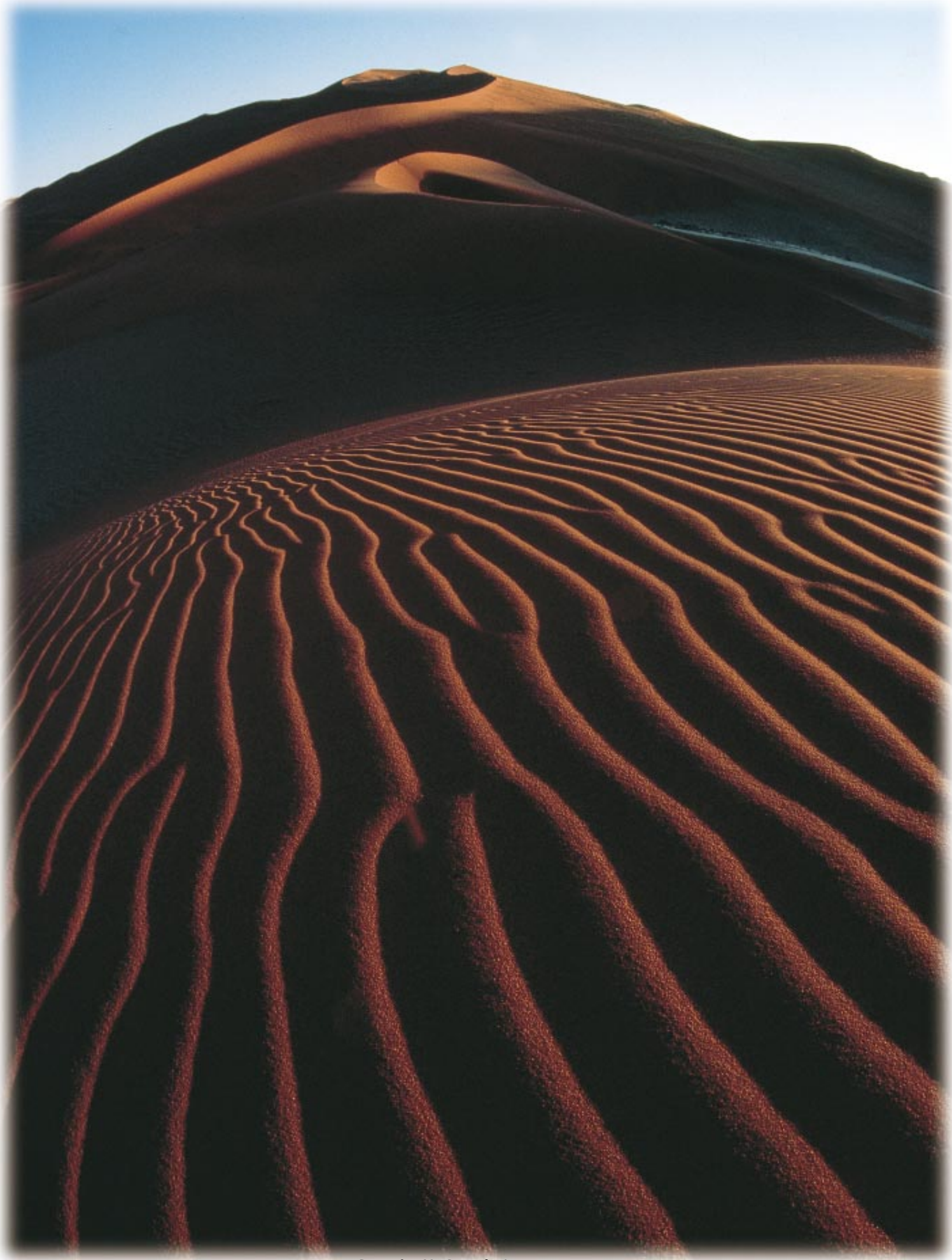
Both kinds of sand must be displaced to make sounds. Walking on some sand, for example, forces the sand underfoot to move down and out, producing squeaks. In the case of booming sand, displacement occurs during avalanches. It is within the avalanche that sound begins and where the answers must be hiding.

Before an avalanche can occur, winds must build a dune up to a certain angle, usually about 35 degrees for dry desert sand. Once the angle is achieved, the sand on the leeward side of the dune begins to slump. Intact layers of sand slip over the layers below, like a sheared deck of cards. At the same time, the individual grains in the upper layers tumble over the grains underneath, momentarily falling into the spaces between them and bouncing out again to continue their downward journey. Their concerted up-and-down motion is believed to be the secret source of sound. Fully developed avalanches, in which sliding plates of sand remain intact for most of their motion, have the greatest acoustic output. In some places, where large amounts of sand are involved, booming can be heard up to 10 kilometers away.

The mysteries of the vibrations are many. To begin with, the multiple frequencies of booming sand are not well understood. In the 1970s David R. Criswell and his collaborators at the University of Houston found that each frequency seems to exhibit its own rise-and-fall time, independent of the others. Taken together, these frequencies can cover a fairly broad range, the width of which is determined by various factors. For example, Sand Mountain booms at roughly 50 to 80 hertz; sands at Korizo, Libya, drone at between 50 and 100 hertz; and in the Kalahari Desert of South Africa, the frequencies range from 130 to 300 hertz. Such output—presumably caused by multiple modes of vibration within the shearing plates—is often unmusical and jarring.

JIM BRANDENBURG *Minden Pictures*

NAMIB DUNES in southern Africa produce deep booms during avalanches. The droning can be heard for miles.

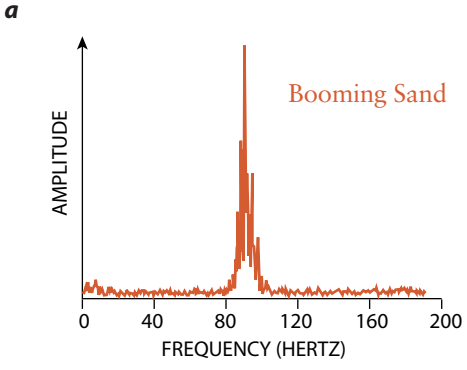


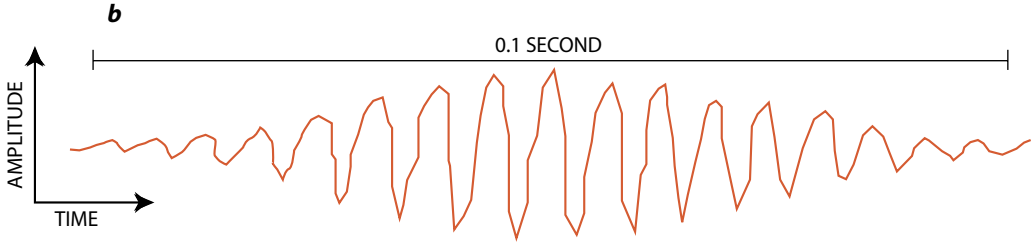
COURTESY OF MICHAEL BRETZ

LAURIE GRACE

TERRENCE MOORE

BOOMING SAND (*red dots*) **is found around the world; some sites are shown in the map and the photographs. Sound produced by booming sand has a range of nearby**





Because it is caused by large volumes of shearing sand, the roaring is also loud. In fact, sounds made by booming sand can be nearly deafening, and the vibrations causing them can be so intense that standing in their midst is nearly impossible.

A good place to start in exploring the vibrational properties of sand is with the grains themselves. The mean diameter of most sand grains, whether acoustically active or not, is about 300 microns. Usually the grains in a booming dune are very similar in size, especially near the leeward crest, where the sound most often originates; such uniformity allows for more efficient shearing. Otherwise, the smaller grains impede the smooth motion of the larger ones.

Similar sizes do not alone allow sand to boom. On the contrary, the booming sands of Korizo and Gelf Kebib, also in Libya, feature an uncharacteristically broad range of particle sizes. Moreover, silent dune sand often contains grains somewhat similar to nearby booming sand.

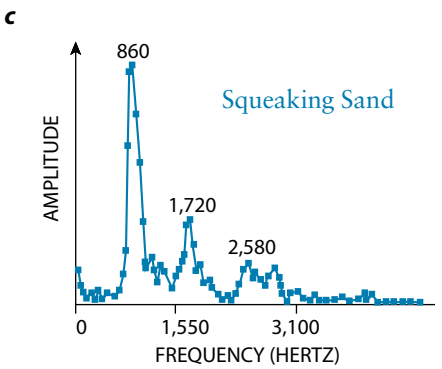
Grains of booming sand also tend to have uncommonly smooth surfaces, with protrusions on the scale of mere microns. Booming dunes are often found at the downwind end of large sand sources; having bounced and rolled across the desert for long distances, the sand grains in these dunes are usually highly polished. Over time a grain can also be polished by repeated shifts within a moving dune. And squeaking sand as well tends to be exceptionally smooth.

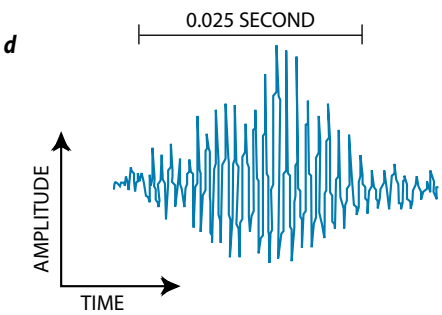
Close inspection of Sand Mountain and Kalahari booming sand, however, reveals that not all grains are highly spherical or rounded. And in 1936 A. D. Lewis in Pretoria, South Africa, even claimed to have produced booming in

DOUGLAS WAUGH *Peter Arnold, Inc.*

JIM BRANDENBURG *Minden Pictures*

frequencies (*a*), pronounced beats and relatively long duration (*b*). Sound from squeaking sand contains harmonics of a fundamental note (*c*) but is very brief (*d*).





LAUREL ROGERS

the cubed grains of ordinary table salt. Conversely, spherical glass beads cannot be made to boom. These findings show that although smoothness and roundness are essential to producing sound, so is some degree of roughness.

Another important factor is humidity, because moisture can modify the friction between the grains or cause sand to clump together, thus precluding shearing. Sounds occur in those parts of the dune that dry the fastest. Precipitation may be rare in the desert, but dunes retain water with remarkable efficiency. Sand near the surface dries quickly, however, and sand around a dune's crest tends to dry the fastest.

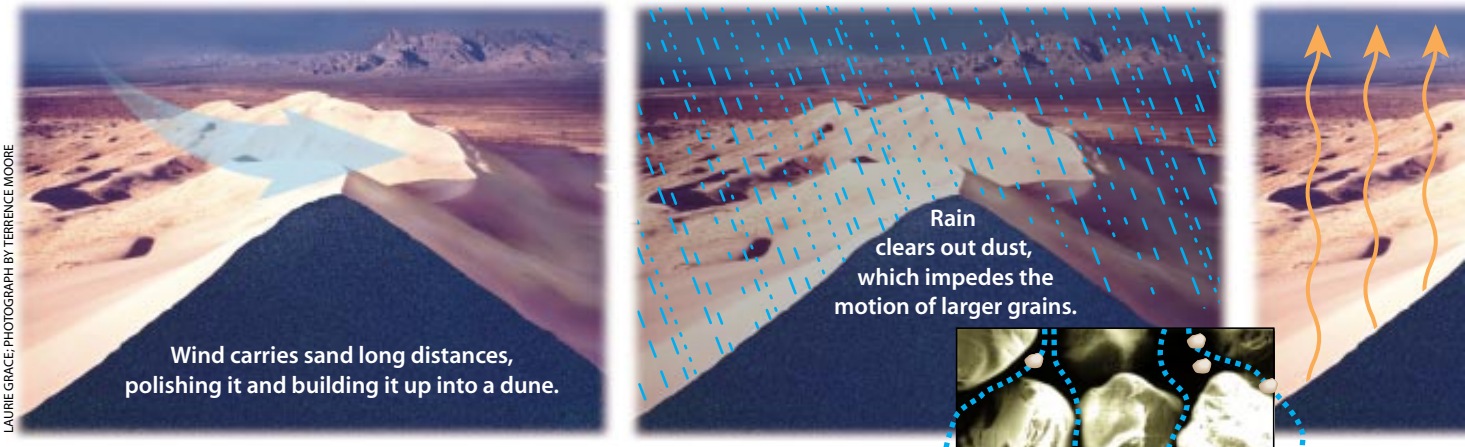
Near the leeward crest, the combination of smooth, well-sorted grains and lack of moisture leads to conditions more likely to produce sounds during shearing. And because wind usually deposits more sand closer to the top of the lee face, sand accumulates there faster than in lower regions, thereby slowly increasing the dune's incline to where avalanches occur.

