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SCIENTIFIC AMERICAN

Fickle Physics:
The Laws of Nature May Change

JUNE 2005
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SUSPENDED ANIMATION

The Preservation of Life Is No Longer a Fantasy

The Overblown Obesity Epidemic

Traps That Catch Antimatter Atoms

Teaching Computers to Sound More Like People

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Bring Back the OTA

In this 21st century, science and politics are intertwined to a greater degree than ever before. Global warming poses a long-term challenge with no easy answers. The prospect of terrorism using technology such as dirty bombs and biowarfare looms large on everybody's radar. Then there is the threat of a bird-flu pandemic, not to mention the issues of embryonic stem cells, energy policy, missile defense, education, voting technologies.... The list goes on and on.

More than ever, those elected to govern are in need of timely, high-quality, impartial advice on matters of science and technology. Yet for nearly a decade now, one of the most successful agencies for providing just such advice—the Office of Technology Assessment (OTA)—has been defunct. Scrapped in September 1995 to save a paltry $22 million from the $2 billion spent each year on congressional operations, the OTA had produced widely hailed reports on an extraordinarily broad range of topics. (The full set of over 750 OTA reports is archived at www.wws.princeton.edu/~ota/)

Rather than spelling out a single prescription, OTA reports usually gave alternatives matched to different goals Congress might want to achieve. Instead of watering down recommendations to achieve a consensus, as is the custom of many blue-ribbon panels, the OTA deliberately sought out conflicting viewpoints. Often people on both sides of an issue would cite the same report during debate. Governments around the world emulated the U.S. example and still have their own versions of the OTA.

Some argue that Congress has other avenues for obtaining scientific advice, such as the Congressional Research Service. But the service is not equipped to provide the detailed technical analysis that was the hallmark of the OTA. The National Academies, another source for scientific advice, do estimable work, but their reports are more expensive and take longer than the OTA's did. The recently released study on Internet traffic entitled "Signposts in Cyberspace," commissioned an appalling seven years ago, is an egregious example.

The executive branch, of course, has the Office of Science and Technology Policy and a variety of departments and agencies at its beck and call, but the legislative branch needs its own independent source of advice. Such checks and balances are all the more necessary in an era as politicized as our own. The Bush administration has been criticized for either ignoring agency scientists who disagree with its policies or pressuring them to change study conclusions. A survey of researchers working for the U.S. Fish and Wildlife Service revealed that more than one in five had been "directed to inappropriately exclude or alter technical information" from a USFWS document. And the Bush administration is hardly the first to spin scientific findings to its own ends; both political parties have been guilty.

Although the OTA was killed by conservatives, today both conservatives and liberals support reestablishing it. Indeed, support from fiscal conservatives should be natural; Congress saved hundreds of millions of dollars by following OTA recommendations.

To bring back the OTA and its independent approach, re-fund it. Representative Rush Holt of New Jersey, a former research physicist, is considering introducing a bill to reestablish the OTA. Holt introduced a similar bill in the previous session of Congress, along with co-sponsors from both sides of the aisle, but it never returned from committee. This time Congress should pass the bill instead of letting it die.

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Skin Cells, Pollen Contribute to Air Pollution

When modeling climate, researchers must account for a large number of variables. One of the most challenging is the effect of small particulates suspended in the atmosphere, which can either reflect or absorb incoming radiation from the sun and thus alter its influence. The most common types of aerosols are soot, ash and other man-made particles, as well as naturally derived dust and salt. Until now, plants and animals have been considered a small source of particulate pollution. But a new study suggests that up to 25 percent of aerosols worldwide could be coming from biological sources, including fur, skin, pollen and bacteria.

Toothless Skull Raises Questions about Compassion among Human Ancestors

A nearly two-million-year-old fossil from the Republic of Georgia may be the earliest evidence of human compassion, scientists say. The remains represent an individual who spent the last years of his life with only one tooth. This shortcoming may have left him dependent on the kindness of others to obtain sufficient sustenance.

Antioxidant-Heavy Diet Provides Protection during Stroke

Antioxidant vitamins from fruits and vegetables have exhibited cholesterol-fighting properties and beneficial effects for heart function. Recent work on rats indicates that they could also provide protection in the event of a stroke by limiting the amount of damage to the brain.

Ask the Experts

How was the Richter scale for measuring earthquakes developed?

William Menke, a seismologist at Lamont-Doherty Earth Observatory of Columbia University, explains.

Exclusive Online Issue: Battle of the Sexes

This special issue explores the sexual divide through a collection of fascinating case studies.

Available for $5 at www.sciamdigital.com

© GURAM GUMBIASHVILI, NATIONAL MUSEUM OF GEORGIA (*top*); NATIONAL PARK SERVICE (*bottom*)

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Letters

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RESPONSES TO the February issue raised a question about belief: Are people who trust in fact any less closed-minded than those who favor faith? In "Sticker Shock," Steve Mirsky satirized the Cobb County, Georgia, school board's attempt to place disclaimer stickers in biology textbooks warning students that they contain material on the theory of evolution. George T. Matzko, chairman of the natural science division at Bob Jones University in South Carolina, suggested "a sticker for *Scientific American* in the same vein as the column: 'Warning, this magazine holds to the theory that all phenomena, including origins, can be explained in terms of natural causes and is therefore atheistic in tone and content.'" But Albert Eatock of Bracebridge, Ontario, pointed to another popular text that may need a disclaimer: "The Bible started as oral history and has been translated and reinterpreted numerous times since its inception. Therefore, it is not factual and should be approached with an open but critical mind." Warning: more disputation and discourse that are highly subjective in tone and content follow.

STICKING IT TO EVOLUTION

Steve Mirsky's column "Sticker Shock" [Anti Gravity] was another attempt to perpetuate the myth that there is a conflict between science and religion.

Because the modern Catholic Church knows its charter is not the physical sciences but rather the salvation of man, it is unfazed by the theory of evolution. Addressing this, Pope John Paul II said, "Truth cannot contradict truth." This comprehension is easily discovered in the catechism and Vatican documents.

As a faithful Roman Catholic, I have never been afraid of science. I have, however, seen many who are afraid to explore faith. For Mirsky to treat fundamentally disparate groups as one entity is not, well, very scientific.

Christopher Halpern
Longwood, Fla.

It was a relief to read Mirsky's articulate and humorous response to the irrational individuals who would destroy our schools by claiming that biblical literature is equivalent to scientific evidence.

The antievolution brushfires have disturbed, even frightened, me for several years. The Cobb County judicial decision is somewhat reassuring. The need to encourage scientific literacy is demonstrated quite well in any issue of *Scientific American* in which many articles require an understanding that the world is more than 5,765 years old.

Len Finn
Needham, Mass.

COPYRIGHT VERSUS COPYLITE

It was wonderful to read in "Beyond the Big ©" [SA Perspectives] of your understanding of and support for "intermediate copyrights" as implemented by Lawrence Lessig and the Creative Commons group. It would have been even better to see you lead by example by identifying your article as covered under an appropriate Creative Commons license.

David J. Ritchie
Naperville, Ill.

THE EDITORS REPLY: Although Scientific American *has yet to take that big step, we can still acknowledge that there's a place for it.*

DIMINUTIVE DIASPORA

Kate Wong describes in "The Littlest Human" how early humans may have migrated to Flores Island: "They may have drifted over on natural rafts quite by accident." This brought to mind the plight of people who were swept out to sea by the tsunami last December.

I pictured a group of early humans living near a coast who were caught by a tsunami and able to cling to debris until they drifted to an island. Just before the

giant wave hit, food gatherers may have ventured into the littoral zone following the receding sea and then been swept away. Though impossible to prove empirically, the idea of such "catastrophic involuntary migration" may explain the dispersion of some early human populations, along with other fauna and flora.

Richard Weiler
Chicago

"The Littlest Human" made me wonder: Why is there a problem with *Homo floresiensis*' tools with respect to brain size? Even if a big brain is critical for tool creation and development, it is not crucial to the social perpetuation of making and learning how to use them. Thus, if *H. floresiensis*' ancestors had developed tools, then toolmaking skills could have persisted, even if *H. floresiensis* could no longer refine them or create new ones.

Kurt D. Steiner
Kane, Pa.

SEEKING APPROVAL

As an orthopedic surgeon, when I read "Avoiding Another Vioxx," by Sara Beardsley [News Scan], it brought to mind the confusion I observe in patients about current pharmaceutical practices and regulations. They see medications advertised and assume that they have been proved safe. Then they hear media reports of studies questioning these same medications. It is no wonder they have lost confidence in the pharmaceutical industry and the regulatory process.

The Food and Drug Administration is under fire, both for being too quick to approve new drugs that may later have safety issues and for being too slow to approve new drugs that may have lifesaving benefits for many patients.

At present, the FDA has three options: to approve, deny or delay a new drug. Once a medication is approved, however, the FDA is powerless to prevent its advertisement to the public. I would propose a fourth option: provisional approval. If the company chooses to accept this status, then it may place the drug on the market and proceed to educate physicians but not advertise to the public. This plan would create a longer review period after wider release of the medication and keep the analysis more in the forum of scientific investigation.

Richard M. Bargar
Andover, Mass.

BEARDSLEY REPLIES: *A number of epidemiologists, including those who reviewed the Vioxx case, have recommended a similar sort of provisional approval—in which a set of agreed-on trials would be mandatory before drugs could be advertised to the public. This proposition is indeed compelling. Yet it rekindles the question (also raised in the article) of whether the FDA is capable of effectively probing and refereeing such trials—even those conducted on a provisional basis.*

NOSEY SEARCH ENGINES?

I found "Seeking Better Web Searches," by Javed Mostafa, interesting and informative. Unfortunately, it also told me that search engine developers are continuing in a direction that is potentially alarming and personally annoying.

DATA JAM: **New contextual search engines will deliver customized results.**

Potentially alarming is the hazard of an online search engine sniffing around the personal data on user hard drives. Whereas user benefits are most likely minimal, the benefits to marketers, hackers, and various other stalkers or potential miscreants are enormous.

I am annoyed that context and user-profile-aware searches are of far more use to marketers funding the search engines than they are to users. I search in two ways: first, I look for updates on subjects that I deal with regularly. If I use a search engine, I know the subject well enough to use key words that bring me to unknown but similar sites. My second search category is for new data. Here Internet searches are most valuable, but an engine that takes my history into account will severely hamper this by herding me back to familiar territory.

Jim Rice
Wheaton, Ill.

WITH APOLOGIES TO APOSTROPHES

In "Making Memories Stick," by R. Douglas Fields, I became confused after reading the following phrase: "When many of the *neurons*' synapses fire together...." I turned back to the previous page because I thought it had been referring to one neuron. How many synapses of how many neurons were we talking about?

Eventually I realized that it should have been *neuron's* (the synapses of *one* neuron). I mention this to show how important apostrophes are and how they can alter the meaning of a sentence or, at least, cause some confusion.

John Richards
The Apostrophe Protection Society
Boston, Lincs, U.K.

ERRATA In "The Littlest Human," by Kate Wong, Dean Falk was incorrectly affiliated with the University of Florida; she is a professor at Florida State University.

In the Ask the Experts column, roentgenium (Rg) was given as the provisional name of element 111. The International Union of Pure and Applied Chemistry (IUPAC) officially approved the name as of November 1, 2004.

In "The New College Try," by Steve Mirsky, James Hillier was incorrectly credited with the invention of the electron microscope. Ernst Ruska, along with Max Knoll, invented the original device in 1931.

NEIL BRENNAN

50, 100 & 150 Years Ago
FROM SCIENTIFIC AMERICAN

Einstein Obituary ▪ Artificial Life ▪ Light from the Dead

JUNE 1955

EINSTEIN—*Niels Bohr:* "With the death of Albert Einstein, a life in the service of science and humanity which was as rich and fruitful as any in the whole history of our culture has come to an end. Mankind will always be indebted to Einstein for the removal of the obstacles to our outlook which were involved in the primitive notions of absolute space and time." *I. I. Rabi:* "His real love was the theory of fields, which he pursued with unremitting vigor to the very end of his more than 50 years of active scientific life. This preoccupation is to a large degree the key to his scientific personality. The theory of general relativity was constructed on the basis of a physical observation of the equivalence of inertial and gravitational mass under certain simple circumstances. Beyond that, his guiding principles were his esthetic and philosophical urge for simplicity and symmetry."

LSD RESEARCH—"Since 1949 we have been studying the effects of LSD at the Boston Psychopathic Hospital. So far we have examined the responses of more than 100 healthy volunteers and a number of psychotic patients. The creation of experimental psychoses with lysergic acid opens the way to studying treatments and the nature of mental illness. We can see the various defenses a subject brings into use, one after another, to protect himself from stressful experiences. Most important, however, is the insight that lysergic acid gives into the mind and feelings of a person afflicted by mental illness. We can telescope a severe psychotic reaction into a period of six to 12 hours and follow the emotional disintegration step by step."

JUNE 1905

FLYING MACHINE—"Even the birds are at times 'up-ended' in battling against the gale, and 'defective equilibrium' epitomizes the failure of practically every attempt at flight with a true flying machine. It is the claim of G. Curtis Gillespie, of New York, the designer of the present machine, that with the great amount of power developed by the seven aluminum propellers, the form of plane used in this machine is not only more difficult to 'up-end' when in flight, but is likewise not so easily capsized laterally."

THE GILLESPIE AEROPLANE, if it had flown as planned, 1905

MASS PRODUCTION—"From the projecting of an automobile factory to the producing of 1,000 machines in nine months is a record that stands unparalleled in the automobile industry. Having produced the first practical runabout for the man of average means, Mr. R. E. Olds turned his inventive ability to the production of a popular-priced, powerful touring car. The Reo Motor Car Company of Lansing, Michigan, has turned out about 1,000 machines since December 15, 1904. Besides the touring car at $1,250, the company also builds a single-cylinder runabout for $650."

MAN-MADE PARTHENOGENESIS—"After painstakingly exact and long-continued experimentation Prof. Jacques Loeb, M.D., of the University of California, has succeeded in fertilizing and subsequently in developing eggs of the sea-urchin by employing artificial means alone. Chemical substances in skillful hands can be made to produce effects upon eggs which imitate, in all essential respects, the results of normal fertilization. Dr. Loeb unequivocally asserts that it is possible to control life phenomena and that such control and nothing less is the true aim of the science of biology. The hope of students of heredity, who have been looking for the means of raising animals which should possess the hereditary traits of one parent only, has been at least attained."

JUNE 1855

GHOST LIGHT?—"The Cleveland *Plaindealer* gives an account of some experiments with a new light which the editor witnessed, and which it states is produced by a machine constructed by Dr. Taylor, of that city—a clairvoyant physician—and all under spiritual direction entirely. Now, if Dr. Taylor constructed that machine under the direction of disembodied spirits, they must be the inventors, not he. It will certainly involve a new principle of law, demanding the presence of those spiritual inventors in a court of law."

GENETICS

RNA to the Rescue

NOVEL INHERITANCE PATTERNS VIOLATE MENDEL'S LAWS **BY JR MINKEL**

The central dogma of modern biology holds that genetic information is inherited in the form of DNA, copied into RNA and expressed as protein; pride of place goes to DNA. But the spectacular discovery that a species of plant can summon up genes its parents have lost highlights biologists' increasing recognition of RNA as a more versatile and important molecule in its own right.

RNA already has a special place among biological molecules. It can store genetic information, as DNA does, but it can also adopt complex three-dimensional shapes and catalyze chemical reactions on itself, as proteins do. "RNA is DNA on steroids," says Robert Reenan, a geneticist at the University of Connecticut. "It can do just about anything." Life probably began as an "RNA world," in which concatenations of RNA molecules pulled double duty as genetic template and reproductive machinery.

MUTATION of fused petals (*left*) disappeared in descendants, which appeared normal (*right*).

SUSAN J. LOLLE *Purdue University*

The mustard plant *Arabidopsis thaliana* may be revealing another way in which life exploits RNA's capacity for genetic storage. Susan J. Lolle and Robert E. Pruitt of Purdue University study *Arabidopsis* whose petals are fused. Such plants have two mutant copies of a gene called *hothead*, which differ from the normal gene by a single base pair. Strangely, in a few percent of the offspring of Lolle and Pruitt's mutants, one copy of *hothead* spontaneously reverted to the normal version, repairing its point mutation. Even one such event is statistically unlikely outside of rapidly reproducing bacterial colonies. The investigators systematically ruled out mundane explanations, such as cross-pollination of a mutant plant by a normal one, an extremely high mutation rate or the presence of another, hidden copy of *hothead*.

Hothead mutants contained changes in other parts of their DNA, too, all of which matched the sequences of the plants' grandparents or great-grandparents but not their parents. This match suggested that a backup copy of the ancestral plants' genome was

NEED TO KNOW: RNA RECODED

The non-Mendelian method of inheritance discovered in *Arabidopsis* plants may be just one example of RNA's ability to introduce variety absent from an organism's DNA. Another is recoding, in which the cell switches a single subunit of an RNA molecule transcribed from DNA, resulting in a different protein form from the one specified by the gene. Geneticist Robert Reenan of the University of Connecticut has found that recoding depends solely on a three-dimensional knot or loop shape adopted by an RNA molecule and not on its sequence. Recoding, which so far is found only in neural proteins, may offer organisms a way of experimenting with new protein designs without permanently altering a crucial gene, Reenan hypothesizes.

somehow being passed down, the researchers reported in the March 24 *Nature*. If true, such leapfrogging would circumvent the normal rules of genetics established by Gregor Mendel in 1865. Because the investigators could find no DNA to play the role, they have proposed that the backup template is double-stranded RNA (which ordinarily has just a single strand). "Double-stranded RNA is hot because that's what's needed for RNA interference," a common way of deactivating genes, says Richard Jorgensen, a plant scientist at the University of Arizona, "but there's no reason it couldn't be a DNA molecule either, and there's no reason it has to be double-stranded."

RNA would be a convenient mechanism, however, because researchers have uncovered several ways in which it modifies the expression or structure of DNA, and it might explain the mysterious production of RNA molecules that do not result in proteins. Several species, including *Arabidopsis*, rice, mice and humans, copy a surprising amount of RNA from the "wrong" DNA strand—that is, the strand opposite the one that specifies a protein. "Maybe this is where some of that template is coming from," says Joseph Ecker, a plant biologist at the Salk Institute for Biological Studies in La Jolla, Calif. Plants have many enzymes capable of duplicating RNA, Ecker notes, as well as a system for transporting the chemical between cells.

The Purdue group speculates that a separate genetic archive may serve as a hedge against hard times, such as an extended drought, by allowing a plant to access genes that helped its ancestors persist. In this sense, it would bear some resemblance to another strange property of RNA, called recoding [*see sidebar at left*].

A next step is determining how widespread the effects are. Unexplained cases of spontaneous reversions also appear in human genetic diseases, although the natural frequency of such events is unclear. Pruitt, for one, would be surprised if the mechanism were exclusive to plants: "It's hard to believe something that general wouldn't persist in other organisms."

JR Minkel is a frequent contributor.

Rare Flare

ODD MAGNETAR BURST PARTLY SOLVES GAMMA-RAY RIDDLE

BY GOVERT SCHILLING

It was the brightest cosmic explosion ever observed, and astronomers are still hotly debating its origin and implications. But already the giant flare of December 27, 2004, produced by a bizarre star in our own Milky Way galaxy, is providing a partial solution to a 10-year-old astrophysical mystery. Such "magnetar" flares in distant galaxies may account for at least some of a particular class of gamma-ray burst that has defied explanation.

Despite its distance of 50,000 light-years, the December flare was brighter than the full moon. Yet no one actually saw it, because it belched out almost all its stupendous power in the form of energetic gamma rays, completely saturating the sensitive Burst Alert Telescope on NASA's Swift satellite, which had been launched into orbit just five weeks earlier. "It was an astonishing event," recalls gamma-ray-burst researcher Ralph Wijers of the University of Amsterdam in the Netherlands.

After learning of the giant flare, Swift scientist David Palmer of Los Alamos National Laboratory immediately had a hunch. If a similar magnetar flare occurred in a distant galaxy, he reasoned, it would be indistinguishable from a so-called short gamma-ray burst, with a duration less than two seconds or so. These short bursts are quite different from their longer cousins, which last from a few seconds to many minutes. Astronomers believe that long gamma-ray bursts, all detected in remote galaxies so far, signal the catastrophic and terminal detonation of supermassive, rapidly spinning stars. This proposed mechanism probably does not apply to short gamma-ray bursts, however.

Palmer developed his idea and found that the magnetar flares offer at least a par-

A PRETTY BIG BANG

The December 27, 2004, flare—the brightest blast ever observed—originated on a relatively nearby neutron star, a small, superdense stellar corpse. Called SGR 1806-20, it sports a magnetic field a quadrillion times as strong as Earth's, potent enough to rob your car keys from your pocket if the star were as close as the moon. Most likely a star quake that suddenly reconfigured the star's magnetic field set off the giant flare. What is more, it could happen again: the blast did not destroy the star.

STAR WITH FLARE: Artist's conception of the December 2004 gamma-ray flare, the brightest burst ever seen, expanding from SGR 1806-20.

NASA

tial explanation. In an analysis to be published in *Nature*, he and his colleagues conclude that at least a few percent of all short bursts are quite likely to be explained in this way. Based on the observed luminosity and expected frequency of giant magnetar flares, a few dozen of these events per year would occur in other, relatively nearby galaxies. This amount is not enough to explain all short gamma-ray bursts, but, Palmer says, "5 percent is a good approximation." He quips that this number "is probably not off by more than a factor of 20, which is actually pretty good in this business."

As for the cause of the other short gamma-ray bursts, Chryssa Kouveliotou of the NASA Marshall Space Flight Center says that the leading explanation is the violent merger of two neutron stars orbiting each other. But Palmer notes: "With the December 27 event, we now know that neutron-star mergers are not responsible for *all* short gamma-ray bursts. Whether they are responsible for *any* of them is still an open question." Wijers agrees that it remains unclear whether a neutron-star merger can produce this type of gamma-ray burst.

The answer may come soon, though. Astronomers expect that the Swift satellite, which became fully operational in early April, will accurately pinpoint sky positions and distances for a number of short bursts, enabling scientists to finally get a grip on these enigmatic phenomena. Palmer, for one, is optimistic: "The next gamma-ray burst we see could bring enlightenment."

Govert Schilling writes about astronomy from Amersfoort, the Netherlands.

HEALTH

Snoring Suspects

FREE RADICALS MAY SET OFF SLEEP APNEA'S CARDIO DANGERS

BY LISA MELTON

Snoring is not just a recipe for marital discord; it can be life-threatening, too, when it is a part of sleep apnea. This disorder, in which breathing stops many times a night, can detonate dangerous cardiovascular stress. But scientists have long puzzled over why we should respond so fiercely to dips in the oxygen supply. Now a new study has identified the tissue and chemical changes that stir up the problem, a finding that could lead to novel drug treatments.

In North America as many as 24 percent of adults suffer from sleep-disordered breathing, a problem exacerbated by obesity. People with obstructive sleep apnea cease breathing for about 15 seconds, every few minutes, hundreds of times a night. Besides feeling drowsy and exhausted the next day, people with sleep apnea face high blood pressure and risk heart attacks and stroke. Indeed, they are about three times as likely to die from a heart attack in the middle of the night as the general population, according to a study in the March 24 *New England Journal of Medicine*. "The consequences of this intermittent [oxygen deprivation], if it persists for years, can be very drastic," says physiologist Nanduri R. Prabhakar of Case Western Reserve University.

BAD SLEEP: Health dangers lurk in snoring.

BSIP/PHOTO RESEARCHERS, INC.

Prabhakar has long been mystified by sleep

VITAMIN NONTHERAPY

Free radicals may help trigger sleep apnea, but is targeting them the answer? Lately antioxidants to target these reactive molecules have flunked almost every therapeutic test. "There have been a lot of studies using antioxidants to prevent disease—vitamin C, vitamin E and beta carotene—with not a huge degree of success. The main reason is that antioxidants don't get to the right place and don't decrease free radical damage," says biochemist Barry Halliwell of the National University of Singapore. According to Halliwell, the best solution for sleep apnea is to tackle the problem at the root. "The antioxidants will never do as much good as would be done by controlling your cholesterol levels and losing weight," he points out.

apnea: Why does a brief shutdown of oxygen intake spark an extreme cardiovascular response? After all, people living at high altitude—for example, in the Andes—adapt perfectly well to a low-oxygen environment without developing hypertension.

To pursue this question in molecular detail, he re-created sleep apnea in rats by cutting the oxygen to their cages with a frequency similar to that experienced by human sufferers. At the same time, other rats breathed continuously in a low-oxygen atmosphere that replicated conditions in mountainous areas. Within 10 days, only the rats exposed to oxygen in fits and starts developed hypertension. The most dramatic difference between both groups, Prabhakar announced at a Novartis Foundation meeting in London this past January, showed up in the carotid body, an oxygen-sensing tissue located in the main artery in the neck.

Normally, when oxygen levels drop, the carotid body tells the nervous system that blood pressure must rise to deliver more oxygen to compensate for the shortfall. These urgent signals are prompted by oxygen free radicals acting as messengers. But when oxygen levels plummet repeatedly, as they do in sleep apnea, free radicals overwhelm the carotid body. The excess jams the carotid body into the "on" mode, so that even when oxygen levels return to normal, blood pressure continues to surge.

Prabhakar speculates that free radical scavengers might counter the devastating effects of sleep apnea. He has tested one such compound—a superoxide dismutase mimetic—in his rat model and found that the chemical averted hypertension. Could a humble antioxidant vitamin supplement do the same for human patients? An antioxidant pill would be an ideal solution, because the only existing therapy is cumbersome: it involves wearing a face mask connected to a positive airway pressure machine during the night to maintain a constant oxygen level.

"Sleep apnea is a much neglected problem," says Prabhakar, whose findings have enhanced our knowledge about the perils that lurk behind these broken nights. He hopes human trials of antioxidant therapy will be able to start soon.

Lisa Melton is a writer based in London.

HOLDING ON TO HYDROGEN

Besides studying cryoadsorption and storing hydrogen chemically in hydrides, researchers are investigating sorbent materials that can hold hydrogen atoms on surfaces physically. Among the more promising (and the organizations working on them):

- **Carbon nanotubes with single walls (Air Products and Chemicals, Allentown, Pa.)**
- **Organo-metallic fullerenes, or "buckyballs" (carbon 60), containing iron or scandium atoms (National Renewable Energy Laboratory, Golden, Colo.)**
- **Porous silica frameworks infused with ammonia borane and related compounds (Pacific Northwest National Laboratory, Richland, Wash.)**

ENERGY

Solid (State) Progress

HYDROGEN-FUEL STORAGE FOR CARS GETS A MATERIALS BOOST **BY STEVEN ASHLEY**

Motorists expect cars to go at least 300 miles between fill-ups. That's not a concern for autos that burn gasoline or diesel, but for a future in which vehicles run on nonpolluting hydrogen, adequate driving range remains a real roadblock [see "On the Road to Fuel-Cell Cars," by Steven Ashley; SCIENTIFIC AMERICAN, March]. Despite considerable effort, engineers have so far failed to find a way to cram enough hydrogen—the lowest-density substance in the universe—onboard cars.

Conventional approaches to compact hydrogen storage—compressing the gas to up to 10,000 pounds per square inch (psi) or cooling it down to cryogenic temperatures so that it liquefies (around –252 degrees Celsius)—can attain only about half

FILL 'ER UP WITH H_2: Any future hydrogen economy will require compact onboard storage as well as a nationwide distribution and refueling system.

KENT SNODGRASS *Precision Graphics*

the energy density needed to fit enough fuel inside something the size of a gas tank. A few years back researchers thought that hydrogen could be extracted chemically onboard from liquid hydrocarbons such as methanol, but those schemes did not pan out. Since then, solutions to this packing problem have been lacking, notwithstanding long-term research programs at General Motors, Toyota, BMW and others. But recently hints of progress have emerged. Scientists at GM and its partner HRL Laboratories in Malibu, Calif., have reported advances in two hydrogen storage technologies—cryoadsorption and destabilized complex metal hydrides.

Cryoadsorption falls somewhere between the compressed and low-temperature storage strategies. It relies on getting the gas to adhere to materials with sizable surface areas, explains James Spearot, who manages GM's hydrogen storage research efforts. First, engineers reduce the volume of the gas by cooling it to the temperature of liquid nitrogen (–196 degrees C), which is easier to attain than liquid-hydrogen temperatures. "Then they compress it to only about 1,000 psi, which forces the hydrogen to adsorb physically into the material's many nooks and crannies," he says. The classic high-surface-area material is powdered activated carbon, but other synthetic substances may offer even more promise, including high-porosity polymers and materials made of organo-metallic molecular "cages"—hydrocarbon frameworks enclosing metal atoms.

GM's other development concerned improvements to metal hydrides, in which lightweight metallic elements hold hydrogen. When heated, these metal hydride powders decompose, liberating the gas. High temperatures are required, however, because the metal atoms grip the hydrogen with strong covalent bonds. In recent years researchers have achieved better performance with compounds such as lithium borohydride, in which the metal atoms form weaker, ionic bonds with groups containing several hydrogen atoms.

Last year a team led by HRL's John Vajo reduced decomposition temperatures substantially by adding substances such as silicon to complex metal hydride systems. Such additives act as destabilization agents. "Essentially the metal and the destabilizer join preferentially and displace the hydrogen," explains Leslie Momoda, director of HRL's sensors and materials laboratory. Using magnesium hydride as a destabilizer for lithium borohydride, for instance, lowers the release temperature from

400 to 275 degrees C. Moreover, the hydride can store 9 percent of its weight as hydrogen, beating the oft-cited target of 6.5 percent. She hopes that HRL staffers can eventually identify a "Goldilocks" compound with sufficient adsorption capacity that will release hydrogen at 150 degrees C or even lower. Momoda admits, however, that the hydrogen pickup rate is still too slow; current materials might take 30 minutes to refuel.

Practical onboard storage would, of course, constitute only half the formula for a successful hydrogen economy; the other half would be a large-scale hydrogen distribution and refueling network. Thankfully, solving the latter issue will not likely require major technical breakthroughs—only boatloads of cash.

LINGUISTICS

Math without Words

NUMERICAL REASONING SEEMS INDEPENDENT OF LANGUAGE

BY PHILIP E. ROSS

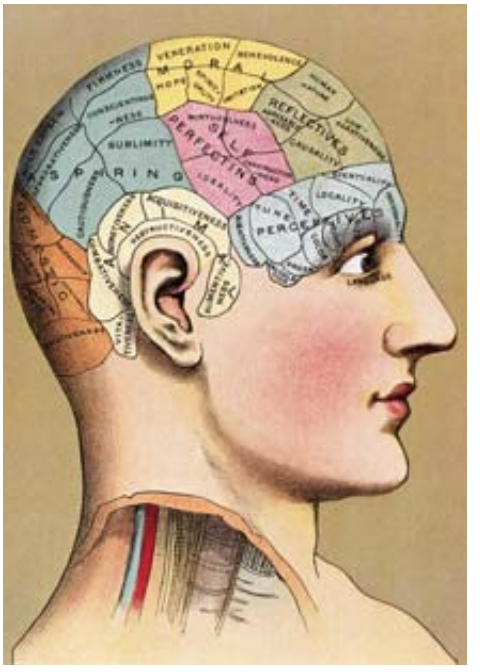
Nineteenth-century German mathematician Carl Friedrich Gauss used to joke that he could calculate before he could talk. Maybe it was no joke. Recent work casts doubt on the notion that language underlies mathematical ability and perhaps other forms of abstract thinking.

Writing in the March 1 *Proceedings of the National Academy of Sciences USA*, scientists from the University of Sheffield in England describe impressive mathematical abilities in three middle-aged men who had suffered severe damage to the language centers of their brains. "There had been case studies of aphasics who could calculate," says study co-author Rosemary Varley. "Our new take was to try to identify roughly parallel mathematical and linguistic operations."

Varley and her colleagues found that although the subjects could no longer grasp grammatical distinctions between, say, "The dog bit the boy" and "The boy bit the dog," they could interpret mathematical formulas incorporating equivalent structures, such as "59 – 13" and "13 – 59."

The researchers found ways to pose more abstract questions as well. For instance, to investigate the subjects' understanding of number infinity, they asked them to write down a number bigger than 1 but smaller than 2, using hand motions for "bigger" and "smaller" and a flash of the eyebrow, indicating surprise, for "but." Then they asked the subjects to make the number bigger but still smaller than 2 and to reiterate the procedure. The subjects got the answer by various means, including the addition of a decimal place: 1.5, 1.55, 1.555 and so forth.

Although subjects easily answered simple problems expressed in mathematical symbols, words continued to stump them.



REGIONAL DIFFERENCES: The brain is not compartmentalized the way 19th-century phrenology maps showed, but it does process math and language abilities in different areas.

BETTMANN/CORBIS

Even the written sentence "seven minus two" was beyond their comprehension. The results show quite clearly that no matter how helpful language may be to mathematicians—perhaps as a mnemonic device—it is not necessary to calculation, and it is processed in different parts of the brain.

The idea that language shapes abstract thought was most forcibly propounded 50 years ago in the posthumously published writings of American linguist Benjamin Lee Whorf. He argued, among other things, that the structure of the Hopi language gave its speakers an understanding of time vastly different from that of Europeans. Although Whorf's hypothesis continues to inspire research, a good deal of his evidence has been discredited. Much more widely respected is the proposal, associated with linguist Noam Chomsky of the Massachusetts Institute of Technology, that language, mathematics and perhaps other cognition all depend on a deeper quality, sometimes called "mentalese."

Chomsky suggested that the key part of this deeper quality might be a quite simple and uniquely human power of "recursive" calculation. Recursion, he and his colleagues argue, may explain how the mind spins a limited number of terms into an infinite number of often complex statements, such as "The man I know as Joe ate my apple tree's fruit." Recursion could also generate mathematical statements, such as "3 × (4/6 + 27)/4."

Chomsky's theory may, perhaps, be reconciled with the new evidence. Some scholars have argued that the brain may build its mathematical understanding with language and that the structure may still stand after the scaffolding is removed. Indeed, the one subject in the Sheffield study who had had doctoral-level training in a mathematical science did no better than the others in arithmetic, but he outperformed them at algebra.

Rochel Gelman, co-director of the Rutgers University Center for Cognitive Science, says that the brain-lesion studies offer much clearer evidence than can be obtained from the more common technique of functional brain scanning. "Pop someone in a scanner and ask a question, and you may get a lot of

NEED TO KNOW: WORD HELP

Despite using different brain circuitry, language can still lend a helping hand to mathematical thought. People quickly pick up simple arithmetic, in part because the natural numbers map easily to the single words used for counting, says Rochel Gelman, co-director of the Rutgers University Center for Cognitive Science. But, she notes, they have much more difficulty grasping the rational numbers (fractions), which do not map onto anything readily at hand.

activation in language areas," she points out. "But it could be just because the subject is talking through the problem—recruiting language, although it's not a crucial component."

The recent work, together with studies of animals and of children, strongly supports the independence of language and mathematics, Gelman says. "There are cases of kids who are bad with numbers and good with words and bad with words and good with numbers, a double dissociation that provides converging evidence."

EVOLUTION

Desert Island

HOW CLIMATE CAN PROMOTE SPECIATION

BY KATE WONG

A bedrock tenet of biogeography holds that organisms separated from their ancestral population will set off on their own evolutionary trajectory. Continental drift provides one such isolating mechanism, illustrated perhaps most spectacularly by the unique flora and fauna found on the island of Madagascar, which broke off from the southern supercontinent of Gondwana some 90 million years ago. Mountain upheaval and river formation can also divide populations. But a new study reveals that the barriers need not be physical. Paleontologists have unearthed fossils of giant amphibians that indicate that climate, too, can effectively isolate organisms and thereby foster endemism.

In a paper published in the April 14 *Nature,* paleontologist Christian A. Sidor of the New York College of Osteopathic Medicine and his colleagues announced their discovery of two new species of amphibian that lived some 250 million years ago in what is now northern Niger. The salamanderlike beasts, *Nigerpeton ricqlesi* and *Saharastega moradiensis*, are surprising not so much for their impressive size (think crocodile proportions) but because they are different from other creatures that lived at the time. For decades, sci-

SAHARAN SANDS entomb the fossils from a giant amphibian called *Saharastega* (*inset*), one of two new species recently found. The creatures inhabited oases dotting a similar desert landscape 250 million years ago, feeding on fish as well as other aquatic tetrapods.

CHRISTIAN A. SIDOR *New York College of Osteopathic Medicine*

entists excavating fossils from this Late Permian interval have come across the same tetrapod forms again and again, regardless of whether they were working in southern locales such as South Africa or northern ones such as Russia. This cosmopolitanism seemed to show that tetrapods wandered anywhere they pleased during this time, when most of the earth's landmasses lay lumped together as an even larger supercontinent, Pangaea.

The new work paints a more complex picture. Whereas previous expeditions had focused on the tropical-to-temperate northern and southern latitudes, Sidor's team selected a locale closer to the paleoequator. Geologic data and climate simulations indicate that by the Late Permian a global change in climate started, shifting the planet from a so-called icehouse world, in which the polar ice sheets extended as far north as southern Africa, to a hothouse world. Ultradry conditions replaced moderate ones in central Pangaea. This shift, the authors argue, effectively isolated pockets of formerly ubiquitous tetrapods by forming a desert around them.

That would explain why *Nigerpeton* and *Saharastega* are so much more primitive than other Late Permian amphibians. Indeed, their closest relatives had lived in North America and Europe 40 million to 90 million years earlier, suggesting that *Nigerpeton* and *Saharastega* are relicts of a radiation previously believed to have disappeared far earlier. Isolation by desiccation would also explain why dicynodonts—mammallike reptiles that dominate fossil assemblages elsewhere during this time—are conspicuously absent at the site that yielded the two new amphibians.

