NUCLEAR WASTE
Yucca Is Dead. Now What?

CELIAC DISEASE INSIGHTS
Clues to Solving Autoimmunity

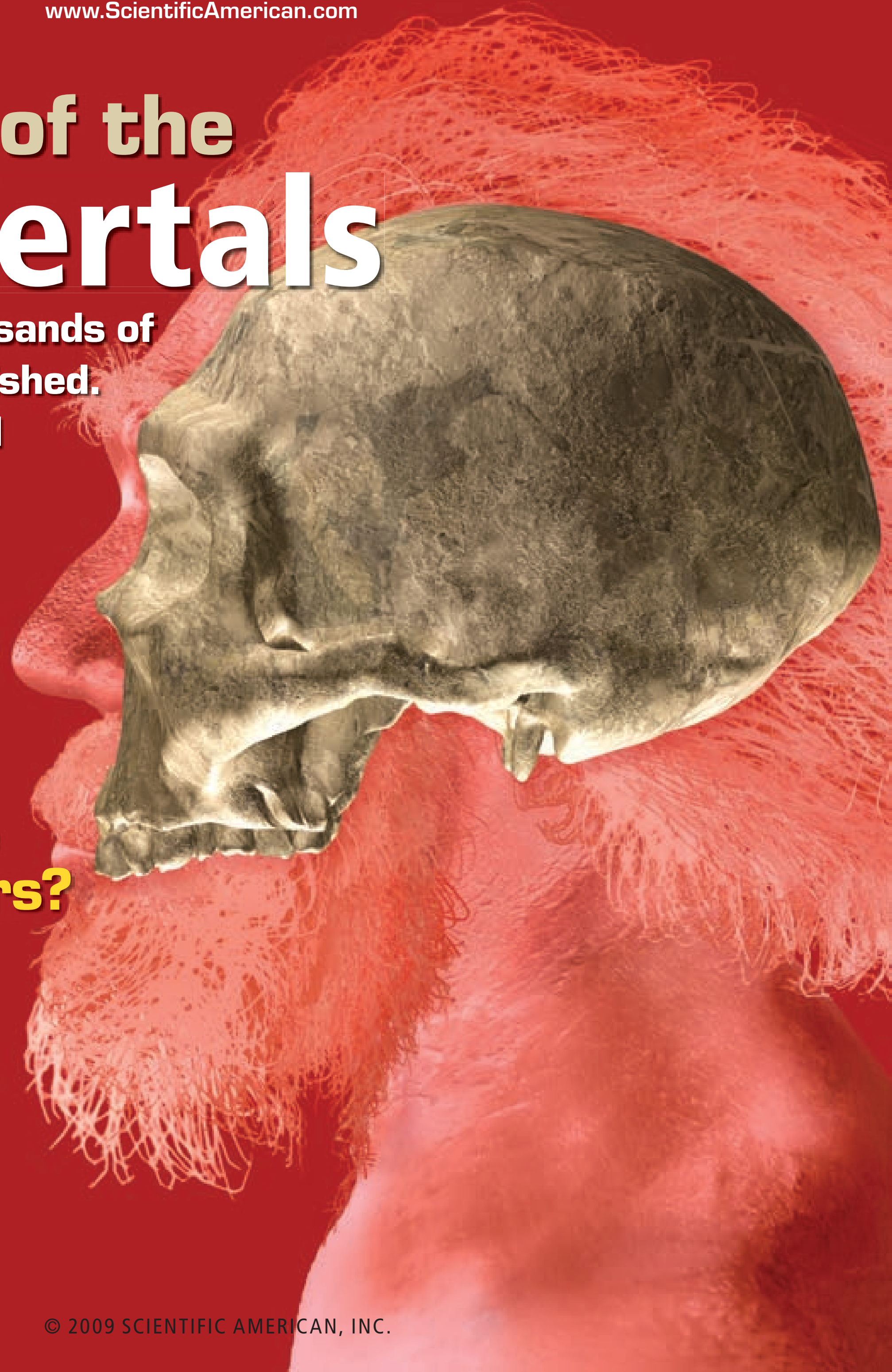
SCIENTIFIC AMERICAN

August 2009 $5.99 www.ScientificAmerican.com

Surprises from General Relativity:
"SWIMMING" IN SPACETIME
page 38

Mysteries of the Neandertals

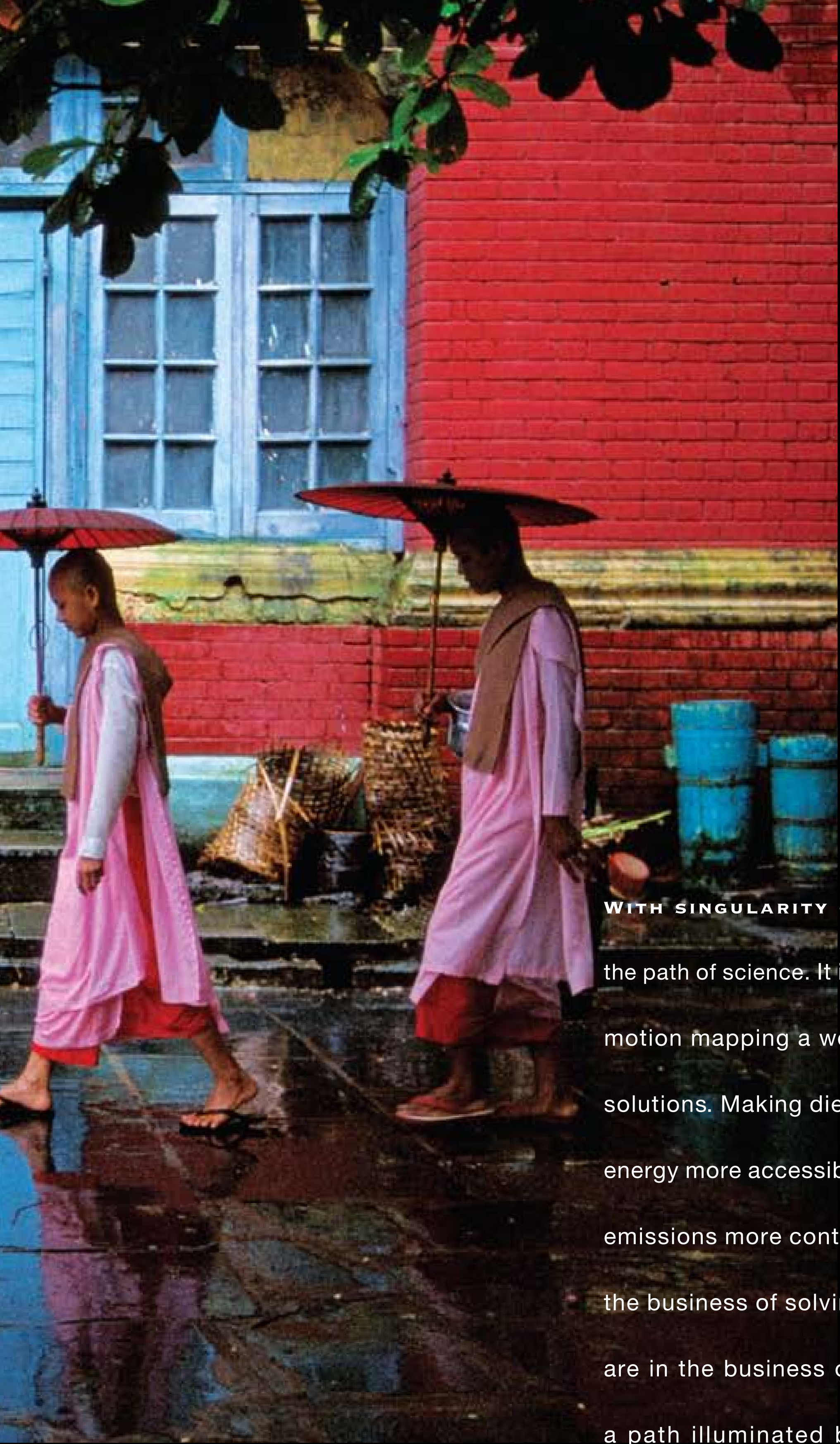
We coexisted for thousands of years before they vanished. Here's what happened



A Way to Reduce Drug Side Effects

Could Iron Reignite Superconductors?

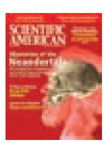

6
Hu
HUMAN
7E+09
www.dow.com/hu
®™ The DOW Diamond Logo and Human Element and design are trademarks of The Dow Chemical Company © 2009



With singularity of purpose. That is the path of science. It is in constant forward motion mapping a world of problems and solutions. Making diesel run cleaner, solar energy more accessible and carbon emissions more containable. Science is in the business of solving problems. And we are in the business of science. Following a path illuminated by the values of the Human Element.

FEATURES

SCIENTIFIC AMERICAN August 2009 ▪ Volume 301 Number 2



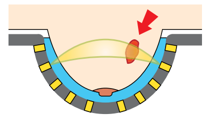
ON THE COVER
Neandertals lived through harsh climate conditions. They made tools and even created symbolic objects. Why did they end up dying out? Image by Jean-Francois Podevin.

In the future, new optical techniques may complement traditional mammograms...

A unique type of mammogram

Getting regular mammograms is very important. But women have long hoped for an easier way to get them. So, Hamamatsu is working to develop a unique new type of mammogram...

One that uses *light* instead of x-rays. And *no breast compression*. A woman simply lies face down on a table and suspends her breast into a cup of warm liquid for maximum comfort.



Shining near-infrared light through the breast can identify tumor locations.

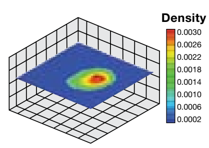
Lining that cup is an array of tiny modules that shine near-infrared light at the breast—and then precisely sense the light that passes through.

By applying unique algorithms to that data, varying with the type of cancer, Hamamatsu is

Hamamatsu is opening the new frontiers of Light

actually able to identify tumors in the breast.

This new principle works by measuring subtle increases in blood volume from the new blood vessels generated by breast cancers. It can even spot changes in tissue structure.



A sliced optical mammogram image from preliminary testing reveals high-density tumor area (red).

For the future, for screening and investigation of breast cancer and as a potential complement to traditional mammograms, Hamamatsu's optical mammography is showing great promise.

For the women of the world, it will be a very welcome development!

http://jp.hamamatsu.com/en/rd/publication/

HAMAMATSU

Photon is Our Business

MORE FEATURES

GO TO SCIENTIFICAMERICAN.COM

IN-DEPTH REPORT: *APOLLO 11* ▼

Forty years after Neil Armstrong, Michael Collins and Buzz Aldrin reached the moon, we look at the harrowing first lunar landing and the Apollo missions that never flew. More at **www.ScientificAmerican.com/aug2009**

COURTESY OF NASA

Slide Show
Top 10 New Species Discovered in 2008
From the smallest sea horse to a naturally decaffeinated coffee tree, newly discovered species show that Earth still has plenty of surprises.

60-Second Solar Blog
What You Really Need to Install Solar Panels: A CPA
If the paperwork-heavy experience of one *Scientific American* editor is anything to go by, a solar boom will create plenty of jobs—in accounting.

Fact or Fiction?
Should We Drink Eight Glasses of Water a Day?
A popular belief holds that healthy people need liquids, even when they are not thirsty.

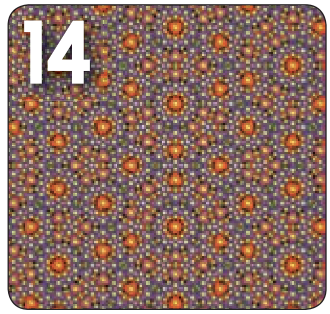
Slide Show
The World's 10 Largest Renewable Energy Projects
From wind and wave to sun and trash, existing power plants are generating electricity from renewable sources on a massive scale.

60-Second Earth Podcast
Is Organic Really Better?
Does consuming organic food truly benefit both eater and environment?

Scientific American (ISSN 0036-8733), published monthly by Scientific American, Inc., 75 Varick Street, 9th Floor, New York, N.Y. 10013-1917. Copyright © 2009 by Scientific American, Inc. All rights reserved. No part of this issue may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying and recording for public or private use, or by any information storage or retrieval system, without the prior written permission of the publisher. Periodicals postage paid at New York, N.Y., and at additional mailing offices. Canada Post International Publications Mail (Canadian Distribution) Sales Agreement No. 40012504. Canadian BN No. 127387652RT; QST No. Q1015332537. Publication Mail Agreement #40012504. Return undeliverable mail to Scientific American, P.O. Box 819, Stn Main, Markham, ON L3P 8A2. Subscription rates: one year $34.97, Canada $49 USD, International $55 USD. Postmaster: Send address changes to Scientific American, Box 3187, Harlan, Iowa 51537. **Reprints available:** write Reprint Department, Scientific American, Inc., 75 Varick Street, 9th Floor, New York, N.Y. 10013-1917; (212) 451-8877; fax: (212) 355-0408. **Subscription inquiries: U.S. and Canada (800) 333-1199; other (515) 248-7684. Send e-mail to sacust@sciam.com** Printed in U.S.A.


nature
At the height of scientific research
Stay informed of the latest research and gain access to landmark specials, news, videos, podcasts and insights. Subscribe today and receive 30% off a 1 year personal subscription!
www.nature.com/SciAmdiscount
nature publishing group npg

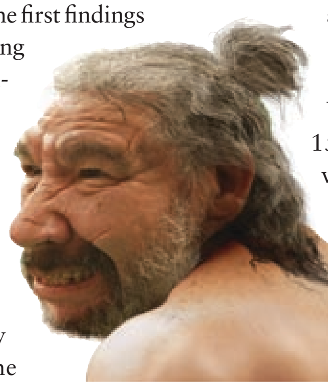
DEPARTMENTS



Species and Spaces

It was August 1856, three years before Charles Darwin would publish *On the Origin of Species*. Workers in a lime quarry in the Neander Valley near Düsseldorf, Germany, unearthed a puzzle in a small cave: a number of ancient-looking bones. Thinking the bones were from a bear, the workers saved some of them for a local schoolteacher and amateur naturalist, Johann Carl Fuhlrott. Fuhlrott later worked with anatomist Hermann Schaaffhausen to study these bones. The two went on to describe and publish the first findings about Neandertals, launching the field of paleoanthropology—and our enduring fascination with this extinct human relative.

Since then, we have learned a lot more about this ancestor from the remains of several hundred additional specimens. Today Neandertals are likely the best known hominid species besides our own—yet they remain mysterious in many ways. Competing theories place them either as an archaic variant of our own species, *Homo sapiens*, with whom we interbred, or as a separate species altogether.



NEANDERTALS, our closest relatives, lived in Europe and western Asia for some 200,000 years.

Either way, Neandertals and *H. sapiens* had much in common. The cranial capacity of Neandertals was about as large as ours. They stood upright, averaging just a few inches shorter than Cro-Magnons, with a heavier build and stronger arms and hands. They dabbled in practices—the creation of finely wrought tools and symbolic objects, including jewelry—that humans do routinely, although they did not achieve our cultural heights. They coexisted with us for thousands of years in Europe before they vanished. They had survived for so long, under harsh environmental conditions, which included long frigid periods. Why did such a durable species die out? And in exploring their regrettable demise, can we get a better understanding of what makes modern humans unique?

