NEW TWISTS ON DNA • 100 YEARS AFTER THE WRIGHT BROTHERS

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Science Has the Answer:

DOES RACE EXIST?

Genetic Results May Surprise You

The Day **the Earth Burned**

Reasons to **Return to the Moon**

december 2003

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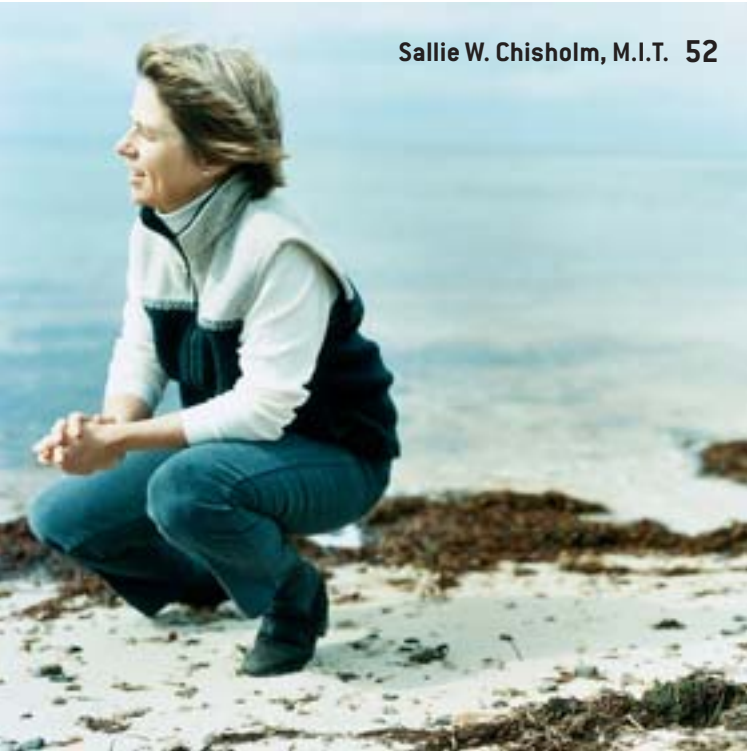

Sallie W. Chisholm, M.I.T. **52**

columns

Cover photoillustration and page 7: Nancy Burson; this page, at left: Kathleen Dooher.

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Racing to Conclusions

In October, California voters did something that will have long-term ramifications for their state. No, we're not talking about the election of actor Arnold Schwarzenegger, but the rejection of Proposition 54, which would have voided requirements for government-affiliated programs to record the race of participants. Medical groups and physicians had claimed that the measure would have blocked doctors from tracking and treating diseases that afflict various racial groups differently. C. Everett Koop, former U.S. surgeon general, even described the vote as a "life-and-death decision" in a television ad.

IS RACE linked to health?

The article by Michael J. Bamshad and Steve E. Olson in this month's issue ["Does Race Exist?" on page 78] calls into question Koop's dire assertion. Commonly used racial and ethnic categories (such as "African-American," "white" and "Hispanic") are often meaningless when it comes to determining a person's DNA makeup. Genetics *can* be used to sort most people roughly into categories according to the geographic region where they were born, but populations that are the result of recent migrations and that have had a great deal of intermixing—such as those in South India and the U.S.—cannot be neatly parsed. Self-described African-Americans, for example, can have anywhere between 20 and 100 percent genetic heritage from Africa, whereas 30 percent of Americans who consider themselves "white" have less than 90 percent European ancestry.

Yet self-described race is being used as a surrogate for genetic differences in research. The U.S. Food and Drug Administration has issued a draft "Guidance for Industry" suggesting that pharmaceutical and biotechnology companies collect data on the race of volunteers in clinical trials to test the safety and efficacy of new treatments. The document recommends that companies ask study participants to identify their race according to the categories used by the U.S. Census.

The FDA's proposed guidelines have elicited outcries from many interested parties, including J. Craig Venter of the Center for the Advancement of Genomics in Rockville, Md. Venter—whose previous company, Celera, issued the first rough sequence of the human genome—wants the FDA to scrap the proposed guidelines and to advise companies instead to collect genetic information from each individual in a clinical trial. Using self-identified race as a surrogate for testing a person directly for a relevant trait is akin to recording the average weight of a group rather than weighing each individual, Venter and his colleague Susanne B. Haga write in the July 25 issue of *Science*.

The complicating factor, of course, is money. Companies assert that genetic testing costs too much right now to be feasible as part of every clinical trial. And it is clear that racial differences in health exist: a disproportionate number of African-American men develop prostate cancer, for example, whereas white women are more prone than black women to breast cancer. The question is whether those variations can be attributed largely to genetics or to continuing race-based disparities in income, education or other factors.

Until the advent of a truly egalitarian society, race will always be a proxy for deeper differences among groups. But the importance of racial identity should not be overinterpreted in clinical trials—particularly when those racial descriptors turn out to be such poor reflections of a person's genetic heritage. The bottom line is: when you read or hear about a new health finding based on race, question it.

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On the Web

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FEATURED THIS MONTH

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Rejection a Real Pain, Brain Study Shows

It seems the old adage about sticks and stones and hurtful words may need revision. Social rejection, researchers report, elicits a brain response similar to the one triggered by physical pain. Subjects snubbed in a virtual game of catch exhibited activity in a brain region called the anterior cingulate cortex, which also plays a role in pain processing.

Electronic Paper Speeds Up for Videos

Someday soon videos may be showing on paper instead of screens. Scientists have created a kind of electronic paper that can switch rapidly from one color to another, giving it the ability to display moving images. A number of research groups hope to develop electronic ink, but so far the screens cannot switch from one image to the next quickly enough for video. In the new work, engineers cleared this hurdle by utilizing a process known as electrowetting.

Ask the Experts

Why does moving one's hands in front of an antenna influence television and radio reception?
David Hysell, an associate professor of earth and atmospheric sciences at Cornell University, explains.

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Letters

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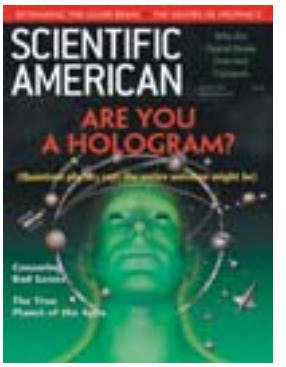
WE'LL ADMIT IT. Theoretical physics is not for everyone. "I have never before read anything so full of 'scientific' balderdash, gobbledygook and obscure theories," groused Wil Short of Boise, Idaho, about Jacob D. Bekenstein's "Information in the Holographic Universe." Fortunately, hundreds of letter writers offered different intriguing impressions of the August issue cover story. Still others praised the multidisciplinary approach of "Questioning the Delphic Oracle," by John R. Hale, Jelle Zeilinga de Boer, Jeffrey P. Chanton and Henry A. Spiller, which professed that petrochemical vapors gave the ancient Greek prophesiers their visions. From physics to fumes, a sampling of our readers' august perspicacity fills the following pages.



UNIVERSAL QUESTIONS

Jacob D. Bekenstein's "Information in the Holographic Universe" contains an odd statement: "Our innate perception that the world is three-dimensional could be an extraordinary illusion." But our visual perception of three-dimensional space is constructed by the brain from light falling on the two-dimensional surface of the retina. Contributing to the 3-D "illusion" are our senses of touch, kinesthesia (the system that relies on feedback from muscles) and hearing. If Bekenstein's assertion is correct, it is hard to understand why evolutionary adaptation would have taken such a complex route to generate this illusion of three dimensions when a more accurate perception of reality might have served us better.

Kellogg Wilson
via e-mail

In an optical hologram, information about the entire image is contained in each part of the hologram, so if it were broken up, the whole image could still be seen in each piece. Would the same concept hold for the universe hologram? Would a piece of matter in one part of the world contain information about matter on the other side of the world—or even about the distant stars—if only we knew how to view it?

Dale Rabinovitz
Twinsburg, Ohio

How does the holographic view affect the big bang description of the origin of the universe? The big bang implies that the universe started from a point object. This would seem to be impossible if the information content of the universe is constant. If this logic is correct, I would be interested in the smallest size that the universe could be and a description of this smallest universe.

Larry Jordan
via e-mail

BEKENSTEIN REPLIES: *Wilson may be right that cerebral processing of ocular and tactile signals is responsible for our sensing a three-dimensional space and that it would have been evolutionarily "cheaper" for our brains to have a different structure if the world really were two-dimensional. Clearly, three dimensions are convenient for describing experimental facts and for expressing the familiar laws of physics that explain those facts. Nevertheless, the holographic principle could be true: the ultimate, fundamental physical laws could operate in a world with a two-dimensional geometry. Sensory physiology and psychology are even more removed from fundamental reality than are the effective laws of physics we use today. We cannot draw conclusions about the ultimate nature of reality from the fact that we literally perceive three dimensions.*

Rabinovitz is correct that an everyday optical hologram contains an entire image (albeit with impaired resolution) in every small section of itself. The holographic principle of particle physics and cosmology does not work that way. To describe the whole universe, we need the whole hologram. The holo-

graphic description is exact. The key "holographic" property is that the description takes fewer dimensions than would seem necessary from the kinds of physical measurements we can make today.

As Jordan's question suggests, the original form of the holographic bound does encounter problems in the early stages of the big bang. Similar problems arise whenever the gravitational field is strong and the system is evolving extremely rapidly. In 1999 these inconsistencies led Raphael Bousso, then at Stanford University, to formulate his version of the holographic bound, in which the entropy is tallied by imaginary beams of light rays. The Bousso holographic bound is consistent with the big bang picture, even the very early stages.

DANGEROUS PROPHECY

"Questioning the Delphic Oracle," by John R. Hale, Jelle Zeilinga de Boer, Jeffrey P. Chanton and Henry A. Spiller, says: "Extraordinarily for misogynist Greece, the Pythia was a woman." I don't see what's so extraordinary. As the article describes it, the Pythia held a dangerous job. The women were occasionally forced into service, and they breathed intoxicating gases that sometimes killed them. Is it really so unusual that a misogynist culture would relegate this task to women of no social standing?

Miguel Muñoz
Los Angeles

A fascinating article. But given all the ethane, methane or ethylene floating around, how is it that the ancient Greeks didn't blow themselves up when they brought in their oil lamps?

Bill Sandidge
Atlanta

Although we share the authors' enthusiasm, we disagree with their contention that the inhalation of ethylene explains the experiences of the Pythias in the underground oracular chamber. The gas is explosive in air! Also, the authors ignore contemporaneous accounts indicating that the "possession" of the Pythias was produced by smoking or ingesting the leaves of the *Laurus nobilis* (laurel or bay leaf), which was sacred to Apollo.

We acknowledge that ethylene in low subexplosive (and subintoxicating) concentrations was very likely present in the chamber but suggest that it may have been significant for its effect on plants rather than its effect on people. Ethylene affects the growth of plants and is produced naturally by many plants to influence plant maturation. We wonder if the plant became sacred to those who tended Apollo's Delphic temple because the trace quantities of ethylene present helped to keep fresh the laurel sprigs carried by the Pythias when they went to work.

Tom Poulton
Omaha, Neb.
Mike Poulton
Lincoln, Neb.

BRIDGEMAN ART LIBRARY

SCIENTISTS NOW STUDY **the oracles that were once consulted by kings.**

I take exception to the last paragraph of this otherwise valuable article. I cannot see that the ancient Greeks could have exhibited a "broad-minded and interdisciplinary attitude" as we understand such to be today. They were convinced of the truth of their religious beliefs and sought to explain the natural phenomena they perceived in terms of those beliefs.

Ken Herrick
Oakland, Calif.

HALE REPLIES: *In answer to Sandidge's letter, we believe that the concentrations of hydrocarbon gas in the oracular shrine at Delphi must have been high enough to trigger a trance state yet low enough to avoid combustion. Oracular sessions were held in the morning, and there are no ancient references to lamps or torches. One side of the Pythia's adytum was open, so she could see and respond to questioners. If the Pythia followed procedures that were standard elsewhere, then the oracular session may have been preceded by three days of fasting, thus heightening her susceptibility to low levels of ethylene.*

Once modern scholars had rejected the ancient testimony concerning Delphi's fissure and gaseous emission, alternative explanations for the Pythia's trance rushed in to fill the void. The Poultons refer to two of these, namely, the smoking or ingestion of laurel. Through frequent repetition in popular literature, these explanations are now widely accepted as fact. The description of the Pythia chewing laurel, or bay leaves, however, comes not from eyewitnesses but from hostile satirists and early Christians who were attacking the oracle. As for the "smoke" theory, it rests only on Plutarch's comment that before going down to the shrine, the Pythia made a burnt offering of simple bay leaves and barley flour rather than expensive laudanum or frankincense. If leaves triggered her trance, then the Pythia should have been able to prophesy anywhere, not just in the sunken adytum of the temple.

Contrary to the current popular belief expressed by Herrick, the Greeks were not uniformly dogmatic or superstitious. As early as the fifth century B.C., the spectrum of belief covered a range similar to that of our own time. At one extreme were scientific researchers such as Anaxagoras and Aristotle,

who sought to observe and explain nature independently of the gods. At the other were religious fundamentalists. Midway between were devout rationalists such as Plutarch. Though serving as a priest of Apollo, Plutarch tried to reconcile science and religion by positing a natural world with its own laws and properties that could be used by the gods for their purposes. For example, this line of thinking might suggest that Apollo used the natural exhalation at Delphi to stimulate the oracle.

BRAINS ON THE MIND

"Rethinking the 'Lesser Brain,'" by James M. Bower and Lawrence M. Parsons, is an excellent overview of the new and evolving science of the cerebellum. A number of recent studies suggest that the cerebellum's role is to expedite the automating of motor and cognitive skills. If certain skills become automatic, the cerebral cortex can spend more time thinking, acquiring new skills, or refining and improving existing skills. Maybe dysfunction or absence of the cerebellum slows down the automating process to a point where it may take much longer to develop or where it may never be achieved. Either circumstance could take a toll on cerebral performance, affecting connections between the senses and physical functions as well as the ability to organize, create, and complete thoughts and tasks. This certainly seems to be the case for the cognitive and motor functioning of patients who have cerebellar dysfunctions.

D. R. Rutherford
Sheffield, England

While reading the article, I was struck by the idea that the cerebellum is basically analogous to an input-output buffer in electronics. Electronics data acquisition equipment most often has some kind of signal-handling buffer. It allows the acquisition equipment to gather simultaneous inputs and to "precondition" the information so the main system can handle it more easily. Many of the findings from recent studies would imply this same kind of functionality for the cerebellum.

Kevin Stokes
Jasper, Ind.

CALCULATING DISASTER

In Perspectives ["Houston, You Have a Problem"], the editors note that the piece of foam insulation indicted in the shuttle disaster "slammed into the … wing at more than 500 miles an hour." When the foam piece separated from the rocket, it was traveling at the same speed as the shuttle. I presume that at one minute and 21 seconds into the flight, the rocket is in pretty thin air and the distance from the breakaway point to the shuttle wing is on the order of tens of feet. How could the relative speeds of the foam and the shuttle diminish by 500 mph so quickly?

Tom Sahagian
via e-mail

THE EDITORS REPLY: The air was thin but not nonexistent. The shuttle had reached an altitude of just over 20 kilometers, where the air density is roughly 8 percent of its sea-level value. Once the foam separated, the airflow blew it back. A simple drag calculation shows that the foam initially accelerated at approximately 3,000 meters per second per second relative to the shuttle. At that rate, it would have reached a relative velocity of more than 300 meters per second in the 0.1 second it took to fall 20 meters. In practice, the foam decelerated as it was swept up in the flow, so it hit the wing at 240 meters per second (540 mph)—which matches what the launch cameras saw. The analysis appears in section 3.4 of the Columbia Accident Investigation Board report and accompanying documents (such as www.caib.us/news/documents/impact_velocity.pdf).

ERRATUM In "Information in the Holographic Universe," by Jacob D. Bekenstein, the William Blake quotation should have read "see a world in a grain of sand," not "see the world in a grain of sand."

50, 100 & 150 Years Ago

FROM SCIENTIFIC AMERICAN

Cosmic Hydrogen ▪ Wright Airplane ▪ Canine Labor

DECEMBER 1953

RADIO TELESCOPES—"The young science of radio astronomy began with investigators simply picking up 'noise' from the sky. But about a year and a half ago a single significant note was discerned through the din. Today listening posts all over the world are tuning in on this high-pitched monotone at 1420 megacycles, and from it they are obtaining a new picture of the universe. The signal carries information about the hydrogen floating in space. One of the first puzzles the new hydrogen telescopes [*see illustration*] are seeking to unravel is the manner in which our galaxy is rotating. Jan H. Oort, H. C. van de Hulst and C. A. Muller have already discerned a spiral arm structure of hydrogen clouds in the Milky Way system."

MODERN MIND—"Is modern life driving many people insane? One way to get at the question is to examine the mental health of a secure, stable society. The Hutterites, an isolated Anabaptist religious sect of the North American Middle West, provide an ideal social laboratory of this kind, and they cooperated generously in the interest of science. We did not find a single Hutterite in a mental hospital. But this appearance of unusual mental health did not stand the test of an intensive screening of the inhabitants. In short, the Hutterite culture provided no immunity to mental disorders. The existence of these illnesses in so secure and stable a social order suggests that there may be genetic, organic or constitutional predispositions to psychosis which will cause breakdowns among individuals in any society, no matter how protective and well integrated. —Joseph W. Eaton and Robert J. Weil"

NEW RADIO TELESCOPE helps to chart the cosmos, 1953

DECEMBER 1903

PLANE FLIGHT—"On December 17, Messrs. Orville and Wilbur Wright made some successful experiments at Kitty Hawk, N.C., with an aeroplane propelled by a 16-horsepower, four-cylinder, gasoline motor, and weighing complete more than 700 pounds. The aeroplane was started from the top of a 100-foot sand dune. After it was pushed off, it at first glided downward near the surface of the incline. Then, as the propellers gained speed, the aeroplane rose steadily in the air to a height of about 60 feet, after which it was driven a distance of some three miles against a twenty-mile-an-hour wind at a speed of about eight miles an hour. Mr. Wilbur Wright was able to land on a spot he selected, without hurt to himself or the machine. This is a decided step in advance in aerial navigation with aeroplanes." [*Editors' note: The description of the takeoff and flight contains several inaccuracies and probably came from secondary sources.* *See "The Equivocal Success of the Wright Brothers," on page 94.*]

DECEMBER 1853

STEAMSHIP COMMERCE—"On the Pacific side of South America, steamships are making good progress in the affections of the people. The Chilian Congress has lately adopted, with only one opposing vote, a project of the Government establishing a line of steamers between their coast and Europe. The proposal is to make an appropriation in aid of a line of vessels, 'with an auxiliary steam engine,' which is to be established between Caldera and Liverpool, touching at Valparaiso, in the Straits of Magellan, and at Rio Janeiro; one vessel to sail every six weeks, and never to be over 70 days in passage. The company is made up entirely of people from the United States."

SCIENTIST'S BEST FRIEND—"Mr. E. Merriam, of Brooklyn Heights, N.Y., has made meteorological records from three instruments, every hour, day and night, for eight years, many of which have been published in the 'Scientific American.' When inquired, 'But, sir, how do you manage to keep your record through the night hours?' The reply was, 'I retire regularly, my dog is stationed in the entry by the clock, and at its striking immediately scratches at the door. I rise, make the record, and in a few minutes am regularly asleep again until the dog gives notice of the expiration of another hour.' We saw the intelligent animal—and also the evidence of his labor performed on the door of the sleeping room of his master."

Breath Takers

A quixotic career-long quest to diagnose disease simply by exhaling By GARY STIX

In 1971 Linus Pauling published a paper in which he analyzed the constituents of human breath. His study showed that an exhalation contained about 200 different compounds, many more than had been previously suspected. In the mid-1970s Michael Phillips, at the time a thirtysomething physician from Western Australia working on his fellowship at the University of California at San Francisco, read the paper with fascination. Phillips was looking for a field of research to which he could devote himself. "Pauling opened up a new area of science," he says. "I thought: if all of these compounds are there, they must be signaling something. This grabbed my attention, and I've pursued it since."

About a quarter of a century later, Phillips received preliminary approval from the U.S. Food and Drug Administration for a device that samples the breath of heart transplant patients for organ rejection in the first year after the operation, a supplement to regular biopsies. He hopes that last year's assent will soon be followed by endorsement from the agency to charge for the procedure. Checking breath would be potentially faster, simpler, cheaper and less invasive than biopsies or other procedures used to detect disease. Phillips's tiny company, Menssana Research, is considering development of breath analyses for ailments ranging from lung cancer to markers of biological aging. At the same time, he continues to battle deep-seated skepticism in the scientific community about the validity of Menssana's approach to creating a diagnostic breath sniffer.

DIAGNOSTIC PUFF MACHINE: Menssana Research chief executive Michael Phillips poses with an apparatus that collects breath that is then analyzed for the presence of a condition such as lung cancer or heart transplant rejection.

NAJLAH FEANNY

The idea of making a diagnosis by examining breath is as old as medicine. Hippocrates observed that the aroma of a patient's exhalation could provide clues to disease. Today testing is done routinely to discern a compound such as alcohol or the breakdown product of a substance fed to a patient, which can confirm the presence of, say, the bacterium *Helicobacter pylori,* implicated in ulcers and other diseases.

In contrast, Phillips, like Pauling, attempts to measure more than a single compound. Formed in the 1990s, Fort Lee, N.J.–based Menssana looks at an entire spectrum of organic chemicals, elevated or diminished levels of which could serve as an indicator of disease. Early work proceeded by first freezing these volatile organic compounds using liquid nitrogen and then identifying the individual components with a gas chromatograph. But the collection device could be used only once, because an ice plug formed in the tube into which the subject blew.

When Phillips set up a laboratory at Bayley Seton Hospital on Staten Island in the late 1980s, he received a small grant that allowed him to adopt a different technical approach. He used an activated-charcoal adsorbent trap to capture volatile organics and a thermal desorber to bake off and concentrate the breath constituents—all equipment that was developed for conducting environmental tests. The chemicals are separated by a gas chro-

matograph and identified using a mass spectrometer. A statistical analysis then searches for a particular "fingerprint" of volatile organics that differs from that of a healthy individual and characterizes, for example, heart transplant rejection or the presence of a lung tumor. The theoretical basis for the breath tests stems from the increase in molecules with unpaired electrons called free radicals that are present in many disease conditions. Free radicals cause damage to certain lipid tissues, which results in higher production of a number of volatile organics.

Phillips, also a clinical professor of medicine at New York Medical College, is widely credited for bringing some recognition to the nascent field of breath testing in a *Scientific American* article that is still cited today, even

Continued on next page

by detractors [see "Breath Tests in Medicine," by Michael Phillips; Scientific American, July 1992]. But he has at times taken an especially risk-laden approach to developing such diagnostics. One of the initial experiments performed during the early 1990s attempted to assess whether a breath analysis machine could diagnose schizophrenia by detecting high levels of pentane and another organic molecule, a finding that seemed to confirm the work of Russian researchers, who had seen a rise in the hydrocarbon pentane during the course of the disease. Phillips acknowledges that schizophrenia, whose biology is not well understood, was a poor first choice. "Looking back on it, it was not a smart move,"

JUST BLOW: Michael Phillips demonstrates the use of Menssana's breath trap.

he says. The 1993 paper based on the research was eventually published in the *Journal of Clinical Pathology* after numerous rejections and criticism.

"It's been a long slog," Phillips comments, adding, "I could paper the walls with the number of my grant applications turned down." One of the main objections from investigators in the small breath-testing community has to do with the organic molecules, called alkanes, measured by the company's assays. Critics contend that a particular fingerprint of alkanes—and alkane derivatives—may not be a product of a sick person's metabolism but rather turns up because of exposure to hydrocarbons from environmental sources, perhaps absorbed from passing vehicles. Phillips and his Menssana colleagues Joel Greenberg, Renee N. Cataneo and Irfan Munawar have tried to compensate for this problem. Samples are drawn from both the patient's breath and the room air. Then the measurements of substances found in the room's air are subtracted. What is left, they contend, should be constituents that result from metabolic processes.

But even this step does not satisfy doubters. Residues of hydrocarbons may persist in body fat for days. So merely taking room air out of the calculation may not suffice. Moreover, the amount of the specified alkanes being detected is so vanishingly small that other researchers question whether the disparity between the breath profile of a diseased and a healthy individual may be nothing more than a statistical fluke. "I don't want someone to come out with a test only to have it be measuring artifacts. That would hurt the field," says Terence H. Risby, a professor of environmental sciences at Johns Hopkins University who is developing breath tests using another method. Sydney Gordon of Battelle Memorial Institute in Columbus, Ohio, believes that if detection issues can be overcome, a more fruitful approach would be to look for nitrogen-, sulfur- or oxygen-based compounds, which might give a clearer signal. In addition, skeptics contend that Menssana's work has yet to be replicated by other laboratories.

Phillips remains a diehard optimist. And he has a response for any debating point. Clinical trials for heart transplant rejection and lung cancer tests show a statistically significant difference in alkane-related levels in the breath of patients with and without the conditions, he emphasizes. Both groups, he argues, have an equal likelihood of being exposed to car exhaust and other environmental contaminants, so the influence of external pollutants should not be a confounding factor.

No matter where these academic discussions go, the company will have to move quickly. It has survived for years on small-business grants from the National Institutes of Health. It has no venture capital. And the transplant rejection tests will probably not produce much revenue. Physicians are comfortable doing standard biopsies and, unless a biopsy is extremely difficult to perform, may be reluctant to utilize the novel breath exams.

Menssana has a clinical trial under way for lung cancer detection, and it has done a pilot study on breast cancer, research inspired by Phillips's wife, a breast-cancer survivor. In the longer term, Phillips contemplates tests for angina and environmental toxins. But it could be a while, if ever, before his vision for the future of this technology is realized: a Tricorder-like device reminiscent of *Star Trek* that lets a patient exhale into it before diagnosing any of a range of diseases. SA

NAJLAH FEANNY

POLICY

Science v. Law

A DECADE-OLD RULE ON SCIENTIFIC EVIDENCE COMES UNDER FIRE **BY PEG BRICKLEY**

The latest climate change to capture the attention of environmental scientists is taking place not in the atmosphere but in the nation's courtrooms. There science is getting a chilly reception, argue researchers with the Project on Scientific Knowledge and Public Policy (SKAPP). They suspect that a 1993 ruling in *Daubert v. Merrell Dow Pharmaceuticals* is keeping reliable research out of legal proceedings and preventing certain science-based lawsuits from moving forward.

The Daubert ruling was supposed to help judges in their role as evidence gatekeepers. Determining when science is good enough to be admitted is no easy job, remarks Judge Pamela A. Rymer of the U.S. Court of Appeals for the Ninth Circuit, sitting in Pasadena, Calif. Rymer chairs the advisory committee for an American Association for the Advancement of Science (AAAS) pilot project that offers independent science experts to judges. "In some cases where the science and technology issues are especially complex, the gatekeeper can benefit from an independent expert," Rymer explains. "The judge has to make the call, but the scientist can serve as a sounding board."

DAUBERT RULING makes judges evaluate science, usually in environmental lawsuits.

STEPHEN SPERA (REPRESENTED BY AD FINEM)

The AAAS project is one approach to the problem the high court tackled in Daubert: How can judges evaluate technical data that are intimidating to most nonscientists? When the U.S. Supreme Court ruled on Daubert, some observers feared that in opening the courtroom doors more widely, the decision would invite "junk science" as well, confusing juries with unsupported, thinly researched theories. But a 2001 study by the Rand Institute for Civil Justice concluded that judges threw out more scientific evidence and testimonies after the decision than before. The biggest spike occurred between July 1996 and June 1997, when the rate at which science evidence was excluded rose to 70 percent, from about 51 percent pre-Daubert.

The rise in inadmissible science has SKAPP

worried, particularly because a defeat on Daubert grounds often means a lawsuit is over. "Anecdotally, we have collected reports that Daubert is having a negative impact on the ability of individuals to get justice," says SKAPP member David M. Michaels, an epidemiologist at George Washington University. "We hope to design studies to find out if that's true." SKAPP's analyses will attempt to capture psychological and economic data, because those forces drive decisions to admit or exclude scientific evidence as much as legal and scientific principles.

Daubert's defenders say the rule saves courts and society time and money. Among them is Christopher C. Horner, an attorney with the Competitive Enterprise Institute, a Washington, D.C., think tank. He points to decisions such as one in June by a federal appeals court in Pennsylvania that upheld a trial court decision. That ruling barred a scientist from testifying in the case of a dry-cleaning worker who had been exposed to perchloroethylene over two years of employment, developed leukemia and wanted to present expert evidence that the chemical had caused her disease. The trial judge, however, knocked the offered expert out for failing to explain adequately the methods he used to draw his conclusions. Such instances, Horner says, demonstrate Daubert's power to head off unworthy lawsuits: "Daubert is a good decision that is yielding very good results."

Daubert contests can consume as much time, money and energy as the trial itself, challenging the skills of lawyers, the patience of judges and the pocketbooks of litigants. A Daubert challenge would most likely mean an expensive, arduous pretrial event; as a result, the challenge swings legal economics away from cases where the science is new, Michaels argues. Unless potential damages top $1 million, some trial lawyers say, the risk of hiring a battery of experts to push the science past a Daubert challenge is not worthwhile.

To SKAPP members, Daubert in action lets lawyers transform what should be a scientific inquiry into a test of the willingness to spend money. In cases involving environmental science, the deepest pockets usually belong to defendants—industries accused of exposing people to toxic chemicals, notes Sheldon Rampton, a journalist who criticized industry-funded scientific witnesses in a 2001 book, *Trust Us, We're Experts!,* written with John Stauber. "The whole argument about junk science was developed by the tobacco industry for the purpose of defending itself against lawsuits, and it has been taken up since then by everyone in industry," Rampton says.

Ironically, science may be its own worst enemy when it comes to Daubert, Michaels observes. Scientists love to keep questioning things, and that inquisitiveness makes judges nervous. "You can manufacture uncertainty because scientists don't always agree," he explains. "Lawyers take differences among scientists and magnify them, and as long as there is any sort of disagreement, the case does not move forward." Rampton argues that good science deserves its day in court but that it does not need a rule to make it so: "Juries are as able to separate spurious science from the real thing as judges or attorneys are."

Peg Brickley is based in Philadelphia.

SETTING THE STAGE

In *Daubert v. Merrell Dow Pharmaceuticals,* parents sued the maker of the morning-sickness drug Bendectin, arguing that it caused birth defects. Merrell Dow (bought by Hoechst AG in 1995) had already voluntarily withdrawn the drug, although the company claimed that standard tests showed that Bendectin posed no danger to human fetuses. Experts for the parents wanted the court to consider newer ways of evaluating the drug. The scientist-witnesses who were called worked either for the parents or for the defendants; not surprisingly, they heartily disagreed with one another.

Lower courts decided against the parents, citing the old rule that only "generally accepted" science can enter the courtroom. But the Supreme Court took up the case and concluded in June 1993 that trial judges should weigh a range of factors in deciding whether to hear new scientific ideas, rather than just determining which of two conflicting theories is most widely accepted.

ARCHAEO-ASTRONOMY

Circles for Space

GERMAN "STONEHENGE" MARKS OLDEST OBSERVATORY **BY MADHUSREE MUKERJEE**

STATE DEPARTMENT FOR ARCHAEOLOGY OF SAXONY-ANHALT; RALF SCHWARZ

A vast, shadowy circle sits in a flat wheat field near Goseck, Germany. No, it is not a pattern made by tipsy graduate students. The circle represents the remains of the world's oldest observatory, dating back 7,000 years. Coupled with an etched disk recovered last year, the observatory suggests that Neolithic and Bronze Age people measured the heavens far earlier and more accurately than scientists had imagined.

Archaeologists reported the Goseck circle's identity and age this past August. First spotted by airplane, the circle is 75 meters wide. Originally, it consisted of four concentric circles—a mound, a ditch and two wooden palisades about the height of a person—in

which stood three sets of gates facing southeast, southwest and north, respectively. On the winter solstice, someone at the center of the circles would see the sun rise and set through the southern gates.

Although aerial surveys have demarcated 200-odd similar circles scattered across Europe, the Goseck structure is the oldest and best preserved of the 20 excavated thus far, and it is the first circle whose function is evident. Though called the German Stonehenge, it precedes Stonehenge by at least two millennia. The linear designs on pottery shards found within the compound suggest that the observatory was built in 4900 B.C.

Perhaps the observatory's most curious aspect is that the roughly 100-degree span between the solstice gates corresponds with an angle on a bronze disk unearthed on a hilltop 25 kilometers away, near the town of Nebra. The Nebra disk, measuring 32 centimeters in diameter, dates from 1600 B.C. and is the oldest realistic representation of the cosmos yet found. It depicts a crescent moon, a circle that was probably the full moon, a cluster of seven stars interpreted to represent the Pleiades, scattered other stars and three arcs, all picked out in gold leaf from a background rendered violet-blue—apparently by applying rotten eggs.

The two opposing arcs, which run along the rim, are 82.5 degrees long and mark the sun's positions at sunrise and sunset. The lowest points of the two arcs are 97.5 degrees apart, signifying sunrise and sunset on the winter solstice in central Germany at the time. Likewise, the uppermost points mark sunrise and sunset on the summer solstice. The sun's position at solstice has shifted slightly over the past millennia, notes Wolfhard Schlosser of the Ruhr University in Bochum, so that the angle between sunrise and sunset is now slightly farther apart than when the Nebra disk and the Goseck circle were made (by 1.6 and 2.8 degrees, respectively).

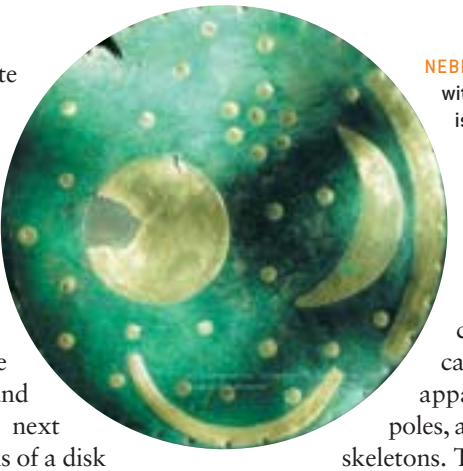
Nearby excavations of wood-and-clay houses have turned up a variety of grains and evidence of domesticated goats, sheep, pigs and cows. Farmers reached this part of the world some 500 years before they built the solar observatory. Although these earliest Neolithic agriculturists most likely measured only the sun's movements, over millennia they came to quantify the lunar cycle and the positions of constellations. The Pleiades, which depart the northern sky in spring and reappear in the fall, still mark crop cycles for many farmers around the world. The Nebra disk may have been a ritual object or, more likely—given its precision—a calculational tool used with observations

SOLAR OBSERVATORY in Goseck, Germany, as it might have appeared in 4900 B.C. The circle, easily seen in aerial views today (*opposite page*), has three gates. To an observer standing at the center of the circle, the sun rises and sets through the southern gates (*above, at top*) on the winter solstice; the northern gate's function is unknown.

STATE DEPARTMENT FOR ARCHAEOLOGY OF SAXONY-ANHALT; KAROL SCHAUER

OPERATION: RECOVER NEBRA

The Nebra disk, the oldest representation of the cosmos, ended up with archaeologists rather unconventionally. Using metal detectors, treasure hunters dug up the disk in 1999 from Mittelberg Hill near Nebra, along with two swords, two axes, chisels and armlets, and then sold the heist to dealers. Because German law dictates that such relics are state property, the police mounted a sting operation, wherein archaeologist Harald Meller of the State Museum for Prehistory at Halle posed as a buyer to recover the cache. One of the discoverers was fined this past September, and another was sentenced to 250 hours of community service. Others indicted in the case remain on trial.



NEBRA DISK, a bronze artifact with markings in gold leaf, is the earliest known reproduction of the sky. It may have been used to time plantings and harvests.

STATE DEPARTMENT FOR ARCHAEOLOGY OF SAXONY-ANHALT; JURAJ LIPTÁK

at Goseck or a similar site to determine planting and harvest times.

The third arc on the disk, believes Francois Bertemes of the University of Halle-Wittenberg, is the stuff of legend. The ancients did not understand how the sun could set in the west and end up in the east the next morning. Representations of a disk in a ship, from Bronze Age Egypt and Scandinavia, reveal an age-old belief that a ship carried the sun across the night sky. The Nebra disk is the first evidence of such a faith in central Europe. That the land-bound cultivators knew of ships is no surprise: Bertemes points out that travelers spread the latest in Bronze Age technology as well as mythology.

The third gate at Goseck remains mysterious, however: it points north, but not quite. It may have nothing to do with astronomy, for the compound was more than a solar station. In addition to pottery shards and arrowheads within, excavators found the decapitated skulls of oxen, apparently displayed on poles, and parts of two human skeletons. The human bones were cleaned of flesh before being buried. Similar skeletons—several with cut marks or with arrowheads in their necks—have turned up in other circles, but archaeologists cannot agree on whether they attest to human sacrifices or to uncommonly gory funeral rites. Nevertheless, such ceremonies anoint the site as a temple, Bertemes notes—and show that science was inextricably entangled with superstition since Neolithic times.

Madhusree Mukerjee writes from Frankfurt, Germany.

NEED TO KNOW: MORE THAN FIBER

Although the fiber-optic link is the primary technical challenge facing engineers of the new hybrid remotely operated vehicle (ROV), other obstacles must be overcome. Building on U.S. Navy expertise, the hybrid ROV will incorporate spherical housings composed of strong but lightweight aluminum oxide ceramic. The high-buoyancy ceramic cases would thus be able to protect onboard electrical equipment from deep-water pressures as great as 16,000 pounds per square inch. Further flotation will derive from syntactic foam—epoxy resin filled with glass microspheres. Pressure-tolerant mechanical connections, cameras, low-power lighting and other apparatus must also be constructed. Because the hybrid ROV will be battery-powered, energy management will be another major concern.

OCEANS

Down to the Deep

CROSSBREEDING TO MAKE EXPLORING THE ABYSS ROUTINE

BY STEVEN ASHLEY

Humans have visited the very bottom of the ocean—the Marianas Trench in the western Pacific, nearly seven miles below the wavetops—only a few times. The first expedition took place in 1960, when Jacques Piccard set the U.S. Navy submersible *Trieste* down on the murky floor; the next occurred some 35 years later, when Japan's *Kaiko,* a multimillion-dollar remotely operated vehicle (ROV), returned briefly to that black realm during several dives. The extreme depths and pressures of the earth's least-explored territory have kept scientists from studying the ocean's abyss up close. An innovative attempt may soon change that.

Engineers at Woods Hole Oceanographic Institution, Johns Hopkins University and the U.S. Navy have begun developing an undersea craft that is designed to do meaningful science at the lowest depths routinely and cost-effectively. The device, explains Woods Hole researcher Andy Bowen, will be a hybrid ROV; it will combine the capabilities of a fully autonomous undersea robot with those of a craft piloted from the surface via a thin optical-communications fiber, the same technology used to guide torpedoes. The one-ton machine and its support equipment are to fit into a pair of standard shipping containers. Thus, the system is intended to be sufficiently compact, lightweight and easily deployed from standard oceanographic vessels, thereby avoiding the need for a dedicated mother ship. These features will make the machine flexible and cheap enough not only for deep diving but for other, traditional survey and sampling jobs. Managers expect that the $5.5-million project, which is being funded by the National Science Foundation, the Office of Naval Research and the National

Oceanic and Atmospheric Administration, will be completed in four years.