"It is an excellent piece of work," comments Robert R. Reisz of the University of Toronto. The next step, he says, is to try to find evidence of coastal migrations during the Late Permian, which would cast light on how the assemblages in the north and south came to be so similar, despite the presence of a vast desert between them.

EQUALITY INDICATORS

Average gender equality score (1995–2001)
Agricultural 61
Industrial 68
Postindustrial 80

Percent of births to mothers younger than 20 (1991–1997)
Agricultural 12
Industrial 11
Postindustrial 4

Percent of fertile women using contraceptives (mid-1990s)
Agricultural 32
Industrial 60
Postindustrial 74

Adult female literacy rate (1997)
Agricultural 56
Industrial 90
Postindustrial 97

Percent of women enrolled in secondary education (1990–1999)
Agricultural 45
Industrial 77
Postindustrial 95

Year women were enfranchised (average)
Agricultural 1955
Industrial 1942
Postindustrial 1922

Percent of members of lower house of legislature who were women (2000)
Agricultural 9
Industrial 11
Postindustrial 25

SOURCE: World Values Survey, 1995–2001 (chart *and* table)

FURTHER READING

Have Changes in Gender Relations Affected Marital Quality? Stacy J. Rogers and Paul R. Amato in *Social Forces*, Vol. 79, No. 2, pages 731–753; December 2000.

Rising Tide: Gender Equality and Cultural Change around the World. Ronald Inglehart and Pippa Norris. Cambridge University Press, 2003.

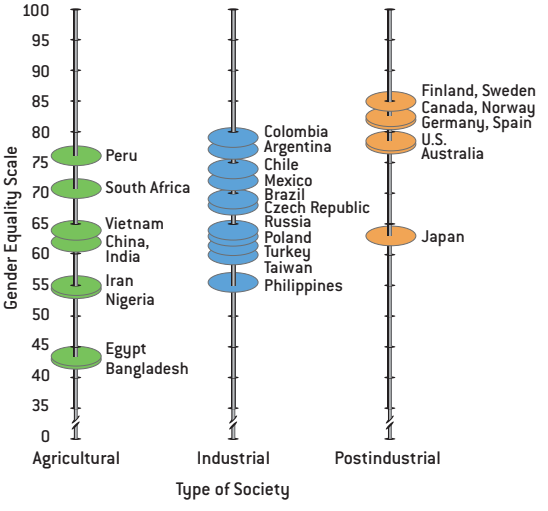
BY THE NUMBERS

Leveling the Playing Field

ECONOMIC DEVELOPMENT HELPS WOMEN PULL EVEN WITH MEN **BY RODGER DOYLE**

Conventional wisdom has long held that attitudes toward the role of women in agricultural societies are much more conservative than those in economically advanced societies, such as western Europe and the U.S. Political scientists Ronald Inglehart of the University of Michigan at Ann Arbor and Pippa Norris of Harvard University have now put this assumption to the test. They analyzed data from the World Values Survey, an ongoing study of attitudes that gauges reactions to various statements such as whether a university education is more important for a boy than a girl and whether women must have children to be fulfilled in life. The researchers constructed a 0-to-100 scale to measure attitudes toward gender equality in 61 countries.

ATTITUDES TOWARD GENDER



The chart depicts the scale for selected countries and shows that attitudes toward gender equality become increasingly more liberal as societies progress from one economic stage to the next. In agricultural societies, fertility is all-important because of high infant and child mortality. Anything that interferes with childbearing—such as divorce, homosexuality, abortion, and jobs for women outside the home—is therefore strongly discouraged. With industrialization, infant and child mortality decline markedly, lessening the pressure on women to reproduce. Women enter the paid labor force in large numbers, typically in factory, clerical and retail jobs, and at the same time become more literate and better educated. They begin to participate in representative government.

In postindustrial societies women have a substantial share of management and professional jobs. Fertility falls, late marriage becomes more acceptable, and the traditional two-parent nuclear family erodes. But even in these societies, women still lag far behind men in political participation. In every society women hold slightly more liberal views than men.

The difference in economic stage does not fully account for the disparities among societies. Religion, political tradition, education and other characteristics exert powerful influences. In Islamic nations, for example, women tend to have less of an economic role than in those with a Christian tradition, which may explain at least part of the difference in scores between agricultural societies such as Peru and Bangladesh. Japan's Confucian heritage may help explain why its views are more conservative compared with those of other postindustrial societies.

Attitudes toward gender in postindustrial societies will most likely continue to liberalize as groups espousing more traditional views—older people, the less educated and women not in the paid workforce—decline in economic importance. What is not clear is how more liberal thinking will affect people's everyday lives. Some evidence suggests that marriages in postindustrial societies are becoming more problematic because of the changing role of women. According to a study reported in 2000, Americans who married between 1981 and 1997 experienced significantly more discord than those who married between 1964 and 1980.

Rodger Doyle can be reached at rdoyle2@adelphia.net

RODGER DOYLE

DATA POINTS: BIGHEARTED

Burmese pythons can get into cardiac shape just by eating. These snakes typically go weeks to months without food. Once they swallow their prey, they boost their metabolism to digest the meal by temporarily making fresh heart muscle. Their cardiac growth is the fastest ever measured, reports a team from the University of California at Irvine in a study of 18 pythons.

Size of (rat) meal, as a percent of python mass: 25

Mass of heart when fasting, in grams: 0.95

Mass when digesting: 1.34

Percent increase: 41

Time of increase: 2 days

Increase in metabolic rate: up to 40-fold

Days to digest a meal: 14

SOURCE: Nature, *March 3*

ASTRONOMY

Twice Burned

When its fuel runs out, an old star expands into a red giant and then collapses to become a white dwarf. Some dwarfs can go through a second period of gianthood because the collapse squeezes and heats leftover fuel, but astrophysicists expected the second red giant phase to last perhaps a few centuries. Now a white dwarf that reignited in 1996 has shown signs of heating up again, indicating that it has already passed through the cooler red giant stage. Radio telescope measurements of the star, known as Sakurai's object or V4334 Sgr, picked up a crackle characteristic of gases ionizing around it, which would require its temperature to have risen quite a bit since the late 1990s. The rapid evolution may be the result of the dwarf's innards mixing poorly, leading the star to burn only the fuel close to its surface, which would quickly run out, hypothesize University of Manchester researchers in the April 8 *Science*. —*JR Minkel*

BEHAVIOR

Laser Bug-Off

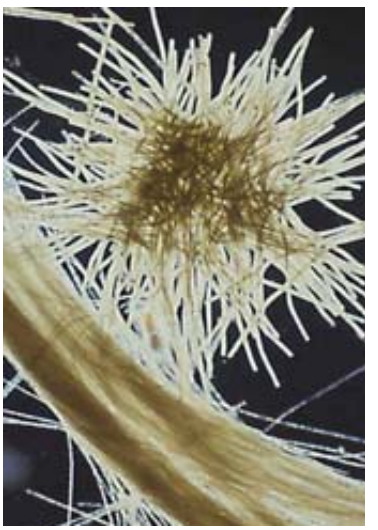
If you want to shoo away a fly without waving your hands, try a laser. Just be sure to bathe its nerves in a light-activated chemical before zapping away at it, as Susana Lima and Gero Misesenböeck of Yale University have done. They engineered specific fly neurons to produce a rat protein that transmits an electrical signal when activated by the molecule ATP. Next they designed a chemical "cage" for ATP that dissolves when hit with ultraviolet laser light. Finally, they took advantage of a fly's emergency "fly away!" reflex, triggered by the insect's central nerve even when its head is gone. The two could send most zapped flies jumping and flying, even when the flies were blinded or beheaded. They also made slow-moving flies buzz around more excitedly by targeting different neurons. The technique, the investigators say in the April 8 *Cell*, may permit more precise studies of behavior and brain circuitry than electrodes do. —*JR Minkel*

TOXINS

Brain-Destroying Algae?

Blue-green algae, or cyanobacteria—arguably the most widespread, abundant and ancient organisms on earth—can produce a toxin called BMAA, which is linked with neurodegenerative disorders such as Alzheimer's and an illness in Guam similar to Lou Gehrig's and Parkinson's diseases. An international team examined cyanobacteria living in marine, brackish and freshwater environments throughout the world along with those living symbiotically with plants and lichens.

Ninety percent of the 41 strains studied generated BMAA, and at the right times or growth conditions all cyanobacteria might produce the toxin, the investigators report in the April 5 *Proceedings of the National Academy of Sciences USA*. The toxin appeared in samples of Baltic Sea and oceanic cyanobacteria blooms, suggesting the microbes could be releasing significant quantities of BMAA. As water pollution and global temperatures rise and trigger blooms, which can cover thousands of square kilometers, the health consequences could prove of increasing concern, the scientists say. —*Charles Q. Choi*



CYANOBACTERIA such as *Trichodesmium thiebautii* from the Caribbean can produce a neurotoxin.

PERCEPTION

Can't Get *g* Out of My Head

GRAVITY'S acceleration may be a hardwired perception.

Despite their awareness of being in microgravity, astronauts often reach for a falling object too soon, as though they expected the normal pull of the earth's gravity. The source of this expectation may be hardwired. Italian researchers showed volunteers two groups of animations, one in which a ball jumped up and bounced down under normal gravity, *g*, and the other in which the ball accelerated upward in each bounce. Subjects were better at predicting the ball's return when its behavior matched that of normal gravity.

Brain scans showed that the subjects were accessing the vestibular cortex, which controls our sense of balance and awareness of body location. The researchers propose that this brain region models the effect of gravity by comparing the head's motion in different directions and sending its calculations to the visual and motor systems. Catch the April 15 *Science* for the weighty details. —*JR Minkel*

GENETICS

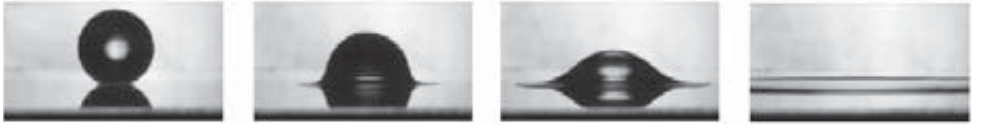
Decloaking Malaria

Malaria parasites are masters of disguise; they evade the immune system by constantly switching a protein used to avoid destruction in the spleen. Each parasite possesses a family of some 60 genes that encode this protein, only one of which is active at any time. Understanding how the parasites switch between these genes could lead to drugs that simultaneously activate all of them at once and thereby help the body seek and destroy malaria.

Parasitologists at the Walter and Eliza Hall Institute of Medical Research in Melbourne, Australia, and their colleagues found that the parasites silence the genes by coiling them up with the help of the Sir2 protein; a gene turns on only when dragged to special compartments in the nucleus. Disrupting Sir2 activated nearly two thirds of the genes, the scientists write in the April 8 *Cell*. Further research will hunt for the mechanisms that are keeping the other genes locked up. —*Charles Q. Choi*

PHYSICS

No-Splash Liquid



FALLING DROPLET spreads rather than splattering here when the air pressure is 17.2 kilopascals, about one-sixth normal atmospheric pressure.

The key for anyone wanting to make a big splash is pressure—of the atmospheric kind, that is. Normally, when a liquid droplet hits a surface, it spreads into an undulating puddle that rips apart into a splatter. Seeking to control splashing, University of Chicago physicists released alcohol drops in a vacuum chamber onto a smooth, dry glass plate and recorded the results with a camera shooting 47,000 frames per second. At roughly one-sixth normal atmospheric pressure, splashing completely disappeared; droplets just pancaked without visible undulations. The investigators suspect that fallen drops splatter because gas pressing on them destabilizes their outward spread. These findings, presented at the March meeting of the American Physical Society, could help control splashing in fuel combustion and in inkjet printing. —*Charles Q. Choi*

BRIEF POINTS

- **Mice with a disrupted circadian rhythm gene overeat and develop problems related to obesity, suggesting that in mammals the 24-hour clock cycle is finely tuned to metabolic functions.**

  Science Express, April 21

- **Elderly nursing-home residents often are not given sleeping pills, for fear that the compounds will increase the risk of falls. Ironically, a study finds that insomnia itself, not sleep medication, predicts future falls.**

  Journal of the American Geriatrics Society, March 30 online

- **Soft organic tissue apparently survived in a fossilized leg bone of a 68-million-year-old *Tyrannosaurus rex*—a surprise because organic molecules should last only 100,000 years. If truly original tissue, the material may hold recoverable genetic data.**

  Science, March 25

- **Farmed salmon seem able to spread potentially lethal parasitic sea lice to wild cousins more readily than previously thought—sometimes out to 30 kilometers from a farm only 200 meters long.**

  Proceedings of the Royal Society B, March 30

LESTER LEFKOWITZ/PHOTOGRAPHER'S CHOICE/GETTY (*top*); LEI XU *University of Chicago* (*bottom*)

Fahrenheit 2777

9/11 has generated the mother of all conspiracy theories

By MICHAEL SHERMER

Noted French left-wing activist Thierry Meyssan's 9/11 conspiracy book, *L'Effroyable Imposture,* became a best-seller in 2002. But I never imagined such an "appalling deception" would ever find a voice in America. At a recent public lecture I was buttonholed by a Michael Moore–wannabe filmmaker who breathlessly explained that 9/11 was orchestrated by Bush, Cheney, Rumsfeld and the Central Intelligence Agency as part of their plan for global domination and a New World Order. That goal was to be financed by G.O.D. (Gold, Oil, Drugs) and launched by a Pearl Harbor–like attack on the World Trade Center and the Pentagon, thereby providing the justification for war. The evidence was there in the details, he explained, handing me a faux dollar bill (with "9-11" replacing the "1," a picture of Bush supplanting that of Washington) chockablock with Web sites.

In fact, if you type "World Trade Center" and "conspiracy" into Google, you'll get more than 250,000 hits. From these sites, you will discover that some people think the Pentagon was hit by a missile; that U.S. Air Force jets were ordered to "stand down" and not intercept Flights 11 and 175, the ones that struck the twin towers; that the towers themselves were razed by demolition explosives timed to go off soon after the impact of the planes; that a mysterious white jet shot down Flight 93 over Pennsylvania; and that New York Jews were ordered to stay home that day (Zionists and other pro-Israeli factions, of course, were involved). Books also abound, including *Inside Job,* by Jim Marrs; *The New Pearl Harbor,* by David Ray Griffin; and *9/11: The Great Illusion,* by George Humphrey. The single best debunking of this conspiratorial codswallop is in the March issue of *Popular Mechanics,* which provides an exhaustive point-by-point analysis of the most prevalent claims.

The mistaken belief that a handful of unexplained anomalies can undermine a well-established theory lies at the heart of all conspiratorial thinking (as well as creationism, Holocaust denial and the various crank theories of physics). All the "evidence" for a 9/11 conspiracy falls under the rubric of this fallacy. Such notions are easily refuted by noting that scientific theories are not built on single facts alone but on a convergence of evidence assembled from multiple lines of inquiry.

For example, according to www.911research.wtc7.net, steel melts at a temperature of 2,777 degrees Fahrenheit, but jet fuel burns at only 1,517 degrees F. No melted steel, no collapsed towers. "The planes did not bring those towers down; bombs did," says www.abovetopsecret.com. Wrong. In an article in the *Journal of the Minerals, Metals, and Materials Society* and in subsequent interviews, Thomas Eagar, an engineering professor at the Massachusetts Institute of Technology, explains why: steel loses 50 percent of its strength at 1,200 degrees F; 90,000 liters of jet fuel ignited other combustible materials such as rugs, curtains, furniture and paper, which continued burning after the jet fuel was exhausted, raising temperatures above 1,400 degrees F and spreading the inferno throughout each building. Temperature differentials of hundreds of degrees across single steel horizontal trusses caused them to sag—straining and then breaking the angle clips that held the beams to the vertical columns. Once one truss failed, others followed. When one floor collapsed onto the next floor below, that floor subsequently gave way, creating a pancaking effect that triggered each 500,000-ton structure to crumble. Conspiricists argue that the buildings should have fallen over on their sides, but with 95 percent of each building consisting of air, they could only have collapsed straight down.

No melted steel, no collapsed towers.

All the 9/11 conspiracy claims are this easily refuted. On the Pentagon "missile strike," for example, I queried the would-be filmmaker about what happened to Flight 77, which disappeared at the same time. "The plane was destroyed, and the passengers were murdered by Bush operatives," he solemnly revealed. "Do you mean to tell me that not *one* of the thousands of conspirators needed to pull all this off," I retorted, "is a whistle-blower who would go on TV or write a tell-all book?" My rejoinder was met with the same grim response I get from UFOlogists when I ask them for concrete evidence: Men in Black silence witnesses, and dead men tell no tales. SA

Michael Shermer is publisher of Skeptic *(www.skeptic.com). His latest book is* Science Friction.

BRAD HINES

A Culture of Death

In the underworld of assisted suicide and euthanasia, Russel Ogden examines the means and methods—even as he is shunned by academia and chased by the law By DIANE MARTINDALE

In 1990 David Lewis, a Vancouver man living with HIV, went to a local newspaper and announced that he had assisted eight friends, all suffering from AIDS, in committing suicide—an act of murder in the eyes of Canadian law. For many people, the news simply affirmed what they had long suspected was happening in the AIDS community. But to Russel Ogden, a criminology graduate student at Simon Fraser University looking for a research project, it was an opportunity to go where no scientist had ventured before.

ANNIE MARIE MUSSELMAN

RUSSEL OGDEN: EXPLORING THE END

- **Studies assisted suicide (helping a person take his or her own life) and euthanasia (mercifully ending someone's life as painlessly as possible).**
- **In the Netherlands, where assisted death is legal, 2.4 percent of yearly fatalities result from euthanasia, 0.3 percent from assisted suicide.**
- **On why he studies the subject: "I want to provide the data so activists on both sides of this debate can inform their activism."**

"I had a population in my backyard that had been living with euthanasia issues for some time," recalls Ogden, who is believed by many to be the first researcher in North America to have formally studied the practices of underground assisted suicide and euthanasia. In 1994 Ogden published his master's thesis, which documented the inner workings of this illicit network. The findings shocked the nation and branded him one of Canada's most controversial researchers.

In the decade since, Ogden has faced legal and ethical roadblocks. The authorities have repeatedly pressured him to identify his informants. Such brushes with the law have convinced him to hide his research: he now keeps his data hidden in several locations around town. And at 42, the Vancouver-based Ogden should by now be a well-established scientist. Instead he is still chasing his Ph.D. long-distance at the University of Groningen in the Netherlands—Canadian universities have shut him out. Lack of the usual academic credentials, however, has not stopped Ogden. He wants to know who asks for assisted death, who provides it and how it is done.

Such grisly details were revealed in Ogden's first study, in which 17 individuals, including doctors, nurses, counselors, social workers and two priests, told him precisely how they had helped AIDS patients kill themselves. But the biggest surprise was that many of these deaths were not the "good deaths" often described in proeuthanasia books, which tend to romanticize the process. Of the 34 euthanasia cases, Ogden found that half were botched and ultimately resulted in increased suffering. In five situations, suffocation was unsuccessful. In one instance, the individual who assisted in the suicide had to resort to shooting the patient—in another, to slitting his wrists with a razor blade. These failed attempts often led to the acts of euthanasia taking several hours or longer to complete; in one case, it took four days for the person to die.

These people were first- or second-timers, "not serial death providers," Ogden remarks. "They weren't sure what they were doing." He concluded that the lack of medical knowledge, as well as the unavailability of suitable drugs and ignorance of lethal doses, contributed to the additional suffering. "This study showed that without medical supervision and formal regulations, euthanasia is happening in horrific circumstances, similar to back-alley abortions," he declares.

In February 1994 news of Ogden's study spread quickly, eventually making its way to the coroner's office. Ogden soon found himself staring at a subpoena demanding that he reveal the names of his informants, each potentially facing prosecution. Ogden refused, never wavering on his promise to his participants, and chose to risk jail time.

Amid the battle, Simon Fraser University abandoned him, leaving Ogden to conduct his own defense. He successfully argued that his research passed Canada's Wigmore criteria, a set of common law privileges that excused him from disclosing his confidential sources. The coroner eventually dropped the charges.

With a tarnished reputation in Canada, Ogden went to the University of Exeter in England in 1995, where he resumed his studies of assisted death in AIDS patients—with assurances that the university would stand behind him and his research subjects. So for three years he interviewed nearly 100 physicians and nonmedical death providers in the U.K., the U.S., Canada and the Netherlands—the last is one of only three countries where national law allows doctors to assist in dying. (Oregon has a state law permitting physician-assisted death.)

Ogden discovered that although the methods used for dying are similar (most involve drug overdose), attitudes toward assisted death are quite different. In Europe, people have a more passive and deferential approach, allowing a dear one to make the decision, usually after the person has lapsed into unconsciousness or has severe dementia, Ogden explains. "In the U.S. and Canada, there is a big push for assisted suicide where patients make the decision of when to die and take the drugs themselves; it's more individualistic and autonomous."

Ogden's study, however, abruptly ended: In 1998 Exeter reneged on its promise, citing concern over institutional liability. Fearing legal intervention, Ogden did not chance publishing his data without protection and thus left the university and his work behind. Ogden returned, sans Ph.D., to Vancouver, where he began teaching criminology as well as shifting his studies to the NuTech movement, a loose coalition of right-to-die activists from several nations. Since 1999 he has collected hundreds of interviews and reports from NuTech and may be the only outsider to have been invited to its secret meetings.

NuTech's approach is to take medicine out of assisted death, with methods that are simple, painless, inexpensive and impossible to trace. Suffocation devices, such as the "debreather," a modified piece of scuba diving equipment, and the "exit bag," a plastic bag equipped with Velcro straps, are commonly used. Most popular, Ogden has found, is the plastic bag in conjunction with helium gas. "This is the quickest way to go; used properly, you're unconscious after the second breath and dead in about 10 minutes," he reveals. Such methods are more efficient and reliable than lethal drugs, but suffocation devices remain unappealing and undignified to people. Most still want something they can drink. In that case, death providers recommend black-market Nembutal, a liquid barbiturate used by veterinarians to put down animals.

NuTech is at the forefront of what Ogden calls the "deathing counterculture," in which nonmedical death practitioners offer referrals, consultations and house calls. "They are taking the place of physicians to deliver virtually undetectable death assistance," says Ogden, who notes that the most famous death provider, Jack Kevorkian, began his career as a pathologist, not a personal physician, and did not see patients. What is more, he has found that this counterculture is growing in direct response to the lack of supporting legislation. But Ogden sees problems with NuTech: no medical or counseling personnel to ensure mental competence, no informed consent and no exploration of treatment alternatives. Hence, the NuTech practice will be difficult to regulate and protect from abuse.

Unregulated euthanasia has occurred under conditions akin to back-alley abortions.

Opponents do not see how Ogden's research can be of any benefit, especially because there is no way to verify if participants' responses are truthful. "Most people who study this want to show that assisted suicide is occurring quite commonly, therefore we should just bite the bullet and legalize it," says Margaret Somerville, director of the Center for Medicine, Ethics and Law at McGill University, who argues that assisted death and euthanasia reduce the respect for life. Still, Ogden's work has informed public and political debates. For example, in Ottawa, Senate committees in Parliament have repeatedly relied on his data for their reports and recommendations.

Ogden expects to receive his doctorate for his NuTech work soon, but beyond that, his future is uncertain. Without a university position, he will have a hard time securing government funding. Thus far he has covered the cost of his research partly with settlement money he received after filing grievances against both Simon Fraser and Exeter.

Despite his years of research, Ogden has not experienced one thing he feels is critical: witnessing covert assisted death. "It's one thing to be told what's happening and it's another to actually see it. To my knowledge, I would be the first researcher to do this," he says. More controversy would surely follow. SA

Diane Martindale is a science writer in Toronto.

BUYING TIME IN

An ability to put the human body on hold could safeguard the
Does the power to reversibly stop our biological clocks

SUSPENDED ANIMATION

critically injured or preserve donor organs for transport.
already lie within us? By Mark B. Roth and Todd Nystul

FANTASY WRITERS HAVE LONG BEEN CAPTIVATED BY

the possibility of preserving human life in a reversible state of suspended animation. In fictional tales the technique enables characters to "sleep" through centuries of interstellar travel or terrestrial cataclysms, then awaken unaffected by the passing of time. These stories are great fun, but their premise seems biologically far-fetched. In reality, we humans do not appear capable of altering our rate of progression through life. We cannot pause the bustling activity of our cells any more than we can stop breathing for more than a few minutes without sustaining severe damage to vital organs.

Nature, however, abounds in organisms that can and do reversibly arrest their essential life processes, in some cases for several years at a time. Scientists describe these phenomena by a variety of terms—quiescence, torpor, hibernation, among others—but all represent different degrees of suspended animation, a dramatic reduction of both energy production (metabolism) and energy consumption (cellular activity). What is more, organisms in this state enjoy extraordinary resistance to environmental stresses, such as temperature extremes, oxygen deprivation and even physical injury.

Sci-fi scenarios aside, if the human body could be placed in such a condition, the implications for medicine alone would be enormous. For example, some human organs destined for transplantation, such as the heart and lungs, can survive outside the body for only up to six hours. Others, such as the pancreas and kidney, cannot last for more than a day. Successful organ transfers thus depend on speed, which means that in some cases potential matches must be passed over for a simple lack of time to transport the organ before it deteriorates. And while tens of thousands of organ transplants are performed successfully every year in the U.S., this urgency sometimes leads to mistakes that might have been averted had there been more time.

If these precious organs could be placed in a suspended state, their viability might be preserved for days or even weeks. Emergency medical teams could also use this technique to buy time for critically injured trauma victims. Putting these patients into suspended animation could stave off deterioration of their tissues while doctors repaired their injuries.

Recent studies in our laboratory at the Fred Hutchinson Cancer Research Center in Seattle and by other researchers have shown that hibernationlike states can be induced on demand in animals that do not naturally hibernate. Moreover, such animals seem to be protected from the usual effects of blood loss, such as oxygen deprivation, while they are in a suspended state. These results raise the exciting possibility that suspended animation may be feasible in humans as well. Indeed, the methods our group has used to induce suspended animation in lab animals and in human tissue suggest this capability could be latent in many organisms through a mechanism with roots in the earliest days of microbial life on earth.

Overview/*Putting Life on Pause*

- Many organisms are naturally able to slow or arrest their life processes, and their suspended state confers protection from environmental conditions that would normally kill them, such as prolonged oxygen deprivation.
- Inadequate oxygen is a major cause of tissue damage and death in explanted donor organs and in people experiencing blood loss or obstruction. Restoring oxygen supply to these tissues is not always immediately possible. Blocking all available oxygen, however, can induce a variety of animals to enter protective suspended animation and might do the same for human injury victims or tissues.
- Hydrogen sulfide, a chemical produced naturally by our bodies, blocks cells from using oxygen and triggers suspended animation in mice. It may be a natural regulator of cellular energy production that could be employed to induce a protective suspended state in humans.

Survival of the Slowest

THE DIVERSE RANGE of creatures known to be capable of stopping some or most of their cellular activity usually do so in response to an environmental stressor and remain "stopped" until it is removed. A developing plant seed, for instance, can stay dormant in the soil for years until conditions favor germination. Similarly, embryos of a species of brine shrimp, *Artemia franciscana*, popularly known as sea monkeys, can live for more than five years without any food, water or oxygen by entering into a seedlike state called quiescence, in which cellular activity is at a virtual standstill. On reexposure to their natural environment, they will resume developing normally toward adulthood.

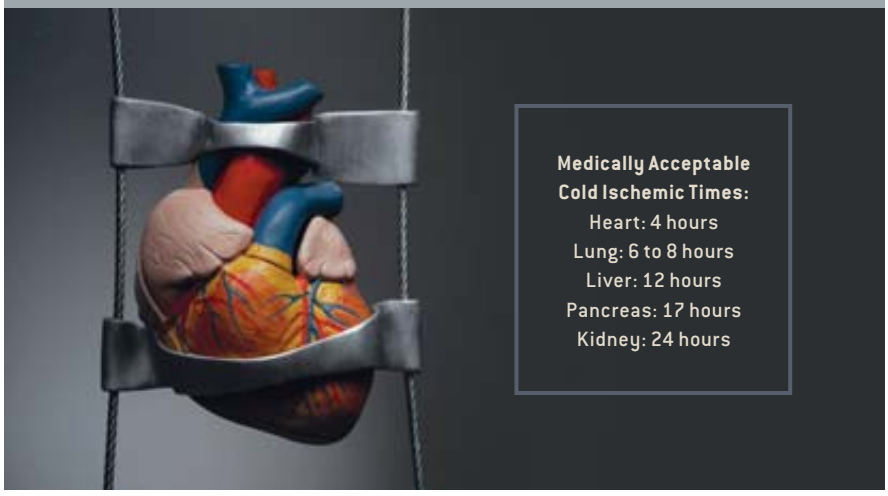
Suspended animation–like states can range from those in which animation is truly halted—all movement within cells visible through a microscope stops—to states where cellular activity continues but at a drastically slowed pace. A variety of adult animals, for example, can radically reduce their need for food and air over long periods by hibernating: their breathing and heart rate become almost imperceptible, their body temperature drops to near freezing, and their cells consume very little energy. Ground squirrels and dozens of other mammalian species pass the cold winter months in this condition every year, whereas other animals, including varieties of frogs, salamanders and fish, take refuge during hot summer months in a similar state called estivation.

The ability to survive even prolonged oxygen deprivation, which these organisms gain by dramatically reducing their need for and production of energy, of-

CARY WOLINSKY; CORBIS (*clockface*); JEN CHRISTIANSEN (*photoillustration*) (*preceding pages*)

BEATING THE CLOCK

Organs become vulnerable to ischemic damage as soon as they are disconnected from their donor's blood supply. Although infused with a cold chemical preservative solution and chilled during transport, organs will fail to function if too much time passes before transplantation. This window of viability is known as "medically acceptable cold ischemic time." According to the United Network for Organ Sharing, 3,216 recovered organs went unused last year, several hundred of these because they could not be matched or transported to a suitable recipient in time.



Medically Acceptable Cold Ischemic Times:
Heart: 4 hours
Lung: 6 to 8 hours
Liver: 12 hours
Pancreas: 17 hours
Kidney: 24 hours

SOURCE: UNITED NETWORK FOR ORGAN SHARING RESEARCH DEPT.; *ORGAN PROCUREMENT AND TRANSPLANTATION*, INSTITUTE OF MEDICINE, 1999 (*data in box*); CARY WOLINSKY (*photograph, top*); REPRINTED FROM *AMERICAN JOURNAL OF PATHOLOGY*, VOL. 158, NO. 6, PAGES 2145–2151, JUNE 2001, WITH PERMISSION FROM THE AMERICAN SOCIETY FOR INVESTIGATIVE PATHOLOGY (*bottom*)

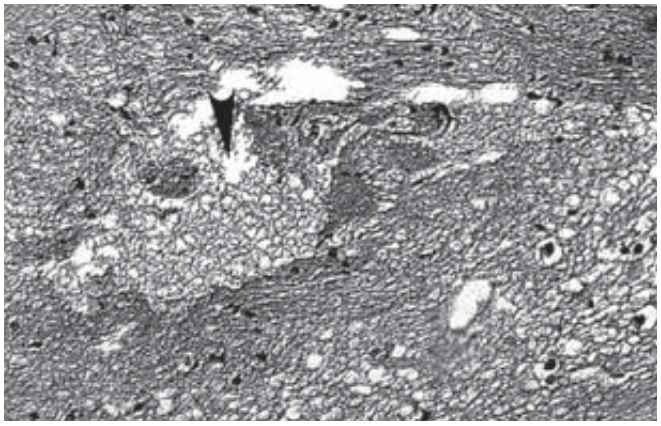
fers a stark contrast to the normal situation of humans. We are thoroughly dependent on a steady supply of oxygen because our cells need it to maintain their constant production of energy. When oxygen levels within our tissues fall below a precise range, cells suffer ischemic damage, leading to tissue death. Thus, ischemia is often the underlying cause of mortality following heart attacks, strokes, or other physical traumas that deprive tissues of blood, and therefore oxygen, even if only for a short time.

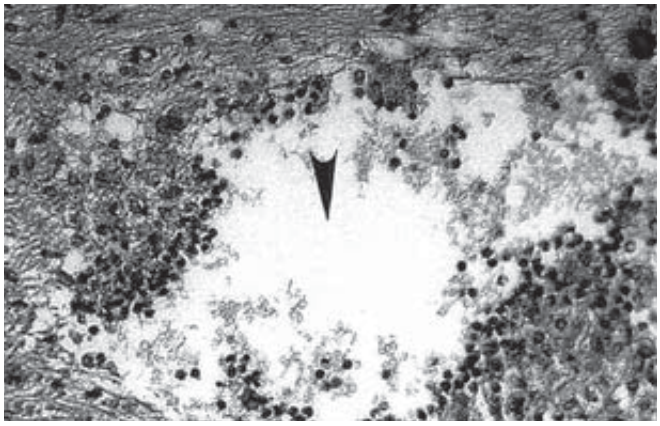
Some of the molecular events that cause tissue damage in ischemia are not yet fully understood, but scientists certainly agree that cells' loss of their ability to fuel essential self-maintenance activities must play a central role. Most of the energy that cells consume comes from molecules of adenosine triphosphate (ATP), which are manufactured primarily by cellular mitochondria in an oxygen-dependent process known as oxidative phosphorylation. When oxygen levels drop, oxidative phosphorylation slows and ATP levels decrease. Because ATP molecules are typically consumed by a cell within seconds after they are produced, ischemic damage is believed to result when cells without sufficient oxygen simply run out of gas.

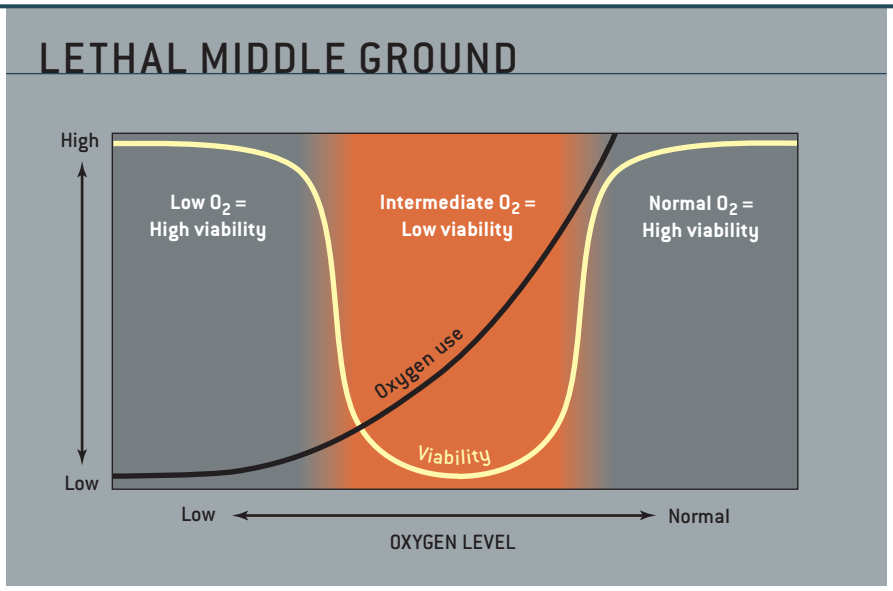
The damage may be worsened when some cellular processes that are less energetically demanding, but equally essential, continue, throwing a cell's overall system out of coordination. Finally, oxidative phosphorylation itself can also harm the cell. When oxygen levels fall below an optimal concentration, the oxidative phosphorylation process becomes less efficient and can release energy prematurely in the form of highly reactive molecules called free radicals. These by-products have become famous for their aging effects because they can damage DNA and other cellular structures. In ischemia, their actions further hinder an oxygen-deprived cell's ability to carry out crucial functions.

The goal, therefore, of CPR and other conventional approaches to preventing ischemic damage in victims of traumatic injury is to restore blood flow—and thus oxygen supply—to tissues as rapidly as possible. Given our cells' strict oxygen requirements, that might seem to be the only possible strategy. We

BRAIN TISSUE from arctic ground squirrels shows the protective effect of natural suspended animation. Three days after slender (0.5-millimeter) probes were inserted into the brains of hibernating and nonhibernating squirrels, the animals were euthanized and their wounds examined. In the hibernating animal's tissue (*left*), a tiny hole made by the probe remains, but no other damage or evidence of inflammation is visible. In the nonhibernating animal, considerable cell death around the original injury left a large hole (*right*) surrounded by darkly stained immune cells.







NORMAL OXYGEN LEVELS promote efficient energy production and cell function in most organisms. The authors and other research groups have also found that conditions of extremely low oxygen (anoxia) can prompt cells to enter a protective state of suspended animation in which they all but cease producing or consuming energy. When oxygen levels are intermediate (hypoxic), however, cells attempt to continue operating normally, yet inadequate oxygen supply makes their activities inefficient and potentially self-destructive. Thus, oxygen-deprived tissues may be rescued by restoring their normal oxygen levels and also perhaps by blocking any remaining oxygen available to them.

have seen, however, that for animals in suspended animation–like states, dramatically reduced cellular activity makes them remarkably resistant to ischemia during oxygen deprivation. Suspecting that inducing the same condition in humans might enable people to avoid ischemic damage during periods of low oxygen, our group began working to understand more about the mechanism that allows organisms to shut down in response to oxygen deprivation.

Lessons from a Worm

WE HAVE STUDIED suspended animation in a variety of popular laboratory workhorse organisms, such as yeast, zebrafish embryos and the soil nematode *Caenorhabditis elegans*. The last is able to enter a state of suspended animation at any stage of life. It will do so when placed in anoxia—an atmosphere with extremely low oxygen content of around 0.001 percent or less—and can maintain this arrest for 24 hours or more.