As science eagerly awaits the treasure trove of data from the first draft of the Neandertal genome, due later this year, researchers have continued to mine clues from the fossil record to answer those questions. In our cover story, "Twilight of the Neandertals," starting on page 32, staff writer Kate Wong relates the subtle and complex factors that may have caused the species' ultimate collapse. While we also celebrate the 150th anniversary of Darwin's masterwork, there is, perhaps, a larger practical and evolutionary lesson for modern society to draw from the experience of the Neandertals: climate shifts that made their surroundings increasingly inhospitable may have been the ultimate executioner.

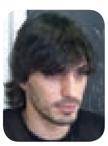
The work of Albert Einstein occurred decades after that of Darwin, but it is no less remarkable in its power to transform our understanding. Some 90 years after the publication of Einstein's theory of general relativity, which showed that gravity arises from spacetime being curved, physicists are still grappling with its implications. Eduardo Guéron explores one of them—the ability to "swim" through a vacuum without needing to push on anything—in "Adventures in Curved Spacetime," beginning on page 38. Based on the latest research, the article offers an armchair journey into the mentally stimulating landscape shaped by Einstein's genius. ■

MARIETTE DiCHRISTINA
acting editor in chief

Among Our Contributors

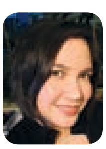
GRAHAM P. COLLINS
is an editor at *Scientific American*. A native of New Zealand, he received his Ph.D. in physics from Stony Brook University in New York State. Follow his tweets at www.twitter.com/gpcollinz

ALESSIO FASANO
directs the Mucosal Biology Research Center and the Center for Celiac Research at the University of Maryland School of Medicine. He studies how intestinal permeability affects autoimmune disorders.



EDUARDO GUÉRON
is associate professor of applied mathematics at the Federal University of ABC in Brazil, where he studies gravitation, dynamical systems and fundamental problems in general physics.

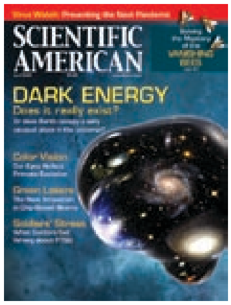
MATTHEW L. WALD
is a reporter at the *New York Times*, where he has covered energy topics since 1979. He has written about oil refining, electricity production, electric and hybrid automobiles, and air pollution.



KATE WONG
is an editor at *Scientific American*. Her first book, co-authored with Donald C. Johanson, is *Lucy's Legacy: The Quest for Human Origins* (Harmony, 2009). See her tweets at www.twitter.com/katewong

ETHAN HILL (*DiChristina*); VIKTOR DEAK (*Neandertal*); COURTESY OF GRAHAM P. COLLINS (*Collins*); COURTESY OF KATE WONG (*Wong*)

PTSD ▪ Expanding Universe ▪ Motion Sickness



APRIL 2009

"The severity of psychiatric illness fluctuates with few visible manifestations, and physicians are neither trained nor well situated for disability determination."
—*Mohinder Partap* ST. LOUIS

Quantifying Quandary

In "The Post-Traumatic Stress Trap," David Dobbs reports on a growing number of experts who believe that post-traumatic stress disorder (PTSD) is being overdiagnosed. In support of this argument, Dobbs cites a 1990s study in which researchers asked veterans "about 19 specific types of potentially traumatic events.… Two years out, 70 percent of the veterans reported at least one traumatic event they had not mentioned a month after returning, and 24 percent reported at least three such events for the first time." These memories are assumed to be "new," but it may be that the subjects simply could not bring themselves to put their experiences into words so soon after those experiences occurred and that after some time they could.

John Dunn
Merrick, N.Y.

As a staff psychiatrist at the St. Louis VA Medical Center for many years (I am currently in private practice), I think concerns about diagnosis of, and disability benefits for, PTSD can be extrapolated to mental illness in general. Psychiatric disability is challenging for the Veterans Health Administration and the Social Security Administration because the severity of illness fluctuates with few visible manifestations, and physicians are neither trained nor well situated for disability determination—they are often conflicted between pursuing treatment that could eliminate disability and encouraging chronic disability so that their patients can receive benefits. PTSD is a good place to start developing procedures and protocols for disability assessment.

Mohinder Partap
St. Louis

Dark Energy Alternatives

"Does Dark Energy Really Exist?" by Timothy Clifton and Pedro G. Ferreira, posits that the apparent accelerated expansion of the universe could be a misconception caused by our living in the center of a giant cosmic void (in which the expansion rate would vary with position, thus making dark energy unnecessary).

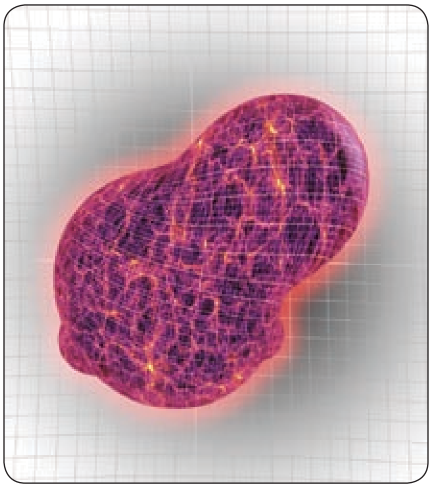
The evidence for the universe's accelerated or uneven expansion is that distant supernovae look dimmer than expected. But could this dimming be explained by a sparse but uniform haze of individual particles? The cosmic microwave background could also be caused by measuring the temperature and distribution of such a haze.

Bill Manzke
Dublin, Ohio

Another explanation for the supernovae dimming could be that light decelerates over time. If light traveled faster in the past, then it would have traveled farther than we think, making its intensity less than expected.

Joel Sanet
Miami

THE AUTHORS REPLY: *What Manzke calls "haze" is usually called dust by astronomers. Lots of dust between supernovae and us could dim the images that* *we measure with our telescopes. But this would mean that distant supernovae would consistently look dimmer as we looked farther and farther away. We can use this as a test because if we look sufficiently far back, the universe was not accelerating (or, alternatively, the supernovae were not in the void), so there will not be the systematic dimming that a haze would produce.*



EFFECTS ATTRIBUTED to dark energy could instead be caused by the uneven expansion of space.

Further, if there were lots of absorption from dust, this would change the spectrum of the light we receive. Astronomers check to see if this is the case.

Hot dust causing the cosmic microwave background is an interesting thought, but it is unlikely to be true. The microwave background radiation is almost perfectly evenly distributed across the sky, and its properties show it was emitted from something in perfect thermal equilibrium. If it were being emitted from dust, it would have a very different spectrum and would be very unlikely to be so perfectly evenly distributed.

Regarding Sanet's letter, the speed of light having a constant value is at the heart of relativity and has been built into modern quantum theories of the fundamental forces. Nevertheless, there are some researchers who have been looking into the possibility that the speed of light could change on cosmological timescales. This would have other implications for cosmological problems and has been used by some to try to explain why the universe looks so smooth on very large scales. But it is very difficult to create a theory in which the speed of light can vary. For now, there is a lot of evidence in support of conventional relativity, and so that is the favored theory.

Balancing Fact?

"Finding Balance," by Brendan Borrell [News Scan], reports on evidence for the theory, posited by Thomas Stoffregen of the University of Minnesota, that motion sickness is caused by poor posture control. Borrell states that Stoffregen hopes to further test his theory by having subjects float in water, where "the human body becomes passively stable, and postural control is no longer an issue," making motion sickness "impossible." I am a frequent scuba diver and have been diving with many who get sick while floating on the surface in rough seas. Less common but still frequent are people who get seasick while underwater in mostly shallow depths of around 25 feet when there is "surge" (back-and-forth water movement).

Chris Albertson
Redondo Beach, Calif.

STOFFREGEN REPLIES: *Motion sickness while floating on the water is not surprising, as people will try to hold their head above the water. When the head is held out of the water, it is not passively stable. More interesting is people having motion sickness while fully submerged in shallow water that is moving. Moving water could lead to unstable control of the body, especially if people are trying to maintain visual contact with something. In this case, water motion would tend to push the body around, destabilizing the attempted visual fixation.*

My proposal for testing our theory is to place people (fully submerged) at neutral buoyancy in calm and stationary water and to show them visual motion stimuli representing things that are effective at making people sick on land. If people get sick underwater but exhibit instability before becoming sick, we would have a confirmation of the theory, together with the disappointing realization that water immersion cannot permit "hard" theory testing after all.

CLARIFICATION "The Post-Traumatic Stress Trap," by David Dobbs, describes Gerald M. Rosen of the University of Washington as a psychiatrist. He is a psychologist.

Letters to the Editor

Scientific American
75 Varick Street, 9th Floor
New York, NY 10013-1917
or editors@SciAm.com

Letters may be edited for length and clarity. We regret that we cannot answer each one. Post a comment on any article instantly at www.ScientificAmerican.com/sciammag

SCIENTIFIC AMERICAN®
Established 1845

PRESIDENT: Steven Inchcoombe
MANAGING DIRECTOR, INTERNATIONAL: Kevin Hause
VICE PRESIDENT, OPERATIONS AND ADMINISTRATION: Frances Newburg

MANAGING DIRECTOR, CONSUMER MARKETING: Christian Dorbandt
ASSOCIATE DIRECTOR, CONSUMER MARKETING: Anne Marie O'Keefe
SENIOR MARKETING MANAGER/RETENTION: Catherine Bussey
SENIOR MARKETING MANAGER/ACQUISITION: Patricia Elliott

VICE PRESIDENT AND PUBLISHER: Bruce Brandfon
VICE PRESIDENT, MARKETING AND SALES DEVELOPMENT: Michael Voss
DIRECTOR, GLOBAL MEDIA SOLUTIONS: Jeremy A. Abbate
SALES DEVELOPMENT MANAGER: David Tirpack
SALES REPRESENTATIVES: Jeffrey Crennan, Thomas Nolan, Stan Schmidt

PROMOTION MANAGER: Diane Schube

VICE PRESIDENT, FINANCE, AND GENERAL MANAGER: Michael Florek
BUSINESS MANAGER: Marie Maher

DIRECTOR, ANCILLARY PRODUCTS: Diane McGarvey

How to Contact Us

SUBSCRIPTIONS
For new subscriptions, renewals, gifts, payments, and changes of address: U.S. and Canada, 800-333-1199; outside North America, 515-248-7684 or www.ScientificAmerican.com

REPRINTS
To order reprints of articles: Reprint Department, Scientific American, 75 Varick Street, 9th Floor, New York, NY 10013-1917; 212-451-8877, fax: 212-355-0408; reprints@SciAm.com

PERMISSIONS
For permission to copy or reuse material: Permissions Department, Scientific American, 75 Varick Street, 9th Floor, New York, NY 10013-1917; 212-451-8877; www.ScientificAmerican.com/permissions or 212-451-8546 for procedures. Please allow three to six weeks for processing.

ADVERTISING
www.ScientificAmerican.com has electronic contact information for sales representatives of Scientific American in all regions of the U.S. and in other countries.

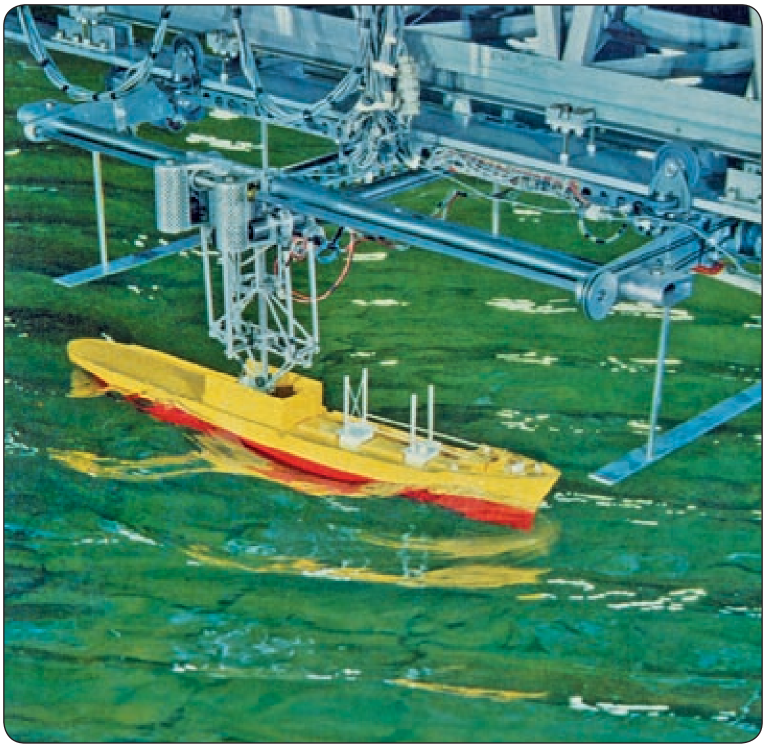
DON DIXON

Making Waves ▪ Flying into History ▪ Looting Gold

Compiled by Daniel C. Schlenoff

AUGUST 1959

WAVES—"Man would like to learn the ways of the waves merely by watching them, but he cannot, because they set him dreaming. Try to count a hundred waves sometime and see. The questions asked by the wave watchers are nonetheless being answered by intensive studies of the sea and by the examination of waves in large experimental tanks. The new knowledge has made it possible to measure the power and to forecast the actions of waves for the welfare of those who live and work on the sea and along its shores. In the large tank at the Stevens Institute of Technology in Hoboken, New Jersey, artificial irregular waves approach the variability of those in the deep ocean. In our photograph, the ship model proceeds under its own power; its motions are recorded by means of the apparatus above it."



SHIP MODEL, five feet long, undergoes tests in a wave tank, 1959

AUGUST 1909

CELESTIAL VISITOR—"The approach of Halley's comet is the most important astronomical event of the years 1909 and 1910. Every seventy-five or seventy-six years this remarkable body completes its far-stretching and extremely elliptical orbit around the sun. It was last seen at the Cape Observatory in May, 1836, but although it vanished from the sight of men, its onward track through space was known with as great accuracy, relatively, as sailors know the way of a ship over the trackless deep. No small emulation is being witnessed between those observatories endowed with large telescopes, as to which one of them will be the first to pick up the returning voyager from far-distant shores."

PROTO-TELEVISION—"Mr. Ernest Ruhmer, of Berlin, well known for his inventions in the field of wireless telephony and telegraphy, has succeeded in perfecting what is probably the first demonstration apparatus which may be said actually to solve the problem of tele-vision. The writer has had an opportunity of inspecting this curious machine immediately before its being sent to Brussels, in order there to be demonstrated before the promoters of the Universal Exhibition planned for next year. In fact, a complete and definite tele-vision apparatus, costing the trifling sum of one and a quarter million dollars, is to be the *clou* of this exposition."

The entire article is available at
www.ScientificAmerican.com/aug2009

BLÉRIOT'S TRIUMPH—"The dramatic flight of Louis Blériot across the English Channel has set a milestone of progress which must forever be memorable. No one, surely, would be so unjust as to belittle this great performance by reference to earlier and longer flights over the land. In point of risk and daring, that bold, early morning dash across the Channel stands in a class by itself. The fact that the first flying machine to cross the Channel was of a monoplane design has raised the prestige of that type."