The crossbreeding approach circumvents the limitations of other, conventional bathyscaphic and teleoperated technologies. Occupied submersibles end up being large and costly to ensure the safety of the people inside. Totally independent robots must be extremely "intelligent" to carry out research activities—an expensive and technically difficult task. Meanwhile the lengthy cables used to tether craft to surface ships are simply too weak and unwieldy to support themselves plus a vehicle exploring broad swaths of the seafloor.

When operated as an autonomous device, the hybrid ROV will conduct wide-area surveys using sonar and other sensors. For detailed investigations, technicians will strap on an optical-fiber canister and a tool sled containing additional thrusters, extra flotation, batteries, an electromechanical arm and sampling equipment. After being winched below the treacherous currents on a steel cable, the craft will be released from a suspended depressor weight. An anchor will then pull the vehicle down to the seafloor, paying out optical fiber during the descent. Once the hybrid ROV arrives at the bottom, it will release the anchor and drive off to do its business, reeling out more microfiber from its stern. On completion of its work, the craft will cut the fiber link and then rendezvous and dock with the depressor weight, making it ready for retrieval by the ship.

If all goes well, the hybrid ROV will let scientists better understand fundamental processes occurring at the deep subduction zones along the continental margins where geochemical recycling of the earth's crust takes place. Further, it will permit exploration of the unknown seas below the polar ice packs (a task that requires long horizontal transits) as well as rapid deployment to study any new undersea phenomenon that emerges unexpectedly.

AEROSPACE

Lowering the Boom

QUIETER WAYS TO BREAK THE SOUND BARRIER

BY PHIL SCOTT

Chuck Yeager ushered in an era when he blasted through the sound barrier at Edwards Air Force Base in 1947. But his Bell X-1 also created a problem: the window- and nerve-rattling sonic boom. Now aeronautical engineers at the same California air base say that although they haven't busted the sonic boom, at least they've taken a swing at muffling it.

Flying faster than the speed of sound—660 miles per hour at 10,000 feet—an airplane produces air-pressure waves that pile up in front. The waves form highly compressed regions called shock waves, which lead to sonic booms.

The boom from a straight-flying craft is actually two booms in one. A supersonic jet forms a shock wave at its nose, which claps back together after its tail. This pressure suddenly spikes a couple of pounds per square foot over ambient atmospheric pressure, then shoots below ambient by about an equal amount, spiking again before returning to ambient pressure. A graph of pressure over time would form the letter N.

"We cannot change the energy of the aircraft flying through the air," says Edward A. Haering, the Dryden Research Center's Shaped Sonic Boom Demonstration (SSBD) principal investigator. "But we can redistribute it" to decrease the pressure changes. Late this past August engineers at Northrop Grumman accomplished this redistribution of energy on a modified F-5. They altered its front with a "nose glove," made from

SUPERSONIC: NOT WORTH IT

Aircraft flying over populated areas must travel at subsonic speeds to avoid producing sonic booms. Considering that more than 60 percent of air traffic crosses land, it would seem that commercial airliners should take an interest in taming sonic booms. But although theories about softer booms have existed for 30 years, "there is no economic driver" to apply the ideas, says Brian Argrow of the University of Colorado at Boulder. A supersonic transport, he explains, requires more energy than an airliner traveling at high subsonic speeds. Burning more fuel is not what cost-conscious airlines like to hear—and explains in part why the Concorde has been retired.

Even the big-budget Pentagon has been leery of investing in boom-softening technology. According to Edward A. Haering of the Dryden Research Center, engineers there tried to modify an SR-71 Blackbird, the world's fastest plane, back in 1995. But they couldn't come up with $3 million for a nose glove.

QUIETER SONIC BOOM was achieved by Northrop Grumman in a test flight this past summer. This F-5 was outfitted with a "nose glove" in the shape of a pelican's beak. The blunter nose creates a pressure spike that dampens the shock wave resulting from supersonic speeds.

NORTHROP GRUMMAN CORPORATION

aluminum and composites and resembling a pelican's beak. The glove elongates the nose and blunts it, which prevents shock waves from the engine inlet and wing from moving forward and coalescing with the main shock from the bow. In the test, the modified F-5 clipped the N-wave, reducing the shock wave from 1.2 pounds per square foot to 0.8 pound, resulting in a quieter boom.

The experiment validates a theory proposed 30 years ago by aerospace engineering professors Richard Seebass and Albert R. George of Cornell University. They proposed that a blunter nose could create a pressure spike ahead of the shock wave. The spike would raise the air temperature and hence increase the speed of sound, which in turn would spread the shock wave, thereby dampening it.

Seebass also had another theory: "Stretching the vehicle can reduce the sonic boom," explains Brian M. Argrow, an aerospace engineering professor at the University of Colorado at Boulder, who collaborated with Seebass before his death in November 2000. "Something on the order of 150 to 200 feet long and weighing less than 100,000 pounds"—which is light for an aircraft of that length. "If you make it slender enough, it can actually fly supersonically with no boom," Argrow states. Dryden's Haering remains skeptical of boom-free supersonics: "Plowing through the air, pushing it faster than it can move out of the way, you're going to get a shock wave."

It might be possible to quiet the boom without modifying the aircraft. In the 1970s Russian researchers proposed generating an electrical field in the airplane's nose, thus creating plasma. By heating the surrounding air, the plasma might reduce the shock wave.

Engineers still have more immediate and practical tricks to try—namely, Haering explains, "by paying attention to placement of the wing, tail and engines and the shape of the fuselage." One possible form is a diamond-shape wing, with no big protuberances or abrupt area changes on either the wing or the fuselage, according to Charles Boccadoro, a program manager at Northrop Grumman. Manufacturers could be ready to unveil quieter supersonic jets within the next 10 years. Chuck Yeager would be proud.

Phil Scott writes about aviation technology from New York City.

BEER could be poured faster with new taps, such as one made by Shurflo for the 2002 World Series.

GREG CORREARD *Shurflo*

FLUID FLOW

Two-Second Drafts

FASTER BEER TAPS FOR THOSE WHO JUST CAN'T WAIT **BY BRENDA GOODMAN**

Thirsty crowds know that where there's a beer, there's a wait. That's because the average draft pint takes at least 25 seconds to pull. Any slower, and the beer comes out flat; any faster, and a frothy lager latte results. In the past two years, with profits shrinking, brewers have become keen to serve more customers without sacrificing quality, and they have sought technology to help.

Pouring beer quickly does not mean simply using bigger spouts. Draft beer's ticklish nature requires a fine balance between temperature and pressure. Most dispensing systems rely on carbon dioxide gas pumped down into the keg to push beer up to a tap. Higher CO_2 pressure would speed delivery—

but produce a river of foam. Every brew needs a slightly different pressure to be served well.

The makers of Guinness, which takes 119 seconds to pour, were the first to try to develop a faster tap. After a year of experimenting, they gave up. The company won't say what went wrong, only that Guinness customers are prepared to wait.

U.K. brewer Carlsberg-Tetley has been more successful. With the University of Birmingham, which had been offering degrees in brewing science since 1903, it devised a "hydrocyclone" system, which spins beer into the tap like a liquid tornado. Some of the carbon dioxide in the beer is released into the center of the funnel, preventing excessive foam at higher pouring speeds. "The controlled gas breakout is the secret," explains George Philliskirk, technical manager for Carlsberg-Tetley. "It creates a tight, creamy head without excessive foam." Philliskirk estimates that since its launch in February 2002, the fast-pour system is operating in more than 100,000 pubs around the U.K., delivering pints in about 14 seconds.

This past spring Shurflo in Cypress, Calif., and Anheuser-Busch launched their version of a faster tap, called the Ultimate Draft System. They borrowed a trick bottlers use to control foam: fill from the bottom up. A flexible tube at the end of a spigot extends to the base of the beer glass, allowing for subsurface pumping that can fill a 20-ounce glass in a blistering two seconds. In a test at Boston's Fenway Park, the system sold 2.4 more kegs per game than conventional taps. Keith D. Lemcke, executive director of the Draught Beer Guild, was impressed: "The amount of carbonation in your mouth is exactly the same."

Coors U.K. and IMI Cornelius in Anoka, Minn., plan to introduce a fast-tap system, too, although they remain tight-lipped. Industry insiders expect it to be a less expensive but slightly slower version of the Shurflo model, pulling a pint in five seconds. Either system will most likely mean that you'll spend more time waiting for the loo than for a brew.

Brenda Goodman is based in Tampa, Fla.

PINT-SIZE SCENARIOS

Taps could also pour beer that stays colder longer. In the U.K., Coors and IMI have recently introduced a superchill system. First a jet of cold water sprays the glass while it spins, frosting it. The glass continues to spin while the beer is poured. Then a blast of ultrasound compresses the carbon dioxide gas, chilling it and causing a flurry of ice crystals to appear in the beer. Coors claims that the beer stays cold for up to 20 minutes longer than a regular pint. U.S. Coors executives have just seen the system used in the U.K. and reportedly aren't giving it the cold shoulder.

DRUG DISCOVERY

Refining Green Gold

HOW BIOPROSPECTING COULD BE MADE TO WORK BY DAVID LABRADOR

People all over the world last year paid more than $400 billion for pharmaceuticals, nearly half of which were discovered in the wild. The reefs and rain forests that yielded those discoveries are found primarily in countries with no pharmaceutical industry, so the compounds were patented and sold by foreign companies. Without a share of the proceeds, the stewards of the world's biodiversity have no incentive to preserve it. So 11 years ago ecologists, indigenous peoples and governments united to bring the profits home. Since the 1992 Earth Summit in Rio de Janeiro, 168 nations have signed the Convention on Biological Diversity and committed themselves to sharing the benefits that come from bioprospecting.

So far the convention hasn't worked. The laws it inspired rely on the sales of blockbuster drugs—which take decades to develop—while destructive industries such as logging pay off immediately. Now some countries are looking for profits in the beginning of the drug development process instead of waiting for a final product—and realizing the dreams of the convention.

The problem with the 1992 agreement has been implementation. Most countries require benefit-sharing agreements that usually call for an up-front cash contribution, training, technology transfer, and royalty payments. For example, a 1994 agreement between Suriname and a consortium of U.S. and Surinamese researchers called for an initial $60,000 payment and $20,000 per year for five years of research.

The total outlay of $160,000 is not going to tip the scales toward conservation, even in such a small country as Suriname. And to date, no blockbuster drugs have come out of regulated bioprospecting. What's more, low-budget, pay-for-access agreements with pharmaceutical giants can seem like legalized biopiracy. That has led to public outrage and has forced the suspension of benefit-sharing agreements (and the research they covered) in Brazil, Mexico and even the U.S. Facing such outrage in 2000, Brazil's president banned virtually all biological material from leaving the country.

The uncertainties are driving away the vast corporations that can turn a marvelous microbe into a billion-dollar drug. "They're shutting down those divisions of their companies, and they're going to genetically engineered products and synthetic chemistry products," says Brian M. Boom, an economic botanist at Columbia University. "I think it's going to take real live [court] cases dealing with a drug that's been developed to figure out how the benefits are going to be shared."

DRUG SEARCH: A local botanist looks for and collects plant samples in one of Panama's national parks.

RAFA AIZPRUA

Rather than waiting for judicial solutions, two nations are shifting their approach to bioprospecting: they hope to capitalize on the enormous research and development industry that underpins drug discovery. "People think that all the drug discovery research is done by pharmaceutical companies, when in fact the whole bottom part of this enormous pyramid is often done in academic institutions and small biotech firms," explains biologist Phyl-

WELCOME TO THE JUNGLE

Because there is no way to know in advance which forest sample will lead to a cancer drug or AIDS vaccine, most countries treat all research as potentially profitable. In some countries, investigators must negotiate with several levels of government. "It puts the kibosh on a lot of basic research that has nothing to do with profit motive," says Columbia University economic botanist Brian M. Boom, who lobbied for the Convention on Biological Diversity for years before it was adopted. Now, he says, "the very people who are most able to get out there and discover and describe and quantify biodiversity are being impeded from doing it. Everyone struggles with the paradox of it."

lis D. Coley of the University of Utah.

In the October *Frontiers in Ecology and the Environment*, Panamanian and U.S. bioprospectors led by Coley and her husband, Thomas A. Kursar, also at the University of Utah, demonstrated how a developing country can quickly establish a drug discovery industry. In 1998 they won a $3-million bioprospecting grant and funded local scientists to analyze what they found instead of paying U.S. labs to do the same work. "By conducting all of the research in Panama, we circumvent the issue of uncertain royalties and provide immediate and lasting benefits," they write. "We're involved in the collections, but that's it," Kursar elaborates. "All the high-tech stuff is being done by Panamanians."

Now Panama has six new laboratories employing 67 researchers who perform bioassays and run toxicity and efficacy trials. And because Panamanian labs developed the intellectual property, it is theirs to license to pharmaceutical companies for immediate profit.

Brazil is also cultivating a drug discovery industry. Last year the government opened the Center for Amazonian Biotechnology. Anyone collecting samples in Brazil must patent them there and contribute toward a goal of $150 million in private funds. The center has more than 80 affiliated research groups and will house 26 laboratories when it is completed.

Brazil's presidential ban on the export of biological material may be undermining this initiative to some degree (it prevents the profitable licensing of promising compounds and discourages foreign collaboration). Still, human and financial capital is accumulating in the Brazilian drug discovery industry and is giving locals a huge stake in keeping the forest intact. And in Panama, Coley reports that a chemist "who couldn't have cared less originally is now a wonderful public speaker on the value of biodiversity." Other countries could gain a similar stake in conservation by following their lead.

David Labrador is a writer and researcher based in New York City.

BY THE NUMBERS

Measuring Modernity

THE U.S. IS NOT NUMBER ONE **BY RODGER DOYLE**

Modernization, the subject of intense scrutiny at least since the time of Marx and Nietzsche, has seldom been measured systematically. One of the most useful attempts to do so has been done by political scientists Ronald Inglehart and Wayne E. Baker of the University of Michigan at Ann Arbor.

In their approach, being modern implies not only a lack of traditional beliefs but also a need for free expression. To measure these attributes, they use responses from the World Values Survey, an international collaborative study based on extensive questioning of people in scores of countries making up more than 80 percent of the world's population. The first of these dimensions—the traditional versus secular-rational scale in the chart—derives from attitudes toward religion, respect for authority, and patriotism. The second dimension—survival versus self-expression—derives from questions about physical security, trust in other people, gender roles, and personal happiness. Self-expression, almost by definition, implies freedom from extreme need.

The data for individual countries are combined into nine cultural groups to form the bounded areas seen in the chart. As might be expected, most Western countries tend to be in the upper right, indicating high modernization scores, whereas developing societies are generally in the lower left, indicating low modernization scores. Countries with a Confucian heritage, which hold relatively secular values, tend to be high on the secular scale but have lower self-expression values than Western countries. The position of former Soviet bloc countries reflects decades of indoctrination in atheism as well as their recent economic troubles.

Among Western countries there are distinct differences, with Protestant Europe occupying the most modern position above Catholic Europe and the English-speaking countries. This positioning reflects extremely low levels of religious involvement together with high levels of well-being and the tolerance and trust characteristic of the European Protestant heritage. Catholic societies, as Inglehart and Baker suggest, may have a lower position on the scale because of the heritage of the Roman Catholic Church, the prototype of a hierarchical, centrally controlled institution. The lower position of the English-speaking countries is a function of, among other influences, their higher religious commitment, particularly in the U.S.

Economic condition and religious-cultural heritage are the basic forces accounting for the position of societies on the chart, but within any society, homogeneity wields substantial power. In the U.S., for example, the basic values of Catholics resemble those of Protestants, rather than those of Catholics in predominantly Catholic countries, whereas in Nigeria the values of Christians are far closer to those of Muslims than to those of Western Christians.

The common wisdom is that the world is becoming Americanized, but the Inglehart-Baker analysis suggests that Americanization is occurring largely at the superficial level of Coca-Cola and Big Macs. As they put it in a February 2000 *American Sociological Review* article, "industrializing societies in general are *not* becoming like the United States . . . [for] its people hold much more traditional values and beliefs than do those in any other equally prosperous society." It is not the U.S. but northern European cultures, such as those of the Nordic countries, that are on the cutting edge of modernity.

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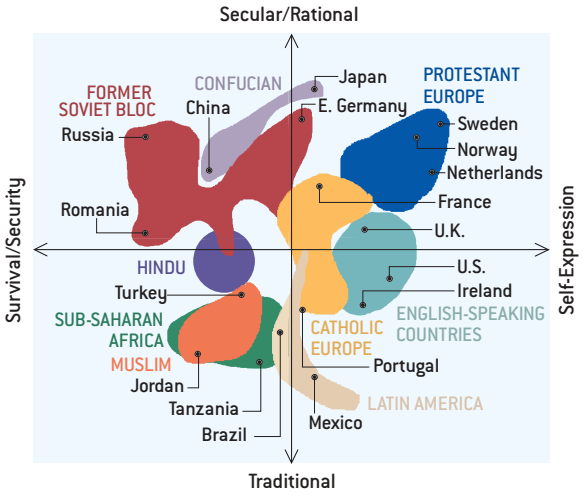
WORLD ATTITUDES, RELATIVE STANDING BY CULTURE GROUP



SOURCE: Rising Tide: Gender Equality and Cultural Change around the World, *by Ronald Inglehart and Pippa Norris (Cambridge University Press, 2003). Data are for 77 countries from the World Values Survey, with most countries being surveyed in 1999–2001. Not all countries are shown.*

RODGER DOYLE

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Democracy and Economic Development: Modernization Theory Revisited. Zehra F. Arat in *Comparative Politics,* Vol. 21, pages 21–36; October 1988.

Modernization, Cultural Change, and the Persistence of Traditional Values. Ronald Inglehart and Wayne E. Baker in *American Sociological Review,* Vol. 65, No. 1, pages 19–51; February 2000.

The Nobel Prizes for 2003

The Royal Swedish Academy handed out four prizes to honor nine men of science for their groundbreaking contributions. Below are commentaries on two of the prizes.

PHYSIOLOGY OR MEDICINE

OUTSIDE LOOKING IN

"The Shameful Wrong That Must Be Righted" screamed the October advertisement. The perceived wrong was committed by those who awarded this year's Nobel Prize in Physiology or Medicine. The committee honored **Paul C. Lauterbur** and **Peter Mansfield** for their contributions to the development of magnetic resonance imaging (MRI) technology—and ignored Raymond V. Damadian, who took out the full-page ad that appeared in the *New York Times* and the *Washington Post*.

Certainly the winners were deserving. Lauterbur discovered that gradients in the applied magnetic field could lead to two-dimensional images. Mansfield showed how the magnetic gradients could be mathematically analyzed, thereby improving the speed and efficiency by which images could be generated. But there is no question that Damadian played a key role in the development of MRI machines routinely used in hospitals today [see "Scanning the Horizon," Profile, by David Schneider; SCIENTIFIC AMERICAN, June 1997]. In 1971 he demonstrated that nuclear magnetic resonance can detect cancer in the body and a year later filed a patent for a whole-body scanner.

Controversies over Nobel prizes are not uncommon. The Nobel committee's decision in this case, however, seemed to be an intentional slap in Damadian's face. Award rules permit up to three winners in each category, so the committee could have included Damadian. Curiously, the Nobel's press release describing the winners, which typically acknowledges other contributors, fails to mention Damadian. Did the committee ignore Damadian because he chose to leave academia and pursue his work as a businessman? Did his relentless self-promotion irritate the judges enough to shun him? Did his creationist viewpoints play any role? (He is on the technical advisory board of the Institute for Creation Research.)

Even if the Nobel committee was unkind to Damadian, at least the MRI field itself has proved generous: in 1997 Damadian won a patent infringement lawsuit against General Electric for $129 million and settled out of court with other MRI manufacturers, probably also for millions. —*Philip Yam*

PHYSICS

HIGH PRIZE FOR LOW TEMPERATURES

The announcement sounded awfully familiar: for the fifth time in eight years, the prize went for work in low-temperature physics, totaling more than in any other specialty. Is it Swedish bias, just rewards, or a statistical anomaly?

"Nobel Prize–winning physics almost by definition is work done at the frontiers," says Eric A. Cornell of the University of Colorado at Boulder, a 2001 Nobel laureate. "Certainly one of the 'hottest' is the frontier of ever lower temperatures." A lag of decades can span a discovery and its Nobel Prize, and Cornell points out that the frontier for achieving low temperatures was pushed down nine orders of magnitude from the 1960s through the 1990s. That realm proved fertile ground for uncovering phenomena and for revealing spectacular predictions of quantum mechanics. The 2003 prize went to **Alexei A. Abrikosov** and **Vitaly L. Ginzburg** for theoretical work into the nature of superconductivity and to **Anthony J. Leggett** for his research on the peculiar properties of liquid helium.

Physicists are fond of the low-temperature realm for its icy simplicity: near absolute zero, physical systems become ever more free of messy heat fluctuations, and their quantum-mechanical properties can shine. The third law of thermodynamics guarantees that absolute zero (and a cessation of all atomic motion) cannot be reached, but physicists have gotten amazingly close—just this past September, Nobel laureate (2001) Wolfgang Ketterle and his group at the Massachusetts Institute of Technology cooled a sodium gas to a record-low 0.0000000005 degree above zero (0.5 nanokelvin).

And as physics progresses, fundamental ideas increasingly tend to overlap arbitrary lines of specialties. For instance, the work of Abrikosov, "apart from its importance in superconductivity, is also an important insight in the context of particle physics," notes Edward Witten, a mathematician and theoretical physicist at the Institute for Advanced Study in Princeton, N.J. —*David Appell*

AP/WIDE WORLD PHOTO

NOBEL'S OTHER WINNERS

- **Chemistry: Peter Agre and Roderick MacKinnon, for elucidating the process by which water and ions cross cell membranes. Coincidentally, MacKinnon is Research Leader of the Year in the SCIENTIFIC AMERICAN 50 awards (*see page 55*).**
- **Economics: Robert F. Engle and Clive W. J. Granger, for statistical methods to analyze economic data over time.**

Details on all the winners are at www.nobel.se and at www.sciam.com/news_directory.cfm

DATA POINTS: HOSPITAL PAINS

The U.S. Agency for Healthcare Research and Quality established a set of 20 patient safety indicators to assess the quality of care in hospitals. A study of 18 indicators found that among the most common are, in order: obstetric trauma during vaginal delivery (when instruments are used), bedsores (decubitus ulcers), sepsis, and embolisms or thrombosis.

Number of extra postoperative days in hospital:
Obstetric trauma: 0.07
Bedsores: 3.98
Sepsis: 10.89
Embolism/thrombosis: 5.36

Excess cost:
Obstetric trauma: $220
Bedsores: $10,845
Sepsis: $57,727
Embolism/thrombosis: $21,709

Annual totals:
Extra hospital days: 2.4 million
Excess charges: $9.3 billion
Attributable deaths: 32,600

SOURCE: Journal of the American Medical Association, *October 8, 2003. Annual totals are based on 18 of 20 patient safety indicators.*

AGRICULTURE

Shrinking to Enlarge

Wheat and rice half as tall as their normal counterparts helped to thwart famine all over India and southeast Asia in the 1960s. Rather than using energy for height, the stunted crops put it toward making grain instead, quadrupling production in some cases. Investigators have now identified a genetic mutation that can keep corn and sorghum from growing tall, which could improve food yields globally. Researchers at Purdue University found that the mutation shuts down production of a sugary protein that controls the flow of auxin, a plant growth hormone. The resulting dwarf crops also have more cells pound for pound in their stalks, making them stronger and perhaps more effective at holding water. Dwarf sorghum could play a key role in Africa, where it is often a staple. Other crops that usually grow tall, such as basmati rice in India and teff, which is cultivated primarily in Ethiopia, may also benefit. The scientists discuss their findings in the October 3 *Science*. —*Charles Choi*


VOLCANIC descendants.

EVOLUTION

Scarred Genes

The Galápagos archipelago's largest population of giant tortoises, which inhabits the slopes of Alcedo volcano, may descend from a few lucky forebears that managed to dodge hot rock. Researchers began to suspect an ancient disaster when they discovered that the Alcedo population is significantly less genetically diverse than four other tortoise populations on the same island. The only known historical event unique to the Alcedo tortoises is the violent eruption of their home volcano about 100,000 years ago, which buried much of their prime habitat in several meters of pumice. The team, led by Luciano B. Beheregaray of Macquarie University in Sydney, concluded that this eruption killed off all but a few progenitors when the group's analyses revealed that the genetic bottleneck occurred around 88,000 years ago. The report appears in the October 3 *Science*.
—*Sarah Simpson*

BOTANY

Leaving Alone

The radiant oranges of a monarch butterfly's wings alert hungry predators that those insects are poison. In much the same way, the dazzling orange, red and yellow displays of forests in fall may be warning would-be leaf munchers of a tree's chemical defenses. Invertebrate biologist Snorre Hagen and his team at the University of Tromsø in Norway monitored the leaves and flowers of a dozen mountain birch trees for two years. Scientists have long thought that the bright colors of autumn foliage were just the by-product of how leaves age when they cease photosynthesis, but Hagen and his colleagues report that the earlier and the more trees changed color, the less damage from chewing occurred the following season. Their report, in the September *Ecology Letters*, also notes that leaf chemistry analyses and tests with color-sensitive herbivores are needed to uncover the mechanisms that reduce insect damage. —*Charles Choi*


FALL COLOR may be a warning sign to insects.

TUI DE ROY *Minden Pictures (top)*; JOHNNY JOHNSON *(bottom)*; ILLUSTRATION BY MATT COLLINS

LIGHT FLIER stays aloft by laser.

AERONAUTICS

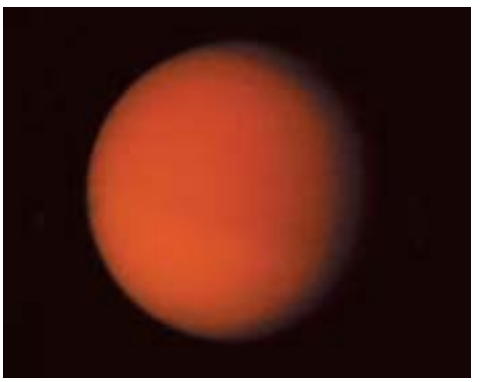
Fly by Light

Science-fiction buffs know that laser power might propel spacecraft between the stars, but the concept has earthly applications, too. Lightweight airplanes or balloons powered by ground-based lasers could serve as cheap communications or surveillance satellites or as unobtrusive probes of the upper atmosphere. Last year a Japanese group propelled a tiny aluminum plane by heating a small drop of water on its surface with a laser. This past October, NASA researchers reported flying the first completely laser-powered aircraft—an 11-ounce, five-foot-wide assemblage of balsa wood, carbon-fiber tubing and Mylar film. The radio-controlled plane circled indoors at a breezy eight miles per hour as long as an infrared laser remained trained on its photovoltaic cells, the power source for the propeller. The group is thinking about how to scale up to a larger aircraft or stationary balloon, says team member Robert V. Burdine of the Marshall Space Flight Center in Huntsville, Ala. *—JR Minkel*

ASTRONOMY

The Methane Seas

Titan, the largest of Saturn's moons and possessor of the only nitrogen-rich atmosphere in the solar system apart from Earth's, keeps its surface obscured below a thick orange haze. Radar observations using Earth-based radio telescopes have pierced those clouds and suggest the presence of lakes composed of liquid hydrocarbons. Researchers found sharp spikes in the radar echoes, indicating smooth, dark reflecting areas on Titan, most likely liquid. What would be liquid on Titan, where surface temperatures are –180 degrees Celsius? Previous analyses of Titan's atmosphere have revealed the presence of methane and other hydrocarbons; these compounds could rain down on the surface (believed to be made of frozen water) and form lakes of liquid methane and ethane. The research was posted online in the October 2 *Science Express*. *—Chris Jozefowicz*



SHROUDED TITAN, Saturn's largest moon, may have hydrocarbon lakes.

ELECTRONICS

A Tunnel for Better Wireless

By governing the flow of current under an applied voltage, diodes form the backbone of the modern electronics world. A diode with an especially useful property is the tunnel diode, in which electrons quantum-mechanically "tunnel" through a layer of material; as a result, the current through the diode rises, drops, then rises again as the voltage increases. Such complex behavior of tunnel diodes can take over the functions of some circuits and thereby simplify the construction of computer chips. But researchers have struggled to make them from silicon to marry them with today's equipment.

Now a group led by Ohio State University researchers has built a silicon tunnel diode that generates strong currents at low voltage—perfect for longer-lasting cell phones and wireless-capable medical devices such as pacemakers. The diode contains thin layers of silicon and silicon-germanium, through which electrons tunnel, sandwiched between a layer heavily doped with boron and another doped with phosphorus. By carefully controlling the growth temperature, the researchers can thin the layers to allow more tunneling without muddying the diode's properties. The results are in the October 20 *Applied Physics Letters*. *—JR Minkel*

BRIEF POINTS

- **The U.S. Navy has agreed to restrict the use of its newest sonar after a report connecting it to the formation of gas bubbles in beaked whales. The sonar may have scared the animals into surfacing too quickly, creating decompression sickness, or even triggered bubble formation directly.**

  Nature, October 9, 2003

- **Fear factor: Unlearning anxiety may be more effective if the feared stimulus is delivered in concentrated bursts, rather than paced out over time.**

  Journal of Experimental Psychology: Animal Behavior Processes, October 2003

- **Protein sequences of the SARS virus indicate that the virus has shuffled its genes around, suggesting the pathogen evolves rapidly and unpredictably.**

  Infection, Genetics and Evolution, September 2003

- **Lipoprotein molecules—familiar from doctor visits as HDL and LDL cholesterol readings—may exert beneficial effects depending on their size. People who produce bigger lipoprotein molecules (either HDL or LDL) have greater odds of a long, healthy life.**

  Journal of the American Medical Association, October 15, 2003

TOM TSCHIDA *NASA Dryden Flight Research Center (top)*; NASA/JET PROPULSION LABORATORY *(bottom)*

Can Cells Be Generic?

As patents expire on its products, the biotechnology industry braces for impact By W. WAYT GIBBS

About half the prescriptions filled in the U.S. last year were for generic drugs. As the nation's health care costs soar ever skyward, the competition from low-priced generics adds essential ballast. But will the makers of generics be able to offer cut-price knockoffs of therapies that are the fruit of biotechnology? The Food and Drug Administration and its European counterpart are pondering the question now, and a great deal of money hinges on their decisions.

The patents on the first lucrative products of biotechnology are at last approaching their expiration dates. If competing firms are permitted to manufacture them, "biogeneric" versions of the off-patent medicines could command $5 billion next year, estimates the Strategic Research Institute, a consultancy in New York City. Regulators face a tough scientific question, however: How should they judge whether a biogeneric is equivalent to the brand-name therapy for which it substitutes?

Unlike drugs, which are synthesized using reproducible chemical procedures, biotech medicines—or "biologics," as insiders call them—are fabricated from bacteria, farm animals and other organisms that have a life of their own. Biologics are typically large molecules, such as hormones, antibodies or cytokines. Most are constructed from proteins, which are too complicated to make from scratch. To function properly, a protein must be folded up a certain way and must have sugars and other chemicals added to particular spots on the macromolecule.

Biotechnology companies spend years figuring out the right combination of mutant host organism and reactor conditions to fashion a protein therapy that is safe and effective. It's closer to brewing than to chemistry. As much as they would like to, biotech firms cannot comprehend and control all the factors that influence the purity and function of the macromolecules that come out of their bioreactors. The best they can do is to find a manufacturing process that works—as proved through a series of expensive, time-consuming clinical trials—and then stick with it.

Generic drugs are cheaper in part because they do an end-run around those trials. Laboratory analysis can prove that the knockoff is chemically identical to the name-brand drug. So a single, abbreviated test in the clinic is usually enough to show that a generic pill performs in patients as well as the original does.

Even the manufacturers of generics agree that the hurdle must be set higher for biologics, because small differences in protein concoctions can have enormous consequences in the body. Ortho Biotech, for example, recently changed one of the chemicals added to its erythropoietin alpha medicine as a stabilizer. The new chemical interacted with the protein to cause an immune reaction in some patients. Rather than alleviating the anemia in these 250 or so people, the "improved" therapy greatly worsened their conditions.

Only a very large trial would have detected the problem with Ortho's revised formulation, because it affects only a small fraction of patients. The dilemma that regulators face is whether to require generics firms to conduct such large, lengthy and expensive trials—thus effectively raising the price of biogenerics—or whether to make informed guesses about whether subtle differences in the generic version will harm patients. It's a tough call, but an important one. Some 40 percent of the medicines now in final-stage clinical trials originated in biotech labs. If there is no place for generics to compete with these future medicines, how many people will be able to afford them? SA

Please let us know about interesting and unusual patents. Send suggestions to: patents@sciam.com

JENNIFER KANE

What's the Harm?

Alternative medicine is not everything to gain and nothing to lose

By MICHAEL SHERMER

After being poked, scanned, drugged and radiated, your doc tells you nothing more can be done to cure what ails you. Why not try an alternative healing modality? What's the harm?

I started thinking about this question in 1991, when my normally intelligent mother presented to a psychiatrist symptoms of cognitive confusion, emotional instability and memory loss. Within an hour it was determined that she was depressed. I didn't buy it. My mom was acting strangely, not depressed. I requested a second opinion from a neurologist.

A CT scan revealed an orange-size meningioma tumor. After its removal, my mom was back to her bright and cheery self—such a remarkably recuperative and pliable organ is the brain. Unfortunately, within a year my mom had two new tumors in her brain. Three more rounds of this cycle of surgical removal and tumor return, plus two doses of gamma knife radiation (pinpoint-accurate beams that destroy cancer cells), finally led to the dreaded prognosis: there was nothing more to be done.

There is only scientific medicine that has been tested and alternative medicine that has not been tested.

What is a skeptic to do? An ideological commitment to science is one thing, but this was my mom! I turned to the literature, and with the help of our brilliant and humane oncologist, Avrum Bluming, determined that my mom should try an experimental treatment, mifepristone, a synthetic antiprogestin better known as RU-486, the "morning after" contraception drug. A small-sample study suggested that it might retard the growth of tumors. It didn't work for my mom. She was dying. There was nothing to lose in trying alternative cancer treatments, right? Wrong.

The choice is not between scientific medicine that doesn't work and alternative medicine that might work. Instead there is only scientific medicine that has been tested and everything else ("alternative" or "complementary" medicine) that has not been tested. A few reliable authorities test and review the evidence for some of the claims—notably Stephen Barrett's Quackwatch (www.quackwatch.org), William Jarvis's National Council against Health Fraud (www.ncahf.org), and Wallace Sampson's journal *The Scientific Review of Alternative Medicine*.

Most alternatives, however, slip under the scientific peer-review radar. This is why it is alarming that, according to the American Medical Association, the number of visits to alternative practitioners exceeds visits to traditional medical doctors; the amount of money spent on herbal medicines and nutrition therapy accounts for more than half of all out-of-pocket expenses to physicians; and, most disturbingly, 60 percent of patients who undergo alternative treatments do not report that information to their physician—a serious, and even potentially fatal, problem if herbs and medicines are inappropriately mixed.

For example, the September 17 issue of the *Journal of the American Medical Association* reported the results of a study on St. John's wort. The herb, derived from a blooming *Hypericum perforatum* plant and hugely popular as an alternative elixir (to the tune of millions of dollars annually), can significantly impair the effectiveness of dozens of medications, including those used to treat high blood pressure, cardiac arrhythmias, high cholesterol, cancer, pain and depression. The study's authors show that St. John's wort affects the liver enzyme cytochrome P450 3A4, essential to metabolizing at least half of all prescription drugs, thereby speeding up the breakdown process and short-changing patients of their lifesaving medications.

But there is a deeper problem with the use of alternatives whose benefits have not been proved. All of us are limited to a few score years in which to enjoy meaningful life and love. Time is precious and fleeting. Given the choice of spending the next couple months schlepping my mother around the country on a wild goose chase versus spending the time together, my dad and I decided on the latter. She died a few months later, on September 2, 2000, three years ago to the day I penned this column.

Medicine is miraculous, but in the end, life ultimately turns on the love of the people who matter most. It is for those relationships, especially, that we should apply the ancient medical principle *Primum non nocere*—first, do no harm. SA

Michael Shermer is publisher of Skeptic *(www.skeptic.com) and author of* How We Believe *and* In Darwin's Shadow.

BRAD HINES

The Cells That Rule the Seas

The ocean's tiniest inhabitants, notes biological oceanographer Sallie W. Chisholm, hold the key to understanding the biosphere—and what happens when humans disturb it By STEVE NADIS

An unseen "forest" of microscopic beings fills the upper 200 meters of ocean, exerting an influence on this planet every bit as profound as the forests on land. The diverse phytoplankton species inhabiting the ocean's surface waters—which mainly consist of single-celled cyanobacteria, diatoms and other kinds of algae—form the base of the marine food web. They account for roughly half the photosynthesis on the earth, remove nearly as much carbon dioxide from the atmosphere as all land plants, and supply about half the oxygen we breathe. Without the activities of these free-floating plantlike organisms, atmospheric carbon dioxide levels would triple.

SALLIE ("PENNY") CHISHOLM: SEEING SMALL

- **Discovered *Prochlorococcus* in 1988. The microbe's minute size enables it to capture sunlight efficiently (there is less self-shading).**
- ***Prochlorococcus* is responsible for roughly half the photosynthesis in the oceans. A drop of seawater contains up to 20,000 cells.**
- **On promoting phytoplankton growth with iron: "Even if you fertilized the entire ocean, it wouldn't make much of a dent on global warming—at best postponing the inevitable by about five years."**

That phytoplankton could accomplish so much with so little recognition from the general public is surprising [see "The Ocean's Invisible Forest," by Paul Falkowski; SCIENTIFIC AMERICAN, August 2002]. Even more remarkable, scientists had no idea which microbial species performed the bulk of these vital functions until 15 years ago, when Sallie W. Chisholm of the Massachusetts Institute of Technology, Robert J. Olson of the Woods Hole Oceanographic Institution and other collaborators discovered marine cyanobacteria from the genus they later named *Prochlorococcus*. They are the smallest and most numerous photosynthetic organisms known and arguably the most plentiful species on the earth, responsible at times for more than half the photosynthesis in the seas. Cyanobacteria such as *Prochlorococcus* were the planet's first oxygen-producing creatures and are, in a broad sense, the ancestors of all higher plants.

Chisholm and Olson made their discovery by sampling ocean water with a flow cytometer—an instrument common in life sciences laboratories but one that had never been taken to sea before. The device helps to characterize single cells as they move past a laser beam. By measuring the scattering of laser light by seawater, the researchers saw hints of tiny cells. After isolating and culturing these cells, Chisholm's team named them *Prochlorococcus,* believing they were related to cyanobacteria called prochlorophytes—a supposition that later proved incorrect. Next, the team documented the abundance of *Prochlorococcus*. The microbe's dominance of the seas shocked the oceanography community. "It's hard to believe we'd overlooked something so important for so long," says Richard T. Barber of the Duke University Marine Laboratory. Chisholm considers the discovery "a lesson in humility, showing just how little we know about nature." This past April she was elect-

PHOTOGRAPH BY KATHLEEN DOOHER, WOODS HOLE, MASS.

ed to the National Academy of Sciences, largely for her role in the discovery and subsequent investigation of *Prochlorococcus*.