Typically, large platelike slabs of sand break off near the crest. In booming sand, these plates tend not to slow into loose flows as they encounter gentler slopes. Instead their upper parts collapse or telescope violently into the lower parts. The plates' eventual breakup is unusually turbulent.

Learning more about sound-producing sand has not been easy. Research has been hindered by the rarity of the phenomenon—especially booming sand—and the difficulty in reproducing sounds in laboratories. In addition, for years researchers did not clearly differentiate between booming and squeaking sands, making the early literature on the topic less than reliable.

A Century of Study

In 1889 the American geologist H. Carrington Bolton published one of the first studies of the phenomenon. He proposed that the sounds result from thin films of soluble impurities deposited on the grains by the gradual evaporation of water. The vibration of elastic air cushions between shearing planes would create acoustic emissions, with the volume and pitch of the sounds being modified by the surface structure of



LAURIE GRACE; PHOTOGRAPH BY TERRENCE MOORE

BOOMING OF A DUNE occurs after a number of events have set up the right conditions—clean, dry, polished and rounded grains of sand near the top of a dune. After it is steeper than a critical angle of 34 degrees, the dune avalanches. Upper layers of sand move faster than lower layers (*a*), rising and settling down repeatedly between the grains (*b–d*). The concerted up-and-down motion is believed to cause the booming.

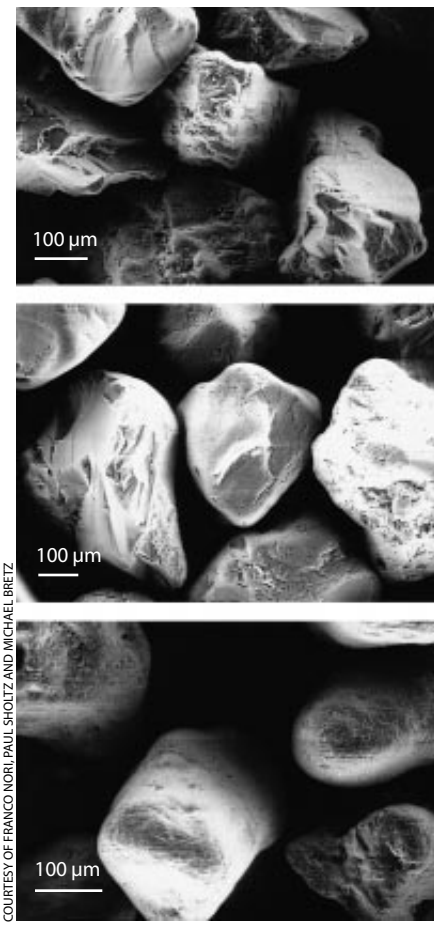
the grains themselves. Bolton concerned himself mainly with squeaking sands but used the same model to explain booming sands.

Around the same time, the British scientist Cecil Carus-Wilson suggested that squeaking sand produced its sounds as a result of the effects of friction on individual grains. He was the first to conclude correctly that grains found in sound-producing sand are usually spherical, well rounded and "well sorted," a term used to describe a high concentration of grains of similar size. Criswell and his collaborators later quantified these results.

In 1966 the British engineer and field commander R. A. Bagnold published "The Shearing and Dilatation of Dry Sand and the 'Singing Mechanism'" in the *Proceedings of the Royal Society*. In the first comprehensive attempt to discuss the phenomenon, Bagnold argued that both squeaking and booming were in fact caused by the same process. His argument is based on the concept of "dilatation," a measure of the empty space between the grains. As one plate slides over another, he argued, it tends to rise up and fall periodically as the grains settle into the spaces between the grains below. The frequency of sound produced by this collective vibration varies as the inverse square root of the mean size of the grains.

Although elegant, the mechanism does not completely describe a booming event. It does not, for example, account for how four or five separate modes of ground vibration could be created simultaneously from a single slab of grains. Nor does it explain the low-frequency beats that typically accompany prolonged flows.

Bagnold's arguments are more conducive to explaining squeaking sand. Stepping on squeaking sand, he proposes, causes it to shear along planes in a manner similar to those that form during avalanches. The only difference, he contends, is the applied force. Whereas the weight of sand itself causes avalanches and booming, the compressional stress of a footstep leads to the shearing that results in squeaking sounds. In fact, the frequencies exhibited by squeaking sand match Bagnold's model better than those caused by booming sand.



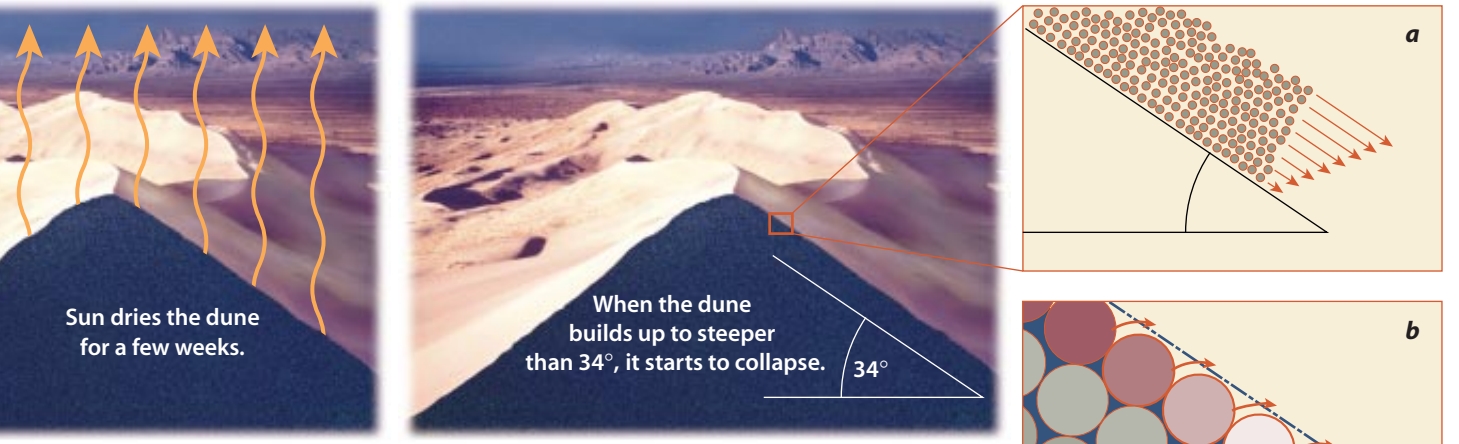
COURTESY OF FRANCO NORI, PAUL SHOLTZ AND MICHAEL BRETZ

ELECTRON MICROGRAPHS show grains of normal beach sand (*top*) collected from Lake Huron at Bay City, Mich., having rough edges. Squeaking beach sand (*middle*) from Lake Michigan at Luddington, Mich., is smoother; even more polished is booming dune sand (*bottom*) from Sand Mountain, Nev.

Probing the Mystery

We have been unable to produce squeaking sounds in booming sand, but as far back as 1889 there have been suggestions that the same type of sand is capable of yielding both. Bolton wrote that sand in Hawaii "possesses the acoustic properties" of both beaches and deserts, producing the same sounds during avalanches as Jebel Nagous, an Egyptian booming dune, and yielding "a peculiar hoot-like sound when struck together in a bag, like the sands of Eigg [in Scotland]; Manchester, Mass.; and other sea-beaches."

In the 1970s Haff also induced high-frequency "squeaks" using booming sand from the Kelso Dunes in southeastern California. This discovery provides some support for Bagnold's theory that the only difference between squeaking and booming sands is the mechanism by which they are produced: compression versus avalanche.



There are, however, differences between booming sand that can be forced to "squeak" in a laboratory and sand known to squeak in its natural setting. Haff's analysis shows that multiple frequencies are present in squeaking emissions from booming sands—unlike the purer notes that are produced by true squeaking sand.

For sand to boom, a few conditions must be met. First, the dune should be far from its original sand source so that winds can carry grains along for great distances, depositing similarly sized, well-rounded grains at or near the top of a dune. A good rain should wash dust and smaller particles out from between the grains. Next, a week or two of drying must occur. Finally, the wind should be sufficient to push sand over the top, causing an avalanche.

The most critical parameter governing the ability of sand to boom appears to be its resistance to shear. Sand that is packed too tightly cannot shear, whereas grains that are too loosely grouped take on the properties of a fluid and do not shear properly. All these factors are known to affect the sounds made by sand, but how they intermix to create them requires further study.

Hawaii may be a good place to start. Back-beach dunes on the islands of Kauai and Niihau are the only known examples of nondesert sand that boom. Their sands possess more moisture than typical desert dunes, and the grains are unusually large—about 460 microns in diameter. Moreover, the sand is unlike any other sound-producing variety: the dunes are composed primarily of calcium carbonate grains formed from seashells and are believed to be the only booming sands not made of quartz. Because the exception sheds the most light on the rule, studying these beaches might prove very profitable.

Booming and squeaking can be reproduced in buckets or bags. To figure out exactly how sound is produced, however, a glimpse deep inside the shearing process is needed. It may be possible to get that look with sophisticated radiological equipment, but such an analysis has not yet been completed.

An intriguing avenue for research is the electrical behavior of sand. When a grain of silica is compressed, it tends to develop opposite electrical charges at either end; this charge separation can cause grains to attract one another. In 1936 Lewis observed that on slowly pouring Kalahari booming sand, grains would occasionally adhere to form filaments as long as half an inch; an electroscope verified that these threads were indeed electrically charged. Nevertheless, we have found that electrically grounding the sand has no effect on its acoustic output. And although electrical effects may help explain why humidity precludes booming, so far no one has collected any strong evidence.

Other promising routes of investigation include systematically probing the mineral composition of booming sand grains to study the importance of shearing strength. Creating synthetic booming sand could also prove fruitful, allowing researchers to manipulate different parameters and thus test their role.

But perhaps the greatest attraction of singing sand is that it remains an unsolved puzzle. SA

The Authors

FRANCO NORI, PAUL SHOLTZ and MICHAEL BRETZ collaborated on the study of booming sand at the University of Michigan at Ann Arbor. Nori obtained his Ph.D. in 1987 from the University of Illinois at Urbana-Champaign and is now an associate professor of physics at Ann Arbor. He has worked on a variety of problems in condensed-matter physics and complex systems. Sholtz earned his B.S. in physics and mathematics at Ann Arbor and is a software developer. Bretz received a Ph.D. from the University of Washington in 1971 and is a professor of physics at Ann Arbor. He studies critical phenomena in numerous physical systems.

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by Shawn Carlson

Unraveling the Secrets of Monarchs

Never underestimate the power of chitchat. Last winter I found myself in the company of a chatty cabby in beautiful Monterey, Calif. In answer to one of his questions, I mentioned my work with amateur scientists. "Oh," he said, "you must be a monarch man." When I assured him that I had no idea what he meant, our cab took an abrupt turn. "Bear with me," he said as we darted across the parking lot of a small shopping center.

He drove up an alley, onto a main thoroughfare, then took one quick turn again and made a sudden stop. "There," he said, pointing out a well-aged eucalyptus tree. I was puzzled until I saw what had appeared to be a falling leaf flutter back toward its perch. I pulled out my trusty binoculars and carefully scrutinized the branches. There were hundreds, if not thousands, of monarch butterflies nestled in the tree waiting for the rising sun to warm them. "It gets pretty busy by midafternoon," my new friend informed me. I've been a monarch enthusiast ever since.