AUGUST 1859

GOLD GRAVES—"The aboriginal inhabitants of Central America, who occupied it at its discovery by the white men of the East, had a custom of burying their dead surrounded with gold. We learn that new discoveries have been made at David, Chiriqui [in Panama]. There is now a great emigration to these novel 'diggins,' and reports say gold is very profuse. But we are inclined to think that after the country has been so well ransacked in the sixteenth century, there cannot be so much as rumor would have us believe. The images are cast and polished, and exhibit much ingenuity in the modeling. The people by whom such objects were made must have been considerably advanced in civilization. The study of American antiquities will doubtless be advanced by the discovery of these remarkable images, and we think they should be preserved, instead of being thrown into the refiner's melting-pot, like an unfashioned nugget or scaly dust."

SCIENTIFIC AMERICAN, VOL. 201, NO. 2; AUGUST 1959

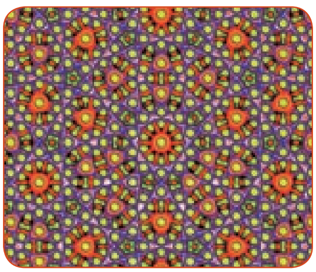
Quasicrystals ▪ Billion-Year Memory Drive ▪ Stem Cells from Proteins ▪ Mars Rovers

Edited by Philip Yam

Natural Quasicrystals

First cooked up in the lab in 1984, quasicrystals are unusual substances that lie somewhere between the crystalline and the amorphous. Specifically, they display ordered arrangements and symmetries but are not periodic—that is, they are not defined by a single unit cell (such as a cube) that repeats itself in three dimensions [see "Quasicrystals"; SciAm, August 1986].

After years of searching, Paul Steinhardt of Princeton University and his colleagues think they have finally found the first natural quasicrystal. They examined substances



QUASICRYSTAL PATTERN cannot be broken down into a unit cell that repeats indefinitely.

chemically similar to quasicrystals that had already been lab-synthesized. That search led them to khatyrkite, a mineral reportedly found in the Koryak Mountains of Russia that consists of an aluminum alloy. A khatyrkite-bearing sample in Italy also contained similar granules of a similar alloy that fit the quasicrystal bill.

Still, some doubts persist concerning khatyrkite's origin, because aluminum alloys do not form easily by natural processes. Steinhardt says that he will continue to consider the various processes that could have formed the sample. "As is often the case for minerals, it is a lot easier to identify and characterize the mineral than it is to explain how it formed," he remarks. Steinhardt's team's work appears in the June 5 *Science*. *—John Matson*

Really Long-Term Memory

Preserving information for future generations has prompted some concern for digital archivists [see "Ensuring the Longevity of Digital Documents"; SciAm, January 1995]. For instance, today's memory cards, holding 10 to 100 gigabits per square inch, last only 10 to 30 years. A solution could lie with an experimental memory device based on an iron nanoparticle that travels inside a carbon nanotube between two electrical contacts; an applied voltage shuttles the nanoparticle between the contacts. The device, described in the June 10 *Nano Letters,* can hold one trillion bits per square inch, and theoretical calculations suggest that the system could remain thermodynamically stable for one billion years. Don't bother with the extended warranty.

All-Protein Mix

Inducing adult cells to revert back to a stem cell state at first required the insertion of four genes, one of which was a cancer gene [see "Potent Alternative"; SciAm, February 2008]. Then scientists figured out a way to make these stem cells without the cancer gene. Now they have gotten adult mouse cells to pluripotency by using only the proteins encoded by the genes. Such a protein-only approach, described in the May 8 *Cell Stem Cell,* ensures that foreign DNA does not unexpectedly integrate into and modify the host cells.

Big Splash

The results of Mars rover Opportunity's two-year exploration of Victoria Crater fills in details about the wet history of Mars ["The Red Planet's Watery Past"; SciAm, December 2006]. In particular, the rover found little spheres of hematite, a form of iron oxide, in Victoria that resembled those found kilometers away. The finding suggests that the conditions that shaped the Martian terrain operated on a regional basis, conclude the researchers in the May 22 *Science.* Opportunity's next target is a crater called Endeavour, nearly 14 kilometers from Victoria. Meanwhile its twin, Spirit, became trapped in soft, sandy soil on the other side of the planet in May. As of mid-June, scientists still had not figured out how to get the rover, which already had a broken wheel, moving again.

CLIFF OF NOTE: This 12-meter-high promontory on the northern rim of Victoria Crater, imaged by Opportunity and shown in false color, holds clues about Mars's wet past.

ERIC HELLER *Photo Researchers, Inc. (quasicrystal)*; COURTESY OF STEVEN W. SQUYRES AND *SCIENCE*/AAAS *(Mars)*

NEWS SCAN

IN THIS ISSUE: High-Speed Rail ■ Dying Bats ■ Climate Errors ■ Salvia ■ Exotic Topology ■ Invisibility ■ "Missing" Link

TRANSPORTATION

The Third Way

Will a boom in government investment bring true high-speed rail to the U.S.? BY MICHAEL MOYER

HIGH LINE: True high-speed rail requires new tracks for the exclusive use of advanced trains, bridges to eliminate road crossings, and tunnels to burrow through hills. The California project pictured above in an artist's conception is expected to cost $65 million per mile to build.

Widespread high-speed rail service, last seen in the U.S. during the Hoover administration (when passenger trains ran faster than they do today), stands ready for its comeback. Last November California voters approved a $10-billion bond toward a rail system that will move passengers the 432 miles between San Francisco and Los Angeles in just over two and a half hours. The federal stimulus package sets aside $8 billion to jump-start rail projects around the country, and the Obama administration has pledged another $1 billion a year for the next five years for high-speed rail.

Infatuations with high-speed rail systems have come to the U.S. before, of course—most recently, Texas and Florida trumpeted regional plans, only to abandon them after a few years. But advocates now see a difference. "It's more than plans this time, it's money," says James RePass, chair of the National Corridors Initiative.

In its quest to build a 21st-century rail network, the U.S. will rely on 20th-century technology. Magnetically levitated trains such as the 19-mile-long Shanghai Transrapid are not under serious consideration. Rather advocates see a potential for systems like those in Japan and Europe, where simple improvements such as dedicated track lines and overhead electrification allow trains to regularly exceed 180 miles per hour. The Japanese Shinkansen ("bullet") trains, for example, average 132 mph between Tokyo and Osaka, a distance of 320 miles. Spain's recently completed AVE line between Madrid and Barcelona covers 386 miles in under three hours; since it started service in February 2008, air travel between the two cities has dropped an estimated 30 percent.

The U.S. is too large to have train service connect the entire country the way it does in Spain and Japan. Instead the U.S. Department of Transportation wants to nurture the development of regional networks. The blueprint is the Northeast corridor, in which Amtrak's Acela Express runs from Boston to New York City and down to Washington, D.C., at an average speed of 80 mph—"high speed" only if one is inclined to grade on a curve. That is fast enough, though, to entice riders concerned about airport delays and highway traffic: Amtrak estimates that the line carries 36 percent of all rail-air traffic between New York and Washington.

Other regions ideal for a high-speed rail network—in which cities are too distant to make driving convenient and too close to make a flight worthwhile—include the Dallas–San Antonio–Houston triangle,

COURTESY OF NC3D

the Floridian triad of Orlando-Tampa-Miami, the upper Midwest Milwaukee-Chicago–St. Louis corridor, and northern and southern California. The federal dollars will go to projects in 10 intrastate regions such as these, connecting cities that are between 100 and 600 miles apart.

A prime goal of these regional networks will be to alleviate travel congestion. In California, for example, a growing population will require an extra 3,000 miles of highway lanes, five large airport runways and 91 airport gates by 2030—improvements that would cost an estimated $100 billion. “That will not happen,” says Quentin Kopp, chair of the California High Speed Rail Authority. “There will be a necessity, a transportation necessity, of using something besides our automobiles.”

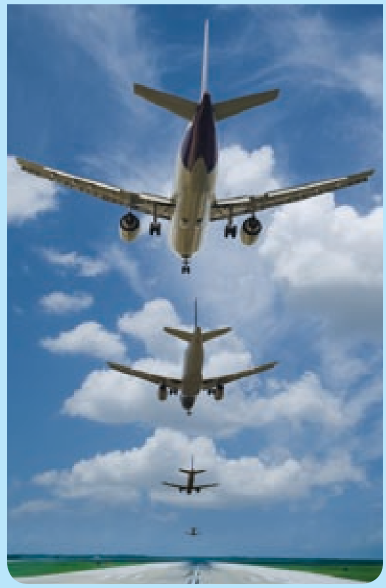
Yet high-speed rail faces tougher challenges in the U.S. than it does in Japan or Europe. The modern geography of the U.S. is based on the Interstate Highway System, and driving here is far cheaper than in other countries. For instance, drivers pay about $90 in tolls during that one-way trip from Tokyo to Osaka, on top of $6.50 a gallon for gas. (The economics may become worse for cars if the U.S. puts a price on carbon—trains are 28 percent more efficient than passenger vehicles on a passenger-per-mile basis.)

In addition, most rail lines in the U.S. are primarily used for freight, and federal regulations, combined with industry practice, discourage passenger trains from exceeding 110 mph on track that freight trains also use. Moving faster than 125 mph requires a rail line akin to a highway—no intersections with road traffic at any point. Hence, true high-speed rail will require miles of new track, elevated above (or sunken below) existing roads, on newly acquired land that cuts the straightest line from A to B. All told, the tab might run from $40 million to $65 million per mile. Although some of the federal money will help start projects with this level of ambition, the rest will be used for more prosaic track and signal upgrades that will squeeze a little extra speed from existing lines.

Critics correctly point out that the rail lines will never make back in passenger fees what they cost to build. Yet neither was the interstate highway system a for-profit venture. It did, however, open the landscape to increased movement of people, goods and ideas. Train advocates hope that high-speed rail will do the same.

The Crowded Skies

Alleviating air traffic congestion is one of the major goals of the new push into high-speed rail. According to a study by the Federal Aviation Administration, without a major overhaul of the air traffic control system, 27 of the 56 largest airports in the country will push past excess capacity by 2025. Even with an overhaul, 14 of them will be over capacity. —*M.M.*



JOE DRIVAS *Getty Images (photoillustration)*

OUTBREAKS

Night Stalker

No end in sight for the bat-killing white nose syndrome BY PETER BROWN

On a summer evening three years ago my wife and I counted 75 little brown bats scrabbling out from behind four small shutters on our house in upstate New York and setting off for a night of insect foraging. A year later the number had swelled to 150; the moth and mosquito populations were becoming less bothersome than ever before. Then things took an abrupt turn for the worse: last year the numbers plummeted, and on a recent summer evening this year only six bats emerged.

The drop would come as no surprise to wildlife biologists in the Northeast. The house is just an hour’s drive from ground zero of the worst disease outbreak in bat populations on record. First observed in Howe Caverns near Albany, N.Y., in early 2006, white nose syndrome has spread north to New Hampshire and Vermont and south to Virginia. At least a million bats in six species have already perished, and death rates at infected hibernacula range between 90 and 100 percent.

Many observers expect a wave of new outbreaks this year, even among previously uninfected bat species (so far the disease seems harmless to humans and other animals). Yet despite widespread concern and media attention, scientists are still trying to figure out exactly what is killing the creatures and are frantically searching for ways to stop it. And because bats are essential to the control of nocturnal flying insects, the outbreak could upset local ecologies, weaken the health of forests and even affect crop yields.

White nose syndrome (WNS) takes its name from a fungus that looks like a white, powdery substance on the muzzles, wings and ears of bats. The fungus, previously unknown to science, has been clas-

sified and named as *Geomyces destructans*. No one has proved it is the killer—it could be just an opportunistic invader taking advantage of some other infection—but many biologists think it is. It grows only between about 36 and 72 degrees Fahrenheit, a relatively cold range for a fungus but typical of the year-round temperatures in the depths of most U.S. caves. So far the only bats infected with the fungus rely on insects for food and on hibernation to survive the insect-free winter months.

According to Marvin Moriarty of the U.S. Fish and Wildlife Service, another piece of evidence that points to the fungus is that when it grows on the wings of the animals, it causes swelling and scarring. The wing membranes are essential for regulating physiological functions such as body temperature and blood pressure. Hibernating bats are already dangerously close to depleting their stored fat reserves before they emerge from torpor. If WNS interferes with their physiology, it could interrupt hibernation and lead the bats to use up more energy than they can afford. In short, they would starve. Supporting this theory is that many WNS victims are also emaciated, and bats from infected caves are unusually active in winter, perhaps in a futile attempt to find food.

To devise a plan to stop WNS, biologists want to know much more about the *Geomyces* fungus—its origins, distribution, mode of transmission and the like—as well as the bats' reaction to it. Such data might, for instance, lead to a vaccine against WNS.

SCOURGE IN THE DARK: **Hibernating bats, here being photographed in an abandoned mine in New York State for conservation purposes, may awaken and then starve to death if infected by white nose syndrome.**

Funds for fighting WNS have been meager, however. A total of only $1.1 million, from government and private funds, has gone to scientific and control efforts since the disease appeared. Yet in testimony before a House subcommittee on June 4, biologist Thomas H. Kurz of Boston University stated that the funding needed to mount a realistic response is at least $17 million. This past May, 25 U.S. Senators and Representatives signed a letter to Interior Secretary Ken Salazar urging emergency funding for agencies with the expertise to "determine a cause and develop solutions to this crisis."

Meanwhile the most visible response to WNS has been to declare caves and mines off-limits to visitors. But whether people are spreading the fungus around is unclear. According to Robert Zimmerman, a caver who has written extensively about the outbreak, the first places WNS appeared in Pennsylvania and West Virginia were "popular recreational caves." Yet WNS has not been detected in other popular caving regions, notably those in Indiana, Tennessee, Alabama and Georgia. David Blehert of the National Wildlife Health Center in Madison, Wis., and his colleagues are working to culture the fungus from the floors and walls of caves, to determine whether clothing and equipment could spread the fungus.

But if the syndrome spreads primarily from bat to bat—as seems the case—closures will have little effect. Unless more answers appear soon, draconian measures such as killing all the bats in infected caves may be all that can keep the spread of WNS from rewriting the ecological rules.

A Bat Disease That's Bad News for Humans, Too

People could soon feel the devastating effects of white nose syndrome (WNS) among bats. The most immediate change may be the number of mosquito bites people get this summer. According to Greg Turner of the Pennsylvania Game Commission, a bat may consume as much as its own weight in insects each night, including mosquitoes. Bat guru Merlin D. Tuttle, who founded Bat Conservation International, notes that bats are the primary predators of pests that "cost American farmers and foresters billions of dollars annually." If WNS spreads to the American South and West, it could also lead to huge losses of crops pollinated by bats. As Turner points out, bats are major pollinators of plantains and avocados and are the sole pollinators of the agave plant; margarita cocktail lovers owe the tequila in their drink to the activities of bats. —***P.B.***

WHITE FUNGUS **is visible around the nose of this little brown bat hibernating in a West Virginia cave.**

MIKE GROLL *AP Photo* (top); JOHN M. BURNLEY *Photo Researchers, Inc.* (bottom)

CLIMATE

Stumbling over Data

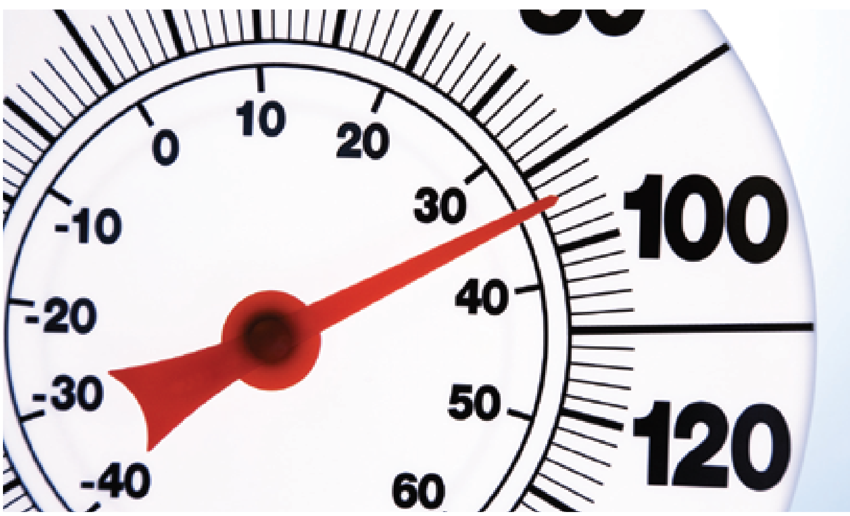
Do minor errors erode public support on climate issues? BY DAVID APPELL

Even as the Obama administration moves ahead with modest plans to tackle global warming, the public relations battle on the issue is as fierce as ever. Some recent scientific stumbles haven't helped. In fact, they have given fodder to climate change skeptics, some of whom have seized on the errors to attack the credibility of scientists and sway public opinion.