Despite its size—just 0.5 to 0.7 micron wide—*Prochlorococcus* has a major impact on climate because of its sheer abundance, up to 20,000 cells per drop of seawater. That's not nearly as dense as soil microbes, which may reach concentrations more than 1,000 times as high. But among photosynthesizers, tiny *Prochlorococcus* is huge. "People had assumed that much bigger organisms were fixing carbon," notes Scripps oceanographer Farooq Azam. "Penny's work has focused attention on the role of the small." (Chisholm is known as Penny to friends and colleagues—a childhood nickname that she adopted to avoid confusion with her mother and grandmother, both also named Sallie.)

Although the 56-year-old Chisholm has indeed kept her gaze on the smallest marine creatures, her career might easily have taken a different turn. In college chemistry experiments more than 30 years ago, she measured manganese concentrations in an upstate New York lake. Every water sample she inspected was filled with specks of phytoplankton. She became fascinated with these organisms and soon jettisoned plans for graduate study in chemistry.

PROLIFIC *Prochlorococcus* might be the most abundant species on the planet.

Instead Chisholm has made *Prochlorococcus* her chief research interest, guided by the conviction that "this organism could open doors for us. The reason to study it is its global importance. Whatever we learn, the multiplier is enormous." Chisholm and her colleagues have identified about 35 *Prochlorococcus* species and strains and have categorized two general classes that inhabit different subsurface layers, adapted to high and low light conditions. The team has subdivided the genus into six additional categories, based on an analysis of the ribosomal RNA gene. But Chisholm hopes to go much further and obtain complete genomes for all known species so that more thorough comparisons can be made.

This past August researchers unveiled complete genomes for three *Prochlorococcus* strains plus a strain of *Synechococcus,* a close relative. Chisholm participated in the analysis of two strains, one having the smallest genome—1.7 million base pairs and 1,700 genes—of any known oxygen-producing photosynthesizer. By seeing which genes a strain possesses—such as a gene to utilize nitrate, nitrite or cyanate—scientists can learn which nutrients are significant and what parameters govern an organism's abundance. This approach can reveal environmental factors that have not been appreciated before.

Her ultimate goal is to determine the biosphere's vital components: "What regulates them, how much we have to preserve for them to function properly, and what pushes them beyond their limits," Chisholm states. That knowledge can only come by studying the system as a whole and piece by piece. Until we understand how the biosphere works, she adds, we can't gauge the extent to which human activities disturb its functions.

What would happen, for instance, if we tried to offset global warming by pouring large quantities of iron into the oceans? The idea, sometimes called the "Geritol" solution, is to add the mineral to iron-poor ocean regions, thereby stimulating phytoplankton growth. The proliferating organisms would then remove carbon dioxide from the air. Although Chisholm has criticized this concept since it was advanced in the late 1980s, she has participated in experiments to test the hypothesis, starting in 1993 with the IRONEX experiment in the eastern equatorial Pacific. On a small scale, iron fertilization can be a powerful research tool, Chisholm maintains.

Yet she is equally convinced that large-scale fertilization would be a mistake. "How can we manipulate this system when we don't know what's in it?" she asks. "The oceans are performing all kinds of functions we don't understand." If the approach works at all—still an open question—it will inevitably alter the food web, promoting the growth of larger cells such as diatoms at the expense of smaller ones such as *Prochlorococcus,* with unknown effects rippling through the trophic levels.

By no means an activist, Chisholm rarely joins causes or signs petitions, but on this issue she feels obliged to speak out. "I didn't spend my life studying how aquatic ecosystems work only to have this fundamental knowledge ignored," she says.

Most ocean scientists agree with Chisholm about iron fertilization. Nevertheless, she observes, "this idea just won't go away." Every year she hears of a different patent filed, a new commercial venture or some other fertilization scheme. Part of the problem is the profit motive, but Chisholm also holds scientists responsible. Although it is essential to clarify iron's role as a limiting nutrient, she says, this research is commonly justified by tying it to ocean fertilization. "Somehow we must evolve to the point where people accept the importance of studying how the biosphere works—what regulates the flow of energy and cycling of elements—in its own right."

Chisholm is similarly irritated by claims that *Prochlorococcus* can be genetically engineered to draw down more carbon, thereby making it "useful" to humans. "These guys are already useful to humans," she says of her favorite cells. "They're out there doing their job in planetary maintenance, helping to regulate the biogeochemical cycles of the biosphere." The job for Chisholm and other humans is to figure out precisely what these organisms do and how they do it. SA

Steve Nadis is based in Cambridge, Mass.

CLAIRE TING

SCIENTIFIC AMERICAN 50

A MICROSCOPE THAT CAN SEE objects smaller than an atom.

The first field test of a fleet of electric vehicles powered by fuel cells. A tariff to limit vehicular traffic in central London. These are but a few of the path-breaking developments that have taken place in recent months in laboratories, corporate suites and the halls of government. For the second year, the SCIENTIFIC AMERICAN 50 recognizes the singular accomplishments of those who have contributed to the advancement of technology in the realms of science, engineering, commerce and public policy. This year's selections by the Board of Editors pay tribute to individuals, teams and companies that have stood out in a wide variety of technological disciplines. It also honors Leaders of the Year for achievements in research, business and policy. Their work again demonstrates the ingenuity and resourcefulness that generate the ever more sophisticated tools and solutions for meeting society's needs.

AEROSPACE

AGRICULTURE

AUTOMOTIVE

CHEMICALS & MATERIALS

COMMUNICATIONS

COMPUTING

DEFENSE

ECONOMIC DEVELOPMENT

ENERGY

ENVIRONMENT

IMAGING

MANUFACTURING

MEDICAL PHYSIOLOGY

MEDICAL TREATMENT

NANOTECHNOLOGY & MOLECULAR ELECTRONICS

PRIVACY & SECURITY

PUBLIC HEALTH & EPIDEMIOLOGY

ROBOTICS

TOM DRAPER DESIGN

SCIENTIFIC AMERICAN

50

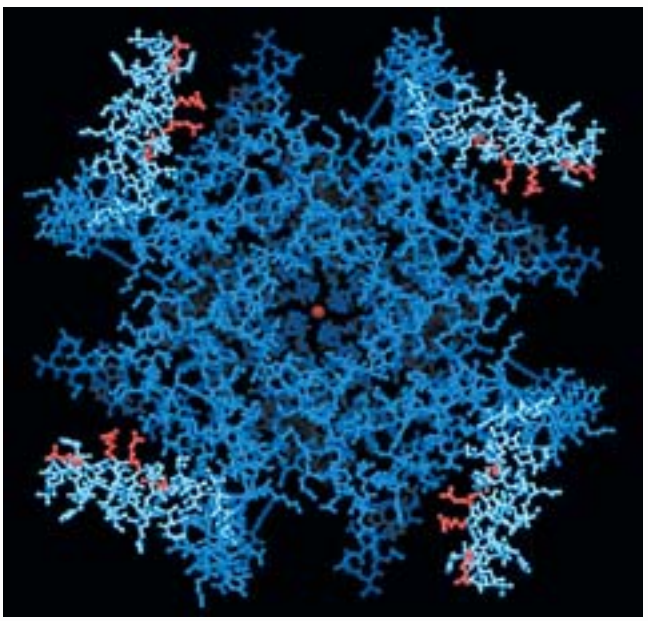
RESEARCH LEADER of the year

RODERICK MACKINNON

Professor of molecular neurobiology and biophysics, Rockefeller University; investigator, Howard Hughes Medical Institute

Elucidated the structure and function of ion channels, particularly the potassium ion channel.

THAT ELECTRICITY MIGHT ANIMATE mere flesh goes all the way back to *Frankenstein,* yet the mechanisms remained vague until Roderick MacKinnon, a physician, worked out the structure of the potassium channel. Then, this past spring, he deduced the mechanism by which a potassium channel senses electricity—its voltmeter, as it were. These achievements won him the 2003 Nobel chemistry prize.



Molecular snapshot reveals the working parts of the voltage-regulated potassium ion channel.

When a channel for any one of three inorganic ions—calcium, sodium or potassium—senses a voltage, it opens to allow ions in or out, changing the concentration and thus effecting a behavior, such as neural discharge, muscular contraction or hormone secretion. We could neither think nor move nor survive for many minutes without these channels, and MacKinnon's explanation of them should guide the development of drugs for neuromuscular and other disorders, such as cystic fibrosis and cardiac arrhythmias. Drug companies should show particular interest in the implications for arrhythmia, a common pharmaceutical side effect in numerous patients that has cost them billions in failed clinical trials.

The challenge here, as in the earlier research, lay in forming a crystal of the pore proteins that was good enough to diffract x-rays into patterns a computer could render into images. The task is hard because the proteins are very large and mixed in oils that must be removed with detergent, which is itself a problem. Furthermore, the volt-sensing element has moving parts that are buried deep inside the protein. Interestingly, MacKinnon studied the voltmeter in an Archaebacterium taken from a superhot ocean vent. That an organism so far removed in evolutionary history from us should have such similar channels indicates that the structures were highly resistant to mutation over eons and thus critical to survival.

PHOTOGRAPHS COURTESY OF THE ROCKEFELLER UNIVERSITY

Other Research Leaders

Aerospace

LARRY CORNMAN and ROBERT SHARMAN

Cornman, project scientist, and Sharman, project scientist, research applications program, National Center for Atmospheric Research, Boulder, Colo.

Discovered an algorithm that allows aircraft radar to better detect turbulence.

THE DOPPLER RADAR carried by commercial airplanes can pick up the strong winds close to the center of thunderstorms, where swirling water droplets are abundant and easy to detect. Building a clear picture of turbulence is a much more difficult problem, especially toward the edges of a storm. But with funding from NASA, physicist Larry Cornman and meteorologist Robert Sharman devised an algorithm to give radar the ability to detect turbulence accurately, even at a storm's fringes. After the first successful flight test of the algorithm in November 2002, Cornman began to work with the Federal Aviation Administration to figure out how to test and certify the improved radar in commercial systems.

Agriculture

JOANNE CHORY

Professor of plant molecular and cellular biology, Salk Institute for Biological Studies, San Diego; investigator, Howard Hughes Medical Institute

Pinpointed a gene that may allow shaded plants to grow more productively.

WHEN PLANTS GROW in the shade, they engage in the shade-avoidance response. First they grow longer stems (and therefore fewer leaves) in an effort to get out of the shade. If that fails, they produce flowers and seeds prematurely—a last-ditch effort to ensure survival of some offspring. In late 2002 Joanne Chory and a colleague identified a gene, *pft1*, that regulates this response. The results potentially have great significance. In agriculture, high density of plantings probably triggers shade avoidance to some degree in all the plants in a field, affecting how they grow and what proportions of stem, leaves and seed are produced. With an understanding of *pft1*'s role, it may be possible to develop plants that, even under shady conditions, still flower and seed late—increasing crop yield.

Shade-avoiding plant (*right*) grows a longer stem and fewer leaves than its ordinary neighbor (*above*).

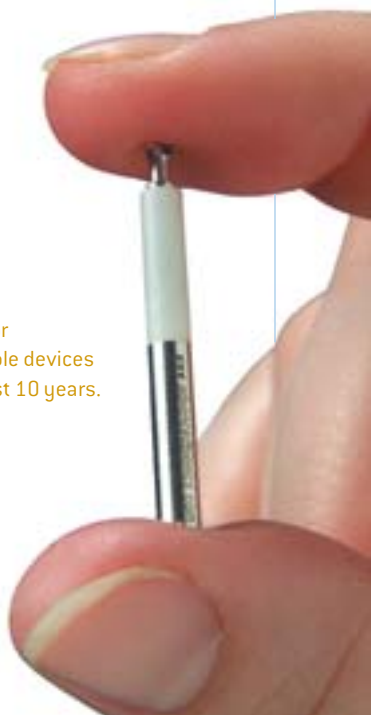
Automotive

KHALIL AMINE

Group leader, Battery Technology Development, Argonne National Laboratory, Argonne, Ill.

Made superior lithium-based batteries for hybrid vehicles and medical devices.

BORN IN MOROCCO and trained in France, Khalil Amine last year led a team of Argonne materials scientists that made notable achievements in the design of lithium batteries. To make batteries suitable for hybrid gasoline-electric vehicles, which require high peak power, they refined a lithium-manganese chemistry that is inherently safer than the alternative process, based on lithium and cobalt. The manganese crystal is also expected to last longer, avoiding the need for an expensive battery change during the life of the car. The researchers also improved a design based on lithium, iron and phosphate for implantable medical devices, where the sticking point is energy storage rather than peak power. Today's implantable batteries last only about three years, but Argonne's version is expected to last 10 years—long enough to make it practical for so-called microstimulators, which are being investigated as a treatment for Parkinson's disease and other disabilities of the central and peripheral nervous systems.



Battery for implantable devices should last 10 years.

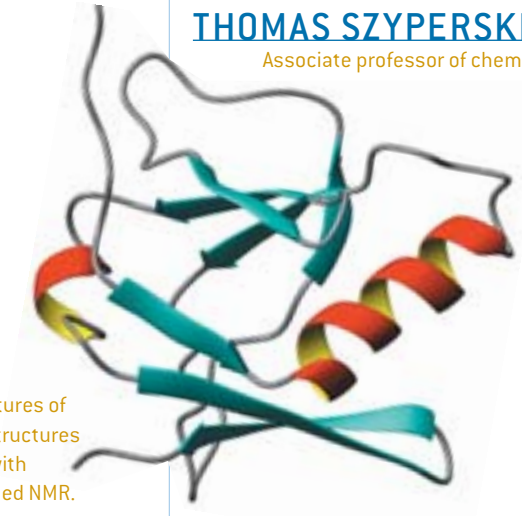
JORGE CASAL *University of Buenos Aires (top)*; ARGONNE NATIONAL LABORATORY (*bottom*)

Other Research Leaders

Chemicals and Materials

THOMAS SZYPERSKI

Associate professor of chemistry and biochemistry, State University of New York, Buffalo



Quick pictures of protein structures emerge with streamlined NMR.

Adapted nuclear magnetic resonance techniques to map a protein's atomic structure in hours, not days.

NUCLEAR MAGNETIC RESONANCE (NMR) is a laboratory technique that uses magnetic fields and radio-frequency pulses to identify and locate the atoms in molecules. As a way to analyze proteins, NMR has always taken a backseat to x-ray crystallography and other methods because it is slow: picking out the connections between individual atoms in a large protein involves going through the results from thousands of radio-frequency spectra, which can take up to a week. But in January, Thomas Szyperski published a paper in the *Journal of the American Chemical Society* describing G-matrix Fourier Transform NMR, a new method to collect data gleaned from radio-frequency pulses. The process reduced the time for protein mapping from days to just hours. Szyperski is the inventor of this technique, which improves the way NMR data are analyzed.

Communications

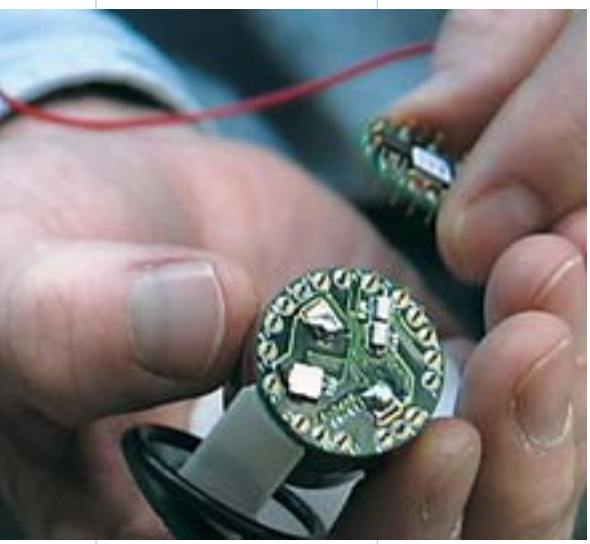
DAVID E. CULLER

Professor of computer science, University of California, Berkeley; former director of the Berkeley laboratory of Intel Research

Field-tested networks of sensors for military and environmental applications.

LAST YEAR David Culler and his colleagues began field-testing sensors that interconnect wirelessly in ad hoc networks that can describe their environment to a base station. Though dubbed "motes" by the Defense Advanced Research Projects Agency (DARPA), the sensors today are each still closer in size to a quarter than to a mote, and they cost several hundred dollars rather than small change. While reducing their size and cost, Culler and his group are trying out sample networks for tracking local stresses on the Golden Gate Bridge, the microenvironment in a redwood grove, the nesting areas of shorebirds and the rescue operations of firefighters. Because the information comes from many points, it can convey the dynamics of situations to firefighters who want, say, to determine whether a burning building is near collapse. And because the network is (or will be) cheap, it can be distributed through potential earthquake zones and battlefields, where the sensors can be consulted from a distance should the need arise.

Mini sensors can track light, temperature and humidity in a redwood grove.



Computing

ARMANDO FOX

Assistant professor of computer science, Stanford University

Showed how software could protect networks from disastrous crashes in individual servers.

COMPUTERS WILL always crash. For the average user, rebooting is a mere nuisance, but a network server crash can cost large businesses thousands of dollars. Armando Fox is a leader of a growing trend in the design of computer networks: the creation of systems designed to cope with inevitable failure. Fox and his team have developed a technique called micro-rebooting that allows the diverse software modules running on a computer at any given time to be restarted independently when a glitch is encountered. Thus, the entire suite of programs does not have to be shut down and restarted from scratch. Last year micro-rebooting was demonstrated successfully in a satellite ground station, the type of facility that often encounters failures [see "Self-Repairing Computers," by Armando Fox and David Patterson; Scientific American, June].

THOMAS SZYPERSKI (*top*); COURTESY OF UNIVERSITY OF CALIFORNIA, BERKELEY (*bottom*)

Defense

FRANK X. HURSEY

President, Z-Medica, Newington, Conn.

Developed a mineral sponge that stops blood loss on the battlefield and on the playground.

BADLY WOUNDED soldiers (like accident victims everywhere) are often at risk of bleeding to death before they can be treated, which is why blood loss is the primary cause of mortality from severe bleeding injuries. Frank Hursey's invention might change that. QuikClot is an inert granular substance that, when poured on a wound, concentrates the clotting factors in the outflowing blood and thereby speeds coagulation. Last year's approval of QuikClot by the U.S. Food and Drug Administration means a home version of the technology should be released in 2004. Hursey, a scientist who works on advanced oxygen-generating systems, discovered the properties of the QuikClot material by serendipity. Many years ago he cut himself while shaving. On a whim, he turned to an adsorptive agent that he had been developing for one of his research projects and applied it to his face. The bleeding stopped immediately.

Granules stem bleeding when poured on a wound.

Economic Development

RICHARD JEFFERSON

Chair, Center for the Application of Molecular Biology to International Agriculture, Canberra, Australia

Helps innovators in the Third World develop biotechnologies.

THE GREEN REVOLUTION—the steady increase in crop yields that started in the 1960s—is starting to bump up against limitations of land use, water supply, pest control and existing plant genetic variety. Biotechnology may be able to help, but so far it has pretty much passed the developing world by. Few have done more to change that than Richard Jefferson. Having made his name in the 1980s by creating a technique for probing protein synthesis, he has dedicated himself to ensuring that scientists and farmers in developing countries share the benefits. In 1991 he established CAMBIA, a nonprofit research institute whose mission is to make often proprietary technology more widely available. For example, CAMBIA is now putting together a do-it-yourself kit that lets start-up companies tinker with genes without having to confront battalions of intellectual-property lawyers.

Energy

JAMES A. DUMESIC

Professor of chemistry, University of Wisconsin–Madison

Pioneered economical catalysts for turning biomass into hydrogen fuel.

IF THE MUCH HERALDED hydrogen economy is ever to arrive, a cheap way to make hydrogen must be discovered. James Dumesic has developed catalytic methods that turn carbohydrates in biomass directly into hydrogen. The processes can operate at low temperature, in the liquid phase, saving a lot of energy compared with other approaches being researched. Last year Dumesic and his colleagues showed how the reaction could be mediated with a platinum catalyst; this year they did it with a far cheaper combination of nickel and tin. The main by-products are water and carbon dioxide. Although carbon dioxide is a greenhouse gas, the biomass grown for the next cycle of energy harvesting would absorb it all, so no net greenhouse gas would be produced.

Environment

DANIEL PAULY

Fisheries scientist, University of British Columbia

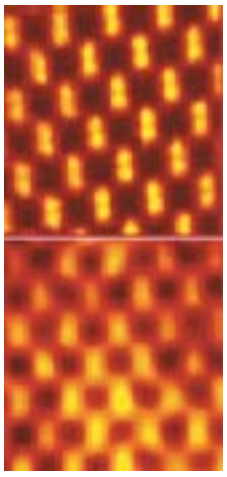
Advances the case for setting up marine reserves so that fisheries can make a comeback.

Marine reserves might combat overfishing.

FOR YEARS, Daniel Pauly has been carefully documenting the devastating effects of overfishing, particularly on large predator species such as cod, snapper and tuna [see "Counting the Last Fish," by Daniel Pauly and Reg Watson; Scientific American, July]. This year Pauly attempted to spread the alarm to the general public with his book *In a Perfect Ocean* (Island Press). An iconoclastic and erudite researcher, he argues that governments must abolish subsidies to fishing fleets and establish marine reserves to allow fisheries to recover. (Present marine reserves cover less than half of 1 percent of the total sea area.) Pauly spent much of his early career developing new methods for estimating fish populations. One of his latest projects is FishBase, an online database with information on more than 28,000 fish species.

COURTESY OF Z-MEDICA (*top*); SANDY HILL *AP Photo* (*bottom*)

Other Research Leaders



Correcting distortions (*top*) improves atomic-level imaging.

Imaging

PHILIP E. BATSON

Researcher, department of physical sciences, IBM Thomas J. Watson Research Center, Yorktown Heights, N.Y.

Demonstrated an electron microscope that can see objects smaller than an atom.

ASTRONOMERS MEASURE instabilities in the atmosphere and in the telescope itself, then use computers to manipulate the lenses, correcting for the distortions. Such "adaptive optics" have now been applied to a complex set of 40-odd magnetic corrective lenses in an electron microscope, allowing researchers to resolve features smaller than an angstrom, about the diameter of a hydrogen atom. Philip Batson, along with non-IBM scientists Ondrej Krivanek and Niklas Dellby, reported in the August 8, 2002, *Nature,* that the instrument leads to a qualitatively new understanding of the atomic-level behavior of nanometer-scale objects. These improvements in electron microscopy will allow routine observation of single-atom behavior within a bulk material.

Manufacturing

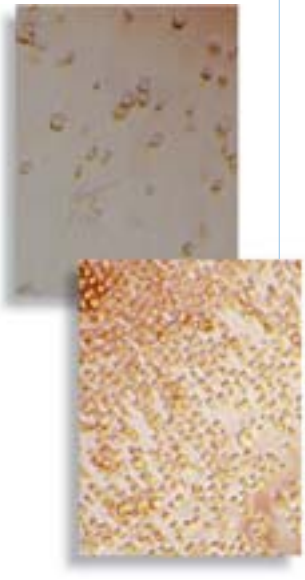
DAVID GRIER

Professor of physics, New York University

Built arrays of optical tweezers that may eventually power micromachines.

OPTICAL TWEEZERS, which use light to move semitransparent objects, date back to the mid-1980s. But arrays of tweezers, created by using holograms to separate light from a single laser into multiple beams, have recently shown promise as powerful tools for use in microscopic and nanoscopic machines. David Grier, a professor at the University of Chicago before moving this month, reported this past spring that holographic optical tweezers could twist light to spin vortices in a fluid. Such vortices can function as microscopic pumps: beads spun by the vortices can propel fluids around the microscopic channels of devices that may eventually be used in pharmaceutical manufacturing. One day they might even spin the gears on micromachines. Grier's work was the inspiration for Arryx, a company that has begun to commercialize holographic optical tweezer technology.

Addition of Wnt to blood-forming stem cells prompts proliferation (*bottom*).



Medical Physiology

ROEL NUSSE

Professor of developmental biology, Stanford University School of Medicine; investigator, Howard Hughes Medical Institute

Purified a molecule that may restore blood cells destroyed through chemotherapy.

IN AN ADVANCE that could benefit cancer patients, Roel Nusse and his colleagues announced last April that they had purified a powerful factor that prompts blood-forming stem cells to proliferate. The molecule, named Wnt, had eluded purification for years because it has a fatty "tag" that makes it stick to test tubes. Scientists are now evaluating Wnt's ability to restore blood cells that are destroyed during chemotherapy for cancer. Physicians might one day remove a sample of a patient's bone marrow, where stem cells for the blood system reside, expose them to Wnt in the laboratory to cause them to divide, and return the expanded population of cells to the patient as a treatment.

Medical Treatment

BAHIGE M. BAROUDY and CHRIS HITCHCOCK

Baroudy, director, department of antiviral therapy, Schering-Plough Research Institute, Kenilworth, N.J., and Hitchcock, senior director of exploratory development, Pfizer Global Research and Development, Sandwich, England

Created drugs that blocked a receptor to prevent HIV from entering cells.

HIV, THE VIRUS that causes AIDS, must bind to several receptor molecules to infect cells. One such receptor is called CCR5. People who have naturally occurring mutations in the receptor show some degree of resistance to HIV infection. Bahige Baroudy and Chris Hitchcock led teams at their respective pharmaceutical companies to formulate small-molecule drugs that can block CCR5, preventing HIV from entering cells and thereby halting its ability to reproduce and spread. Both companies' compounds entered clinical trials in human patients in the past year. Preliminary results suggest that the potential drugs have few side effects and are well tolerated by patients.

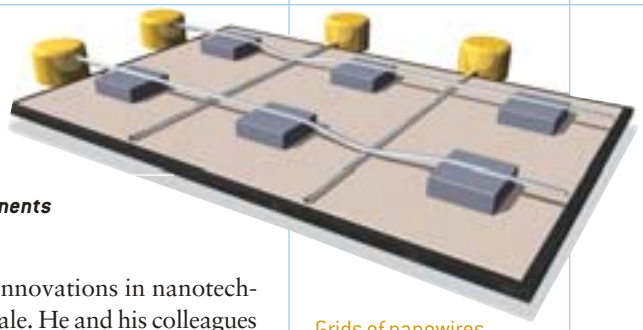
IBM RESEARCH (*top*); COURTESY OF REYA AND DUNCAN *Duke University* (*bottom*)

Nanotechnology and Molecular Electronics

CHARLES LIEBER

Professor of chemistry, Harvard University

Made nanowires, switches, sensors and lasers; fabricated electronic components and devices with features only billionths of a meter across.



Grids of nanowires may form circuits in future computers.

CHARLES LIEBER'S laboratory is responsible this year for several key innovations in nanotechnology, the controlled manipulation of matter at the atomic or molecular scale. He and his colleagues have achieved better control over nanowire growth, gaining the ability to build wires of differing lengths and thicknesses. In addition, the laboratory has made nano "on/off" switches that might be useful for digital memory storage. With such electronic controls, nanowire lasers could potentially be used to transmit information across a silicon chip, to etch microchips or to give laser surgery greater precision. In January, Lieber published a paper that described how a cadmium-sulfide nanowire could produce laser light from the ends. Last year saw the creation of a nanoscale biosensor, in which certain molecules (antigens) present in the bloodstream activate a nanowire transistor.

Privacy and Security

RAKESH AGRAWAL

Fellow, IBM Almaden Research Center, San Jose, Calif.

Devised methods to preserve the privacy of information in large databases.

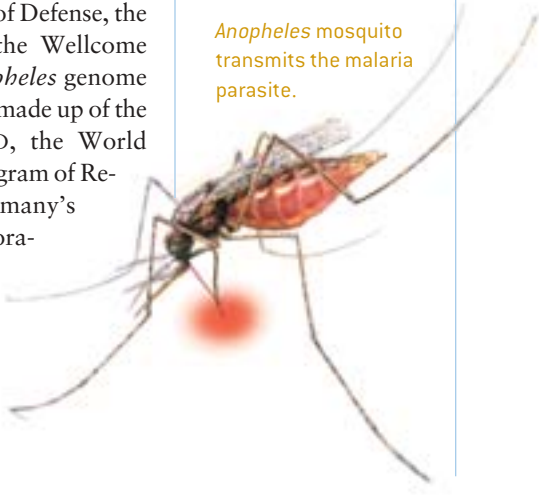
WE FORGET THINGS we do not need or want; perhaps databases must cull their memories in the same way to keep sensitive data from falling into the wrong hands. As a pioneer of data mining—the art of extracting useful patterns from masses of data—Rakesh Agrawal knew that this technology could take off only if privacy could be assured. Because the most important data are indeed sensitive—involving purchasing decisions, online searches, health records and the like—he sought ways to make misuse impossible once the information had been analyzed into a general trend. Recently he developed software that enables a computer to decide what to delete or, in less onerous cases, to quarantine data from all but the most privileged users. Another method he has investigated would safeguard one data point among many like it—say, an individual's age, as entered on a Web site form—by adding or subtracting a random number to it. The system would then aggregate all the data points and statistically reconstruct the overall distribution of ages with reasonable accuracy, while keeping each individual's age a secret.

Public Health and Epidemiology

THE MALARIA PARASITE/MOSQUITO GENOME PROJECTS

Unraveled the genetic information of the parasite that causes malaria and of the mosquito that spreads it.

MALARIA CONTINUES to be the most deadly disease in human history, slaying millions every year. Late in 2002 two international research consortia announced that they had sequenced the DNA for the malaria parasite *Plasmodium* and for the *Anopheles* mosquito, which transmits the parasite from person to person. The extraordinary potential of this achievement should accelerate the design of a vaccine and of drugs targeted to these organisms' genetic vulnerabilities. It will also encourge the development of environmentally sound methods to control mosquitoes. The sequencing of the *Plasmodium* genome was done by a partnership composed of the Institute for Genomic Research (TIGR), the U.S. National Institute of Allergy and Infectious Diseases (NIAID), the Wellcome Trust, the Burroughs Wellcome Fund, the U.S. Department of Defense, the Stanford Genome Center and the Wellcome Trust Sanger Institute. The *Anopheles* genome was sequenced by a collaboration made up of the Celera Genomics Group, NIAID, the World Health Organization's Special Program of Research on Tropical Diseases, Germany's European Molecular Biology Laboratory, the Institute of Molecular Biology and Biotechnology in Crete, the Pasteur Institute in Paris, TIGR, Genoscope (the French National Sequencing Center), and the universities of Iowa, Rome, Notre Dame and Texas A&M.



Anopheles mosquito transmits the malaria parasite.

SLIM FILMS (*top*); ROBERTO OSTI (*bottom*)

BUSINESS LEADER of the year

TOYOTA MOTOR CORPORATION

Toyota City, Japan

Commercialized affordable hybrid cars.

WHEREAS MOST OTHER automakers have merely talked of combining internal-combustion engines with electric motors, Toyota has actually been selling such a hybrid car for years. Called the Prius, it came out first in Japan in the late 1990s and soon after in the U.S. Toyota's 2004 Prius, due out in October, appears to get around the dismal engineering trade-offs associated with hybrids by improving performance and fuel economy over last year's model while keeping the price the same, around $20,000.

Prius, a hybrid vehicle from Toyota, saves fuel and cuts down on pollution by pairing a small engine with an electric motor.

Hybrid power plants do away with big engines and their extravagance with both fuel and pollution by substituting a small engine, to provide steady power, and an electric motor to assist it during acceleration. The strategy pays off best in stop-and-go city driving (which the Environmental Protection Agency test emphasizes strongly), when a big engine goes almost entirely to waste. Indeed, the Prius actually gets better mileage in the city than on the highway. Unlike the so-called mild hybrids, the Prius does not use the motor solely as an assist but is capable of cruising around on electricity alone.

The new model has been lengthened just enough to move it into the midsize category, giving it more legroom. It also has better acceleration. Yet according to preliminary estimates by the EPA, it now gets 59 miles per gallon in the city and 51 miles per gallon on the highway, up from 52 and 45 mpg, respectively, for the 2003 model. The Prius now goes about twice as far on a gallon of gasoline as the average car in the U.S. fleet; if all vehicles did that well, it would save the U.S. some 1.5 billion barrels of imported oil a year.

TOYOTA PRODUCT COMMUNICATIONS

Aerospace

BURT RUTAN

President, Scaled Composites, Mojave, Calif.

Designed a reusable suborbital passenger spacecraft.

SpaceShipOne, a passenger spacecraft, comes in for a landing.

BURT RUTAN first gained wide recognition when his twin-engine, polymer-composite Voyager airplane became, in 1986, the first aircraft to travel around the world nonstop. Rutan and his collaborators have completed more than 35 truly innovative manned and unmanned aircraft. In April his company, Scaled Composites, unveiled its entry to the X Prize, a privately funded contest established in 1996 that will award $10 million to the first firm that builds and flies a reusable suborbital passenger spacecraft. Scaled Composites's design, called SpaceShipOne, is similar to the U.S. Air Force's late-1950s X-15, which was launched from an airborne B-52. One of the most innovative qualities of the design forwarded by Rutan is a tail that flips up to brake through the air during reentry. (The company has not released any information regarding how much it would cost for someone to take a ride on the completed spacecraft.) Scaled Composites is one of the few companies that are taking an active role in privately funded space research.

Agriculture

FERNANDO DE CASTRO REINACH

General partner, Votorantim Ventures, São Paulo, Brazil

Started biotechnology companies that are trying to improve Brazilian crops.

AS A UNIVERSITY professor, Fernando de Castro Reinach has made a name for himself by initiating a project that in 2000 sequenced the genome of *Xylella fastidiosa,* a bacterium that destroys millions of dollars' worth of Brazilian citrus every year. That effort put Brazil on the international biotech map and produced a national cadre of highly trained scientists. In 2002 Reinach also took on the role of general partner at Votorantim Ventures, one of Brazil's largest venture capital funds. The fund has started up (among others) the companies Alellyx and Canavialis, both with Reinach as temporary CEO. This past spring Alellyx determined that a mutant of the tristeza virus was the cause of $20-million damage to Brazil's 2002 orange crop. Alellyx is now working on a laboratory test for detecting the disease and developing a genetically modified orange tree with resistance to the mutant strain. Canavialis, meanwhile, is laboring on disease-resistant sugar cane.

Automotive

DAIMLERCHRYSLER

Stuttgart, Germany

Pushed fuel-cell cars toward the commercial marketplace.

Oxygen goes in and mere water comes out of DaimlerChrysler's fuel bus.

SINCE THE MID-1990s, DaimlerChrysler has spearheaded a fuel-cell project. Recently the company began the first field test of a fleet of electric vehicles powered by the technology, which is essentially hydrolysis in reverse. About 30 such buses were distributed to a number of European cities this year; cars, based on the Mercedes-Benz A-Class, are to be tested in the U.S. by the end of this year. In fuel cells, ambient oxygen reacts with hydrogen (stored as compressed gas), producing mere water. They thus achieve the California-mandated goal of zero smog and zero greenhouse emissions. The first cars will serve as package delivery vehicles for UPS and will tank up at the EPA's office in Ann Arbor, Mich.

COURTESY OF SCALED COMPOSITES (*top*); MERCEDES-BENZ USA (*bottom*)

Other Business Leaders

Enzymes that break down the leaves and stalks of corn and other biomass products to create ethanol fuel may now be made more inexpensively.

Chemicals and Materials

NOVOZYMES

Bagsvaerd, Denmark

Launched a program to reduce by an order of magnitude the cost of enzymes for making ethanol.

"WHITE BIOTECHNOLOGY" involves finding natural organisms and compounds that can perform the work done today by petroleum-based chemicals. A major player in this arena is Novozymes, the world's largest producer of industrial enzymes. The company is just completing a successful three-year effort funded by the U.S. Department of Energy's biomass program to seek a 10-fold reduction in the cost of producing a critical enzyme blend for the making of ethanol from the leaves and stalks of corn. The blend is used to create sugar mixtures required in the production of clean, renewable biomaterials for industries such as chemicals and transportation fuels. Another company—Genencor—is independently pursuing the same research. An enzymatic process to produce these sugars offers the best prospects for making this approach competitive with petroleum-based fuels and chemicals. Before this breakthrough, enzymes were considered too expensive to be utilized for the conversion of cellulose to sugars. The teams used a variety of advanced biochemical, genetic and engineering technologies to enhance enzyme activities. Novozymes has also recently released other innovative enzymes for various industrial applications using a process it licenses called directed evolution, which introduces new combinations of genes and then screens for the best enzymes.

Communications

STEVEN JOBS

CEO, Apple Computer, Cupertino, Calif.

Started an online music service that serves as a model for the rest of the record industry.

TWO TECHNOLOGIES, the MPEG audio file format and decentralized file-sharing software, have made life difficult for the recording industry. Although a few companies launched pay-for-play online music stores this year, Apple's iTunes stood out from the pack for its simplicity and low cost (only 99 cents per song). It also received attention for its popularity: by September, more than 10 million songs had been purchased. Unlike some other services, it allowed downloading by the track and did not require a subscription fee. Originally, iTunes was open exclusively to Macintosh users; the company recently unveiled a Windows version of the service. Its chances for long-term success are still unknown, but Apple has at least made a stab at a workable approach to online music distribution.

iTunes stands out among music services for its simplicity and low cost.

COURTESY OF APPLE (*bottom*)

Computing

INTEL CORPORATION

Santa Clara, Calif.

Crafted possible solutions for Internet bottlenecks and constructed chip sets that make wireless networking easier.

THERE ARE MANY promising ideas that the Internet cannot try out by itself, either because it would bog down in a flood of data or lay itself open to malicious attacks. In June, to provide an independent test bed for those ideas, Intel formally launched PlanetLab, contributing the first 100 of a planned 1,000 computer nodes maintained by heavy Net users around the world, mostly universities. The project is already helping to monitor system usage, locate bottlenecks, and set traps for the propagators of viruses and worms. Meanwhile, to encourage consumer use of network services, Intel has launched its Centrino line of wireless products, which take advantage of the increasing number of Wi-Fi "hot spots," in places such as food courts and city squares. Centrino laptops contain a wireless communications card, a communications chip and a microprocessor all optimized to work together. To make portable Internet access more practical, the computers squeeze more processing power out of each watt, extending battery life—perhaps the single greatest impediment to mobility.

Defense

CEPHEID

Sunnyvale, Calif.

Enabled some post offices to track anthrax through use of biodetectors.

THE ANTHRAX ATTACKS in the fall of 2001 set off a scramble to find readily deployable technology for detecting biological weapons. Cepheid has become a leader in this emerging marketplace by making biodetectors that distinguish pathogens from benign microbes by analyzing their DNA. The company supplies its GeneXpert technology to Northrop Grumman, which received a $175-million contract from the U.S. Postal Service earlier this year to install technology in its facilities to detect anthrax. GeneXpert speeds the process of carrying out the polymerase chain reaction, which amplifies samples of DNA. The process, which usually takes several hours, can be completed within 30 minutes with the Cepheid device. After the anthrax attacks, the company bolstered revenues substantially by selling its products to the U.S. military and federal and state public health laboratories.

Identification of the anthrax bacterium (*above*) now takes place in minutes, not hours.

Energy

CHANGING WORLD TECHNOLOGIES

West Hempstead, N.Y.

Devised a method for turning solid waste into oil.