When blood flow to human tissue is cut off, however, whether by blood loss or a vascular blockage, oxygen concentrations probably never drop low enough to make the tissue completely anoxic. Residual oxygen in remaining blood and in the tissue itself could allow low levels of oxidative phosphorylation to occur. But ATP production would be insufficient to support normal rates of cellular activity, and damaging free radical production would increase.

To mimic these ischemic conditions for humans, we can expose developing *C. elegans* embryos to "hypoxic" oxygen concentrations, between 0.01 and 0.1 percent O_2—still well below the 21 percent oxygen in normal room air (normoxia) but slightly higher than anoxia. In hypoxia, the embryos do not enter into suspended animation as they would in anoxia. Instead they attempt to continue their progression through embryogenesis, resulting in obvious cellular damage and death after 24 hours.

If we increase the oxygen concentration in the embryos' atmosphere just slightly, to 0.5 percent O_2, they progress normally through embryogenesis just like embryos in normoxia. Thus, even though the nematodes are capable of surviving in anoxia by entering into suspended animation and can develop normally in as little as 0.5 percent O_2, the 10-fold range of oxygen concentrations between these two spaces is lethal.

We have also shown in our work with *C. elegans* that the embryos' shift into suspended animation under anoxic conditions is not merely a passive result of their running out of oxygen but rather seems to be a purposeful mechanism. We identified two genes functioning during anoxia, but not hypoxia, that appear essential to arresting the embryos' cell cycle. When exposed to anoxia, embryos lacking these genes fail to suspend their cell divisions, their chromosomes segregate improperly, and many die.

These results suggest that ischemic damage can be avoided not only by increasing the amount of oxygen available to cells, as conventional wisdom would predict, but also by *decreasing* available oxygen. This idea may fly in the face of current medical practice, yet it has strong implications for preserving human tissues: it is difficult to keep an individual organ destined for transplantation oxygenated or to supply enough oxygen to the damaged tissues of injury victims, but it might be possi-

THE AUTHORS

MARK B. ROTH and *TODD NYSTUL* investigated the cellular mechanisms and protective effects of suspended animation together while Nystul was a graduate student in Roth's laboratory at the Fred Hutchinson Cancer Research Center. Roth's work encompasses many basic cellular processes, such as how cells regulate their own size, the expression of their genes, and their functional specialization. Nystul earned his Ph.D. from the University of Washington in 2004 and is now a postdoctoral fellow at the Carnegie Institution in Baltimore, where he studies stem cell regulation in the fruit fly *Drosophila*. In addition to preserving donor organs or critically injured patients, Roth and Nystul think that understanding the mechanisms of suspended animation may shed light both on stem cells' ability to remain quiescent and on certain cancerous tumor cells that are resistant to radiation because they exist in a similar low-oxygen and low-energy state.

JEN CHRISTIANSEN

The shift into suspended animation seems to be a purposeful mechanism.

ble to decrease their available oxygen.

One effective way to reduce a cell's access to oxygen is to add a mimetic—a substance that physically resembles oxygen at a molecular level and thus can bind to many of the same cellular sites but that does not behave like oxygen chemically. Carbon monoxide, for example, can compete with oxygen for binding to cytochrome *c* oxidase, a component of the oxidative phosphorylation machinery within the cell that normally binds oxygen, but the bound carbon monoxide cannot be used to produce ATP.

We therefore wondered if we could protect *C. elegans* embryos from the ischemic damage they faced in intermediate oxygen concentrations by simultaneously adding carbon monoxide to their hypoxic atmosphere—effectively simulating anoxia by blocking the small amount of remaining oxygen available to the embryos. Indeed, we found that under these conditions the embryos entered into suspended animation and avoided the lethal effects of ischemia.

By 2003 these encouraging results made us eager to test this concept further. Previous studies of larger animals and intriguing stories of human accident victims surviving conditions of low oxygen suggested to us the mechanism that rescued our worms might also exist in more complex organisms.

Inducing a Protective Pause

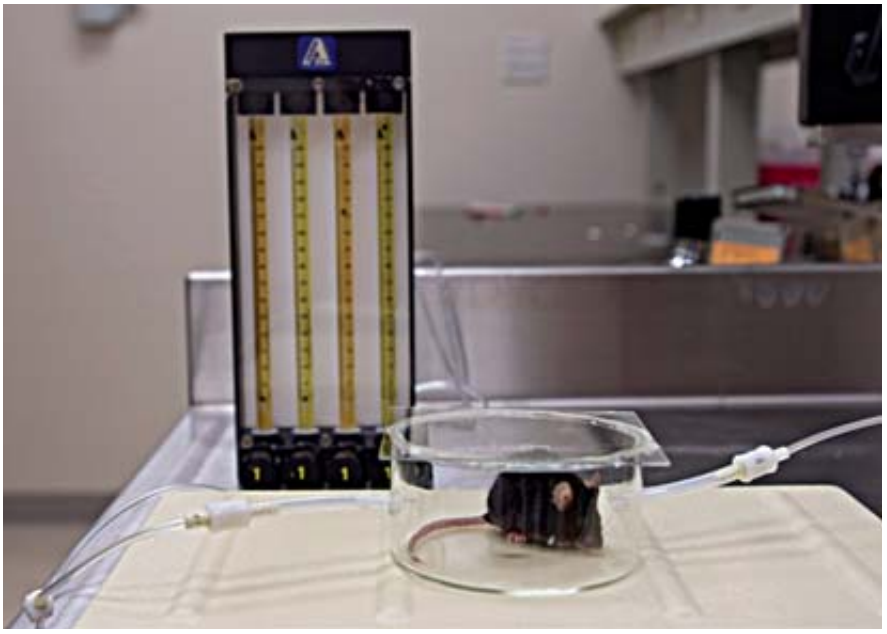
CONSIDERABLE ANIMAL research supports the idea that even in larger mammals, decreasing levels of available oxygen can prevent damage to tissues. When animals hibernate naturally, for instance, the suspended state appears to protect them from injuries. Experiments by Kelly L. Drew of the Institute of Arctic Biology at the University of Alaska Fairbanks and her colleagues found that when the brains of hibernating arctic ground squirrels were pierced with microscopic probes, little or no brain tissue died. The same injury inflicted on nonhibernating squirrels caused rapid tissue deterioration [*see illustration on page 51*].

Such evidence has led several researchers to try to induce a hibernation-like state in animals that do not normally hibernate to see whether the cellular slowdown itself could be achieved safely and whether it might protect tissues long enough to repair an injury. The late Peter Safar and his co-workers at the University of Pittsburgh worked for nearly two decades with dogs to perfect a process for creating a state of suspended animation. Last year Safar's group described its most recent experiments. To create the suspended state, cardiac arrest was induced in each of 14 dogs, and then the blood was drained out of the animals' bodies while a cold saline solution was infused into them. Saline has a much lower capacity for carrying oxygen than blood, so this procedure dramatically reduces the amount of oxygen in the dogs' tissues. Afterward, the dogs were unconscious, did not breathe and had no heartbeat.

Safar's team then separated the dogs into a control group of six animals and a second group of eight that would undergo surgical removal of their spleens, a nonessential organ. After 60 minutes in the suspended state, all the dogs were revived by reinfusion of blood. Seventy-two hours later the dogs were all still alive, and none of the control dogs showed any functional or neurological ill effects from their time in suspended animation. Four of the eight surgery dogs were also normal, although the other four displayed some neurological deficits.

Peter Rhee and his colleagues at the Uniformed Services University of the Health Sciences used a similar technique to induce suspended animation in 15 adult Yorkshire swine. They then performed vascular repair surgery on some of the animals. Rhee reported that the memory and learning abilities of all the test animals were completely unaffected by their experience.

AIRTIGHT GLASS CHAMBER was used by Roth and his co-workers to administer nonlethal doses of hydrogen sulfide (H_2S) gas to individual laboratory mice of the type shown here for as long as six hours. In the group's experiments, the degree and speed of reduction in the animals' core body temperature and metabolic rate correlated with the H_2S concentration in the chamber, supporting their hypothesis that H_2S can induce a suspended animation–like state similar to natural hibernation in a mammal that does not normally hibernate.



ANNIE MARIE MUSSELMAN

Because the physiology of dogs and pigs is so similar to that of humans, this line of research has prompted enthusiastic speculation that such procedures could soon be perfected and tested on human patients in emergency rooms.

Although this method may hold promise, exsanguination is a drastic action with great potential for complications, so our group has been searching for less invasive ways to temporarily deprive living cells of oxygen. For instance, in blood-free human tissues, such as an organ that has been removed from a donor, suspended animation might be induced by placing the organ in an airtight container and perfusing the tissue with carbon monoxide, as we did with the *C. elegans* embryos. When doctors were ready to implant the organ, they would need only infuse it with blood to restore its oxygen supply. In our lab, we have experimented with this technique to preserve human tissue samples from normal cellular deterioration, and we believe this approach could significantly extend the viability of human organs destined for transplantation.

The effects of carbon monoxide would be easily reversed in explanted organs, although the same would probably not be true in living organisms with blood coursing through their bodies. Because carbon monoxide molecules bind tenaciously to red blood cells at the sites where oxygen would normally attach itself, using this gas in trauma victims would be impractical. We have therefore also been experimenting with alternative oxygen mimetics.

Most of the substances we have tested are, like carbon monoxide, considered human poisons precisely because they can block cells' ability to use oxygen. Pockets of hydrogen sulfide gas, for example, are a deadly hazard to workers in many industrial settings, such as sewers and "sour gas" fields in the petrochemical industry. For this reason, occupational safety research has defined lethal doses of hydrogen sulfide (H_2S), largely through studies using rodents. This work provided a helpful starting point as we began to test nonlethal doses of H_2S on laboratory mice to see whether it could induce a reversible state of suspended animation.

In a sealed chamber, we exposed mice to atmospheres containing as much as 80 parts per million H_2S. At that lev-

LIFE IN BALANCE

Earth's earliest unicellular life-forms began evolving some four billion years ago in an atmosphere that was nearly devoid of oxygen but very likely to have been chock-full of sulfur-containing molecules, such as hydrogen sulfide (H_2S). These primordial organisms came to generate their own energy supply by using H_2S in much the same way that most modern life uses oxygen. Indeed, many essential components of the oxidative phosphorylation pathway appear to have evolved from this earlier sulfur-based respiration mechanism. Cytochrome *c* oxidase, for example, the component in the oxidative phosphorylation machinery that normally binds oxygen, closely resembles the analogous component in sulfur-based respiration, and it can bind to hydrogen sulfide.

Oxygen metabolism and sulfur metabolism may share more than a simple ancestral relation, however. Even today H_2S is produced naturally by our bodies, which might seem incongruous given that H_2S binding to cytochrome *c* oxidase would inhibit oxygen's ability to do so. Yet it is possible that as ancient organisms started to make the transition to oxygen respiration, hydrogen sulfide took on a new role as an essential antagonist to oxygen.

The two molecules are highly reactive with one another and a constant give-and-take of electrons is fundamental to all life: some atoms give up their electrons in a process known as oxidation, whereas others take on electrons by "reducing" some other molecule's supply. These reduction-oxidation, or "redox," processes underlie energy production in all biological systems, and many organisms seek an environment where the potential for redox reactions is maximized.

In calm ocean water, for example, where dissolved gases mix primarily by diffusion, oxygen produced by photosynthetic organisms near the surface penetrates downward during the day and recedes at night, whereas H_2S constantly diffuses from below, an end product of metabolism by organisms that live off decaying material on the seafloor. The constant battle between these two gases creates a chemically unstable vertex where electrons are swapped at an alarming rate. This gradient is exactly the location that a host of organisms, such as the motile filamentous bacterium *Beggiatoa alba,* as well as many unicellular eukaryotes, choose to inhabit. These creatures' density can become so great that they form vast mats, which rise and fall in depth with the daily oxygen/H_2S cycle.

Perhaps our bodies and those of other oxygen-breathing organisms are like microbial mats seeking redox equilibrium. We do not live next to a source of H_2S, however, so we make our own, enabling our cells to remain in the optimal chemically unstable environment from which we evolved. I speculate that hydrogen sulfide's ability to bind to cytochrome *c* oxidase may have caused it to become part of an intrinsic cellular program to naturally slow or stop oxidative phosphorylation in the presence of oxygen. This protective mechanism would be useful at those times when cells risk harming themselves by struggling to produce and use energy under anoxic conditions or, in the opposite situation, when an overdose of oxygen would cause cellular generators to overwork and potentially "fry" the cells. If H_2S were such a natural trigger for protective biological arrest, our success in employing it to induce hibernationlike states on demand would be explained. —*M.B.R.*

LECHUGUILLA CAVE in New Mexico is one of many enclaves, such as deep-sea volcanic vents, where sulfur-oxidizing bacteria that probably resemble Earth's primordial life still thrive.

In effect, treatment converted our mice from warm-blooded to cold-blooded.

el we observed a threefold drop in their carbon dioxide output within the first five minutes, and their core body temperatures began to fall. The animals ceased all movement and appeared to lose consciousness. Over the course of several hours in this environment, the animals' metabolic rate continued to decrease, as measured by their carbon dioxide output, ultimately falling 10-fold. Their breathing rate slowed from a norm of 120 breaths per minute to fewer than 10.

The animals' core body temperature kept dropping from their usual 37 degrees Celsius until it reached a level approximately two degrees C above the air temperature, regardless of what that was. We were able to bring their average body temperatures as low as 15 degrees C simply by cooling their chamber. In naturally hibernating animals, this same tendency of body temperature to rise or fall along with ambient temperature is common.

In effect, treatment with H_2S converted our mice from warm-blooded to cold-blooded, which is just what happens to animals during hibernation. We kept the mice in this condition for six hours, and after they revived we gave them a battery of tests to see if their suspended animation experience had left any functional or behavioral ill effects. The mice all seemed perfectly normal.

NORMAN THOMPSON

From Mice to Men

WE ARE NOW continuing this line of research in larger animals, and we believe that hydrogen sulfide may be the key to safely inducing such suspended animation–like states in organisms that do not normally hibernate, including humans. Although H_2S is considered a poison, it is also produced naturally within our own bodies. Indeed, H_2S may have a unique unrecognized role in regulating cellular energy production in oxygen-breathing organisms because it once played oxygen's molecular part in metabolism when our planet was young and oxygen was scarce [*see box on opposite page*]. Many other questions still remain to be answered, however, before H_2S-induced suspended animation can be studied in people.

The biggest unknown is whether humans are even capable of entering a state of suspended animation. Compelling evidence certainly indicates that human beings are sometimes able to withstand several hours without oxygen. In one remarkable example just a few years ago, a Norwegian backcountry skier was rescued after an accident that left her under ice-cold water for more than an hour. When the emergency crew found her, she was clinically dead—not breathing, without a heartbeat, and with a core body temperature of 14 degrees C (57 degrees Fahrenheit). Despite requiring nine hours of resuscitation, she has since made an "excellent" recovery, according to her doctors.

Another 32 cases of severe hypothermia in which core body temperatures ranged from 17 to 25 degrees C (63 to 77 degrees F) and many of the victims lacked vital signs when rescued were analyzed by Beat H. Walpoth of the University of Bern in Switzerland. He found that nearly half—15 patients—recovered from the trauma without any long-term impairment.

Because these people were not breathing, oxygen levels in their tissues were undoubtedly very low, suggesting that, on occasion, the human body also possesses the flexibility to reversibly slow or stop cellular activity in response to a stress. But which occasions? What variables allow some people to live under these conditions, whereas others die? Understanding the links between natural and induced suspended animation in animals and the largely unexplained survival of certain human patients may reveal that the capacity to enter a protective state of suspended animation already exists within all of us. SA

MORE TO EXPLORE

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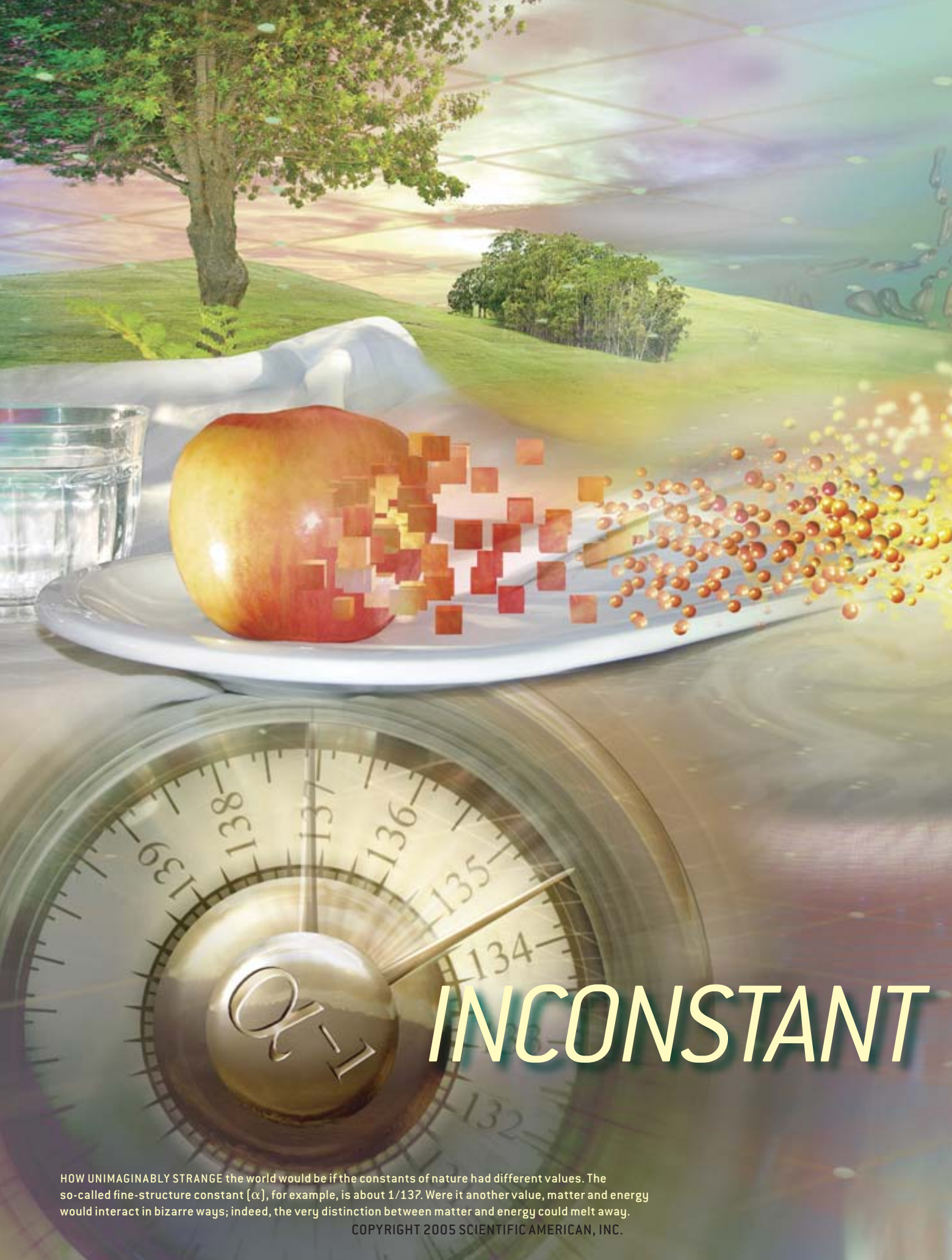


INCONSTANT

HOW UNIMAGINABLY STRANGE the world would be if the constants of nature had different values. The so-called fine-structure constant (α), for example, is about 1/137. Were it another value, matter and energy would interact in bizarre ways; indeed, the very distinction between matter and energy could melt away.

Do the inner workings of nature change with time?

CONSTANTS

By John D. Barrow and John K. Webb

Some things never change. Physicists call them the constants of nature. Such quantities as the velocity of light, c, Newton's constant of gravitation, G, and the mass of the electron, m_e, are assumed to be the same at all places and times in the universe. They form the scaffolding around which the theories of physics are erected, and they define the fabric of our universe. Physics has progressed by making ever more accurate measurements of their values.

And yet, remarkably, no one has ever successfully predicted or explained any of the constants. Physicists have no idea why they take the special numerical values that they do. In SI units, c is 299,792,458; G is 6.673×10^{-11}; and m_e is $9.10938188 \times 10^{-31}$—numbers that follow no discernible pattern. The only thread running through the values is that if many of them were even slightly different, complex atomic structures such as living beings would not be possible. The desire to explain the constants has been one of the driving forces behind efforts to develop a complete unified description of nature, or "theory of everything." Physicists have hoped that such a theory would show that each of the constants of nature could have only one logically possible value. It would reveal an underlying order to the seeming arbitrariness of nature.

In recent years, however, the status of the constants has grown more muddled, not less. Researchers have found that the best candidate for a theory of everything, the variant of string theory called M-theory, is self-consistent only if the universe has more than four dimensions of space and time—as many as seven more. One implication is that the constants we observe may not, in fact, be the truly fundamental ones. Those live in the full higher-dimensional space, and we see only their three-dimensional "shadows."

Meanwhile physicists have also come to appreciate that the values of many of the constants may be the result of

mere happenstance, acquired during random events and elementary particle processes early in the history of the universe. In fact, string theory allows for a vast number—10^{500}—of possible "worlds" with different self-consistent sets of laws and constants [see "The String Theory Landscape," by Raphael Bousso and Joseph Polchinski; SCIENTIFIC AMERICAN, September 2004]. So far researchers have no idea why our combination was selected. Continued study may reduce the number of logically possible worlds to one, but we have to remain open to the unnerving possibility that our known universe is but one of many—a part of a multiverse—and that different parts of the multiverse exhibit different solutions to the theory, our observed laws of nature being merely one edition of many systems of local bylaws [see "Parallel Universes," by Max Tegmark; SCIENTIFIC AMERICAN, May 2003].

No further explanation would then be possible for many of our numerical constants other than that they constitute a rare combination that permits consciousness to evolve. Our observable universe could be one of many isolated oases surrounded by an infinity of lifeless space—a surreal place where different forces of nature hold sway and particles such as electrons or structures such as carbon atoms and DNA molecules could be impossibilities. If you tried to venture into that outside world, you would cease to be.

Thus, string theory gives with the right hand and takes with the left. It was devised in part to explain the seemingly arbitrary values of the physical constants, and the basic equations of the theory contain few arbitrary parameters. Yet so far string theory offers no explanation for the observed values of the constants.

A Ruler You Can Trust

INDEED, THE WORD "constant" may be a misnomer. Our constants could vary both in time and in space. If the extra dimensions of space were to change in size, the "constants" in our three-dimensional world would change with them. And if we looked far enough out in space, we might begin to see regions where the "constants" have settled into different values. Ever since the 1930s, researchers have speculated that the constants may not be constant. String theory gives this idea a theoretical plausibility and makes it all the more important for observers to search for deviations from constancy.

Such experiments are challenging. The first problem is that the laboratory apparatus itself may be sensitive to changes in the constants. The size of all atoms could be increasing, but if the ruler you are using to measure them is getting longer, too, you would never be able to tell. Experimenters routinely assume that their reference standards—rulers, masses, clocks—are fixed, but they cannot do so when testing the constants. They must focus their attention on constants that have no units—they are pure numbers—so that their values are the same irrespective of the units system. An example is the ratio of two masses, such as the proton mass to the electron mass.

One ratio of particular interest combines the velocity of light, c, the electric charge on a single electron, e, Planck's constant, h, and the so-called vacuum permittivity, ε_0. This famous quantity, $\alpha = e^2/2\varepsilon_0 hc$, called the fine-structure constant, was first introduced in 1916 by Arnold Sommerfeld, a pioneer in applying the theory of quantum mechanics to electromagnetism. It quantifies the relativistic (c) and quantum (h) qualities of electromagnetic (e) interactions involving charged particles in empty space (ε_0). Measured to be equal to 1/137.03599976, or approximately 1/137, α has endowed the number 137 with a legendary status among physicists (it usually opens the combination locks on their briefcases).

If α had a different value, all sorts of vital features of the world around us would change. If the value were lower, the density of solid atomic matter would fall (in proportion to α^3), molecular bonds would break at lower temperatures (α^2), and the number of stable elements in the periodic table could increase ($1/\alpha$). If α were too big, small atomic nuclei could not exist, because the electrical repulsion of their protons would overwhelm the strong nuclear force binding them together. A value as big as 0.1 would blow apart carbon.

The nuclear reactions in stars are especially sensitive to α. For fusion to occur, a star's gravity must produce temperatures high enough to force nuclei together despite their tendency to repel one another. If α exceeded 0.1, fusion would be impossible (unless other parameters, such as the electron-to-proton mass ratio, were adjusted to compensate). A shift of just 4 percent in α would alter the energy levels in the nucleus of carbon to such an extent that the production of this element by stars would shut down.

Nuclear Proliferation

THE SECOND experimental problem, less easily solved, is that measuring changes in the constants requires high-precision equipment that remains stable long enough to register any changes.

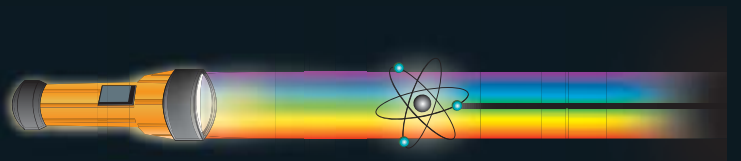
Overview/*Constants of Physics*

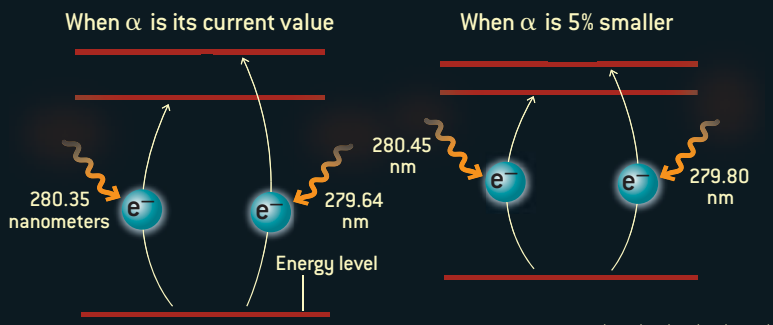
- The equations of physics are filled with quantities such as the speed of light. Physicists routinely assume that these quantities are constant: they have the same values everywhere in space and time.
- Over the past six years, the authors and their collaborators have called that assumption into question. By comparing quasar observations with laboratory reference measurements, they have argued that chemical elements in the distant past absorbed light differently than the same elements do today. The difference can be explained by a change in one of the constants, known as the fine-structure constant, of a few parts per million.
- Small though it might seem, this change, if confirmed, would be revolutionary. It would mean that the observed constants are not universal and could be a sign that space has extra dimensions.

JEAN-FRANCOIS PODEVIN (*preceding pages*)

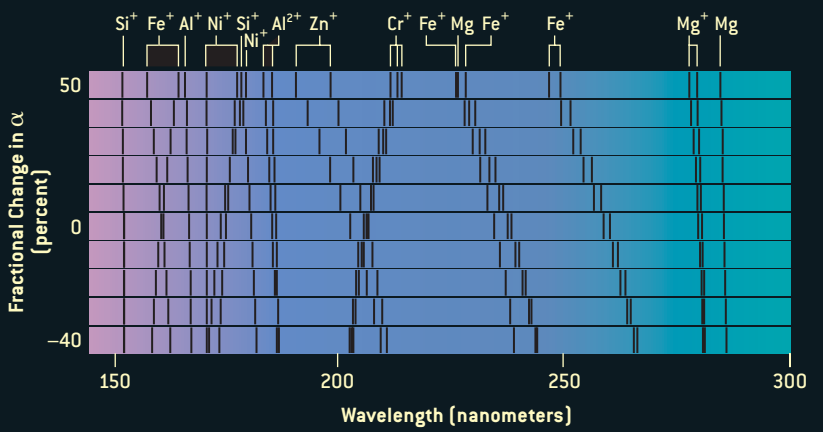
LIGHT AND THE FINE-STRUCTURE CONSTANT

Several of the best-known constants of nature, including the speed of light, can be combined into the fine-structure constant (α)—a number that represents how strongly particles interact through electromagnetic forces. One such interaction is the absorption of photons by atoms. Illuminated by light, an atom absorbs specific colors, each corresponding to photons of a certain wavelength.





ENERGY LEVELS of electrons within the atom describe the absorption process. The energy of a photon is transferred to an electron, which jumps up the ladder of allowable levels. Each possible jump corresponds to a distinct wavelength. The spacing of levels depends on how strongly the electron is attracted to the atomic nucleus and therefore on α. In the case of magnesium ions (Mg^+), if α were smaller, the levels would be closer together. Photons would need less energy (meaning a longer wavelength) to kick electrons up the ladder.



SIMULATED SPECTRA show how changing α affects the absorption of near-ultraviolet light by various atomic species. The horizontal black lines represent absorbed wavelengths. Each type of atom or ion has a unique pattern of lines. Changes in the fine-structure constant affect magnesium (Mg), silicon (Si) and aluminum (Al) less than iron (Fe), zinc (Zn), chromium (Cr) and nickel (Ni).

Even atomic clocks can detect drifts in the fine-structure constant only over days or, at most, years. If α changed by more than four parts in 10^{15} over a three-year period, the best clocks would see it. None have. That may sound like an impressive confirmation of constancy, but three years is a cosmic eyeblink. Slow but substantial changes during the long history of the universe would have gone unnoticed.

Fortunately, physicists have found other tests. During the 1970s, scientists from the French atomic energy commission noticed something peculiar about the isotopic composition of ore from a uranium mine at Oklo in Gabon, West Africa: it looked like the waste products of a nuclear reactor. About two billion years ago, Oklo must have been the site of a natural reactor [see "A Natural Fission Reactor," by George A. Cowan; Scientific American, July 1976].

In 1976 Alexander Shlyakhter of the Nuclear Physics Institute in St. Petersburg, Russia, noticed that the ability of a natural reactor to function depends crucially on the precise energy of a particular state of the samarium nucleus that facilitates the capture of neutrons. And that energy depends sensitively on the value of α. So if the fine-structure constant had been slightly different, no chain reaction could have occurred. But one did occur, which implies that the constant has not changed by more than one part in 10^8 over the past two billion years. (Physicists continue to debate the exact quantitative results because of the inevitable uncertainties about the conditions inside the natural reactor.)

In 1962 P. James E. Peebles and Robert Dicke of Princeton University first applied similar principles to meteorites: the abundance ratios arising from the radioactive decay of different isotopes in these ancient rocks depend on α. The most sensitive constraint involves the beta decay of rhenium into osmium. According to recent work by Keith Olive of the University of Minnesota, Maxim Pospelov of the University of Victoria in British Columbia and their colleagues, at the time the rocks formed, α was within two parts in 10^6 of its current value. This result is less precise than the Oklo data but goes back further in time, to the origin of the solar system 4.6 billion years ago.

To probe possible changes over even longer time spans, researchers must look

ALISON KENDALL; SOURCE: JOHN K. WEBB

LOOKING FOR CHANGES IN QUASAR LIGHT

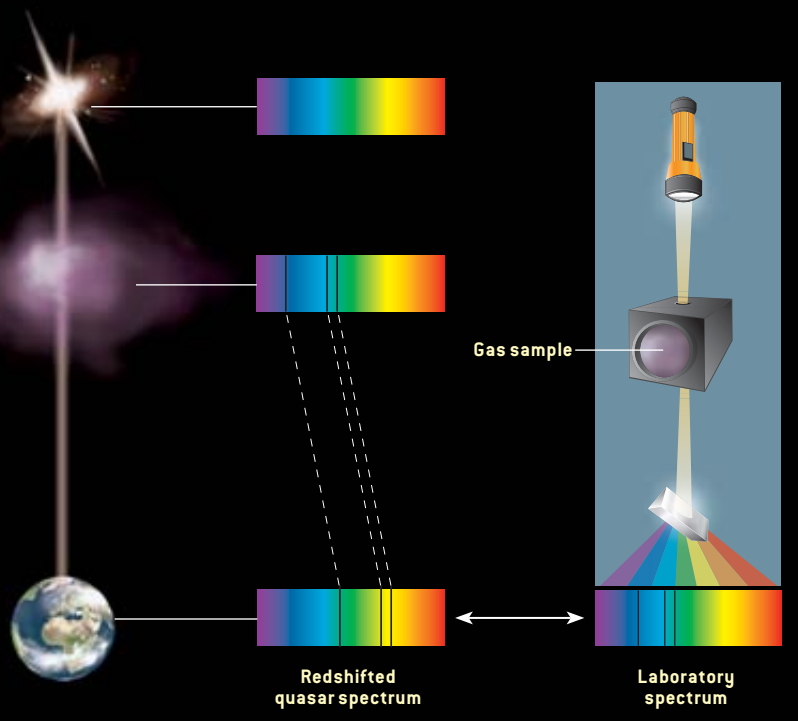
A distant gas cloud, backlit by a quasar, gives astronomers an opportunity to probe the process of light absorption—and therefore the value of the fine-structure constant—earlier in cosmic history.

1 Light from a quasar begins its journey to Earth billions of years ago with a smooth spectrum

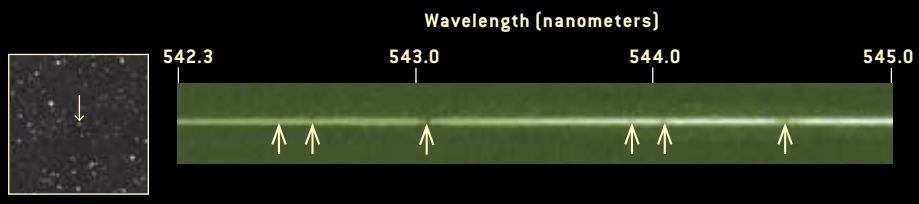
2 On its way, the light passes through one or more gas clouds. The gas blocks specific wavelengths, creating a series of black lines in the spectrum. For studies of the fine-structure constant, astronomers focus on absorption by metals

3 By the time the light arrives on Earth, the wavelengths of the lines have been shifted by cosmic expansion. The amount of shift indicates the distance of the cloud and, hence, its age

4 The spacing of the spectral lines can be compared with values measured in the laboratory. A discrepancy suggests that the fine-structure constant used to have a different value



QUASAR SPECTRUM, taken at the European Southern Observatory's Very Large Telescope, shows absorption lines produced by gas clouds between the quasar (*arrowed at right*) and us. The position of the lines (*arrowed at far right*) indicates that the light passed through the clouds about 7.5 billion years ago.



to the heavens. Light takes billions of years to reach our telescopes from distant astronomical sources. It carries a snapshot of the laws and constants of physics at the time when it started its journey or encountered material en route.

Line Editing

ASTRONOMY FIRST entered the constants story soon after the discovery of quasars in 1965. The idea was simple. Quasars had just been discovered and identified as bright sources of light located at huge distances from Earth. Because the path of light from a quasar to us is so long, it inevitably intersects the gaseous outskirts of young galaxies. That gas absorbs the quasar light at particular frequencies, imprinting a bar code of narrow lines onto the quasar spectrum [*see box above*].

Whenever gas absorbs light, electrons within the atoms jump from a low energy state to a higher one. These energy levels are determined by how tightly the atomic nucleus holds the electrons, which depends on the strength of the electromagnetic force between them—and therefore on the fine-structure constant. If the constant was different at the time when the light was absorbed or in the particular region of the universe where it happened, then the energy required to lift the electron would differ from that required today in laboratory experiments, and the wavelengths of the transitions seen in the spectra would differ. The way in which the wavelengths change depends critically on the orbital configuration of the electrons. For a given change in α, some wavelengths shrink, whereas others increase. The complex pattern of effects is hard to mimic by data calibration errors, which makes the test astonishingly powerful.

Before we began our work seven years ago, attempts to perform the measurement had suffered from two limitations. First, laboratory researchers had not measured the wavelengths of many of the relevant spectral lines with sufficient precision. Ironically, scientists used to know more about the spectra of quasars billions of light-years away than about the spectra of samples here on Earth. We needed high-precision laboratory measurements against which to compare the quasar spectra, so we persuaded experimenters to undertake them. Initial measurements were done by Anne Thorne and Juliet Pickering of Imperial College London, followed by groups led by Sveneric Johansson of

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Lund Observatory in Sweden and Ulf Griesmann and Rainer Kling of the National Institute of Standards and Technology in Maryland.

The second problem was that previous observers had used so-called alkali-doublet absorption lines—pairs of absorption lines arising from the same gas, such as carbon or silicon. They compared the spacing between these lines in quasar spectra with laboratory measurements. This method, however, failed to take advantage of one particular phenomenon: a change in α shifts not just the spacing of atomic energy levels relative to the lowest-energy level, or ground state, but also the position of the ground state itself. In fact, this second effect is even stronger than the first. Consequently, the highest precision observers achieved was only about one part in 10^4.

In 1999 one of us (Webb) and Victor V. Flambaum of the University of New South Wales in Australia came up with a method to take both effects into account. The result was a breakthrough: it meant 10 times higher sensitivity. Moreover, the method allows different species (for instance, magnesium and iron) to be compared, which allows additional cross-checks. Putting this idea into practice took complicated numerical calculations to establish exactly how the observed wavelengths depend on α in all different atom types. Combined with modern telescopes and detectors, the new approach, known as the many-multiplet method, has enabled us to test the constancy of α with unprecedented precision.