Danaus plexippus is just an ordinary butterfly in South America, but harsh winters have chiseled the North American variety into one of the most remarkable animals on this continent. Here the monarch is the only insect to migrate both north and south every year, just as birds do. From late August through October, millions head south from as far north as Canada. Those that travel west of the Rocky Mountains overwinter along the Pacific Coast, from Los Angeles to Monterey. The vagabonds on the eastern route roost in just 10 small patches of fir trees in the mountains of central Mexico. Some butterflies travel 4,000 kilometers (2,500 miles) to reach their winter roosts—quite an impressive feat for an insect that tips the scale at barely half a gram.

What is more, no individual lives long enough to complete the migration. The winter survivors mate on the return leg, and, for butterflies, sex is far more lethal than the rigors of a cross-country trek. So these rugged travelers quickly die. Their progeny continue their parents' journey, but many of them also mate, lay eggs and die along the way. Indeed, it takes from three to five generations of butterflies to bring the migratory cycle full circle.

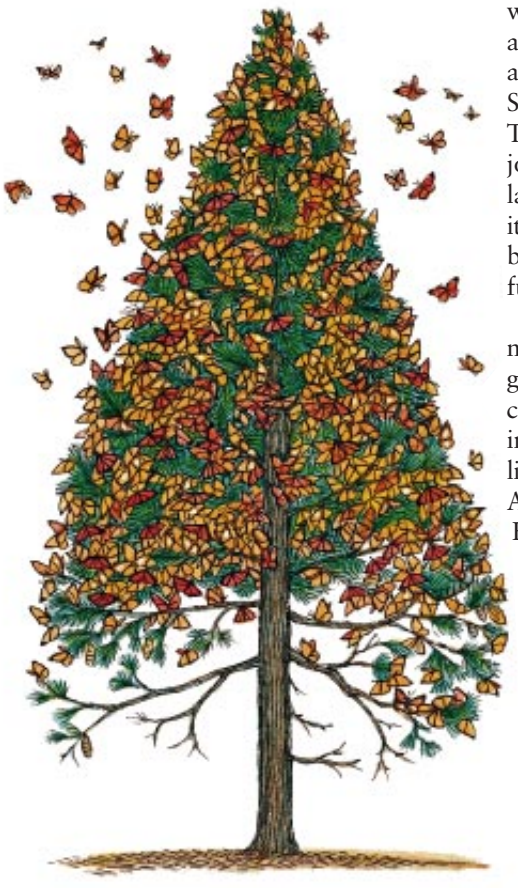
Scientists do not understand why the monarchs of South America do not migrate at all—or, for that matter, why their cousins in Australia (where they are an introduced species) do. And they know little about how the monarchs of North America manage their yearly odyssey. How, for instance, do they sense when to leave their summer homes up north? What factors turn off their reproductive instincts on their southern sojourns but make them sexy on the return passage? And, having never before visited their winter roosts, how do they ever find their way? No one knows.

These deep mysteries can be plumbed with inexpensive apparatus and a little determination, making this field ripe for amateur work. July's column described how to catch and rear butterflies. Here I complete my exposition of sciences lepidopterous by describing some professionally based research in which your entire family can get involved.

The largest of these efforts is called Monarch Watch; it is run by the University of Kansas at Lawrence. Scarcely five years old, the organization already boasts 1,500 paid members and has a program for schools that reaches another 100,000 students and teachers. These numerous amateurs are able to generate many more observations than professionals could collect on their own.

Most volunteers for Monarch Watch take part in its tagging program. These people capture tens of thousands of butterflies and mark each with a small paper tag on the underside of one hind wing. The tags identify when and where the butterfly was first netted. Of the 90,000 insects tagged so far, only 137 have been recaptured. Yet those catches, along with some earlier efforts at tagging these butterflies, have revealed surprising facts about the migration of monarchs [*see illustration on opposite page*]. For one, there does not seem to be a single route. Some monarchs make a beeline for Mexico, whereas others actually head southeast and fly toward the Carolinas. Are these insects lost? Do they fly out to sea and die, or do they follow the coast and ultimately make it to Mexico? With more taggers, Monarch Watch may be able to find out.

Monarch Watch is also exploring the possibility of tracking butterflies using various kinds of natural chemical tags that are indicative of the insects' home turf. This year a limited number of volunteers will raise larvae on native milkweed watered by local rainwater. These amateurs will then return the mature butterflies to the University of Kansas

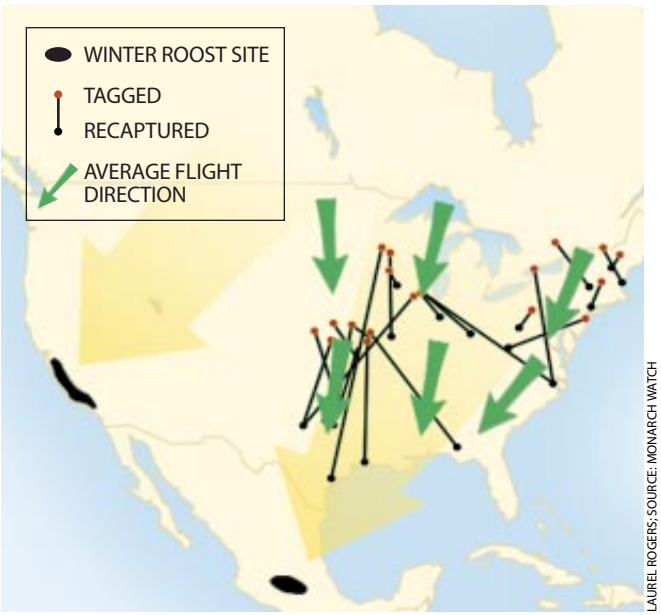


PATRICIA J. WYNNE

NORTH AMERICAN MONARCH BUTTERFLIES ***roost in the same areas every winter, where they converge on certain trees in great numbers.***

for analysis. The researchers hope to identify a chemical signature that will betray a butterfly's point of origin. Then, by sampling the migrating insects at different locations, they should be able to determine the precise routes of migration. Last year volunteers raised the necessary broods in 86 different locales. By this year's end, the organizers of this effort hope to cover all of North America east of the Rocky Mountains.

Maybe then more secrets of butterfly navigation will yield to scientific scrutiny. The observers at Monarch Watch have already discovered one of the ways these long-ranging insects guide themselves. First, they divided a captured brood of migrants into two cages. Using electric lights to mimic the daylight hours, the researchers "time-delayed" one group by shifting the light cycle to start six hours after dawn. They left the daily cycle of the other group unchanged to serve as a control. After spending two weeks conditioning the insects, the experimenters released the butterflies on several sunny afternoons and recorded their direction of flight.



LAUREL ROGERS; SOURCE: MONARCH WATCH

EASTERN AND WESTERN MONARCH POPULATIONS diverge (yellow arrows) *during their autumn migrations. The eastern butterflies head, on average, for central Mexico; their western counterparts steer toward California. Black lines show butterflies tagged and recaptured by Monarch Watch in 1996.*

The best route toward the winter roosting sites was just west of due south. In the morning, that direction is well west of the sun's position; in the afternoon, it is east of the sun. The control butterflies knew it was afternoon and correctly headed toward their destination. But the time-delayed monarchs thought it was morning, and they flew toward the northwest, far to the west of the sun's position. This result clearly demonstrates that monarchs are able to find their way, at least in part, by synchronizing their internal clocks with the sun's position.

Yet this ability cannot be the whole story. After all, monarchs seem perfectly capable of navigating even under overcast skies. The butterflies may be following the earth's magnetic field or contours in the land. The answers are waiting for some clever scientist—professional or amateur—to discover.

You can extend the techniques described in July's column to rear monarchs for your own experiments. The folks at Monarch Watch keep up to 150 adults at a time in a space about one meter on a side. To duplicate their success, first connect 12 wooden slats to form a one-meter cube. Cover the top with a hard, clear plastic sheet. Next, staple a one-meter square of fine-mesh plastic window screen one third of the way down the front face and, for easy access to the interior, secure the rest of the square to the wood with Velcro strips. Finally, staple fine-mesh screen over the four remaining surfaces.

You'll need to control light and temperature. Full-spectrum lights are a must. The researchers at Monarch Watch place 10 G.E. daylight fluorescent bulbs 15 centimeters above each of their cages. Use a timer to turn the lights on and off in alternating two-hour intervals starting at 6:30 A.M. with lights-out for the night at 10:30 P.M. This makes for a choppy 16 hours of daytime, but the many dark respites inspire good feeding and mating. Keep the temperature between 23 and 27 degrees Celsius (74 and 80 degrees Fahrenheit). Feed the butterflies solutions of 20 percent sugar water seasoned with a pinch of bee pollen (available at your local health food store) to supply necessary amino acids.

A plastic pot scrubber placed in a shallow dish of the sugar solution makes a dandy fake flower from which the butterflies can feed. Change the solution and sterilize the scrubber every day (or, for a feeding solution that never goes bad, see the instructions on Monarch Watch's World Wide Web site).

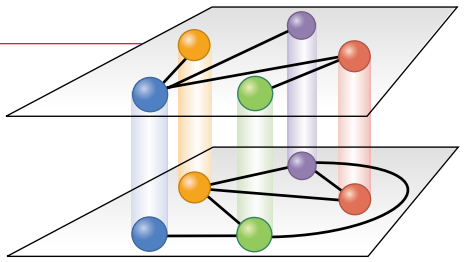
In the wild, monarchs lay their eggs only on milkweed plants. In captivity, they still prefer this plant, but green paper can serve as artificial milkweed if the butterflies sense it has carbohydrates that could sustain their young. So if you don't have immediate access to milkweed, try collecting the eggs by hanging inside the cage strips of green blotting paper that have been soaked in sugar water with pollen and allowed to dry. But you'll need to rear the larvae on milkweed. (See July's column for general tips on raising caterpillars.) If you cannot collect these plants locally, Monarch Watch can provide you with seeds. Indeed, if you reside in the East or the Midwest, Monarch Watch can supply you with butterfly larvae, too. And after you raise them to maturity, you can enlist them in Monarch Watch's experiments or test your own theories of how these charming insects behave. SA

If you would like to get involved in their research and live east of the Rocky Mountains, send $10 to Monarch Watch, University of Kansas, Department of Entomology, Haworth Hall, Lawrence, KS 66045-2106, or call them (toll free) at 1-888-TAGGING. You can check out their site at www.keil.ukans.edu/~monarch/home.html on the World Wide Web. People west of the Rockies should contact the Monarch Program, P.O. Box 178671, San Diego, CA 92177 (e-mail: Monarchprg@aol.com).

For information about other activities for amateur scientists, contact the Society for Amateur Scientists, 4735 Clairemont Square, Suite 179, San Diego, CA 92117. Visit the society's Web site at www.thesphere.com/SAS/ or call (619) 239-8807 or leave a message at (800) 873-8767.

by Ian Stewart

Empires and Electronics



JENNIFER C. CHRISTIANSEN

"SANDWICH" represents a graph of thickness two: two planar graphs in which the respective nodes have been stretched into vertical lines.

This past month I took a look at map-coloring problems. Although they appear frivolous, the mathematics behind them is useful. The maps are related to graphs, diagrams in which a set of nodes are joined by lines known as edges. The thickness of a graph, a concept that we derived from empires on Earth and the moon, has recently been turned to advantage in manufacturing electronic circuit boards. The connection is made in an article in *Mathematics* magazine (Vol. 66, No. 4, October 1993) by Joan P. Hutchinson of Macalester College in St. Paul, Minn.

The application was discovered by researchers at AT&T Bell Laboratories in Murray Hill, N.J. Recall that a graph is planar if it can be drawn in the plane without any edges crossing one another. The next step up is a graph of thickness two, whose edges can be separated into two sets in such a manner that either set is planar. A graph has thickness three if its edges can be separated into three such sets, and so on.