MOTHER EARTH learned long ago how to turn biomass into oil, but for those of us who cannot wait for eons while subterranean plates grind, heat and decompose dead plants, Changing World Technologies has evolved a plan. It runs a slurry of biomass through a pressure cooker to break down the longer polymers, then releases the material into a much lower pressure to boil off half the water. The oil in the remaining sludge can then be separated by centrifuge and cracked, just as with natural oil. The company has already demonstrated the process in a small plant in Philadelphia, and this past summer it opened a larger plant in Missouri that plans to convert 200 metric tons of offal from a nearby turkey processing plant into 10 tons of gas and 600 barrels of oil. Even if the idea contributes only a smidgen to our energy needs, it will certainly help get rid of burgeoning waste.

Fuel cell developed at Los Alamos could become a key component of zero-emission coal plants.

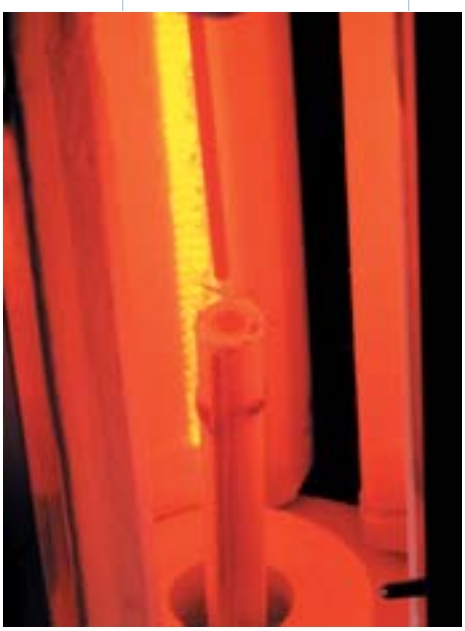
Environment

ZECA CORPORATION and LOS ALAMOS NATIONAL LABORATORY

Calgary, Canada, and Los Alamos, N.M.

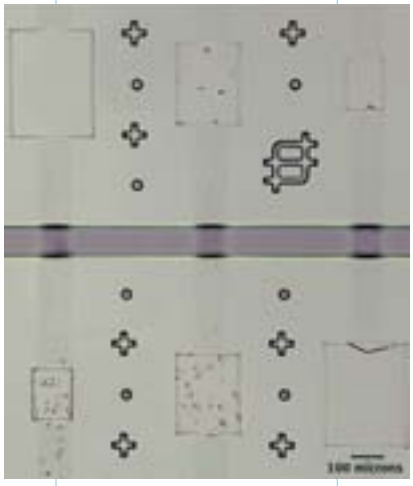
Commercialized a process to convert coal into hydrogen fuel.

NORTH AMERICA is blessed with vast seams of coal, but conventional coal-fired power plants release large amounts of the greenhouse gas carbon dioxide and other emissions into the atmosphere. In recent years, researchers at Los Alamos National Laboratory have been developing a zero-emission concept for power generation. The process would convert coal into methane, which would in turn be reformed into hydrogen and calcium carbonate. The hydrogen would go to a fuel cell to generate electricity while the calcium carbonate would be broken down to calcium oxide and carbon dioxide. The latter gas could be incorporated into a mineral (magnesium carbonate), then disposed underground. In essence, the carbon would return to the earth from which it was mined. The process is about 70 percent efficient, roughly twice that of current coal-fired plants. A consortium of energy companies and research institutes formed the Zero Emission Coal Alliance in 1999. The for-profit ZECA Corporation replaced the alliance in 2001 and is now working to design and construct a pilot plant.



JEFF JOHNSON (*top*); COURTESY OF LOS ALAMOS NATIONAL LABORATORY (*bottom*)

Protein crystals grow in wells of the Topaz Crystallizer chip.



Manufacturing

FLUIDIGM

South San Francisco, Calif.

Built microscopic channels, pumps and valves that will create the fluidic equivalent of microchips.

A START-UP co-founded by Stephen R. Quake, a young professor of biophysics from the California Institute of Technology, continues to distinguish itself as a leader in the emerging field of microfluidics. Fluidigm moved ahead during the past year with the release of the Topaz Crystallizer, a system that can very rapidly crystallize large numbers of proteins for the purpose of learning their structures. Moreover, the system can work with extremely small volumes of protein solutions, enabling many tests to be run in parallel. To build the microfluidic system, Quake used a novel lithography technique that constructs three-dimensional networks of microscopic channels, valves and reaction chambers. It creates these structures using a silicone-based rubber stamp. In September 2002 the company announced that it had employed a microfluidic valve technology, built using this so-called soft lithography method, to partition a sample into 20,000 polymerase chain reactions (gene amplifications), with the solution in each reaction holding less than a billionth of a liter.

Medical Treatment

GENENTECH

South San Francisco, Calif.

Developed the first commercial drug that stops blood vessel growth in tumors.

GENENTECH is poised to become the first company to make a commercial success of drugs to block angiogenesis, the formation of new blood vessels. To survive and spread, cancers must make yards of new vessels, called capillaries. Compounds that stifle the growth of new vessels were shown years ago to shrink tumors in animals, but supportive data in humans have been slow to appear. Genentech's angiogenesis inhibitor is bevacizumab, trademarked as Avastin. It is a monoclonal antibody—a specific molecule produced by the immune system—that targets a growth factor crucial to vessel formation. Last May the company announced that Avastin improved the survival of patients with metastatic colorectal cancer when administered along with traditional chemotherapy. Several large-scale clinical trials involving people with breast cancer and nonsmall-cell lung cancer are also in progress, and the drug has been granted fast-track status by the U.S. Food and Drug Administration.

Nanotechnology and Molecular Electronics

NANOSYS

Palo Alto, Calif.

Funded the development of nanotechnology.

Vials hold semiconductor nanocrystals for which Nanosys controls the intellectual-property rights.

NANOSYS spent 2003 snapping up proprietary rights to some of the year's key nanotechnology innovations, including nanowire lasers and nanocomposite solar-cell technology. By May the firm had secured an additional $38 million in funding, giving it a total of nearly $70 million to continue its buying spree. In June, Nanosys forged an exclusive licensing agreement with Yissum, the technology-transfer subsidiary of the Hebrew University of Jerusalem. Thanks to that arrangement, Nanosys now controls the patents for more than 120 basic nanocrystal materials and applications. These deals give the company the ability to commercialize a vast array of nanotechnology products. Improved solar cells, for example, could be on the market as early as 2006. Nanosys intends to bring these products to market through corporate partnerships in various industries.

COURTESY OF FLUIDIGM (*top*); COURTESY OF NANOSYS (*bottom*)

Privacy and Security

ANONYMIZER

San Diego, Calif.

Protected the anonymity of those offering tips about corporate malfeasance.

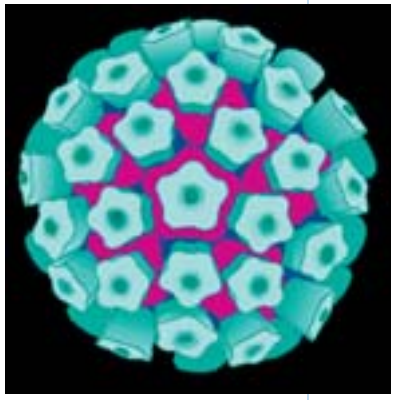
WITH THE PASSAGE of the Sarbanes-Oxley Act of 2002, companies are now required to refrain from an act of retribution against employees who blow the whistle on accounting practices they deem dubious. How to be seen to be in compliance with the law remains an open question, one to which an answer has been offered by the Internet security firm Anonymizer. In April the company launched SECtips.com, a Web-based service that any company can join. Member companies must provide their employees with a password that would enable them to submit tips from any computer without fear of identification. Despite the name of the site, the tips do not go directly to the Securities and Exchange Commission but rather to the company's own compliance officer. The compliance officers do not themselves enjoy anonymity; if they receive a tip and sit on it, they can assume that prosecutors will eventually find out.

Public Health and Epidemiology

MERCK RESEARCH LABORATORIES

West Point, Pa.

Created a vaccine that may help eliminate cervical cancer.



Human papillomavirus vaccine has the potential to combat the virus that accounts for almost all cervical tumors.

CERVICAL CANCER kills 250,000 women every year, more than any other type in developing countries. In November 2002 scientists at Merck Research Laboratories announced that they had developed a vaccine that protects women from viral infections caused by a strain of human papillomavirus (HPV-16) found in roughly half of all cervical tumors. The researchers made the vaccine by mass-producing one of two proteins that form a shell around the HPV-16 virus. The protein then elicits an immune reaction. To test the vaccine's effectiveness, a study at multiple research centers tracked 2,392 women, half of whom received the vaccine and half a placebo. In regular samples taken during the course of the study, none of the women receiving the vaccine tested positive for the virus, but 41 in the placebo group did.

Robotics

iROBOT

Burlington, Mass.

Introduced the first truly mass-market household robot.

Roomba robot vacuums the floor unaided.

FOR DECADES, technopundits have been predicting that robots would soon whiz into our daily lives: fetching the paper, cleaning the house and fixing dinner. If that vision is now starting to become a reality, it is in large measure thanks to iRobot. The company was founded in 1990 by three leading roboticists at the M.I.T. Artificial Intelligence Lab—among them the lab director, robotics pioneer Rodney Brooks. In the fall of 2002 the company introduced Roomba, the first mass-market household robot. Roomba will automatically vacuum and sweep a floor while avoiding obstacles. The breakthrough was not the technology per se—most of the components were available back in the 1980s—but the packaging into a useful, durable and affordable unit. Another iRobot product, a remote-controlled tanklike robot called PackBot, was deployed by U.S. forces in Afghanistan during 2002. There, and later in Iraq, PackBots inspected potential booby traps and ambush positions.

LINDA STANNARD *University of Cape Town (top)*; COURTESY OF iROBOT *(bottom)*

SCIENTIFIC AMERICAN 50

POLICY LEADER of the year

GRO HARLEM BRUNDTLAND

Former secretary general, World Health Organization

Coordinated a rapid global response to stem the SARS outbreaks.

WITH TYPICAL SCANDINAVIAN understatement, Gro Harlem Brundtland, then the secretary general of the World Health Organization, worked mainly undercover to meet the challenge of SARS. But she recognized the need to concentrate minds with decisive strokes and did so on three occasions last year. She issued the first global health alert ever, warned about travel to Toronto and other cities, and frankly criticized the Chinese government, which had suppressed news of the outbreak in Guangdong Province.

Children in Hong Kong have surgical masks put on in early April in the hopes of fending off SARS.

Quarantines, perhaps helped along by the simple changing of the seasons, contained the outbreak, and that is why the unprecedented toughness is now seen as fully justified. In any case, the old-fashioned containment measures have bought time for the molecular biologists to develop better diagnostic tests and the first vaccines. Furthermore, by setting the precedent of exerting pressure on influential member states (of which there are 192), Brundtland has made life easier for her successors if they should face similar situations. In all these actions, she worked together closely with David Heymann, director of the WHO's office of communicable diseases, and with the Centers for Disease Control and Prevention, whose director, Julie Gerberding, lent critical support. The CDC's Thomas Ksiazek led a team that quickly identified the coronavirus responsible for SARS.

Brundtland, a medical doctor, honed her political talents in a variety of senior governmental jobs in her native Norway before becoming its prime minister, a position she held for three terms. At WHO, she used those skills to raise the organization's profile and to cultivate support in the United Nations. By vigorous fund-raising, particularly among private foundations, she increased the WHO budget by about two thirds, to about $1 billion a year. The money goes to finish old projects, such as the eradication of polio, and the new ones she started, including bringing low-cost drugs to poor countries and improving the surveillance system for emerging diseases, such as SARS. Although Brundtland would very likely have sailed into a second term, she decided to retire, citing her age, which is 64.

PAUL HILTON *EPA Photo (top)*; ANAT GIVON *AP Photo (bottom)*

Aerospace

HAROLD W. GEHMAN, JR.

Chair, Columbia Accident Investigation Board

Distinguished himself for a hard-nosed approach to investigating the* Columbia *accident.

EARLY CRITICS of the board that NASA appointed to investigate the destruction of the space shuttle *Columbia* said the all-government panel would not be independent enough to uncover the underlying factors that led to the orbiter's breakup during reentry on February 1. The board's August 26 report may have forever silenced those doubters. The panel blamed the mishap not only on the damage to the left wing by a chunk of foam shortly after the launch but also on the institutional culture that allowed a preventable accident to occur. But even before the report was released, the chief investigator, Harold Gehman, had already stood out as someone who would not be constrained by the space agency. His leadership of the accident board may serve as a model for how to bring needed scrutiny to bear on an organization in crisis.

Agriculture

PAUL R. POLAK

President, International Development Enterprises, Lakewood, Colo.

Encouraged local markets to improve access to water for Third World farmers.

PAUL POLAK has pioneered an approach to poverty alleviation that has already markedly improved the lives of millions of people. By providing small land holders with access to affordable microirrigation technologies—such as low-cost drip irrigation—Polak aims to help more than 30 million rural farm families in the developing world rise out of poverty by 2015. He has been pursuing this goal by spearheading the Smallholder Irrigation Market Initiative (SIMI) of International Development Enterprises. SIMI, active in both Africa and Asia, operates not by providing handouts, which often do not produce sustainable change, but by encouraging participation of local markets in developing improvements in irrigation—a $100-an-acre drip-irrigation package in India, for instance. In the summer of 2002 SIMI Net was launched to compile and disseminate useful knowledge related to smallholder irrigation.

Low-cost drip irrigation delivers water to plant roots.

Automotive

KEN LIVINGSTONE

Mayor, London, England

Implemented tariffs to regulate city traffic.

ECONOMISTS HAVE LONG fretted about externalities—the exploitation of common resources by some people at the expense of others. Driving a car in a city and thereby clogging traffic offers a classic example of such an externality, one that can be balanced only by imposing a tax so unpopular that politicians never dared to try it on a large scale, until early this year, when London's mayor, Ken Livingstone, showed the necessary courage. The foray into such social-cost pricing has worked: now that drivers must pay a £5—nearly $8—fee, traffic jams are a third less common and the drivers themselves are happy with the trade-off. Livingstone's show of guts and leadership was widely questioned at first, and many commentators thought that he might forfeit his office because of it. Now it looks like he'll be getting another term—and mayors of other big cities, including those on this side of the Atlantic, are taking notice.

Charging fees for road use has unclogged the streets in central London, making traffic jams much less common.

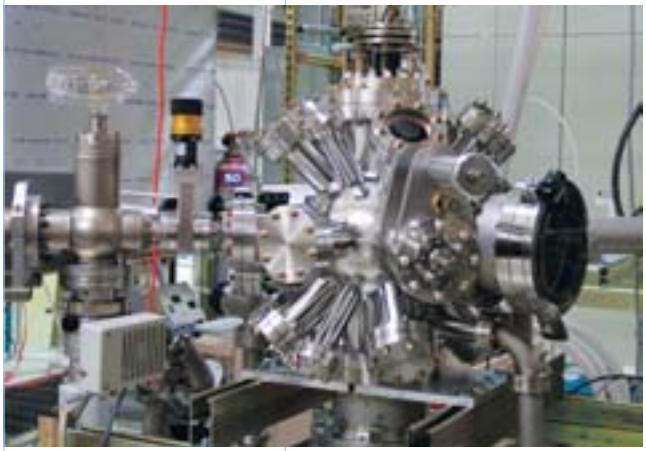
RICHARD T. NOWITZ *Corbis (top)*; RICHARD OLIVIER *Corbis (bottom)*

Other Policy Leaders

Chemicals and Materials

ANTHONY J. MUSCAT

Associate professor of chemical and environmental engineering, University of Arizona



Reactor vessel uses an environmentally friendly process to clean and build microelectronic devices.

Introduced environmentally friendly chipmaking technologies.

THE BEST INCENTIVE for the semiconductor industry to adopt environmentally friendly chipmaking technologies is if those same manufacturing methods also save piles of money. Last year Anthony Muscat and his team of researchers demonstrated techniques using supercritical carbon dioxide (in a pressurized state poised between liquid and gas) to clean the porous insulating material used in today's most advanced microchips. Supercritical carbon dioxide cleans better than the chemicals currently used. In addition, supercritical CO_2 can be acquired from the copious emissions from most heavy industries and is easily recycled. Muscat's group is also researching chemicals that can block out areas of a chip surface like masking tape around a painted wall, eliminating costly and polluting steps in the chip-etching process.

Communications

EDWARD FELTEN

Professor of computer science, Princeton University

Persistently criticized proposed digital TV standards.

CORPORATIONS INTENT on monopolizing the digital economy have come to fear Edward Felten, who has fought their claims with technical analysis sharpened by a sense of the ridiculous. When Microsoft, in its antitrust case, claimed that its browser could not be separated from its operating system, Felten separated them. When the Recording Industry Association of America unveiled a music-encryption technology, he found holes in it (and was almost sued for publishing the holes). Now he is fighting Hollywood's efforts to introduce legislation mandating privacy devices for all digital products, particularly digital television. In testimony before Congress, he pointed out that a would-be pirate could already videotape a movie for a few dollars rather than go the digital route, which would cost hundreds of dollars. His Web site posts comical examples of devices, such as toys, that a proposed law would digitally bind and gag.

Computing

HENRY CHESBROUGH

Visiting assistant professor, Institute of Management, Innovation and Organization, University of California, Berkeley

Advocated the abolition of the not-invented-here syndrome that afflicts many companies.

WHILE WORKING for disk-drive maker Quantum in the 1980s, Henry Chesbrough began to wonder why large corporations such as IBM and AT&T couldn't seem to reap the market benefits of the advanced technologies they created. The problem, he decided, was that these megacorporations were too insular: the companies used only concepts conceived in-house. Recently technological upheavals in computing and communications, often fostered in start-ups or university research centers, have made some of these companies realize that they no longer have a monopoly on ideas. In his influential book *Open Innovation: The New Imperative for Creating and Profiting from Technology,* published this year, Chesbrough suggests that the solution is to eliminate the boundaries that traditionally exist among businesses and universities. Although companies may share their research, what they gain in return may outweigh the cost of this sacrifice.

IBM Research has opened its doors to new ideas.

COURTESY OF ANTHONY J. MUSCAT (*top*); COURTESY OF IBM (*bottom*)

Defense

ARTHUR K. CEBROWSKI

Director, Office of Force Transformation, U.S. Department of Defense

Articulated the "network-centric" approach to warfare implemented during the Iraq conflict.

THE OUTSTANDING performance of U.S. military forces in this year's war in Iraq can be ascribed in large part to the remarkable coordination of action among all the participants. This radical approach to war fighting, which links units from multiple services electronically to permit rapid decision making on the battlefield, is known as network-centric warfare. Since 1995 Arthur Cebrowski has led the effort to develop and implement this information-based strategy within the Pentagon, where he is known informally as its transformation czar. Cebrowski is credited not only with best articulating and advancing the cause of network-centric warfare but also with laying much of the groundwork for this vision in his prior roles as director of command, control, communications and computers on the Joint Chiefs of Staff and as head of the Naval War College.

Linking units from multiple military services permits rapid decision making on the battlefield.

Economic Development

FRANCES J. STEWART

Professor of development economics, University of Oxford

Promoted antipoverty campaigns to help quell armed conflicts in developing nations.

WHEN TRYING to make sense of the wars and other struggles that wrack the world today, journalists and policymakers tend to trace the political roots, especially ethnic tensions. But Frances Stewart is beginning to convince people that the economic roots are just as important. Stewart started the Center for Research on Inequality, Human Security and Ethnicity this past April. Since the 1960s she has studied and promoted poverty alleviation, particularly in the form of long-term aid that assists people in helping themselves, political institutions that defend the interests of the poor, and the removal of trade barriers against developing nations' exports. Her recent work on conflict has influenced institutions such as the United Nations, which traditionally paid little attention to the economics of civil conflicts. Stewart argues that long-standing antipoverty programs should carry on even while war rages; by reducing inequalities, they can hasten the end of conflict.

Energy

KURT YEAGER

Chief executive officer, Electric Power Research Institute (EPRI), Palo Alto, Calif.

Lobbied for a major overhaul of the power industry long before the 2003 blackouts.

AFTER AUGUST'S great blackout in the U.S., no one needs to be reminded that the electric grid has not kept pace with rising demand and sweeping market deregulation. Yet Kurt Yeager began reminding the country in 1996, when he took the top job at EPRI. One of his first actions as chief executive was to assemble experts from industry and government to chart the future and lay out the needed technologies and the money they would cost. Their conclusions were summarized in the EPRI Electricity Technology Roadmap and continually updated. They included a call for reductions in greenhouse emissions, improvements in power quality and—notably—a 250 percent increase in spending on transmission infrastructure. The spending would have covered not only new power lines but also grid-level electric storage and other features that would have come in handy on August 14, 2003. Since that dark day, Yeager has argued that after years of borrowing against the future, the infrastructure bill has finally come due.

August 14, 2003, was a dark day for New York City and a big swath of the rest of North America.

EVAN VUCCI *EPA Photo (top)*; JASON SZENES *EPA Photo (bottom)*

Other Policy Leaders

Environment

ANDREW BALMFORD

Conservation scientist, University of Cambridge; co-founder, Cambridge Conservation Forum

Described how economic motives can justify preserving natural habitats.

Forest clearance can decrease the economic benefits reaped from a habitat.

CAN YOU PUT a price tag on nature? In an influential article last year in *Science*, Andrew Balmford attempted to do just that. He and his co-authors reviewed studies of five habitats in Malaysia, Cameroon, Thailand, Canada and the Philippines that had been converted to private use. The researchers found that the economic benefits from the habitats consistently decreased after they were razed, drained or dynamited for logging, farming or fishing. For example, the profits earned from turning a Thai mangrove into a shrimp farm were far outweighed by the costs of damage to offshore fisheries and the loss of storm protection. But Balmford has gone beyond simply publishing these results; he works with conservation groups to determine the best ways to reverse the shrinkage of natural habitats. In 2000 he co-founded the Cambridge Conservation Forum to strengthen the links between researchers and conservation practitioners.

Medical Treatment

ANTHONY S. FAUCI

Director, National Institute of Allergy and Infectious Diseases

Convinced the Bush administration to commit $15 billion to combat AIDS in Africa and the Caribbean.

IN HIS FEBRUARY State of the Union address, President George W. Bush asked the U.S. to commit $15 billion over the next five years to combat AIDS in Africa and the Caribbean. Much of the credit for bringing about this development, according to AIDS activists, goes to Anthony Fauci, who worked to convince administration officials to dedicate resources on a large scale. Congress is expected to pledge between $2 billion and $3 billion to the initiative in fiscal year 2004. Among the project's goals are to prevent 60 percent of the 12 million new infections anticipated in 14 targeted countries, to offer antiretroviral drugs to two million HIV-positive people, and to provide care for 10 million AIDS patients and orphans. An estimated 42 million people worldwide are living with HIV, and 20 million more have died of AIDS, according to the Joint United Nations AIDS Program.

Preventing newborns from contracting AIDS is a priority.

Manufacturing

HEATHER WHITE

Founder and executive director, Verité, Amherst, Mass.

Campaigned to extricate migrant workers from virtual slavery.

FOR 15 YEARS, Heather White tracked down outside contractors who could serve as suppliers to apparel companies. Today she is a watchdog of the contractors she once hired. Verité, an organization that she started in 1995, has become one of the foremost groups involved in monitoring factory conditions worldwide to identify worker exploitation and health and safety infractions. Last summer Verité started a campaign to combat debt bondage in Asia. Workers from Vietnam, Thailand and the Philippines migrate to Taiwan and other countries that want to stay competitive with mainland China. They pay high placement fees and deposits to find jobs and are often relegated to a form of indentured servitude. Since it opened its doors, Verité has performed 1,000 "social audits" in factories to assess compliance with workplace standards. Since 2002 the State of California Public Employees' Retirement System has based some of its investment decisions on Verité's ratings of labor practices in developing countries.

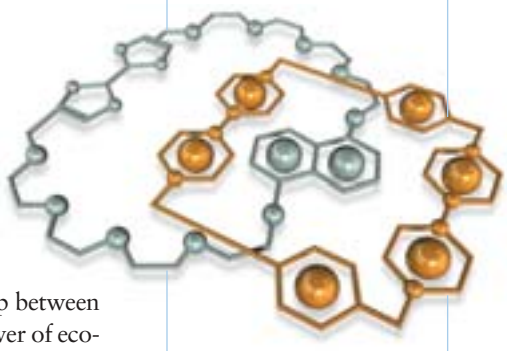
COURTESY OF ANDREW BALMFORD (*top*); GIDEON MENDEL *Corbis* (*bottom*)

Nanotechnology and Molecular Electronics

PHILLIP J. BOND

U.S. undersecretary of commerce for technology

Promoted nanotechnology effectively within the executive branch.



Molecular transistors may become a linchpin of the nanotechnology era.

FROM THE TIME he was sworn into office in October 2001, Phillip Bond has been an outspoken public supporter of nanotechnology. Bond is particularly keen on making sure that the U.S. is prepared to blaze a trail in this new frontier that bridges the gap between basic science and applied technology. In his view, nanotechnology will become a key driver of economic growth and will promote the nation's leadership in technology, but the country will need to invest substantially in nanotech to realize that benefit. The Commerce Department supports research on nanotechnologies, mostly through the National Institute of Standards and Technology. The Bush administration has requested $46.2 million for NIST for the 2004 federal fiscal year, more than 5 percent of the proposed $847 million in federal spending on nanotechnology.

Privacy and Security

JOE SIMITIAN and STEVE PEACE

Simitian, state assemblyman (Palo Alto),
and Peace, former state senator (San Diego County), California State Legislature

Sponsored law that requires issuing warnings when possible identity theft occurs.

THE THEFT of data, like other forms of white-collar crime, is so embarrassing that companies are loath to report it. As a result, many people never learn that hackers or criminals working on the inside have invaded their privacy. Thanks to the sponsorship of Assemblyman Joe Simitian and former state senator Steve Peace, a law remedying that problem took effect in California in July. From now on, companies must notify by letter or e-mail anyone whose name, Social Security number, driver's license number or bank account data may have fallen into the wrong hands. Companies that do not work hard enough to make their employees aware of the need for such disclosures are subject to class-action lawsuits. The two legislators' leadership has already had wider repercussions: U.S. Senator Dianne Feinstein has said that she will introduce a federal bill modeled on the California law.

Public Health and Epidemiology

BILL & MELINDA GATES FOUNDATION

Seattle, Wash.

Gave hundreds of millions of dollars to meet the challenges of global health.

Bill and Melinda Gates visit Mozambique.

OVER THE PAST YEAR the Gates Foundation, which was established in 2000, evinced the power of its carefully honed vision and its huge endowment. Its strong philosophical base holds that millions of people in the developing world die every year from treatable diseases and that we in the developed world possess the means to prevent much of this suffering and death. Toward this end, the foundation's Global Health Program has committed more than $3 billion in grants to expand access to existing interventions for malaria, tuberculosis, trachoma and AIDS and to fund research into new tools. Two important milestones occurred in 2003. One was the establishment of Grand Challenges in Global Health, a $200-million program in partnership with the National Institutes of Health that will identify critical health problems and increase research on diseases of the developing world. The other is a $168-million grant to accelerate malaria research, the largest ever single donation toward fighting the mosquito-borne disease. The number of lives that will be touched by the foundation's vision and by its intelligent and generous implementation is probably without precedent.

SLIM FILMS (*top*); BILL & MELINDA GATES FOUNDATION (*bottom*)

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DOES RACE EXIST

By Michael J. Bamshad and Steve E. Olson

IF RACES ARE DEFINED AS GENETICALLY DISCRETE GROUPS, NO. BUT RESEARCHERS CAN USE SOME GENETIC INFORMATION TO GROUP INDIVIDUALS INTO CLUSTERS WITH MEDICAL RELEVANCE

Look around on the streets of any major city, and you will see a sampling of the outward variety of humanity: skin tones ranging from milk-white to dark brown; hair textures running the gamut from fine and stick-straight to thick and wiry. People often use physical characteristics such as these—along with area of geographic origin and shared culture—to group themselves and others into "races." But how valid is the concept of race from a biological standpoint? Do physical features reliably say anything informative about a person's genetic makeup beyond indicating that the individual has genes for blue eyes or curly hair?

The problem is hard in part because the implicit definition of what makes a person a member of a particular race differs from region to region across the globe. Someone classified as "black" in the U.S., for instance, might be considered "white" in Brazil and "colored" (a category distinguished from both "black" and "white") in South Africa.

Yet common definitions of race do sometimes work well to divide groups according to genetically determined propensities for certain diseases. Sickle cell disease is usually found among people of largely African or Mediterranean descent, for instance, whereas cystic fibrosis is far more common among those of European ancestry. In addition, although the results have been controversial, a handful of studies have suggested that African-Americans are more likely to respond poorly to some drugs for cardiac disease than are members of other groups.

Over the past few years, scientists have collected data about the genetic constitution of populations around the world in an effort to probe the link between ancestry and patterns of disease. These data are now providing answers to several highly emotional and contentious questions: Can genetic information be used to distinguish human groups having a common heritage and to assign individuals to particular ones? Do such groups correspond well to predefined descriptions now widely used to specify race? And, more practically, does dividing people by familiar racial definitions or by genetic similarities say anything useful about how members of those groups experience disease or respond to drug treatment?

In general, we would answer the first question yes, the second no, and offer a qualified yes to the third. Our answers rest on several generalizations about race and genetics. Some groups do differ genetically from others, but how groups are divided depends on which genes are examined; simplistically put, you might fit into one group based on your skin-color genes but another based on a different characteristic. Many studies have demonstrated that roughly 90 percent of human genetic variation occurs within a population living on a given continent, whereas about 10 percent of the variation distinguishes continental populations. In other words, individuals from different populations are, on average, just slightly more different from one another than are individuals from the same population. Human populations are very similar, but they often can be distinguished.

Overview/*Genetics of Race*

- The outward signs on which most definitions of race are based—such as skin color and hair texture—are dictated by a handful of genes. But the other genes of two people of the same "race" can be very different. Conversely, two people of different "races" can share more genetic similarity than two individuals of the same race.
- Nevertheless, scientists can use genetics to sort most large populations according to their ancestral geographic origin. This approach does not work as well for populations resulting from recent mixing with other groups, however.
- The medical implications of racial genetic differences are still under debate.

Classifying Humans

AS A FIRST STEP to identifying links between social definitions of race and genetic heritage, scientists need a way to divide groups reliably according to their ancestry. Over the past 100,000 years or so, anatomically modern humans have migrated from Africa to other parts of the world, and members of our species have increased dramatically in number. This spread has left a distinct signature in our DNA.

To determine the degree of relatedness among groups, geneticists rely on tiny variations, or polymorphisms, in the DNA—specifically in the sequence of base pairs, the building blocks of DNA. Most of these polymorphisms do not occur within genes, the stretches of DNA that encode the information for making proteins (the molecules that constitute

PHOTOILLUSTRATIONS BY NANCY BURSON (*preceding page*)

Individuals from different populations are, on average, just slightly more different from one another than are individuals from the same population.

much of our bodies and carry out the chemical reactions of life). Accordingly, these common variations are neutral, in that they do not directly affect a particular trait. Some polymorphisms do occur in genes, however; these can contribute to individual variation in traits and to genetic diseases.

As scientists have sequenced the human genome (the full set of nuclear DNA), they have also identified millions of polymorphisms. The distribution of these polymorphisms across populations reflects the history of those populations and the effects of natural selection. To distinguish among groups, the ideal genetic polymorphism would be one that is present in all the members of one group and absent in the members of all other groups. But the major human groups have separated from one another too recently and have mixed too much for such differences to exist.

Polymorphisms that occur at different frequencies around the world can, however, be used to sort people roughly into groups. One useful class of polymorphisms consists of the *Alu*s, short pieces of DNA that are similar in sequence to one another. *Alu*s replicate occasionally, and the resulting copy splices itself at random into a new position on the original chromosome or on another chromosome, usually in a location that has no effect on the functioning of nearby genes. Each insertion is a unique event. Once an *Alu* sequence inserts itself, it can remain in place for eons, getting passed from one person to his or her descendants. Therefore, if two people have the same *Alu* sequence at the same spot in their genome, they must be descended from a common ancestor who gave them that specific segment of DNA.

One of us (Bamshad), working with University of Utah scientists Lynn B. Jorde, Stephen Wooding and W. Scott Watkins and with Mark A. Batzer of Louisiana State University, examined 100 different *Alu* polymorphisms in 565 people born in sub-Saharan Africa, Asia and Europe. First we determined the presence or absence of the 100 *Alu*s in each of the 565 people. Next we removed all the identifying labels (such as place of origin and ethnic group) from the data and sorted the people into groups using only their genetic information.

Our analysis yielded four different groups. When we added the labels back to see whether each individual's group assignment correlated to common, predefined labels for race or ethnicity, we saw that two of the groups consisted only of individuals from sub-Saharan Africa, with one of those two made up almost entirely of Mbuti Pygmies. The other two groups consisted only of individuals from Europe and East Asia, respectively. We found that we needed 60 *Alu* polymorphisms to assign individuals to their continent of origin with 90 percent accuracy. To achieve nearly 100 percent accuracy, however, we needed to use about 100 *Alu*s.

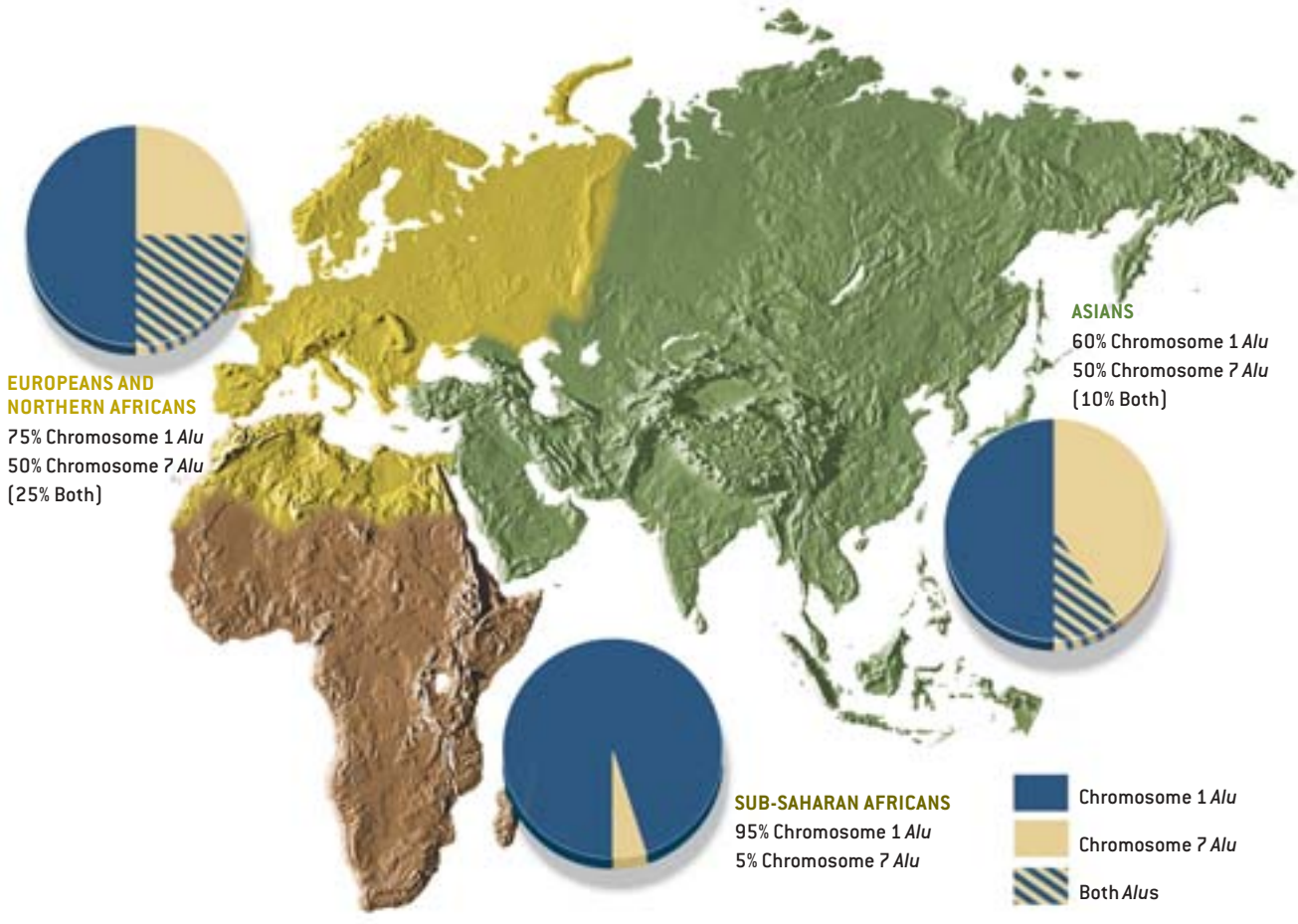
Other studies have produced comparable results. Noah A. Rosenberg and Jonathan K. Pritchard, geneticists formerly in the laboratory of Marcus W. Feldman of Stanford University, assayed approximately 375 polymorphisms called short tandem repeats in more than 1,000 people from 52 ethnic groups in Africa, Asia, Europe and the Americas. By look-

THE AUTHORS

MICHAEL J. BAMSHAD and *STEVE E. OLSON* have come to the subject of human genetic variation from different directions. Bamshad, a geneticist at the University of Utah School of Medicine, studies the genetics of populations to better understand human history and the origins of disease. Olson, a science writer who lives outside Washington, D.C., is the author of *Mapping Human History: Genes, Race, and Our Common Origins,* which was nominated for the 2002 National Book Award in nonfiction. They met during the writing of *Mapping Human History* and have been working together ever since to explore and explain patterns of human genetic variation worldwide.

HUMAN GENETIC DIVERSITY

RESEARCHERS OFTEN USE SHORT PIECES of DNA called *Alu* polymorphisms to determine whether various populations are related to one another. *Alu*s have no known function, yet they copy and insert themselves at random throughout a person's genome. Because previously inserted *Alu*s do not excise themselves, *Alu* patterns can be used as yardsticks to estimate how close two people—and, on average, two populations—are genetically. For example, an *Alu* polymorphism on chromosome 1 occurs in roughly 95 percent of sub-Saharan Africans who have been sampled, 75 percent of Europeans and northern Africans, and 60 percent of Asians, whereas a different *Alu* polymorphism on chromosome 7 is carried by approximately 5 percent of sub-Saharan Africans, 50 percent of Europeans and northern Africans, and 50 percent of Asians. Some individuals carry both polymorphisms. No single polymorphism can, by itself, distinguish all the members of one major human group from all the members of another group, but by analyzing hundreds of these polymorphisms, scientists can group individuals sampled from different locations on the basis of their genetic profiles. *—M.J.B. and S.E.O.*



ing at the varying frequencies of these polymorphisms, they were able to distinguish five different groups of people whose ancestors were typically isolated by oceans, deserts or mountains: sub-Saharan Africans; Europeans and Asians west of the Himalayas; East Asians; inhabitants of New Guinea and Melanesia; and Native Americans. They were also able to identify subgroups within each region that usually corresponded with each member's self-reported ethnicity.