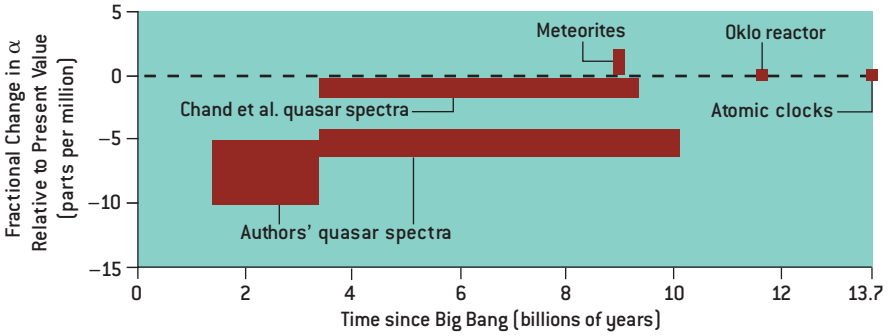
Changing Minds

WHEN EMBARKING ON this project, we anticipated establishing that the value of the fine-structure constant long ago was the same as it is today; our contribution would simply be higher precision. To our surprise, the first results, in 1999, showed small but statistically significant differences. Further data confirmed this finding. Based on a total of 128 quasar absorption lines, we found an average increase in α of close to six parts in a million over the past six billion to 12 billion years.

Extraordinary claims require extraordinary evidence, so our immediate thoughts turned to potential problems with the data or the analysis methods. These uncertainties can be classified into two types: systematic and random. Random uncertainties are easier to understand; they are just that—random. They differ for each individual measurement but average out to be close to zero over a large sample. Systematic uncertainties, which do not average out, are harder to deal with. They are endemic in astronomy. Laboratory experimenters can alter their instrumental setup to minimize them, but astronomers cannot change the universe, and so they are forced to accept that all their methods of gathering data have an irremovable bias. For example, any survey of galaxies will tend to be overrepresented by bright galaxies because they are easier to see. Identifying and neutralizing these biases is a constant challenge.

The first one we looked for was a distortion of the wavelength scale against which the quasar spectral lines were measured. Such a distortion might conceivably be introduced, for example, during the processing of the quasar data from their raw form at the telescope into a calibrated spectrum. Although a simple linear stretching or compression of the wavelength scale could not precisely mimic a change in α, even an imprecise mimicry might be enough to explain our results. To test for problems of this kind, we substituted calibration data for the quasar data and analyzed them, pretending they were quasar data. This experiment ruled out simple distortion errors with high confidence.

For more than two years, we put up one potential bias after another, only to rule it out after detailed investigation as too small an effect. So far we have identified just one potentially serious source of bias. It concerns the absorption lines produced by the element magnesium. Each of the three stable isotopes of magnesium absorbs light of a different wavelength, but the three wavelengths are very close to one another, and quasar spectroscopy generally sees the three lines blended as one. Based on laboratory measurements of the relative abundances of the three isotopes, researchers infer



MEASUREMENTS of the fine-structure constant are inconclusive. Some indicate that the constant used to be smaller, and some do not. Perhaps the constant varied earlier in cosmic history and no longer does so. (The boxes represent a range of data.)

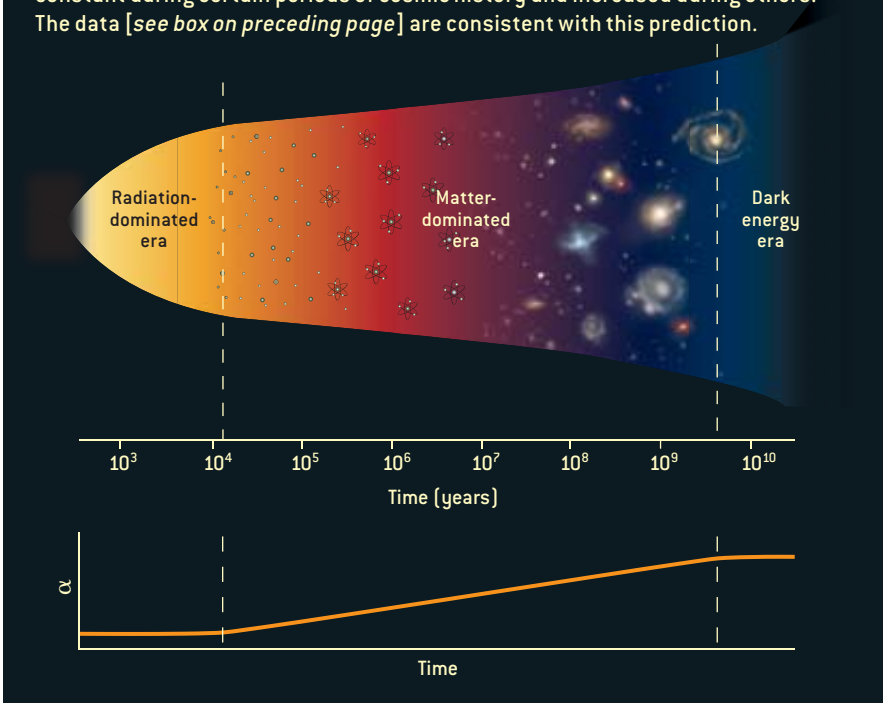
ALISON KENDALL; SOURCE: JOHN K. WEBB

THE AUTHORS

JOHN D. BARROW and *JOHN K. WEBB* began to work together to probe the constants of nature in 1996, when Webb spent a sabbatical with Barrow at the University of Sussex in England. Barrow had been exploring new theoretical possibilities for varying constants, and Webb was immersed in quasar observations. Their project soon drew in other physicists and astronomers, notably Victor V. Flambaum of the University of New South Wales in Australia, Michael T. Murphy of the University of Cambridge and João Magueijo of Imperial College London. Barrow is now a professor at Cambridge and a Fellow of the Royal Society, and Webb is a professor at New South Wales. Both are known for their efforts to explain science to the public. Barrow has written 17 nontechnical books; his play, *Infinities,* has been staged in Italy; and he has spoken in venues as diverse as the Venice Film Festival, 10 Downing Street and the Vatican. Webb regularly lectures internationally and has worked on more than a dozen TV and radio programs.

SOMETIMES IT CHANGES, SOMETIMES NOT

According to the authors' theory, the fine-structure constant should have stayed constant during certain periods of cosmic history and increased during others. The data [*see box on preceding page*] are consistent with this prediction.



the contribution of each. If these abundances in the young universe differed substantially—as might have happened if the stars that spilled magnesium into their galaxies were, on average, heavier than their counterparts today—those differences could simulate a change in α.

But a study published this year indicates that the results cannot be so easily explained away. Yeshe Fenner and Brad K. Gibson of Swinburne University of Technology in Australia and Michael T. Murphy of the University of Cambridge found that matching the isotopic abundances to emulate a variation in α also results in the overproduction of nitrogen in the early universe—in direct conflict with observations. If so, we must confront the likelihood that α really has been changing.

The scientific community quickly realized the immense potential significance of our results. Quasar spectroscopists around the world were hot on the trail and rapidly produced their own measurements. In 2003 teams led by Sergei Levshakov of the Ioffe Physico-Technical Institute in St. Petersburg, Russia, and Ralf Quast of the University of Hamburg in Germany investigated three new quasar systems. Last year Hum Chand and Raghunathan Srianand of the Inter-University Center for Astronomy and Astrophysics in India, Patrick Petitjean of the Institute of Astrophysics and Bastien Aracil of LERMA in Paris analyzed 23 more. None of these groups saw a change in α. Chand argued that any change must be less than one part in 10^6 over the past six billion to 10 billion years.

How could a fairly similar analysis, just using different data, produce such a radical discrepancy? As yet the answer is unknown. The data from these groups are of excellent quality, but their samples are substantially smaller than ours and do not go as far back in time. The Chand analysis did not fully assess all the experimental and systematic errors—and, being based on a simplified version of the many-multiplet method, might have introduced new ones of its own.

One prominent astrophysicist, John Bahcall of Princeton, has criticized the many-multiplet method itself, but the problems he has identified fall into the category of random uncertainties, which should wash out in a large sample. He and his colleagues, as well as a team led by Jeffrey Newman of Lawrence Berkeley National Laboratory, have looked at emission lines rather than absorption lines. So far this approach is much less precise, but in the future it may yield useful constraints.

Reforming the Laws

IF OUR FINDINGS prove to be right, the consequences are enormous, though only partially explored. Until quite recently, all attempts to evaluate what happens to the universe if the fine-structure constant changes were unsatisfactory. They amounted to nothing more than assuming that α became a variable in the same formulas that had been derived assuming it is a constant. This is a dubious practice. If α varies, then its effects must conserve energy and momentum, and they must influence the gravitational field in the universe. In 1982 Jacob D. Bekenstein of the Hebrew University of Jerusalem was the first to generalize the laws of electromagnetism to handle inconstant constants rigorously. The theory elevates α from a mere number to a so-called scalar field, a dynamic ingredient of nature. His theory did not include gravity, however. Four years ago one of us (Barrow), with Håvard Sandvik and João Magueijo of Imperial College London, extended it to do so.

This theory makes appealingly simple predictions. Variations in α of a few parts per million should have a completely negligible effect on the expansion of the universe. That is because electromagnetism is much weaker than gravity on cosmic scales. But although changes in the fine-structure constant do not affect the expansion of the universe significantly, the expansion affects α. Changes to α are driven by imbalances between the electric field energy and magnetic field energy. During the first tens of thousands of years of cosmic history, radiation dominated over charged particles and kept the electric and magnetic fields in balance. As the universe expanded, radiation thinned out, and matter became the dominant constituent of the cosmos. The electric and magnetic energies became unequal,

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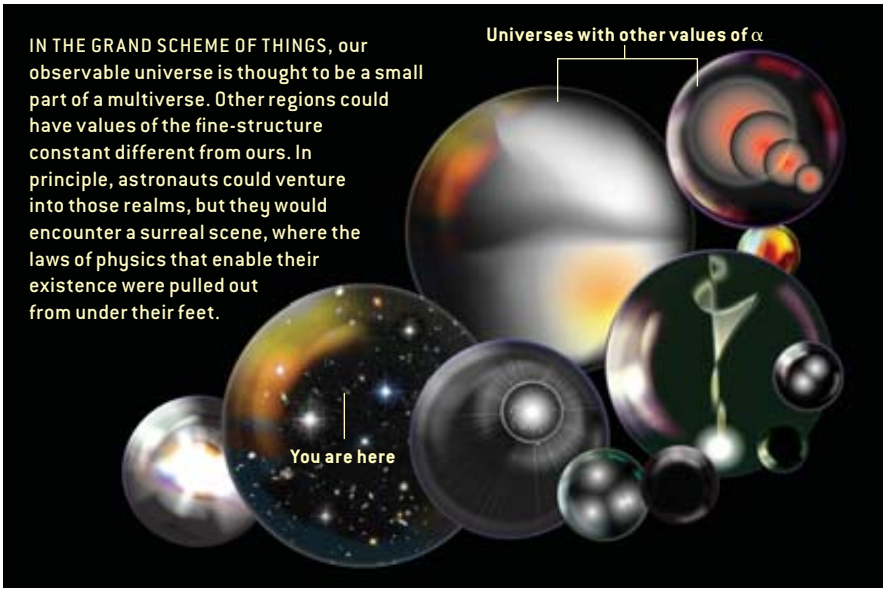
and α started to increase very slowly, growing as the logarithm of time. About six billion years ago dark energy took over and accelerated the expansion, making it difficult for all physical influences to propagate through space. So α became nearly constant again.

This predicted pattern is consistent with our observations. The quasar spectral lines represent the matter-dominated period of cosmic history, when α was increasing. The laboratory and Oklo results fall in the dark-energy-dominated period, during which α has been constant. The continued study of the effect of changing α on radioactive elements in meteorites is particularly interesting, because it probes the transition between these two periods.



Alpha Is Just the Beginning

ANY THEORY worthy of consideration does not merely reproduce observations; it must make novel predictions. The above theory suggests that varying the fine-structure constant makes objects fall differently. Galileo predicted that bodies in a vacuum fall at the same rate no matter what they are made of—an idea known as the weak equivalence principle, famously demonstrated when Apollo 15 astronaut David Scott dropped a feather and a hammer and saw them hit the lunar dirt at the same time. But if α varies, that principle no longer holds exactly. The variations generate a force on all charged particles. The more protons an atom has in its nucleus, the more strongly it will feel this force. If our quasar observations are correct, then the accelerations of different materials differ by about one part in 10^{14}—too small to see in the laboratory by a factor of about 100 but large enough to show up in planned missions such as STEP (*s*pace-based *t*est of the *e*quivalence *p*rinciple).

There is a last twist to the story. Previous studies of α neglected to include one vital consideration: the lumpiness of the universe. Like all galaxies, our Milky Way is about a million times denser than the cosmic average, so it is not expanding along with the universe. In 2003 Barrow and David F. Mota of Cambridge calculated that α may behave differently within the galaxy than inside emptier regions of space. Once a young galaxy condenses and relaxes into gravitational equilibrium, α nearly stops changing inside it but keeps on changing outside. Thus, the terrestrial experiments that probe the constancy of α suffer from a selection bias. We need to study this effect more to see how it would affect the tests of the weak equivalence principle. No spatial variations of α have yet been seen. Based on the uniformity of the cosmic microwave background radiation, Barrow recently showed that α does not vary by more than one part in 10^8 between regions separated by 10 degrees on the sky.

So where does this flurry of activity leave science as far as α is concerned? We await new data and new analyses to confirm or disprove that α varies at the level claimed. Researchers focus on α, over the other constants of nature, simply because its effects are more readily seen. If α is susceptible to change, however, other constants should vary as well, making the inner workings of nature more fickle than scientists ever suspected.

The constants are a tantalizing mystery. Every equation of physics is filled with them, and they seem so prosaic that people tend to forget how unaccountable their values are. Their origin is bound up with some of the grandest questions of modern science, from the unification of physics to the expansion of the universe. They may be the superficial shadow of a structure larger and more complex than the three-dimensional universe we witness around us. Determining whether constants are truly constant is only the first step on a path that leads to a deeper and wider appreciation of that ultimate vista. SA

MORE TO EXPLORE

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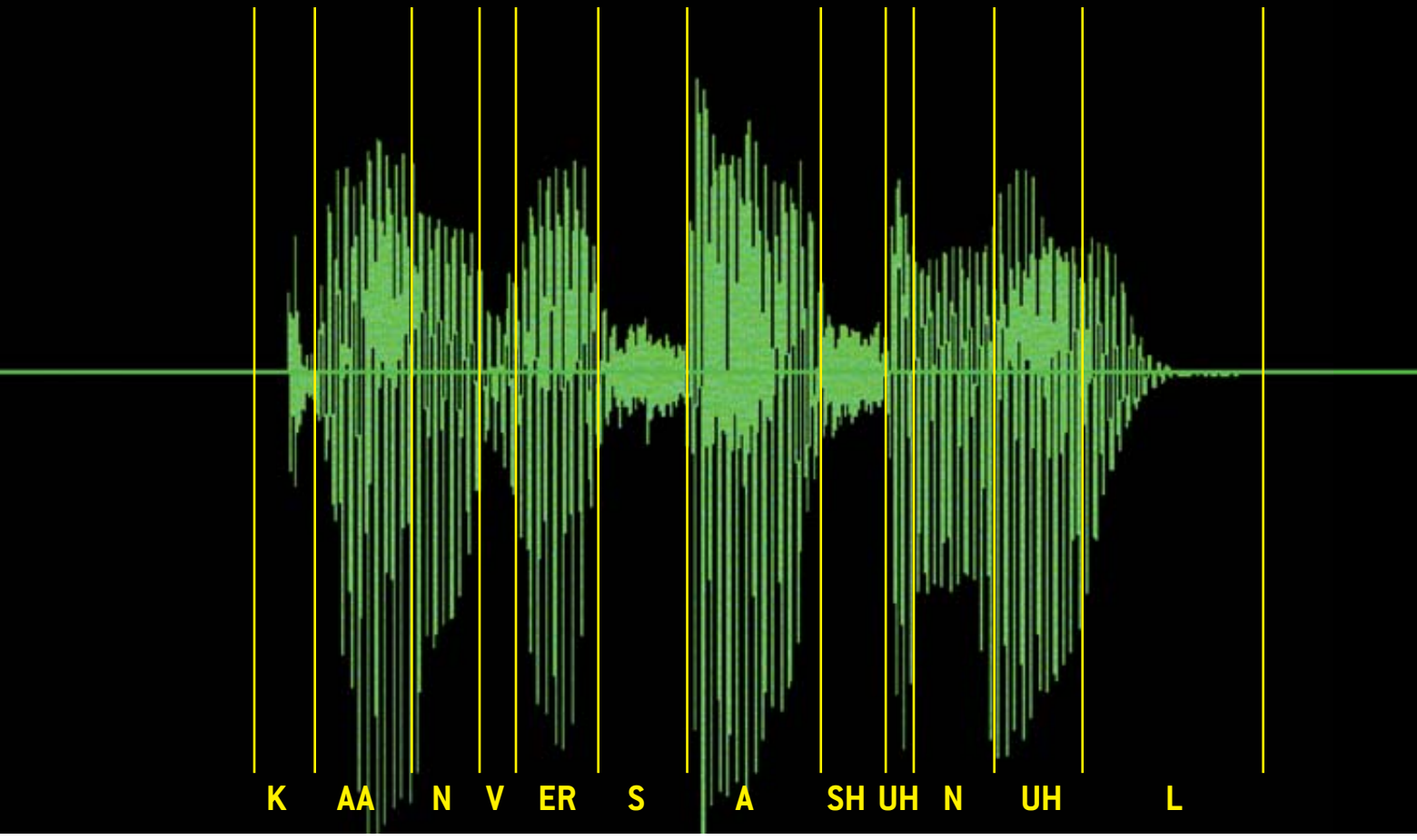
RICHARD SWORD

CONVERSATIONAL



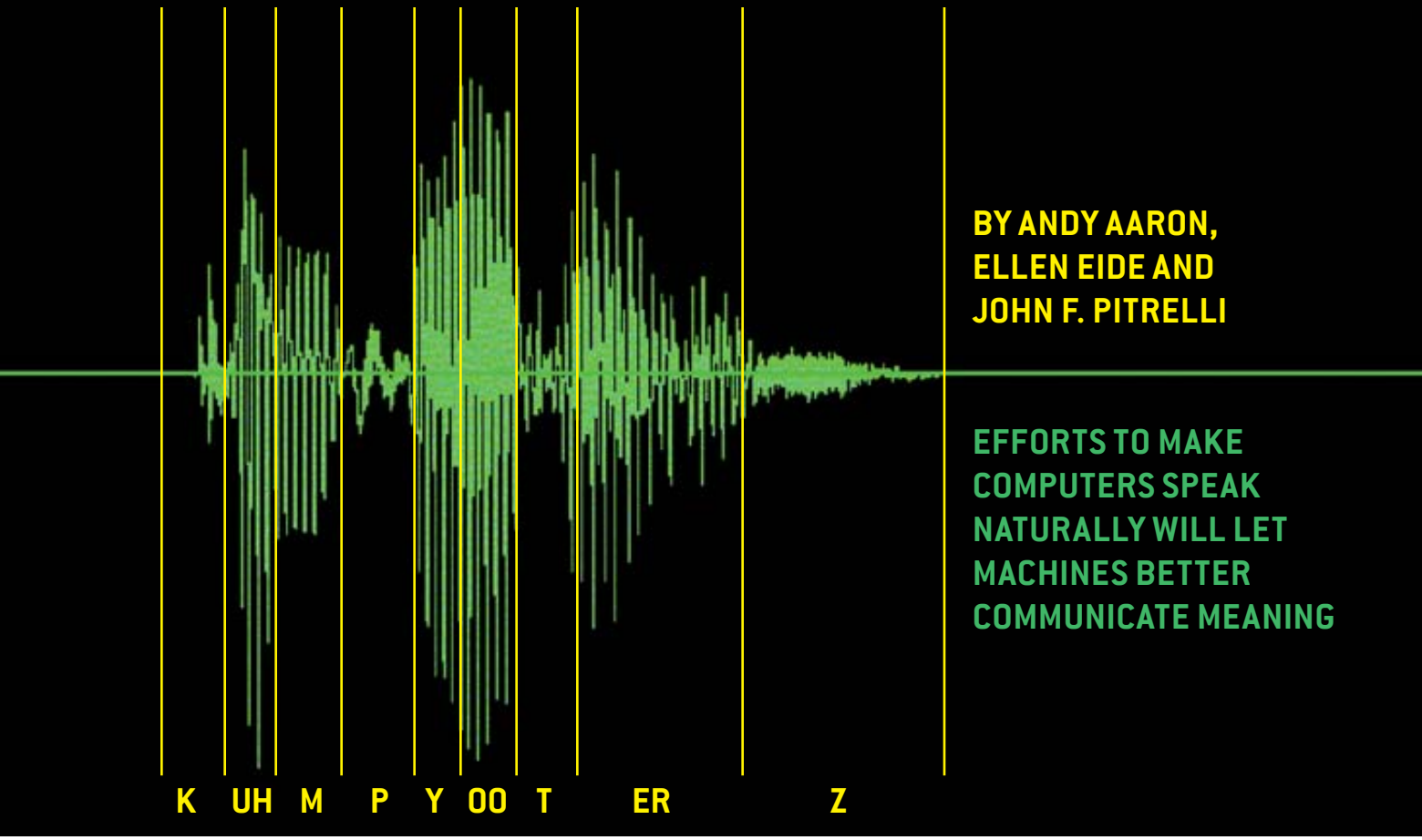
Call a large company these days, and you will probably start by having a conversation with a computer. Until recently, such automated telephone speech systems could string together only prerecorded phrases. Think of the robotic-sounding "The number you have dialed ... 5 ... 5 ... 5 ... 1 ... 2 ... 1 ... 2...." Unfortunately, this stilted computer speech leaves people cold. And because these systems cannot stray from their canned phrases, their abilities are limited.

Computer-generated speech has improved during the past decade, becoming significantly more intelligible and easier to listen to. But researchers now face a more formidable challenge: making synthesized speech closer to that of real humans—by giving it the ability to modulate tone and expression, for example—so that it can better communicate meaning. This elusive goal requires a deep understanding of the components of speech and of the subtle effects of a person's volume, pitch, timing and emphasis. That is the aim of our research group at IBM and those of other U.S. companies, such as AT&T, Nuance, Cepstral and ScanSoft, as well as investigators at institutions including Carnegie Mellon University, the University of California at Los Angeles, the Massachusetts Institute of Technology and the Oregon Graduate Institute. Like earlier phrase-splicing approaches, the latest generation of speech technology—our version is code-named the IBM Natural Expressive Speech Synthesizer, or the NAXPRES Synthesizer—is based on recordings of human speakers and can respond in real time. The difference is that the new systems can say anything at all—including natural-sounding words the recorded speakers never said.

Commercial and institutional enterprises worldwide spend billions of dollars annually on speech-enabled information service centers. The centers rely on a suite of technologies: speech recognition, language understanding, database searching, text generation and, finally, speech synthesis. Synthetic speech, produced by linking words or pieces of words recorded by human speakers, serves as the personification, or human face, of the whole system; hence, people often judge the system by the quality of the voice they hear. An expressive voice, for instance—one whose tone adjusts appropriately both when the system can accommodate your reservation request and when it can-

ANDY AARON AND JOHN F. PITRELLI

COMPUTERS



BY ANDY AARON, ELLEN EIDE AND JOHN F. PITRELLI

EFFORTS TO MAKE COMPUTERS SPEAK NATURALLY WILL LET MACHINES BETTER COMMUNICATE MEANING

not—means a more pleasant and effective experience for callers.

Consumers will soon benefit from a variety of new services made possible by this fast-evolving technology. These services will offer verbal delivery of up-to-the-minute news and weather reports that would otherwise be available only as text. The technology can also tirelessly read aloud written materials for the handicapped or foreign-language students. Other helpful capabilities are vocal human-machine interaction to control automotive functions, including recital of automated driving directions that contain the many millions of different street names in the world and retrieval of e-mail messages over the phone—or from any information system—without need for a visual display.

In time, natural-sounding synthetic speech will give meaningful voice to handheld and household devices. And at some point, the technology will be used to generate lifelike speech for characters in video and computer games and even in motion pictures.

Speaking Machines

SYNTHESIZED SPEECH is both a triumph of technology and the latest incarnation of an old dream. Attempts to simulate human speech date to the late 1700s, when Hungarian scientist Wolfgang von Kempelen built what he called a Speaking Machine, which employed an elaborate set of bellows, reeds, whistles and resonant chambers to produce rudimentary words.

By the 1970s digital computing had enabled the first generation of modern text-to-speech systems to reach fairly wide use. Makers of these systems attempted to model the entire human physiological speech production process directly, using a relatively small number of parametric features. The model typically has an audio source, which takes on the role of a person's larynx, and an audio filter, which acts as the rest of a human vocal tract. The system adjusts physical aspects of the sound (resonance, bandwidth, periodicity and fundamental frequency) continuously to create the sequence of sounds needed to compose speech.

The result was intelligible, though mechanical-sounding, speech. An early example of a mass-market product incorporating this technology was the Speak & Spell toy launched in 1978. Such synthesizers still have a place nowadays because they are simple to make

and can generate intelligible speech at tremendous speeds—up to 600 words a minute. (English is generally spoken at 140 to 190 words a minute.) Those willing to trade natural-sounding speech for speed, such as the visually impaired, find these systems useful.

The advent of faster computers and inexpensive data storage in the late 1990s made possible today's most advanced synthesizers. Researchers, including our team at IBM, base designs on linguistic building blocks called phonemes and arrange sequences of recorded phonemes to create any given word. The word "school," for example, contains four phonemes, which we might call S, K, OO and L. Languages differ in the numbers of phonemes they contain. English makes use of about 40 distinct phonemes, whereas Japanese has about 25 and German 44. Just as typesetters once sequenced letters of metal type in trays to create printed words, current synthesizers fit together chunks of speech to create spoken words. Engineers call these systems concatenative synthesizers because they link together small pieces of sound. We will explain how we build such a system and then describe how the synthesizer produces lifelike speech in real time [*see box on opposite page*].

Build Me a Voice

CONCATENATIVE SPEECH synthesis starts with a human voice, so when our group develops a new system, we audition dozens of candidate speakers. Unless a foreign inflection is required, as for, say, a character in a movie or on a Web site, our preference is usually for speakers free of regional accents; they use the general American English dialect of many television news anchors. A selected speaker then sits in a recording booth and reads aloud more than 10,000 sentences, a task that takes about two weeks. We pick the sentences in part for their relevance to real-world applications and in part for their diverse phoneme content, which ensures that we capture many examples of all the English phonemes in different contexts.

The result is about 15 hours of recorded speech. Ensuring the consistency of the entire 15 hours is no small task, however. Because the recordings are destined to be chopped up and reassembled as needed, a speech sound recorded one day may wind up next to another archived a week later. Thus, a director or voice coach guides speakers and listens for deviations in their speaking rate, emotional tone, overall pitch and loudness, helping them maintain uniformity. At least once an hour the speakers hear a sample sentence recorded on the first day for reference, much as a musician uses a pitch pipe to stay in tune.

The software then converts the words from the text that was spoken into a series of phonemes using a pronunciation dictionary, a reference that lists the phonemes that make up each word. It notes specific features of each phoneme occurrence, such as what phonemes preceded and followed it and whether it begins or ends a word or a sentence. The system also identifies the part of speech of each word in the text.

Once the text has been processed, our software analyzes the audio recordings, measuring them for three characteristics: pitch, timing and loudness—collectively called prosody. Knowing these features for each phoneme recording helps us decide which example to use to synthesize a given phrase.

Next, using techniques borrowed from speech recognition—dictation programs that translate speech into text—the computer code associates each recorded phoneme with its text counterpart. With the audio and the text aligned, our software can analyze each recording and pinpoint the boundaries at which each phoneme begins and ends. This procedure is key, because once the phonemes are located and labeled, the software can then precisely catalogue them for use in a searchable database.

The database for our NAXPRES Synthesizer contains an average of 10,000 recorded samples of each of the 40 or so phonemes in the English language. That might at first appear to be taking redundancy to absurd levels. But when words are combined into sentences, the relative loudness and pitch of each sound change, based on the speaker's mood, what he or she wants to emphasize, and the type of sentence (think about the difference between a question and an exclamation). So the phoneme samples derived from these sentences can vary significantly: some were spoken with different prosodies, others were employed in differing phonemic contexts, and so forth.

Because human speech is so amazingly subtle and complex, experts understand only a few of the many effects that contribute to natural-sounding speech. Hence, we need computers to help do the job. We use our speakers' database to build a statistical model to infer automatically the general properties that govern the rise and fall of pitch, as well as the duration and loudness of each person's speech. The model will apply the properties later to make the system's speech sound more humanlike.

Talk to Me

NOW THAT WE HAVE described the elements of a modern speech synthesizer, let us take a closer look at one in action. IBM's speech synthesizer does all the following processing in milliseconds—fast enough that people can con-

Overview/*Making Machines Speak*

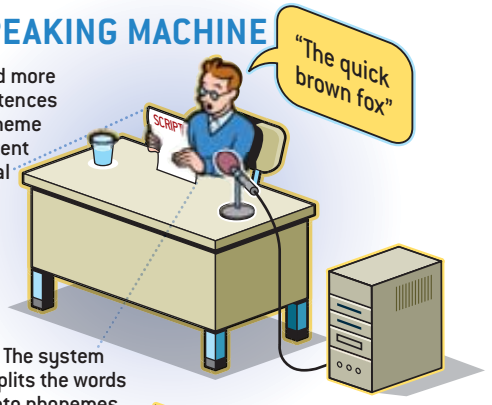
- As computer-generated voice transactions become increasingly common in everyday life, researchers are coming ever closer to synthesizing human-sounding speech.
- Drawing on huge databases of recorded word fragments (phonemes), new speaking machines can modulate tone and expression to better communicate meaning to users.
- These systems are finding applications in mobile electronic devices such as automotive navigation systems. At some point, video and computer games and even films will take advantage of lifelike artificial speech capabilities.

HOW RESEARCHERS GIVE VOICE TO COMPUTERS

The process by which speech-synthesis researchers and engineers make it possible for a computer to speak in a humanlike fashion is a complex one, involving recording a person's voice and then rearranging the component sounds—known as phonemes—to produce words and sentences they never said.

BUILDING A SPEAKING MACHINE

1 Sound engineers record more than 10,000 sample sentences selected for diverse phoneme (component sound) content and relevance to practical applications

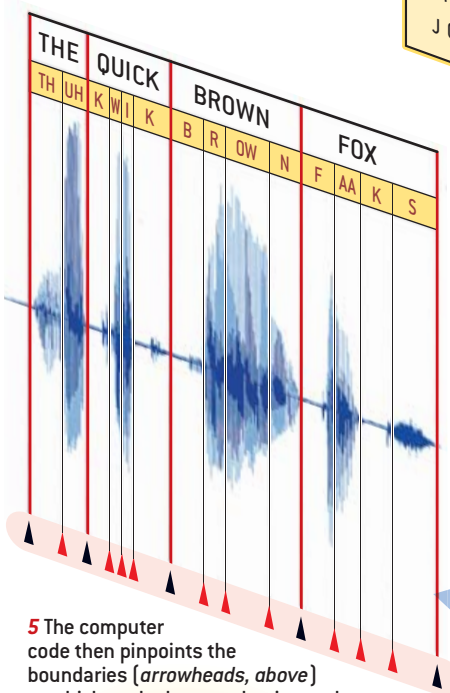


- The quick brown fox
- Thank you for calling
- The Dow Jones rose four . . .

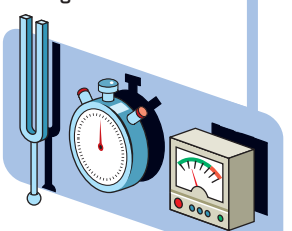
2 The system splits the words into phonemes

PHONETIC DICTIONARY

- TH UH K W I K B R OW N F AA K S
- TH A NG K Y OO F AW R K AU L I NG
- TH UH D OW J O N Z R O Z . . .

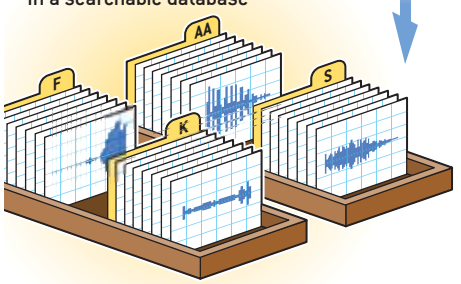


3 Software analyzes the recordings, measuring their pitch, timing and loudness



4 Speech-recognition software correlates each recorded phoneme with its text counterpart

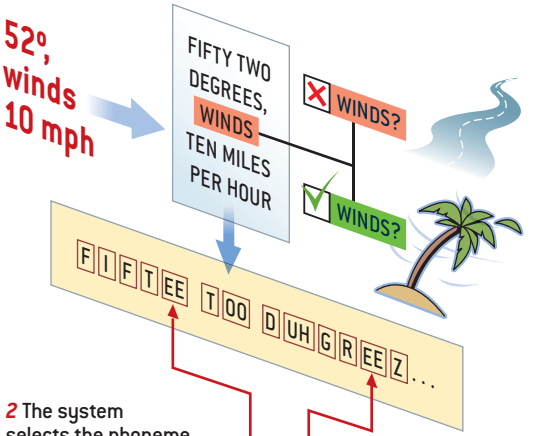
5 The computer code then pinpoints the boundaries (*arrowheads, above*) at which each phoneme begins and ends and catalogues them for use in a searchable database



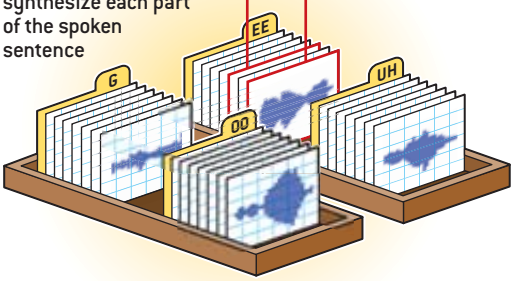
6 Using the speaker's database, researchers build a statistical model to infer automatically the general properties that govern the rise and fall of pitch, as well as the duration and loudness of each person's speech. The model will apply the properties later to make the system's speech sound nearly human

RUNNING A SPEAKING MACHINE

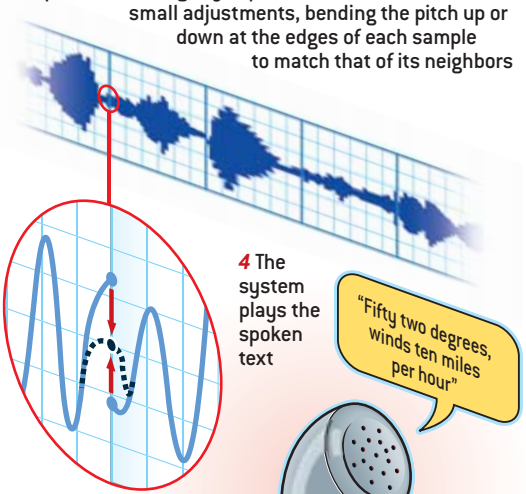
1 Given text to be converted into speech, the system translates any symbols or abbreviations into words and then analyzes the sentences' grammar as well as any pronunciation ambiguities to produce a string of suitable phonemes



2 The system selects the phoneme examples with the most appropriate pitch, timing and loudness features to best synthesize each part of the spoken sentence



3 With the best phonemes assembled in a row, the system smoothes out discontinuities that result from splicing sounds together. For example, when adjacent samples deviate slightly in pitch, the software makes small adjustments, bending the pitch up or down at the edges of each sample to match that of its neighbors



4 The system plays the spoken text

"Fifty two degrees, winds ten miles per hour"

SAMUEL VELASCO

INDUSTRIAL TEXT-TO-SPEECH RESEARCH

COMPANY	PRODUCT NAME	WEB SITE
Acapela Group BELGIUM	Acapela TTS	www.brightspeech.com
Advanced Telecommunications Research (ATR) JAPAN	*No name*	www.slt.atr.jp/ss-e
AT&T U.S.	Natural Voices	www.naturalvoices.att.com
Cepstral U.S.	Cepstral Voices	www.cepstral.com
Fonix U.S.	DECtalk	www.fonix.com/page.cfm?name=espeech_dectalk
IBM U.S.	NAXPRES Synthesizer	www.research.ibm.com/tts
iFLYTEK CHINA	InterPhonic	www.iflytek.com/english/products.htm
Infotalk HONG KONG	InfoTalk-Speaker	www.infotalkcorp.com
Loquendo ITALY	Loquendo TTS	www.loquendo.com
Nuance U.S.	Vocalizer	www.nuance.com
Scansoft U.S.	RealSpeak	www.scansoft.com
SVOX SWITZERLAND	SVOX-TTS	www.svox.com
Toshiba JAPAN	*No name*	www.toshiba.co.jp/rdc/mmlab/tech/w21e.htm

verse with the computer in real time. First we will give it something to say in text form, such as "Permits cost $80/yr." The system converts these written symbols into phonemes. Of course, this process is more difficult than it initially appears. The sentence contains punctuation and abbreviations that need to be pronounced, so the first step is to translate the text into the corresponding series of words for the synthesizer to say. The NAXPRES Synthesizer employs a set of rules to clear up ambiguities such as multiple ways of interpreting abbreviations. "St. Charles St.," for example, contains two identical abbreviations, which the system must correctly read as "Saint Charles Street."

With the sequence of words established, the system needs to figure out how it should say them. For some words, pronunciation depends on the part of speech. For instance, the word "permits" is spoken *per*mits when it is used as a noun and per*mits* when it is a verb. So we use a grammar parser to determine the part of speech of each word:

> permits (noun) cost (verb) eighty (adjective) dollars (noun) per (preposition) year (noun)

At this stage, our synthesizer is ready to convert the words into phonemes. Synthesizers have to handle all the idiosyncratic pronunciations of English, such as silent letters (*k* in "knife," *t* in "often"), proper names ("Reagan" does not start like "real") and words like "permits" that can be pronounced in multiple ways. It is a rare sentence that does not contain some verbal anomalies.