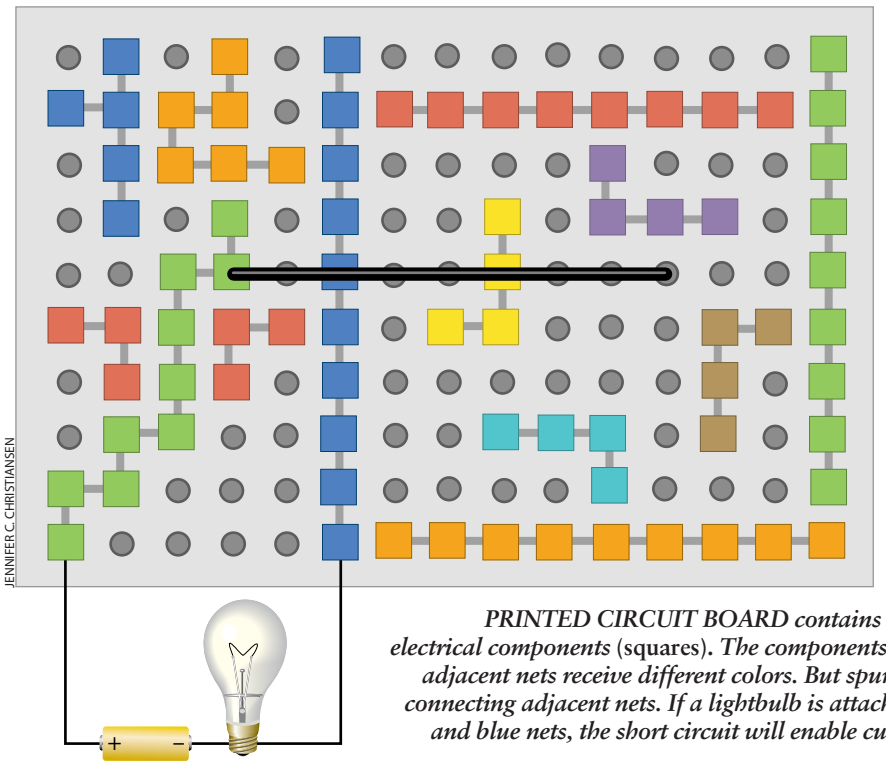
You can imagine a graph of thickness two as a kind of "sandwich." On one slice of bread we draw the edges in the first set, none of them crossing; on the second slice, we draw the rest of the edges, again with none crossing. The nodes, extended into vertical lines, form the filling. A graph that needs t layers of bread has thickness t.

To begin with, think of an electronic circuit as a graph in its own right. The nodes are the electronic components, and the edges are electrical connections. If the circuit is to be constructed on one side of a printed circuit board (or PCB), it must be planar to avoid short circuits. By using both sides of the board—analogous to the two slices of bread in the sandwich—graphs of thickness two become available. With several boards, the thickness of the graph can be increased. Similar considerations apply in the more high-tech world of silicon chips, because VLSI (very large scale integrated) circuits have to be built in layers.

A typical PCB is a 100×100 array of holes, where components can be attached, joined by horizontal and vertical lines that can be plated with "tracks" of conducting material. The tracks serve as wires connecting the components. An important problem for manufacturers of PCBs is to detect boards with spurious connections—extra bits of track that join components together electrically where they shouldn't be.

For practical reasons, manufacturers arrange the components on a PCB into "nets." A net is a collection of components connected by tracks, such that the tracks contain no closed loops. The problem that concerns us here is to determine whether two distinct nets have inadvertently been linked by a short circuit. The most obvious way to do this is to check all pairs of nets to see whether they are connected. One can make a circuit running from one net to the positive pole of a battery and from the negative pole through a lightbulb to the second net. If the two nets are inadvertently connected, current will flow and the bulb will light. If not, it won't.

Of course, a practical test device would use more sophisticated electronics—such as a computer attached to a robot that automatically discards a faulty board—but that's the basic idea. The practical snag is that with n nets this method requires $n(n-1)/2$ tests—the number of pairs of nets. Because 500 nets is typical, that means 125,000 tests per board, which is far too many.



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PRINTED CIRCUIT BOARD contains holes (circles) *in which are fixed electrical components* (squares). *The components are linked by tracks of metal into "nets"; adjacent nets receive different colors. But spurious tracks* (black) *can cause faults by connecting adjacent nets. If a lightbulb is attached, via a battery, to probes on the green and blue nets, the short circuit will enable current to flow and the bulb to light up.*

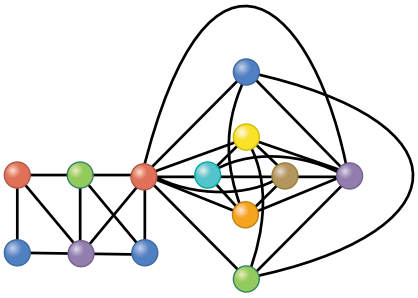
Applying the concept of the thickness of a graph reduces the number of tests to a mere 11. In fact, a little extra thought reduces that number to just four.

The starting point is to turn the PCB design into a graph that conveys information about short circuits. Let me call this the net graph of the circuit design. Because we are looking for shorts between different nets, we assign one node to each net.

The edges of the net graph represent potential short circuits, not actual ones (because if we knew where the actual shorts were, we wouldn't need to test the circuit). To be precise, two nodes of the net graph will be joined by an edge whenever the corresponding nets are "adjacent"—meaning that they can be connected by a horizontal or vertical straight line that passes through no intermediate net.

Of course, in principle a short circuit might connect nonadjacent nets. But nearly all such short circuits must also connect adjacent nets. Typically the fabrication device makes two passes over the board: one each for the horizontal and vertical connections. Errors arise when it lays down too much conducting material, inadvertently linking two nets. I'll call such an error a "fabrication fault." (There are other, far rarer ways to produce a faulty board, but we shall ignore them.) The extra line of conducting material may run across several nets, but two of these will necessarily be adjacent. Thus, looking at only adjacent nets is sufficient.

I said earlier that the graph for a PCB has thickness two, one for each side of the PCB. The net graph also has thickness two, for the same reason. But according to a theorem by 19th-century



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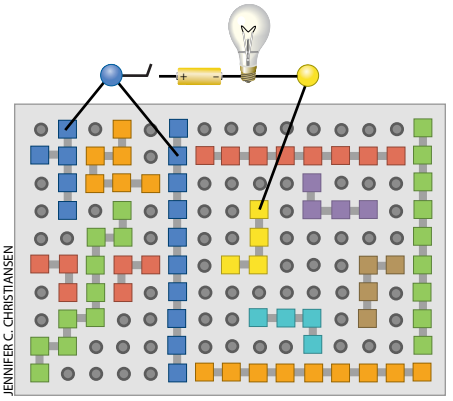
NET GRAPH for the PCB at top on the opposite page has thickness two, for the two sides of the board. Each net is depicted by a node; adjacent nodes are connected by edges—potential short circuits.



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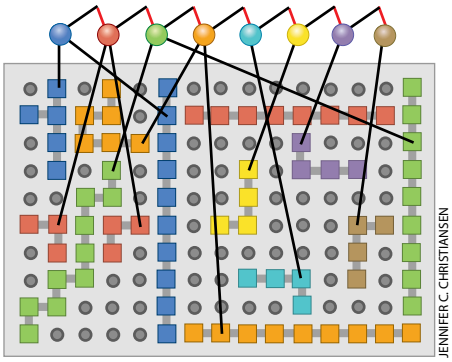
PROBE connects all nets of a given color. Placing a lightbulb between the yellow and blue probes can then detect a short between nets of these colors.



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GATES or switches connect each probe in succession, reducing the total number of tests for short circuits.

British mathematician Percy John Heawood, any graph of thickness two can be 12-colored. That is, each node can be assigned one of 12 colors so that nodes that are joined by an edge always have different colors. So the net graph of any PCB can be 12-colored. We can transfer this coloring (conceptually) to the nets on the PCB. Thus, the nets can each be assigned one of 12 colors, in such a way that nets of the same color are never adjacent to one another.

Because we are seeking short circuits that link adjacent nets, we know that we can restrict our search to shorts between nets of different colors. We can lump all the nets of each color together, in the following sense. For each of the 12 colors, we construct a "probe." This is a treelike structure made from conducting material that connects all the nets of a given color.

Suppose that we choose two colors—say, blue and yellow. We attach both the blue and yellow probes to the PCB, keeping them separate. Now we connect a battery and a lightbulb across the two probes and see whether any current flows.

If the PCB has been correctly made, no current will flow, because the blue probe connects only to blue nets, the yellow probe connects only to yellow nets, and on the PCB no blue net should connect to any yellow net. But if there is a fabrication fault linking a blue net to a yellow one, current will flow.

Notice that this test doesn't tell us where the error is. Because we are discarding all faulty PCBs (and not repairing them), we don't need to know. The upshot is that to detect the presence of a fabrication fault, it is enough to check all possible pairs of probes. There are only 12 probes, so the number of such pairs is $12 \times 11/2 = 66$. Instead of 125,000 or more tests, we need only 66—a major improvement.

We can, however, easily do better. Test probe 1 against probe 2; throw out any PCBs with connections between them. Now add a gate or switch to connect probes 1 and 2. Test probe 3 to see if it connects to the circuit formed by probes 1, 2 and the gate. If so, then probe 3 connects either to probe 1 or to probe 2. Either eventuality is a mistake, so we just throw the PCB out. Now add a second gate connecting probe 3 to the previous two and continue in this manner. That gets the number of checks down to 11.

Allen J. Schwenk of West Michigan University in Kalamazoo realized that a further reduction can be made. Write the numbers 1, 2, … , 12 in binary: 0001 up to 1100. Number the probes accordingly. Make a "superprobe" that connects all probes starting with 0; make another that connects those starting with 1. Test whether these two superprobes are connected; if so, throw out the PCB. If not, create two more superprobes connecting probes that have the same binary digit in the second place and check whether these are connected. Do the same for the third place and the fourth place in the binary expression. That's it. To see why it works, note that if two distinct probes are connected by a short circuit, their binary expressions must differ in at least one of the four places, so one of the four tests will detect the mistake.

A reduction from 125,000 tests per board to only four is well worth having as soon as the production run becomes reasonably big—because you need build those complicated probes and superprobes only once for each PCB design.

A month ago we started out coloring maps in Earth-moon empires, and now we've ended with a money-saving test technique for PCB manufacturers. What matters in mathematics is not the particular realization of an idea but what that idea opens up when you pursue it with skill and imagination. SA

FEEDBACK

The April column featured the traditional topic of knight's tours. Solomon W. Golomb of the University of Southern California points out that he proved several of the results in an article, "Of Knights, Cooks, and the Game of Cheskers" (*Journal of Recreational Mathematics,* Vol. 1, No. 3, pages 130–138; July 1968). These include the theorem attributed to Louis Pósa—that there is no closed knight's tour on any $4 \times n$ board—and the existence of closed tours on a 3×10 board.