Many scientific organizations, such as the NASA Goddard Institute for Space Studies, now put data (some near real-time) on their Web sites. The information ranges from raw numbers from weather stations to computed values of, for instance, monthly global temperature anomalies, which represent temperature deviations from a historical average. Typically researchers make corrections and adjustments as they check equipment and replicate experiments.

In today's politically charged environment, though, these routine corrections have become ammunition in the warming war. For example, last November Internet users found that raw data erroneously replicated from Russian weather stations contributed to a suspiciously high temperature anomaly that Goddard published. Two years ago the blog Climate Audit, run by amateur scientists and self-described "science auditor" Steve McIntyre, found that an error in a computer algorithm had ranked 1998 as the warmest U.S. year, instead of the correct 1934. (The change did not significantly affect global values: 1998 was still the earth's warmest year as ranked by satellites, although Goddard has 2005 as slightly warmer.)

But perhaps the mistake that got the most publicity for skeptics happened in February as an automated system of the U.S. National Snow and Ice Data Center (NSIDC) published information on the extent of Arctic sea ice. It contained a small but strange hitch indicating that enough ice to cover California was suddenly gone. Internet readers pounced, sending e-mails to the center and also to skeptical bloggers such as meteorologist Anthony Watts. His blog, Watt's Up with That?, is read daily by about 21,000 people around the world (according to Quantcast, which compiles Web site statistics), and Watts's



GEORGE DIEBOLD *Getty Images*

BAD READ: **Small errors in temperature data may have influenced the climate debate.**

post about the error mushroomed across the Web. Within hours the NSIDC withdrew the data, ultimately finding that the glitch resulted from a faulty sensor on a satellite. The NSIDC scientists admitted the mistake, corrected the problem using a different sensor and audited all past data.

But the public-relations damage was done. Skeptical bloggers and their readers called the NSIDC's competence into question and accused it of tweaking data. The NSIDC sent out a press release pointing out that real-time data are always less reliable than thoroughly reviewed archived data.

Word of the otherwise prosaic issue spread via news reports, and the NSIDC took its lumps. "We were too naive," admits Walt Meier, a researcher at the center. "We weren't prepared for how closely people were watching." The science community knows that such adjustments happen all the time, he says, but "the undermining of public confidence in our data comes from ignorance of use." But he still believes that open-source data are "ultimately a great thing."

Marc Morano, executive director of the dissenting site Climate Depot, says, "I think the fluctuations and errors of a few data sets are important." But drawing attention to these errors, he argues, is not the main reason skeptics are gaining ground.

Rather he believes that "lack of warming in recent years" has helped his cause—although this decade is the hottest in recorded history, there hasn't been a record-breaking year in 10 years. Moreover, recent papers suggest that natural climate fluctuations might continue to mask the expected warming trend for up to three decades. He also notes the "sheer number of scientists speaking out to dissent for the first time," although a University of Illinois survey in January of some 3,000 scientists found that 97 percent of them think humans play a role in climate change.

Although the scientific case for anthropogenic climate change has never been stronger, the stumbles and the attacks may be influencing a U.S. public that does not fully understand how science works. A poll in May by Rasmussen Reports found 39 percent of voters believe humans are to blame for global warming, down from 47 percent a year ago. These days climate researchers have to scrutinize their work for not only its scientific implications but also for the public-relations ramifications, too.

David Appell is based in St. Helens, Ore.

NEUROSCIENCE

Salvia on Schedule

New rules on a mind-altering herb could slow medical research BY DAVID JAY BROWN

As the source of the most powerful natural hallucinogen known, salvia is drawing scrutiny from U.S. authorities who want to restrict this Mexican herb, now used recreationally by some. But neuroscientists worry that controlling it before studies have determined its safety profile is premature and could hamper research of the drug's medicinal value. Increasingly, evidence is piling up that it could lead to new and safer antidepressants and pain relievers, as well as even help in improving treatments for such mental illnesses as schizophrenia and addiction.

The plant, formally known as *Salvia divinorum,* has a long tradition of shamanic usage by the Mazatec people of central Mexico. Salvinorin A, the primary psychoactive component, is part of a class of naturally occurring organic chemicals called diterpenoids, and it affects neural receptors in the brain similar to those that respond to opiate painkillers such as morphine—but without euphoric and addictive properties. That is because salvinorin A binds mostly to only one type of receptor (the so-called kappa opioid receptor) and not significantly to receptors that could lead to addiction (such as the mu opioid receptor).

ALTERED STATES: **The Mexican herb *Salvia divinorum* contains the most powerful natural hallucinogen known. Scientists think that it could treat several types of mood disorders but worry that regulations could stonewall research.**

EDWARD KINSMAN *Photo Researchers, Inc.*

As the popularity of salvia has risen over the past 16 years—its psychoactive properties were discovered in 1993 by Daniel Siebert, an independent ethnobotanist based in Malibu, Calif.—calls to treat the plant as an illegal drug have grown louder.

Twelve states have recently placed *S. divinorum* in their most restrictive controlled substance category, and four others have laws restricting sales. The U.S. Drug Enforcement Administration has listed salvia as "a drug of concern" and is looking into the drug to determine whether it should be declared a Schedule I controlled substance, on par with heroin and LSD.

The unusual properties of salvinorin A intrigue scientists. Psychiatric researcher Bruce Cohen and his colleagues at Harvard Medical School have been developing analogues of salvinorin A and studying their possible mood-modulating properties. The team's work with salvinorin A in animals suggests "that a drug that would block kappa opioid receptors might be an antidepressant drug—probably a nonaddictive one—or a mood stabilizer for patients with bipolar disorder," Cohen remarks. By activating the kappa opioid receptors, drugs such as salvinorin A could reduce dependence on stimulants and the mood-elevating and mood-rewarding effects of cocaine. Because salvinorin A can produce distortions of thinking and perception, researchers speculate that blocking the receptors might alleviate some symptoms of psychoses and dissociative disorders.

Some investigators, including the team at Harvard, believe that modified forms of salvinorin A could bolster its medicinal value. Tom Prisinzano, a medicinal chemist at the University of Kansas, points out that some chemical transformations of salvinorin A have different pharmacological abilities—such as a longer-lasting action or an enhanced ability to bind to receptors—and no hallucinogenic properties. Modifying its novel structure, he says, "could potentially treat a number of different central nervous system disorders."

But if salvinorin A becomes a federally scheduled drug, research on it would become "much more difficult," predicts Rick Doblin, director of the Multidisciplinary Association for Psychedelic Studies, a nonprofit based in Santa Cruz, Calif. Prisinzano agrees, saying that "there will be a lot more paperwork involved," subsequently making approval for clinical studies harder to obtain. For example, human studies with LSD were essentially blocked for more than 35 years because of federal restrictions, and currently only one human study with LSD is being conducted in the world. As Doblin puts it, approval boards at universities and research institutions view proposals involving criminalized drugs with extreme caution. "And funders are reluctant to look at potentially beneficial uses of drugs of abuse," he adds.

Right now only two labs conduct human studies with salvinorin A: one run by psychiatric researchers Deepak Cyril D'Souza and Mohini Ranganathan, both at the Yale University School of Medicine, and the other by pharmacologist John Mendelson of the University of California, San Francisco. Both groups are performing preliminary tests to determine how best to administer salvinorin A to human volunteers and collect basic data. D'Souza and Ranganathan argue that scheduling the drug should wait until evidence about its effects and toxicity become clear.

The neuroscience community has yet to throw its collective weight behind formal battles against legal restrictions. "This has been more of a simmering back-burner than a flaming front-burner issue. Still, the issue is a serious one, with implications for policy, drug enforcement and research," Cohen says. Many people have begun letter-writing campaigns to their representatives in Washington, D.C. Scientists as much as salvia fans undoubtedly hope that such grassroots activity could eventually alter the government's mind.

David Jay Brown is author of six books about the frontiers of science and medicine, including Mavericks of Medicine *(Smart Publications, 2007).*

TOPOLOGY

Hypersphere Exotica

A 45-year-old problem on higher-dimensional spheres is solved—probably BY DAVIDE CASTELVECCHI

Relax. Until recently, lurking in the dark recesses of mathematical existence, there might have been a really weird sphere of 254 dimensions, or 510, or 1,026. In fact, for all you knew, you might have had to worry about weird spheres when visiting any space with numbers of dimensions of the type $2^k - 2$.

Not anymore. "We can all sleep a bit better tonight," joked mathematical physicist John Baez of the University of California, Riverside, in his blog. Baez was referring to the announcement made by mathematicians Michael Hopkins of Harvard University, Michael Hill of the University of Virginia and Douglas Ravenel of the University of Rochester that they had cracked a 45-year-old question known as the Kervaire invariant problem. If confirmed, their result puts the finishing touch to a glorious piece of 1960s mathematics: the classification of "exotic," higher-dimensional spheres. The Kervaire problem was a major stumbling block in understanding multidimensional spaces, and its solution could have implications in equally exotic fields of physics such as string theory.

When mathematicians talk about higher-dimensional spaces, they are referring to the number of variables, or dimensions, needed to locate a point in such a space. The surface of the earth is two-dimensional because two coordinates—latitude and longitude—are needed to specify any point on it. In more formal terms, the standard two-dimensional sphere is the set of points equidistant from a point in 2 + 1 = 3 dimensions. More generally, the standard n-dimensional sphere, or n-sphere for short, is the set of points that are at the same distance from a center point in a space of n + 1 dimensions. Spheres are among the most basic spaces in topology, the branch of mathematics that studies which properties are unchanged when an object is deformed without crushing or ripping it. Topology comes up in many studies, including those trying to determine the shape of our universe.

In recent years mathematicians have

completed the classification of 3-D spaces that are "compact," meaning that they are finite and with no edges [see "The Shapes of Space," by Graham P. Collins; Scientific American, July 2004]. (A sphere is compact, but an infinite plane is not.) Thus, they have figured out the topologies of all possible universes, as long as those universes are compact and three-dimensional. In more than three dimensions, however, the complete classification has turned out to be intractable and even logically impossible. Topologists had hoped at least that spaces as simple as spheres would be easy enough.

John Milnor, now at Stony Brook University, complicated matters somewhat in the 1950s, when he discovered the first "exotic" 7-sphere. An exotic n-sphere is a sphere from the point of view of topology. But it is not equivalent to a standard n-sphere from the point of view of differential calculus, the language in which physics theories are formulated. The discrepancy has consequences for equations such as those that describe the motion of particles or the propagation of waves. It means that solutions to such equations (or even their formulation) on one space cannot be mapped onto the other without developing kinks, or "singularities." Physically, the two spheres are different, incompatible worlds.

In 1963 Milnor and his colleague Michel Kervaire calculated the number of exotic 7-spheres and found that there were exactly 27 different ones. In fact, they calculated the number of n-spheres for any n from five up. Their counts, however, had an ambiguity—a possible factor of two—when n is an even number. William Browder of Princeton University later removed that ambiguity, except for dimensions of the type $n = 2^k - 2$, starting with $k = 7$—specifically, 126, 254, 510, and so on. In other words, mathematicians could only guess the number of exotic spheres in these dimensions to within a factor of two, known as the Kervaire invariant because of its relation to an earlier concept invented by Kervaire.

Hopkins and his colleagues think that they have found a way to remove that ambiguity. In their proof, which involves an intricate hierarchy of algebraic systems called homology groups, they show that the factor of two did not exist in any of those dimensions except possibly in the case 126, which, for technical reasons, their proof strategy did not address. (There is actually still another major exception: the 4-D case. Although there are no exotic 1-, 2- or 3-spheres, no one has any clue whether exotic 4-spheres exist or not.)

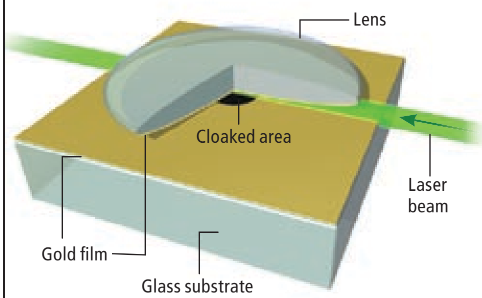
Although the researchers have not yet published their proof, Hopkins says, "I'm as confident as I possibly could be" without peer review that the proof is correct. Gunnar Carlsson, a topologist at Stanford University, says he has only heard "the most cursory outline of the proposed proof" from Hopkins but is "optimistic that the ingredients may very well be there for a resolution of this problem." And not a moment too soon, if you've stayed up worrying about weird spheres.

PHYSICS

Cloaking Made Simpler

Invisibility without sophisticated metamaterials BY JOHN MATSON

In recent years optics researchers have come up with numerous concepts for invisibility cloaks—camouflaging that would effectively reroute light around an object to be concealed. Most of these approaches have relied on so-called metamaterials, which are carefully engineered structures that have bizarre optical properties. A much simpler cloaking apparatus could do away with



CLOAKING DEVICE can be made from a gold-coated lens and glass. Laser light shining in edgewise bends around a central spot, effectively rendering that area invisible.

the need for metamaterials entirely.

Researchers at BAE Systems in Washington, D.C., Towson University and Purdue University have devised a cloaking device based on two gold surfaces, one coated on a curved lens and one on a flat piece of glass. Stacked together, they can conceal an area in between by forming what is known as a tapered waveguide. The trick lies in the gradient of the material's refractive index, which allows light shining parallel into the stack to bend around a central area "like water flowing around a stone," says study co-author Vladimir M. Shalaev, a professor of electrical and computer engineering at Purdue.

Shalaev was part of a group that in 2007 designed a visible-light cloak using metamaterials. But that cloak worked only at a predefined wavelength of light and concealed a very small area. In contrast, the waveguide appears to work for multiple wavelengths of visible light and can hide a bigger area. "From the very beginning we realized the huge challenge" of making such a cloak, Shalaev says. "It's not fundamentally impossible, but it's really, really hard."

John Pendry, a physicist at Imperial College London, says that the tapered waveguide strategy is "a very clever idea." Physicist Ulf Leonhardt of the University of Saint Andrews in Scotland agrees, calling the paper, in the May 29 *Physical Review Letters,* "a brilliant piece of work, a wonderfully simple idea." Both researchers point out, however, that the new approach conceals a two-dimensional area rather than a three-dimensional one. "The things you might want to cloak are probably not confined to two dimensions," Pendry remarks. Still, the system could find use in optical communications.