Our system applies rules to convert letters to phonemes, making use of the part-of-speech information when necessary. To get an idea of just how tricky this task can be, think about all the ways that "ough" can be turned into phonemes. Think of "bough" (OW), "cough" (AW F), "dough" (OH), "rough" (UH F) and "through" (OO).

After the software converts the words in the sample sentence into phonemes, it looks like this:

> P ER M I T S / K AW ST /
> AY T EE / D AA L ER Z /
> P ER / Y EE R

Selecting Sounds

DETERMINING WHICH phoneme example should be selected to synthesize each part of the sentence is challenging. Each sound in a sequence varies slightly, depending on the sounds that precede and follow it, a phenomenon called coarticulation. [*For more on coarticulation, see box on opposite page.*] The "permits" example contains 23 individual phonemes. Because each has about 10,000 original samples to choose from, we have a staggering $10{,}000^{23}$ (that is, 10^{92}) possible combinations—too many even to consider. The system therefore exploits a technique called dynamic programming to search the database efficiently and determine the best fit.

Once the synthesizer has assembled the best phoneme recordings in a row, all that remains is smoothing out the discontinuities that result from splicing sounds together. When adjacent samples deviate slightly in pitch, the sentence ends up with a jumpy, warbling sound. The system fixes this kind of problem by making small pitch adjustments to correct the mismatch, bending the pitch up or down at the edges of each sample to fit that of its neighbors, just as a carpenter sands glued joints to create a smooth surface transition.

Up for Discussion

ALTHOUGH WE ARE PLEASED with our progress on our synthesizer, we always keep an eye on how we can make improvements. Our team often debates

THE AUTHORS

ANDY AARON, ELLEN EIDE and *JOHN F. PITRELLI* work on speech synthesis technology at the IBM Thomas J. Watson Research Center. Aaron studied physics at Bard College and subsequently developed sound for motion pictures at Zoetrope Studios, Lucasfilm's Skywalker Sound and elsewhere. Eide received her doctorate in electrical engineering and computer science from the Massachusetts Institute of Technology. Her research interests include statistical modeling, speech recognition and speech synthesis. Pitrelli also obtained his doctoral degree in electrical engineering and computer science from M.I.T. Speech synthesis, prosody, handwriting and speech recognition count among his research focuses. Collectively they have published more than 40 papers and hold 19 patents.

what some call the holy grail of text-to-speech technology: Should machine speech be indistinguishable from a human speaker, as in the well-known Turing test for artificial intelligence? Our conclusion: probably not. For one, people are not likely to feel comfortable with the notion that they might be being "tricked" when they dial in to a company's service center. In addition, natural human speech is not the best choice for some situations, such as warning signals for drivers or voices in toys, cartoons, and video and computer games. A better goal for the technology might be a pleasing, expressive voice to which people feel comfortable listening.

Or perhaps the ultimate aim should be a system sufficiently sophisticated to exploit humans' social and communication skills. Consider this example:

> *Caller:* I'd like a flight to Tokyo on Tuesday morning.
> *Computer:* I have two flights available on Tuesday *evening*.

The software's ability to emphasize the word "evening" to contrast it with "morning" would simplify the exchange enormously. The caller then understands that no flights are available in the morning and that the computer is offering an alternative. A completely unexpressive system could cause the caller to assume that the computer had misunderstood the inquiry, requiring it to be repeated. By the same token, if the response were, "I'm sorry, there are no flights available on Tuesday," engineers would want the voice to sound somewhat apologetic about the lack of flights or at least not as cheerful as the system's standard opening line, "How may I help you?"

Our team at IBM has recently developed new prototype systems that can deliver speech incorporating several such expressions. Beyond the basic, neutral expression, the technology can synthesize a sentence to sound cheerful, questioning or apologetic. The developing technologies can also emphasize individual words for effect.

Even though our speech synthesizer and its counterparts already sound astonishingly close to live human speech, truly expressive vocalization is the next big challenge facing this class of technology. After all, the software does not really comprehend what it is saying, so it may lack the nuanced changes in speaking style that one would expect from, say, an eighth grader, who can interpret what he or she is reading. Given the limitless range of the human voice, synthetic speech researchers certainly have their work cut out for them. SA

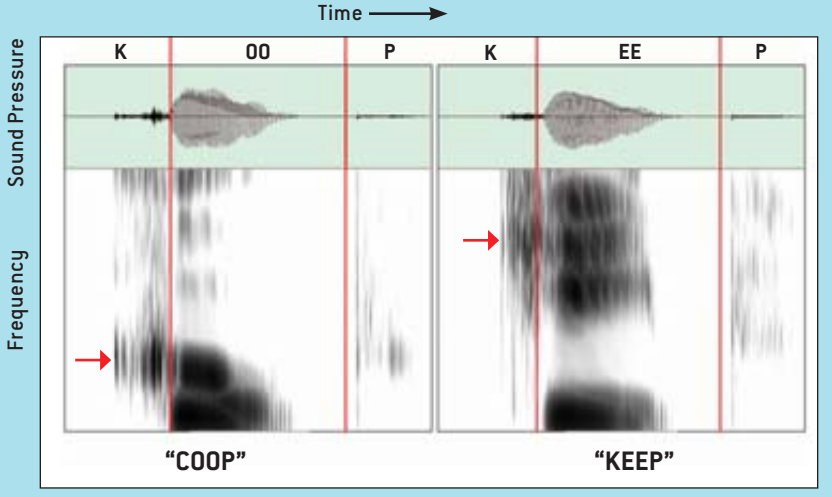
Variations in Phoneme Pronunciation

Machines cannot produce natural-sounding speech unless they become better at sequencing and mixing sounds together the way people do. This coarticulation occurs as the tongue and mouth begin getting into position to make the next sound before the first has ended. As a person pronounces the K sound in "keep," for example, the tongue is already moving forward, anticipating the EE, whereas in "coop" the tongue moves backward, anticipating the OO.

Coarticulation complicates matters for speech synthesizers. English speakers, for instance, hear K, P and T as three distinct sounds. But the K sound in "coop" and the K in "keep" are actually very different from each other; in fact, they are as dissimilar as either of them is from P or T. To hear the differences in the K's, ask someone to start to say "keep" or "coop" but say only the K sound; you will be able to tell which word was begun. People simply learn to hear the K's as equals and the P and T as different. In speech synthesis, engineers have to keep these distinctions straight—each K must be put in the proper place, because the wrong K will not sound right.

Context is not all that can affect phonemes. How phonemes are arranged in syllables and words matters, too. A classic example is "gray train" versus "great rain." Both have the same phonemic sequence, G R AY T R AY N, but we can easily hear the difference between the two. The T in "gray train" has a loud burst of the tongue off the front of the palate, as is typical for a T at the beginning of a word. But the T in "great rain," being at the end of a word, may be produced with no burst at all.

—A.A., E.E. and J.F.P.



AUDIOGRAMS show how a "K" sound (*red arrows*) can vary subtly because the mouth moves differently in anticipation of enunciating the following sound.

MORE TO EXPLORE

IBM text-to-speech research (includes a demonstration system): **www.research.ibm.com/tts**

Guidelines for evaluating text-to-speech systems: **www.speechtechmag.com/issues/6_3/cover/88-1.html**

History of text-to-speech systems: **www.cs.indiana.edu/rhythmsp/ASA/Contents.html**
Audio recordings appendix is at **www.cslu.ogi.edu/tts/research/history/**

Technical details on current speech synthesis systems: **http://tcts.fpms.ac.be/synthesis/introtts.html**

TTS Update. TMA Associates Web site: **www.ttsupdate.com/**

ANDY AARON AND RAIMO BAKIS

Obesity: An *Overblown* Epidemic?

A growing number of dissenting researchers accuse government and medical authorities—as well as the media—of misleading the public about the health consequences of rising body weights

By W. Wayt Gibbs

Could it be that excess fat is not, by itself, a serious health risk for the vast majority of people who are overweight or obese—categories that in the U.S. include about six of every 10 adults? Is it possible that urging the overweight or mildly obese to cut calories and lose weight may actually do more harm than good?

Such notions defy conventional wisdom that excess adiposity kills more than 300,000 Americans a year and that the gradual fattening of nations since the 1980s presages coming epidemics of diabetes, cardiovascular disease, cancer and a host of other medical consequences. Indeed, just this past March the *New England Journal of Medicine* presented a "Special Report," by S. Jay Olshansky, David B. Allison and others that seemed to confirm such fears. The authors asserted that because of the obesity epidemic, "the steady rise in life expectancy during the past two centuries may soon come to an end." Articles about the special report by the *New York Times*, the *Washington Post* and many other news outlets emphasized its forecast that obesity may shave up to five years off average life spans in coming decades.

And yet an increasing number of scholars have begun accusing obesity experts, public health officials and the media of exaggerating the health effects of the epidemic of overweight and obesity. The charges appear in a recent flurry of scholarly books, including *The Obesity Myth,* by Paul F. Campos (Gotham Books, 2004); *The Obesity Epidemic: Science, Morality and Ideology,* by Michael Gard and Jan Wright (Routledge, 2005); *Obesity: The Making of an American Epidemic,* by J. Eric Oliver (Oxford University Press, August 2005); and a book on popular misconceptions about diet and weight gain by Barry Glassner (to be published in 2006 by HarperCollins).

HUGH KRETSCHMER

These critics, all academic researchers outside the medical community, do not dispute surveys that find the obese fraction of the population to have roughly doubled in the U.S. and many parts of Europe since 1980. And they acknowledge that obesity, especially in its extreme forms, does seem to be a factor in some illnesses and premature deaths.

They allege, however, that experts are blowing hot air when they warn that overweight and obesity are causing a massive, and worsening, health crisis. They scoff, for example, at the 2003 assertion by Julie L. Gerberding, director of the Centers for Disease Control and Prevention, that "if you looked at any epidemic—whether it's influenza or plague from the Middle Ages—they are not as serious as the epidemic of obesity in terms of the health impact on our country and our society." (An epidemic of influenza killed 40 million people worldwide between 1918 and 1919, including 675,000 in the U.S.)

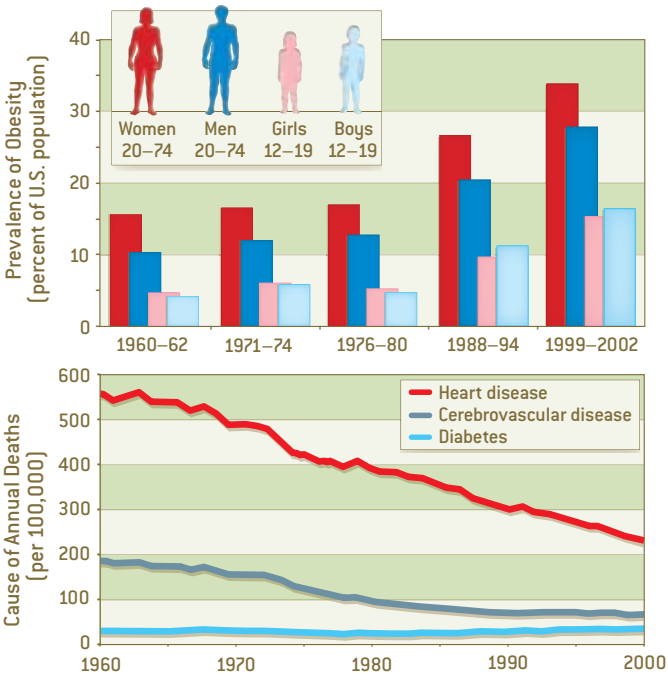
What is really going on, asserts Oliver, a political scientist at the University of Chicago, is that "a relatively small group of scientists and doctors, many directly funded by the weight-loss industry, have created an arbitrary and unscientific definition of overweight and obesity. They have inflated claims and distorted statistics on the consequences of our growing weights, and they have largely ignored the complicated health realities associated with being fat."

One of those complicated realities, concurs Campos, a professor of law at the University of Colorado at Boulder, is the widely accepted evidence that genetic differences account for 50 to 80 percent of the variation in fatness within a population. Because no safe and widely practical methods have been shown to induce long-term loss of more than about 5 percent of body weight, Campos says, "health authorities are giving people advice—maintain a body mass index in the 'healthy weight' range—that is literally impossible for many of them to follow." Body mass index, or BMI, is a weight-to-height ratio [*see box on opposite page for the definition of weight categories*].

By exaggerating the risks of fat and the feasibility of weight loss, Campos and Oliver claim, the CDC, the U.S. Department of Health and Human Services and the World Health Organization inadvertently perpetuate stigma, encourage unbalanced diets and, perhaps, even exacerbate weight gain. "The most perverse irony is that we may be creating a disease simply by labeling it as such," Campos states.

Overview/*A Crisis in Question*

- According to conventional wisdom, excess fat is an important cause of chronic disease, and the epidemic increase in obesity portends a coming health crisis.
- Four recent and forthcoming books by academic researchers argue that in fact the consequences of this trend for public health remain far less certain—and almost certainly less dire—than commonly suggested by obesity experts, government authorities and media reports.



PREVALENCE OF OBESITY has roughly doubled in the U.S. since 1980 among adults and has tripled among children (*top*). Although deaths caused by diabetes have risen somewhat, predicted increases in mortality from heart disease and stroke have not materialized (*bottom*).

LUCY READING-IKKANDA; SOURCES: *HEALTH, UNITED STATES, 2004*, U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES; *STATISTICAL ABSTRACT OF THE UNITED STATES: 2004–2005*, U.S. CENSUS BUREAU

A Body to Die For

ON FIRST HEARING, these dissenting arguments may sound like nonsense. "If you really look at the medical literature and think obesity isn't bad, I don't know what planet you are on," says James O. Hill, an obesity researcher at the University of Colorado Health Sciences Center. New dietary guidelines issued by the DHHS and the U.S. Department of Agriculture in January state confidently that "a high prevalence of overweight and obesity is of great public health concern because excess body fat leads to a higher risk for premature death, type 2 diabetes, hypertension, dyslipidemia [high cholesterol], cardiovascular disease, stroke, gall bladder disease, respiratory dysfunction, gout, osteoarthritis, and certain kinds of cancers." The clear implication is that any degree of overweight is dangerous and that a high BMI is not merely a marker of high risk but a cause.

"These supposed adverse health consequences of being 'overweight' are not only exaggerated but for the most part are simply fabricated," Campos alleges. Surprisingly, a careful look at recent epidemiological studies and clinical trials suggests that the critics, though perhaps overstating some of their accusations, may be onto something.

Oliver points to a new and unusually thorough analysis of three large, nationally representative surveys, for example, that found only a very slight—and statistically insignificant—increase in mortality among mildly obese people, as compared with those in the "healthy weight" category, after subtracting the effects of age, race, sex, smoking and alcohol consumption. The three surveys—medical measurements collected in the early 1970s, late 1970s and early 1990s, with

subjects matched against death registries nine to 19 years later—indicate that it is much more likely that U.S. adults who fall in the overweight category have a *lower* risk of premature death than do those of so-called healthy weight. The overweight segment of the "epidemic of overweight and obesity" is more likely reducing death rates than boosting them. "The majority of Americans who weigh too much are in this category," Campos notes.

Counterintuitively, "underweight, even though it occurs in only a tiny fraction of the population, is actually associated with more excess deaths than class I obesity," says Katherine M. Flegal, a senior research scientist at the CDC. Flegal led the study, which appeared in the *Journal of the American Medical Association* on April 20 after undergoing four months of scrutiny by internal reviewers at the CDC and the National Cancer Institute and additional peer review by the journal.

These new results contradict two previous estimates that were the basis of the oft-repeated claim that obesity cuts short 300,000 or more lives a year in the U.S. There are good reasons to suspect, however, that both these earlier estimates were compromised by dubious assumptions, statistical errors and outdated measurements [*see box on page 75*].

When Flegal and her co-workers analyzed just the most recent survey, which measured heights and weights from 1988 to 1994 and deaths up to 2000, even severe obesity failed to show up as a statistically significant mortality risk. It seems probable, Flegal speculates, that in recent decades improvements in medical care have reduced the mortality level associated with obesity. That would square, she observes, with both the unbroken rise in life expectancies and the uninterrupted fall in death rates attributed to heart disease and stroke throughout the entire 25-year spike in obesity in the U.S.

But what about the warning by Olshansky and Allison that the toll from obesity is yet to be paid, in the form of two to five years of life lost? "These are just back-of-the-envelope, plausible scenarios," Allison hedges, when pressed. "We never meant for them to be portrayed as precise." Although most media reports jumped on the "two to five years" quote, very few mentioned that the paper offered no statistical analysis to back it up.

The life expectancy costs of obesity that Olshansky and his colleagues actually calculated were based on a handful of convenient, but false, presuppositions. First, they assumed that every obese American adult currently has a BMI of 30, or alternatively of 35—the upper and lower limits of the "mild obesity" range. They then compared that simplified picture of the U.S. with an imagined nation in which no adult has a BMI of more than 24—the upper limit of "healthy weight"—and in which underweight causes zero excess deaths.

To project death rates resulting from obesity, the study used risk data that are more than a decade old rather than the newer ratios Flegal included, which better reflect dramatically improved treatments for cardiovascular disease and diabetes. The authors further assumed not only that the old mortality risks have remained constant but also that future advances in medicine will have no effect whatsoever on the health risks of obesity.

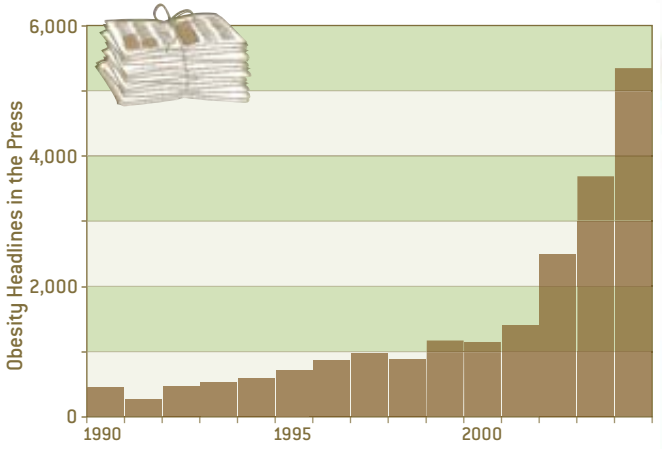
If all these simplifications are reasonable, the March paper concluded, then the estimated hit to the average life expectancy of the U.S. population from its world-leading levels of obesity is four to nine months. ("Two to five years" was simply a gloomy guess of what could happen in "coming decades" if

A Disease by Definition

U.S. federal policy and WHO guidelines assign weight categories according to body mass index, or BMI, using the following formula and table:

$$\text{BMI} = \frac{(\text{weight in kilograms})}{(\text{height in meters})^2}$$

Below 18.5	18.5 to 24.9	25 to 29.9	30 to 34.9	35 to 39.9	40 or over
Underweight	Healthy weight	Overweight	Mild (class I) obesity	Moderate (class II) obesity	Severe (class III) obesity



MEDIA STORIES on obesity are exploding in number, but Michael Gard and Jan Wright, authors of *The Obesity Epidemic: Science, Morality and Ideology,* charge the media with oversimplifying research results in ways that reinforce public prejudices and superstitions about body weight.

an increase in overweight children were to fuel additional spikes in adult obesity.) The study did not attempt to determine whether, given its many uncertainties, the number of months lost was reliably different from zero. Yet in multiple television and newspaper interviews about the study, coauthor David S. Ludwig evinced full confidence as he compared the effect of rising obesity rates to "a massive tsunami headed toward the United States."

Critics decry episodes such as this one as egregious examples of a general bias in the obesity research community. Medical researchers tend to cast the expansion of waistlines as an impending disaster "because it inflates their stature and allows them to get more research grants. Government health agencies wield it as a rationale for their budget allocations," Oliver writes. (The National Institutes of Health increased its funding for obesity research by 10 percent in 2005, to $440 million.) "Weight-loss companies and surgeons employ it to get their services covered by insurance," he continues. "And the pharmaceutical industry uses it to justify new drugs."

"The war on fat," Campos concurs, "is really about making some of us rich." He points to the financial support that many influential obesity researchers receive from the drug and diet industries. Allison, a professor at the University of Alabama at Birmingham, discloses payments from 148 such companies, and Hill says he has consulted with some of them as well. (Federal policies prohibit Flegal and other CDC scientists from accepting nongovernmental wages.) None of the dissenting authors cites evidence of anything more than a potential conflict of interest, however.

The overweight segment of the "epidemic of overweight and obesity" is more likely reducing death rates than boosting them.

Is Fat Good for the Old?

"A lot of data suggest that the effect of obesity on mortality is less strong for old people than it is for young people," says Katherine M. Flegal of the CDC. "Some studies suggest that a high BMI is not a major risk factor among the elderly. Having a nutritional reserve seems to make people more resilient if they are hospitalized. So when you make estimates of deaths from obesity, it is very important which estimates you use for the oldest group. Obesity might be a tremendous risk factor in young people, but their death rates are very low."

RONNIE KAUFMAN *Corbis*

Those Confounded Diseases

EVEN THE BEST mortality studies provide only a flawed and incomplete picture of the health consequences of the obesity epidemic, for three reasons. First, by counting all lives lost to obesity, the studies so far have ignored the fact that some diversity in human body size is normal and that every well-nourished population thus contains some obese people. The "epidemic" refers to a sudden increase in obesity, not its mere existence. A proper accounting of the epidemic's mortal cost would estimate only the number of lives cut short by whatever amount of obesity exceeds the norm.

Second, the analyses use body mass index as a convenient proxy for body fat. But BMI is not an especially reliable stand-in. And third, although everyone cares about mortality, it is not the only thing that we care about. Illness and quality of life matter a great deal, too.

All can agree that severe obesity greatly increases the risk of numerous diseases, but that form of obesity, in which BMI exceeds 40, affects only about one in 12 of the roughly 130 million American adults who set scales spinning above the "healthy" range. At issue is whether rising levels of overweight, or of mild to moderate obesity, are pulling up the national burden of heart disease, cancer and diabetes.

In the case of heart disease, the answer appears to be no—or at least not yet. U.S. health agencies do not collect annual figures on the incidence of cardiovascular disease, so researchers look instead for trends in mortality and risk factors, as measured in periodic surveys. Both have been falling.

Alongside Flegal's April paper in *JAMA* was another by Edward W. Gregg and his colleagues from the CDC that found that in the U.S. the prevalence of high blood pressure dropped by half between 1960 and 2000. High cholesterol followed the same trend—and both declined more steeply among the overweight and obese than among those of healthy weight. So although high blood pressure is still twice as common among the obese as it is among the lean, the paper notes that "obese persons now have better [cardiovascular disease] risk profiles than their leaner counterparts did 20 to 30 years ago."

The new findings reinforce those published in 2001 by a 10-year WHO study that examined 140,000 people in 38 cities on four continents. The investigators, led by Alun Evans of

Mortal Mistakes

Media coverage of the obesity epidemic surged in 1999 following a report in the *Journal of the American Medical Association* by David B. Allison and others that laid about 300,000 annual deaths in the U.S. at the doorstep of obesity. The figure quickly acquired the status of fact in both the popular press and the scientific literature, despite extensive discussion in the paper of many uncertainties and potential biases in the approach that the authors used.

Like election polls, these estimates involve huge extrapolations from relatively small numbers of actual measurements. If the measurements—in this case of height, weight and death rates—are not accurate or are not representative of the population at large, then the estimate can be far off the mark. Allison drew statistics on the riskiness of high weights from six different studies. Three were based on self-reported heights and weights, which can make the overweight category look riskier than it really is (because heavy people tend to lie about their weight). Only one of the surveys was designed to reflect the actual composition of the U.S. population. But that survey, called NHANES I, was performed in the early 1970s, when heart disease was much more lethal than it is today. NHANES I also did not account as well for participants' smoking habits as later surveys did.

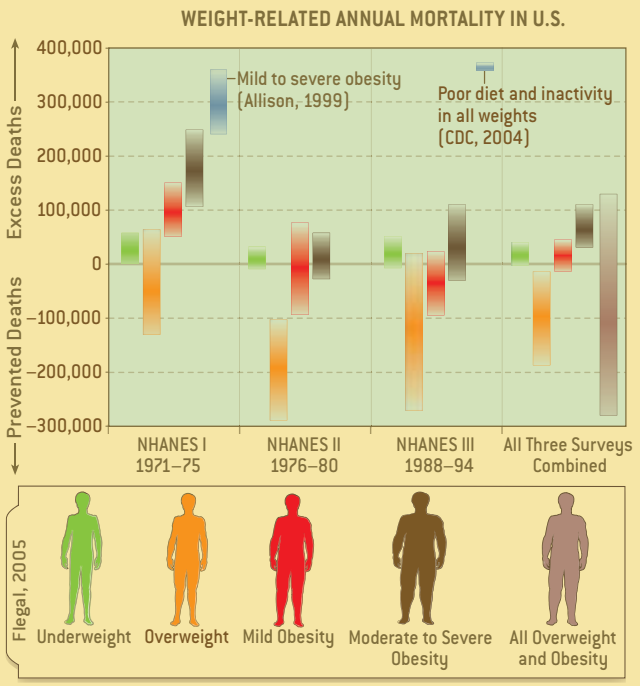
That matters because smoking has such a strong influence on mortality that any problem in subtracting its effects could distort the true mortal risks of obesity. Allison and his colleagues also used an incorrect formula to adjust for confounding variables, according to statisticians at the CDC and the National Cancer Institute.

Perhaps the most important limitation noted in the 1999 paper was its failure to allow the mortality risk associated with a high BMI to vary—in particular, to drop—as people get older [*see box on opposite page*].

Surprisingly, none of these problems was either mentioned or corrected in a March 2004 paper by CDC scientists, including the agency's director, that arrived at a higher estimate of 400,000 deaths using Allison's method, incorrect formula and all. Vocal criticism led to an internal investigation at the CDC; in January the authors published a "corrected" estimate of 365,000 obesity-related deaths a year, which they labeled as stemming from "poor diet and inactivity." The new figure corrected only data-entry mistakes, however.

Meanwhile another CDC scientist, Katherine M. Flegal, was preparing to publish a new and much improved estimate based entirely on nationally representative surveys that actually measured weights and heights. Flegal's analysis allows for risks that vary with age and claims to correct properly for confounding factors. But "the biggest reason that we get different results is that we used newer data," she asserts.

As illustrated in the chart below, the new analysis suggests that it is still far from certain whether there is any measurable mortality toll at all among overweight and obese Americans as a group. Even among the moderately and severely obese (those whose BMI exceeds 35), the plausible annual mortality found in the 1988–1994 survey ranges from 122,000 extra to 7,000 fewer deaths than one would expect based on the death rates of "healthy weight" people. —*W.W.G.*



the Queen's University of Belfast, saw broad increases in BMI and equally broad declines in high blood pressure and high cholesterol. "These facts are hard to reconcile," they wrote.

It may be, Gregg suggests, that better diagnosis and treatment of high cholesterol and blood pressure have more than compensated for any increases from rising obesity. It could also be, he adds, that obese people are getting more exercise than they used to; regular physical activity is thought to be a powerful preventative against heart disease.

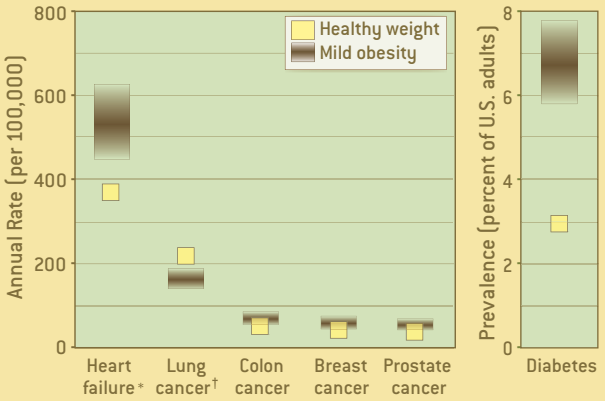
Oliver and Campos explore another possibility: that fatness is partially—or even merely—a visible marker of other factors that are more important but harder to perceive. Diet composition, physical fitness, stress levels, income, family history and the location of fat within the body are just a few of 100-odd "independent" risk factors for cardiovascular disease identified in the medical literature. The observational studies that link obesity to heart disease ignore nearly all of them and in doing so effectively assign their causal roles to obesity. "By the same criteria we are blaming obesity for heart disease," Oliver writes, "we could accuse smelly clothes, yellow teeth or bad breath for lung cancer instead of cigarettes."

As for cancer, a 2003 report on a 16-year study of 900,000 American adults found significantly increased death rates for several kinds of tumors among overweight or mildly obese

LUCY READING-IKKANDA; SOURCES: NATIONAL CENTER FOR HEALTH STATISTICS; *JAMA*, VOL. 282, PAGE 1530, OCTOBER 27, 1999, AND VOL. 291, PAGE 1238, MARCH 10, 2004

Obesity and Illness

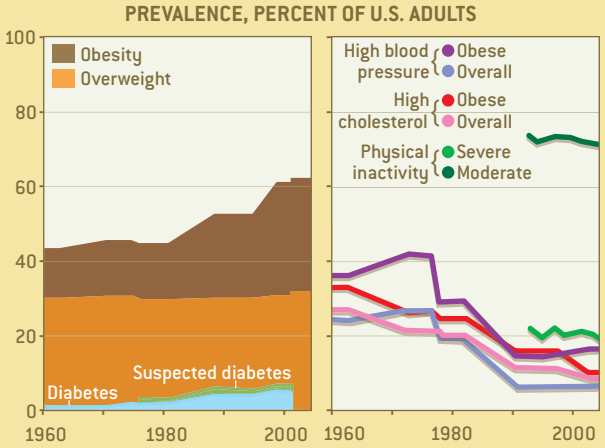
MILD AND MODERATE obesity seem in some studies to elevate risks of several serious diseases (*top chart*). Yet the trends in these diseases (*middle* and *bottom charts*) reveal no simple connection between the epidemic rise in obesity and public health in the U.S.

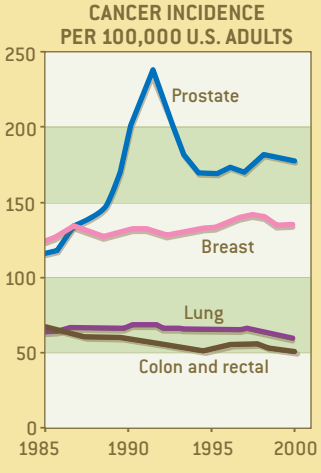


* Rate for heart failure includes all obesity (BMI >30)

† Rates for cancers represent mortality; lung and colon cancer in men only

DIABETES HAS RISEN along with obesity, but it did not spread significantly in the 1990s (*below, left*). And major contributors to heart disease have fallen in recent decades (*below, right*).





INCIDENCE OF CANCERS linked to obesity (*left*) also paints a complicated picture. New diagnoses of colon and of lung cancer have fallen slightly. (Fatness may actually protect against some lung cancer.) The upward trend in diagnosis of breast and prostate tumors may be a result mainly of increased screening for these diseases, as more sensitive and affordable tests catch tumors that previously escaped detection.

people. Most of these apparently obesity-related cancers are very rare, however, killing at most a few dozen people a year for every 100,000 study participants. Among women with a high BMI, both colon cancer and postmenopausal breast cancer risks were slightly elevated; for overweight and obese men, colon and prostate cancer presented the most common increased risks. For both women and men, though, being overweight or obese seemed to confer significant *protection* against lung cancer, which is by far the most commonly lethal malignancy. That relation held even after the effects of smoking were subtracted [*see box at left*].

Obesity's Catch-22

IT IS THROUGH type 2 diabetes that obesity seems to pose the biggest threat to public health. Doctors have found biological connections between fat, insulin, and the high blood sugar levels that define the disease. The CDC estimates that 55 percent of adult diabetics are obese, significantly more than the 31 percent prevalence of obesity in the general population. And as obesity has become more common, so, too, has diabetes, suggesting that one may cause the other.

Yet the critics dispute claims that diabetes is soaring (even among children), that obesity is the cause, and that weight loss is the solution. A 2003 analysis by the CDC found that "the prevalence of diabetes, either diagnosed or undiagnosed, and of impaired fasting glucose did not appear to increase substantially during the 1990s," despite the sharp rise in obesity.

"Undiagnosed diabetes" refers to people who have a single positive test for high blood sugar in the CDC surveys. (Two or more positive results are required for a diagnosis of diabetes.) Gregg's paper in April reiterates the oft-repeated "fact" that for every five adults diagnosed with diabetes, there are three more diabetics who are undiagnosed. "Suspected diabetes" would be a better term, however, because the single test used by the CDC may be wildly unreliable.

In 2001 a French study of 5,400 men reported that 42 percent of the men who tested positive for diabetes using the CDC method turned out to be nondiabetic when checked by a "gold standard" test 30 months later. The false negative rate—true diabetics missed by the single blood test—was just 2 percent.

But consider the growing weights of children, Hill urges. "You're getting kids at 10 to 12 years of age developing type 2 diabetes. Two generations ago you never saw a kid with it."

Anecdotal evidence often misleads, Campos responds. He notes that when CDC researchers examined 2,867 adolescents in the NHANES survey of 1988 to 1994, they identified just four that had type 2 diabetes. A more focused study in 2003 looked at 710 "grossly obese" boys and girls ages six to 18 in Italy. These kids were the heaviest of the heavy, and more than half had a family history (and thus an inherited risk) of diabetes. Yet only one of the 710 had type 2 diabetes.

Nevertheless, as many as 4 percent of U.S. adults might have diabetes because of their obesity—if fat is in fact the most important cause of the disease. "But it may be that type 2 diabetes causes fatness," Campos argues. (Weight gain is a

LUCY READING-IKKANDA; SOURCES: *INTERNATIONAL JOURNAL OF OBESITY*, VOL. 26, PAGE 1050 (*heart failure*); *NEJM*, VOL. 348, PAGES 1625–1638 (*cancer mortality*); *JAMA*, VOL. 293, PAGE 1871 (*diabetes*); *JAMA*, VOL. 288, PAGE 1724, VOL. 291, PAGE 2847, AND *HEALTH, UNITED STATES, 2004* (*obesity and overweight*); *DIABETES CARE*, VOL. 27, PAGE 2809 (*diabetes trend*); *JAMA*, VOL. 293, PAGE 1871 (*blood pressure and cholesterol*); CDC BEHAVIORAL RISK FACTOR SURVEILLANCE SYSTEM (*physical activity*); NATIONAL CANCER INSTITUTE (*cancer incidence*)

DISTORTED VIEWS of medical research largely fuel the public's anxiety about the obesity epidemic, claims Paul Campos, author of *The Obesity Myth.* He castigates health authorities for a "constant barrage of scientifically baseless propaganda" about the risks of fat.

common side effect of many diabetes drugs.) "A third factor could cause both type 2 diabetes and fatness." Or it could be some complex combination of all these, he speculates.

Large, long-term experiments are the best way to test causality, because they can alter just one variable (such as weight) while holding constant other factors that could confound the results. Obesity researchers have conducted few of these so-called randomized, controlled trials. "We don't know what happens when you turn fat people into thin people," Campos says. "That is not some oversight; there is no known way to do it"—except surgeries that carry serious risks and side effects.

"About 75 percent of American adults are trying to lose or maintain weight at any given time," reports Ali H. Mokdad, chief of the CDC's behavioral surveillance branch. A report in February by Marketdata Enterprises estimated that in 2004, 71 million Americans were actively dieting and that the nation spent about $46 billion on weight-loss products and services.

Dieting has been rampant for many years, and bariatric surgeries have soared in number from 36,700 in 2000 to roughly 140,000 in 2004, according to Marketdata. Yet when Flegal and others examined the CDC's most recent follow-up survey in search of obese senior citizens who had dropped into a lower weight category, they found that just 6 percent of nonobese, older adults had been obese a decade earlier.

Campos argues that for many people, dieting is not merely ineffective but downright counterproductive. A large study of nurses by Harvard Medical School doctors reported last year that 39 percent of the women had dropped weight only to regain it; those women later grew to be 10 pounds heavier on average than women who did not lose weight.

Weight-loss advocates point to two trials that in 2001 showed a 58 percent reduction in the incidence of type 2 diabetes among people at high risk who ate better and exercised more. Participants lost little weight: an average of 2.7 kilograms after two years in one trial, 5.6 kilograms after three years in the other.

"People often say that these trials proved that weight loss prevents diabetes. They did no such thing," comments Steven N. Blair, an obesity researcher who heads the Cooper Institute in Dallas. Because the trials had no comparison group that simply ate a balanced diet and exercised without losing weight, they cannot rule out the possibility that the small drop in subjects' weights was simply a side effect. Indeed, one of the trial groups published a follow-up study in January that concluded that "at least 2.5 hours per week of walking for exercise during follow-up seemed to decrease the risk of diabetes by 63 to 69 percent, largely independent of dietary factors and BMI."

"H. L. Mencken once said that for every complex problem there is a simple solution—and it's wrong," Blair muses. "We have got to stop shouting from the rooftops that obesity is bad for you and that fat people are evil and weak-willed and that the world would be lovely if we all lost weight. We need to take a much more comprehensive view. But I don't see much evidence that that is happening." SA

W. Wayt Gibbs is senior writer.

MORE TO EXPLORE

Physical Activity in the Prevention of Type 2 Diabetes in *Diabetes*, Vol. 54, pages 158–165; January 2005.

Excess Deaths Associated with Overweight, Underweight and Obesity. Katherine M. Flegal et al. in *Journal of the American Medical Association,* Vol. 293, pages 1861–1867; April 20, 2005.

Secular Trends in Cardiovascular Disease Risk Factors according to Body Mass Index in US Adults. Edward W. Gregg et al. in *Journal of the American Medical Association,* Vol. 293, pages 1868–1874; April 20, 2005.

MARC POKEMPNER

ANTIHYDROGEN ATOMS composed of a positron (*red*) orbiting an antiproton (*green*) drift away from their formation point and strike the surrounding material wall, where they are annihilated in a burst of energetic particles.