Andy Campbell of West Hartford, Conn., recalled the problem of a magic knight's tour. This is a closed knight's tour of the 8×8 board with this property: if successive positions of the knight are numbered 1 through 64, the numbers form a magic square. (That is, all rows, columns and diagonals sum to the same number.) The existence of such a tour has neither been proved nor disproved, but several near misses are known:

(*a*) A knight's tour with all row and column sums equal to 260, but not the diagonal sums

(*b*) A magic square made from two half knight's tours (1–32 and 33–64), each covering half the board

(*c*) A magic king's tour —*I.S.*

a

46	55	44	19	58	9	22	7
43	18	47	56	21	6	59	10
54	45	20	41	12	57	8	23
17	42	53	48	5	24	11	60
52	3	32	13	40	61	34	25
31	16	49	4	33	28	37	62
2	51	14	29	64	39	26	35
15	30	1	50	27	36	63	38

b

15	20	17	36	13	64	61	34
18	37	14	21	60	35	12	63
25	16	19	44	5	62	33	56
38	45	26	59	22	55	4	11
27	24	39	6	43	10	57	54
40	49	46	23	58	3	32	9
47	28	51	42	7	30	53	2
50	41	48	29	52	1	8	31

c

61	62	63	64	1	2	3	4
60	11	58	57	8	7	54	5
12	59	10	9	56	55	6	53
13	14	15	16	49	50	51	52
20	19	18	17	48	47	46	45
21	38	23	24	41	42	27	44
37	22	39	40	25	26	43	28
36	35	34	33	32	31	30	29

JENNIFER C. CHRISTIANSEN

DUSK OF THE DINOSAURS

Review by Michael J. Benton

T. Rex and the Crater of Doom
BY WALTER ALVAREZ
Princeton University Press,
Princeton, N.J., 1997 ($24.95)

The Great Dinosaur Extinction Controversy
BY CHARLES OFFICER AND JAKE PAGE
Addison-Wesley,
Reading, Mass., 1996 ($25)

The extinction of the dinosaurs is one of the great mysteries of evolution, and scientific sleuths are not shy about reconstructing the crime. "A world first dark and frozen, then deadly hot, a world poisoned by acid and soot. This was the global aftermath of the Yucatán impact," Walter Alvarez writes, advancing his theory that an asteroid brought about the dinosaurs' demise. Meanwhile Charles Officer and Jake Page assert: "The Alvarez hypothesis has collapsed under the weight of accumulated geologic and other evidence to the contrary, as well as from an increasingly obvious absence of scientific evidence proffered in its support." How can leading scientists who have been involved in this debate for nearly 20 years arrive at such different conclusions?

The story effectively began in 1980, when Luis W. Alvarez (Walter's father) and his colleagues published a paper in *Science* asserting that a 10-kilometer-wide asteroid hit the earth 65 million years ago. The impact, they contended, threw up a global dust cloud that blacked out the sun, halted plant photosynthesis and triggered a wave of extinction. With their food gone, the herbivores died out; the carnivores then followed. This simple model was built on limited observational support and was, needless to say, highly controversial.

The main piece of evidence supporting the Alvarez scenario was the now famous "iridium spike." Concentrations of iridium, normally around 0.1 to 0.3 part per billion, shot up to nine parts per billion in sediments from the time of the dinosaur extinction (known as the Cretaceous-Tertiary, or K-T, boundary). On the earth, iridium comes almost exclusively from space—specifically, from meteorites. The low background levels derive from the numerous minor impacts that occur all the time. Alvarez proposed that the spike indicated an unusually high rate of iridium deposition on the earth and, hence, a huge impact. The 1980 *Science* paper attracted instant and massive press coverage.

Walter Alvarez tells the story leading up to the 1980 paper, and the events since then, in an engaging and witty manner. Although much of the tale is common knowledge, he offers new insights into the published and unpublished stages of the debate. Most geologists and paleontologists initially objected to the Alvarez theory. They argued, first, that dinosaurs and other groups died out gradually (over at least a million years) rather than instantaneously; second, that the iridium layer was a local feature that represented some minor peculiarity in the sediments; third, that Alvarez and his crew were a bunch of physicists and chemists who should stick to their own patch; and fourth, that the whole notion was pitched at the press and had no scientific basis. From the start, the debate mixed science and personalities, hype and hypotheses.

Officer and Page, who began as skeptics of the Alvarez hypothesis and never wavered, thread their book with some wonderful gossip, backbiting and accounts of scurrilous deeds by impact proponents. They report extensive evidence for bias in reporting and funding of the pro- and anti-impact viewpoints. They are uncomfortable with the perceived pecking order in science: math and physics good, chemistry a form of

PATRICIA J. WYNNE

DINOSAURS were a diverse group, adding to the mystery of their extinction.

physics and so acceptable, biology and geology pretty dodgy, psychology and geography beneath contempt. The authors characterize Luis Alvarez as little more than the devil incarnate, one of the most extraordinary character assassinations of a recently deceased person that I have ever read.

But what of the science? The 1980 *Science* paper cited iridium spikes from two locales. Such enhancements have now been found at more than 200 sites all over the earth, in sediments deposited in shallow and deep seas, in rivers and on land. The iridium is frequently associated with small, glassy beads (the results of melting) and shocked quartz and stishovite (the results of high pressures)—pieces of confirming evidence that were not even predicted in 1980. Searchers found the Chicxulub crater in Mexico in 1991. This 150-kilometer-wide depression is surrounded by thick deposits of ejecta and by deposits around the shores of the proto-Caribbean that show the effects of tsunamis set off by the impact.

Alvarez does not dismiss all contrary evidence and allows some role for volcanism in the mass extinction. He is also honest in telling of the dead ends that he and his colleagues pursued, such as the failed attempt to use beryllium 10 to calculate rates of sedimentation and studies of the Manson crater in Iowa (an early candidate for the K-T impact but too small). *T. Rex and the Crater of Doom* is strongest in presenting the evidence for the impact and its immediate physical effects but rather weaker in explaining just how the dust clouds, darkness, freezing, tidal waves and other environmental challenges actually killed the dinosaurs.

Officer and Page have taken on the task of presenting a cohesive opposition to the prevailing impact hypothesis. They have made things much more difficult for themselves, however, by seeking not only to deny the impact extinction model but also to deny the existence of the impact as well. As a result, they fail miserably. They spend most of the book attempting to show that the geologic evidence—the iridium spike, shocked quartz, glassy spherules and other phenomena—points to volcanism. To do so, the authors make selective use of the literature. As they observe, Hawaiian-type volcanoes may emit iridium, some volcanoes produce glassy melt spherules, and certain high-pressure eruptions may give rise to a kind of shocked quartz. But no known volcano, ancient or modern, produces all these materials together, with the peculiar characteristics seen at the K-T boundary.

Presentation of the paleontological data should have been a strength of Officer and Page's book. Here the evidence is fairly equally balanced: there are signs that some groups of organisms died out instantaneously, whereas others seem to have become extinct over spans of five to 10 million years. I was staggered to see that *The Great Dinosaur Extinction Controversy* treats the fossil record in only a few pages of mostly obsolete and sometimes misleading data. For example, Officer and Page represent the decline of ammonites by illustrations from papers published in 1969 and 1991. The latter diagram, by Peter Ward of the University of Washington, is said to show a gradual decline of ammonites, even though Ward himself interprets it as evidence of patchy collecting. The authors' account of the dinosaurs' disappearance is vague in the extreme and takes little account of extensive research work since 1970. Moreover, the two do not mention at all the recent large-scale studies of dinosaur decline through the Hell Creek Beds in Montana.

At the very least, Officer and Page develop their alternative to the impact model fairly well. They outline recent work on what might have been the long-term environmental effects of the events that gave rise to the Deccan Traps, enormous outpourings of lava that occurred at the end of the Cretaceous in what is now India. Without a strong paleontological underpinning, however, this argument falls a little flat. Officer and Page cannot make precise links between environmental crises during the past 10 million years of the Cretaceous and specific phases of the extinction.

THE CD ILLUSTRATED

Creatures
CD-ROM for Windows or Macintosh. Mindscape Entertainment, Novato, Calif., 1997 ($40)

Move over Tamogotchi—make way for the Norn, the artificial life-forms that star in this new interactive program. *Creatures* makes serious attempts to bring some science into the play, allowing the user to monitor the genetic, hormonal and bioelectrical status of the artificial creatures. The goal is to raise your Norns and establish a successful breeding population. These creatures are appealing in a cartoonish way (*below*), and their environment is cleverly realized. Maybe too cleverly: as with real pets, Norns require a lot of attention, and their life progress is painfully slow. *—Corey S. Powell*

MINDSCAPE ENTERTAINMENT

These shortcomings are unfortunate, because the impact hypothesis still has significant holes in it. The reality of the K-T impact is now essentially undeniable. How else to explain the iridium layer, the shocked quartz, the stishovite and, above all, the gigantic Chicxulub crater? Yet I cannot see how a single impact could produce such a complex extinction event as the one at the K-T boundary. Furthermore, there is almost no evidence linking an impact to any of the other mass extinctions. Equally, there have been a number of well-dated large impacts, such as the Manicouagan event in British Columbia, that caused no extinctions at all.

Read Alvarez first, for an excellent account of the pro-impact position and for insight into how scientists pose questions and seek to resolve them by sometimes roundabout means. Read Officer and Page as a spicy account of the politics of science. But bear in mind that whether or not they are right about Luis Alvarez's character, even abrasive scientists may have the right ideas.

MICHAEL J. BENTON is a paleontologist in the department of geology at the University of Bristol.

SOUND WORK

Review by Robert Zatorre

Music, the Brain, and Ecstasy: How Music Captures Our Imagination
BY ROBERT JOURDAIN
William Morrow, New York, 1997 ($25)

Imagine a distant alien civilization observing our human world from light-years away. After some time simply watching us, they would probably be able to discern without much difficulty how and why we eat, breathe, walk, sleep and mate. They might even figure out that we used sound signals emitted by our mouths to communicate with one another. But imagine how perplexed they would be by music: people all over the planet pound on objects of all sizes, blow through tubes, scrape or pluck strings and vibrate their vocal cords, sometimes for hours on end, to make all manner of strange noises, all with no evident explicit purpose. In fact, we ourselves do not have much insight into this inexplicable realm of sound: most people listen to music because they like it, and no more explanation than that is needed.

In his book Robert Jourdain probes this question: Why do we like music so much? He illuminates for the interested reader everything from psychoacoustics to neuroscience, with many an entertaining musical anecdote in between. The book is well suited to the musician who knows little of science but is eager to know more as it relates to music and to the scientist who may enjoy music but does not know much about its structure. Most of all, it is fun, exploring all aspects of what could be a difficult topic with wit and vim. Jourdain manages a good balance between scientific accuracy and journalistic license: most of the facts are correct, but he knows when to simplify details that are relevant only for the specialist.

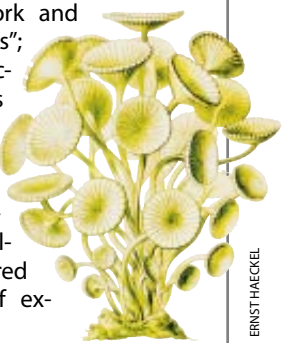
Music, the Brain, and Ecstasy starts at the most basic level with an explanation of how sound is produced and proceeds through progressive elaborations to tone, melody, harmony and the more complex aspects of music. Jourdain takes a look at how music interacts with the brain during listening, performance and understanding, culminating with the emotional aspect of music—the "ecstasy" of the title. In some ways, this chapter may prove a bit disappointing to a reader who expects "the answer" to emerge. Jourdain cannot even hint at a solid scientific explanation for the emotional power of music. He provides thoughtful considerations, but he does not (and could not reasonably be expected to) give clear-cut explanations.

Even without a final answer to the conundrum that music has posed for millennia, science does have a great deal to say to music lovers. In recent years, many research labs have begun to explore the neural underpinnings of music. This development is a timely one for Jourdain, who has assimilated a large amount of relevant information from various sources; he even has a knack for anticipating what new research may elucidate. At the same time, he performs an extremely useful service by showing due skepticism in the presentation of neuroscience findings that too often fall into the gee-whiz school of science reporting. When he discusses the specialization of the two cerebral hemispheres,

BRIEFLY NOTED

THE END OF CERTAINTY: TIME, CHAOS AND THE NEW LAWS OF NATURE, *by Ilya Prigogine. Free Press, New York, 1997 ($24).* **CELESTIAL ENCOUNTERS: THE ORIGINS OF CHAOS AND STABILITY,** *by Florin Diacu and Philip Holmes. Princeton University Press, Princeton, N.J., 1996 ($24.95).*
These two offer idiosyncratic but enlightening perspectives on the "new" discipline of chaos theory. Ilya Prigogine, a doyen of the field, argues forcefully that science is undergoing a singular break with its deterministic roots; his philosophical musings are the highlight of this brief volume. Mathematicians Florin Diacu and Philip Holmes take a very different position in their thorough look at the historic roots of chaos. Notions of nonlinear dynamics, they emphasize, grew out of quite traditional attempts to understand the long-term stability of the solar system.