GEORGE RETSECK

EVOLUTION

Weak Link

Skepticism about a fossil cast as a missing link in human ancestry BY KATE WONG

On May 19 the world met a most unlikely celebrity: the fossilized carcass of a housecat-size primate that lived 47 million years ago in a rain forest in what is now Germany. The specimen, a juvenile female, represents a genus and species new to science, *Darwinius masillae,* although the media-savvy researchers who unveiled her were quick to give her a user-friendly nickname, Ida. And in an elaborate public-relations campaign, in which the release of a Web site, a book and a documentary on the History Channel were timed to coincide with the publication of the scientific paper describing her in *PLoS ONE,* Ida's significance was described in no uncertain terms as the missing link between us humans and our primate kin. In news reports, team members called her "the eighth wonder of the world," "the Holy Grail," and "a Rosetta Stone."

The orchestration paid off, as Ida graced the front page of countless newspapers and made appearances on the morning (and evening) news programs. Gossip outlets, such as *People* and Gawker, took note of her, too. And Google incorporated her image into its logo on the main search page for a day.

But a number of outside experts have criticized these claims. Not only is Ida too old to reveal anything about the evolution of humans in particular (the earliest putative human ancestors are a mere seven million years old), but she may not even be particularly closely related to the so-called anthropoid branch of the primate family tree that includes monkeys, apes and us.

PRIMEVAL PRIMATE *Darwinius masillae* lived 47 million years ago. The scientists who descibed the fossil, dubbed Ida, argue that key traits link Ida to the primate group that includes monkeys, apes and humans. But other researchers contend that she is more closely related to the group that includes lemurs, bush babies and lorises.

SOURCE: "COMPLETE PRIMATE SKELETON FROM THE MIDDLE EOCENE OF MESSEL IN GERMANY: MORPHOLOGY AND PALEOBIOLOGY," BY JENS L. FRANZEN ET AL., IN *PLoS ONE,* VOL. 4, NO. 5; MAY 2009

Scientists have long debated the origin of the anthropoids, also known as the higher primates. The predominant view holds that a group of tarsierlike creatures known as the omomyiforms spawned the anthropoids. Some authorities, however, believe that anthropoids instead arose from a group of extinct primates called the adapiforms.

Enter Ida. University of Oslo paleontologist Jørn H. Hurum and his team classify Ida as an adapiform and contend that she also exhibits a number of anthropoidlike characteristics, such as the spatulate shape of her incisor teeth, the absence of a so-called grooming claw on her second toe, and a partially fused lower jaw. They believe that Ida could be on the line leading to anthropoids, thus linking that group and the adapiforms.

Critics concur that Ida is an adapiform, but they dispute the alleged ties to anthropoids. Robert Martin of the Field Museum in Chicago charges that some of the traits used to align Ida with the anthropoids do not in fact support such a relationship. Fusion of the lower jaw, for instance, is not present in the earliest unequivocal anthropoids, suggesting that it was not an ancestral feature of this group. Moreover, the trait has arisen independently in several lineages of mammals—including some lemurs—through convergent evolution. Martin further notes that Ida also lacks a defining feature of the anthropoids: a bony wall at the back of the eye socket. "I am utterly convinced that *Darwinius* has nothing whatsoever to do with the origin of higher primates," he declares.

Adapiforms "are related to the strepsirrhine group of living primates that include lemurs from Madagascar and galagos [bush babies] and lorises from Africa and Asia," insists paleontologist Richard F. Kay of Duke University. Claims by the authors to the contrary notwithstanding, he adds, "they are decidedly not in the direct line leading to living monkeys, apes and humans." Kay and others believe that a primitive primate from China called *Eosimias* is a better candidate ancestor of anthropoids than is *Darwinius*.

If the detractors are right, Ida is irrelevant to the question of anthropoid—and thus, human—origins. That does not mean she is without value, though. Unlike *Eosimias*, which is known only from its fossilized teeth and jaws, Ida is spectacularly complete. Her entire skeleton is preserved, as well as traces of her last meal and impressions of her body contour and fur. Already Hurum's team has deduced that Ida was good at running and leaping in the trees of her rain forest home, that she grew up relatively quickly, that she dined on leaves and fruits, and that she may have been nocturnal.

Further analyses of the fossil will no doubt reveal even more about the life and times of this ancient primate. Perhaps they will also clarify her position in the family tree.

In Brief

SKIN SO BACTERIAL

Skin hosts many more bacteria than previously thought. Researchers at the National Institutes of Health's new Human Microbiome Project sequenced genes from skin samples from healthy volunteers and found bacteria that hailed from 19 different phyla and 205 genera and that possessed more than 112,000 individual gene sequences. Previous studies of skin cultures supposed that just one type of bacteria, *Staphylococcus*, was the main resident. The scientists aim to establish a bacterial baseline so as to better treat skin diseases, such as acne or eczema, where bacterial populations might be out of balance. *—Katherine Harmon*

CARIBOU HUNTING IN LAKE HURON

The bottom of Lake Huron may have once been a rich hunting site for Paleo-Indians. The area in the lake between modern-day Presque Isle, Mich., and Point Clark, Ontario, was once a land bridge some 7,500 to 10,000 years ago. Using sonar and remote-operated vehicles, researchers have found traces of what appear to be stone structures, hunting blinds, dwelling sites and caribou drive lanes hidden under the lake's mussels and algae. The discovery overturns past presumptions that most sites are lost after such a long period underwater, and intact artifacts and ancient landscapes could still be preserved at the lake bottom. *—Katherine Harmon*

LIQUID FLOWING UP

Researchers at the University of Rochester have devised a way to make a room-temperature liquid flow against gravity. Using a high-intensity laser, they etched tiny channels in a metal plate. By means of evaporation and capillary action, methanol was pulled up the channels at a speed that the scientists say is unprecedented, even when the plate was held vertically. Such passive transport of fluids, described in the June 2 *Applied Physics Letters,* could find use in microfluidics devices, which depend on the movement of minute amounts of liquid. *—John Matson*

BIOCHEMISTRY

Killer Smile

A toxin that forces a condemned victim to smile really seems to exist. The Greek bard Homer coined the term "sardonic grin" after ceremonial killings that supposedly took place in Sardinia, where Phoenician colonists gave to elderly people who could no longer take care of themselves and to criminals an intoxicating potion that put a smile on their face. (They were then dropped from a high rock or beaten to death.) Scientists at the University of Eastern Piedmont in Italy and their colleagues think they now have identified the herb responsible: hemlock water dropwort (*Oenanthe crocata*), which is common on Sardinia, where it is popularly known as "water celery." Their analysis revealed the presence of highly toxic chemicals in the plant that could make facial muscles contract into a grimace, or rictus. The finding appears in the May 22 *Journal of Natural Products.* *—Charles Q. Choi*

ENVIRONMENT

Nitro Burn

Humanity is upsetting not just levels of carbon in the air but those of nitrogen as well. Although the burning of fossil fuels is known to release nitrogen oxides that can excessively fertilize ecosystems or react with other compounds to form smog and acid rain, researchers have had difficulty pinpointing the extent to which people have disrupted nitrogen levels in the atmosphere. To investigate, scientists at Brown University and the University of Washington analyzed an ice core from Greenland, which trapped nitrate deposits over the past three centuries. They found that levels of the rare nitrogen 15 isotope had plummeted over the past 150 years when compared with the more common nitrogen 14. This skewing likely results from an influx of nitrogen oxides from fuel combustion, which for uncertain reasons generates nitrogen oxides depleted in nitrogen 15. The shift, described in the June 5 *Science,* also coincides with the industrial age—indeed, the greatest rate of change happened between 1950 and 1980, after a rapid increase in fossil-fuel emissions. *—Charles Q. Choi*

HAZY SHADE OF NITROGEN: Los Angeles smog is one result of nitrogen oxide emissions.

BALLYSCANLON *Getty Images (hand on back)*; IZZY SCHWARTZ *Getty Images (Los Angeles)*

MEDICINE

Cancer Clue from Down Syndrome

People who have Down syndrome hardly ever get tumors, an observation that has long puzzled scientists. They suspected that patients might be getting a bonus dose of cancer-protective genes, because the disorder is caused by an extra copy of a chromosome—specifically, chromosome 21. Researchers at Children's Hospital Boston and their colleagues found that an added copy of *DSCR1*, one of the 231 genes on chromosome 21, could inhibit the spread of mouse and human tumors. The gene suppresses the growth of new blood vessels that cancers need by blocking the activity of the protein calcineurin, suggesting a new target for future cancer drugs. The investigators, whose findings were posted online May 20 by *Nature* (*Scientific American* is part of the Nature Publishing Group), add that chromosome 21 might possess four or five antiangiogenesis genes.

PROTECTED: Those with Down syndrome rarely get tumors.

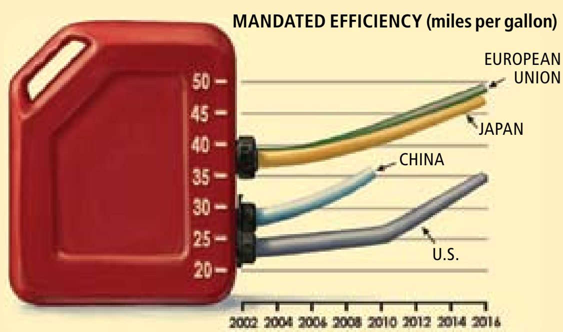
The extra chromosome arises as a mistake in cell division during embryonic development. Researchers at Tufts Medical Center and their colleagues discovered that the amniotic fluid surrounding Down syndrome fetuses shows evidence of oxidative stress that could harm cells, particularly neural and cardiac tissue. The signs, unfortunately, appear in the second trimester, too late for antioxidants to treat the hallmarks of Down syndrome that arise in the first trimester, such as mental impairment. Still, the team suggests in the June 9 *Proceedings of the National Academy of Sciences USA* that second-trimester antioxidants might fend off aspects of the syndrome that are yet to be discovered.

—Charles Q. Choi

Data Points

Gallons per Mile

The Obama administration in May announced that the mileage of cars and light trucks sold in the U.S. must rise from the current 25 miles per gallon to 35.5 mpg by 2016. That's a 40 percent improvement. But perhaps a more meaningful measure of fuel efficiency is fuel consumption per distance traveled. People who drive an average vehicle for 100 miles a week will see their weekly gas usage drop from four gallons to 2.8 gallons—a 30 percent reduction in both expenses and carbon dioxide emissions. And though significant, the efficiency gains will not be enough to bring the U.S. in line with what vehicles sold in Japan and Europe already consume now.



SOURCES: International Council on Clean Transportation; www.mpgillusion.com; U.S. Environmental Protection Agency (http://epa.gov/otaq/climate/regulations.htm)

SCI AM

Read More . . .

News Scan stories with this icon have extended coverage on **www.ScientificAmerican.com/aug2009**

BRUCE ROBERTS *Photo Researchers, Inc. (child)*; ILLUSTRATION BY MATT COLLINS

Scientific American Perspectives

A Seedy Practice

Scientists must ask seed companies for permission before publishing independent research on genetically modified crops. That restriction must end

BY THE EDITORS

Advances in agricultural technology—including, but not limited to, the genetic modification of food crops—have made fields more productive than ever. Farmers grow more crops and feed more people using less land. They are able to use fewer pesticides and to reduce the amount of tilling that leads to erosion. And within the next two years, agritech companies plan to introduce advanced crops that are designed to survive heat waves and droughts, resilient characteristics that will become increasingly important in a world marked by a changing climate.

Unfortunately, it is impossible to verify that genetically modified crops perform as advertised. That is because agritech companies have given themselves veto power over the work of independent researchers.

To purchase genetically modified seeds, a customer must sign an agreement that limits what can be done with them. (If you have installed software recently, you will recognize the concept of the end-user agreement.) Agreements are considered necessary to protect a company's intellectual property, and they justifiably preclude the replication of the genetic enhancements that make the seeds unique. But agritech companies such as Monsanto, Pioneer and Syngenta go further. For a decade their user agreements have explicitly forbidden the use of the seeds for any independent research. Under the threat of litigation, scientists cannot test a seed to explore the different conditions under which it thrives or fails. They cannot compare seeds from one company against those from another company. And perhaps most important, they cannot examine whether the genetically modified crops lead to unintended environmental side effects.

Research on genetically modified seeds is still published, of course. But only studies that the seed companies have approved ever see the light of a peer-reviewed journal. In a number of cases, experiments that had the implicit go-ahead from the seed company were later blocked from publication because the results were not flattering. "It is important to understand that it is not always simply a matter of blanket denial of all research requests, which is bad enough," wrote Elson J. Shields, an entomologist at Cornell University, in a letter to an official at the Environmental Protection Agency (the body tasked with regulating the environmental consequences of genetically modified crops), "but selective denials and permissions based on industry perceptions of how 'friendly' or 'hostile' a particular scientist may be toward [seed-enhancement] technology."

Shields is the spokesperson for a group of 24 corn insect scientists that opposes these practices. Because the scientists rely on the cooperation of the companies for their research—they must, after all, gain access to the seeds for studies—most have chosen to remain anonymous for fear of reprisals. The group has submitted a statement to the EPA protesting that "as a result of restricted access, no truly independent research can be legally conducted on many critical questions regarding the technology."

It would be chilling enough if any other type of company were able to prevent independent researchers from testing its wares and reporting what they find—imagine car companies trying to quash head-to-head model comparisons done by *Consumer Reports*, for example. But when scientists are prevented from examining the raw ingredients in our nation's food supply or from testing the plant material that covers a large portion of the country's agricultural land, the restrictions on free inquiry become dangerous.

Although we appreciate the need to protect the intellectual property rights that have spurred the investments into research and development that have led to agritech's successes, we also believe food safety and environmental protection depend on making plant products available to regular scientific scrutiny. Agricultural technology companies should therefore immediately remove the restriction on research from their end-user agreements. Going forward, the EPA should also require, as a condition of approving the sale of new seeds, that independent researchers have unfettered access to all products currently on the market. The agricultural revolution is too important to keep locked behind closed doors. ■

MATT COLLINS

Sustainable Developments

Good News on Malaria Control

The best price for getting antimosquito bed nets to the poor proves to be "free"

BY JEFFREY D. SACHS

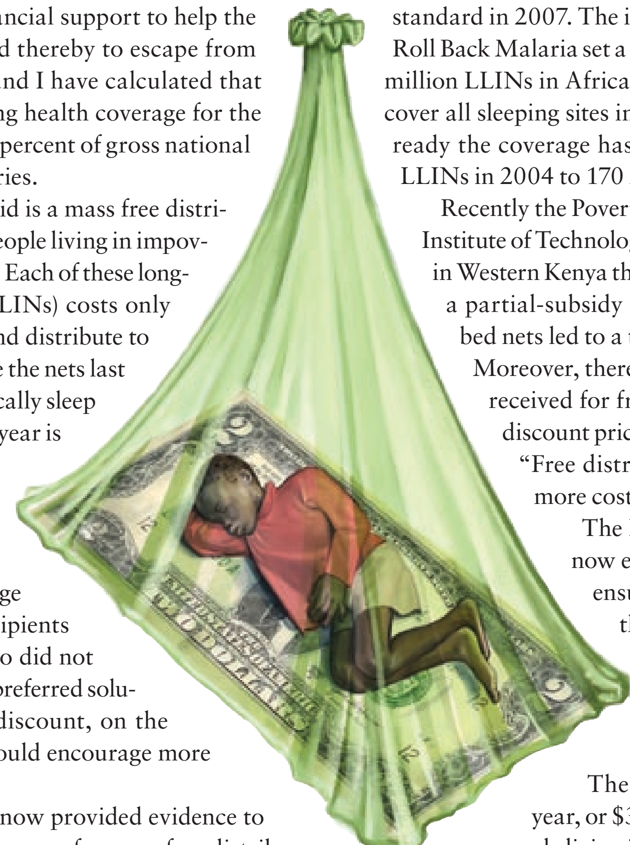
A persistent question about sustainable development is how to help the world's poorest people. Their incomes are so low that they lack access to the most basic goods and services: adequate nutrition, safe drinking water, sanitation and vital health interventions. One strategy is to provide targeted financial support to help the poor to meet their basic needs and thereby to escape from the poverty trap. My colleagues and I have calculated that the cost of ensuring basic lifesaving health coverage for the world's poor would be around 0.1 percent of gross national product of the high-income countries.