Low-energy atoms of antihydrogen will enable researchers to test a fundamental property of the universe

By Graham P. Collins

MAKING COLD ANTIMATTER

It is the nemesis of normal matter: antimatter.

Like evil twins of ordinary particles, antimatter versions mirror their mundane counterparts in every way, except for having the opposite charge, and they promise violent annihilation if ever the twain should meet. Indeed, the conflagration of a single gram of antimatter particles merging with their normal matter siblings would release energy equivalent to about 40 kilotons of TNT, or enough to power nearly 5,000 households for a year.

Fortunately for our safety and unfortunately for our energy policy, antimatter is rare in the natural world. Some radioactive substances emit positrons, the antiparticles to electrons, and are used in PET (positron-emission tomography) scans. A small number of antiprotons constantly sleet down from space among cosmic rays. In addition, the giant showers of particles produced when a high-energy cosmic-ray particle strikes an atom in the atmosphere contain numerous antiparticles.

But when it comes to actual chunks of material, antimatter is simply not to be found. Even lone atoms of antimatter, or antiatoms, are not known to exist in nature. Yet theory suggests that the study of antiatoms could contribute unique insights into the laws of physics. So scientists have set about trying to manufacture their own. In recent years, they have devised clever technologies and enjoyed some success.

Particle physicists have been creating beams of antiprotons since 1955. That achievement came at the Bevatron accelerator at Lawrence Berkeley National Laboratory, by smashing protons into a piece of copper. The process is the reverse of annihilation—some of the pure energy of the collisions is converted into pairs of newly minted protons and antiprotons. Today Fermi National Laboratory in Batavia, Ill., takes antiprotons circulating in huge rings and collides them head-on with a similar beam of protons to study particle physics at extremely high energies.

The first antiatoms ever to exist were made in 1995 by scientists at CERN, the European laboratory for particle physics near Geneva. They arranged for a beam of antiprotons circulating in a storage ring to cross a jet of xenon atoms. Occasionally a collision produced an electron-positron pair, with the positron and antiproton flying off together and forming an antihydrogen atom. The team observed nine such antiatoms racing along at nearly the speed of light. A similar experiment at Fermilab in 1998 produced 57 antiatoms.

But such high-velocity antiatoms are not very useful. To study the properties of antiatoms more thoroughly, scientists want to hold them in an atom trap, which means they must slow them down and cool them to less than 0.5 kelvin. Two fiercely competitive research groups working at CERN have been pursuing that goal. The ATRAP collaboration, led by Gerald Gabrielse of Harvard University, sprang out of an earlier group (TRAP) that pioneered the capturing and cooling of

BRYAN CHRISTIE DESIGN

antiprotons [see "Extremely Cold Antiprotons," by Gerald Gabrielse; Scientific American, December 1992]. ATHENA, a group led by Rolf Landua of CERN, joined the fray late in the game but in 2002 was the first (by a few weeks) to publish a research paper announcing detection of cold antihydrogen atoms. Another team, ASACUSA, is studying exotic helium atoms in which one electron is replaced by an antiproton.

Although some researchers hold out hope of one day using antimatter for propulsion [*see box on page 85*], the primary immediate goal of investigating antiparticles has to do with the study of what is called the CPT symmetry theorem, which relates the properties of a particle species with those of its antiparticle. The theory predicts that both should follow the same physical laws. Given enough trapped antiatoms, scientists hope to see if antihydrogen emits and absorbs light at exactly the same frequencies as hydrogen does. If CPT symmetry is obeyed, the two spectra should be identical.

Historically, symmetries related to CPT symmetry have a losing track record: each one has turned out to be violated by the real world. Every time that a symmetry prediction has been overturned, startled physicists have learned important new information about the properties of the fundamental particles and forces. Violation of CPT symmetry by antihydrogen would be the granddaddy of broken symmetries and would have major consequences for physicists' conceptions of reality.

To understand more precisely what CPT symmetry is and why it is so important, split it into the individual component parts that the three letters stand for: charge reversal, parity inversion and time reversal. Charge reversal is the replacement of all particles with antiparticles. Parity inversion is essentially reflection in a mirror (more exactly, it is inversion of space about a point). And time reversal means playing the "movie" of reality backward.

Saying that P symmetry is operating, or that nature is "invariant" under P symmetry, means that any physical process observed in a mirror still follows the same laws as the unreflected process. If you imagine yourself tossing a ball in the air in front of a mirror, P symmetry seems intuitively obvious. How could it not be obeyed in every process? Amazingly, as was discovered in 1956, P symmetry is broken by the weak nuclear interaction, which is involved in certain radioactive decays. Cobalt 60 decaying in reality looks different from decaying cobalt 60 viewed in a mirror. Like a person swinging a tennis racket in her *right* hand (whose reflection therefore is *left*-handed), the decay of cobalt 60 has an intrinsic handedness that is reversed by a mirror.

ATHENA APPARATUS at CERN near Geneva is one of two facilities that have been producing cold antihydrogen.

In many situations where P symmetry is broken, CP symmetry is nonetheless preserved. That is, a mirror image of an anticobalt atom behaves identically to a real cobalt atom. It is as if the antiperson is left-handed, so that her reflection is right-handed—the same as the original, unreflected person.

To physicists' amazement, in 1964 they learned that CP symmetry is also broken on rare occasions in certain processes. Despite its great rarity, broken CP symmetry might play a role in explaining the predominance of matter over antimatter in the universe [*see box on opposite page*].

That leaves CPT symmetry: the equivalent of what you would see if you watched a movie that starred antiparticles run backward in a mirror. CPT invariance means that the crazy reversed antimovie would follow exactly the same laws of physics as reality. If the behavior of the reversed antimovie differed in any way from that of reality, that difference would be a "violation" of CPT symmetry.

CPT symmetry has deep mathematical foundations. It is hardwired into the equations of quantum field theory that describe the fundamental particles and forces. For more than half a century, all of particle physics theory has been based on quantum field theory; the violation of CPT would signal its breakdown. Such a result would be a major clue to how to develop a theory of physics that goes beyond the Standard Model of particle physics.

Physicists have inferred from particle physics experiments involving unstable particles that any violation of CPT symmetry must be very small. In addition, when Gabrielse's TRAP

Overview/*The First Antiatoms*

- Antiparticles have a charge opposite to that of their corresponding particles, and if the two meet, they annihilate, releasing a large amount of energy. Recently physicists have succeeded in creating the first relatively slow-moving atoms of antimatter (antiatoms).
- In the future, these antiatoms—consisting of antihydrogen—could be used to test a fundamental property of the universe known as CPT symmetry. Even a tiny violation of CPT symmetry would be a profound discovery and would hint at new physics.
- So far, however, the antihydrogen atoms seem to have a temperature of about 2,400 kelvins—far hotter than the 0.5 K needed to trap them for studies of CPT. The next major goal is to produce antiatoms at still lower temperatures and in states suitable for spectroscopy.

group conducted experiments comparing trapped antiprotons with protons, they verified CPT symmetry for this class of particle to greater precision than anyone had previously achieved. But the search must go on, at ever finer levels of precision, for there are reasons to expect that CPT violation could happen at some smaller scale [see "The Search for Relativity Violations," by Alan Kostelecký; SCIENTIFIC AMERICAN, September 2004]. Hydrogen spectroscopy is very precise. If the same precision could be achieved with antihydrogen, a comparison of the two spectra would take physics well beyond the present CPT frontier for stable particles.

As well as violating CPT symmetry at times, antimatter might be affected by gravity differently than matter. It is not that antimatter would experience "antigravity" and be repelled by matter, as some people mistakenly think. Rather a tiny component of the force of gravity might be reversed for antimatter. Such a discovery would profoundly revise our understanding of gravity. Studies of charged antiparticles such as positrons and antiprotons are hopeless for examining the effects of gravity; perturbations caused by stray electric and magnetic fields are far too great. Conceivably, however, neutral antiatoms might be cooled to extremely low temperatures and observed freely falling, as has been done with laser-cooled regular atoms. Gravity experiments will be orders of magnitude more technically challenging than the CPT tests, however.

Anti-ingredients

TO MAKE the antihydrogen atoms needed for these experiments takes two ingredients—positrons and antiprotons, which are starkly different in their ease of manufacture. Positrons are comparatively simple to come by; numerous radioactive isotopes emit them in a process called beta decay. Antiprotons must be made out of whole cloth.

The experiments at CERN use the isotope sodium 22 as their source of positrons. A one-gram chunk of sodium 22 emits 200 trillion positrons every second. But those positrons are emitted with 550 kilo-electron volts of energy, equivalent to a temperature of six billion degrees Celsius. To be of use in making cold antihydrogen, they must be slowed down from their emission speed, nearly nine tenths the speed of light, to mere kilometers per second. The slowing is achieved by a series of different processes [*see box on next two pages*]. After about five minutes, the ATHENA group accumulates around 75 million positrons suspended by magnetic and electric fields in the high vacuum of a Penning trap (named after physicist Frans Michel Penning, who invented the design in 1936). ATRAP, in contrast, captures about five million positrons. The traps hold the positrons very securely: after an hour, an insignificant number of them are lost.

Because antiprotons are not produced by any convenient radioactive source, researchers have to create these antiparticles out of pure energy, which they do by firing protons into a metal target. This process produces, among other particles, a high-energy pulse of antiprotons. To make cold antihydrogen, the experimenters must slow down the antiprotons to a temperature similar to that of the positrons. Much the same technology that accelerates particle beams is used in reverse to perform the first stage of the deceleration process. Since 2000 this deceleration has been carried out by the Antiproton Decelerator at CERN.

Every minute and a half, the Antiproton Decelerator emits a pulse of about 20 million antiprotons. They travel at a mere one tenth the speed of light, or an energy of about five mega-electron volts. These are further slowed by a thin aluminum window and ultimately reduced to just a few electron volts of energy in a Penning trap. Successive bunches of antiprotons from the Antiproton Decelerator can be added to the trap, a process invented by TRAP called stacking. The ATHENA trap can hold its 10,000 antiprotons for many hours; ATRAP, with a better vacuum, has held half a million with no measurable losses for two months.

Nested Traps

THE TRAPPING of charged particles was pioneered decades ago, but the standard traps work only for particles that all have the same sign of electric charge (the same "polarity"). For example, a cylindrical Penning trap that holds positrons will not hold antiprotons. In this trap design, a magnetic field confines the particles radially and an electric field raises the potential at each end of the cylinder.

Matter Asymmetry in the Universe

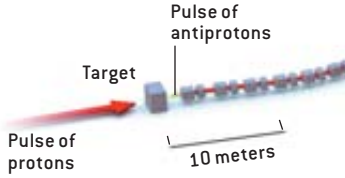
When the universe began in the big bang, the energy released should have produced equal amounts of matter and antimatter. How could such a universe evolve to what we see today, where almost everything is made of matter? The great Russian physicist Andrei Sakharov answered that question in 1967, when he showed that one of the necessary conditions for such evolution is a phenomenon called CP violation, which allows particles to decay at different rates than antiparticles.

Two experiments now under way—BaBar at the Stanford Linear Accelerator Center (SLAC) and Belle in Tsukuba, Japan—are studying CP violation in the decay of particles and antiparticles called B mesons. In August 2004 both announced direct observation of a large amount of CP violation by B mesons: a specific type of decay occurred much more often for the particles than for the antiparticles.

So far the amounts of CP violation observed mostly match the predictions of the Standard Model of particle physics. One particular reaction, however, does show a slight excess of CP violation. If confirmed, it would be a pointer to physics involving as yet undiscovered particles [see "The Dawn of Physics beyond the Standard Model," by Gordon Kane; SCIENTIFIC AMERICAN, June 2003]. The amount of violation observed so far, however, does not seem sufficient for Sakharov's model to account for the matter-antimatter asymmetry of our universe. —*G.P.C.*

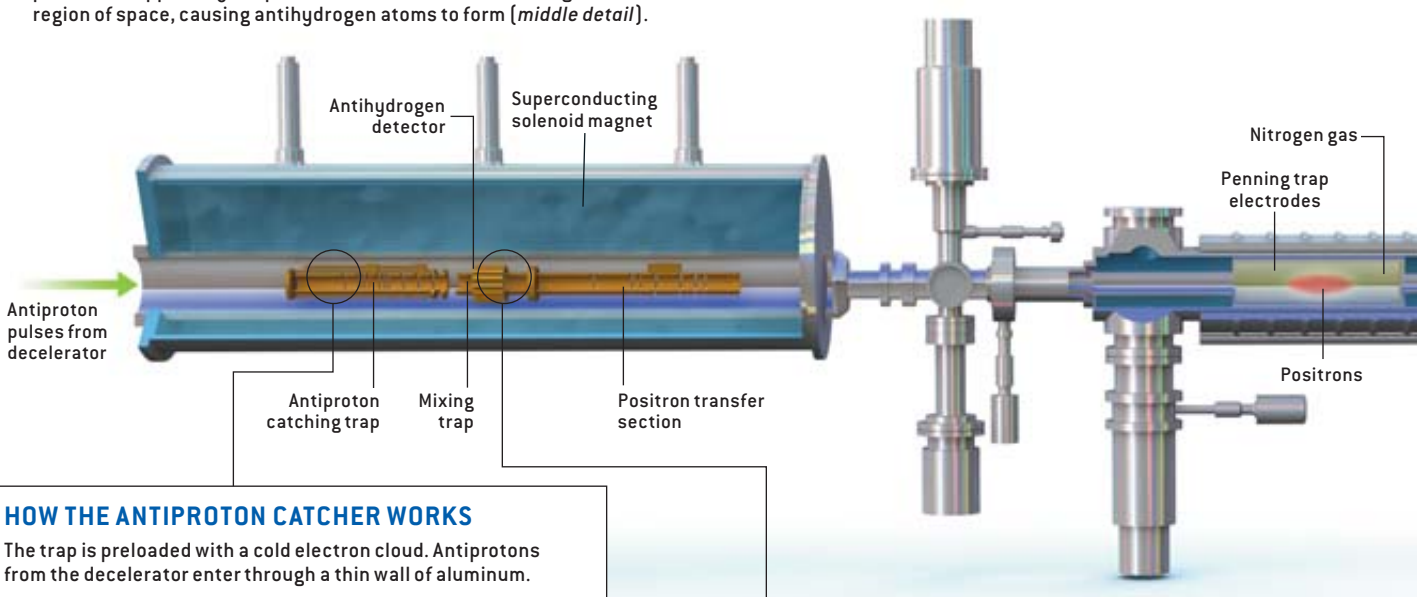
MAKING AND DETECTING COLD ANTIHYDROGEN

To make antihydrogen atoms, physicists must produce and bring together antiprotons and positrons. CERN's antiproton decelerator (*right*) supplies relatively low energy antiprotons to three experiments—ATRAP, ATHENA and ASACUSA. Magnetic and electric fields trap those antiprotons and positrons at each end of an evacuated, tubelike apparatus (*below*). The fields are then manipulated to bring the particles together in a mixing trap, where they form antihydrogen atoms, which are detected. The operating principles of the mixing trap were pioneered by the ATRAP group and its predecessor, TRAP. The diagrams below relate to the ATHENA apparatus.



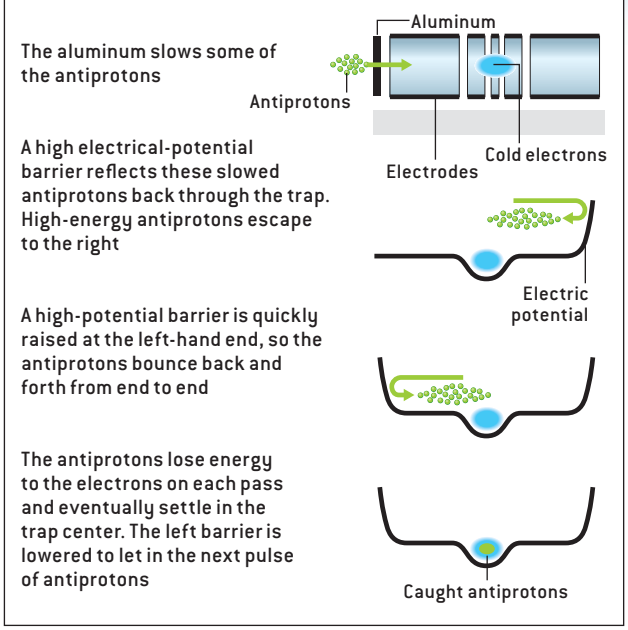
ANTIPROTON CATCHER AND MIXING TRAP

The antiproton catcher (*left*) collects pulses of antiprotons from the decelerator (*left detail*). When enough antiprotons have been accumulated, they are transferred to the mixing trap. That trap holds the antiprotons and positrons supplied by the positron accumulator shown at right in the same region of space, causing antihydrogen atoms to form (*middle detail*).



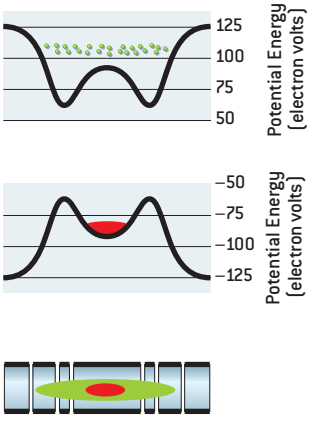
HOW THE ANTIPROTON CATCHER WORKS

The trap is preloaded with a cold electron cloud. Antiprotons from the decelerator enter through a thin wall of aluminum.

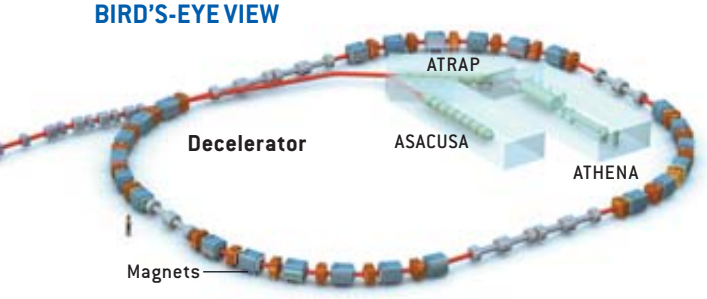


HOW THE NESTED MIXING TRAP WORKS

Positrons cannot be collected in the same potential well that gathers a cloud of antiprotons, so their trap must be nested within the antiproton trap.

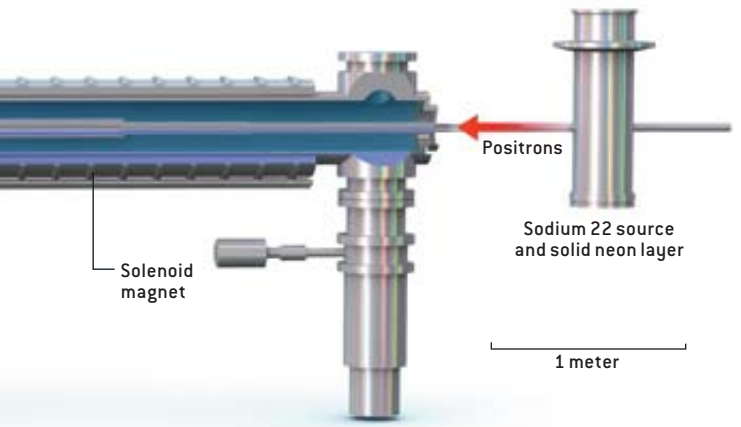


BIRD'S-EYE VIEW



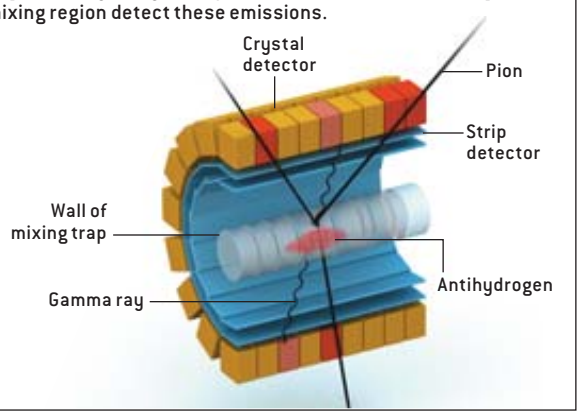
POSITRON ACCUMULATOR

Positrons emitted by a sodium 22 source (*far right*) are slowed first by passing through a thin layer of solid neon and then by collisions with nitrogen gas. A Penning trap captures the slowed positrons. When enough positrons have been accumulated, the nitrogen is pumped out and the positrons are transferred to the mixing trap.



HOW THE DETECTOR WORKS

When antihydrogen atoms form in the mixing trap, the antiatoms, being neutral, drift out of the trap and hit the walls of the container. There the antiproton and the positron are annihilated, producing three high-energy pions and a pair of gamma rays. Layers of particle detectors surrounding the mixing region detect these emissions.



BRYAN CHRISTIE DESIGN

For the positrons, one can think of the end potential as a ramp and the particle as a ball rolling up the ramp. Positrons moving slowly enough are brought to a halt and turned around on the ramp, keeping them inside the trap. Unfortunately, antiprotons, with the opposite polarity, will see not upward-sloping ramps at each end but plummeting ones over which they will pour out, ultimately colliding with the material walls that maintain the vacuum of the trap and becoming lost. To trap antiprotons, one would have to reverse the electric field, thus inverting the potential.

The trick to trapping species of opposite polarity together was suggested in 1988 by Gabrielse and his co-workers: one puts a shallow trap for particles of one polarity inside a deeper trap for particles of the opposite polarity. The species trapped by the outer walls sees a deep well with a raised mound in the center, like the bottom of a wine bottle. The other species sees all the potentials inverted, and the mound becomes a mountaintop depression that holds them. Both ATRAP and ATHENA use a trap of this nested design to hold their antiprotons and positrons together; in the region of the mound, both particles coexist. Gabrielse and his colleagues demonstrated this scheme with protons and electrons in 1996 and with antiprotons and positrons in 2001.

Collisions among the jointly trapped particles occasionally result in a positron and an antiproton moving together along the same trajectory. These promptly end up orbiting one another, and, voilà, an antihydrogen atom is born.

Detection

HAVING MADE antihydrogen atoms, investigators face two problems: First, how do you detect the atoms, to prove that they are really there? Second, you have to do this quickly because the antihydrogen atoms, being electrically neutral, are held by neither of the two nested electromagnetic traps. The atoms fly rapidly out of the trap with whatever velocity they happened to have had when they were created.

The ATHENA collaboration uses this second problem as the solution to the first. When the departing atoms encounter the material walls of the container, they come to a halt. Almost immediately the positron gets annihilated by meeting an electron from an atom in the wall, and the antiproton gets annihilated in a nucleus. The first reaction typically generates two gamma rays of characteristic energy (511 keV) traveling in opposite directions; the latter creates two or three particles called pions. All those particles are relatively easy to detect. Whenever the detectors see the appropriate gamma rays and pions originating from the same place in the wall at the same time, the researchers know an antihydrogen atom was created and has now been destroyed.

Except it is not quite that simple. Some antiproton annihilations produce a shower of positrons, which in turn produce 511-keV gamma rays, two of which may be detected. Lone antiprotons can thus mimic the antihydrogen signal. The level of false signals has to be measured and deducted from the data.

The ATRAP group uses a markedly different technique that

eliminates the background altogether. The team counts only the antihydrogen atoms that happen to travel along the axis of the cylindrical trap and happen to be weakly bound (all those traveling in other directions or in more tightly bound states escape undetected). These neutral antiatoms pass effortlessly through a high-potential barrier that blocks all stray antiprotons that are not part of an antiatom. Next the antiatoms encounter a strong electric field that strips apart the antiproton and positron of the weakly bound antiatoms. Finally, the newly naked antiprotons are captured in another electromagnetic trap. After a collection period, these antiprotons are released and detected by their annihilations on the nearby walls.

When positrons are absent from the nested trap, no antiprotons are detected, proving that lone antiprotons cannot surmount the potential barrier to get into the far trap. The count when the positrons *are* present is thus the count of neutral antihydrogen atoms that happened to be weakly bound and traveling in the right direction. No background has to be deducted.

In 2004, in a clever elaboration of this basic technique using an oscillating stripping field, ATRAP gathered information on how fast its antihydrogen atoms were moving—in other words, their temperature. The result was somewhat discouraging: the atoms produced and detected by the ATRAP collaboration have a temperature of 2,400 K, much higher than the 4.2 K of the liquid-helium-cooled trap components. To do detailed spectroscopy of antiatoms will require that they be well below 0.5 K, so that they can be collected in a neutral atom trap and studied by seeing how they absorb laser beams of various frequencies.

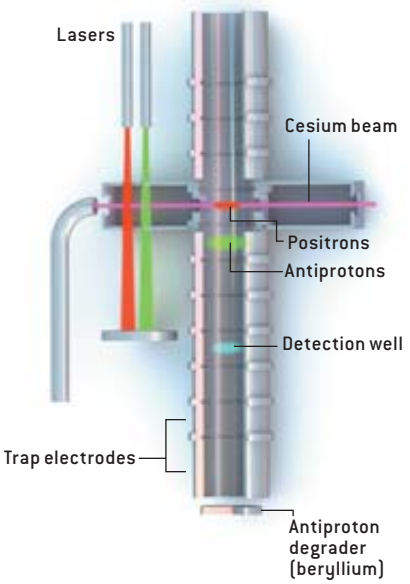
Laser-Controlled Production

IN AN EFFORT to create lower-temperature antiatoms, the ATRAP collaboration has developed a laser-controlled system for antihydrogen production. This system does away with the nested trap. Instead the positrons and antiprotons are held in adjoining but separate potential wells [*see box below*]. A chain of reactions, starting with a beam of laser-excited cesium atoms, transfers the positrons to the antiprotons to form antihydrogen. The chain of reactions is designed to transfer very little energy to the antiatom that is formed.

The ATRAP group carried out this experiment over the course of only a few hours at the very end of the experimental run in 2004, so they did not have time to optimize the method or to collect very many antiatoms. Indeed, they detected only 13 in total. Gabrielse explains that there is "good reason to believe that these atoms are far colder than the atoms produced in a nested Penning trap." Many more are needed, however, to verify this hypothesis. Even then, a further step will be required before the antiatoms could be used for precision tests of CPT: the antiatoms are formed in bloated, highly excited states (called Rydberg states), and these will have to be

LASER-CONTROLLED PRODUCTION

The ATRAP collaboration has introduced a laser-controlled method of producing antihydrogen atoms without the need for nested traps (*device below; process below right*). Instead the antiprotons and positrons are held in adjacent traps, and neutral positronium "atoms" (a co-orbiting electron and positron) transfer the positrons to the antiprotons. The sequence of reactions should ensure that the resulting antihydrogen atoms have low velocities (that is, a low temperature), but that has not yet been confirmed.

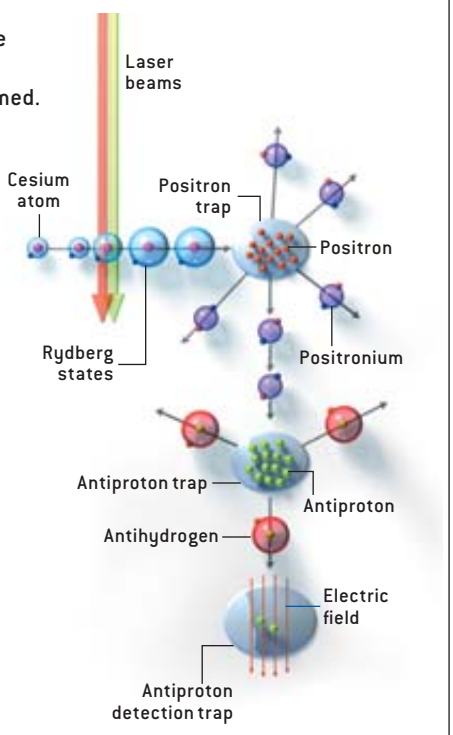


1 Cesium atoms from an oven pass through laser beams tuned to excite the atoms to bloated Rydberg states

2 Positrons in a trap capture the excited electrons from the cesium atoms, forming positronium, also in Rydberg states. Being neutral, the positroniums escape from the trap in all directions

3 Some of the positroniums travel to an antiproton trap where the antiprotons pick up the positrons, forming antihydrogen atoms, which escape from the trap in all directions

4 Some of the antihydrogen atoms travel to a second antiproton trap, where a high electric field strips off the positrons. The now trapped antiprotons are detected, proving the antihydrogen atoms were made



BRYAN CHRISTIE DESIGN

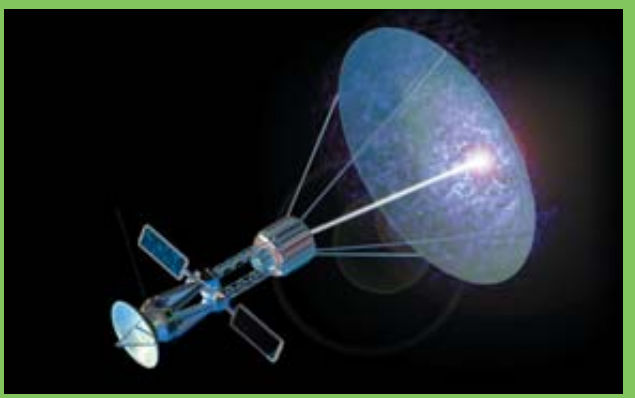
Antimatter Propulsion: What Would It Take?

According to NASA, 42 milligrams of antiprotons possess energy equal to the 750,000 kilograms of fuel and oxidizer stored in a space shuttle's external tank. The usefulness of such a concentrated source of energy for propulsion seems obvious, yet many difficult problems would need to be overcome before antimatter-powered space travel could become a reality.

The first requirement, of course, is a practical way to produce milligram quantities of antimatter. CERN's Antiproton Decelerator produces 20 million antiprotons every 100 seconds. If it ran 24/7 for a year, it would generate just 10 picograms of antiprotons.

Second, a way to store large quantities of antimatter is needed. Typical neutral atom traps hold only millions of atoms. In one scheme, proposed by Steven D. Howe and Gerald P. Jackson of Hbar Technologies at a NASA conference in 2003, antihydrogen ("$\bar{H}$" or "H-bar") would be stored in the form of solid pellets (hydrogen, and hence antihydrogen, freezes at 14 kelvins). The pellets, perhaps around 150 microns in diameter, would be electrically charged and suspended in an array of electrostatic traps.

Even given a significant store of antimatter, the energy of annihilation must be converted into thrust. When an electron and a positron annihilate, the energy is released as two gamma rays, which promptly fly off in opposite directions. Proton-antiproton annihilation produces short-lived particles called pions with high energy. These particles could be used to heat a tungsten core over which hydrogen was passed. The thermal expansion of the hydrogen would provide thrust.



PROPOSED ANTIMATTER PROPULSION system uses antimatter pellets to trigger fission explosions on a uranium-coated sail.

An engine that used magnetic fields to direct the pions themselves as the propellant would be far more efficient, but the total thrust would be much lower because of the tiny amount of propellant they would amount to.

Howe and Jackson proposed a third way using their antimatter pellets to power a sail system. The sail would be made of uranium-coated carbon, and the uranium would be induced to undergo nuclear fission when solid pellets of antihydrogen were fired into it. The ejection of debris from the fissions would propel the sail, which would pull along the spacecraft. That antimatter would induce the fission efficiently is entirely speculation at this point, however. —*G.P.C.*

"de-excited" before practical spectroscopy can be performed.

Also toward the end of 2004, the ATHENA group succeeded in compressing their antiprotons into a thin, dense column at the very center of their trap. Such a configuration may be very useful for future experiments involving magnetic traps (which will be needed to hold the antihydrogen atoms).

In other work, ATHENA members have examined properties of the antihydrogen production process. They have found that even when their positrons are at room temperature (300 K), almost as many antiatoms are produced as at ATHENA's usual 10 K operating temperature. That flies in the face of the simplest theories of how the antiatoms are formed, which predict thousands to millions of times fewer antihydrogens. Landua strongly believes that some additional mechanism is helping to stabilize the antihydrogen in the hotter plasma. (Gabrielse is highly skeptical of that conclusion.) If the process is actually reducing the antiatoms to their lowest energy state, as is desired for spectroscopy, that discovery would be good news for those wishing to test CPT symmetry.

Both researchers agree that producing antihydrogen atoms that are suitable for spectroscopy is the central challenge facing the groups now. Such antiatoms must have two properties: not only must they be cooler than 0.5 K, so that magnetic traps can hold them, they must also be in their ground state.

The Antiproton Decelerator usually runs from May to November every year, but it will not be run at all during 2005—CERN's accelerators have been shut down as a cost-cutting measure, following projected budget overruns from the Large Hadron Collider construction. The antiatom researchers will have to wait until May 2006 before they can resume their battle to beat hydrogen's evil twin into submission. SA

Graham P. Collins is a staff writer and editor.

MORE TO EXPLORE

Production and Detection of Cold Antihydrogen Atoms. M. Amoretti et al. in *Nature,* Vol. 419, pages 456–459; October 3, 2002.

Background-Free Observation of Cold Antihydrogen with Field-Ionization Analysis of Its States. G. Gabrielse et al. in *Physical Review Letters,* Vol. 89, No. 21, pages 213401-1–213401-4; November 18, 2002.

The Antiproton: a Subatomic Actor with Many Roles. John Eades in *CERN Courier,* Vol. 43, No. 6; July/August 2003. Available online at **cerncourier.com/main/article/43/6/17**

First Measurement of the Velocity of Slow Antihydrogen Atoms. G. Gabrielse et al. in *Physical Review Letters,* Vol. 93, No. 7, pages 073401-1–073401-4; August 13, 2004.

The ATHENA Web site is at **athena.web.cern.ch/athena/**

The ATRAP Web site is at **hussle.harvard.edu/~atrap/**

Additional information about antimatter and tests of CPT symmetry is online at **www.sciam.com/ontheweb**

BRYAN CHRISTIE DESIGN

PERSONAL ADORNMENT with jewelry and body paint may have started far earlier than previously thought. Early indications of such symbol use—believed by many archaeologists to be a key component of modern human behavior—include 75,000-year-old shell beads (*left*) from Blombos Cave in South Africa.

The Morning of the Modern Mind

Controversial discoveries suggest that the roots of our vaunted intellect run far deeper than is commonly believed

BY KATE WONG

CAPE TOWN, SOUTH AFRICA—Christopher Henshilwood empties a tiny plastic bag and hands me a square of worn blue cardstock to which 19 snail shells no larger than kernels of corn have been affixed in three horizontal rows. To the casual onlooker, they might well appear unremarkable, a handful of discarded mollusk armor, dull and gray with age. In fact, they may be more precious than the glittering contents of any velvet-lined Cartier case.

The shells, discovered in a cave called Blombos located 200 miles east of here, are perfectly matched in size, and each bears a hole in the same spot opposite the mouth, notes Henshilwood, an archaeologist at the University of Bergen in Norway. He believes they were collected and perforated by humans nearly 75,000 years ago to create a strand of lustrous, pearllike beads. If he is correct, these modest shells are humanity's crown jewels—the oldest unequivocal evidence of personal adornment to date and proof that our ancestors were thinking like us far earlier than is widely accepted.

Snail shells were collected from an estuary 12 miles away from Blombos Cave and then pierced with a bone awl. Wear marks around the holes indicate that they were strung together to create perhaps a necklace or bracelet.

A Behavioral Big Bang

BY MOST ACCOUNTS, the origin of anatomically modern *Homo sapiens* was a singularly African affair. In 2003 the unveiling of fossils found in Herto, Ethiopia, revealed that this emergence had occurred by 160,000 years ago. And this past February researchers announced that they had redated *H. sapiens* remains from another Ethiopian site, Omo Kibish, potentially pushing the origin of our species back to 195,000 years ago.

Far less clear is when our kind became modern of mind. For the past two decades, the prevailing view has been that humanity underwent a behavioral revolution around 40,000 years ago. Scholars based this assessment primarily on the well-known cultural remains of Ice Age Europeans. In Europe, the relevant archaeological record is divided into the Middle Paleolithic (prior to around 40,000 years ago) and the Upper Paleolithic (from roughly 40,000 years ago onward), and the difference between the two could not be more striking. Middle Paleolithic people seem to have made mostly the same relatively simple stone tools humans had been producing for tens of thousands of years and not much else. The Upper Paleolithic, in contrast, ushered in a suite of sophisticated practices. Within a geologic blink of an eye, humans from the Rhône Valley to the Russian plain were producing advanced weaponry, forming long-distance trade networks, expressing themselves through art and music, and generally engaging in all manner of activities that archaeologists typically associate with modernity. It was, by all appearances, the ultimate Great Leap Forward.

Perhaps not coincidentally, it is during this Middle to Upper Paleolithic transition that humans of modern appearance had begun staking their claim on Europe, which until this point was strictly Neandertal territory. Although the identity of the makers of the earliest Upper Paleolithic artifacts is not known with certainty, because of a lack of human remains at the sites, they are traditionally assumed to have been anatomically modern *H. sapiens* rather than Neandertals. Some researchers have thus surmised that confrontation between the two populations awakened in the invaders a creative ability that had heretofore lain dormant.