VIEWS OF THE CELL: A PICTORIAL HISTORY, *by Joseph G. Gall. American Society for Cell Biology, Bethesda, Md., 1996 ($29).*
Sixty full-page images document three centuries of progress in understanding the makeup of living things. In the 1660s Robert Hooke observed tiny chambers in cork and called them "cells"; by the 1950s electron micrographs were mapping out such fine structures as the endoplasmic reticulum. Each illustration is paired with a page of explanatory text.


ERNST HAECKEL

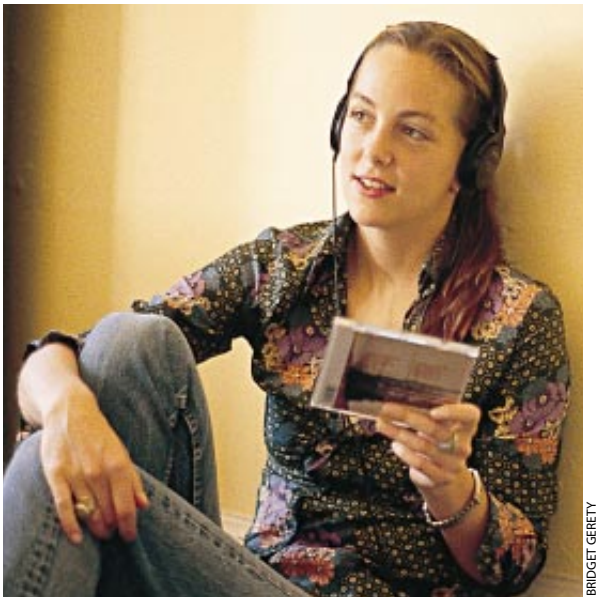
ALLERGIC TO THE TWENTIETH CENTURY, *by Peter Radetsky. Little, Brown and Company, Boston, 1997 ($24.95).*
Peter Radetsky clearly considers so-called environmental illnesses, such as Gulf War syndrome, to be organic maladies. But true to his training as a science reporter, he looks at both sides of the story. The result is a book with multiple personalities. Radetsky never convincingly refutes the mainstream medical opinion that these ailments are more psychological than physiological in nature, yet he pointedly describes the victims as "canaries in the coal mine."

for example, Jourdain is quite careful to point out how much nonsense has been written about the "coldly logical" left hemisphere and its twin, the "emotional, mystically intuitive" right hemisphere. No such simple division is possible.

Jourdain does a good job of debunking these notions without throwing the baby out with the bathwater. There are important functional differences between the two sides of the brain, and those differences are relevant to music in many ways. Furthermore, techniques such as brain scanning can yield all manner of information about how the brain processes patterns of sound. But that does not mean one can speak of something like musical appreciation as being located in one hemisphere or one region just because it lights up during a brain scan. Jourdain conveys the subtler, less flashy mainstream thinking of contemporary neuroscience in describing how different brain modules—which may indeed be localized within a particular brain region—interact in myriad ways via complicated circuitry to produce the multifaceted phenomenon we call music.

Jourdain also explains many basic psychological functions that happen to be relevant to music, in particular the concepts of working memory and pattern recognition. Working memory is such a fundamental component of music and indeed of all auditory perception that it is often passed over without comment. Sounds unfold over time: melodies extend over many seconds or even minutes. For our brain to make sense of them, it must be able to hold on to a sequence of recent acoustic events to compare them with what is happening now. The resulting capacity to perceive relations among musical elements is central to our musical enjoyment. It is these relations and their hierarchical organization, Jourdain argues, that form the core of music.

Musical pattern recognition, especially being able to hear a tune in the "mind's ear," is similarly crucial to our enjoyment of music. It allows a kind of internal rehearsal of musical sounds even when the real sound is absent. Although Jourdain speaks of such musical imagination primarily in the context of the supposed extraordinary abilities of composers, it is an ability that almost all people possess to some degree. This fact brings up an interesting issue, which Jourdain sidesteps to some extent: Should music be thought of as a special cultural artifact, an ability reserved for expert, trained performers and listeners? Or is it perhaps better conceptualized as an innate, species-specific behavior, ubiquitous in all humans, resulting from the very makeup of our brain?



BRIDGET GERETY

PLEASURE OF MUSIC ***seems deeply ingrained in the human brain.***

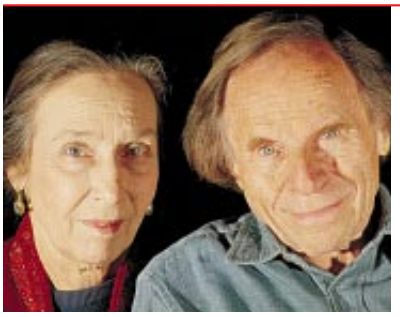
Most of the information in his book clearly favors the latter view, yet Jourdain seems to favor the former. He downplays the musicality of infants and children, for example, pointing out how poorly controlled a toddler's singing is. And yet, as in the old joke about the talking dog that gets the punch line wrong, the fact that small children can sing and recognize tunes at all is remarkable. When babies first walk they are pretty clumsy, too, but unless there is something quite wrong, they all become expert walkers. And so it is with music: no special training is needed to perform sophisticated tasks, such as recognizing the *Sesame Street* theme when played in a new key on a different instrument and then singing it back, albeit off key. Artificial-intelligence algorithms are not up to this task, and yet most kids do it without prompting (indeed, sometimes despite parents' pleas to the contrary!). In this sense, essentially all normal people are expert musicians.

Jourdain takes a somewhat idiosyncratic approach to the issue of expert musicianship as well, occasionally allowing his biases to come through the otherwise careful prose. When he asserts that the "phonograph has been as disastrous to the development of the musical imagination as television has been to the literary imagination," Jourdain appears grumpy rather than reflective. Putting aside the fact that there are arguably as many fine authors and poets now as ever, television notwithstanding, there is not a shred of evidence that musical recordings have had any deleterious effect on music in any way. As Jourdain later admits, people today are exposed to vastly more and a wider variety of music than at any time in history, all thanks to recordings.

The amazing diversity of styles and genres that one can currently sample is without parallel, and this, coupled with the relative economic accessibility afforded by recordings, in fact fosters much more musicality in the population (even if you do not happen to like what they are listening to). When he claims that "the growing use of synthesizers may only worsen this trend," he sounds like a medieval bishop railing against the use of newfangled pipe organs. Synthesizers and computer music in general offer yet another novel way for us to play with sound—that is the essence of music, after all.

Music will probably always inspire some controversy, but that is perhaps as it should be. If music can lead people to experience ecstasy, it can also engender loathing, and this is part of its power over us. After reading Jourdain's book, nothing will feel better than sitting down to listen to a Bach fugue—or a Piazzolla tango or a Balinese gamelan ensemble or whatever you prefer. We may not yet know *why* we like these sonic objects; still, we should all be thankful for the specialized circuitry in our brains that allows us to enjoy them.

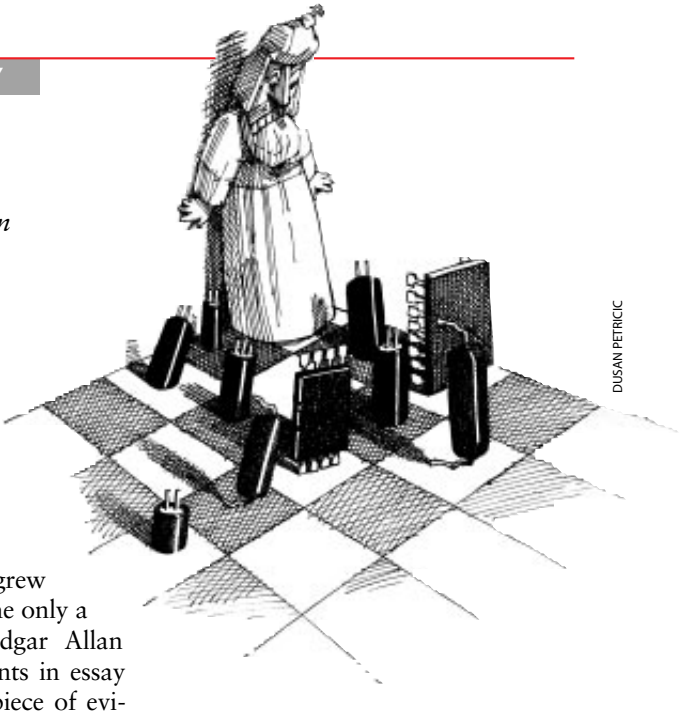
ROBERT ZATORRE is a cognitive neuroscientist at the Montreal Neurological Institute of McGill University.



WONDERS

by Philip and Phylis Morrison

Illusions



DUSAN PETRICIC

Together Grandmaster Garry Kasparov and young Deep Blue have made a lasting mark on the history of chess. Did any who attended to their engagement suggest that perhaps *both* players were human, that Deep Blue was merely the pseudonym for some secret great-grandmaster? Almost no one thinks so, for these days computers have a deservedly good press.

But long ago, from 1769 on, a chess-playing automaton was displayed before half the royal courts of Europe. Its sponsor was Empress Maria Theresa herself; its designer, builder and presenter was a gentleman of her coterie and a gifted engineer, Baron Wolfgang von Kempelen of Hungary. Certainly inspired by the genuine clockwork musicians and sketchers that had dazzled the epoch, this engine was an effigy clad as a princely Turk, who appeared seated within a large, low cabinet, its elegant base studded with drawers. The Turk's steady mechanical hand moved pieces over the board spread on the cabinet top. By no means did the silent Turk win every time—his defeat always delighted the locals—but manifestly he was a player of rank, if an inconsistent one.

Could a chest of marvelous gears really compete with the chessmasters of the time? Of course not. Grandmaster Turk was a working hoax, a human hidden within a big cabinet of clockwork. Over the 70 years during which the Turk could earn a good living, many different players chose his moves. Each of them, concealed in turn within, moved the Turk's arm to play. Whenever the Turk was rolled out as a match began, the ritual included a swift opening and closing of the drawers, to reveal the gleam of brass wheels. It may be (here fact and legend mix) that the first human surrogate was a chess-playing old soldier, shortened by the loss of both legs in war. On the Turk's journeys abroad, other physically small players were privately sought out in each host country.

For decades, a literature grew up around the Turk. Was he only a machine? Critics—even Edgar Allan Poe—offered their arguments in essay after essay. One favorite piece of evidence is subtle but telling, the insight of a University of Cambridge professor in the early 19th century. The dissembling inspection closed with a ritual. As soon as a uniformed attendant brought in a large lighted candle to set beside the chessboard, the match began. The procedure was unfailing, even if the room be ever so bright. Mere formality? No.

The illusion of all illusions, the oldest and the grandest, is nature's own.

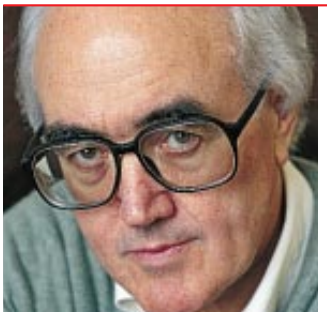
Inside the dark cabinet a small lit candle was essential to allow the hidden player to see from below whatever telltales marked the squares occupied by the moving pieces. Air passages for use by man and candle were easily contrived to baffle any glimpse of the dim flame, but the odor of burning wax is hard to stifle. How better to disarm this hint than to display to everyone a candle overtly burning in all its fragrance?