The results of these studies indicate that genetic analyses can distinguish groups of people according to their geographic origin. But caution is warranted. The groups easiest to resolve were those that were widely separated from one another geographically. Such samples maximize the genetic variation among groups. When Bamshad and his co-workers used their 100 *Alu* polymorphisms to try to classify a sample of individuals from southern India into a separate group, the Indians instead had more in common with either Europeans or Asians. In other words, because India has been subject to many genetic influences from Europe and Asia, people on the subcontinent did not group into a unique cluster. We concluded that many hundreds—or perhaps thousands—of polymorphisms might have to be examined to distinguish between groups whose ancestors have historically interbred with multiple populations.

NADIA STRASSER

Genetic analyses can distinguish groups of people according to their geographic origin. But caution is warranted.

The Human Race

GIVEN THAT PEOPLE can be sorted broadly into groups using genetic data, do common notions of race correspond to underlying genetic differences among populations? In some cases they do, but often they do not. For instance, skin color or facial features—traits influenced by natural selection—are routinely used to divide people into races. But groups with similar physical characteristics as a result of selection can be quite different genetically. Individuals from sub-Saharan Africa and Australian Aborigines might have similar skin pigmentation (because of adapting to strong sun), but genetically they are quite dissimilar.

In contrast, two groups that are genetically similar to each other might be exposed to different selective forces. In this case, natural selection can exaggerate some of the differences between groups, making them appear more dissimilar on the surface than they are underneath. Because traits such as skin color have been strongly affected by natural selection, they do not necessarily reflect the population processes that have shaped the distribution of neutral polymorphisms such as *Alu*s or short tandem repeats. Therefore, traits or polymorphisms affected by natural selection may be poor predictors of group membership and may imply genetic relatedness where, in fact, little exists.

Another example of how difficult it is to categorize people involves populations in the U.S. Most people who describe themselves as African-American have relatively recent ancestors from West Africa, and West Africans generally have polymorphism frequencies that can be distinguished from those of Europeans, Asians and Native Americans. The fraction of gene variations that African-Americans share with West Africans, however, is far from uniform, because over the centuries African-Americans have mixed extensively with groups originating from elsewhere in Africa and beyond.

Over the past several years, Mark D. Shriver of Pennsylvania State University and Rick A. Kittles of Howard University have defined a set of polymorphisms that they have used to estimate the fraction of a person's genes originating from each continental region. They found that the West African contribution to the genes of individual African-Americans averages about 80 percent, although it ranges from 20 to 100 percent. Mixing of groups is also apparent in many individuals who believe they have only European ancestors. According to Shriver's analyses, approximately 30 percent of Americans who consider themselves "white" have less than 90 percent European ancestry. Thus, self-reported ancestry is not necessarily a good predictor of the genetic composition of a large number of Americans. Accordingly, common notions of race do not always reflect a person's genetic background.

Membership Has Its Privileges

UNDERSTANDING the relation between race and genetic variation has important practical implications. Several of the polymorphisms that differ in frequency from group to group have specific effects on health. The mutations responsible for sickle cell disease and some cases of cystic fibrosis, for instance, result from genetic changes that appear to have risen in frequency because they were protective against diseases prevalent in Africa and Europe, respectively. People who inherit one copy of the sickle cell polymorphism show some resistance to malaria; those with one copy of the cystic fibrosis trait may be less prone to the dehydration resulting from cholera. The symptoms of these diseases arise only in the unfortunate individuals who inherit two copies of the mutations.

Genetic variation also plays a role in individual susceptibility to one of the worst scourges of our age: AIDS. Some people have a small deletion in both their copies of a gene that encodes a particular cell-surface receptor called chemokine receptor 5 (CCR5). As a result, these indi-

viduals fail to produce CCR5 receptors on the surface of their cells. Most strains of HIV-1, the virus that causes AIDS, bind to the CCR5 receptor to gain entry to cells, so people who lack CCR5 receptors are resistant to HIV-1 infection. This polymorphism in the CCR5 receptor gene is found almost exclusively in groups from northeastern Europe.

Several polymorphisms in CCR5 do not prevent infection but instead influence the rate at which HIV-1 infection leads to AIDS and death. Some of these polymorphisms have similar effects in different populations; others only alter the speed of disease progression in selected groups. One polymorphism, for example, is associated with delayed disease progression in European-Americans but accelerated disease in African-Americans. Researchers can only study such population-specific effects—and use that knowledge to direct therapy—if they can sort people into groups.

In these examples—and others like them—a polymorphism has a relatively large effect in a given disease. If genetic screening were inexpensive and efficient, *all* individuals could be screened for *all* such disease-related gene variants. But genetic testing remains costly. Perhaps more significantly, genetic screening raises concerns about privacy and consent: some people might not want to know about genetic factors that could increase their risk of developing a particular disease. Until these issues are resolved further, self-reported ancestry will continue to be a potentially useful diagnostic tool for physicians.

Ancestry may also be relevant for some diseases that are widespread in particular populations. Most common diseases, such as hypertension and diabetes, are the cumulative results of polymorphisms in several genes, each of which has a small influence on its own. Recent research suggests that polymorphisms that have a particular effect in one group may have a different effect in another group. This kind of complexity would make it much more difficult to use detected polymorphisms as a guide to therapy. Until further studies are done on the genetic and environmental contributions to complex diseases, physicians may have to rely on information about an individual's ancestry to know how best to treat some diseases.

About the Photoillustrations

NEW YORK ARTIST Nancy Burson used her invention, called the Human Race Machine, to generate the series of composite photographs that appears on page 79 (two also appear elsewhere in this article). The machine takes a photograph of an individual—in this case, a white woman—and adds and subtracts various outward features of racial identity to show what a person might look like if he or she were a member of another race. Burson says she seeks to use her work to underscore the commonality of humanity. And indeed, outward features often say little about the bulk of a person's genetic makeup. The Human Race Machine was one of the most popular attractions at the Millennium Dome in London, where it drew hundreds of thousands of people. More about the artist and her work can be found on her Web site, www.nancyburson.com

COURTESY OF NANCY BURSON

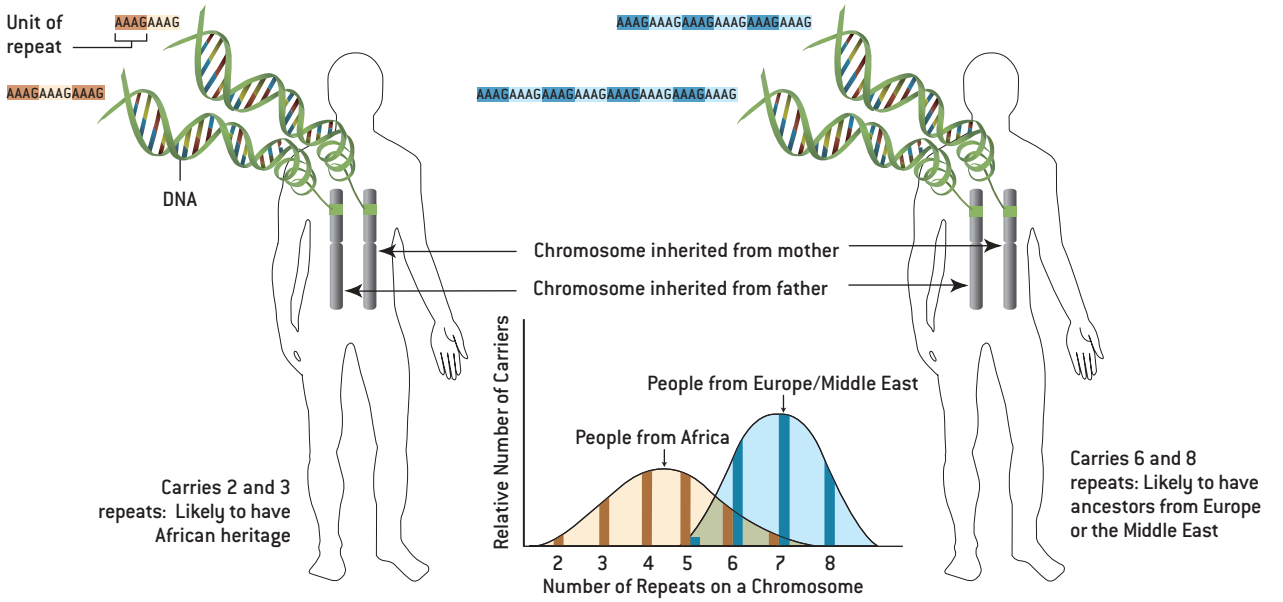
Race and Medicine

BUT THE IMPORTANCE of group membership as it relates to health care has been especially controversial in recent years. Last January the U.S. Food and Drug Administration issued guidelines advocating the collection of race and ethnicity data in all clinical trials. Some investigators contend that the differences between groups are so small and the historical abuses associated with categorizing people by race so extreme that group membership should play little if any role in genetic and medical studies. They assert that the FDA should abandon its recommendation and instead ask researchers conducting clinical trials to collect genomic data on each individual. Others suggest that only by using group membership, including common definitions of race based on skin color, can we understand how genetic and environmental differences among groups contribute to disease. This debate will be settled only by further research on the validity of race as a scientific variable.

A set of articles in the March 20 issue of the *New England Journal of Medicine* debated both sides of the medical implications of race. The authors of one article—Richard S. Cooper of the Loyola Stritch School of Medicine, Jay S. Kaufman of the University of North Carolina at Chapel Hill and Ryk Ward of the University of Oxford—argued that race is not an adequate criterion for physicians to use in choosing a particular drug for a given patient. They pointed out two findings of racial differences that are both

Tracing Human Origins

COUNTING THE NUMBER of DNA units called short tandem repeats on chromosomes can allow scientists to group individuals according to probable ancestry. One such repeat, AAAG, occurs between two and seven times in people with African heritage but between five and eight times in those whose ancestors came from Europe or the Middle East. (Every person inherits one set of repeats from their mother and one from their father.) Accordingly, someone who carries two and three repeats is likely to have African heritage, whereas someone with six and eight repeats probably has ancestors from Europe or the Middle East. People with between five and seven repeats occur in both populations, however, making these individuals more difficult to classify using only this particular repeat. *—M.J.B. and S.E.O.*



now considered questionable: that a combination of certain blood vessel–dilating drugs was more effective in treating heart failure in people of African ancestry and that specific enzyme inhibitors (angiotensin converting enzyme, or ACE, inhibitors) have little efficacy in such individuals. In the second article, a group led by Neil Risch of Stanford University countered that racial or ethnic groups can differ from one another genetically and that the differences can have medical importance. They cited a study showing that the rate of complications from type 2 diabetes varies according to race, even after adjusting for such factors as disparities in education and income.

The intensity of these arguments reflects both scientific and social factors. Many biomedical studies have not rigorously defined group membership, relying instead on inferred relationships based on racial categories. The dispute over the importance of group membership also illustrates how strongly the perception of race is shaped by different social and political perspectives.

In cases where membership in a geographically or culturally defined group has been correlated with health-related genetic traits, knowing something about an individual's group membership could be important for a physician. And to the extent that human groups live in different environments or have different experiences that affect health, group membership could also reflect nongenetic factors that are medically relevant.

Regardless of the medical implications of the genetics of race, the research findings are inherently exciting. For hundreds of years, people have wondered where various human groups came from and how those groups are related to one another. They have speculated about why human populations have different physical appearances and about whether the biological differences between groups are more than skin deep. New genetic data and new methods of analysis are finally allowing us to approach these questions. The result will be a much deeper understanding of both our biological nature and our human interconnectedness. SA

MORE TO EXPLORE

Mapping Human History: Genes, Race, and Our Common Origins. Steve Olson. Mariner Books, 2003.

Human Population Genetic Structure and Inference of Group Membership. Michael J. Bamshad et al. in *American Journal of Human Genetics,* Vol. 72, No. 3, pages 578–589; March 2003.

The Importance of Race and Ethnic Background in Biomedical Research and Clinical Practice. Esteban González Burchard et al. in *New England Journal of Medicine,* Vol. 348, No. 12, pages 1170–1175; March 20, 2003.

Race and Genomics. Richard S. Cooper, Jay S. Kaufman and Ryk Ward in *New England Journal of Medicine,* Vol. 348, No. 12, pages 1166–1170; March 20, 2003.

NADIA STRASSER

The New Moon

BY PAUL D. SPUDIS

Recent lunar missions have shown that there is still much to learn about Earth's closest neighbor

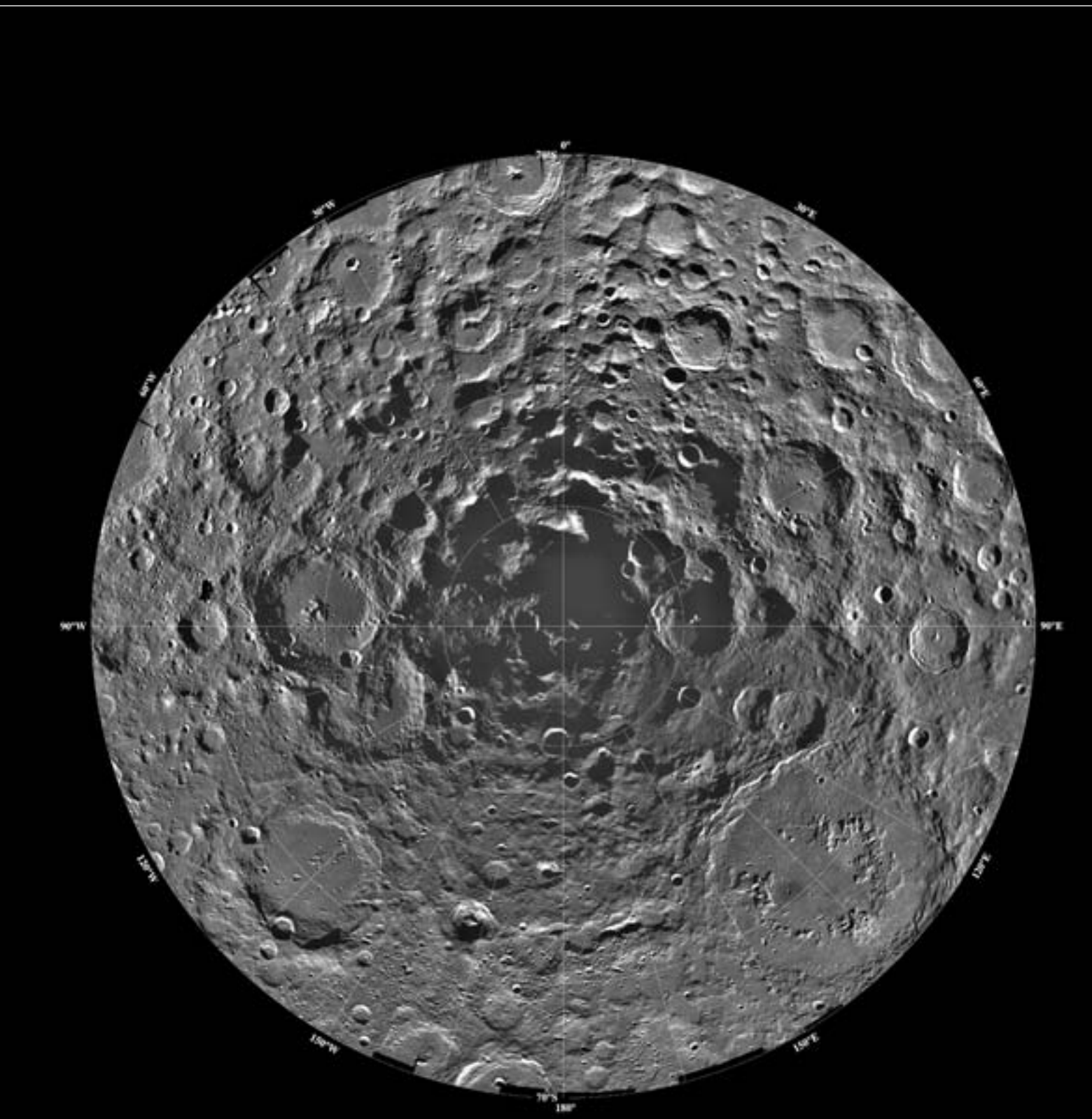
THE MOON does not yield her secrets easily.

Although Earth's airless satellite was the first planetary object to be explored by spacecraft and the only body ever visited by astronauts, scientists still have many unanswered questions about its history, composition and internal structure. In recent years, researchers have called for renewed exploration of the moon; the European Space Agency and Japan are planning to send probes into lunar orbit, and NASA is considering landing an unmanned spacecraft on the moon's far side. By studying the moon, these missions may also illuminate the history of all the rocky planets in the inner solar system: Mercury, Venus, Mars and especially Earth. Because the moon's surface has remained relatively unchanged for the past three billion years, it may hold the key to understanding how the inner planets formed and evolved.

When astronomers first gazed at the moon through telescopes 400 years ago, they found that its surface consists of two principal types of terrain: bright, rugged, heavily cratered highlands and dark, more sparsely cratered lowlands. Galileo Galilei, the 17th-century astronomer, called the lowlands *maria*—Latin for "seas"—because of their smooth, dark appearance. One of the biggest surprises of the space age came in 1959, when the Soviet spacecraft Luna 3 photographed the moon's far side, which had never been seen before because it is always turned away from Earth. The photographs showed that it almost completely lacks the dark maria that are so dominant on the near side. Although scientists now have some theories that could explain this dichotomy of terrain, it remains an unsolved puzzle.

Analysis of the lunar rocks and soil brought back to Earth by the Apollo astronauts and by unmanned Luna landers allowed researchers to get a glimpse of the moon's evolution. The evidence suggests that the moon was created about 4.5 billion years ago when a Mars-size body hit the early Earth. This collision sent a spray of vaporized rock into orbit around Earth, and these small bodies rapidly coalesced into the moon. They accumulated so quickly that the heat generated by the process melted the outer portion of the nascent moon and formed a global ocean of liquid rock, or magma. The

NASA



MOON'S SOUTH POLE is shown in this mosaic of 1,500 images taken by the Clementine spacecraft's ultraviolet/visible camera in 1994. The pole is at the center of the mosaic; the lunar latitude of 70 degrees south is at the edge. Both Clementine and the Lunar Prospector orbiter found evidence of water ice in the permanently shadowed areas near the moon's poles.

lunar crust then formed from low-density minerals that floated to the surface of this magma ocean.

This early phase was followed by a violent pelting of the moon's surface by comets, asteroids and meteoroids. Some of the larger objects blasted out enormous basins more than 2,000 kilometers in diameter. Most craters and basins, at least on the near side, were filled with iron-rich basaltic lava over the next 300 million to 400 million years, forming the dark maria seen today. As time went on, the bombardment eased, with impacts becoming less frequent and less powerful. This fact explains why the maria, which are younger than the highlands, have fewer and smaller craters. Little has occurred on the moon since about three billion years ago; after the volcanic fires died, the only activity has been the occasional formation of an impact crater, the constant rain of micrometeorites and the six blink-of-an-eye visits by a dozen astronauts more than 30 years ago.

Because the moon has experienced impact, volcanism and tectonic activity, it can serve as a touchstone for understanding those processes. In particular, the moon's companionship to Earth makes it an ideal place for studying the extraplanetary events that occurred in this part of the solar system during its early history. Nearly all traces of the asteroids and comets that struck Earth billions of years ago have been erased from our planet's geologically active surface. Yet this record is preserved on the moon, where it can be recovered and read.

Scientists learned much from the Apollo explorations, but many mysteries remained after that program ended. Researchers realized that they needed to map the moon globally with a variety of remote-sensing instruments. A hint of the fascinating discoveries awaiting global reconnaissance came from two flybys of the Earth-moon system in the early 1990s by the Jupiter-bound Galileo spacecraft. In the southern hemisphere of the moon's far side, mission scientists saw an unusual signature of high-iron rocks in the floor of the South Pole–Aitken (SPA) basin, the largest basin on the moon. Galileo also mapped some of the maria using spectral filters that provided information on surface composition; the results suggested that researchers could use remote spacecraft data to delineate the sequence of lava flows in the maria.

Maria and Highlands

IN 1994 the U.S. Department of Defense launched the Clementine spacecraft. Its goal was to test lightweight sensors developed for national ballistic-missile defense while traveling in a polar orbit of the moon. Clementine successfully orbited the moon for 71 days. It obtained a complete global map of the lunar surface in 11 wavelengths in the visible and near-infrared parts of the spectrum. The spacecraft also carried a laser ranger that allowed researchers to make a topographic map of the entire moon for the first time. In addition, radio tracking of the spacecraft's orbit provided better information on the moon's gravity field. And an improvised radar experiment uncovered tantalizing hints that water ice exists in the permanently shadowed areas near the lunar south pole.

Following up on Clementine, NASA sent the Lunar Prospector spacecraft into a polar orbit of the moon in 1998. One of NASA's Discovery-class missions, Lunar Prospector mapped the moon's surface composition using gamma-ray and neutron spectroscopy. It confirmed Clementine's detection of ice near the south pole and discovered additional deposits at the north pole. An alpha-particle spectrometer measured gas emissions from the lunar interior while a magnetometer mapped the distribution of local surface magnetic anomalies. Additional radio tracking of the spacecraft improved our knowledge of the moon's gravity field. Finally, ground controllers deliberately crashed it into the moon in an attempt to induce a release of water vapor from the surface. Telescopes on Earth and in space were trained on the crash site to observe a vapor plume, but none was detected.

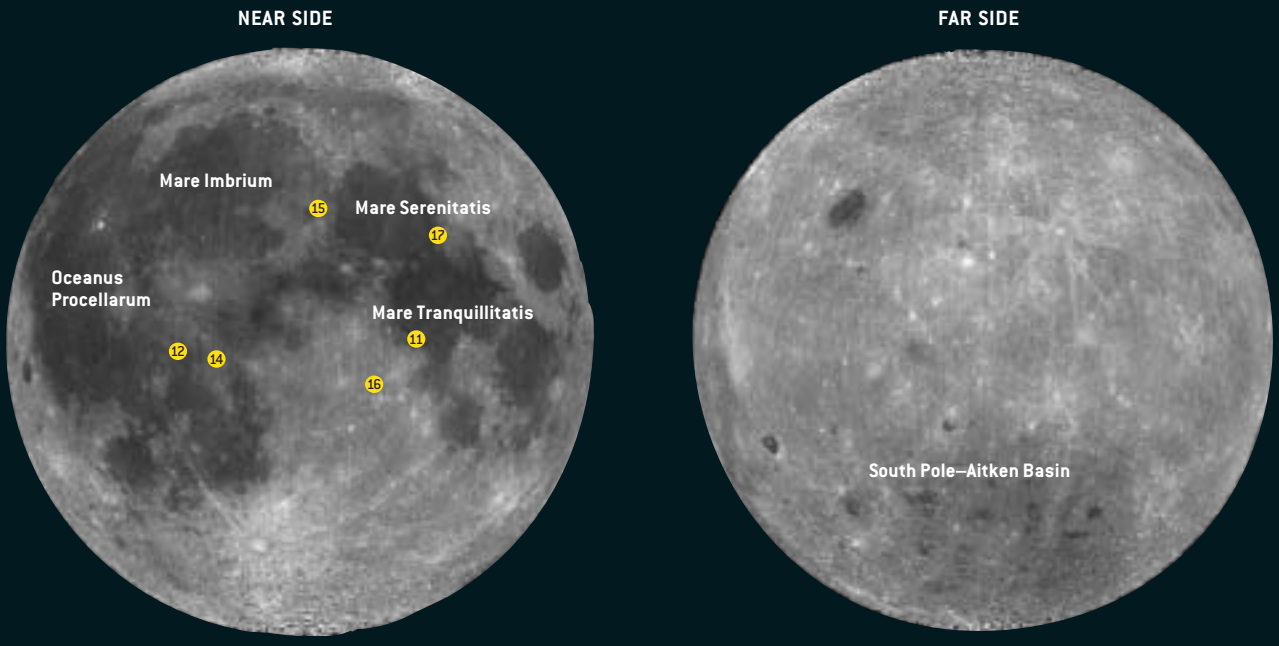
By putting the Apollo discoveries in a global context, the Clementine and Lunar Prospector measurements prompted scientists to revise their understanding of the moon and its history. For example, in the Oceanus Procellarum, a huge depression in the western part of the moon's near side, the astronauts of *Apollo 12* and *Apollo 14* found anomalous basaltic rocks that were rich in trace elements collectively known as KREEP ("K" for potassium, "REE" for rare-earth elements and "P" for phosphorus). Geologists refer to these trace elements as incompatible—that is, they do not fit well into the crystal structures of common rock-forming minerals. The presence of KREEP-rich rocks indicates that the early moon underwent intense melting and differentiation, a process in which the incompatible elements were concentrated in the molten part of an increasingly solid, crystallized system. Lunar Prospector revealed that the highest concentrations of KREEP occur in the Oceanus Procellarum, although the reason for this unusual distribution is not clear.

Furthermore, the lunar orbiters confirmed that the highlands of the moon are dominated by anorthosite, an igneous rock composed primarily of the mineral feldspar and rich in calcium and aluminum. These rocks were created early in lunar history, when the outer portion of the moon was completely molten; the low-density anorthosite floated to the sur-

Overview/*The Moon's Mysteries*

- In the 1990s the Clementine and Lunar Prospector spacecraft provided scientists with global maps of the moon's topography, surface composition, gravitational variations and magnetic anomalies.
- The findings gave context to the discoveries made by the Apollo missions but also raised new questions. In particular, researchers want to know more about the violent bombardment of the moon that occurred about four billion years ago.
- The European Space Agency, Japan and the U.S. plan to send more unmanned probes to the moon to solve some of the lingering lunar mysteries.

Light and Dark



CLEMENTINE'S IMAGES of the moon's near side show the two principal types of terrain: bright, heavily cratered highlands and dark, smooth lowlands called maria. In contrast, the far side almost completely lacks maria. Six Apollo missions visited the near side (the yellow circles show the landing sites and mission numbers). Now NASA wants to send a robotic lander to the far side.

face of the magma ocean. Although scientists had postulated this phase of lunar history based on the Apollo samples, the proof came from the Clementine and Lunar Prospector data, which indicated the global distribution and large abundance of anorthosite. Because the only source of heat that could melt the entire moon would be a very rapid accumulation of small bodies, the presence of large quantities of anorthosite in the lunar crust supports the theory that the moon coalesced from the debris of a planetary collision.

The lunar orbiters also explained one of the more puzzling discoveries of the Apollo missions: the unusually high content of titanium in the mare basalts collected by the *Apollo 11* astronauts during the first moon landing. Lunar geologists had been hard-pressed to explain how very high density, titanium-rich magmas could have ascended through the moon's low-density anorthosite crust. Clementine and Lunar Prospector showed that the high-titanium lavas found by *Apollo 11* are actually quite rare on the moon. Although mare basalts have a range of titanium concentrations, only a small fraction have the extreme compositions observed at the first landing site in the Sea of Tranquility. Lunar researchers learned a valuable lesson: samples from a single location on the moon are not necessarily representative of large regions.

Because lava flows typically have uniform and distinct compositions, the data from Clementine and Lunar Prospector can be used to map the flows that have occurred in the maria. The age of each flow can then be determined by measuring its density of impact craters. Older mare flows have been exposed to bombardment longer than younger flows, so they have higher crater densities. Scientists already know the ages of the mare flows at the Apollo sites from analyzing the radioisotopes in the rock samples, so they can estimate the ages of other flows by comparing their crater densities with those of the landing-site flows. The results show that although the moon has mare lavas of widely varying compositions and ages, the bulk erupted between 3.8 billion and three billion years ago.

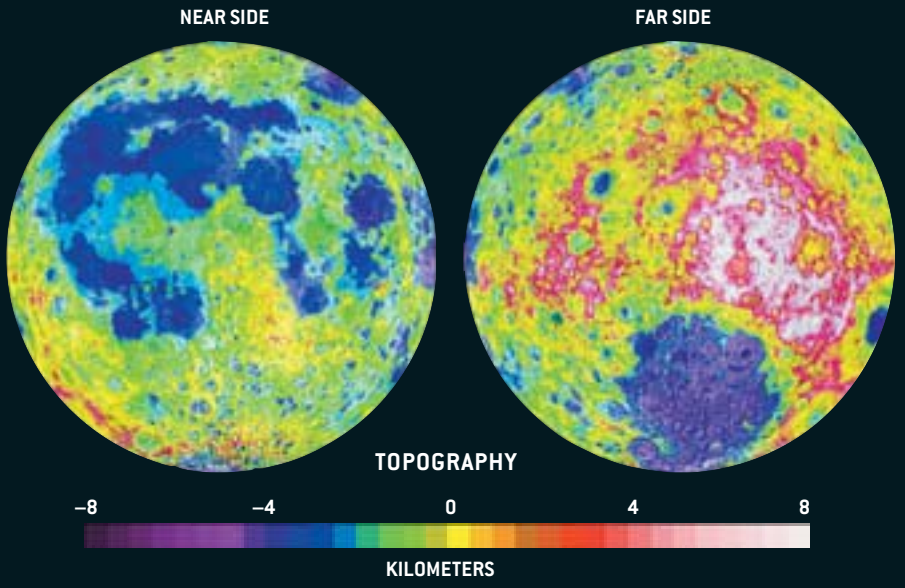
Although maria are recognized by their dark color, certain areas of the highlands appear to be intermediate in reflectance and contain relatively high amounts of iron. Some of these surfaces are mare deposits that have been covered by blankets of highland debris—layers of ejected rock spread by the impacts that created the moon's basins. Because these mare lavas predate the highland debris layers, which were laid down during basin formation 3.8 billion years ago, they indicate that the eruption of lava onto the moon began well before the ages of the oldest mare flows sampled by Apollo. Global mapping has shown that these ancient mare flows are very widespread across the far side of the moon and the limb regions (the border between the near and far sides).

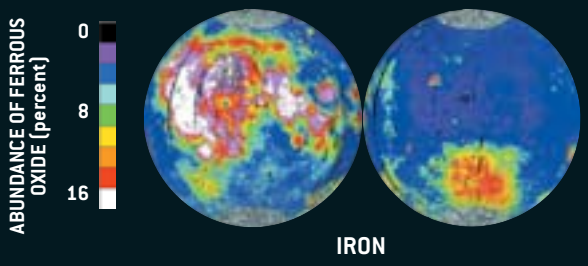
THE AUTHOR

PAUL D. SPUDIS is a senior professional staff member at the Applied Physics Laboratory of Johns Hopkins University. Since 1982 he has been a principal investigator in the Planetary Geology Program of the NASA Office of Space Science, specializing in research on the processes of impact and volcanism on the planets. From 1980 to 1990 he was a geologist with the U.S. Geological Survey's Branch of Astrogeology, and from 1990 to 2002 he was a staff scientist at the Lunar and Planetary Institute in Houston. He was deputy leader of the science team for the U.S. Department of Defense's Clementine mission to the moon in 1994.

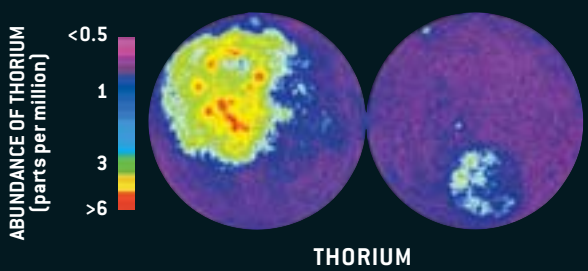
Moon Maps

THE OBSERVATIONS made by the Clementine and Lunar Prospector spacecraft enabled scientists to draw the first detailed global maps of the moon's surface. Clementine carried a laser ranger that measured the distance to the surface once a second during each polar orbit. The results showed the enormous extent of the South Pole–Aitken basin (*purple splotch on moon's far side*), an impact feature that stretches 2,600 kilometers across.

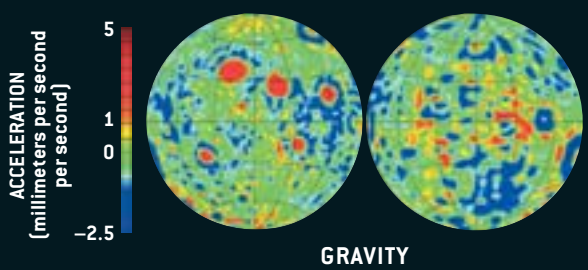




CLEMENTINE'S CAMERAS captured images in 11 wavelengths in the visible and near-infrared parts of the spectrum. Using data from two of those wavelengths (750 and 950 nanometers), researchers created a map showing the concentration of iron in the soils of the lunar surface. Iron levels are highest in the maria on the near side and lowest in the central part of the far side (above the South Pole–Aitken basin).

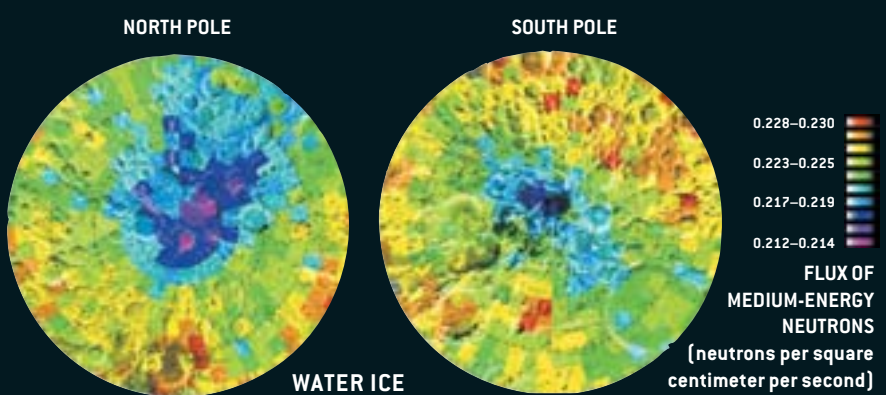


GAMMA-RAY SPECTROMETER was used by Lunar Prospector to measure the abundance of 10 elements in the moon's crust. One of those elements was thorium, which behaves much like the trace elements collectively known as KREEP—it does not fit well into the crystal structures of common rock-forming minerals. The highest levels of thorium occur in the Oceanus Procellarum on the near side, but the reason for this unusual distribution is not clear.



TRAVELING IN AN ORBIT that came as close as seven kilometers to the lunar surface, Lunar Prospector was able to precisely measure variations in the moon's gravity. Careful tracking of the spacecraft's orbit revealed stronger than expected gravity (*red areas*) above some of the youngest impact basins. One possible explanation is that plugs of dense rock from the lunar mantle may have risen toward the surface of the basins after impact.

LUNAR PROSPECTOR also discovered evidence of water ice at the moon's poles. The craft's neutron spectrometer found a lack of medium-energy neutrons bouncing off permanently shadowed areas (*purple*). Ice slows down neutrons because of collisions with hydrogen atoms in water molecules. The results confirmed Clementine's detection of ice in these dark areas.



PAUL D. SPUDIS AND LUNAR AND PLANETARY INSTITUTE (*topography, iron and thorium maps*); REPRINTED BY PERMISSION FROM A. S. KONOPLIV ET AL. IN *SCIENCE*, VOL. 281, PAGES 1496–1500; 1998 (*water ice map*); © 1998 AAAS

Bumpy and Lumpy

THE MOON IS a very rough world. The difference in altitude from its lowest point (within the SPA basin) to its highest (on the rim of the Korolev basin on the far side) is more than 16 kilometers. On Earth, where the maximum altitude differential is about 20 kilometers, surface topography is the result of tectonic activity that creates high mountain belts and deep ocean trenches. The moon, in contrast, has a static outer shell; the lunar crust has been cold and rigid for at least the past four billion years. Topographic relief on the moon is entirely related to impact craters and basins. It is no accident that the largest basin on the moon is also the locale for the greatest extremes in altitude, although it is somewhat surprising that such a large and old feature still retains most of its original relief.

Internally, the moon also appears to be quite lumpy. Radio tracking of the trajectory of Lunar Prospector, which traveled in a low orbit that came as close as seven kilometers to the lunar surface, showed stronger than expected gravity above some of the youngest impact basins. Scientists do not think the mare basalts in the basins are the source of the gravity anomalies; individual lava flows appear to be quite thin—from a few meters to a few tens of meters—and total accumulations are typically 200 meters or less. Rather researchers believe the mass concentrations are plugs of dense rock from the lunar mantle that rose toward the surface of the basins after impact.

The moon's unusual dichotomy of terrain, with the near side dominated by dark maria and the far side by bright highlands, may also be explained by structural differences under the surface. Although scientists have not definitively resolved this problem, the most likely reason for the dichotomy is that the crust on the near side is relatively thinner, and therefore ascending magmas can reach and break through the surface more easily there than on the far side. The enormous SPA basin contains most of the mare lavas on the far side, yet even these deposits are very thin and of limited extent. The SPA basin as a whole is largely unfilled by mare lavas, whereas even the smallest basin on the near side tends to have copious lava fill.

The topographic map produced by Clementine's laser ranger revealed the astounding dimensions of the SPA basin, which stretches 2,600 kilometers across, making it the largest impact crater in the entire solar system. Clementine also documented the presence of numerous additional basins, some of which were unknown before the orbiter's flight. Researchers now estimate that the moon has more than 45 basins (defined as impact features with diameters greater than 300 kilometers). Based on crater densities within the basins, SPA appears to be the oldest and Orientale the youngest.

Scientists, however, know the absolute ages of only the basins that were visited by the Apollo and Luna missions. Radioisotope dating of the impact-melt samples—rocks that melted when an asteroid or comet struck the moon, therefore revealing when an impact occurred—shows that all these basins formed in a narrow interval between 3.9 billion and 3.8 billion years ago. This small range of basin ages has been interpreted to mean that the moon experienced a very high impact rate for a short period, which has been dubbed the lunar cataclysm.

But how could such a deluge have occurred? Models of the solar system's early history posit that the frequency of impacts should have tapered off between 4.5 billion and four billion years ago because most of the planetesimals—the small rocky bodies that formed from the solar nebula—were gradually cast out of the inner solar system or absorbed by the outer planets. If researchers can confirm that the lunar cataclysm did indeed occur, the discovery would have profound implications for the history of all the inner planets. It is possible, for example, that a very large body in the asteroid belt broke apart about 3.9 billion years ago and that the debris was swept toward the Earth-moon system. If that is the case, it could mean that lunar cratering history is unique and cannot be used as a guide for dating features on other planets besides Earth.

One way to tell whether the lunar cataclysm actually occurred would be to determine the absolute age of the SPA basin. Scientists know that SPA must be older than any other lunar basin, and the oldest of the basins that can be reliably dated from impact-melt samples is Mare Serenitatis, which is estimated to be 3.87 billion years old. The impact that created SPA clearly happened after the lunar crust solidified, which occurred about 4.3 billion years ago. The age of SPA must therefore fall between these dates, but nearer to which end?

If SPA is found to be close in age to the other basins, then scientists would have a strong argument for the lunar cataclysm. On the other hand, if SPA's age is determined to be close to the solidification age of the lunar crust, there would be no need to postulate a lunar cataclysm. The moon's cratering history could be seen as evidence of an exponentially declining frequency of impacts. In this case, the lunar record could indeed serve as a guide to the interpretation of cratering on inner planets such as Mars. To date the SPA basin, however, researchers would need to obtain samples of its impact melt.

Perhaps the most exciting result of the Clementine and Lunar Prospector mis-

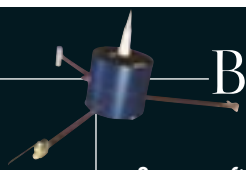
The moon may hold the key to understanding how the INNER PLANETS FORMED AND EVOLVED.