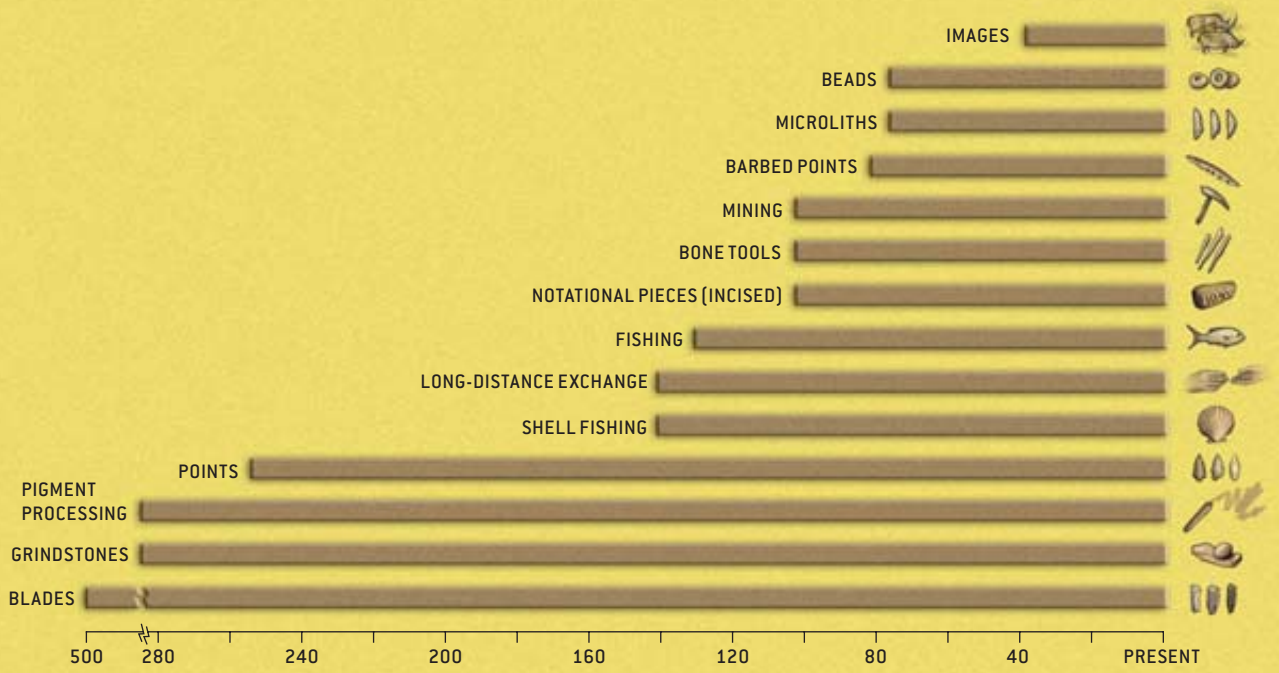
Other specialists argue that the cultural explosion evident in Europe grew out of a shift that occurred somewhat earlier in Africa. Richard G. Klein of Stanford University, for one, contends that the abrupt change from the Middle to the Upper Paleolithic mirrors a transition that took place 5,000 to 10,000 years beforehand in Africa, where the comparative culture periods are termed the Middle and Later Stone Age. The impetus for this change, he theorizes, was not an encounter with another hominid type (for by this time in Africa, *H. sapiens* was free of competition with other human species) but rather a genetic mutation some 50,000 years ago that altered neural processes and thereby unleashed our forebears' powers of innovation.

Overview/*Evolved Thinking*

- Archaeologists have traditionally envisioned *Homo sapiens* becoming modern of mind quickly and recently—sometime in the past 50,000 years, more than 100,000 years after attaining anatomical modernity.
- New discoveries in Africa indicate that many of the elements of modern human behavior can be traced much farther back in time.
- The finds suggest that our species had a keen intellect at its inception and exploited that creativity in archaeologically visible ways only when it was advantageous to do so—when population size increased, for instance.
- *H. sapiens* may not have been the only hominid to possess such advanced cognition: some artifacts hint that Neandertals were comparably gifted.

FRANCESCO D'ERRICO *University of Bordeaux*; AFRICAN HERITAGE RESEARCH INSTITUTE AND UNIVERSITY OF BERGEN (*snail shell beads, page 86 and above*); RANDY HARRIS (*preceding page*)

STONE AGE SOPHISTICATION



Archaeological discoveries in Africa have revealed that elements of modern human behavior can be traced back far beyond the 40,000-year mark (*above*), contrary to earlier claims based on the European record. But experts agree that many more people routinely engaged in these practices after that date than before it. A number of hypotheses for what set the stage for this tipping point—not all of which are mutually exclusive—have been put forth (*below*).

Symbolism. The invention of external storage of information—whether in jewelry, art, language or tools—was the watershed event in modern human behavioral evolution, according to Christopher Henshilwood of the University of Bergen in Norway. *Homo sapiens* probably had the hardware required for symbolic thought by the time the species arose, at least 195,000 years ago, hence the occasional early glimpses of it in the archaeological record. But only once symbolism became the basis for human behavioral organization—resulting in the formation of trade and alliance networks, for example—was its full potential realized.

Ecological disaster. Genetic data suggest that *H. sapiens* experienced a bottleneck some 70,000 years ago. Stanley H. Ambrose of the University of Illinois posits that it was the fallout from an eruption of Sumatra's Mount Toba at around that time that may have brought on a devastating six-year-long volcanic winter and subsequent 1,000-year ice age. Those individuals who cooperated and shared resources with one another—beyond their local group boundaries—were the best equipped to survive in the harsh environs and pass their genes along to the next generation. The extreme conditions favored a transition from the troop level of social organization to that of the tribe.

Projectile technology. The innovation of projectile weapons between 45,000 and 35,000 years ago allowed humans to kill large game—and other humans—from a safe distance. This, says John Shea of Stony Brook University, provided people with a strong incentive to cooperate, which would in turn have fostered the development of social networks through which information could be readily shared.

Population growth. Modern ways bubbled up and disappeared at different times and in different places until the population size reached critical mass. At that point, confrontation between groups and competition for resources sparked symbolic behavior and spurred technological innovation, contend researchers, including Alison Brooks of George Washington University and Sally McBrearty of the University of Connecticut. And with more people to pass on these traditions, they began to stick, rather than dying out with the last member of a group.

Brain mutation. A genetic mutation roughly 50,000 years ago had the lucky effect of rewiring the human brain such that it was capable of symbolic thought—including language—argues Richard G. Klein of Stanford University. Humans carrying this mutation had a considerable advantage over those who did not and quickly outcompeted and replaced them.

ALISON KENDALL; SOURCE: UPDATED FROM S. MCBREARTY AND A. S. BROOKS IN *JOURNAL OF HUMAN EVOLUTION*, VOL. 39, NO. 5, PAGES 453–563; NOVEMBER 2000

Mapping Modernity

Humans who looked like us had evolved by 195,000 years ago, as evidenced by *Homo sapiens* fossils from the site of Omo Kibish in Ethiopia. But received archaeological wisdom holds that humans did not begin behaving like us until nearly 150,000 years later. That notion stems largely from cultural remains uncovered in Europe, where art, ritual, technological advances and other indications of modern thinking flowered spectacularly and suddenly after about 40,000 years ago, around the time that anatomically modern humans started colonizing Europe.

Recent finds, including those from Blombos Cave in South Africa, are revealing that many sophisticated practices emerged long before 40,000 years ago at sites outside of Europe, suggesting that humans were our cognitive equals by the time they attained anatomical modernity, if not earlier. Indeed, the fact that at least some Neandertals appear to have thought symbolically raises the possibility that such capacities were present in the last common ancestor of Neandertals and *H. sapiens.* The map below shows the locations of the sites mentioned in the article.

Neandertal-made pierced tooth from Arcy-sur-Cure, France: 33,000 years old

Oldest evidence of painting in Africa from Apollo 11 Rock Shelter in Namibia: 28,000 years old

SCHÖNINGEN, Germany 400 KYA

HOHLE FELS CAVE, Germany 30–35 KYA

SUNGIR, Russia 28 KYA

ARCY-SUR-CURE, France 33 KYA

TATA, Hungary 50–100 KYA

KRAPINA, Croatia 130 KYA

CHAUVET, France 35 KYA

ISTURITZ, France 32 KYA

QAFZEH, Israel 92 KYA

QUNEITRA, Israel 60 KYA

HERTO, Ethiopia 160 KYA

OMO KIBISH, Ethiopia 195 KYA

BARINGO, Kenya 510–550 KYA

LOIYANGALANI, Tanzania 70 KYA

ENKAPUNE YA MUTO, Kenya 43 KYA

KATANDA, Democratic Republic of the Congo 80 KYA

MUMBA ROCK SHELTER, Tanzania 130 KYA

TWIN RIVERS CAVE, Zambia 200 KYA

ǂGI, Botswana 77 KYA

APOLLO 11 ROCK SHELTER, Namibia 28 KYA

KLASIES RIVER MOUTH CAVE, South Africa 100 KYA

DIEPKLOOF, South Africa 60 KYA

BLOMBOS CAVE, South Africa 75 KYA

- Earliest anatomically modern *Homo sapiens* physical remains
- Known and presumed *H. sapiens* cultural remains
- Neandertal cultural remains
- Older human cultural remains

KYA = thousand years ago

LUCY READING-IKKANDA (*map*); RANDALL WHITE *New York University* (*pierced tooth*); GERALD NEWLANDS (*Apollo 11 painting*); HILDE JENSEN *University of Tübingen* (*ivory water bird*); GAVRIEL LARON AND ERELLA HOVERS *Institute of Archaeology, Hebrew University of Jerusalem* (*red ochre*); CHIP CLARK *National Museum of Natural History* (*bone harpoon*); ARIZONA STATE UNIVERSITY (*ostrich eggshell bead*)

Key evidence for this model, Klein says, comes from a site in central Kenya called Enkapune Ya Muto, the "twilight cave," that places the origin of the Later Stone Age at 45,000 to 50,000 years ago. There Stanley H. Ambrose of the University of Illinois and his team have uncovered obsidian knives, thumbnail-size scrapers and—most notably—tiny disk-shaped beads fashioned from ostrich eggshell in Later Stone Age levels dating back some 43,000 years. Strands of similar beads are still exchanged as gifts today among the !Kung San hunter-gatherers of Botswana. Ambrose posits that the ancient bead makers at Enkapune Ya Muto created them for the same reason: to foster good relationships with other groups as a hedge against hard times. If so, according to Klein, a genetically conferred ability to communicate through symbols—in concert with the cognitive prowess to conceive of better hunting technology and resource use—may have been what enabled our species finally, nearly 150,000 years after it originated, to set forth from its mother continent and conquer the world.

Seeds of Change

IN RECENT YEARS, however, a small but growing number of archaeologists have eschewed the big bang theories of the origin of culture in favor of a fundamentally different model. Proponents believe that there was no lag between body and brain. Rather, they contend, modern human behavior emerged over a long period in a process more aptly described as evolution than revolution. And some workers believe that cognitive modernity may have evolved in other species, such as the Neandertals, as well.

The notion that our species' peerless creativity might have primeval roots is not new. For years, scientists have known of a handful of objects that, taken at face vaue, suggest that humans were engaging in modern practices long before *H. sapiens* first painted a cave wall in France. They include three 400,000-year-old wooden throwing spears from Schöningen, Germany; a 233,000-year-old putative figurine from the site of Berekhat Ram in Israel; a 60,000-year-old piece of flint incised with concentric arcs from Quneitra, Israel; two 100,000-year-old fragments of notched bone from South Africa's Klasies River Mouth Cave; and a polished plate of mammoth tooth from Tata in Hungary, dated to between 50,000 and 100,000 years ago. Many archaeologists looked askance at these remains, however, noting that their age was uncertain or that their significance was unclear. Any sign of advanced intellect that did seem legitimately ancient was explained away as a one-off accomplishment, the work of a genius among average Joes.

That position has become harder to defend in the face of the growing body of evidence in Africa that our forebears' mental metamorphosis began well before the start of the Later Stone Age. In a paper entitled "The Revolution That Wasn't: A New Interpretation of the Origin of Modern Human Behavior," published in the *Journal of Human Evolution* in 2000, Sally McBrearty of the University of Connecticut and Alison S. Brooks of George Washington University laid out their case.

Many of the components of modern human behavior said to emerge in lockstep between 40,000 and 50,000 years ago, they argued, are visible tens of thousands of years earlier at Middle Stone Age locales. Moreover, they appear not as a package but piecemeal, at sites far-flung in time and space.

At three sites in Katanda, Democratic Republic of the Congo, Brooks and John Yellen of the Smithsonian Institution have found elaborate barbed harpoons carved from bone that they say date to at least 80,000 years ago, which would place them firmly within the Middle Stone Age. These artifacts exhibit a level of sophistication comparable to that seen in 25,000-year-old harpoons from Europe, not only in terms of the complexity of the weapon design but the choice of raw material: the use of bone and ivory in tool manufacture was not thought to have occurred until the Later Stone Age and Upper Paleolithic. In addition, remains of giant Nile catfish have turned up with some of the Katanda harpoons, suggesting to the excavators that people were going there when the fish were spawning—the kind of seasonal mapping of resources previously thought to characterize only later humans.

Blombos ochre, engraved with a stone point, may reflect record keeping or a design aesthetic. The effort required to prepare the substrate and produce the markings suggests a premeditated act, rather than doodling.

Other Middle Stone Age sites, such as ≠Gi (the "≠" denotes a click sound) in Botswana's Kalahari Desert, which is dated to 77,000 years ago, have yielded butchered animal remains that have put paid to another oft-made claim, namely, that these ancient people were not as competent at hunting as Later Stone Age folks. The residents at ≠Gi appear to have regularly pursued such large and dangerous prey as zebra and Cape warthog. And Hilary J. Deacon of Stellenbosch University has suggested that at sites such as South Africa's Klasies River Mouth Cave humans more than 60,000 years ago were deliberately burning grassland to encourage the growth of nutritious tubers, which are known to germinate after exposure to fire.

Some discoveries hint that certain alleged aspects of behavioral modernity arose even before the genesis of *H. sapiens*. Last summer excavations by McBrearty's team at a site near Lake Baringo in Kenya turned up stone blades—once a hallmark of the Upper Paleolithic material cultures—more than 510,000 years old. At a nearby locality, in levels dated to at least 285,000 years ago, her team has uncovered vast quantities of red ochre (a form of iron ore) and grindstones for processing it, signaling to McBrearty that the Middle Stone Age people at Baringo were using the pigment for symbolic purposes—to decorate their bodies, for instance—just as many humans do today. (Baringo is not the only site to furnish startlingly ancient evidence of ochre processing—Twin Rivers Cave in Zambia has yielded similar material dating back to more than 200,000 years ago.) And 130,000-year-old tool assemblages from Mumba Rock Shelter in Tanzania include flakes crafted from obsidian that came from a volcanic flow about 200 miles away—compelling evidence that the hominids who made the implements traded with other groups for the exotic raw material.

Critics, however, have dismissed these finds on the basis of uncertainties surrounding, in some cases, the dating and, in others, the intent of the makers. Ochre, for one, may have been used as mastic for attaching blades to wooden handles or as an antimicrobial agent for treating animal hides, skeptics note.

Smart for Their Age

IT IS AGAINST this backdrop of long-standing controversy that the discoveries at Blombos have come to light. Henshilwood discovered the archaeological deposits at Blombos Cave in 1991 while looking for much younger coastal hunter-gatherer sites to excavate for his Ph.D. Located near the town of Still Bay in South Africa's southern Cape, on a bluff overlooking the Indian Ocean, the cave contained few of the Holocene artifacts he was looking for but appeared rich in Middle Stone Age material. As such, it was beyond the scope of his research at the time. In 1997, however, he raised the money to return to Blombos to begin excavating in earnest. Since then, Henshilwood and his team have unearthed an astonishing assemblage of sophisticated tools and symbolic objects and in so doing have sketched a portrait of a long-ago people who thought like us.

From levels dated by several methods to 75,000 years ago have come an array of advanced implements, including 40 bone tools, several of which are finely worked awls, and hundreds of bifacial points made of silcrete and other difficult-to-shape stones, which the Blombos people could have used to hunt the antelopes and other game that roamed the area. Some of the points are just an inch long, suggesting that they may have been employed as projectiles. And the bones of various species of deep-sea fish—the oldest of which may be more than 130,000 years old—reveal that the Blombos people had the equipment required to harvest creatures in excess of 80 pounds from the ocean.

Hearths for cooking indicate that the cave was a living site, and teeth representing both adults and children reveal that a family group dwelled there. But there are so many of the stone points, and such a range in their quality, that Henshilwood wonders whether the occupants may have also had a workshop in the tiny cave, wherein masters taught youngsters how to make the tools.

CHAD HENNING; AFRICAN HERITAGE RESEARCH INSTITUTE AND UNIVERSITY OF BERGEN

They may have passed along other traditions as well. The most spectacular material to emerge from Blombos is that which demonstrates that its occupants thought symbolically. To date, the team has recovered one piece of incised bone, nine slabs of potentially engraved red ochre and dozens of the tiny beads—all from the same 75,000-year-old layers that yielded the tools. In addition, sediments that may date back to more than 130,000 years ago contain vast quantities of processed ochre, some in crayon form.

Scientists may never know exactly what meaning the enigmatic etchings held for their makers. But it is clear that they were important to them. Painstaking analyses of two of the engraved ochres, led by Francesco d'Errico of the University of Bordeaux in France, reveal that the rust-colored rocks were hand-ground on one side to produce a facet that was then etched repeatedly with a stone point. On the largest ochre, bold lines frame and divide the crosshatched design.

Bead manufacture was likewise labor-intensive. Henshilwood believes the marine tick shells, which belong to the *Nassarius kraussianus* snail, were collected from either of two estuaries, located 12 miles from the cave, that still exist today. Writing in the January issue of the *Journal of Human Evolution,* Henshilwood, d'Errico and their colleagues report that experimental reconstruction of the process by which the shells were perforated indicates that the precocious jewelers used bone points to punch through the lip of the shell from the inside out—a technique that commonly broke the shells when attempted by team members. Once pierced, the beads appear to have been strung, as evidenced by the wear facets ringing the perforations, and traces of red ochre on the shells hint that they may have lain against skin painted with the pigment.

In the case for cognitive sophistication in the Middle Stone Age, "Blombos is the smoking gun," McBrearty declares. But Henshilwood has not convinced everyone of his interpretation. Doubts have come from Randall White of New York University, an expert on Upper Paleolithic body ornaments. He suspects that the perforations and apparent wear facets on the *Nassarius* shells are the result of natural processes, not human handiwork.

BLOMBOS CAVE was a veritable garden of Eden when humans lived there 75,000 years ago, observes discoverer Christopher Henshilwood. Freshwater springs burbled at the base of the cliff, and the bounty of the sea lay in the backyard. Tasty eland and other antelope roamed the area, and the climate was about as mild as it is today. Henshilwood and his team have been digging in the cave's Middle Stone Age deposits since 1997, carefully recording the location of each artifact unearthed. This year marks their ninth excavation season.

CHRISTOPHER S. HENSHILWOOD *African Heritage Research Institute and University of Bergen*

Here Today, Gone Tomorrow

IF READ CORRECTLY, however, the remarkable discoveries at Blombos offer weighty evidence that at least one group of humans possessed a modern mind-set long before 50,000 years ago, which may in some ways make previous claims for early behavioral modernity easier to swallow. So, too, may recent finds from sites such as Diepkloof in South Africa's Western Cape, which has produced pieces of incised ostrich eggshell dated to around 60,000 years ago, and Loiyangalani in Tanzania, where workers have found ostrich eggshell beads estimated to be on the order of 70,000 years old.

Yet it remains the case that most Middle Stone Age sites show few or none of the traits researchers use to identify fully developed cognition in the archaeological record. Several other locales in South Africa, for example, have yielded the sophisticated bifacial points but no evidence of symbolic behavior. Of course, absence of evidence is not evidence of absence, as prehistorians are fond of saying. It is possible the people who lived at these sites did make art and decorate their bodies, but only their stone implements have survived.

Perhaps the pattern evident thus far in the African record—that of ephemeral glimpses of cognitive modernity before the start of the Later Stone Age and ubiquitous indications of it after that—is just an artifact of preservational bias or the relatively small number of African sites excavated so far. Then again, maybe these fits and starts are exactly what archaeologists should expect to see if anatomically modern *H. sapiens* possessed the capacity for modern human behavior from the

get-go but tapped that potential only when it provided an advantage, as many gradualists believe.

The circumstances most likely to elicit advanced cultural behaviors, McBrearty and others hypothesize, were those related to increased population size. The presence of more people put more pressure on resources, forcing our ancestors to devise cleverer ways to obtain food and materials for toolmaking, she submits. More people also raised the chances of encounters among groups. Beads, body paint and even stylized tool manufacture may have functioned as indicators of an individual's membership and status in a clan, which would have been especially important when laying claim to resources in short supply. Symbolic objects may have also served as a social lubricant during stressful times, as has been argued for the beads from Enkapune Ya Muto.

"You have to make good with groups around you because that's how you're going to get partners," Henshilwood observes. "If a gift exchange system is going on, that's how you're maintaining good relations." Indeed, gift giving may explain why some of the tools at Blombos are so aesthetically refined. A beautiful tool is not going to be a better weapon, he remarks, it is going to function as a symbolic artifact, a keeper of the peace.

Tools from Blombos are more sophisticated than those typically found at Middle Stone Age sites. The bone implements include awls worked to a fine point and polished with ochre to achieve a smooth patina.

Conversely, when the population dwindled, these advanced practices subsided—perhaps because the people who engaged in them died out or because in the absence of competition they simply did not pay off and were therefore forgotten. The Tasmanians provide a recent example of this relationship: when Europeans arrived in the region in the 17th century, they encountered a people whose material culture was simpler than even those of the Middle Paleolithic, consisting of little more than basic stone flake tools. Indeed, from an archaeological standpoint, these remains would have failed nearly all tests of modernity that are commonly applied to prehistoric sites. Yet the record shows that several thousand years ago, the Tasmanians possessed a much more complex tool kit, one that included bone tools, fishing nets, and bows and arrows. It seems that early Tasmanians had all the latest gadgetry before rising sea levels cut the island off from the mainland 10,000 years ago but lost the technology over the course of their small group's separation from the much larger Aboriginal Australian population.

This might be why South African sites between 60,000 and 30,000 years old so rarely seem to bear the modern signature: demographic reconstructions suggest that the human population in Africa crashed around 60,000 years ago because of a precipitous drop in temperature. Inferring capacity from what people produced is inherently problematic, White observes. Medieval folks doubtless had the brainpower to go to the moon, he notes. Just because they did not does not mean they were not our cognitive equals. "At any given moment," White reflects, "people don't fulfill their entire potential."

Symbol-Minded

THE DEBATE OVER when, where and how our ancestors became cognitively modern is complicated by the fact that experts disagree over what constitutes modern human behavior in the first place. In the strictest sense, the term encompasses every facet of culture evident today—from agriculture to the iPod. To winnow the definition into something more useful to archaeologists, many workers employ the list of behavioral traits that distinguish the Middle and Upper Paleolithic in Europe. Others use the material cultures of modern and recent hunter-gatherers as a guide. Ultimately, whether or not a set of remains is deemed evidence of modernity can hinge on the preferred definition of the evaluator.

Taking that into consideration, some experts instead advocate focusing on the origin and evolution of arguably the most important characteristic of modern human societies: symbolically organized behavior, including language. "The ability to store symbols externally, outside of the human brain, is the key to everything we do today," Henshilwood asserts. A symbol-based system of communication might not be a perfect proxy for behavioral modernity in the archaeological record, as the Tasmanian example illustrates, but at least researchers seem to accept it as a defining aspect of the human mind as we know it, if not *the* defining aspect.

It remains to be seen just how far back in time symbolic culture arose. And discoveries outside of Africa and Europe are helping to flesh out the story. Controversial evidence from the rock shelters of Malakunanja II and Nauwalabila I in Australia's Northern Territory, for instance, suggests that people had arrived there by 60,000 years ago. To reach the island continent, emigrants traveling from southeastern Asia would have to have built sturdy watercraft and navigated a minimum of 50 miles of open water, depending on the sea level. Scholars mostly agree that any human capable of managing this feat must have been fully modern. And in Israel's Qafzeh Cave, Erella Hovers of the Hebrew University of Jerusalem and her team have recovered dozens of pieces of red ochre near 92,000-year-old graves of *H. sapiens*. They believe the lumps of pig-

HARRY TYLER; AFRICAN HERITAGE RESEARCH INSTITUTE AND UNIVERSITY OF BERGEN

SYMBOLIC BEHAVIOR may not have originated in Europe, but its early record there is rich. Chauvet Cave, in the Ardèche region of France, contains the oldest cave paintings in the world. Its galleries showcase a menagerie of Ice Age creatures, including lions (*top left*), rendered in ochre 35,000 years ago. Ancient Europeans also had a love of music, as evidenced by this 32,000-year-old bone flute from Isturitz, France (*bottom left*). And they buried their dead with sometimes breathtaking ceremony, as seen above in this replica of a 28,000-year-old burial of two children and thousands of beads and other grave goods from Sungir, Russia.

JEAN CLOTTES; FRENCH MINISTRY OF CULTURE (*Chauvet Cave*); RÉUNION DES MUSÉES NATIONAUX/ART RESOURCE, NY (*bone flute*); KENNETH GARRETT *National Geographic Image Collection* (*Sungir burial*)

ment were heated in hearths to achieve a specific hue of scarlet and then used in funerary rituals.

Other finds raise the question of whether symbolism is unique to anatomically modern humans. Neandertal sites commonly contain evidence of systematic ochre processing, and toward the end of their reign in Europe, in the early Upper Paleolithic, Neandertals apparently developed their own cultural tradition of manufacturing body ornaments, as evidenced by the discovery of pierced teeth and other objects at sites such as Quinçay and the Grotte du Renne at Arcy-sur-Cure in France [see "Who Were the Neandertals?" by Kate Wong; Scientific American, April 2000]. They also interred their dead. The symbolic nature of this behavior in their case is debated because the burials lack grave goods. But this past April at the annual meeting of the Paleoanthropology Society, Jill Cook of the British Museum reported that digital microscopy of remains from Krapina Rock Shelter in Croatia bolsters the hypothesis that Neandertals were cleaning the bones of the deceased, possibly in a kind of mortuary ritual, as opposed to defleshing them for food.

Perhaps the ability to think symbolically evolved independently in Neandertals and anatomically modern *H. sapiens*. Or maybe it arose before the two groups set off on separate evolutionary trajectories, in a primeval common ancestor. "I can't prove it, but I bet [*Homo*] *heidelbergensis* [a hominid that lived as much as 400,000 years ago] was capable of this," White speculates.

For his part, Henshilwood is betting that the dawn of symbol-driven thinking lies in the Middle Stone Age. As this article was going to press, he and his team were undertaking their ninth field season at Blombos. By the end of that period they will have sifted through a third of the cave's 75,000-year-old deposits, leaving the rest to future archaeologists with as yet unforeseen advances in excavation and dating techniques. "We don't really need to go further in these levels at Blombos," Henshilwood says. "We need to find other sites now that date to this time period." He is confident that they will succeed in that endeavor, having already identified a number of very promising locales in the coastal De Hoop Nature Reserve, about 30 miles west of Blombos.

Sitting in the courtyard of the African Heritage Research Institute pondering the dainty snail shells in my hand, I consider what they might have represented to the Blombos people. In some ways, it is difficult to imagine our ancient ancestors setting aside basic concerns of food, water, predators and shelter to make such baubles. But later, perusing a Cape Town jeweler's offerings—from cross pendants cast in gold to diamond engagement rings—it is harder still to conceive of *Homo sapiens* behaving any other way. The trinkets may have changed somewhat since 75,000 years ago, but the all-important messages they encode are probably still the same. SA

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MORE TO EXPLORE

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Industry groups are fighting government regulation by fomenting scientific uncertainty

DOUBT Is Their Product

By David Michaels

Photographs by Mindy Jones

Few scientific challenges are more complex than understanding the health risks of a chemical or drug. Investigators cannot feed toxic compounds to people to see what doses cause cancer. Instead laboratory researchers rely on animal tests, and epidemiologists examine the human exposures that have already happened in the field. Both types of studies have many uncertainties, and scientists must extrapolate from the evidence to make causal inferences and recommend protective measures. Because absolute certainty is rarely an option, regulatory programs would not be effective if such proof were required. Government officials have to use the best available evidence to set limits for harmful chemicals and determine the safety of pharmaceuticals.

Uncertainty is an inherent problem of science, but manufactured uncertainty is another matter entirely. Over the past three decades, industry groups have frequently become involved in the investigative process when their interests are threatened. If, for example, studies show that a company is exposing its workers to dangerous levels of a certain chemical, the business typically responds by hiring its own researchers to cast doubt on the studies. Or if a pharmaceutical firm faces questions about the safety of one of its drugs, its executives trumpet company-sponsored trials that show no significant health risks while ignoring or hiding other studies that are much less reassuring. The vilification of threatening research as "junk science" and the corresponding sanctification of industry-commissioned research as "sound science" has become nothing less than standard operating procedure in some parts of corporate America.

In 1969 an executive at Brown & Williamson, a cigarette maker now owned by R. J. Reynolds Tobacco Company, unwisely committed to paper the perfect slogan for his industry's disinformation campaign: "Doubt is our product since it is the best means of competing with the 'body of fact' that exists in the mind of the general public." In recent years, many other industries have eagerly adopted this strategy. Corporations have mounted campaigns to question studies documenting the adverse health effects of exposure to beryllium, lead, mercury, vinyl chloride, chromium, benzene, benzidine, nickel, and a long list of other toxic chemicals and medications. What is more, Congress and the administration of President George W. Bush have encouraged such tactics by making it easier for private groups to challenge government-funded research. Although in some cases, companies may be raising legitimate arguments, the overall result is disturbing: many corporations have successfully avoided expense and inconvenience by blocking and stalling much needed protections for public health.

The Taxicab Standard

A GOOD EXAMPLE of the current battles between industry and science is the controversy over beryllium. This lightweight metal is vital to the production of nuclear warheads because it increases the yield of the explosions; throughout the cold war, the U.S. nuclear weapons complex was the nation's largest consumer of the substance. Beryllium and its alloys are now used to make electronics equipment and even golf clubs. But the metal is also extremely toxic—breathing in tiny amounts can cause chronic beryllium disease (CBD), a debilitating ailment that scars the lungs. Victims have included not just the machinists who worked directly with the metal but others simply in the vicinity of the milling and grinding processes, often for very short periods. One accountant developed CBD after working for a few weeks each year in an office near where beryllium was being processed. CBD has also been diagnosed in people living near beryllium factories.

As assistant secretary of energy for environment, safety and health from 1998 to 2001, I was the chief safety officer for the nuclear weapons complex, responsible for protecting the health of workers at production and research facilities as well as for safeguarding the surrounding communities and environment. When President Bill Clinton appointed me, the Department of Energy's exposure standard for beryllium had not changed since 1949, some years after the substance's health dangers had become clear. In response to a crisis involving many sick workers and community residents, two scientists working with the Atomic Energy Commission estimated what

DRUG COMPANIES fund most of the research on the health risks of their products. All too often the firms highlight studies showing that the drugs are safe and downplay less reassuring results.

they thought to be a safe level—two micrograms of beryllium per cubic meter of air—while they were riding in a taxicab on their way to a meeting. The commission, the predecessor of the DOE, then implemented the so-called taxicab standard.

When the Occupational Safety and Health Administration (OSHA) was established in 1971 to protect the health of workers in the private sector, it, too, adopted the taxicab standard for beryllium. Over the following decades, however, it became clear that workers exposed to beryllium levels well below the standard were falling sick. In the 1990s the DOE and OSHA began the time-consuming legal process of changing their exposure limits for beryllium. Brush Wellman, the nation's leading producer of the metal, hired Exponent, a Menlo Park, Calif., consulting firm specializing in product defense. Sharing authorship with Brush Wellman's scientists, these consultants wrote a series of papers suggesting it was possible that the size, surface area and number of beryllium particles may be more important than previously thought in the development of CBD. They also raised the hypothesis that skin exposure could play a larger role in disease risk. The consultants concluded that the current standard for beryllium might not be protective but that more research was required before changing it.

After reviewing all the studies and taking testimony from industry and independent scientists, the DOE leadership in the later years of the Clinton administration decided that although more research is always desirable, the department had more than enough information to warrant immediate implementation of a stricter standard for beryllium. We issued a new rule, reducing the acceptable workplace exposure level by a factor of 10. Although we could not prove that the lower limit would eliminate the health risks, we chose a level that we believed would prevent most cases of CBD and that was also technologically feasible. This new standard, however, applies only to DOE workers; workers in the private sector, who fall under OSHA's umbrella, do not enjoy the same protection. In 1998 OSHA declared its intention to follow DOE's lead, but three years later the agency dropped that initiative. In November 2002 the agency implicitly accepted the industry's arguments by issuing a call for additional data on the relation of beryllium disease to, among other things, the size, surface area and number of particles and the extent of skin contact. That is where matters stand today.

CORPORATE HURDLES are impeding the regulation of unsafe chemicals and drugs.

As it happens, most scientists believe that beryllium also increases the risk of lung cancer; several studies conducted by epidemiologists at the Centers for Disease Control and Prevention support this conclusion. In 2002, however, statisticians from another product-defense firm, Roth Associates in Rockville, Md., and the University of Illinois published a reanalysis of a 10-year-old CDC study. By changing some key parameters, the authors raised the estimates for the background rate of lung cancer so that the elevation caused by beryllium was no longer statistically significant. (This procedure is rather easily accomplished, whereas the opposite—turning insignificance into significance—is extremely difficult.) Brush Wellman and NGK Metals, a producer of beryllium alloys, had funded the research. The new analysis was published in *Inhalation Toxicology*, a peer-reviewed journal—not one primarily focused on epidemiology but peer-reviewed nonetheless—and the industry now touts its study as evidence that everyone else is wrong.

Many corporations have avoided expense by STALLING PROTECTIONS for public health.

This pattern is not unique to the beryllium industry. Many other companies that produce hazardous chemicals have hired researchers to dispute and reanalyze data showing adverse health effects. Their conclusions are almost always the same: the evidence is ambiguous, so regulatory action is unwarranted. Out of the almost 3,000 chemicals produced in large quantities (more than one million pounds annually), OSHA enforces exposure limits for fewer than 500. In the past 10 years the agency has issued new standards for a grand total of two chemicals; the vast majority of the others are still "regulated" by voluntary standards set before 1971, when the newly created agency adopted them uncritically and unchanged. New science has had no impact on them. I conclude that successive OSHA

administrators have simply recognized that establishing new standards is so time- and labor-intensive, and will inevitably call forth such orchestrated opposition from industry, that it is not worth expending the agency's limited resources on the effort.

Emphasizing uncertainty on behalf of big business has become a big business in itself. The product-defense firms have become experienced and successful consultants in epidemiology, biostatistics and toxicology. In fact, it is now unusual for the science behind any proposed public health or environmental regulation *not* to be challenged, no matter how powerful the evidence. Currently representatives of indoor tanning salons are hard at work disparaging the designation of ultraviolet radiation as a cause of skin cancer. Furthermore, the denial of scientific evidence and the insistence on an impossible certainty are not limited to business interests. For instance, some zealous environmentalists remain adamantly opposed to food irradiation—the use of gamma rays, x-rays or electron beams to kill microbes in meats and produce—even though the benefits of the practice greatly outweigh the risks.

PPA and Vioxx

THE POWER OF COMPANIES to influence and distort research is also strong in the pharmaceutical industry. Consider the Food and Drug Administration's belated clampdown on phenylpropanolamine (PPA), the over-the-counter drug that was widely used as a decongestant and appetite suppressant for decades. Reports of hemorrhagic strokes in young women who had taken a PPA-containing drug began circulating in the 1970s. Over the next 20 years, the FDA raised questions about PPA's safety, but the trade association representing the drug's manufacturers—including Bayer, Sandoz (now part of Novartis), Wyeth and GlaxoSmithKline—rejected the agency's concerns, employing scientists and lobbyists to keep PPA on the market. Eventually a compromise was reached that allowed the companies to select an investigator and fund an epidemiological study whose design would be approved by both the manufacturers and the FDA. They chose the Yale University School of Medicine; in 1999 the study confirmed that PPA causes hemorrhagic stroke.

Did the manufacturers withdraw the drug, which by then had annual sales of more than $500 million? No. Instead they turned to the Weinberg Group, a product-defense consulting firm based in Washington, D.C., to attack the study and had their attorneys put the researchers through grueling legal depositions. David A. Kessler, former head of the FDA and now dean of the University of California at San Francisco School of Medicine, said, "With the amount of hassle and harassment that [the Yale scientists] had to endure, I'm sure the next time they're asked to undertake something like this, they'll wonder if it's worth the cost." The FDA finally advised manufacturers to stop marketing PPA in November 2000. The agency estimates that the chemical caused between 200 and 500 strokes a year among 18- to 49-year-old people.

Or consider rofecoxib, more commonly known as Vioxx,

GOVERNMENT AGENCIES have been slow to act even in cases where the evidence for stricter regulation is overwhelming.

the once popular pain reliever made by Merck. Even before the FDA approved Vioxx in May 1999, the agency had reviewed data suggesting that the drug could increase the risk of heart disease. Several independent scientists (that is, ones not on Merck's payroll) also raised red flags, but for the most part the FDA ignored them. Then, in early 2000, the results of a clinical trial showed that participants who took Vioxx for an average of nine months had five times the risk of heart attack as those taking the comparison painkiller, naproxen (sold under the brand name Aleve).

Merck's scientists faced a dilemma. They could interpret this finding to mean either that Vioxx increased heart attack risk by 400 percent or that naproxen reduced the risk by an astounding 80 percent, making it about three times as effective as aspirin in protecting the cardiovascular system. Unsurprisingly, the company's researchers chose the latter interpretation. But Merck abruptly turned about and took Vioxx off the market last September when another trial found that participants taking the drug for more than 18 months suffered twice as many heart attacks and strokes as those taking a placebo. One FDA analyst estimated that Vioxx caused between 88,000 and 139,000 heart attacks—30 to 40 percent of which were probably fatal—in the five years the drug was on the market.