The Turk was often matched against royal heads; it is said that Napoleon I was one crowned challenger, who at once bought the fabulous automaton. Over the years a succession of impresarios and collectors owned the Turk. (One of them was inventor Johann Maelzel, duly preserved in musical memory by Ludwig van Beethoven, in gratitude for Maelzel's celebrated metronome.) As time went by, the frayed mechanical chessmaster lost social standing. By the 1830s he was no longer touring royal courts, only exhibition halls in republican America. After one performance in Baltimore, two young men remained furtively behind after the hall was cleared, to witness and to report the private opening of the Turk's cabinet, out of which emerged a thoroughly relieved human chess player, ready for lunch and a smoke. The mystery of a lifetime had ended for good, in just about the years when Charles Babbage was trying to realize the first programmed brasswork computer. Deep Blue will not suffer such exposure. It richly encodes human intentions and experience, but it has no player inside—or so you and we reasonably believe.

Consider again the ostentatious candle set next to the Turk to offer a perceived cause for the odor we might scent from the one hidden within. Such imposed false consistency is a brilliantly instructive joke on theoretical science. Surely to disclose the means of illusion is unfair to both artist and audience, worse than telling your neighbor as the movie opens that the butler did it! But if you lack inner knowledge, an outsider's conjecture betrays no trust. Theorists may well be wrong; often they are, for nature is more ingenious.

The illusion of all illusions, the oldest and the grandest, is nature's own. The motion of the sky as a whole makes sun, moon and stars appear to circle the earth more or less uniformly as time passes. That piece of planetary stage magic was

Continued on page 101



CONNECTIONS

by James Burke

Take Two Acronyms

DUSAN PETRICIC

On the odd occasion, doing the preparation for this column can involve working my way through material that would give *anybody* a splitting headache.

Example: "The mathematical chance that more males than females shall be born in a year is shown by theorem to be less than 1 to 2; but to make the argument stronger, it is stated as 1 to 2 for a single year. The chance that the same thing will happen for 82 years in succession is, then, 1 to 2 with the exponent 82, or very slight; and if not only 82 years but 'ages and ages' and not only London but all the world, be included, the chance becomes an infinitely small quantity, at least less than any assignable Fraction."

You try reading John Arbuthnot's statistical study of male-female births in London between 1629 and 1710 and see if it doesn't give you instant catatonia or worse. Fortunately, the good Dr. Arbuthnot (physician to Queen Anne and the person who first said the study of math was good for the moral health of young men) had a lighter aspect to an otherwise harrumph personality. On the side, he wrote a number of satirical pamphlets about British political efforts to achieve peace in Europe, pamphlets that would put the "John Bull" character into the British national consciousness. This spare-time jingoism was part of his creative output associated with membership in an avant-garde London literary society known as the Scriblerus Club. There, once every two weeks, adepts at verbal vitriol (such as Alexander Pope and Jonathan Swift) would send their fellow clubmen into paroxysms with a scatological send-up of some particularly devious politico or other.

One regular Scribleran enjoying the fortnightly fulminations was a hedonist heterosexual named John Gay, who, on January 29, 1728, made his name forever by staging the first night of his *Beggar's Opera*. Talk about boffo. A run of 62 sold-out performances. And the talk of the town. Which is probably why Voltaire's pals (including Pope and Swift) took him to see the show while the famous Frenchman was on a secret visit to London, keeping a low profile after a bit of a dustup back in Paris with a well-connected aristocrat who had had Voltaire mugged for having the temerity to suggest that the two of them duel over some imagined slight. (Well, Voltaire *was* common.) A year later, when the dust had settled, the eminent philosopher went back home to spend the rest of his life being a thorn in the flesh of anybody in power and, not surprisingly, a permanent fugitive from one or another French national chief of police.

See if reading a statistical study of births in London between 1629 and 1710 doesn't give you instant catatonia.

He did, however, manage a few happy and relatively trouble-free years closeted away with the lovely Marquise du Châtelet at her castle in deepest Champagne. During this idyllic sojourn, the brilliant couple (she was knocking off something on Newton's math, and so was he) had the kind of effect you might expect from a better intellectual mousetrap. A path to Voltaire was beaten by everybody who was anybody. Plus one nobody, name of Karl Viktor von Bonstetten, a young German-Swiss nobleman on the grand tour and looking for a bit of enlightenment.

That's not all he was looking for. Shortly thereafter (this was in 1774), he talked himself into what's often referred to as a "leg-over situation" with the unhappy wife of a fat, drunken, pox-ridden, pompous old womanizer living in Italy and calling himself King Charles III of England. Which he wasn't, although he had been a serious contender for the title a few years earlier. Back in 1745, Charles Edward Louis Philip Casimir Stewart had gone down in history as the dashing young Bonnie Prince Charlie, Scottish Pretender to the English Throne. He even got his ragtag Highlander army within a few miles of London, before being let down by the French, who had promised to support his play with massive reinforcements from across the Channel and then chickened out at the last minute. Ironically, the manifesto justifying this Gallic intervention in *les affaires britanniques* had been written by none other than Voltaire.

One of the people who spirited Charlie away one step ahead of the sheriff (after the final and disastrous Battle of Culloden, during which the Pretender lost because his men used broadswords and the redcoats used artillery) was a woman called Flora Macdonald. This intrepid type smuggled him—dressed up as a female—out of the danger zone to the island of Skye and a boat for the Continent. After Flora's inevitable capture and imprisonment by the English, she made her own miraculous escape to the Cape Fear region of North Carolina. Where the only work to be found for many of the Highlanders who also fled there was in the production of naval stores for the British. You roasted the long-leaf pine trees (with which Cape Fear is still well stocked), and they gave up resin. This could then be boiled or distilled into various substances, such

as pitch, tar and turpentine, that would make anything you liked waterproof. This included ships' hulls, ropes and planking, as well as your insides, given that doctors at the time favored the ingestion of turpentine for most respiratory or dermatological conditions. Be that as it may, come 1776, when that whole unfortunate revolutionary thing happened, we Brits lost N.C. (and the rest), and a new source of pitch, tar and turpentine had urgently to be found, or else Britain wasn't going to be ruling any waves any longer.

This was the reason, shortly thereafter, why an impecunious Scottish earl of the name Archibald Cochrane, whose family had backed the wrong king and the wrong horse for several generations, was roasting coal just outside Edinburgh. By this time Cochrane's patrimony was reduced to little more than a few tinpot mines. His idea was that this coal-cooking activity would solve the Royal Navy's pitch, tar and turpentine deficit (and therefore that of Cochrane's bank balance) by producing lots of black stuff from which he'd make lots of green stuff. The day the noble lord turned up in London to offer his amazing new gunk-making process to the navy was, alas, the very same day the Admiralty in London decided to copper-bottom all naval ships. So Cochrane was left with a useless load of sticky muck and would eventually end up dying in poverty in Paris.

So much for the vagaries of history. Cochrane's muck turned out to be coal tar. And we all know what *that* turned out to be. Almost anything you (or a chemist) would care to name: artificial dye stuffs, phenol, antiseptics, creosote, pyridine—I'll stop. Except to add that in 1890 one of the many compounds being discovered in coal tar was just a couple of easy steps from phenol. A German chemist, Felix Hoffmann, working for Bayer, was to derive from phenol a substance called salicylic acid. No distance from there to acetylsalicylic acid. Now, in its natural state, salicylic acid comes from the plant meadowsweet (Latin: *Spiraea ulmaria*). So Hoffmann gave his new wonder drug an acronym: A (for acetyl), SPIR (for *spiraea*) and IN (for a reason nobody knows).

The full acronym (line up the letters) solved my earlier problem with Dr. Arbuthnot. I'm going to lie down now. SA

Wonders, *continued from page 99*

dispelled first by Aristarchus and much later by Copernicus, writing an early golden page of modern science. Now we know that the remote luminaries do not literally rise and set; rather it is the edge of our smoothly turning earth that sets, to disclose the sun at dawn, and rises again at dusk, to hide it.

The television networks still present theater illusionists to large audiences: grand physical feats such as the disappearance of the Statue of Liberty from New York Harbor, for example. We may discount the possibility of a major physical displacement of the Lady, the more since no public dismay is heard from people outside the range of the magician's discourse. The TV-viewing millions share the experience with a casual audience of a few dozen people, enough real witnesses to make collusion implausible. They enter a small harborside theater. What we then see on the TV screen is what they see, too; the video itself—which indeed can easily lie—is here honest. The curtain opens to show a distant view of the glowing colossus across shimmering waters. Then it closes; after a pause, the distant view is opened again. Now no Liberty appears in the watery distance. After a second curtain close, she safely reappears.

A hidden stage mirror can redirect optical sight lines. But in this case no plausibly large mirror can provide the effect far out there across the waters. We offer a Copernican explanation, a transformation not of the external scene but of our own viewpoint. While the curtain was closed, the small theater has been rotated slowly, silently and smoothly, probably under stagehand power. Neither live audience nor TV audience notes any motion within, for the walls and small stage all turn right along with the witnesses seated at their ease. The window frame was simply turned to exclude Liberty. Just as the distant stars do not swing around us on a single crystal sphere every night, Liberty stays fixed as well; it is the witnesses and the camera that rotate all as one.

Your columnists have no insider's knowledge; we only propose this here as the wonderful secret of the TV illusionists. But we admire them intensely for carrying off so enormous, so truly Copernican, an illusion—even if somehow they really do it another way! SA