NASA

sion was the evidence of water ice at the lunar poles. Because the moon's spin axis is inclined just 1.5 degrees—that is, its axis is almost perpendicular to the plane of Earth's orbit around the sun—the sun is always at or near the horizon when viewed from the lunar poles. (In contrast, Earth's axis is tilted about 23 degrees.) If a place near the lunar pole is about 600 meters above the average surface elevation, it is in permanent sunlight; if it is at least 600 meters below the surface, it is in perpetual shadow. In the latter areas, the only sources of heat would be the meager amount of radioactive decay from the lunar interior and the feeble cosmic radiation. Scientists estimate that these permanently dark regions, which have existed for two billion to three billion years, are extremely cold—on the order of –223 to –203 degrees Celsius. These cold traps could accumulate water ice derived from comets and meteorites hitting the moon, because the ice would never be vaporized by sunlight.

Although Clementine did not carry any instruments specifically designed to search for polar ice, the mission's science team was able to improvise an experiment using the radio transmitter onboard the spacecraft. Whereas rocky surfaces scatter radio waves randomly, ice partly absorbs the waves and reflects some of them coherently. When Clementine directed radio waves at permanently shadowed regions near the moon's south pole, the reflected signals were characteristic of an icy surface. Four years later the neutron spectrometer carried by Lunar Prospector showed large amounts of hydrogen in the dark regions of both poles; the most likely explanation is that the craft detected the hydrogen in water ice. Current estimates indicate that more than 10 billion tons of ice exist within the upper foot or so of the surface at both poles. Researchers do not know, however, the physical state of this material, its exact composition, purity or accessibility. This knowledge can be acquired only by future missions to the moon.

The images from Clementine also showed that some regions near the moon's poles appear to be in near-constant sunlight. An area near the rim of Shackleton crater, for example, is illuminated for more than 75 percent of the lunar rotation period. These areas have a relatively benign thermal environment, with surface temperatures ranging from –60 to –40 degrees C. (In contrast, temperatures near the lunar equator swing from –150 to 100 degrees C.) Locating an unmanned or manned outpost in one of the sunlit areas near the poles would greatly ease the challenge of designing equipment to survive the temperature extremes of the lunar surface. And if ice could be retrieved from a permanently



Back to the Moon

The resurgence of scientific interest in the moon has inspired space agencies to plan new lunar missions.

Spacecraft	Country	Launch Date	Mass without Fuel (kilograms)	Lunar Research
PAST AND PRESENT MISSIONS				
Clementine	U.S.	Jan. 25, 1994	227	Used cameras and laser ranger to map surface composition and topography. Radar experiment found first evidence of water ice at the lunar poles.
Lunar Prospector	U.S.	Jan. 7, 1998	158	Spectrometers revealed abundance of elements in the crust and detected further evidence of ice. Magnetometer and electron reflectometer measured magnetic fields.
SMART-1	European Space Agency	Sept. 27, 2003	280	On arrival at the moon in early 2005, camera and spectrometers will chart the moon's minerals and peer into dark craters to search for ice.
FUTURE MISSIONS				
Lunar A	Japan	Aug.–Sept. 2004	520	The orbiter will drop two penetrators that will burrow into the surface on opposite sides of the moon. Seismometers and heat-flow sensors will probe the lunar interior.
SELENE	Japan	2005	1,600	Large array of cameras, spectrometers and other instruments will map the moon's surface composition, topography, gravity and magnetic fields in even greater detail.
South Pole–Aitken Basin Sample Return	U.S.	Before 2010	To be determined	Robotic lander will collect samples of rock and soil from the basin floor and rocket them to Earth for analysis of age and composition.

LUNAR AND PLANETARY INSTITUTE

dark area nearby, the base would have a source of water that could be used for life support as well as for rocket fuel (by breaking the water into liquid hydrogen and oxygen, the most powerful chemical propellants).

Return to the Moon

AS A RESULT of the successes of Clementine and Lunar Prospector, a spate of new lunar missions are in various stages of preparation. In September the European Space Agency launched the SMART-1 spacecraft, whose primary mission is to test an ion-propulsion engine during a 16-month journey to the moon. After entering lunar orbit, SMART-1 will use a camera and x-ray sensor to map the moon's surface. In 2004 Japan is scheduled to launch Lunar A, an orbiter that will drop two hard-landing probes, called penetrators, to the moon's surface. Equipped with seismometers and heat-flow sensors, the probes will gather information on the moon's interior and possibly map its core. And in 2005 Japan plans to follow up the mission with a larger orbiter called SELENE. This craft will map the moon in even greater detail using x-ray and gamma-ray spectrometers, a terrain camera, a laser altimeter and a radar sounder.

In addition, the newly appreciated significance of the SPA basin has revived the idea of landing a robotic probe there to collect samples and rocket them to Earth for analysis. A 2002 report by a panel of scientists sponsored by the National Academy of Sciences advocated such a mission. The primary goal of the effort would be to obtain samples of the SPA basin's impact melt. By revealing when the basin formed, these rocks could settle the question of whether there was a lunar cataclysm. Moreover, because the impact melt is a composite of all the rocks that were struck by the colliding asteroid or comet, studying it could reveal the composition and structure of the lunar crust in the basin target site. Some researchers suspect that the colliding object may well have penetrated the crust and exposed parts of the upper mantle, possibly from depths as great as 120 kilometers. If the impact melt contains some material from the mantle, scientists may be able to characterize in some detail the composition of the deep lunar interior.

A sample-return mission to the SPA basin is simple in concept but difficult to execute. Mission planners must select a landing site that would yield the proper samples to solve the scientific issues concerning the SPA's age and composition. Researchers can use existing remote-sensing information to identify areas that, by virtue of their composition and geologic setting, are good candidates to yield the desired rocks. Because the sites would be on the moon's far side, the lander would have to either operate autonomously or communicate with ground controllers through a relay satellite.

What is more, the spacecraft must obtain both rocks and soil from the landing site. Rocks are needed to analyze the mineralogy and date the samples, whereas the soil enables scientists to determine whether the collected rocks are actually representative of the area. (The soil may also contain small fragments of rare or exotic rock types.) The samples must be packed into a small Earth-return vehicle carried by the lander. This vehicle would then use a rocket engine to lift it off the moon and put it on a course back to Earth. After using Earth's atmosphere to decelerate, the vehicle would land in a remote area and turn on a radio beacon to attract the recovery team. All these elements make the mission ambitious and technically challenging, but it is well within our capabilities.

NASA has already requested proposals for a sample-return mission to the SPA basin, which could be launched before 2010. But when will astronauts return to the moon? There are numerous scientific reasons for human exploration. A manned mission would provide excellent opportunities for a whole range of studies, from planetary exploration to astronomy. And the existence of water ice at the lunar poles could make it much easier to establish a permanent human presence. NASA has recently sketched out proposals that would permit new human missions to the moon using existing launch and space transportation infrastructure, thereby saving billions of dollars in development costs.

The return of astronauts to the moon requires a political rationale, NOT A SCIENTIFIC JUSTIFICATION.

But the return of astronauts to the moon requires a political rationale, not a scientific justification. It will never be undertaken solely for scientific purposes, nor should it. The missions must address a wide range of national concerns. Once we do return, though, new vistas of scientific possibilities will beckon. We have read part of the moon's story, but much is still murky. Future exploration will most likely show us that the history of our closest neighbor is more complicated and interesting than we ever imagined. SA

MORE TO EXPLORE

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NASA

The Equivocal Success of the Wright Brothers

The Wrights used aerial control as the key to building and flying the first airplane. But trying to refine their invention in secret nearly cost them their glory

By Daniel C. Schlenoff

WILBUR AND ORVILLE WRIGHT (*left* and *right*), printers, bicycle mechanics, inventors of the powered airplane.

On December 17, 1903, Orville Wright took off in a powered airplane, flew for 12 seconds and 120 feet, then bumped down into the sand. A century later we honor the date as an aviation milestone, but for that flight alone it is hard to argue that the Wrights were more successful than other inventors who had already flown farther (and crashed harder).

It took two more years for the Wrights to build and fly the world's first truly controllable airplane. Unfortunately, until they felt sure of the sale of their perfected machine, their secretiveness invited skepticism from *Scientific American* and other publications of the day and left them underappreciated by their peers and the general public.

Other contenders for the "first airplane" laurels merely made short or uncontrolled flights. Clement Ader can be credited with the first powered takeoff in 1890. But his steam-powered aircraft reached an altitude of eight inches, sufficient to classify it as a flight only to his French countrymen. German-born Gustave Whitehead was adept at fabricating stories about flying in the U.S., but he never built a workable airplane. New Zealanders are proud of Richard Pearse: in March 1903 this reclusive, eccentric farmer flew his bamboo-and-canvas monoplane for about 450 feet before crashing into a gorse hedge. His example illustrates, rather painfully, the need for controllability in aerial navigation.

Control Is the Key

WILBUR WRIGHT, in a talk before the Western Society of Engineers in Chicago in September 1901, said that the greatest obstacle to a functional airplane was "the balancing and steering of the machine after it is actually in flight." The Wrights therefore gave priority to working out a method of aerial control. They also re-

AP PHOTO

THE WRIGHT AIRPLANE is publicly demonstrated by Wilbur for the first time. His flights in the Model A on August 8, 1908, at a racetrack near Le Mans, France, showed that the Wrights were far ahead of any competitor.

alized that just as a cyclist needed to learn how to ride a bicycle, a pilot would have to learn how to fly.

The Wrights studied the work of Otto Lilienthal, a German engineer widely considered to be the world's first pilot. Lilienthal made thousands of flights in sophisticated gliders of his own design, steering by shifting his body just as hang gliders do today. He perished after a flying accident, however, and the Wrights decided they needed a method of control more suitable for airplanes big enough to carry a motor. They thought that if the wingtips could be warped while in flight, then the balance and the direction of the flying machine could be maintained.

In August 1899 the Wrights, taking a break from their profitable bicycle business in Dayton, Ohio, constructed a small biplane kite with a five-foot wingspan to test some of their theories. The kite was rigged with wires that slightly twisted the wings while aloft. An elevator, a small wing set forward of the main wing, stabilized the pitch (up-and-down motion) of the craft. Promising results encouraged them to make a scaled-up version in 1900 with a wing area of 165 square feet.

They took this kite to Kitty Hawk, on the Outer Banks of North Carolina, where consistently steady breezes blew off the Atlantic Ocean and the gently sloping sand dunes provided space and a soft landing. The Wrights were pleased enough with the results of their experiments to return in 1901 with an ambitiously larger glider, but they went back to Dayton puzzled by problems they had encountered with the contemporary aeronautical data. To refine their wing designs, they tested more than 60 model cross sections in a wind tunnel they built.

From the information they gleaned came the 1902 glider, with an efficient, long, narrow wing design. They added a twin vertical tail to control yaw (side-to-side movement). The pilot lay prone in a hip cradle, and his own lateral movement pulled wires that warped the wings and controlled flight direction. At Kitty Hawk during the late summer and early fall, both brothers logged many hours of unpowered flight in this glider.

Having constructed and learned how to fly an unpowered aircraft, the Wrights then embarked on creating a more robust, motorized version. Most automobile engines being too heavy, they designed their own and built it using an aluminum-copper alloy.

To find the optimal shape for propellers, they turned again to wind-tunnel testing, treating the propeller as a small revolving wing. Their design had an efficiency of almost 70 percent, just 10 percent less than modern versions. They mounted two of these propellers at the back of the aircraft [*see illustration on opposite page*], rotating in opposite directions to counter effects from torque.

The Great Day

AT KILL DEVIL HILLS near Kitty Hawk on December 17, 1903, the Wrights sat their Flyer 1 on the launching rail, laid on flat sand. Orville was at the controls (decided by a coin toss). They started the motor and, with Wilbur running alongside guiding the wing, the craft became airborne—briefly. If it is debatable whether the first flight of the day was a controlled flight or a hop, the fourth and last, with Wilbur at the controls, was definitive: it covered 852 feet in 59 seconds. The Wrights had flown a powered, heavier-than-air machine in free, controlled, sustained flight. Nine days later *Scientific American* cautiously noted: "This is a decided step in advance in aerial navigation with aeroplanes" [see 50, 100 & 150 Years Ago, on page 22].

The Wrights were triumphant aircraft inventors. Unfortunately, they were terrible aviation businessmen. They became so concerned about losing financial control of their invention that they kept it away not only from the prying eyes of competitors but also from potential customers and those who could have helped spread word of their progress. Even after they were awarded patent number 821,393 in May 1906 (after a wait of three years), they did not believe that it offered much protection—an opinion that turned out to be justified.

Back in Dayton, at Huffman Prairie, the Wrights continued work on producing a salable flying machine. With their Flyer 2 they made more than 100 short flights, later on using a catapult to facilitate takeoff. Still, they avoided the limelight, much to the frustration of aviation enthusiasts excited by snippets of news. In June 1904, with rumors trickling in from Dayton, *Scientific American* complained: "Great secrecy was maintained about the test, and but few witnessed it."

There was at least one witness, Amos Ives Root, and he wrote an article about what he had seen. He published it in his magazine, *Gleanings in Bee Culture,* on January 1, 1905. Root claimed that *Scientific American* had rejected his offer to publish the article. We have no record of why the editors might have done so, but perhaps the style was too flowery for their taste. Here is the first sentence as it appeared in *Bee Culture:* "I have a wonderful story to tell you—a story that, in some respects, out rivals the Arabian Nights fables—a story, too, with a moral that I think many of the younger ones need, and perhaps some of the older ones too if they will heed it."

THEORIZE, TEST, REFINE: The Wrights applied the lessons they learned from more simple flying machines. This photograph, more than a century old, shows them conducting experiments on their glider/kite near Kitty Hawk, N.C., in 1901.

COURTESY OF SPECIAL COLLECTIONS AND ARCHIVES, WRIGHT STATE UNIVERSITY

A Wright Brothers Myth

A POPULAR MYTH about the Wright brothers is that "they were considered cranks because everyone knew that flying was impossible." Untrue. This fiction is based on the turn-of-the-century writings of several skeptics, principally Simon Newcomb, a prominent astronomer, who noted the difficulty of scaling up the power needed for working models to full-size aircraft. The reality is that people had been flying since 1783, thanks to the invention in France of a practical hot-air balloon by brothers Joseph-Michel and Jacques-Étienne Montgolfier. By 1903 powered balloon flights and glider soaring were commonplace, and engines were becoming lighter and producing more horsepower. Fitting the elements together was acknowledged as tricky, risky and expensive, but few people thought that airplane flying would always be "impossible." It was the Wrights' secretiveness that made this magazine (and many others) skeptical about their accomplishment. —*D.S.*

The Flyer 2 and the Flyer 3 were as difficult to control as the Kitty Hawk Flyer, and hard landings were frequent (points worth remembering by those attempting modern re-creations of the aircraft). A crash in July 1905 forced the Wrights into a radical and fortuitous reconstruction of the Flyer 3. They enlarged the control surfaces and placed them farther from the center of balance. On October 5, 1905, with Wilbur at the controls, the airplane flew 24 miles in 39.5 minutes.

The Wrights had developed the world's first truly practical airplane and clinched their status as aviation pioneers. But it was a laurel conferred by history alone, because the Wrights allowed so few people to observe—or photograph—the aircraft flying. It was not until 1990 that the Flyer 3 was designated as a National Historic Landmark, the sole airplane ever to receive that honor.

The Wrights offered to sell the airplane to, variously, the U.S. secretary of war, the French, the British and the Germans. But they refused to demonstrate its flight capabilities without a signed sales contract. Not surprisingly, customers balked at buying so novel a device without seeing whether it worked.

PAINTING of a section of the 1903 Flyer, with one of its 8.5-foot-long propellers, graces the cover of our July 1979 issue.

Unable to get additional information from, or about, the Wrights, *Scientific American* commented huffily in a January 1906 article, "It seems that these alleged experiments were made at Dayton, Ohio, a fairly large town, and that the newspapers of the United States, alert as they are, allowed these sensational performances to escape their notice."

The French dubbed the Wrights "*bluffeurs*." A German aeronautical journal called their flights "*ein amerikanischer 'bluff.'* " The Wrights, however, did not think their flying machine sufficiently advanced to demonstrate it yet.

Fame Slips Away

MEANWHILE, FAR AWAY from Dayton, in France, Brazilian-born Alberto Santos-Dumont made the first public demonstration of flight. He took off from a field on November 12, 1906, and flew for 722 feet. Because there was no proof to the contrary at the time, he was hailed as the first man to fly. His countrymen today still revere Santos-Dumont as the Father of Aviation.

In an effort to encourage innovation in aeronautics, the Aero Club of America and this magazine offered a prize in 1907 to the first person who could take off and fly one kilometer in a straight line. The Wrights chose to pursue sales contracts and did not compete for the prize. Glenn Hammond Curtiss and the Aerial Experiment Association, backed by Alexander Graham Bell, entered and won the trophy with their June Bug aircraft in a triumphal flight on July 4, 1908. Because of this feat and the prominence of Curtiss in early American aviation as a pilot and inventor, many in the U.S. believed he was the first to fly.

The Wrights waited until they were close to selling airplanes to both the U.S. Army Signal Corps and to a French syndicate before showing their aircraft publicly. Starting on August 8, 1908, at a racetrack near Le Mans, France, in a Wright Model A Flyer, Wilbur astonished viewers with multiple flights of unprecedented piloting skill and technological advance, and the Wrights were hailed as heroes.

By 1909 the Wrights reached the peak of their fame. In the autumn of that year perhaps a million astounded onlookers saw Wilbur fly over New York Harbor and around the Statue of Liberty; a few days later a similarly huge crowd saw him take an aerial trip up the Hudson River.

Yet the burgeoning field of aviation was rapidly overtaking the Wrights as money and talent poured into this exciting new industry. By 1911 several companies, mostly in Europe, were manufacturing aircraft that were safer, faster and more maneuverable than the Wright flyers.

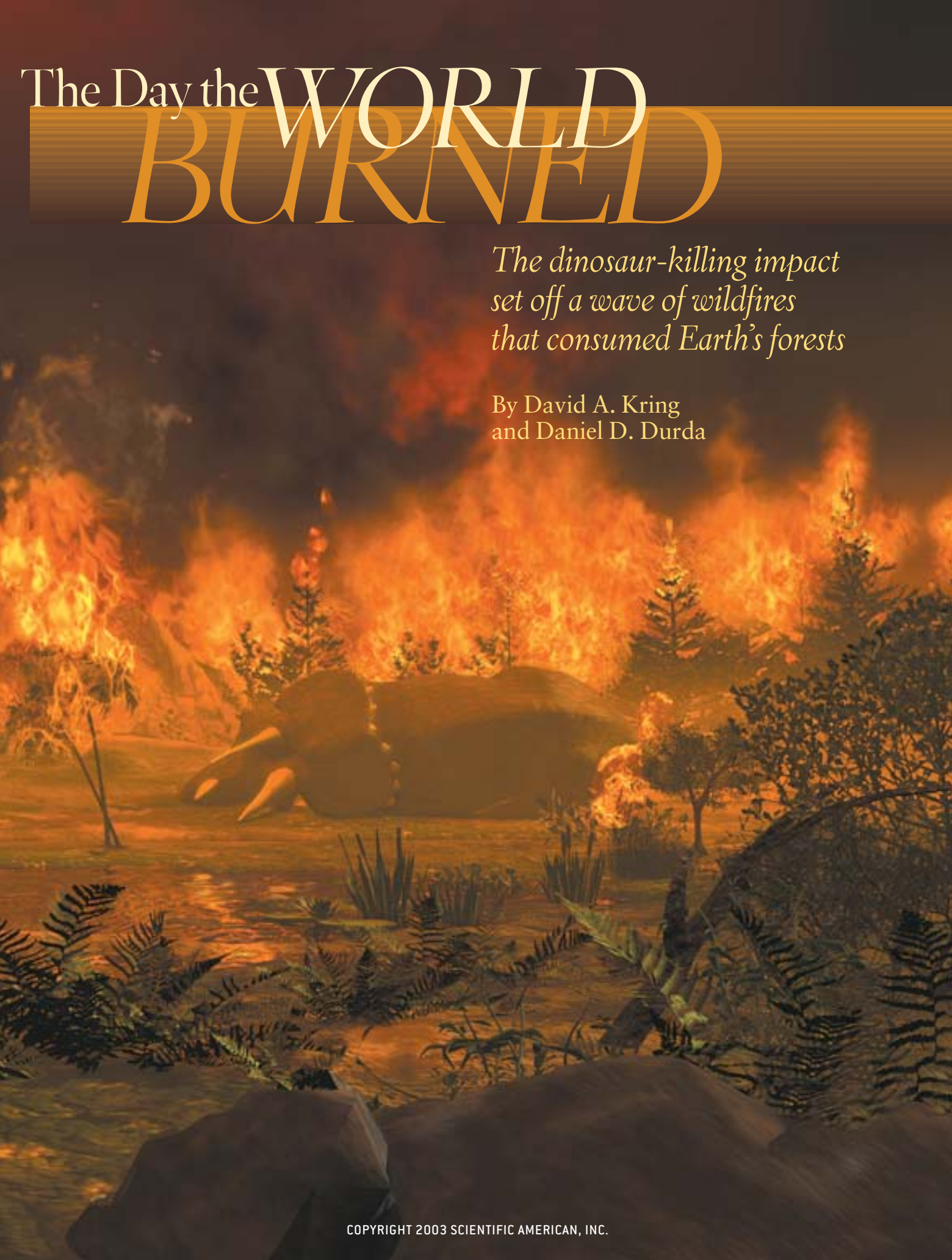
When Wilbur died of typhoid fever in 1912, Orville was left floundering against the rising tide of competition and fighting protracted patent-infringement lawsuits. By 1915 he had tired of the flying business, and he quit. But he never gave up struggling to secure his status in the history books as half of the team that had worked so hard and so successfully to solve the problem of airplane flight. SA

Daniel C. Schlenoff edits the 50, 100 & 150 Years Ago column in Scientific American.

The Day the WORLD BURNED

The dinosaur-killing impact set off a wave of wildfires that consumed Earth's forests

By David A. Kring and Daniel D. Durda



By now it is common knowledge that the impact of an asteroid or comet brought the age of the dinosaurs to an abrupt end. Less well known, though, is exactly how they and so many other species became extinct and how ecosystems managed to rebuild themselves afterward. The cataclysm went far beyond the regular insults from which living things must recover. The asteroid or comet flashed through the sky more than 40 times as fast as the speed of sound. It was so large that when its leading edge made contact with ground, its trailing edge was at least as high as the cruising altitude of a commercial airliner. It produced an explosion equivalent to 100 trillion tons of TNT, a greater release of energy than any event on our planet in the 65 million years since then.

The remnants of that collision lie below the tropical forest of the Yucatán, the Maya ruins of Mayapán, the seaport village of Progreso and the waters of the Gulf of Mexico. The crater, called Chicxulub after modern Maya villages in the area, is approximately 180 kilometers in diameter and is surrounded by a circular fault 240 kilometers across, apparently produced when the crust reverberated with the shock of the impact.

Science sometimes overwhelms science fiction in its capacity to startle and amaze. Such is the case for this impact. It destroyed one world and made way for a new one. But studies over the past several years suggest that the impact did not kill off species directly or immediately. Rather it had a variety of severe and complex environmental effects that spread the devastation worldwide. One of the most destructive forces was the ignition of vast wildfires that swept across continents. The fires wiped out critical habitats, wrecked the base of the continental food chain and contributed to a global shutdown of photosynthesis.

Overview/*Dinosaur Barbecue*

- The Chicxulub impact is notorious as the cause of the Cretaceous-Tertiary mass extinction, which claimed the dinosaurs and more than 75 percent of animal and plant species on Earth. Less well known are the global wildfires that the impact ignited.
- As fast-moving debris superheated the atmosphere, vegetation burst into flame over much of the planet. Animals had nowhere to flee. Ecosystems collapsed. Fire was among the most destructive of the impact-generated environmental calamities.
- Not all areas were equally affected. Far to the north of the impact site, for example, many species survived. From these niches, life repopulated the planet.

Broiler Oven

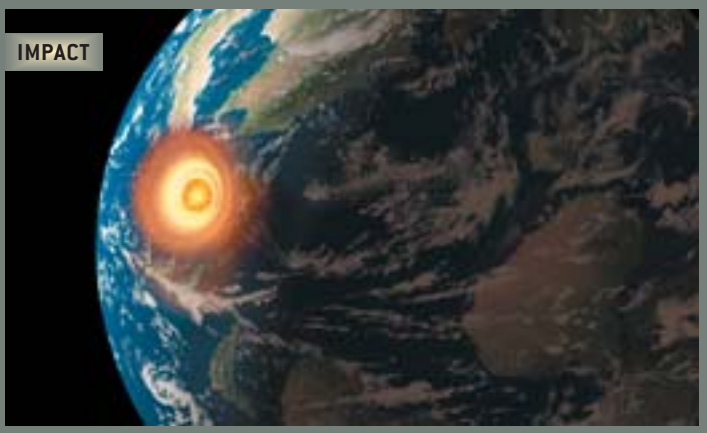
TO SEE THE IMPRINT of mass death for yourself, you can visit any number of rock outcrops in the western U.S., southern Europe and elsewhere. An especially good location is the Raton Basin in Colorado and New Mexico [*see illustration on page 104*]. Sandwiched between rock layers from the Cretaceous (K) period of the dinosaurs and the subsequent Tertiary (T) period is a one-centimeter layer of clay laced with exotic elements. Looking closely at the layer in various locations around the world, Wendy S. Wolbach of DePaul University and her colleagues made a startling discovery in 1985. They found microscopic particles of soot—spherical particles of carbon often clustered like grapes, with a composition that matches the smoke from forest fires. Globally the soot amounts to nearly 70 billion tons of residue. It is the ash of the Cretaceous world.

At the time, the soot interested researchers mainly as additional evidence that the mass extinction was caused by an impact rather than by volcanoes, whose effect would not have been so abrupt or widespread [see "An Extraterrestrial Impact," by Walter Alvarez and Frank Asaro; SCIENTIFIC AMERICAN, October 1990]. In 1990 University of Arizona planetary scientist H. Jay Melosh and his colleagues described how an im-

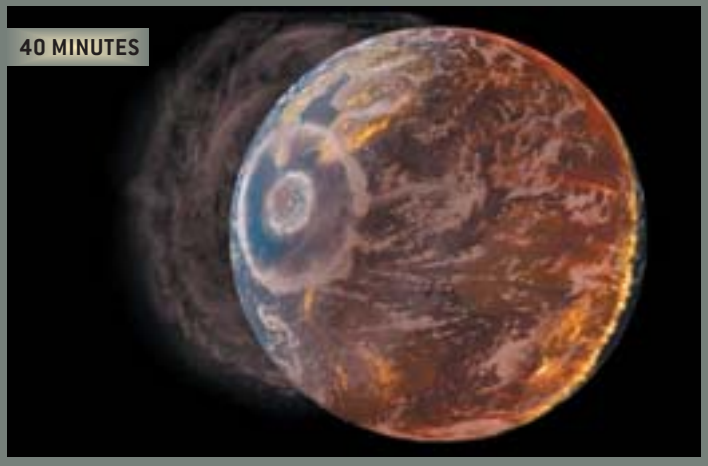
ALFRED T. KAMAJIAN (*preceding pages*)

A World Lost, a World Remade

LATE CRETACEOUS swamps and rivers in North America had a mix of coniferous, broad-leaved evergreen and deciduous trees. They formed canopied forests and open woodlands with understories of ferns, aquatic plants and flowering shrubs.



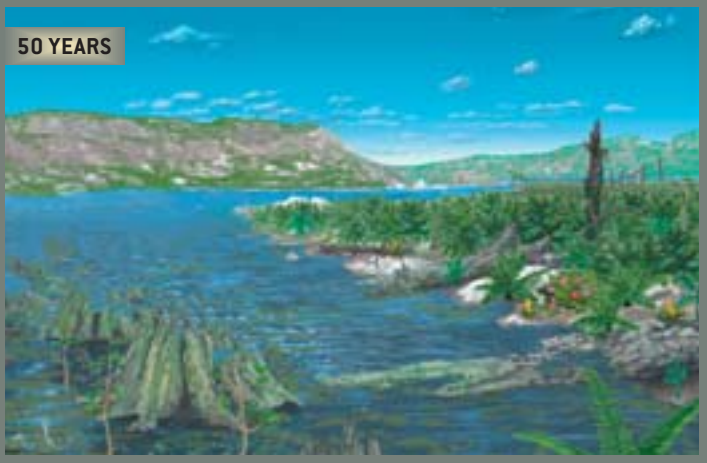
THE CHICXULUB IMPACT occurred in a shallow sea and immediately lofted rocky, molten and vaporous debris into the atmosphere. The bulk of the debris rained down on nearby continental regions, but much of it rose all the way into space.



THE VAPOR-RICH PLUME of material expanded to envelop Earth. As material in that plume fell back to the ground, it streaked through the atmosphere like trillions of meteors, heating it in some places by hundreds of degrees.

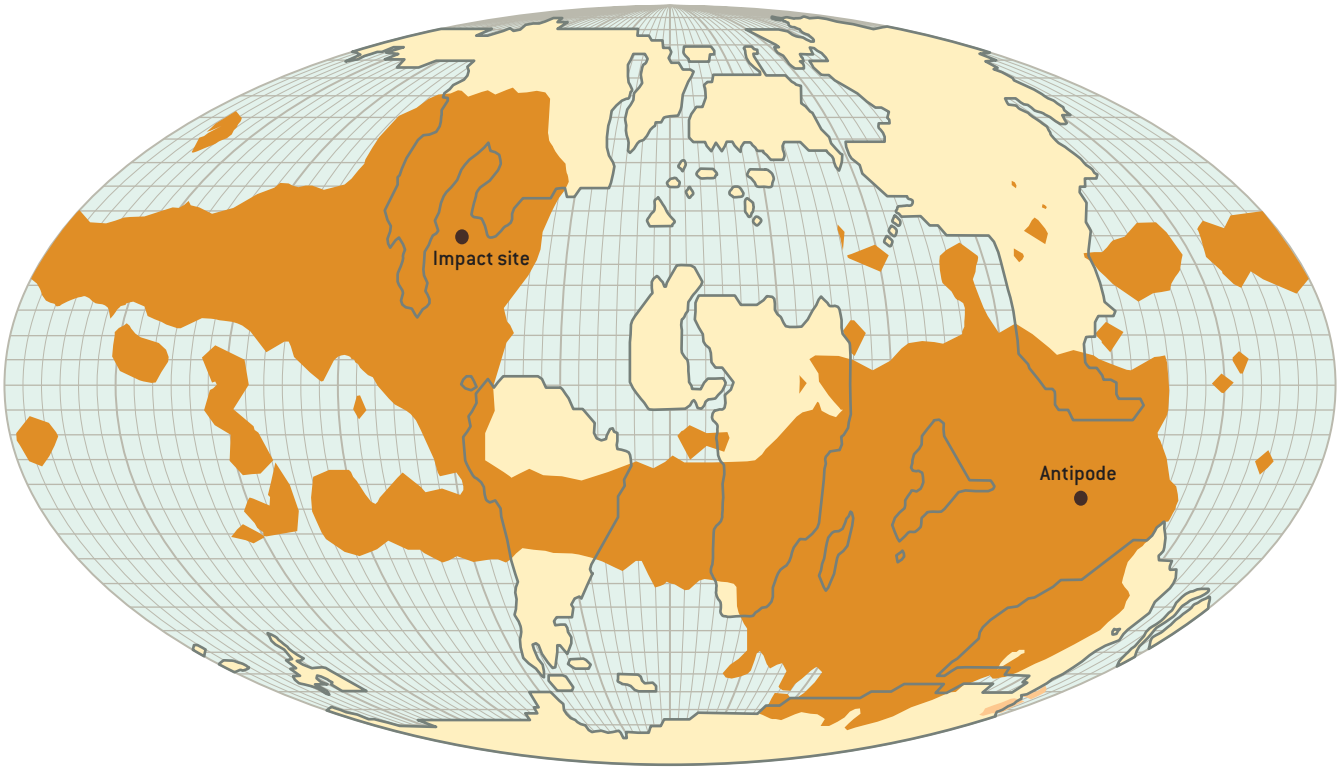
AFTER FIRES had ravaged the landscape, only a few stark trunks and skeletons remained. Soot from the fires and dust from the impact slowly settled to the ground. Sunlight was dramatically, if not totally, attenuated for months.

THE POSTIMPACT ENVIRONMENT was less diverse. Ferns and algae were the first to recover. Plant species in swamps and swamp margins generally survived better than species in other types of ecosystems. Conifers fared particularly badly.



SHRUBS TOOK ADVANTAGE of the vacant landscape and began to cover it. Species pollinated by the wind did better than those that relied on insects. Trees began to grow, but it took years for forest canopies to rebuild. The recovery time is uncertain.

CHRIS BUTLER



TOASTED PLANET: To dry out plants and set them on fire takes 12,500 watts of heating per square meter for at least 20 minutes. These conditions were reached in two main areas, centered on Chicxulub and its antipode in India. From these regions, corridors of fire stretched westward as Earth rotated beneath the hail of reentering debris. This computer simulation assumes a certain impact configuration; other scenarios incinerated even larger areas.

pact could have set off fires around the world. As it hit, the asteroid or comet disintegrated and vaporized a chunk of Earth's crust, creating a plume of debris. With increasing speed, the fiery plume rose out of the crater and rocketed through the atmosphere, carrying crystals of quartz that, only moments before, had been as deep as 10 kilometers below the surface.

The plume swelled to a diameter of 100 to 200 kilometers, punching its way into space and expanding until it enveloped the entire Earth. Material then began to fall back under the influence of gravity, plowing into the atmosphere with nearly all the energy with which it had been launched from Chicxulub. Moving at speeds of 7,000 to 40,000 kilometers an hour, the particles lit up the sky like trillions of meteors and heated a large volume of the atmosphere to several hundred degrees, before slowly settling to the ground and forming the layer we see today.

Melosh's team calculated that the reentering debris could have ignited vegetation over a huge fraction of the globe. But nobody in 1990 knew the location or precise size of the impact, so the team could not determine the total amount of heating or the distribution of the fires. Although soot had been found throughout the world, fires need not have erupted everywhere, because soot could have been blown to some sites by the wind.

A Blue Rain Doth Fall

SOON AFTER MELOSH REPORTED his findings, a team of seven American, Canadian and Mexican scientists (including one of us, Kring) discovered that Chicxulub was the impact site. This discovery settled the argument over the root cause of the extinction. Since then, researchers' attention has turned to the details of the event.

Last year the two of us completed a new study of the wildfires. Knowledge of the impact location allowed us to reconstruct the trajectories and distribution of material ejected from the crater and evaluate the extent of the fires. Our calculations suggest that some of the material reached halfway to the moon before plummeting back to Earth. Within four days almost all of it had returned to Earth. Slightly more than 10 percent escaped Earth's gravity altogether, to be flung across the solar system and possibly to collide with other planets. (Similarly, pieces of Mars and the moon have landed on Earth, although the ejection process differed.)

The reentering debris heated the atmosphere so severely that it ignited wildfires in the southern and central areas of North America, central South America, central Africa, the Indian subcontinent and southeast Asia (which, because of continental drift, were in different positions than they are today). Depending on the trajectory of the impacting asteroid or comet, fires may have also struck other parts of those continents and possibly Australia, Antarctica and Europe.

The two worst places to be were the Chicxulub region and, ironically, the place farthest away: India, which 65 million years ago was located on the opposite side of the planet from Chicxulub, making it a focus point for debris. In the hours and days that followed, Earth's rotation carried landmasses to the east,

SOURCE: DAVID A. KRING AND DANIEL D. DURDA; LAURIE GRACE (*illustration*)

CRETACEOUS PARK

THE CLIMATE during the late Cretaceous period, just before the comet or asteroid impact 65 million years ago, was warmer than it is now. No ice covered the polar regions, and some dinosaurs migrated as far north as today's Alaska and as far south as the Seymour Islands of Antarctica. A seaway cut through North America, joining the Gulf of Mexico with the Arctic Ocean. Ecosystems ranged from swamps to deciduous forest. Paleobiologists have mapped out those in North America, where the continental sediments that contain fossils are well preserved. (Little is known about late Cretaceous vegetation in other parts of the world.)

In what is now southern Colorado and northern New Mexico, meandering streams flowed from the nascent Rocky Mountains to a coastal plain in the east. Charles L. Pillmore and his colleagues at the U.S. Geological Survey have mapped several sedimentary settings, including stream channels, overbank deposits, floodplains and swamps. Using fossil leaves in those sediments, Jack Wolfe and Garland Upchurch of the USGS have shown that the vegetation was dominated by near-tropical, broad-leaved evergreen trees that formed an open canopy woodland.

In what is now the Dakotas, Kirk R. Johnson of the Denver Museum of Nature and Science has found fossil leaves that suggest the vegetation was a woodland dominated by angiosperms (flowering plants), mostly small trees (the size of dogwoods) to medium ones (the size of aspen). Wolfe and Upchurch have argued that conditions became wetter farther to the north, supporting a broad-leaved evergreen forest. This forest was denser, and the canopy was probably closed in some areas. Some vines had large leaves with drip tips—long, drawn-out extensions from which water could drain.

Arthur Sweet of the Geological Survey of Canada and his colleagues have shown that, in contrast to the flowering plants that dominated in the U.S., conifers and other cone-bearing plants were the most common in what is now western Canada. *—D.A.K. and D.D.D.*

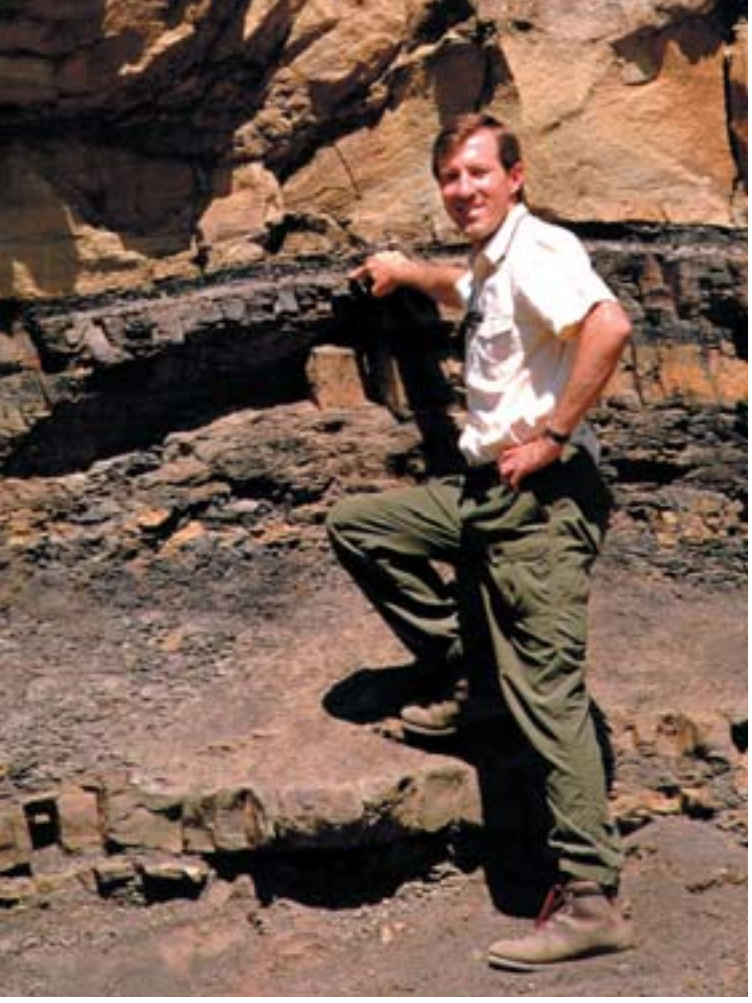
CRETACEOUS FOREST was warm and wet, home to broad-leaved and palm trees, tropical paddle-leaved and herbaceous plants, and ferns.