One example of such targeted aid is a mass free distribution of antimalaria bed nets to people living in impoverished malarious regions of Africa. Each of these long-lasting insecticide-treated nets (LLINs) costs only about $10 to produce, transport and distribute to households in rural Africa. Because the nets last for five years and two children typically sleep under each net, the cost per child a year is a mere $0.50. Even at this remarkably low cost, however, some critics have opposed such an approach. They have claimed that free nets would "go missing" in large numbers because of waste by recipients and others in the supply chain who did not properly value them. These critics' preferred solution is market sales of nets at a discount, on the grounds that even a small price would encourage more efficient use of the nets.

Experiments and real life have now provided evidence to resolve this debate convincingly: the case for mass free distribution of bed nets has proved to be stunningly powerful. After many years in which bed-net coverage was extremely low, it is now soaring, and malaria cases are falling sharply where mass bed-net distribution is being deployed.

Here is how events have unfolded. Because Africa's rural poor are so destitute, attempts to sell them subsidized LLINs from 2000 to 2005 not surprisingly fell badly short, even at prices as low as $2 to $3 per net. The incidence of taking up these bed nets in Africa through sales was very small and covered only a tiny fraction of those in need.

In 2002 and 2003 the International Committee of the Red Cross and UNICEF began experimenting with a mass free distribution of LLINs in some trial sites. Spot checks of the recipient communities a few months later verified that distributed bed nets were indeed in the households in high percentages. As the evidence of success of mass distribution continued to grow, the World Health Organization adopted that strategy as its basic standard in 2007. The international partnership known as Roll Back Malaria set a goal to freely distribute around 300 million LLINs in Africa during the period 2008 to 2010 to cover all sleeping sites in malaria-transmission regions. Already the coverage has jumped from perhaps 10 million LLINs in 2004 to 170 million as of the end of 2008.



PHOTOGRAPH BY BRUCE GILBERT/EARTH INSTITUTE; ILLUSTRATION BY MATT COLLINS

Recently the Poverty Action Lab at the Massachusetts Institute of Technology carried out a detailed experiment in Western Kenya that compared mass distribution with a partial-subsidy approach: even a small charge for bed nets led to a tremendous drop in their adoption. Moreover, there was no greater wastage of the nets received for free than for those purchased at the discount price. The study's conclusion was clear: "Free distribution is both more effective and more cost-effective than cost-sharing."

The Roll Back Malaria Partnership has now embarked on a coordinated effort to ensure comprehensive malaria control throughout Africa that includes not only LLINs but also medicines, rapid diagnostic tests and community health workers trained to deliver such essential interventions. The cost will be around $3 billion a year, or $3 annually for each of the one billion people living in the high-income donor countries.

It is time to take the demonstrated successes of mass free distribution for such assistance to full scale. ■

Jeffrey D. Sachs is director of the Earth Institute at Columbia University (www.earth.columbia.edu).

For more background on these distribution programs, see readings posted at www.earth.columbia.edu/sachs/bednets

SCI AM An extended version of this essay is available at **www.ScientificAmerican.com/aug2009**

Skeptic

Shakespeare, Interrupted

The anti-Stratfordian skeptics are back, and this time they have a Supreme Court justice on their side

BY MICHAEL SHERMER

For centuries, Shakespeare skeptics have doubted the authorship of the Stratfordian Bard's literary corpus, proffering no fewer than 50 alternative candidates, including Francis Bacon, Queen Elizabeth I, Christopher Marlowe and the leading contender among the "anti-Stratfordians," Edward de Vere, 17th earl of Oxford. And for nearly as long, the Shakespeare skeptics have toiled in relative obscurity, holding conferences in tiny gatherings and dreaming of the day their campaign would make front-page news. On April 18, 2009, the *Wall Street Journal* granted their wish with a feature story on how U.S. Supreme Court Justice John Paul Stevens came to believe (and throw his judicial weight behind) the skeptics.

Stevens's argument retreads a well-worn syllogism: Shakespeare's plays are so culturally rich that they could only have been written by a noble or scholar of great learning. The historical William Shakespeare was a commoner with no more than a grammar school education. Ergo, Shakespeare could not have written Shakespeare. For example, Stevens asks, "Where are the books? You can't be a scholar of that depth and not have any books in your home. He never had any correspondence with his contemporaries, he never was shown to be present at any major event—the coronation of James or any of that stuff. I think the evidence that he was not the author is beyond a reasonable doubt."

But reasonable doubt should not cost an author his claim, at least not if we treat history as a science instead of as a legal debate. In science, a reigning theory is presumed provisionally true and continues to hold sway unless and until a challenging theory explains the current data as well and also accounts for anomalies that the prevailing one cannot. Applying that principle here, we should grant that Shakespeare wrote the plays unless and until the anti-Stratfordians can make their case for a challenger who fits more of the literary and historical data.

I explained this to John M. Shahan, chair of the Shakespeare Authorship Coalition (www.DoubtAboutWill.org), who insisted that although most skeptics hold that the true playwright was the earl of Oxford, their mission has merely been to sow the seeds of doubt. I understood why when I examined the case for de Vere. For example, de Vere's partisans exalt his education at both the University of Cambridge and the University of Oxford and believe that the plays could only have been penned by someone of such erudition. Yet the plays make many allusions to the grammar school education that Shakespeare had and not to that university life held so dear by the skeptics: instead of Cambridge masters and Oxford dons, Shakespeare routinely references schoolmasters, schoolboys and schoolbooks.

As for Shakespeare's humble upbringing, his father was a middle-class landowner whose estate was valued at the then respectable sum of £500 (you could purchase a modest home for £50) and whose social standing was as high as or higher than that of either Marlowe or Ben Jonson, who were themselves sons of a shoemaker and bricklayer, respectively, and somehow managed to master the belles lettres.

In the end, it's not enough merely to plant doubts about Will. Some anti-Stratfordians question Shakespeare's existence, but the number of references to him from his own time could only be accounted for by a playwright of that name (unless de Vere used Shakespeare as a nom de plume, for which there is zero evidence). And although Shakespeare's skeptics note that there are no manuscripts, receipts, diaries or letters from him, they neglect to mention that we have none of these for Marlowe, either.

In other words, reasonable doubt is not enough to dethrone the man from Stratford-upon-Avon, and to date, no overwhelming case has been made for any other author. In contrast, hundreds of examples of historical and literary consilience have been compiled by Purchase College theatre professor and playwright Scott McCrea in his aptly titled book *The Case for Shakespeare* (Praeger, 2008), which demonstrates beyond a reasonable doubt that, in the Bard's own words from *Julius Caesar,* Shakespeare was not just a man but *the* man: "the elements / So mix'd in him, that Nature might stand up, / And say to all the world, This was a man!" ■

Michael Shermer is publisher of Skeptic *(www.skeptic.com) and author of* How We Believe.

PHOTOGRAPH BY BRAD SWONETZ; ILLUSTRATION BY MATT COLLINS

Anti Gravity

Waste Management

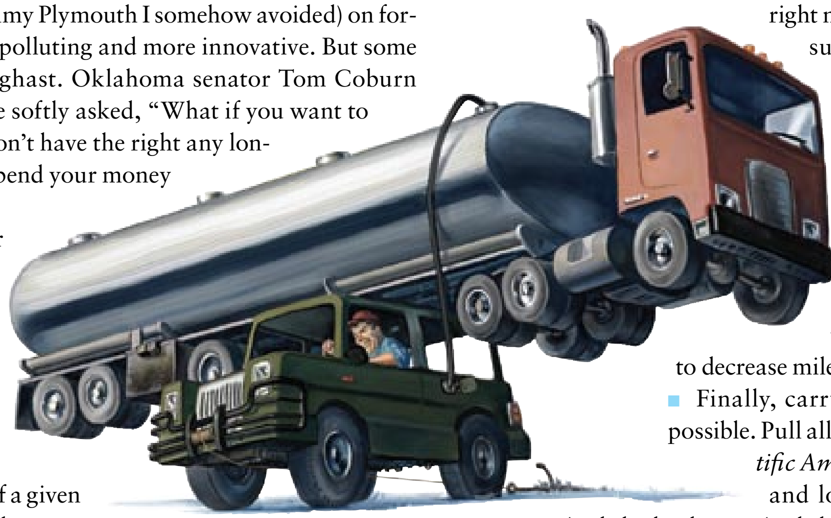
Tips for the kind of gas mileage you really want

BY STEVE MIRSKY

On May 19 President Barack Obama announced a new federal gas mileage standard: by 2016 the nation's entire car and light truck fleet should average 35.5 miles per gallon. Or just slightly less than the highway mileage I get in my 17-year-old Honda Civic.

The increase in the mileage requirement is actually modest. "The automakers' fleet average has been 27.5 mpg for years," according to an automobile insurance expert I spoke to. "However, this 'whole fleet average' is [expletive]. The rules by which they are allowed to achieve the fleet average are a joke." So when the rubber meets the road, 35.5 will be more like 32 or 28 or, more frighteningly, whatever number General Motors's stock happens to be trading at in 2016.

Nevertheless, the new standard may seem like a valiant (a mediocre Plymouth I drove in the 1970s) initiative on the horizon (a truly lousy Plymouth I owned in the 1980s) to make the country a bit less reliant (a crummy Plymouth I somehow avoided) on foreign oil, as well as less polluting and more innovative. But some fossil-fuel fans were aghast. Oklahoma senator Tom Coburn seemed near tears as he softly asked, "What if you want to drive a gas hog? You don't have the right any longer in this country to spend your money to drive a gas hog?"

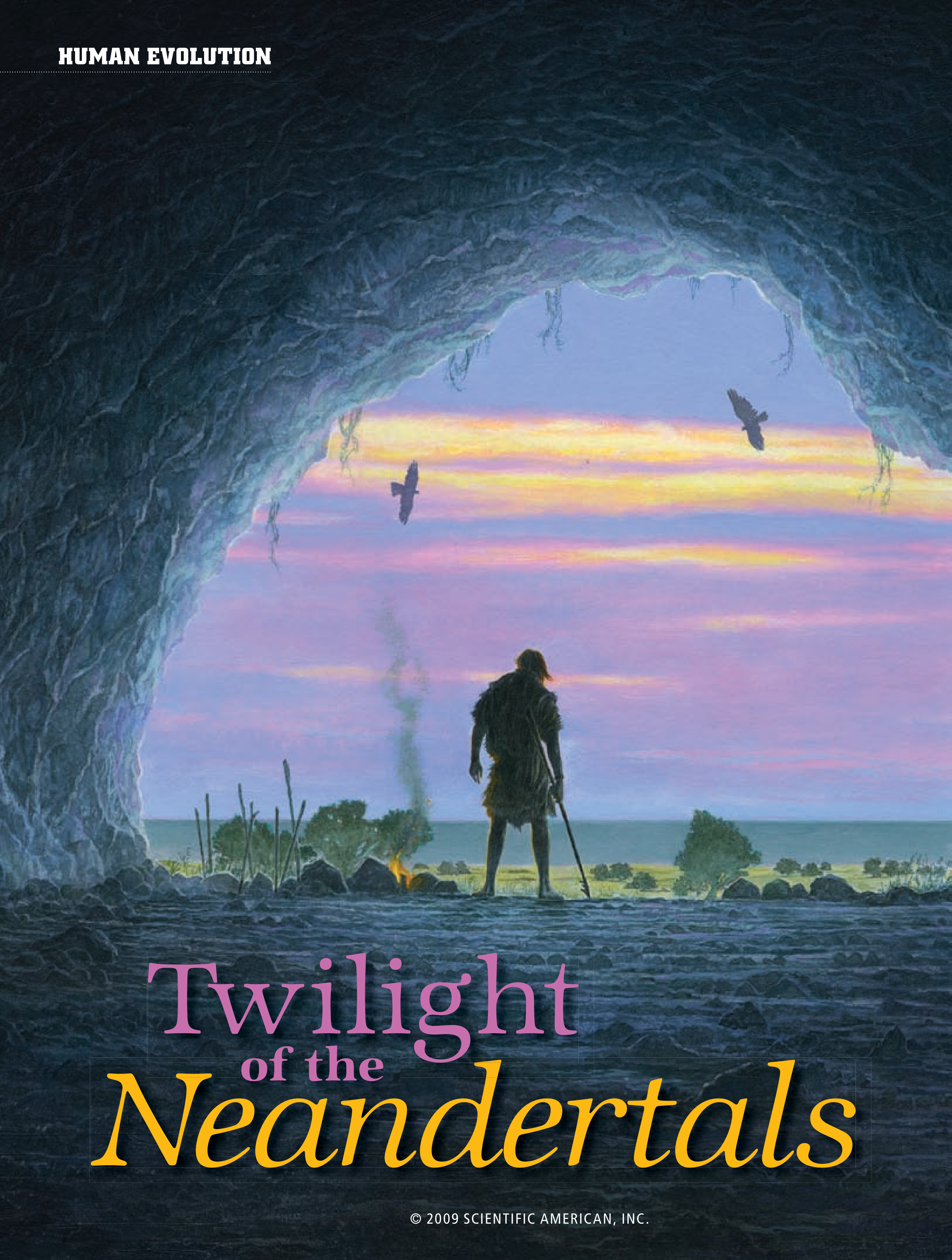


Senator, I feel your pain. But I offer you a solution, based on American ingenuity, sweat and spirit: with proper maintenance and driving behavior, it's possible to ooze many fewer miles out of a given gallon of gas than whatever standard the feds might impose on us. Here are some tips for turning even the most fuel-efficient vehicle they can force us to drive into a gas-guzzling petroleum pig:

- Always do jackrabbit starts. It's easy, wastes gas and makes enough noise to let your fellow drivers know that you've got money to burn.
- Make sure to accelerate and brake a lot as you drive, which can lower your highway mileage by a third.
- Banish the phrase "cruise control" from your lexicon, unless you're trying to keep Tom from expounding on the history of psychiatry or from jumping on Oprah's couch.
- Keep the tires underinflated. It's a small thing, but every 3 percent loss in energy efficiency is a waste worth working for.
- Never, ever get tune-ups. Such vigilant lack of vigilance should squander about another 4 percent.
- Idle whenever possible. The only thing more efficient at being inefficient than this zero-mpg activity is to put the car up on blocks and run the engine with a brick on the accelerator. (If you commit to that latter effort, be sure not to do it in the garage—despite what some other members of Congress may insist, carbon emissions can be dangerous!)
- Never stow anything in the truck if you can tie it on the roof. Aerodynamic drag will also drag down the mileage. Run the air conditioner with the windows open to increase wind resistance as well.
- Never combine trips. If the supermarket and the dry cleaner are right next to each other, go to the supermarket, go home to drop off the groceries, then go back to the dry cleaner. (They probably need the extra time to finish the Martinizing, anyway.) Best time for these elective trips? Rush hour. Getting stuck in traffic is always a great way to decrease mileage.
- Finally, carry as much deadweight as possible. Pull all those back issues of *Scientific American* out of the basement and load them into the trunk. And the backseat. And the floor. Other magazines, newspapers and books also do a dandy job of filling space with weight that fritters away fuel. If you've gone digital on the reading front, try filling the car with lumber, concrete blocks or gold bars. Which may come in handy for buying gas in 2016.