WORKING KNOWLEDGE

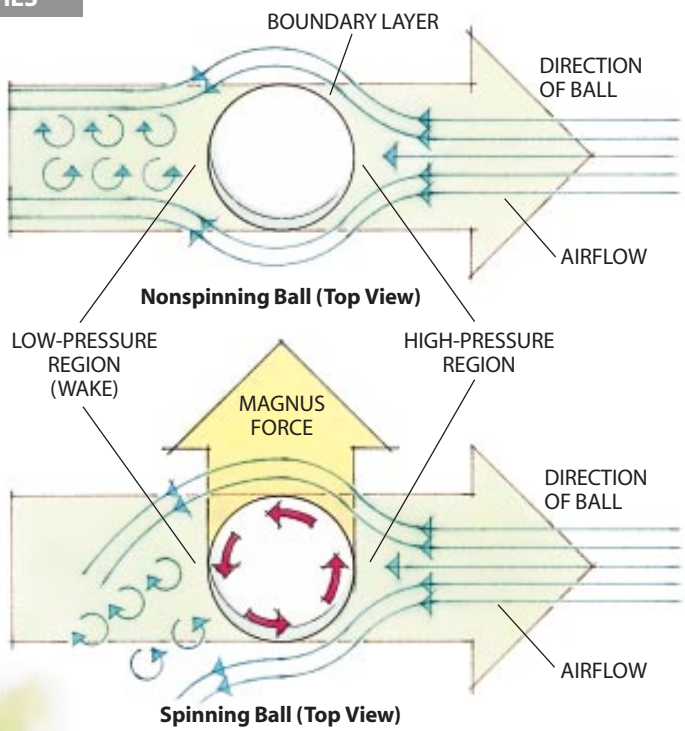
BASEBALL PITCHES

by Alan M. Nathan

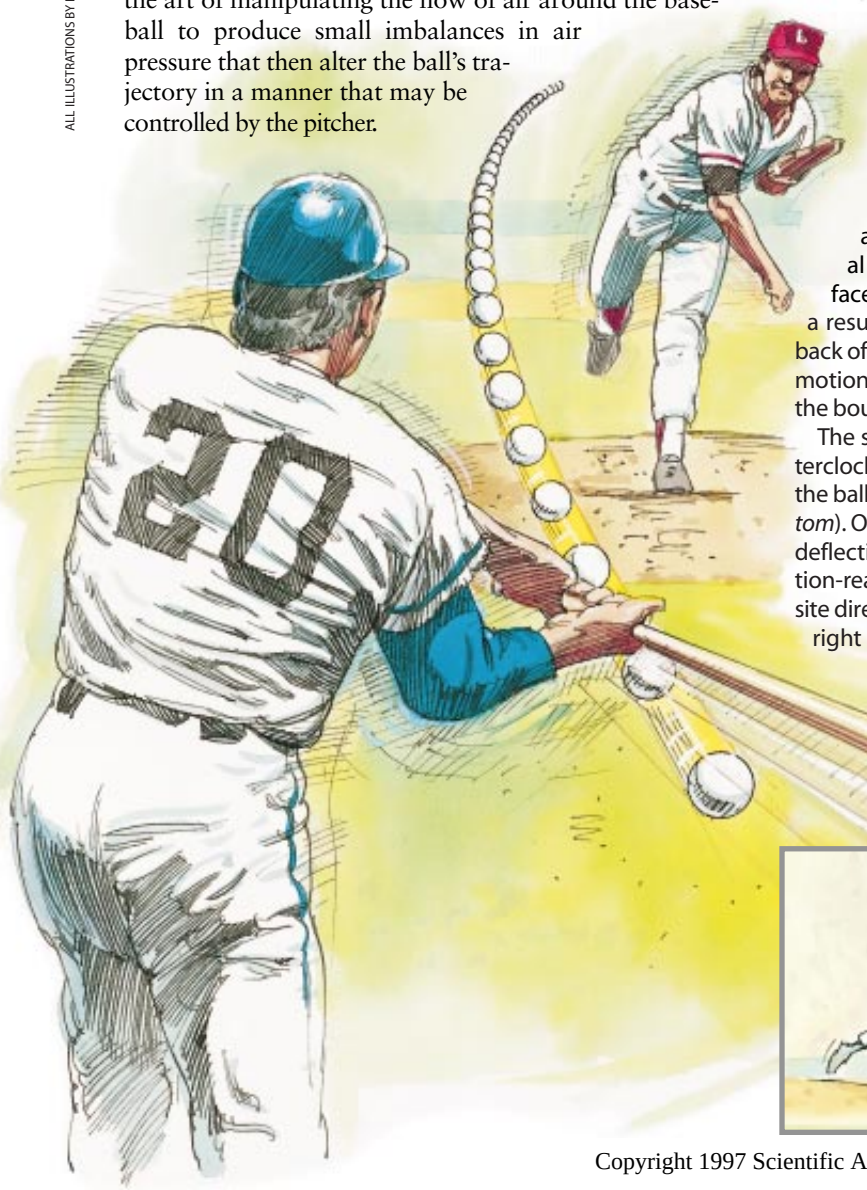
Professor of Physics,
University of Illinois at Urbana-Champaign

"Hitting is timing; pitching is upsetting timing." So said Warren Spahn, possibly the greatest left-handed pitcher of all time. One way that a good pitcher can upset the batter's timing is by altering the trajectory of the baseball in a manner not expected by the batter. If baseball were played in a vacuum, a pitch would be affected only by the downward tug of gravity. The resulting trajectory would be completely predictable, and no experienced batter would be fooled.

But the game runs its course in the often sweltering atmosphere of the summer ballpark. Much of the pitch's subtlety arises from the interaction between the ball and the surrounding air. Indeed, the art of pitching is largely the art of manipulating the flow of air around the baseball to produce small imbalances in air pressure that then alter the ball's trajectory in a manner that may be controlled by the pitcher.

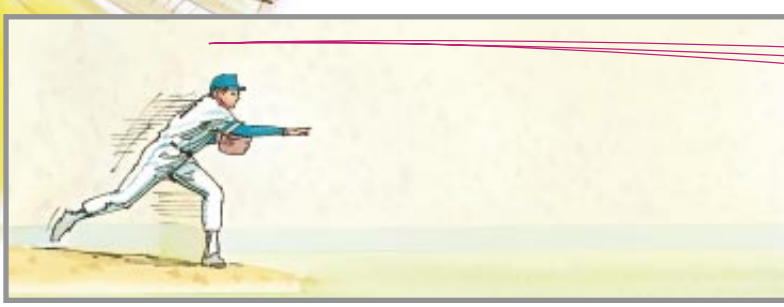


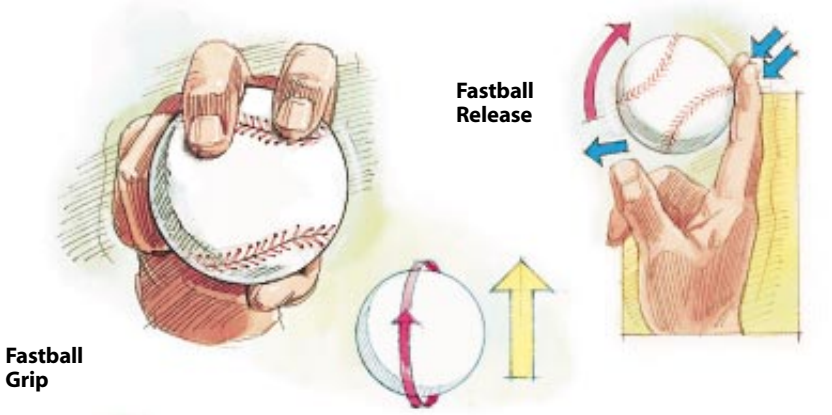
ALL ILLUSTRATIONS BY BARRY ROSS



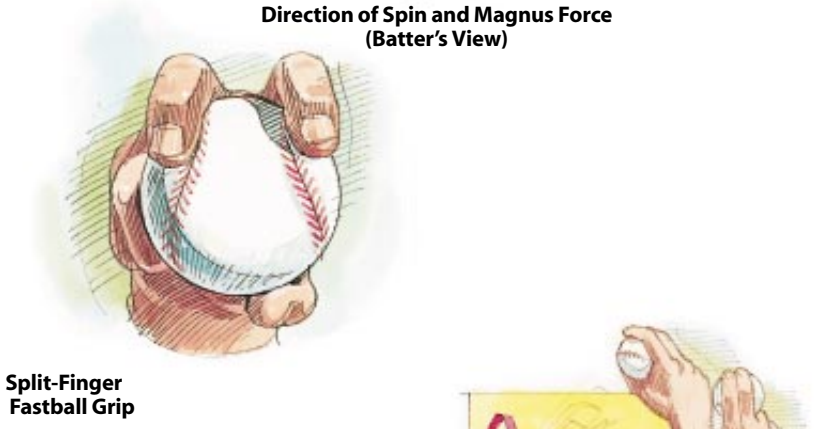
AERODYNAMICS OF A PITCH As a baseball moves, it disrupts the flow of air in its vicinity. The air follows a streamlined path partway around the ball, forming a thin "boundary layer" that adheres to the surface. Yet both the shape of the ball and frictional forces conspire to cause the boundary layer to peel off the surface, leaving behind a swirling low-pressure wake (*above at top*). As a result, the delicate balance between air pressure on the front and back of the ball is disrupted, giving rise to a drag force that opposes the motion of the ball. The faster the air is flowing, the farther to the front the boundary layer begins to separate, resulting in greater drag.

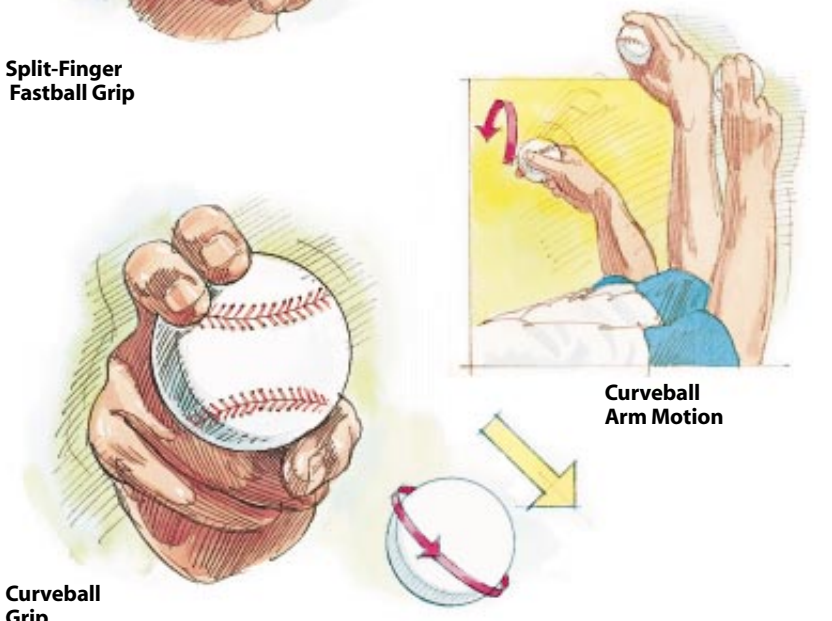
The spin of a ball must also be considered. For a ball spinning counterclockwise (viewed from above), the flow of air past the right side of the ball (relative to a pitcher) is faster than on the left side (*above at bottom*). On the faster side, the boundary layer separates farther upstream, deflecting the trailing wake toward the right side. Newton's law of action-reaction tells us that the air exerts a force on the ball in the opposite direction—from the batter's perspective, the ball breaks from left to right (*left*). This so-called Magnus force is responsible for the "hop" of the rising fastball and for the break in the curveball and slider. The Magnus force grows as rotation increases; the ball always breaks in the direction toward which the front of the ball is turning.



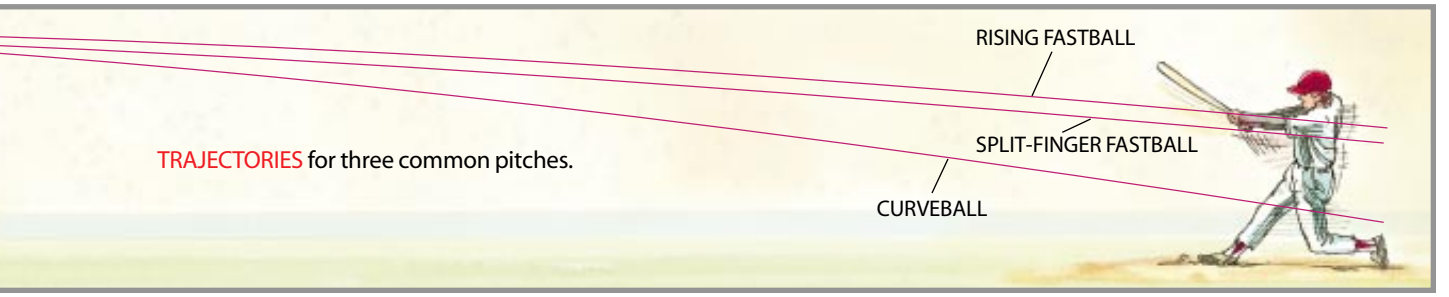


FASTBALL The natural way to throw a fastball is with backspin, which is induced by friction between the fingers and the ball and its stitches. Because of the backspin, the Magnus force opposes gravity, leading to what is erroneously called a rising fastball. Gravity alone would make a 90-mile-per-hour fastball fall about three feet between the pitcher's mound and home plate. With a typical spin of 1,600 revolutions per minute, the Magnus force is only about 20 percent of gravity, so the ball drops only about 2.4 feet. (For the fastball to rise, the Magnus force would have to exceed gravity, an unlikely occurrence, although a fastball that drops less than expected may appear to hop.) A clever pitcher can make the batter's job difficult by varying the rotational velocity to control the amount by which the ball drops. A popular variation is the split-finger fastball, which is thrown by gripping the ball with the fingers far apart, thereby reducing the natural tendency to put backspin on the ball. With very little spin at all and somewhat slower speed, the ball drops about six to 12 inches more than a normal fastball. If the batter's eye does not pick up the reduced spin, he is fooled into thinking the ball will cross the plate higher than it actually does, and his swing goes over the ball.





CURVEBALL The curveball is thrown with greater spin than the fastball, up to 1,900 revolutions per minute, thereby producing a larger Magnus force. It is also thrown at a slower speed, usually at about 70 to 75 miles per hour, giving the Magnus force a longer time to act and resulting in a larger deflection. Typically the rotation has both sidespin and topspin, so that the ball breaks both to the side and down by as much as 15 inches. Making matters worse for the batter, half of the deflection occurs over the last 15 feet of the 60-foot, six-inch journey to home plate, giving rise to the illusion that the ball "falls off the table." A variation is the slider, which is thrown a bit faster and with more sidespin than topspin.



TRAJECTORIES for three common pitches.