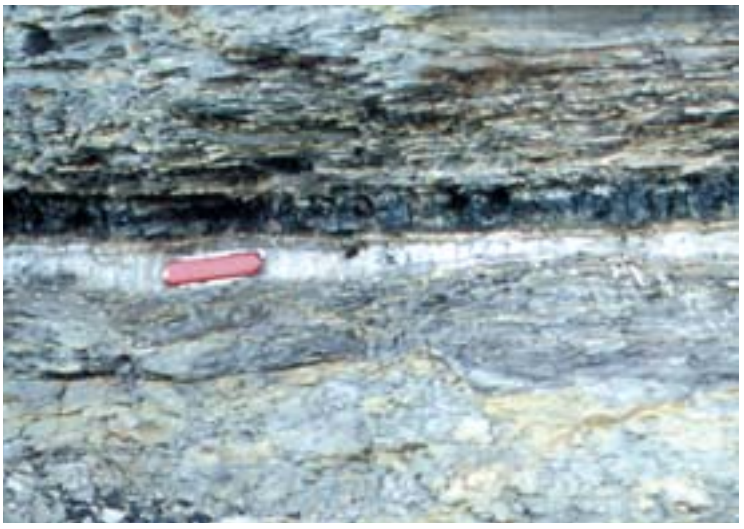
TERTIARY FOREST initially had less biodiversity. The earlier fern and herbaceous cover gave way to relatives of modern sycamore, walnut and palm trees.

bringing them under the hail of ejected material. Thus, the global wave of wildfire ignition shifted westward, slowly diminishing in intensity.

In most areas, it did not really matter whether vegetation was growing in a dry place or in a humid swamp. Hot temperatures lasted so long that moisture was driven from wet vegetation, like wood in a kiln, and then set ablaze. Did animals panic when the sky began to glow with falling debris? Were they alarmed when the temperatures began to rise? Did they stand completely still, or did they run in some direction—toward water, for example? Mercifully, most animals would have fallen unconscious as the temperatures rose and never felt the fire bursting out in the bushes and trees around them.

In addition to ravaging forests, the fires produced severe air pollution. Soot and impact-generated dust choked the sky over the entire planet, making it impermeable to sunlight. Some calculations suggest that the surface was as dark as a lightless cave, although the precise amount of darkening remains uncertain. In any event, photosynthetic plants died and food chains collapsed, even in areas untouched by wildfires, such as the sea. This phase has been likened to "nuclear winter," a cold spell that some modelers have suggested may follow a nuclear exchange [see





MASS GRAVE left by the Chicxulub cataclysm has been preserved as a light-colored layer of clay, which is about as thick as a Swiss Army knife (*above*). One of the authors (Kring) points to this layer in a rock outcrop in the Raton Basin of the southwestern U.S. (*left*). A detailed view of the layer (*right*)

"The Climatic Effects of Nuclear War," by Richard P. Turco, Owen B. Toon, Thomas P. Ackerman, James B. Pollack and Carl Sagan; SCIENTIFIC AMERICAN, August 1984]. The dirt took months to wash out, probably falling as blue rain similar to the blue ash-rich rain seen after modern volcanic eruptions.

Using modern forest fires as a guide, we have estimated that the conflagrations also released 10,000 billion tons of carbon dioxide, 100 billion tons of carbon monoxide and 100 billion tons of methane—an amount of carbon equivalent to 3,000 years of modern fossil-fuel burning. Therefore, the dark, wintry conditions were followed by an interval of greenhouse warming. The fires also produced debilitating gases such as pyrotoxins, chlorine and bromine, the latter two of which helped to destroy the ozone layer. All these effects dramatically compounded the other environmental consequences of the impact, such as nitric acid rain, sulfuric acid rain, and the vaporization of carbon dioxide stored in rocks at the impact site.

The Day After

THE FOSSIL RECORD contains a pattern of ecological disturbance that matches what one would expect from the mother of all wildfires. In the sediments deposited immediately after the impact is a classic biological signature of fire: an anomalously high concentration of fern spores, first seen by Robert H. Tschudy and his colleagues at the U.S. Geological Survey. Ferns (*Cyathidites*) were thus the first plant species to repopulate the denuded landscape—the same pioneering behavior they exhibit when forests are scorched today. The ferns sometimes occurred together with a wind-pollinated flowering plants, *Ulmoideipites*. In some ecosystems without ferns, blooms of algae dominated the postimpact environment.

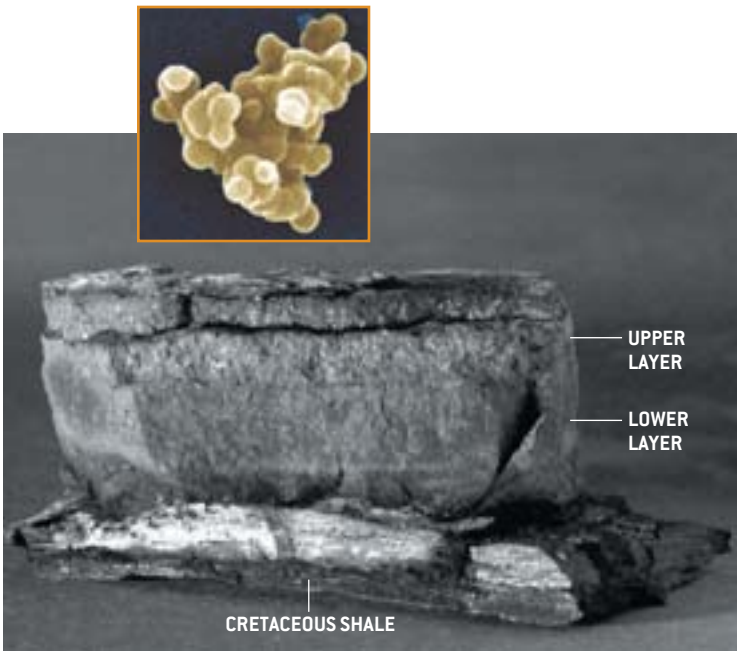
In sediments deposited in what is now Colorado and Montana, Iain Gilmour and his colleagues at the Open University in England have found chemical and isotopic fingerprints of methane-oxidizing bacteria—a sign that the loss of so much life may have temporarily created anoxic, or oxygen-starved, conditions in small freshwater ecosystems. Although the success of these bacteria is not a signature of fire per se, it does indicate the pervasiveness and abruptness of death, which requires a mechanism such as a global conflagration to explain.

One might ask how anything managed to survive the inferno at all. A crucial factor was the uneven distribution of fire. Simulations indicate, and paleobotanists have confirmed, that northernmost North America and Europe escaped the worst of the devastation. In what is now the Northwest Territories, Arthur Sweet of the Geological Survey of Canada found that

THE AUTHORS

DAVID A. KRING and *DANIEL D. DURDA* met while they were both working at the University of Arizona. Kring was on the team that attributed the Chicxulub crater to an impact and linked it to the Cretaceous/Tertiary mass extinction. Durda was studying the collisional and dynamical evolution of asteroids. Combining their expertise, they worked out the sequence of events that must have unfolded after the impact. Kring is still at Arizona and has studied the environmental effects of nearly two dozen impacts. His favorite haunt is the Barringer Meteorite Crater (a.k.a. Meteor Crater) in Arizona, the world's best preserved impact site. Durda is now at the Southwest Research Institute in Boulder, Colo. He has made astronomical observations from high-performance jet aircraft. An avid pilot, he has logged time in more than a dozen types of aircraft, including the F/A-18 Hornet, and he is also a well-known astronomical artist.

DANIEL D. DURDA (*left*); DAVID A. KRING (*center* and *right*); WENDY S. WOLBACH *DePaul University* (*inset*)



shows two sublayers. The lower one appears only in sites fairly near the impact and consists of molten rock ejected from the crater. The upper one contains debris that rocketed into space and settled back onto the ground, as well as soot from fires (*inset*).

the abundance of gymnosperm pollen (from conifers and their relatives) decreased dramatically but did not go to zero. Thus, part of the forest canopy survived the wildfires even in cases where fires consumed the undergrowth, which consisted mostly of angiosperms (flowering plants). In these and other comparatively safe regions, the heat was less intense, so swamps or swamp margins afforded plants and animals some protection.

Based on studies of fossil plants, spores and pollen, Kirk R. Johnson of the Denver Museum of Nature and Science and his colleagues concluded that 51 percent of angiosperm species, 36 percent of gymnosperms, and 25 percent of ferns and fern allies were extinguished in North America. The fossil pollen and leaves suggest that deciduous trees survived better than evergreen trees, perhaps because they could lie dormant.

Trees that were wind-pollinated also seem to have survived better, because they could prosper even if pollinating insects and other animals were exterminated. Indeed, Conrad C. Labandeira of the Smithsonian Institution and his associates have argued that many insects disappeared or went extinct, based on a dramatic drop in the frequency of insect-damaged leaves in the fossil record of North Dakota, which escaped the direct brunt of the impact. Researchers still do not know the detailed effects on other animal species.

Sweet has shown that the initial "survival" ecosystem, dominated by the most robust species, soon gave way to an "opportunistic" ecosystem, composed of a different type of fern (*Laevigatosporites*) and several kinds of flowering plants that were able to take advantage of the ecological clean slate. Together these plants produced an herbaceous ground cover. In the final stage of recovery, the forest canopy returned. Based on observations of modern forests, that regrowth took at least 100 years. Both Sweet and Upchurch have argued that the process was, in fact, far slower—taking up to 10,000 years, judging from the rate at which fossil plants occur in postimpact sediments.

Another measure of the recovery time is the response of the global carbon cycle. The loss of forests, which contain more than 80 percent of aboveground carbon (at least today), and the emission of carbon dioxide from fires and vaporized limestone at the impact site sharply increased the amount of carbon in the atmosphere. In an isotopic analysis of sediments deposited after the impact, Nan C. Arens of the University of California at Berkeley and A. Hope Jahren of Johns Hopkins University concluded that it may have taken 130,000 years for the carbon cycle to return to equilibrium in continental settings. In the marine environment, Steven L. D'Hondt of the University of Rhode Island and other investigators suggest that it took three million years for the flux of organic material to the deep sea to return to normal.

Silent Spring

THE WORLD AFTER the Chicxulub impact event looked, smelled and even sounded different. We have all been magically transported to the Amazon and other forests by audio recordings of bird, insect and monkey sounds. If we had a recording from the Cretaceous, we might hear dinosaurs moving through the brush, their calls to one another and the buzz of some insects. Mammals would have been relatively quiet, only rustling among the leaves much as moles do today. But in the months after the impact, the world was far quieter. Wind, flowing water and falling rain dominated the soundscape. Gradually insects, then mammals, could be heard again. Hundreds of years, if not hundreds of thousands of years, were needed for ecosystems to build new, robust architectures.

The firestorm created by the Chicxulub impact and the subsequent pollution were devastating. But it was probably the combination of so many environmental effects that proved to be so deadly. They attacked different ecosystems in different ways on different timescales, ranging from days for reentering ejecta to months for dust in the stratosphere to years for sulfuric acid aerosols.

Life's diversity was its salvation. Although multitudes of species and countless individual organisms were lost, some forms of life survived and proliferated. The impact opened ecological niches for mammalian evolution, which eventually led to the development of our own species. In this sense, the Chicxulub crater is the crucible of human evolution. SA

MORE TO EXPLORE

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T. rex and the Crater of Doom. Walter Alvarez. Princeton University Press, 1997.

Night Comes to the Cretaceous. James Lawrence Powell. Harvest Books, 1999.

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IDENTICAL TWINS have identical DNA sequences. Yet in most cases where one twin develops a complex disease known to have a genetic component, such as schizophrenia, bipolar disorder or childhood diabetes, the other twin does not. Environmental factors may play a role, but increasingly biologists are realizing that important traits can be transmitted epigenetically, through the chromosomes but outside the DNA.

The Unseen Genome: Beyond DNA

BY W. WAYT GIBBS

DNA was once considered the sole repository of heritable information. But biologists are starting to decipher a separate, much more malleable layer of information encoded within the chromosomes. Genetics, make way for epigenetics

"Human Genome Placed on Chip"
read the headline this past October

as the *New York Times* reported that three biotech companies have made thumbnail-size devices that can record the activity of all the genes in a sample of human tissue. Thus is fulfilled one of the promises of the Human Genome Project: by scanning the human DNA sequence, scientists can now guess which bits are the genes that are transcribed into RNA messages and then translated into functional proteins.

When the "final draft" of the sequence was released in April, many said that the string of three billion A, T, G and C bases in human DNA represents—choose your metaphor—the book of inheritance, the source code of cells, the blueprint for a life. But in truth, all these metaphors mislead.

A genome, the sum of heritable information that is held in the chromosomes and that governs how an organism develops, is not a static text passed from one generation to the next. Rather a genome is a biochemical machine of awesome complexity. Like all machines, it operates in three-dimensional space, and it has distinct and dynamic interacting parts.

Protein-coding genes make up just one of those parts—and often a small one at that, accounting for less than 2 percent of the total DNA in each human cell. But for the better part of five decades, those genes were enshrined by the central dogma of molecular biology as the repository of heritable traits. Hence the notion of the genome as a blueprint.

As far back as the 1960s, experimenters had uncovered important information hiding elsewhere in the chromosomes. Some was tucked among the "noncoding" DNA, and some lay outside the DNA sequence altogether. The tools of genetic engineering worked best on conventional genes and proteins, however, so scientists looked hardest where the light was brightest.

In recent years, geneticists have been exploring the less visible parts of the genome more thoroughly, in search of explanations for anomalies that contradict the central dogma: illnesses that run in families but pop up unpredictably, even differing among identical twins; genes that switch on or off in cancers yet harbor no mutations; clones that usually die in the womb. They have found that these second and third layers of information, distinct from the protein-coding genes, connect in surprisingly deep and potent ways to inheritance, development and disease.

In the November issue of *Scientific American,* "The Unseen Genome: Gems among the Junk" described those connections for the second layer, which consists of myriad "RNA only" genes sequestered within vast stretches of noncoding DNA. Science had dismissed such DNA as the useless detritus of evolution, because no proteins are made from it. But it turns out that these unconventional genes do give rise to active RNAs, through which they profoundly alter the behavior of normal genes. Malfunctions in RNA-only genes can inflict severe damage.

The third part to the genomic machine, as fascinating as active RNA genes and probably even more important, is the "epigenetic" layer of information stored in the proteins and chemicals that surround and stick to DNA. Epigenetic marks are so named because they can dramatically affect the health and characteristics of an organism—some are even passed from parent to child—yet they do not alter the underlying DNA sequence.

Geneticists have yet to decipher the complex code by which epigenetic marks interact with the other components of the genome. But in working out some of the critical mechanisms, researchers have noticed that the epigenetic part of the genome seems to play crucial roles in growth, aging and cancer. "Epimutations" are also suspected of contributing to diabetes, schizophrenia, bipolar disorder and many other complex ailments.

Epigenetics may suggest new ways to treat these diseases. Whereas cells doggedly protect their DNA against mutation, they routinely add or erase epigenetic marks. In principle, drugs could tinker with the epigenetic code to turn entire sets of rogue genes on and off. New medicines may be able to reverse some of the genetic damage that accompanies aging and precedes cancer.

Overview/*Epigenetics*

- Most traits are transmitted by genes in the DNA that encode proteins. But a separate code, written in chemical marks outside the DNA sequence, also has dramatic effects on the health and appearance of organisms.
- The epigenetic code may explain why some diseases skip generations and affect only one in a pair of identical twins. Epigenetic mistakes seem to play a role in cancer.
- A genome operates like a machine with several complex interacting parts. The epigenetic part should be easier to modify with medicine than the DNA sequence has been.

RANDY HARRIS PHOTOGRAPHY (*preceding page*)

HUGE HINDQUARTERS distinguish a *callipyge* ewe (*far left*) and ram (*right center*) from their normal siblings. The bizarre pattern of inheritance of the *callipyge* trait can be explained only by the interaction of three distinct layers of information in the genome.

SAM JACKSON *Texas Tech University*

Beautiful Buttocks

THE STORY OF SOLID GOLD illustrates how the three parts of the genome can interact to confound conventional notions of inheritance. Born in 1983 on an Oklahoma sheep ranch, a young ram was christened "Solid Gold" after its rear end grew to prodigiously meaty proportions. Sensing a moneymaking mutation, the rancher promptly put the ram out for stud.

Big-bottomed sons of Solid Gold were crossed with normal ewes. Half the offspring, both male and female, took after dad. Researchers called them *callipyge* (pronounced "kalipeezh"), Greek for "beautiful buttocks." A 50–50 split is just what one would expect from a mutation on a dominant gene. "But then things got more interesting," recalls Michel Georges, a researcher at the University of Liège in Belgium who had been called in as a consultant.

When female *callipyge* sheep were mated with normal males, not a single lamb of any sex showed the maximal gluteus so characteristic of its mother, even though some did inherit the mutation. It seemed as if *callipyge* had suddenly switched from a dominant to a recessive characteristic.

The geneticists next tried crossing normal-looking rams who were carriers of the mutation with completely normal ewes. *Et voilà,* half the lambs were *callipyge*. So the trait was appearing only when sheep inherited the mutation from their sires.

"Things got really bizarre," Georges recalls, when breeding yielded sheep bearing two *callipyge* alleles (in other words, the same mutation on both copies of the chromosome). If *callipyge* were a standard gene, then animals inheriting the mutant form from both parents should have been guaranteed thunderous thighs. Yet all the doubly mutated sheep looked perfectly normal [*see illustration on next page*]. What was going on?

Ten years of experiments have finally answered that question. In May, Georges and his co-workers published a recipe for the *callipyge* trait and pedigree: a standard protein-making gene, one or more RNA-only genes, plus two epigenetic effects. The final ingredient is a tiny mutation, a G base where an A normally appears, at a particular spot "in the middle of a gene desert, 30,000 bases from the nearest known gene," Georges says. Somehow the DNA at that spot controls the activity of the recipe's protein-coding and RNA-only genes on the same chromosome.

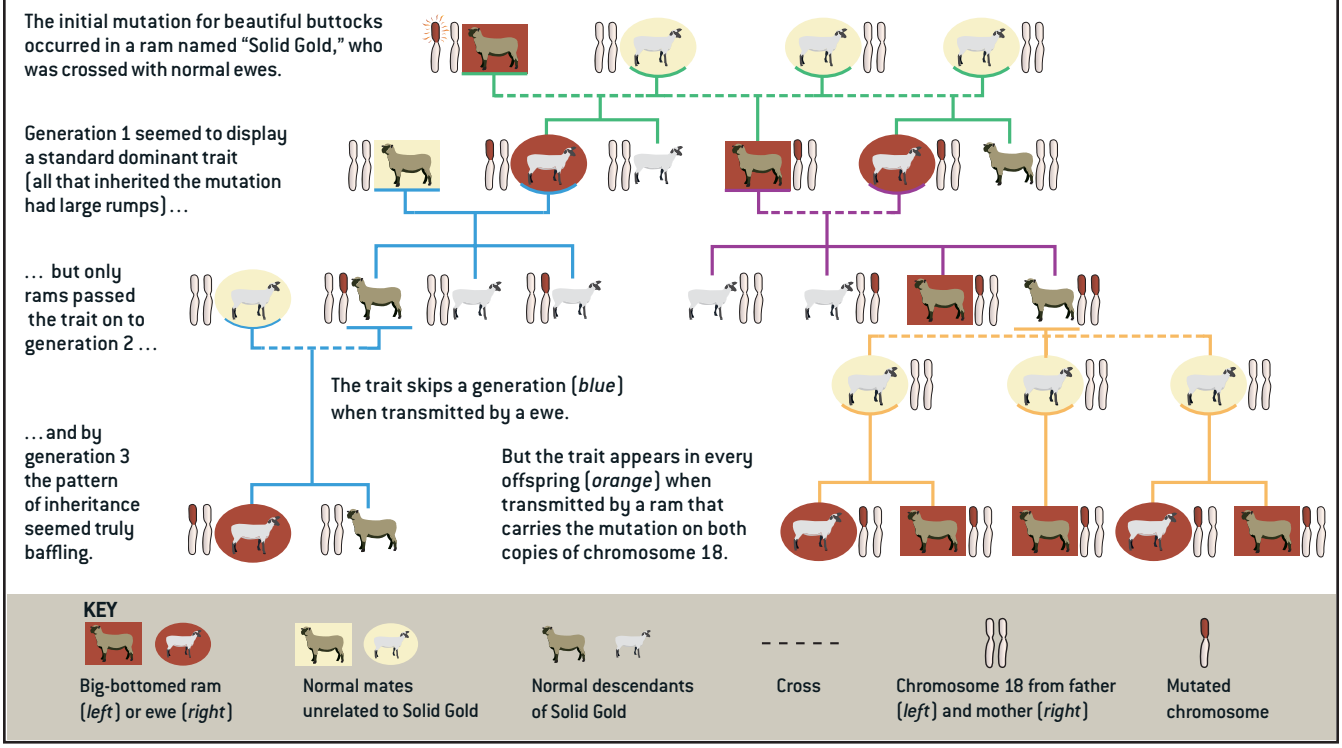
The A-to-G alteration can make those genes hyperactive, so that too much protein or active RNA is made in muscle cells. Excess protein explains the huge hindquarters—but not the odd inheritance pattern. Georges and others see an epigenetic phenomenon, imprinting, at work in the family tree.

For most genes, both the maternal and paternal alleles turn on or off at the same time. Imprinting disrupts this balance. For some imprinted genes, only the copy that came from dad is expressed; the allele inherited from mom is silenced. The protein-making, rump-plumping gene involved in *callipyge* works this way. That is why sheep receiving the A-to-G mutation from mom look normal; the mutation cannot override the selective censorship imposed by imprinting.

The opposite form of imprinting affects the *callipyge* gene (or genes) that makes active RNAs. Those RNAs are produced only from the allele on the maternal chromosome. This second bit of epigenetic wizardry helps to explain why the trait disappears from animals carrying two *callipyge* alleles.

TWISTS AND TURNS IN A FAMILY TREE

TWENTY YEARS AGO a sheep named "Solid Gold" was born with a mutation on chromosome 18 that caused its rump to grow unusually large. Solid Gold passed the trait to about half its offspring (*green*), the typical pattern for a dominant gene. Later generations revealed, however, that sheep inheriting the mutation from their mother look normal (*blue*)—even if they get a second copy of the gene from their father (*purple*). Because of epigenetic effects, the only sheep that develop big bottoms are those that receive just one copy of the mutation, from their father (*orange*).



In these double-mutant sheep the mutation on dad's chromosome throws the protein-making gene into overdrive. At the same time, the copy of the A-to-G mutation on mom's chromosome boosts levels of active RNAs from the RNA-only genes. Somehow the amplified RNAs block the amplified growth signal, and so the lamb looks svelte.

Such "overdominance" effects seem to be rare. Imprinting, however, is quite common, especially in flowering plants. Randy L. Jirtle of Duke University keeps a running list of imprinted human genes; the number is now up to 75. Many more may await discovery. Maxwell P. Lee of the National Cancer Institute reported in August that a scan of 602 genes in seven people found one allele to be significantly more active than the other in half the genes. For 170 of those genes, the difference between the alleles' expression exceeded a factor of four.

In the first few days after conception, nearly all imprinting is removed from the chromosomes. How this happens is a mystery. But sometime between then and mid-gestation, the epigenetic state is reestablished, says Emma Whitelaw of the University of Sydney. Reprogramming mistakes do happen, however.

The human gene for insulin growth factor 2 (*IGF2*), for instance, normally is imprinted; the maternal copy is deactivated. Yet about one person in 10 has no imprinting at the *IGF2* gene. "When we go into the clinic, we find that defect in 40 percent of people who have sporadic colon cancer," notes Carmen Sapienza of Temple University. "It is just an association, but it is very interesting," he says. A blood test that detects the loss of *IGF2* imprinting is already being evaluated as a way to predict the risk of colon cancer. Faulty imprinting is also a prime suspect in several rarer genetic diseases, such as Prader-Willi, Angelman and Beckwith-Wiedemann syndromes. The last causes facial deformities and an elevated risk of childhood cancer.

Epigenetic variations "could explain the odd discordance of diseases among identical twins," Whitelaw suggests. Identical twins share identical DNA sequences. But when one acquires a disease with a genetic component, such as schizophrenia, bipolar disorder or childhood diabetes, the other "identical" twin usually does not. Last year a group led by Rosanna Weksberg of the Hospital for Sick Children in Toronto compared twins discordant for Beckwith-Wiedemann syndrome and found that in every case the affected twin had lost imprinting within a critical area on chromosome 11, whereas the healthy twin had not.

"Clearly for cancer, for development, for birth defects, it is a very important phenomenon," says Francis Collins, director of the National Human Genome Research Institute. "How imprinting works is still not entirely understood. But DNA methylation seems to play a very significant role."

SOURCE: CAROLE CHARLIER AND MICHEL GEORGES *University of Liège, Belgium*; NADIA STRASSER (*illustration*)

This Be Madness, Yet There Is Methyl in It

SIMPLE YET POWERFUL, methyl consists of a carbon, three hydrogens and a hankering to bond to—to methylate—something else. Methyl has a special affinity for the C (cytosine) bases of DNA. Special-purpose enzymes take methyl molecules derived from basic nutrients, such as folic acid and vitamin B_{12}, and stick them onto certain C bases throughout the genome.

In general, the more methylated a stretch of DNA, the less likely it is to be transcribed to RNA and to carry out its function. The silent allele of an imprinted gene is almost always highly methylated, for example. But imprinting may be a side job for DNA methylation; it mainly seems to defend the genome against parasitic genetic elements called transposons.

"We like to think of the genome as this pristine endowment," observes Timothy H. Bestor of Columbia University. "But revolting as it may seem, our DNA is filled with genetic parasites." Roughly 45 percent of the human DNA sequence consists of viral genes (or gene fragments) that have copied themselves into the genome during the course of evolution. Fortunately for us, nearly all of this selfish DNA is heavily methylated and rendered inactive.

Jirtle's lab at Duke demonstrated the tight link between methyls and transposons this summer in a fascinating experiment with agouti mice, whose fur color varies from yellow to black under the control of a parasitic element. One group of pregnant agouti mice ate a normal diet; about 60 percent of their offspring grew yellow coats. But another group was fed chow enriched with vitamin B_{12}, folic acid and other good sources of methyl. The high-methyl diet changed the hair color of the resulting litter; now 60 percent developed brown coats. The shift appeared to be the result solely of increased methylation (and reduced expression) of the agouti transposon DNA.

But what happens if the methyl defense falters? In a famous study five years ago, genetic engineers disabled one of the methyl-adding enzymes in embryonic stem cells. With the methyl guard lowered, many transposons became active. The rate of DNA mutations in the cells shot up 10-fold. Such experiments raised an intriguing possibility: Could epigenetic abnormalities accelerate—perhaps even initiate—the genetic chaos that leads to cancer?

After all, tumor cells often contain both too little methylation in the genome overall and, confusingly, too many methyl molecules attached to certain genes that normally prevent deranged cells from becoming malignant. "In colon polyps [benign growths from which tumors often arise], we can already see a genome-wide reduction in DNA methylation" occurring even before mutations knock out key antigrowth genes on the road to cancer, says Stephen B. Baylin of Johns Hopkins University.

No one knows why so many methyls fall off the DNA in the first place—no methyl-removing enzyme has been positively identified. But researchers suspect that methyl-poor chromosomes are more likely to malfunction during cell division, taking a step toward malignancy.

Work this year by Rudolph Jaenisch of the Whitehead Institute at M.I.T. reinforced that suspicion. His group created mice with an inborn deficiency of a methylating enzyme. In most of the mice, at least one of the undermethylated chromosomes became unstable. Mutations accumulated quickly, and 80 percent of the mice died from cancer within nine months.

The idea that a lack of methyl on the DNA can lead to human cancer is still just a hypothesis, and in any case oncologists have no drugs that can correct genome-wide undermethylation. But doctors are testing several anticancer drugs that attack the other methyl problem: too much of it stuck on some cancer-related genes. Until recently, many scientists believed that a tumor could take hold only after mutation had knocked tumor suppressor genes out of commission. Yet in many tumor cells these cancer-fighting genes have a perfectly normal DNA sequence. Methylation mistakes, not mutations, lay the genes low.

> "When the drug works, the leukemia goes away: 99.9 percent of the cancerous cells are gone."

Drugs such as the anesthetic procaine, the mood stabilizer valproic acid and the chemotherapy agent decitabine all seem to either strip methyl groups from DNA or prevent methyl tags from being attached to newly formed cells. Jean-Pierre Issa has been testing decitabine in patients with advanced leukemia at his clinic at the M. D. Anderson Cancer Center at the University of Texas. Like most chemotherapies, the compound is quite toxic. But "when the drug works," Issa says, "the leukemia goes away: 99.9 percent of the cancerous cells are gone." Eight of 130 patients had such good fortune, in a controlled trial Issa published in August, and in 22 others the demethylating medicine sent the disease into partial remission.

"These drugs are quite promising," avers Sabine Maier of Epigenomics, a biotech company in Berlin that is working with Roche in Basel, Switzerland, to develop methylation-based diagnostics for cancer. "But there is one problem," she adds. "The drugs all lead to demethylation of the whole genome. This probably causes side effects."

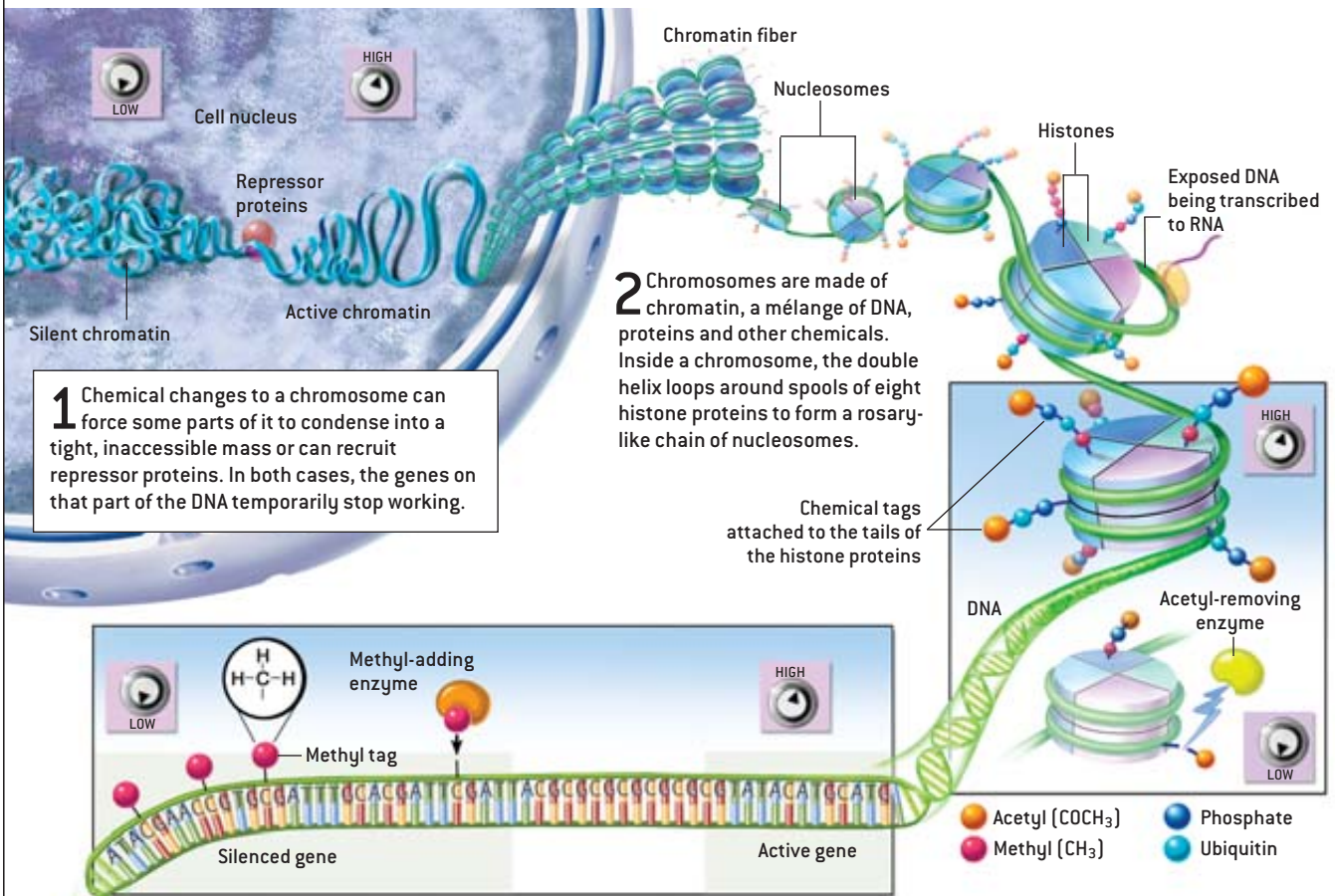
Another worry is that the effect is temporary: methyl tags soon start popping up again, and the tumor suppressor genes switch back off. "The drug-induced change in gene expression may not be permanent," Issa acknowledges, "but if it changes in such a way that the immune system can identify the tumor cell or that induces apoptosis [cell suicide], then the cell is still dead."

Breaking the Code

THE REEMERGENCE of a distinctive DNA methylation pattern after drugs wipe it clean strangely echoes the reprogramming of an embryo's imprinting marks shortly after conception. What directs the methyl-adding enzymes back to those tumor-suppressing genes or to those few alleles that should be imprinted?

VOLUME CONTROLS FOR GENES

THE DNA SEQUENCE is not the only code stored in the chromosomes. So-called epigenetic phenomena of several kinds can act like volume knobs to amplify or mute the effect of genes. Epigenetic information is encoded as chemical attachments to the DNA or to the histone proteins that control its shape within the chromosomes. Among their many functions, the epigenetic volume controls muffle parasitic genetic elements, called transposons, that riddle the genome.

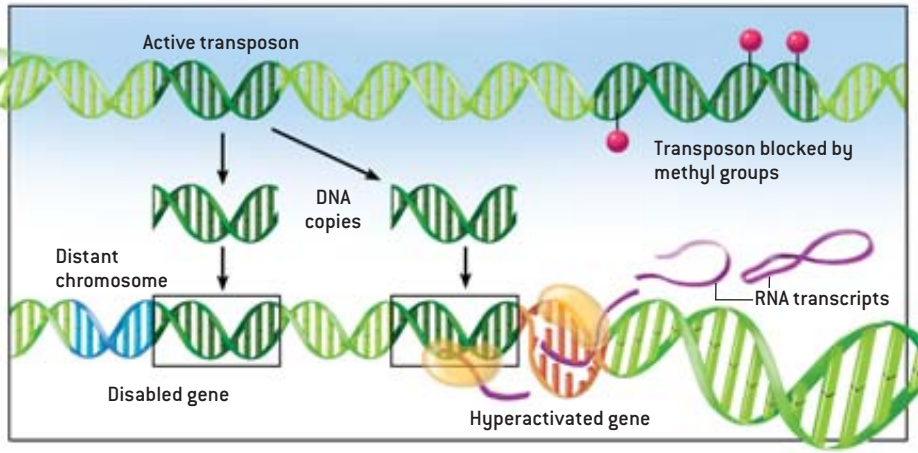


1 Chemical changes to a chromosome can force some parts of it to condense into a tight, inaccessible mass or can recruit repressor proteins. In both cases, the genes on that part of the DNA temporarily stop working.

2 Chromosomes are made of chromatin, a mélange of DNA, proteins and other chemicals. Inside a chromosome, the double helix loops around spools of eight histone proteins to form a rosary-like chain of nucleosomes.

3 An intricate histone code—written in chemical tags stuck to the histones' tails (*above*)—governs gene expression as well. Acetyl tags usually amplify nearby genes, whereas acetyl-removing enzymes mute them. But the rest of the code remains to be deciphered.

4 Genes can also be suppressed by methyl tags that stick directly to the DNA, usually at places where a C base is followed by a G. Whether DNA methylation turns down genes independently or only in combination with histone tags is still a mystery.



5 Transposons, also called jumping genes, can clone themselves and then insinuate the copies into distant sections of the genome, sometimes disabling or hyperactivating genes. One major function of DNA methylation seems to be the suppression of transposons, which make up almost half the human genome.

TERESE WINSLOW

That question must be answered if cloning is ever to become routine. Currently epigenetic reprogramming goes terribly awry in clones that are made by replacing the DNA in a fertilized egg with DNA from an adult cell. "The majority of such clones display abnormal patterns of methylation and gene expression," says David Wells, a cloning expert at AgResearch in Hamilton, New Zealand. Even though their DNA sequence may be fine, 90 percent of the animals die before birth; half of those born alive never make it to adulthood. The few that survive to maturity tend to suffer obesity and diseases of the immune system.

To permanently prevent or reverse the methylation errors so common in clones, tumors and imprinting disorders, researchers must decipher a related epigenetic code—one altogether separate from DNA. "Methylation alone doesn't silence the genes," Baylin of Johns Hopkins says, "it just locks in the silent state." The methyl-adding enzymes seem to take their orders from elsewhere.

Zoom in on a chromosome, and you will find that it is not (as often drawn) a haphazard tangle of DNA, nor even a single object, but a dynamic assembly of DNA, proteins and other chemicals. This filamentlike assemblage, called chromatin, does more than support the DNA. It also controls access to it.

Chromatin contains half as much DNA as it does protein, most of which is in the form of histones. Histones are nature's answer to the question: How does a cell fit 1.8 meters of DNA into its nucleus? In a word, clever packaging. DNA wraps around histone spools to form a rosarylike chain, which is then twisted into a bundle [*see illustration on opposite page*]. Sections of chromatin can condense and expand independently, effectively hiding whole swaths of the DNA from view while exposing other sections for transcription.

Females, for example, start out life with two active X chromosomes; males inherit just one. A female embryo must muzzle the extra X to prevent its cells from getting a double dose of X-borne genes. To do this, two parts of the genomic machine conspire to shut down the third. A noncoding gene named *Xist* produces an active RNA that coats the unneeded X chromosome. The needed X meanwhile produces "antisense" RNA, which acts like an antidote to protect it from *Xist*. A chain reaction spreads down the unwanted chromosome: methyls tag much of the DNA, histones shed the chemical acetyl from their tails, and the chromatin compacts into an inaccessible, RNA-coated mass. The silent X chromosome is then passed down, inactive, to every genome-bearing cell as the woman grows.

The role of histones in this drama is not clear, but recent work has shown that the protein tails that hang off the histone spools can sport an impressive array of chemical additions. Where acetyls adorn certain spots on the histones, for example, the chromatin is usually open for business, allowing the cell's transcription machinery to read the DNA in that part of the chromosome.