Although the *Wall Street Journal* has reported that certain documents suggest that Merck executives were aware of the increased risk of heart attacks, it is hard to imagine that the company's scientists were deliberately promoting a drug they knew was unsafe. At the same time, it is hard to imagine they honestly thought naproxen reduced the risk of heart attack by 80 percent. If they did, they should have urged the government to pour it straight into the water supply. It seems more likely that their allegiances were so tightly linked with the products they worked on, as well as the financial health of their employers, that their judgment became fatally impaired. And the FDA? That agency has neither the legal authority nor the resources to effectively identify the adverse outcomes caused by drugs already on the market.

As a result, civil lawsuits have become the primary means for protecting the public from unsafe drugs and chemicals. Recent rulings of the U.S. Supreme Court, however, have made it harder for plaintiffs to introduce scientific testimony to support their cases. Under the precedents set by *Daubert v. Merrell Dow Pharmaceuticals* and two related rulings, federal trial judges are now required to determine whether the testimony is reliable and relevant. What began as a well-intentioned effort to improve the quality of scientific evidence has had troubling consequences: according to an analysis pub-

THE AUTHOR

DAVID MICHAELS is an epidemiologist who served as the U.S. Department of Energy's assistant secretary for environment, safety and health from 1998 to 2001. He is currently professor and associate chairman in the department of environmental and occupational health at the George Washington University School of Public Health and Health Services.

lished in 2002 in the *Journal of the American Medical Association,* federal judges have barred respected researchers from testifying in drug lawsuits because their evidence—such as medical case reports and toxicological studies on animals—did not meet the strict new standards. Corporate defendants have become increasingly emboldened to challenge any expert testimony on the grounds that it is based on "junk science."

Data Quality

INDUSTRY GROUPS have tried to manipulate science no matter which political party controls the government, but the efforts have grown more brazen since George W. Bush became president. I believe it is fair to say that never in our history have corporate interests been as successful as they are today in shaping science policies to their desires. In 2002, for example, the Bush administration remade a committee that advises the CDC on the issue of childhood lead poisoning. Secretary of Health and Human Services Tommy Thompson replaced prominent researchers with individuals more likely to side with the lead industry. (One new member had testified on behalf of the lead paint industry in a suit brought by the state of Rhode Island to recover the costs of treating children with lead poisoning and cleaning contaminated homes.) Since then, the CDC has not moved to strengthen the federal standards for lead poisoning despite research showing that even very low levels of lead in the blood can sharply reduce a child's IQ.

What is more, this administration has tried to facilitate and institutionalize the corporate strategy of manufacturing uncertainty. Its most significant tool is the Data Quality Act (DQA), a midnight rider attached to a 2001 appropriations bill and approved by Congress without hearings or debate. The DQA authorized the development of guidelines for "ensuring and maximizing the quality, objectivity, utility, and integrity of information." This sounds harmless, even beneficial; who wouldn't want to ensure the quality of government-disseminated information? In practice, however, industry groups use the DQA to slow or stop attempts at regulation by undercutting scientific reports. The law gives corporations an established procedure for killing or altering government documents with which they do not agree. It has been used by groups bankrolled by the oil industry to discredit the National Assessment on Climate Change, a federal report on global warming; by food industry interests to attack the World Health Organization's dietary guidelines, which recommend lower sugar intake to prevent obesity; and by the Salt Institute to challenge the advice of the National Institutes of Health that Americans should reduce their salt consumption.

Even better for industry would be a way to control information *before* it becomes part of an official government document. To accomplish this tantalizing goal, in August 2003 the Office of Management and Budget (OMB) rolled out a new proposal entitled "Peer Review and Information Quality." Under the plan, all covered information would undergo some form of peer review before being issued by a government agency, and any information that might affect major regulations or that could have a "substantial impact" on public policies or private-sector decisions would be put through a cumbersome system in which the information was reviewed by experts independent of the agency. Because the proposed peer-review process would exclude all scientists receiving grants or contracts from the agency, it seemed designed to maximize the ability of corporate interests to manufacture and magnify scientific uncertainty.

Enough was enough. In November 2003 the usually quiescent science community finally rose up in protest at a meeting sponsored, at the OMB's request, by the National Academy of Sciences. In the face of this opposition—dozens of organizations fired off scathing letters to the White House—the OMB retreated and implemented a less onerous program that did not exclude the most qualified scientists from the peer-review process.

A new regulatory paradigm is needed, but the Bush administration is heading in the WRONG DIRECTION.

A new regulatory paradigm is clearly needed, but the Bush administration is heading in the wrong direction. Instead of encouraging industry groups to revise the reports of government scientists, agencies should be focusing more scrutiny on the data and analyses provided by corporate scientists and product-defense firms. And instead of allowing uncertainty to be an excuse for inaction, regulators should return to first principles: use the best science available but do not demand certainty where it does not exist.

A good example of such an approach is the program to provide compensation for weapons workers sickened after exposure to radiation or chemicals at DOE sites. (I helped to design the initiative, which was enacted by Congress in 2000.) Because it is impossible to definitively determine whether a particular cancer has been caused by radiation exposure, the program estimates probabilities based on the cancer rates among survivors of the nuclear blasts at Hiroshima and Nagasaki. The model is not perfect, but the estimates are as accurate as the available data and methods allow.

In that case, we did the right thing. Now it is time for industry to do the right thing. We need a better balance between health and money. SA

MORE TO EXPLORE

Deceit and Denial: The Deadly Politics of Industrial Pollution. Gerald Markowitz and David Rosner. University of California Press, 2002.

Science for Judges I–III. Edited by Margaret Berger. *Journal of Law and Policy,* Vols. 12–13; 2003–2005. Available online at **www.brooklaw.edu/students/journals/jlp.php**

More information about the use of scientific evidence in public policy is available at **www.DefendingScience.org**

HYBRID VEHICLES

Lean *and* Mean

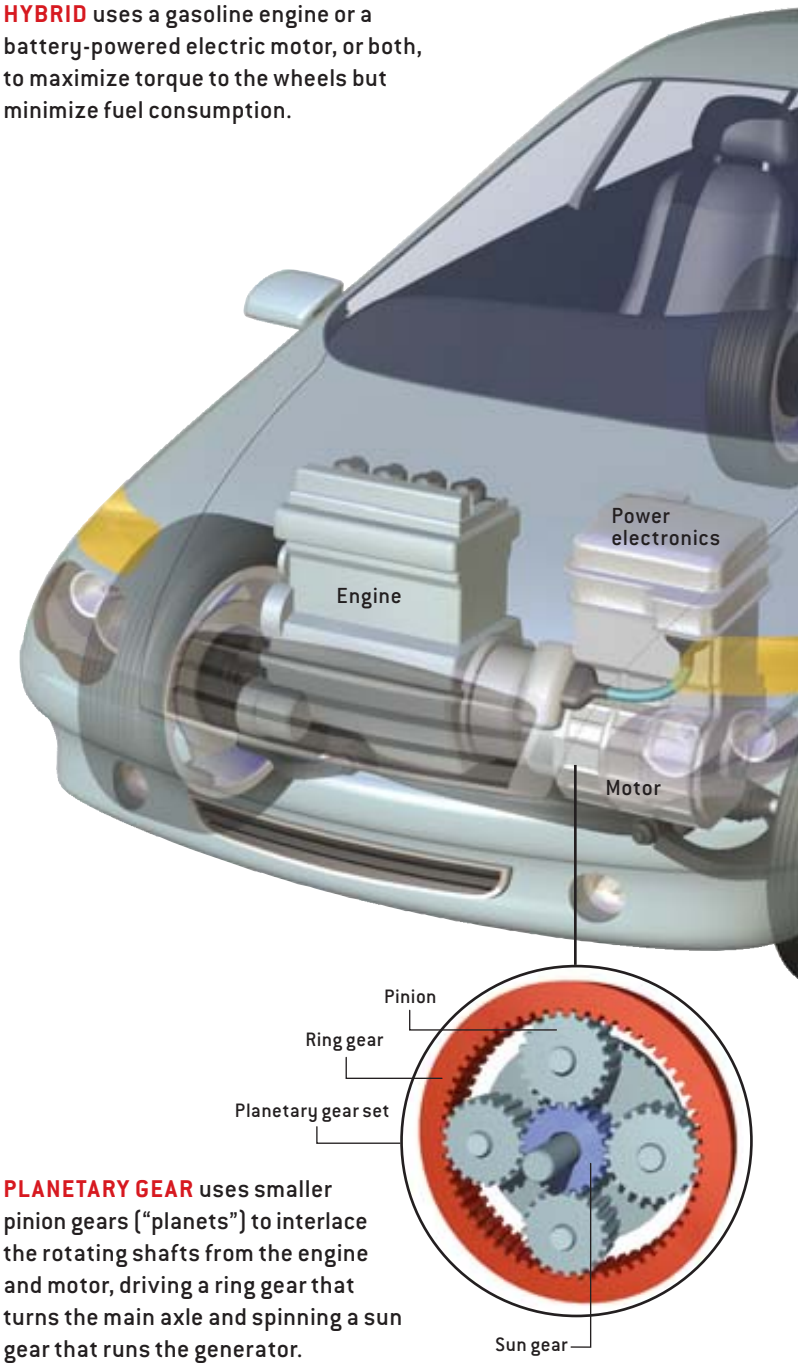
Hybrid cars made a dent in the market by offering superior fuel economy. Now they're poised for a bigger impact based on performance.

A "full hybrid" like the Toyota Prius saves gasoline in several ways. When the car stops—at a light or in traffic—the engine shuts off, and the batteries and electric motor run the vehicle's systems. When it is time to proceed, the motor propels the vehicle until efficient engine operation is possible, from 10 to 40 miles per hour. During hard acceleration or at higher speeds, the motor and engine operate together; a computer controller adjusts gear ratios between them so the transmission works at maximum efficiency, saving fuel. "The key is the controller, which makes sure all the pieces play nice together," says David Hermance, executive engineer for environmental engineering at the Toyota Technical Center in Los Angeles. In a "mild hybrid" or "hybrid assist," like the Honda Insight, a small motor helps the engine but cannot propel the car on its own. (Illustrations represent full hybrids.)

The downside is price. Hermance says the Toyota, Honda and Ford vehicles cost $2,500 to $3,500 more than comparable, nonhybrid models. This premium has limited sales to U.S. consumers, because few have shown they will pay up front for fuel savings later. But the equation is changing. The 2005 Prius averages 55 miles per gallon. For gasoline at two dollars a gallon, an owner will recover the added purchase expense in about four years and save money afterward—a more tempting deal.

More important to U.S. drivers, engineers are using the improving electronics, motor and gearing to add muscle. Earlier hybrids were sluggish, but Hermance says the 2005 Prius accelerates just as quickly as conventional competitors. The 2006 Lexus RX400h hybrid goes from zero to 60 miles per hour in under seven seconds—a full second faster than the nonhybrid. According to *Consumer Reports*, the 2005 Honda Accord hybrid reaches 60 miles per hour a half-second faster and has 15 more horsepower than the regular model, even with the added battery and motor weight. "Americans value performance and will pay for it," Hermance says. —*Mark Fischetti*

HYBRID uses a gasoline engine or a battery-powered electric motor, or both, to maximize torque to the wheels but minimize fuel consumption.



PLANETARY GEAR uses smaller pinion gears ("planets") to interlace the rotating shafts from the engine and motor, driving a ring gear that turns the main axle and spinning a sun gear that runs the generator.

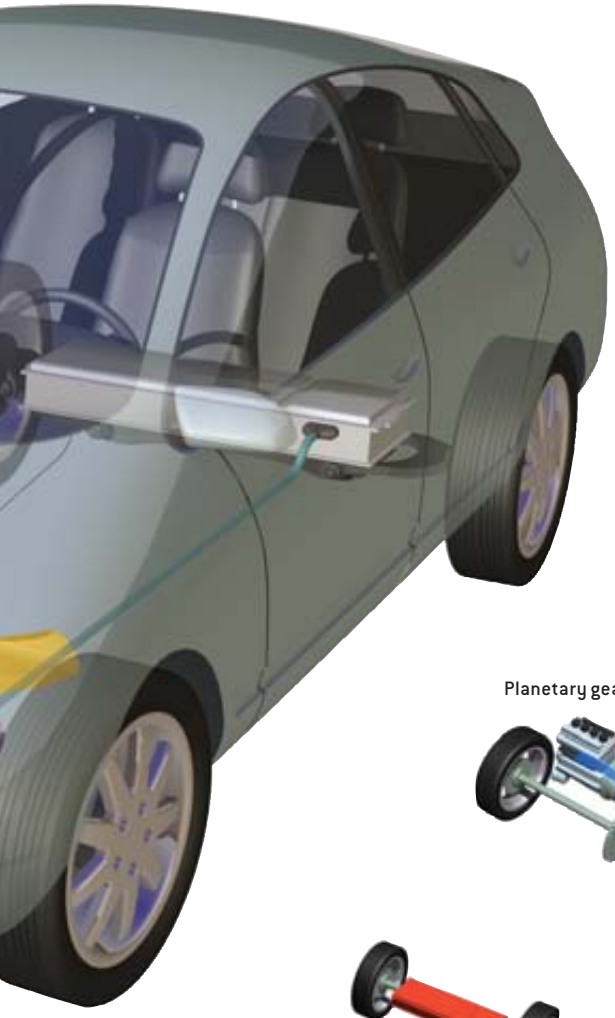
GEORGE RETSECK

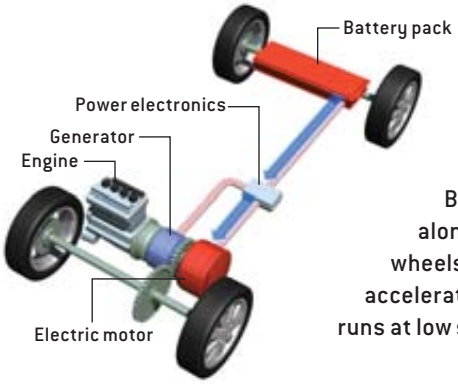
DID YOU KNOW...

- PICK A VOLTAGE: Batteries in the Honda Insight and Civic hybrids produce direct current at 144 volts, those in the Toyota Prius at 202 volts, the Lexus RX at 288 volts and the Ford Escape at 300 volts. The motors and generators typically operate at battery voltage but in some models function at around 500 volts, so power-integrated circuits boost the supply. A converter also steps the battery feed down to the 12-volt level at which most interior amenities operate.

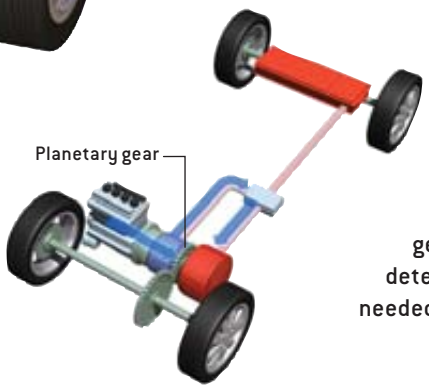
- COOL CHEMISTRY: Hybrid battery packs consist of many small cells connected in series, bound tightly into a block the size of a small suitcase that is stuffed behind or underneath the backseat. Most systems are nickel metal hydride and are cooled with air drawn from the passenger compartment with a fan. In cold weather, heat is pulled in instead. "Batteries prefer 20 to 30 degrees Celsius," Toyota's Hermance says, "just like people."

- WELL-TO-WHEEL: The overall fuel efficiency and environmental impact of any transportation mode include extracting or producing the fuel, getting it to the vehicle and consuming it on board. Calculations of this so-called well-to-wheel efficiency by various experts put hybrids at the top of automobile types. Representative numbers from the American Society of Mechanical Engineers tell the tale: gasoline, 19 percent; all-electric, 21 percent; hydrogen fuel cell, 27 percent; gasoline-electric hybrid, 32 percent.

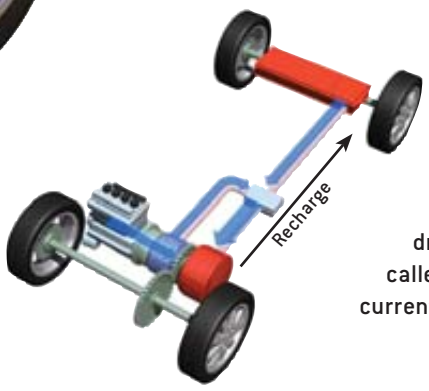




START-UP: Batteries and motor alone power the wheels when a hybrid accelerates from a stop or runs at low speeds.



CRUISING: During routine driving, engine output is split via planetary gear to the wheels and to a generator that powers the motor. A computer controller determines which mix maximizes the efficiency or torque needed, adjusted by power electronics.



ACCELERATION: For hard acceleration, the batteries add extra boost to the motor. During deceleration the motor reverses, becoming a generator that adds drag to the drivetrain and turns friction into current that recharges the batteries (a procedure called regenerative braking). The generator converts some engine power into recharging current if batteries become too depleted.

Topic suggested by reader Shwetal Patel.
Send ideas to workingknowledge@sciam.com

The Multipath to Clarity

RECEIVING HDTV OVER THE AIR TAKES LUCK AND LOTS OF PATIENCE BY PHILIP YAM

Keep the antenna level. Rotate it 90 degrees. Move it a few inches to the left. Stand to the right. Hold it a bit higher … there—nope. Try again.

That has been my high-definition television (HDTV) experience. I plunged into the alphabet-soup world of digital television (DTV) in 2003, shortly after I replaced my electron-gun boob tube with a 42-inch plasma flat panel. I hoped to enjoy beautifully crisp images—only to see what a lousy picture my Manhattan cable company was piping in. The larger screen amplified flaws in the analog signals, which not only produced images muted in detail and color but also added faint lines and speckles, not to mention scratchy audio. I was too cheap to fork over the $15 monthly fee for digital cable, which included only a few HDTV channels anyway. So I decided to snag the signals over the air, just like the old days.

Local stations around the country are making the change to digital, thanks to a 1997 Federal Communications Commission mandate (see www.dtv.gov). To smooth the transition, the FCC allows broadcasters to deliver both analog and digital signals over the TV spectrum (channels 2 to 69). If you can get standard over-the-air television, the mantra goes, then you can get digital.

So I spent some $300 for a set-top box, the Samsung SIR-T351 HDTV receiver, and then rooted around in one of my storage bins for the right antenna. Broadcasters in my area beam DTV on the UHF band (channels 14 to 69), so I grabbed the outline bow-tie antenna. (Rabbit ears work for the VHF channels 2 to 13.) I laid the bow tie against my west-facing window, trying to catch the signals originating from transmitters atop the Empire State Building a mile to the north. I turned on the receiver and watched my TV screen flash to life—with a "No Signal" message.

Actually the problem was too many signals. Reception in cities is notoriously bad, because the broadcast bounces around as it strikes the tall buildings. As a result, signals arrive at an antenna along many paths and at different times. The receiver has to sort through this mess and figure out which signal to lock on to. It's like trying to identify the real lightbulb in a hall of mirrors.

DIRECT TV: To capture high-def signals, it is best to have a view of the transmitter. Good luck if you don't.

JOHN FRASER

In analog TV, such multipath distortion shows up as ghosts. As a kid, I used to tweak the antenna continually and maybe even pound the top of our TV's wood cabinet. Reception did not have to be perfect: I could still follow *Get Smart* through the multiply warped images.

No such luck with digital, which is all-or-nothing: if the multipath problem is severe, the tuner will not produce any image or sound whatsoever. The only recourse I had was fiddling with the antenna (plasma TVs are too thin to pound). I managed to pull in digital broadcasts of WPIX (channel 33) and WABC (channel 45) and only sporadically at that.

I had stumbled headlong into the problem identified in the late 1990s by the Sinclair Broadcast Group, based near Baltimore. The company conducted field tests suggesting that indoor reception may not be possible. The U.S. transmission format is called 8-VSB (for 8-level vestigial sideband), which is more susceptible to multipath distortion than the European system, called coded orthogonal frequency division multiplexing, or COFDM. The 8-VSB format requires less power to broadcast and packs in more data each second (19.4 megabits compared with 18.66 for COFDM)—useful for "datacasting" services. But 8-VSB did so poorly in multipath environments that Sinclair urged the FCC to switch.

TECHNICALITIES

UHF ANTENNAS vary in sensitivity and selectivity depending on the design. Clockwise from left: a four-bay bow tie (about $70); the Silver Sensor (sold under various brands, $40); and a simple outline bow tie ($4).

Although my experiences echoed Sinclair's findings, I figured I should give 8-VSB an honest shot with a better antenna. Based on posts on the AVS Forum (www.avsforum.com), a consumer electronics board, I tried the Gemini Silver Sensor. Looking like a miniature rooftop Christmas-tree antenna, this indoor model is supposed to be a ghost buster.

I also sought help from www.antennaweb.org, which recommends an antenna based on street address. The site shows the channels that you can receive and the direction to point your antenna. It told me to aim at the Empire State Building, which I knew couldn't work—too many intervening buildings. The only way I could receive HDTV was to capture a strong reflected signal.

In the antenna world, bigger is often better, so I also tried something more radical and not particularly aesthetic: an outdoor UHF antenna, used indoors. Called a four-bay bow-tie antenna, it spans about two feet by three feet—among the more compact types of roof antenna. (Even so, you had better have an exceptionally understanding family.) Sure enough, it enabled me to pick up WNBC.

Still, reception was sporadic. I would stand in the corner of the room, moving the cumbersome antenna slightly this way and that as the receiver teased me with moments of signal lock. At other times, I located a sweet spot and left the antenna in place, only to lose the channel when the weather changed.

In January I suddenly picked up WCBS with my Silver Sensor pointed south. Then came WWOR, followed by WNYW after I put the antenna on top of a couple of boxes stacked on a speaker. Finally, I could pick up all the channels being transmitted from the Empire State, albeit with some effort. Something had changed. I looked down the avenue and saw an apartment tower going up a few blocks south. New York City's ever changing skyline had redirected HDTV toward me, at least for the moment.

I live on the 11th floor, and I cannot imagine that those closer to street level will be able to pick up local stations reliably, a fact that could be important once broadcasters cease analog transmissions. At that time they will give up channels 52 to 69. Four of those will go to public safety; the others will be auc-

TERK BY AUDIOVOX (*left*); ZENITH (*right, top*); RADIOSHACK (*right, bottom*)

tioned off for wireless services. The target turn-off date is December 31, 2006, on the condition that 85 percent of the market served by the broadcasters can get digital (2009 or 2010, realistically). Unfortunately, the 85 percent figure counts those who have the equipment even if they cannot receive DTV because of multipath distortion. In sticking with 8-VSB, the FCC gambled that improving technology would save the day.

It is shaping up to be a smart bet, as receivers get better: first-generation models handled ghosts that lagged the main signal by no more than 10 microseconds and were no stronger than half the main signal. New circuitry made by LG Zenith can cope with time differences of 90 microseconds and multipath signals as strong as the main one, the company claims. Its performance convinced Sinclair to drop its objections to 8-VSB. As of this past March, however, LG had not offered these units for sale.

New antennas may also help. Dotcast, based in Kent, Wash., designed an active E-field antenna, which is being marketed by Winegard Company and Terk Technologies. It looks like a mini version of the radar antenna on vintage aircraft carriers. A special amplifier inside boosts only the electric field signal picked up by the antenna, Dotcast says, while ignoring other radio-frequency waves. The narrow, 27-inch-long Dotcast antenna, which should be available this year for about $120, is supposed to function as well as a five-foot-long roof antenna.

HDTV does not transform the viewing experience the way TiVo and DVDs do. And there are growing pains. On WCBS football games, some on-screen graphics did not show up. A space shuttle launch momentarily appeared during a high-def broadcast of ABC's *Desperate Housewives* (it was not a lame sex joke). But once you see the clarity and color and hear the digital 5.1 sound, there's no turning back. I want my HDTV. I just wish it were easier to get. SA

A Customer Base of One

PERSONAL FABRICATORS AIM AT LETTING YOU MANUFACTURE YOUR OWN PRODUCTS **BY GEORGE JOHNSON**

FAB: THE COMING REVOLUTION ON YOUR DESKTOP—FROM PERSONAL COMPUTERS TO PERSONAL FABRICATION
by Neil Gershenfeld
Basic Books, 2005 ($26)

Thirteen years ago I unboxed my new Apple Macintosh, plugged it into the phone line, and discovered the existence of another world. Spirited, unruly discussions on everything from quantum physics to punk rock ebbed and flowed across a borderless electronic forum called Usenet. Anyone anywhere could join in. More definitive sources of information—how to combat an infestation of pine-tip moths, join two boards with a dado joint or locate the great nebula in Orion—resided among a far-flung collection of computers called Gopher servers, a precursor to the World Wide Web. So much had been happening beyond my awareness. I felt like an African bushman turning on a radio for the first time.

It wasn't just words and pictures that had been lurking out there. With the chirps and squawks of modem tones, I could download animated clocks, perpetual calendars, a gizmo that made my keyboard clack and ding like an old Smith Corona typewriter. Legions of amateur programmers were creating and distributing, largely for their own amusement, a multitude of virtual machines.

I hadn't thought of it this way until I read Neil Gershenfeld's new book, *Fab: The Coming Revolution on Your Desktop—From Personal Computers to Personal Fabrication,* but I was witnessing the revival of a spirit that had been fading since the Industrial Revolution: that of the artisan. While corporations like Microsoft and Oracle were employing droves of programmers to homogenize products for the mass market, these technological craftsmen were working on a personal scale. Crafting their code in home workshops, they enjoyed the same satisfaction that comes from building a bookshelf or caning a chair.

Gershenfeld, director of the Center for Bits and Atoms at the Massachusetts Institute of Technology—the futuristic name is quintessential M.I.T.—believes that what is true now for virtual commodities will soon apply to physical ones. Give people personal computers and they can write their own software. Give them devices called personal fabricators and they can make their own things. What this will mark, he predicts, is a return to the days before "art became separated from artisans and mass manufacturing turned individuals from creators to consumers."

Turning the pages, I could barely wait for the revolution to begin. With a smattering of Unix, I have been able to custom-tailor my own virtual machinery—an algorithm that checks in hourly with Amazon, recording the sales rank of my newest book; another that intercepts unwanted e-mail press releases, dispatching to persistent senders increasingly testier replies.

But what about more solid stuff, like the knob that broke off the toaster? Or, even more annoying, all the extraneous, cryptically labeled buttons cluttering the TV remote control, when all I really want is On, Off, Channel, Volume and Mute? With mouse and keyboard, I could describe my needs to a personal

DEFENSIBLE DRESS defines personal space. Inspired by the porcupine, the garment's fringes are actually stiff piano wire controlled by proximity sensors. Designed by Meejin Yoon, a professor in the architecture department at M.I.T. and a student in the author's class "How to Make (Almost) Anything."

COURTESY OF PERSEUS BOOKS

replicator, hit enter, and wait for the product to emerge. If it wasn't quite right, I could tinker and try again. If someone else wanted to make one, I could post the code—the input for the fabricator—on my Web site or e-mail it to friends. The physical world, Gershenfeld promises, will become as malleable as the digital world, and we will no longer have to settle for the imperfect cobbling together of compromises available at the mall.

It was a little disappointing to learn that for now personal fabricators are actually rooms full of expensive equipment called "fab labs." But be patient: a few decades ago a computer equivalent to a laptop weighed tons. In a class Gershenfeld teaches called "How to Make (Almost) Anything," laser cutters, water-jet cutters, numerically controlled milling machines—the kind of tools used in CAD-CAM (computer-aided design and manufacture)—give students the feeling of mastery that comes from taking an idea into the real world. Industrialists use this equipment to make prototypes, exact replicas of items they intend to manufacture. In the fab labs, as Gershenfeld puts it, the prototype is the product. Each is designed for a customer base of one.

A student who had trouble getting up in the morning made her own fiendish alarm clock. Silencing it required touching a series of sensors in exactly the right order, a task certain to rouse her awake. A visitor to the lab, the actor Alan Alda, fabricated an accessory for his digital camera: a flash periscope that raises the bulb high enough that his subjects don't come out looking like red-eyed children of the damned.

Even when a fab lab can be shrunk to the size of a suitcase, most people will probably content themselves with what is offered at Wal-Mart, just as they do with what's on TV. Where the revolution seems likelier to find traction is in the developing world. The best parts of Gershenfeld's book describe his adventures setting up experimental fab labs in places like Ghana and India, encouraging locals to try making tools that are unavailable or unaffordable: portable solar collectors that can turn shafts and wheels, inexpensive electronic gauges farmers can use to measure the quality of their crops, giving them an edge when they haggle with the brokers.

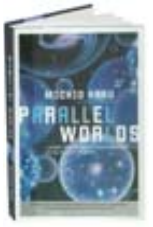
All this may sound utopian, but it is hard not to be taken with Gershenfeld's enthusiasm. Today we have open-source software—all these free Unix and Linux programs streaming through the Net. Imagine a world with open-source hardware. Come up with a really great product, and you can share it with the world—to be hacked and modified by the people who actually use it, warrantied against obsolescence by the irrepressible nature of human ingenuity. SA

George Johnson is a science writer based in Santa Fe, N.M. His recent books include Miss Leavitt's Stars: The Untold Story of the Woman Who Discovered How to Measure the Universe *and* A Shortcut through Time: The Path to the Quantum Computer.

THE EDITORS **RECOMMEND**

PARALLEL WORLDS: A JOURNEY THROUGH CREATION, HIGHER DIMENSIONS, AND THE FUTURE OF THE COSMOS

by Michio Kaku. Doubleday, 2005 ($27.95)



In the end, as our universe is dying, will civilization be able to move to another universe? Kaku, professor of theoretical physics at the City University of New York, thinks the possibility of such a transition appears in "the emerging theory of the multiverse—a world made up of multiple universes, of which ours is but one." Our universe is now expanding. "If this antigravity force continues, the universe will ultimately die in a big freeze." That is a law of physics. "But it is also a law of evolution that when the environment changes, life must either leave, adapt, or die." Moving to another universe is one possibility cited by Kaku. Another is that civilization could build a "time warp" and travel back into its own past, to an era before the big freeze. A third is that "an entire civilization may inject its seed through a dimensional gateway and reestablish itself, in its full glory." Kaku is good at explaining the cosmological ideas—among them string theory, inflation, wormholes, space and time warps, and higher dimensions—that underpin his argument.

EMPIRE OF THE STARS: OBSESSION, FRIENDSHIP, AND BETRAYAL IN THE QUEST FOR BLACK HOLES

by Arthur I. Miller. Houghton Mifflin, 2005 ($26)

Miller, professor of history and philosophy of science at University College London, weaves two stories into one, making this scientific chronicle read like a novel. One story traces the steps whereby black holes came to be accepted in astrophysics as the way many stars end their lives. The other story describes the bitter relations between Subrahmanyan Chandrasekhar (universally known as Chandra), who in 1935 provided the first mathematical description of what later came to be called black holes, and Sir Arthur Eddington, the most prominent astrophysicist of the time.

Chandra presented his theory at a meeting of the Royal Astronomical Society in January 1935. He had discussed the theory with Eddington, who had flirted with the same idea, and supposed that Eddington would support him. Instead Eddington rose at the same meeting to declare that "there should be a law of Nature to prevent a star from behaving in this absurd way!" Eddington's stature was such that his view prevailed. "The encounter cast a shadow over both their lives," Miller writes, "and hindered progress in astrophysics for nearly half a century."

Dim Wits

ACADEMIC EXAMS TAKEN BY TRUE AND FALSE PEOPLE **BY STEVE MIRSKY**

Despite their names—Brightly and Leitner—this is a dark story. Wayne Brightly was a social studies teacher at the John Philip Sousa School in New York City, with a conspicuous record of nonachievement that included multiple failures of his teaching certification exam. Rubin Leitner had spent part of his life homeless and reportedly has Asperger's syndrome, a developmental disorder marked by "an obsessive focus on a subject of interest, poor relationships and communication difficulties"—according to, well, me, in the Anti Gravity of August 2003.

But Asperger's is not necessarily an impediment to brainy accomplishments. As that 2003 column noted, British researchers theorized that Isaac Newton and Albert Einstein both had the condition. Leitner shined intellectually as well, enough to receive an advanced degree in history. Brightly had already enlisted Leitner as a tutor for the former's previous efforts at the teaching exam. Having successfully learned from that failing experience, Brightly allegedly intimidated Leitner into taking the exam in his place last summer. Brightly reportedly paid Leitner two dollars for his services, which would cover a one-way subway trip to the test site.

Brightly's scheme broke down, however, when Leitner did so much better than Brightly had in his prior attempts at the test that authorities got suspicious. In March the cover got blown off of Brightly's caliginous caper, and after getting the third degree he's facing charges of first-degree coercion.

Now, I told you that story so I could tell you this one. There's been something on my chest for more than 25 years that I feel I have to confess, especially as the statute of limitations has surely run out by now: while still misspending my youth, I adopted a false name, learned a fake signature and got paid to take the infamous Scholastic Aptitude Test, or SAT, for someone else.

(Forgive this digression into personal history, but I've been listening to a lot of old Jean Shepherd radio broadcasts, now available on the Web, in which the humorist tells stories based on his own feckless childhood. He also often discusses science—one show is devoted to quarks, one to a contemplation of the seismological effect of millions of people jumping up and down in unison, and one to symmetry theory, in which Shepherd refers to the aforementioned John Philip Sousa: "You can play *The Stars and Stripes Forever* from either end, and it sounds the same.")

Anyway, my transgression would have been far worse had I been taking the SAT for an actual person. But I was enlisted to take part in this scheme by a writer hoping to pose as a freshman at the same university from which he had graduated and discuss the experience from the vantage point of the 30-year-old he then was. He had already gotten a friend in some school system to create a student identity out of thin air. He now needed to get that fictional student some SAT scores to continue to navigate the college entrance bureaucracy.

So one blustery Saturday morning I drove to a school reasonably far from my home turf, to avoid being recognized, and endeavored to put up numbers good enough for admission into the writer's college of choice but not so good as to be memorable. Instead I wound up being stupidly smart, doing better than I was supposed to—when the test results arrived, the writer called me and said, "We're going to jail, you idiot." (He also paid me only half my promised fee, which was still well more than what Leitner got.) In fact, I even did significantly better than when I previously took the SATs for real, for myself. In that first effort I scored much higher on the math side than on the verbal exam, which could explain why these columns may be forgettable, but they almost always exactly meet the assigned count of 650 words. Seriously, they do. SA

ILLUSTRATION BY MATT COLLINS; PHOTOGRAPH BY FRANK VERONSKY

How are past temperatures determined from an ice core?

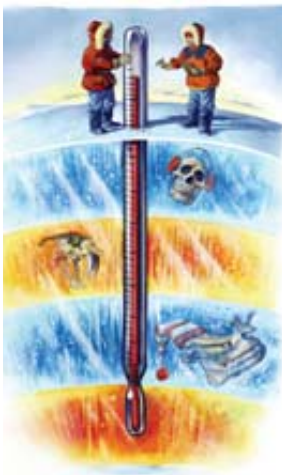
—G. Spencer, Longwood, Fla.

Robert Mulvaney, a glaciologist with the British Antarctic Survey, offers this answer:

Temperature is not measured directly but is inferred from the levels of certain isotopes (chemically identical atoms with the same number of protons but differing numbers of neutrons) of water molecules released by melting the ice cores.

Water is composed of molecules comprising two atoms of hydrogen (H) and one of oxygen (O). The isotopes of particular interest for climate studies are ^{16}O (with eight protons and eight neutrons); ^{18}O (eight protons and 10 neutrons); ^{1}H (with one proton and no neutrons); and ^{2}H (one proton and one neutron, also known as deuterium, D).

Using mass spectrometers, researchers measure the ratio of the oxygen and hydrogen isotopes in ice-core samples and compare the result with the isotopic ratio of an average ocean-water standard known as SMOW (standard mean ocean water). The water molecules in ice cores contain slightly less of the heavy isotopes than SMOW, and the difference compared with the standard is expressed as delta (or change of) ^{18}O or D. Both these values tell essentially the same story—namely, that there is less ^{18}O and D during cold periods than during warm ones. Why? Simply put, it takes more energy to evaporate the water molecules containing heavy isotopes from the surface of the ocean. As the moist air is transported poleward and cools (loses energy), those water molecules containing heavier isotopes are preferentially lost in precipitation.



Plotting either delta ^{18}O or delta D with depth along the length of an ice core can reveal seasonal oscillations in temperature and longer-term shifts in the climate. From the very deepest ice cores, reaching depths of more than three kilometers in the Antarctic ice sheet, we can clearly see the steady pulsing of the ice ages on a period of about 100,000 years. From a site called Dome C in Antarctica, we have recently reconstructed the climate spanning the past three quarters of a million years and have shown seven ice ages, each interspersed with a warm interglacial climate, such as the one we are living in today.

Why do people have different blood types?

—Nichole, Detroit, Mich.

Harvey G. Klein, chief of the department of transfusion medicine for the National Institutes of Health, explains:

The short answer: blood types can aid survival under certain conditions. The specific proteins, glycoproteins and glycolipids found (or expressed) on the surface of red blood cells define blood types, which are inherited. In 1900 Karl Landsteiner described the original classifications—A, B and O—and doctors now recognize 23 blood-group systems with hundreds of different subtypes.

Most such molecules do not seem to be essential for blood cell operation, but some have specific jobs on the red cell membrane. Blood-type factors may be transporters, for instance, allowing materials to enter and exit the red cell, or receptors that permit the binding of certain substances to the cell surface.

Environmental selective pressures clearly play a role in the persistence of some blood types. For example, a "Duffy" blood-type receptor enables certain malarial parasites to enter the red cell. Thus, in some malarial areas of Africa, populations who lack the Duffy blood factor gain a measure of protection against malaria, a distinct survival advantage.

We do not yet know the functions of the A and B blood-group factors. (O blood does not contain A or B factors.) They are probably important in some way, because they appear on many cells and tissues in addition to blood cells and circulate in plasma as well. Also, statistical differences in the frequency of certain malignancies associated with a given A, B or O group suggest that these factors play a role in these diseases. SA

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

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