For more valuable tips such as these, go to the federal government's gas mileage tips Web site, www.fueleconomy.gov, and do the opposite of the advice listed. Because, Senator Coburn, they can make the fleet average higher. But they'll have to pry the gas pedal from my cold lead foot. ■

PHOTOGRAPH BY FLYNN LARSEN; ILLUSTRATION BY MATT COLLINS



Twilight of the Neandertals

KAZUHIKO SANO

Paleoanthropologists know more about Neandertals than any other extinct human. But their demise remains a mystery, one that gets curiouser and curiouser

By Kate Wong

Some 28,000 years ago in what is now the British territory of Gibraltar, a group of Neandertals eked out a living along the rocky Mediterranean coast. They were quite possibly the last of their kind. Elsewhere in Europe and western Asia, Neandertals had disappeared thousands of years earlier, after having ruled for more than 200,000 years. The Iberian Peninsula, with its comparatively mild climate and rich array of animals and plants, seems to have been the final stronghold. Soon, however, the Gibraltar population, too, would die out, leaving behind only a smattering of their stone tools and the charred remnants of their campfires.

Ever since the discovery of the first Neandertal fossil in 1856, scientists have debated the place of these bygone humans on the family tree and what became of them. For decades two competing theories have dominated the discourse. One holds that Neandertals were an archaic variant of our own species, *Homo sapiens*, that evolved into or was assimilated by the anatomically modern European population. The other posits that the Neandertals were a separate species, *H. neanderthalensis*, that modern humans swiftly extirpated on entering the archaic hominid's territory.

Over the past decade, however, two key findings have shifted the fulcrum of the debate away from the question of whether Neandertals and moderns made love or war. One is that analyses of Neandertal DNA have yet to yield the signs of interbreeding with modern humans that many researchers expected to see if the two groups mingled significantly. The other is that improvements in dating methods show that rather than disappearing immediately after the moderns invaded Europe, starting a little more than 40,000 years ago, the Neandertals survived for nearly 15,000 years after moderns moved in—hardly the rapid replacement adherents to the blitzkrieg theory envisioned.

These revelations have prompted a number of researchers to look more carefully at other factors that might have led to Neandertal extinction. What they are

KEY CONCEPTS

- Neandertals, our closest relatives, ruled Europe and western Asia for more than 200,000 years. But sometime after 28,000 years ago, they vanished.
- Scientists have long debated what led to their disappearance. The latest extinction theories focus on climate change and subtle differences in behavior and biology that might have given modern humans an advantage over the Neandertals.

—The Editors

[HYPOTHESIS 1]

Did Climate Change Doom the Neandertals?

Starting perhaps around 55,000 years ago, climate in Eurasia began to swing wildly from frigid to mild and back again in the span of decades. During the cold snaps, ice sheets advanced and treeless tundra replaced wooded environments across much of the Neandertals' range. Shifts in the available prey animals accompanied these changes. Wide spacing between past climate fluctuations allowed diminished Neandertal populations sufficient time to bounce back and adapt to the new conditions.

This time, however, the rapidity of the changes may have made recovery impossible. By 30,000 years ago only a few pockets of Neandertals survived, hanging on in the Iberian Peninsula, with its comparatively mild climate and rich resources. These groups were too small and fragmented to sustain themselves, however, and eventually they disappeared. The map below shows conditions associated with the last glacial maximum, some 20,000 years ago, which provide an approximation of the extreme conditions Neandertals probably endured toward the end of their reign.

finding suggests that the answer involves a complicated interplay of stresses.

A World in Flux

One of the most informative new lines of evidence bearing on why the Neandertals died out is paleoclimate data. Scholars have known for some time that Neandertals experienced both glacial conditions and milder interglacial conditions during their long reign. In recent years, however, analyses of isotopes trapped in primeval ice, ocean sediments and pollen retrieved from such locales as Greenland, Venezuela and Italy have enabled investigators to reconstruct a far finer-grained picture of the climate shifts that occurred during a period known as oxygen isotope stage 3 (OIS-3). Spanning the time between roughly 65,000 and 25,000 years ago, OIS-3 began with moderate conditions and culminated with the ice sheets blanketing northern Europe.

Considering that Neandertals were the only hominids in Europe at the beginning of OIS-3 and moderns were the only ones there by the end of it, experts have wondered whether the plummeting temperatures might have caused the Neandertals to perish, perhaps because they could not find enough food or keep sufficiently warm. Yet arguing for that scenario has proved tricky for one essential reason: Neandertals had faced glacial conditions before and persevered.

In fact, numerous aspects of Neandertal biology and behavior indicate that they were well suited to the cold. Their barrel chests and stocky limbs would have conserved body heat, although they would have additionally needed clothing fashioned from animal pelts to stave off the chill. And their brawny build seems to have been adapted to their ambush-style hunting of large, relatively solitary mammals—such as woolly rhinoceroses—that roamed northern and central Europe during the cold snaps. (Other distinctive Neandertal features, such as the form of the prominent brow, may have been adaptively neutral traits that became established through genetic drift, rather than selection.)

But the isotope data reveal that far from progressing steadily from mild to frigid, the climate became increasingly unstable heading into the last glacial maximum, swinging severely and abruptly. With that flux came profound ecological change: forests gave way to treeless grassland; reindeer replaced certain kinds of rhinoceroses. So rapid were these oscillations that over the course of an individual's lifetime, all the plants and animals that a person had grown up with could vanish and be replaced with unfamiliar flora and fauna. And then, just as quickly, the environment could change back again.

It is this seesawing of environmental conditions—not necessarily the cold, per se—that gradually pushed Neandertal populations to the point of no return, according to scenarios posited by such experts as evolutionary ecologist Clive Finlayson of the Gibraltar Museum, who directs the excavations at several cave sites in Gibraltar. These shifts would have demanded that Neandertals adopt a new way of life in very short order. For example, the replacement of wooded areas with open grassland would have left ambush hunters without any trees to hide behind, he says. To survive, the Neandertals would have had to alter the way they hunted.

LAURIE GRACE; SOURCE FOR MAP: "RAPID ECOLOGICAL TURNOVER AND ITS IMPACT ON NEANDERTAL AND OTHER HUMAN POPULATIONS," BY CLIVE FINLAYSON AND JOSE S. CARRION, IN *TRENDS IN ECOLOGY AND EVOLUTION*, VOL. 22, NO. 4; 2007

Some Neandertals did adapt to their changing world, as evidenced by shifts in their tool types and prey. But many probably died out during these fluctuations, leaving behind ever more fragmented populations. Under normal circumstances, these archaic humans might have been able to bounce back, as they had previously, when the fluctuations were fewer and farther between. This time, however, the rapidity of the environmental change left insufficient time for recovery. Eventually, Finlayson argues, the repeated climatic insults left the Neandertal populations so diminished that they could no longer sustain themselves.

The results of a genetic study published this past April in *PLoS One* by Virginie Fabre and her colleagues at the University of the Mediterranean in Marseille support the notion that Neandertal populations were fragmented, Finlayson says. That analysis of Neandertal mitochondrial DNA found that the Neandertals could be divided into three subgroups—one in western Europe, another in southern Europe and a third in western Asia—and that population size ebbed and flowed.

Invasive Species

For other researchers, however, the fact that the Neandertals entirely disappeared only after moderns entered Europe clearly indicates that the invaders had a hand in the extinction, even if the newcomers did not kill the earlier settlers outright. Probably, say those who hold this view, the Neandertals ended up competing with the incoming moderns for food and gradually lost ground. Exactly what ultimately gave moderns their winning edge remains a matter of considerable disagreement, though.

One possibility is that modern humans were less picky about what they ate. Analyses of Neandertal bone chemistry conducted by Hervé Bocherens of the University of Tübingen in Germany suggest that at least some of these hominids specialized in large mammals, such as woolly rhinoceroses, which were relatively rare. Early modern humans, on the other hand, ate all manner of animals and plants. Thus, when moderns moved into Neandertal territory and started taking some of these large animals for themselves, so the argument goes, the Neandertals would have been in trouble. Moderns, meanwhile, could supplement the big kills with smaller animals and plant foods.

VIKTOR DEAK

RESURRECTING THE NEANDERTAL

Later this year researchers led by Svante Pääbo of the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany, are expected to publish a rough draft of the Neandertal genome. The work has prompted speculation that scientists might one day be able to bring back this extinct human. Such a feat, if it were technically possible, would raise all sorts of ethical quandaries: What rights would a Neandertal have? Would this individual live in a lab, or a zoo, or a household?

Moral concerns aside, what could researchers actually learn from a resurrected Neandertal? The answer is: less than you might think. A Neandertal born and raised in a modern setting would not have built-in Ice Age wisdom to impart to us, such as how to make a Mousterian stone tool or bring down a woolly rhinoceros. Indeed, he would not be able to tell scholars anything about the culture of his people. It is possible, however, that studying Neandertal biology and cognition could reveal as yet unknown differences between these archaic hominids and modern ones that might have given moderns a survival advantage.

"Neandertals had a Neandertal way of doing things, and it was great as long as they weren't competing with moderns," observes archaeologist Curtis W. Marean of Arizona State University. In contrast, Marean says, the moderns, who evolved under tropical conditions in Africa, were able to enter entirely different environments and very quickly come up with creative ways to deal with the novel circumstances they encountered. "The key difference is that Neandertals were just not as advanced cognitively as modern humans," he asserts.

Marean is not alone in thinking that Neandertals were one-trick ponies. A long-standing view holds that moderns outsmarted the Neandertals with not only their superior tool technology and survival tactics but also their gift of gab, which might have helped them form stronger social networks. The Neandertal dullards, in this view, did not stand a chance against the newcomers.

But a growing body of evidence indicates that Neandertals were savvier than they have been given credit for. In fact, they apparently engaged in many of the behaviors once believed to be strictly the purview of modern humans. As paleoanthropologist Christopher B. Stringer of London's Natural History Museum puts it, "the boundary between Neandertals and moderns has gotten fuzzier."

Sites in Gibraltar have yielded some of the most recent findings blurring the line between the two human groups. In September 2008 Stringer and his colleagues reported on evidence that Neandertals at Gorham's Cave and next-door Vanguard Cave hunted dolphins and seals as well as gathered shellfish. And as yet unpublished work shows that they were eating birds and rabbits, too. The discoveries in Gilbraltar, along with finds from a handful of other sites, upend the received wisdom that moderns alone exploited marine resources and small game.

More evidence blurring the line between Neandertal and modern human behavior has come from the site of Hohle Fels in southwestern Germany. There paleoanthropologist Bruce Hardy of Kenyon College was able to compare artifacts made by Neandertals who inhabited the cave between 36,000 and 40,000 years ago with artifacts from modern humans who resided there between 33,000 and 36,000 years ago under similar climate and environmental conditions. In a presentation given this past April to the

Paleoanthropology Society in Chicago, Hardy reported that his analysis of the wear patterns on the tools and the residues from substances with which the tools came into contact revealed that although the modern humans created a larger variety of tools than did the Neandertals, the groups engaged in mostly the same activities at Hohle Fels.

These activities include such sophisticated practices as using tree resin to bind stone points to wooden handles, employing stone points as thrusting or projectile weapons, and crafting implements from bone and wood. As to why the Hohle Fels Neandertals made fewer types of tools than did the moderns who lived there afterward, Hardy surmises that they were able to get the job done without them. "You don't need a grapefruit spoon to eat a grapefruit," he says.

The claim that Neandertals lacked language, too, seems unlikely in light of recent discoveries. Researchers now know that at least some of them decorated their bodies with jewelry and probably pigment. Such physical manifestations of symbolic behavior are often used as a proxy for language when reconstructing behavior from the archaeological record. And in 2007 researchers led by Johannes Krause of the Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany, reported that analyses of Neandertal DNA have shown that these hominids had the same version of the speech-enabling gene *FOXP2* that modern humans carry.

Tiebreakers

With the gap between Neandertal and modern human behavior narrowing, many researchers are now looking to subtle differences in culture and biology to explain why the Neandertals lost out. "Worsening and highly unstable climatic conditions would have made competition among human groups all the more fierce," reflects paleoanthropologist Katerina Harvati, also at Max Planck. "In this context, even small advantages would become extremely important and might spell the difference between survival and death."

Stringer, for his part, theorizes that the moderns' somewhat wider range of cultural adaptations provided a slightly superior buffer against hard times. For example, needles left behind by modern humans hint that they had tailored clothing and tents, all the better for keeping the cold at bay. Neandertals, meanwhile, left behind no such signs of sewing and are believed by some to have had more crudely assembled apparel and shelters as a result.

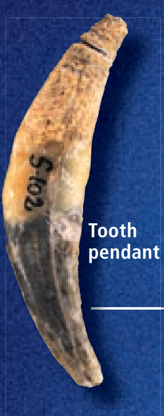
Neandertals and moderns may have also differed in the way they divvied up the chores among group members. In a paper published in *Current Anthropology* in 2006, archaeologists Steven L. Kuhn and Mary C. Stiner, both at the University of Arizona, hypothesized that the varied diet of early modern Europeans would have favored a division of labor in which men hunted the larger game and women collected and prepared nuts, seeds and berries. In contrast, the Neandertal focus on large game probably meant that their women and children joined in the hunt, possibly helping to drive animals toward the waiting men. By creating both

Knife

[HYPOTHESIS 2]

Were the Neandertals Outsmarted by Modern Humans?

A long-standing theory of Neandertal extinction holds that modern humans outcompeted Neandertals with their superior smarts. But mounting evidence indicates that Neandertals engaged in many of the same sophisticated behaviors once attributed to moderns alone (*table*). The findings reveal that at least some Neandertals were capable of symbolic thought—and therefore probably language—and that they had the tools and the know-how to pursue a wide range of foods. Still, these practices seem to have been more entrenched in modern human culture than in that of Neandertals, which may have given moderns the upper hand.



Tooth pendant

Bone awl

Seal jaw

EVIDENCE OF MODERN BEHAVIOR AMONG NEANDERTALS

TRAIT	COMMON	OCCASIONAL	ABSENT	UNCERTAIN
Art				✓
Pigment use	✓			
Jewelry		✓		
Symbolic burial of dead				✓
Long-distance exchange				✓
Microliths		✓		
Barbed points			✓	
Bone tools		✓		
Blades		✓		
Needles			✓	
Exploitation of marine resources		✓		
Bird hunting		✓		
Division of labor			✓	

COURTESY OF CLIVE FINLAYSON *Gibraltar Museum* (*jaw*); LABORATORY OF PREHISTORIC ETHNOLOGY, LA VARENDE COLLECTION (*artifacts*)

LAST BASTION of the Neandertals may have been a group of coastal caves in the British territory of Gibraltar, where the archaic hominids lived as recently as 28,000 years ago. Gibraltar and the rest of the Iberian Peninsula would have had a relatively mild climate and abundant food resources compared with much of Ice Age Europe.

a more reliable food supply and a safer environment for rearing children, division of labor could have enabled modern human populations to expand at the expense of the Neandertals.