Compact, silent chromatin generally lacks acetyls in the special positions and instead will often have methyl groups stuck at different points on the histone tails. The histones also play host to phosphate groups and to the peptide ubiquitin—and all of these tags appear in a bewildering variety of locations and combinations. The histone code will not be easy to crack.

Unlike the stable genetic code of DNA, many epigenetic marks are in constant flux. When one section of chromatin condenses, the silence can spread along the chromosome until it hits a barrier. Xin Bi of the University of Rochester recently identified boundary elements that recruit acetyl-adding enzymes to histones, ensuring that they stay active. Sometimes a physical gap where the DNA floats free of any histones can halt the spread, Bi says. At other places, there is no boundary, just a continual tug-of-war between the active and silent regions of the chromosome.

Issa thinks this struggle might explain why cancer risk rises so steadily with age. Perhaps the barriers in the chromosomes that separate the tightly condensed, highly methylated and silent portions from the accessible, unmethylated and active portions break down over the years as cells divide or grow old.

"There is a whole new universe out there that we have been blind to. It is very exciting."

The darker parts of the genome are still perceived only dimly. But it is quite clear, Sapienza asserts, that "the Human Genome Project was just the beginning of the job. We now need to produce a similar description of the epigenetic landscape." In October, Epigenomics and the Wellcome Trust Sanger Institute in the U.K. undertook to do just that, launching a five-year Human Epigenome Project to map all the DNA methylation sites. The consortium also announced its completion of a map of more than 100,000 methyl tags attached to the major histocompatibility complex, a section of chromosome 6 linked to many diseases.

The new view of the genomic machine is energizing, because it opens avenues to genomic engineering. Those 30,000-odd protein-coding genes, so important yet so immutable, are not the only instruction set to which cells refer. Noncoding DNA matters. Chemical attachments to DNA and to the histones matter. The shape of chromatin matters. And all of these are subject to manipulation. "There is a whole new universe out there that we have been blind to," Bestor says. "It is very exciting." SA

W. Wayt Gibbs is senior writer.

MORE TO EXPLORE

The Epigenome: Molecular Hide and Seek. Edited by Stephan Beck and Alexander Olek. Wiley, 2003.

Controlling the Double Helix. Gary Felsenfeld and Mark Groudine in *Nature,* Vol. 421, pages 448–453; January 23, 2003.

The Callipyge Locus: Evidence for the *Trans* Interaction of Reciprocally Imprinted Genes. Michel Georges, Carole Charlier and Noelle Cockett in *Trends in Genetics,* Vol. 19, No. 5, pages 248–252; May 2003.

Summaries of recent research, lists of imprinted genes, and other information on epigenetics are available online at **geneimprint.com**

ELECTRONIC SKIS

At the Moment

For decades, skiers slid down snow-covered hills on long rectangular planks. But in the mid-1990s companies began offering skis with an hourglass shape. They turned more easily because they concentrated the skier's weight at the middle of the ski's inside blade edge. The focus makes the ski less likely to slip out of the track that the blade carves as it traverses the inevitable microbumps of snow on any slope. Today "shaped" or "carving" skis dominate the market.

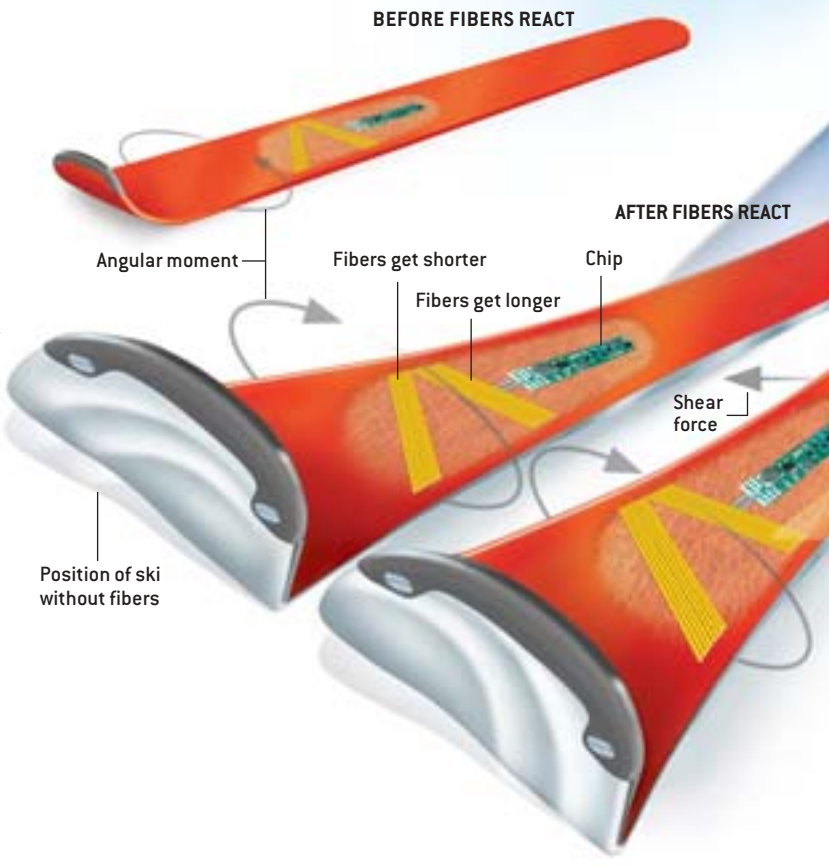
There's a subtle catch, however. The concentrated forces create a strong angular moment within the ski. To maintain structural integrity, the ski must be built with more rigidity. But that means the ski is apt to vibrate, which is annoying and can even lift it off the snow, causing a skier to wipe out.

In the past six years, manufacturers have laid various synthetics in the ski to dampen vibrations. But the most effective option may be piezoelectric fibers, already employed in tennis rackets, which convert vibration, compression or bending energy into electric current. A chip embedded in the ski accumulates, reverses and returns the current, making the fibers expand and contract, countering the angular momentum and creating a smooth, easy turn. A growing number of pro skiers are using piezo designs. "It's a quieter ride," says Joe Cutts, equipment editor for *Ski* magazine. The skis are also "more versatile" in various snow conditions, says Peter Keelty, co-founder of RealSkiers.com.

Unfortunately, chip-controlled, or "active," piezo skis cost about 50 percent more. And some reviewers think the benefits may be lost on recreational skiers, making a noticeable difference only at higher speeds on icy snow. K2, a large ski maker, has dropped its piezo models, which used piezo patches that passively absorbed vibrations rather than a chip for active feedback. Other designers maintain that a smartly devised layer of rubber can provide almost the same benefits at a fraction of the cost.

But Herfried Lammer, senior design engineer at Head Sport AG in Kennelbach, Austria, the piezo leader, says that skiers prefer the electronic glide. "At the end of the day, skiers must like what they feel on the slopes. And they do." —*Mark Fischetti*

DURING A TURN, a skier's weight presses down near the ski's center while the snow's reactive force pushes up along the ski's inside edge. The offset creates an angular moment in the ski's top layer that tends to lift the edge from the snow (*single ski, left*), which the skier must resist to prevent a skid. The moment changes throughout the turn, setting up vibrations that the skier feels as "chatter"—bumping and downslope slippage.



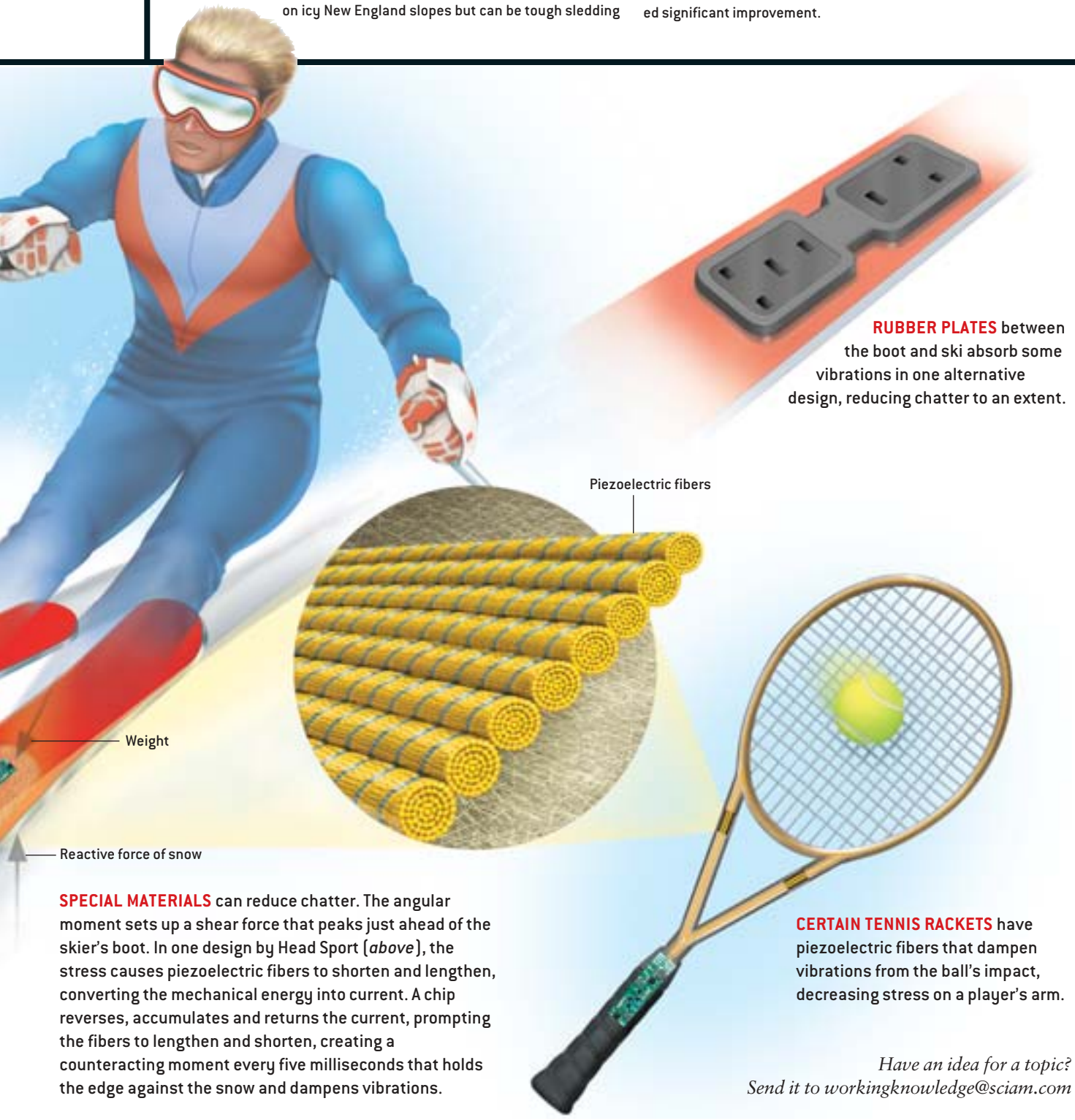
SOURCE: HEAD SPORT AG; ILLUSTRATIONS BY KENT SNODGRASS *Precision Graphics*

DID YOU KNOW . . .

➤ HOT SHOES: Advanced Cerametrics in Lambertville, N.J., is developing self-heated hiking and ski boots powered by piezomaterials in the heel, plus military boots that recharge batteries. It is also devising self-powered fishing lures that emit the sounds of a fish's prey.

➤ EVANGELIST ON SKIS: For years, John Howe was director of product development for Head Ski in Baltimore and later consulted for other ski equipment giants. But today the mechanical engineer works from his Waterford, Me., home, annually handcrafting 50 to 100 pairs of a radical product he calls the Claw. It has a rubber layer that he claims dampens vibrations more than any other design. Reviewers say it is superb on icy New England slopes but can be tough sledding in soft snow. Howe sees many commercial innovations as hype. He also sells a book, *The New Skiing Mechanics,* which extensively describes the forces encountered during skiing as it evangelizes the Claw.

➤ TENNIS ELBOW?: Head Sport first deployed piezomaterials in tennis rackets, to reduce vibrations in the handle after hitting a ball. In July 2002 Werner Zirngibl of the Institute of Orthopedics and Sports Medicine in Munich gave piezo rackets to 55 recreational players who were being treated for either temporary or chronic tennis elbow. After six weeks of regular play, enthusiasts with a chronic condition found little or no relief, but those who had had transient pain reported significant improvement.



RUBBER PLATES between the boot and ski absorb some vibrations in one alternative design, reducing chatter to an extent.

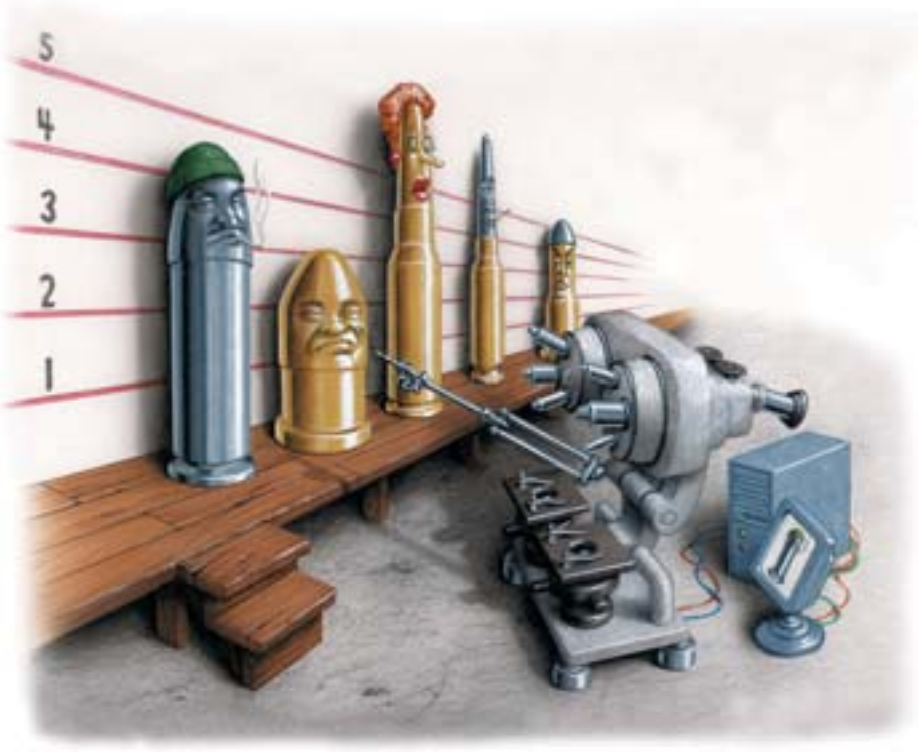
SPECIAL MATERIALS can reduce chatter. The angular moment sets up a shear force that peaks just ahead of the skier's boot. In one design by Head Sport (*above*), the stress causes piezoelectric fibers to shorten and lengthen, converting the mechanical energy into current. A chip reverses, accumulates and returns the current, prompting the fibers to lengthen and shorten, creating a counteracting moment every five milliseconds that holds the edge against the snow and dampens vibrations.

CERTAIN TENNIS RACKETS have piezoelectric fibers that dampen vibrations from the ball's impact, decreasing stress on a player's arm.

Have an idea for a topic? Send it to workingknowledge@sciam.com

Science for Cops

A BEHIND-THE-SCENES LOOK AT A HIGH-TECH POLICE LAB **BY MARK ALPERT**



COMPARING BULLETS fired from seized guns with bullets found at crime scenes is just one of the many tasks performed at forensic laboratories, which also analyze drugs and trace evidence.

JOHN FRASER

I admit it: I'm a *Law & Order* fan. I love watching television show detectives Lennie Briscoe and Ed Green trade wisecracks as they slip the cuffs on another homicide suspect. But, like millions of other fans, I've sometimes wondered how realistic the show is. In particular, I was skeptical of that stock scene (it occurs in nearly every episode) in which the geeky technician in the police laboratory uncovers a piece of evidence that blows the case wide open. Come on, I thought, how often does that actually happen? And are police labs really that technologically sophisticated? I felt compelled to see for myself, so I arranged a visit to the New York City Police Department's forensic laboratory, the real-life counterpart of the lab on *Law & Order*.

The police lab is located in an unglamorous building in the borough of Queens. Much of the work done there is also unglamorous: far more drug cases than homicides. According to Lieutenant Paul Scardino, commanding officer of the lab's controlled substances analysis section, seized drugs from about 200,000 cases are delivered to the lab every year. The contraband ranges from garbage bags full of uprooted marijuana plants to glassine envelopes packed with heroin. Top priority goes to analyzing heroin, cocaine and other felony drugs; to bring an indictment under New York State law, the lab has only five business days to identify a suspected sample and measure its purity, which reveals the weight of the drug. (The severity of the charge depends on the weight.)

Until recently, the lab used color and crystal tests to determine whether a sample contained heroin or cocaine. Investigators would put a few crumbs of powder in five wells on a spot plate, then add a different chemical to each well. The presence of heroin or cocaine would be confirmed by a distinctive set of reactions: the chemicals would change color in some of the wells and form crystals in others. Although this method worked reliably for decades, forensic scientists argued that there was a small chance that an unknown or rare compound could produce exactly the same reactions as the illegal drugs. So over the past five years the police lab has shifted to a high-tech tool more commonly seen in university research facilities: the gas-chromatography mass spectrometer (GCMS).

How does the GCMS work? First, technicians dissolve the drug sample in methanol and place a small amount of the liquid in a vial. The GCMS vaporizes the liquid and uses helium to carry the mix of gases through 15 meters of slender glass tubing coiled inside the machine. Different molecules travel through the tubing at different rates because of interactions with a thin coating on the tube's inside surface. Therefore, the GCMS is able to

isolate the heroin and cocaine molecules, which are then bombarded with electrons to ionize them. The ions pass through a magnetic field, and the amount of deflection reveals their molecular weight. If the GCMS fingerprint of a sample matches that of heroin or cocaine, it is nearly impossible for even the best defense lawyer to challenge the result successfully. To ensure the accuracy of the machines, the lab technicians recalibrate each GCMS every morning by testing vials of pure heroin and cocaine obtained from pharmaceutical companies.

New York City's police lab is actually more surprising and fascinating than ***Law & Order's***.

The new technology doesn't come cheap: each GCMS costs about $80,000, and the police lab uses two dozen. And because certain drugs—such as LSD, MDMA (better known as Ecstasy) and ketamine ("Special K")—are destroyed by high temperatures, the lab also has two liquid-chromatography mass spectrometers that don't require vaporizing the sample. Overall, the controlled substances section employs about 60 people, who are officially called criminalists. Very few conform to the pasty-faced *Law & Order* stereotype; on the contrary, the staff reflects the extraordinary ethnic diversity of Queens, with a particularly large number of people from India.

Next to drugs, guns are the police lab's biggest commodity. Every year about 10,000 seized guns are sent to the firearms section in the lab's basement. The examiners there first determine whether the guns are operable. (Most firearms used by criminals are not in the best condition.) Then the examiners test-fire the guns to see if the markings imprinted on the shells or bullets match any evidence previously found at crime scenes.

Robert Tamburri, a detective in the firearms section, gave me a vivid demonstration of the test-firing process. He picked up a worn and weathered-looking semiautomatic pistol and took me into a soundproof room. Inside was a large metal tank containing 600 gallons of water. The detectives fire into the tank because water can stop the bullets without damaging the telltale marks made by the gun. I got a bit nervous as Tamburri inserted two nine-millimeter bullets into the pistol's magazine and prepared to fire into the tank's gun port; I'd never been so close to a cocked semiautomatic before. (And I sincerely hope that I never get that close again!) Then the shots rang out—luckily, I was wearing ear protectors—and the shells landed in a net below the gun port. Tamburri opened the tank's lid, and we fished out the two bullets using a suction hose.

We took the shells and bullets to a comparison microscope, which is basically a pair of microscopes joined together so that two objects can be viewed side by side. Looking at both bullets through the stereoscopic eyepiece, I could see that they shared the same pattern of marks left by the rifling (the spiraling grooves inside the gun's barrel that spin the bullet to give it flight stability). But even more striking was the similarity between the marks on the shells: the circular pits made by the firing pin when it struck the shell's primer and the parallel lines imprinted on the shell casing when it recoiled against the breech face. The firearms lab routinely

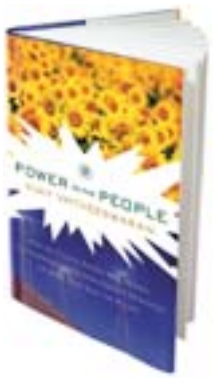
digitizes these images and compares them with the images stored in the Integrated Ballistics Identification System, which archives bullet and shell evidence from crime scenes across the U.S. The software calls up the closest matches; if two images appear to be identical, the examiner retrieves the physical evidence and does a firsthand inspection.

Last but not least, I visited the police lab's trace analysis section, which handles the forensic work most often depicted on TV—examining fibers, paints, papers and other crime scene evidence. This section has enough high-tech instruments to make it the envy of any chemistry department. In one room, investigators use an x-ray diffraction machine to look for crystals in explosive materials; across the hall, they employ a scanning electron microscope to search for the spherical particles present in gunshot residue. Other rooms contain infrared microscopes, an x-ray fluorescence machine and a Raman spectrometer. Tools such as these are indeed used in homicide investigations, but that's just a small fraction of their workload. For example, the lab can find evidence of arson by identifying kerosene or butane in fire debris.

Although some of this work may sound mundane, New York City's police lab is actually more surprising and fascinating than *Law & Order*'s. At one point in my tour of the firearms section, Tamburri led me into a room that contained dozens of old guns, many used for spare parts when investigators need to fix a seized weapon before test-firing it. He picked up a pair of scuffed revolvers that were lying on a desk. One was the gun that Mark David Chapman had used to kill John Lennon in 1980; the other had belonged to David Berkowitz, the "Son of Sam" killer who murdered half a dozen people in the mid-1970s. Staring at the ugly gray weapons, I felt disoriented. My god, I thought. This is a lot stranger than anything I've ever seen on TV. SA

The Quest for Affordable Energy

ASKING THE HARD QUESTIONS—AND PROVIDING SOME ANSWERS **BY JOHN P. HOLDREN**



POWER TO THE PEOPLE: HOW THE COMING ENERGY REVOLUTION WILL TRANSFORM AN INDUSTRY, CHANGE OUR LIVES, AND MAYBE EVEN SAVE THE PLANET
by Vijay Vaitheeswaran
Farrar, Straus and Giroux, 2003 ($25)

Energy is the lifeblood of industrial civilization and an absolutely necessary (albeit certainly not sufficient) condition for lifting the world's poor from their poverty. But current methods of mobilizing civilization's energy are more disruptive of local, regional and global environmental conditions and processes than anything else that humans do.

This dichotomy defines the core of the energy challenge in the century before us: How can we supply enough affordable energy to permit the billions who are currently poor (and the billions more who will be added to their numbers in the decades ahead) to attain prosperity—and to sustain and expand the prosperity of those already rich—without suffering intolerable damage to the environmental dimensions of human well-being in industrial and developing countries alike?

How difficult will meeting this challenge be? Is the "business as usual" approach—subsidizing fossil-fuel supply and nuclear energy and large hydro projects, maintaining low energy prices to consumers by keeping environmental and political costs "external," propping up oil supply by every available means—part of the solution or part of the problem? Can the privatization of energy sectors in the developing countries and the restructuring and deregulation of energy sectors in industrial countries be accomplished in ways that provide the economic benefits of competition while still preserving essential public benefits such as the reliability and resilience of the electricity system?

In his book, *Power to the People,* Vijay Vaitheeswaran tackles these and the other hard questions at the core of society's energy dilemmas with style, balance and insight. The style is entertaining and accessible. The balance is impeccable—Vaitheeswaran generally lets the most forceful and effective exponents on different sides of the major issues state their case in their own words—but after ventilating the various positions he is not afraid to let the reader know where he comes out.

And this is where the insight comes in. Vaitheeswaran brings to these questions the respect for markets and marketlike mechanisms of a writer for the *Economist,* the understanding of technology of an M.I.T.-trained engineer, and the sympathy for the plight of the world's poor of an individual born in India—all of which he happens to be. He also happens to have, in my judgment, a good sense of how to think about—and convey—the interplay of the economic, technological, environmental and sociopolitical dimensions of the energy issue as well as the reasons that the uncertainties afflicting our knowledge of all the dimensions do not add up to a good reason for inaction.

Among the critically important points about all this that the book convincingly conveys:

- Civilization is in no immediate danger of running out of energy or even just out of oil. But we are running out of environment—that is, out of the capacity of the environment to absorb energy's impacts without risk of intolerable disruption—and our heavy dependence on oil in particular entails not only environmental but also economic and political liabilities.
- Choices that countries make about energy supply commit them to those choices for decades, because power plants and other energy facilities typically last

WIND FARM in the Baltic Sea off the coast of Denmark, which generates more of its power by wind than any other country—18 percent in 2002.

FRANCIS DEAN *NewsCom*

for 40 years or more and are too costly to replace before they wear out. This is one of the reasons it is imprudent in the extreme to wait for even more evidence than we already have before letting climate-change risks start to influence which energy options we choose.

- Energy technologies that exist or are under development could greatly increase energy efficiency in residences and businesses, reduce dependence on oil, accelerate the provision of energy services to the world's poor, increase the reliability and resilience of electricity grids, and shrink the impacts of energy supply on climate and other environmental values. The most promising of these options include renewable sources of a variety of types, advanced fossil-fuel technologies that can capture and sequester carbon, and hydrogen-powered fuel cells for vehicle propulsion and dispersed electricity generation.
- These prosperity-building, stability-enhancing and environment-sparing options will not materialize in quantity matching the need unless and until three conditions are met: The massive subsidies favoring continuation of energy business as usual are ended. The massive risks of greenhouse gas–induced climate change are at least partly internalized with a carbon tax or its equivalent. And the industrial nations commit to helping the developing ones "leapfrog" past the inefficient and dirty-energy technologies that fueled the industrialization of the former but mortgaged the environment in the process.

There are a few small technical slips in the elaboration of all this, but not many, and none that matter to the thrust of the argument.

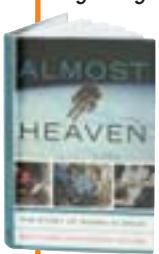
Written for the intelligent layperson, Vaitheeswaran's book is by far the most helpful, entertaining, up-to-date and accessible treatment of the energy-economy-environment problematique available. Its title, *Power to the People*, might strike some at first as too cute or too presumptuous. By the time I finished the book, though, I thought the title was apt, and in more ways than one. One must hope that knowledge translates to power in the political sense and that the knowledge to the people conveyed here will help lead to the political outcomes needed to bring the book's optimistic vision into being. SA

John P. Holdren is Teresa and John Heinz Professor and director of the Program on Science, Technology and Public Policy at the John F. Kennedy School of Government at Harvard University.

THE EDITORS **RECOMMEND**

ALMOST HEAVEN: THE STORY OF WOMEN IN SPACE

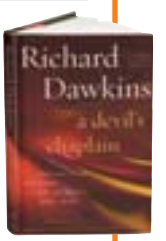
by Bettyann Holtzmann Kevles. Basic Books, 2003 ($25.95)



"It was midnight at Cape Canaveral on July 18, 1999, and still hot and humid." The opening sentence takes us to a launch of the space shuttle *Columbia*—the first time in history that a woman, U.S. Air Force Lieutenant Eileen Collins, would be in command. The final pages describe *Columbia*'s fatal flight in January 2003 with two female astronauts on board. And from beginning to end, this book is riveting. Meticulously researched, the story of women's struggle to gain a place in space is framed by the historical context of cold war competition and the American women's movement. Within this larger frame, the entire sweep of women's fight "to decide for themselves what risks they were willing to take" plays out: The first 13 women (the FLATS, or Fellow Lady Astronaut Trainees) who tried and failed to become astronauts in the early 1960s. The Soviet women cosmonauts, who faced their own version of sexism. At long last, in 1983, Sally Ride's historic flight. Right up to the present, when there are "so many women astronauts that few people recognize their names." References to popular culture—*Barbarella, Star Trek,* the criticism of Ride's shorts—are often as telling as the key events. It is a testament to the skill of Kevles, who teaches history at Yale University, that the story never slows or loses focus despite its scope and its many threads.

A DEVIL'S CHAPLAIN: REFLECTIONS ON HOPE, LIES, SCIENCE, AND LOVE

by Richard Dawkins. Houghton Mifflin, Boston, 2003 ($24)



Dawkins, a renowned evolutionary biologist who now holds an endowed chair as professor of the public understanding of science at the University of Oxford, is a man of firm opinions, which he expresses with clarity and punch. His topics in this collection of essays range widely—academic obscurantism, his "distrust of the jury system" and "where we go wrong in education" among them. He also enlarges on concepts he put forward in his acclaimed book *The Selfish Gene* and in introducing the meme. That is the name he gave to "mind viruses," or the idea "that self-replicating information leaps infectiously from mind to mind." He sees religions as such viruses. "To describe religions as mind viruses," he writes, "is sometimes interpreted as contemptuous or even hostile. It is both.... As a lover of truth, I am suspicious of strongly held beliefs that are unsupported by evidence."

All the books reviewed are available for purchase through www.sciam.com

You Don't Say!

BY DENNIS E. SHASHA

But I repeat myself. But you repeat yourself.

You might have read the first sentence as an intriguing lead. What was there to repeat? In the second sentence, you might have observed the parallel structure but wondered what was going on.

In this puzzle, the goal is to study such parallel repetition. Let's call a sequence of symbols (each one representing a word or perhaps several words) "surprising" if, for every pair of symbols X and Y and every distance D, there is at most one position in the sequence where X precedes Y by distance D. The top two sentences have the same distance between "But" and "repeat," so the eight-word utterance they form would not be considered surprising.

Here are other symbolic examples: AAB is surprising, as is AABA, but AABB is not, because there are two instances when A is followed by B two symbols away (by distance 2). Similarly, AAXYBB is not surprising, because A is followed by B four symbols away two times.

To warm up, explain why the following sequence composed from the symbols A, B and C is not surprising: BCBABCC. And find a surprising sequence using A, B and C that is at least seven symbols long.

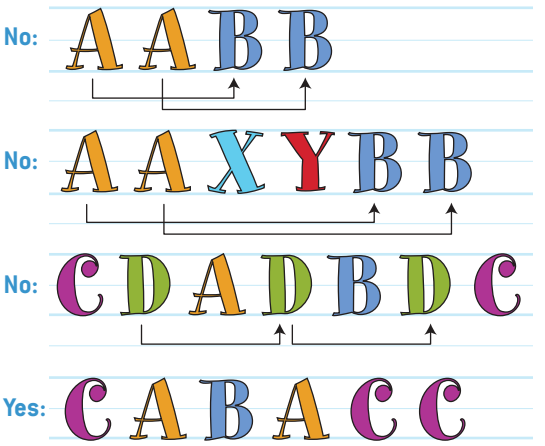
Here are three much harder challenges: Construct the longest surprising sequence you can that is composed from five distinct symbols. Then find the longest sequence you can make using 10 and 26 distinct symbols, respectively. For convenience, use the letters of the alphabet as symbols (A through E, A through J, and A through Z, respectively). You will find that the length doesn't increase very fast, and I believe that even for 26 symbols, the longest surprising sequence is less than 100 letters long.

The notion of surprise above is called 2-surprising because only pairs are involved. We could also define 3-surprising to mean that for any triplet of symbols and distances D1 and D2, there is at most one position in the sequence where the first symbol (X) precedes the second (Y) by distance D1 and the Y precedes the third (Z) by D2.

What is the longest 3-surprising sequence composed of the first five letters of the alphabet you can find? I know of no simple rule that will give the longest possible *k*-surprising sequences composed from sets of *n* symbols for any *k* and *n*. Can you find a pretty theory? SA

Dennis E. Shasha is professor of computer science at the Courant Institute of New York University.

Surprising, or Not?



Answer to Last Month's Puzzle

The following permutations are not possible with three levels of switches:

A D E C B
A E D B C
B C D E A
C E D A B
D E A C B
E A B C D

All these permutations would be possible, however, if there were four levels of switches.

Web Solution

For more discussion of last month's problem and a peek at the answer to this month's problem, visit www.sciam.com

ANSWER TO WARM-UP PROBLEM: BCBABCC is not surprising, because the letter B precedes a second B by distance 2 twice. A surprising sequence of length seven is BACCBCA.

NINA FINKEL

Quod Error Demonstrandum

SOMETIMES LOGIC ITSELF CAN BE THE FLAW IN THE OINTMENT **BY STEVE MIRSKY**

Observation followed by deduction is standard practice in science. But it's not foolproof, because, as has often been noted, fools can be so ingenious. Small children, though no fools, can likewise be exceptionally clever. I was recently reminded just how nimble their little minds can be when I listened to an old episode of the excellent radio program *This American Life*. The show in question (see www.thislife.org, June 22, 2001) was entitled "Kid Logic" and dealt with what happens when the scientific method is employed by those whose hands aren't quite big enough to hold it.

For example, a woman named Rebecca recalled a conversation with her friend Rachel from when they were both little kids. Rachel told her that she had lost a tooth and, following the usual procedure, put it under her pillow. She happened to wake up while the tooth was being exchanged for money and saw exactly who was making the switch: her father.

Now, to the adult mind the logical conclusion is (probably) that parents are behind the mysterious appearance of subpillow cash and that credit goes to the tooth fairy. But Rachel's conclusion was that her father *was* the tooth fairy. And her pal Rebecca, hearing the facts of the case, thus firmly believed that the tooth fairy was a guy named Ronnie Loeberfeld.

Later in the same show, an interviewer asked children what they thought the tooth fairy does with all those teeth. A boy came up with one molar solution, conjecturing that the tooth fairy builds entire tooth houses. The interviewer then asked why the tooth fairy wouldn't simply make a house out of bricks. To which a kid responded: "Because no one doesn't have brick teeth." Feel free to take a second to get your wind back.

Kid logic, of course, isn't limited to kids. Adults can be just as guilty of not so much leaping as tunneling to conclusions. For example, the *New Haven Register* reported in September the story of

one James Perry, who had perpetrated an identity theft, one of the fastest-growing crimes in America. The apparently logical conclusion reached by Perry was along the lines of "I'm such a loser that anybody's identity has to be better than mine." Wrong.

Perry, who wanted a Connecticut driver's license despite his four drunk-driving arrests, allegedly stole the identity of one Robert Kowalski. Perry as Kowalski got the driver's license and some credit cards and seemed to have achieved his desire to eat, drink and be not Perry.

How then did Perry wind up desperately trying to convince the authorities that he in fact was *not* Robert Kowalski? Well, Perry got himself arrested for disorderly conduct, and all his identification had him being Kowalski. The police were happy to get their hands on Kowalski, what with him being a convicted sex offender who had failed to register in Connecticut in accordance with state law. Perry ultimately diskowalskified himself and now faces only his own tribulations and possible trials.

Also in September another misnamed perpetrator was in the news in New England. Little Joe, a 300-pound adolescent gorilla at Boston's Franklin Park Zoo, escaped. He was found two hours later, near a football stadium, which could have been a fantastic hiding place for a large, hairy, grunting primate.

Anyway, this same Little Joe had gotten loose before, just a month earlier. The poor logic employed by zoo officials was that the gorilla, having demonstrated the ability to negotiate a moat and a wall, would be stopped by the addition of an electrified wire that supplies a painful, but not injurious, shock. Little Joe, previously nicknamed "The Scientist," either figured out a way to disable the electricity or used the oldest trick in the book to deal with pain, namely, not minding. He's now back in custody, where he probably faces a brighter future than either Perry or Kowalski. Perhaps he'd find it tougher to bust out of one of those tooth houses. SA

ILLUSTRATION BY MATT COLLINS; PHOTOGRAPH BY FRANK VERONSKY

ASK THE EXPERTS

Q What is game theory and what are some of its applications?

—B. Royce, New York City

Saul I. Gass, professor emeritus at the University of Maryland's Robert H. Smith School of Business, explains:

Game theory is a formal way of analyzing competitive or cooperative interactions among people who are making decisions—whether on a game board or in society at large. Starting simply, we can draw some generalizations about common games such as tic-tac-toe or chess. These games are said to have perfect information because all the rules, possible choices and past history of play are known to all participants. That means players can win such games by using a pure strategy, which is an overall plan that specifies moves to be taken in all eventualities that can arise in play. Games without perfect information, such as stone-paper-scissors or poker, offer no pure strategy that ensures a win. If a player employs one strategy too often, his or her opponent will catch on. This is where the modern mathematical theory of games comes into play. It offers insights regarding optimal mixes of strategies and the frequency with which one can expect to win.

Stone-paper-scissors is called a two-person zero-sum game, because any money one player wins, the other loses. Mathematician John von Neumann proved that all two-person zero-sum games have optimal strategies for both players. Such a game is said to be fair if both players can expect to win nothing over a long run of plays, as is the case in stone-paper-scissors, although not all zero-sum games are fair.

The power of game theory goes far beyond the analysis of these relatively uncomplicated games. In many-person competitive situations, some players can form coalitions against other players, games may have an infinite number of strategies, and there are nonzero-sum games, to name a few possibilities. Mathematical analysis of such games yields an equilibrium solution (a set of mixed strategies), one solution for each player, such that no one has a reason to deviate from that game plan (assuming all the players stick to their equilibrium approaches). As mathematician John Nash proved, any many-person, noncooperative, finite-strategy game has at least one equilibrium solution.

The greater significance of game theory is that such contests are metaphors for other interactions and can be used to analyze real-world situations, including missile defense, labor management negotiations and consumer price wars. It is important to note, however, that for many circumstances game theory does not really solve the problem at hand. Instead it helps to illuminate the task by offering a different way of interpreting the competitive interactions and possible results.

Q Why do we get goose bumps?

—D. Polevoy, Kitchener, Ontario

George A. Bubenik, a physiologist and professor of zoology at the University of Guelph in Ontario, offers this answer:

Getting goose bumps is a physiological phenomenon inherited from our mammalian ancestors that was useful to them but not much help to us. So named because they resemble the skin of poultry after the feathers have been plucked, goose bumps result from the contractions of miniature muscles attached to the hairs on our body. Each contracting muscle creates a shallow depression on the skin surface, which causes the area surrounding the hair to protrude and the hair to stand up. In animals with a thick coat the raised hairs expand the layer of air that serves as insulation. Humans lack a thick coat, but goose bumps persist, perhaps because contraction of the muscles around body hair constricts blood flow to the skin, reducing heat loss.

Hair will also stand up on many animals when they feel threatened, presumably to increase their apparent size and thus frighten potential attackers. Both this reaction and the hair-raising response to cold stem from the stimulation of the autonomic nervous system. Humans get goose bumps not only when they are cold but also in situations that elicit strong emotional responses—even when they hear favorite songs from long ago or watch a horror movie. SA

For a complete text of these and other answers from scientists in diverse fields, visit www.sciam.com/askexpert

MATT COLLINS

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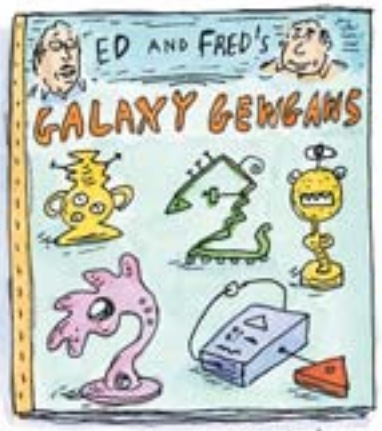
HOLIDAY CATALOGUES OF TOMORROW



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