However the Neandertals obtained their food, they needed lots of it. "Neandertals were the SUVs of the hominid world," says paleoanthropologist Leslie Aiello of the Wenner-Gren Foundation in New York City. A number of studies aimed at estimating Neandertal metabolic rates have concluded that these archaic hominids required significantly more calories to survive than the rival moderns did.

Hominid energetics expert Karen Steudel-Numbers of the University of Wisconsin–Madison has determined, for example, that the energetic cost of locomotion was 32 percent higher in Neandertals than in anatomically modern humans, thanks to the archaic hominids' burly build and short shinbones, which would have shortened their stride. In terms of daily energy needs, the Neandertals would have required somewhere between 100 and 350 calories more than moderns living in the same climates, according to a model developed by Andrew W. Froehle of the University of California, San Diego, and Steven E. Churchill of Duke University. Modern humans, then, might have outcompeted Neandertals simply by virtue of being more fuel-efficient: using less energy for baseline functions meant that moderns could devote more energy to reproducing and ensuring the survival of their young.

One more distinction between Neandertals and moderns deserves mention, one that could have enhanced modern survival in important ways. Research led by Rachel Caspari of Central Michigan University has shown that around 30,000 years ago, the number of modern humans who lived to be old enough to be grandparents began to skyrocket. Exactly what spurred this increase in longevity is uncertain, but the change had two key consequences. First, people had more reproductive years, thus increasing their fertility potential. Second, they had more time over which to acquire specialized knowledge and pass it on to the next generation—where to find drinking water in times of drought, for instance. "Long-term survivorship gives the potential for bigger social networks and greater knowledge stores," Stringer comments. Among the shorter-lived Neandertals, in contrast, knowledge was more likely to disappear, he surmises.

More clues to why the Neandertals faded away may come from analysis of the Neandertal genome, the full sequence of which is due out this year. But answers are likely to be slow to surface, because scientists know so little about the functional significance of most regions of the modern genome, never mind the Neandertal one. "We're a long way from being able to read what the [Neandertal] genome is telling us," Stringer says. Still, future analyses could conceivably pinpoint cognitive or metabolic differences between the two groups, for example, and provide a more definitive answer to the question of whether Neandertals and moderns interbred.

The Stone Age whodunit is far from solved. But researchers are converging on one conclusion: regardless of whether climate or competition with moderns, or some combination thereof, was the prime mover in the decline of the Neandertals, the precise factors governing the extinction of individual populations of these archaic hominids almost certainly varied from group to group. Some may have perished from disease, others from inbreeding. "Each valley may tell its own story," Finlayson remarks.

As for the last known Neandertals, the ones who lived in Gibraltar's seaside caves some 28,000 years ago, Finlayson is certain that they did not spend their days competing with moderns, because moderns seem not to have settled there until thousands of years after the Neandertals were gone. The rest of their story, however, remains to be discovered. ■

➥ MORE TO EXPLORE

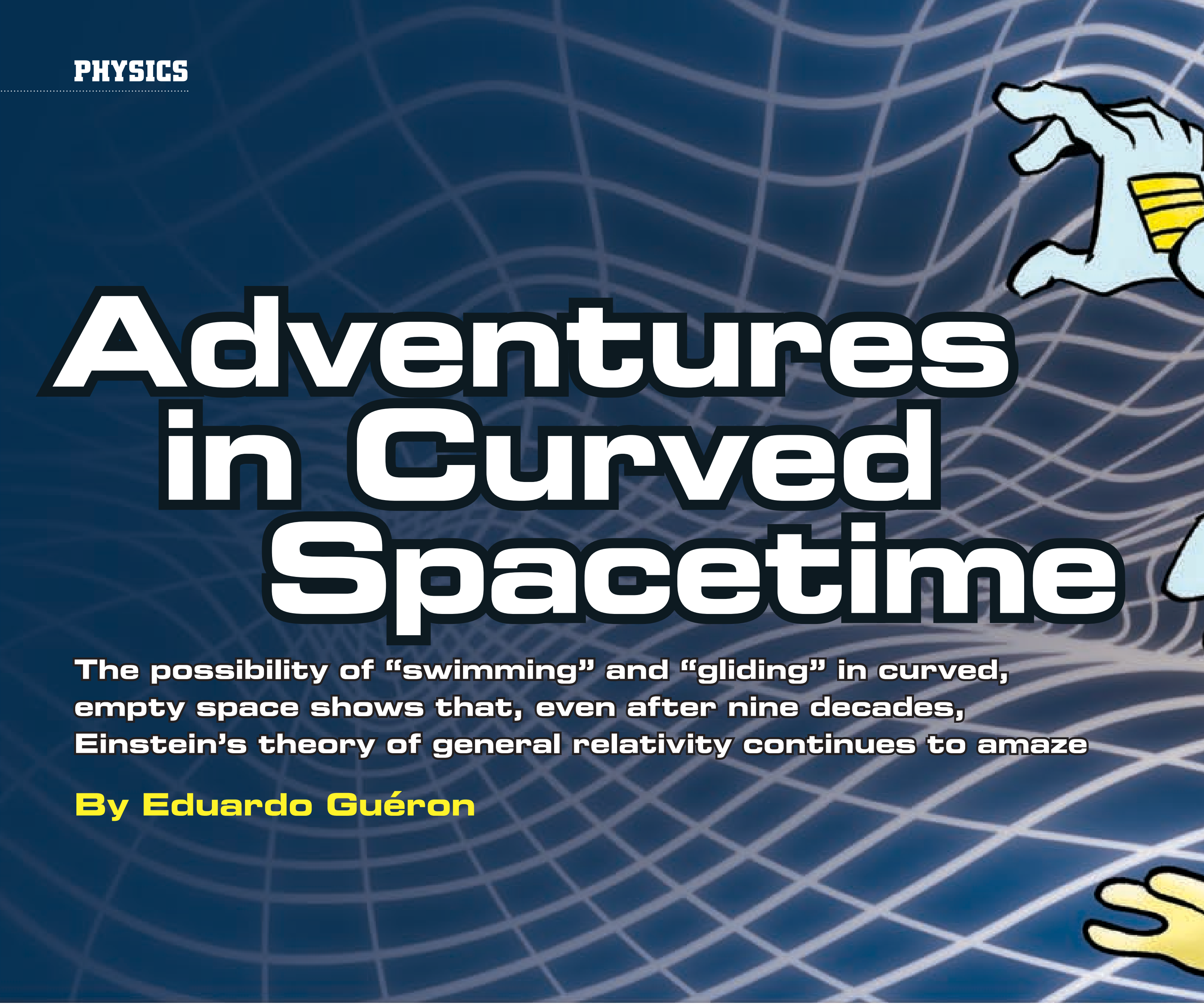
Older Age Becomes Common Late in Human Evolution. Rachel Caspari and Sang-Hee Lee in *Proceedings of the National Academy of Sciences USA,* Vol. 101, No. 30, pages 10895–10900; July 27, 2004.

Rapid Ecological Turnover and Its Impact on Neanderthal and Other Human Populations. Clive Finlayson and José S. Carrión in *Trends in Ecology and Evolution,* Vol. 22, No. 4, pages 213–222; 2007.

Heading North: An Africanist Perspective on the Replacement of Neanderthals by Modern Humans. Curtis W. Marean in *Rethinking the Human Revolution.* Edited by Paul Mellars et al. McDonald Institute for Archaeological Research, Cambridge, 2007.

Neanderthal Exploitation of Marine Mammals in Gibraltar. C. B. Stringer et al. in *Proceedings of the National Academy of Sciences USA,* Vol. 105, No. 38, pages 14319–14324; September 23, 2008.

NATURAL HISTORY MUSEUM, LONDON (*caves*); LAURIE GRACE (*map*)



Adventures in Curved Spacetime

The possibility of "swimming" and "gliding" in curved, empty space shows that, even after nine decades, Einstein's theory of general relativity continues to amaze

By Eduardo Guéron

KEY CONCEPTS

- In Albert Einstein's theory of general relativity, gravity arises from spacetime being curved. Today, 90 years after Einstein developed the theory's equations, physicists are still uncovering new surprises in them.
- For example, in a curved space, a body can seemingly defy basic physics and "swim" through a vacuum without needing to push on anything or be pushed by anything.
- Curved spacetime also allows a kind of gliding, in which a body can slow its fall even in a vacuum. *—The Editors*

In a famous series of stories in the 1940s, physicist George Gamow related the adventures of one Mr. C.G.H. Tompkins, a humble bank clerk who had vivid dreams of worlds where strange physical phenomena intruded into everyday life. In one of these worlds, for instance, the speed of light was 15 kilometers per hour, putting the weird effects of Einstein's theory of special relativity on display if you so much as rode a bicycle.

Not long ago I figuratively encountered one of Mr. Tompkins's great grandsons, Mr. E. M. Everard, a philosopher and engineer who is carrying on his ancestor's tradition. He told me of an amazing experience he had involving some recently discovered aspects of Einstein's theory of general relativity, which I will share with you. His remarkable story is replete with curved spacetime, cats twisting in midair, an imperiled astronaut dog paddling through a vacuum to safety—and Isaac Newton perhaps spinning in his grave.

Dangerous Curves Ahead

In a far-off region of the cosmos, Mr. Everard had gone outside his spaceship to repair an errant antenna. He noticed that the beautiful lights of the distant stars looked distorted, as though he were viewing them through a thick lens. He felt, too, something gently stretching his body. Suspecting he knew what was afoot, he took a laser pointer and a can of shaving cream from his utility belt and turned on his jet pack to test his idea.

With the laser beam serving as a guide, he jetted straight out 100 meters, turned left to travel several dozen meters in that direction and finally returned to his starting point, drawing a

ALL ILLUSTRATIONS BY MIRACLE STUDIOS *www.miraclestudios.com*

triangle of foam like a cosmic skywriter. Then he measured his triangle's vertex angles with a protractor and added them up. The result was more than 180 degrees.

Far from being nonplussed by this apparent violation of the rules of geometry, Mr. Everard fondly remembered a mischievous non-Euclidean incident in his childhood, when he drew triangles on the globe in his parents' study. There, too, the angles added up to more than 180 degrees. He concluded that the space around him also must be curved much like the surface of that globe, so many years and light-years away. The curvature would account for the distorted starlight and the slightly unpleasant feeling of being stretched.

Thus, Mr. Everard understood he was experiencing textbook effects of general relativity. Experiments of a rather more refined nature than his jaunting about with shaving cream had confirmed these effects long ago: matter and energy cause space and time to curve, and the curvature of spacetime causes matter and energy (such as his laser beam and the light from the stars) to follow curved trajectories. His feet and his head "wanted" to follow slightly different curves, and the discrepancy produced the stretching sensation.

Musing on these facts, Mr. Everard pressed the button to engage his jet pack again to return to his spaceship—and nothing happened. Alarmed, he saw his fuel gauge was at zero, and he was a good (or rather, bad) 100 meters from the safety of his air lock. In fact, he and his triangle of foam were drifting away from his spacecraft at a constant velocity.

Acting quickly, he flung his protractor, laser,

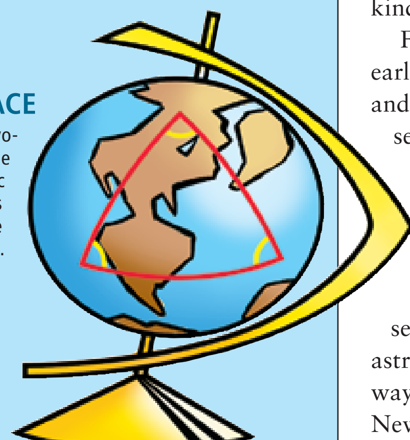
[BASICS]

CURVED SPACETIME

General relativity describes gravity as arising from the curvature of spacetime, but what does it mean for spacetime to be curved and what are some of the consequences?

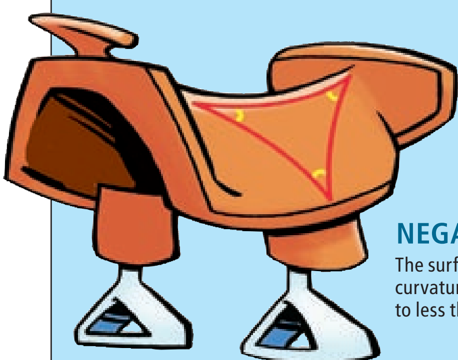
FLAT SPACE

The geometry taught in school is Euclidean, or the geometry of “flat” space. In such a space, the angles of a triangle add up to 180 degrees. A two-dimensional plane, such as the surface of a billiards table, is a flat space. To a very good approximation, so, too, is the three-dimensional world around us: if you “draw” a triangle in the air using three laser beams to mark the sides, the angles will add up to 180 degrees anywhere that you draw it.



CURVED SPACE

The surface of a sphere is an example of a curved two-dimensional surface. On a sphere, the angles of a triangle add up to more than 180 degrees, which is a characteristic of a region with “positive” curvature. The triangle’s sides may look curved to us in three dimensions, but they are perfectly straight to an ant crawling across the sphere.

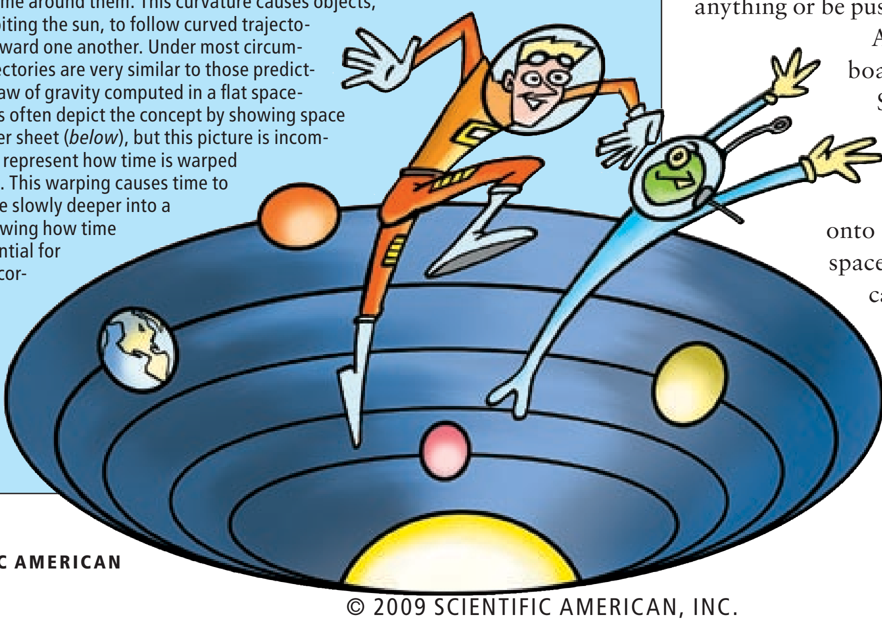


NEGATIVE CURVATURE

The surface of a saddle shape has negative curvature—the angles of a triangle add up to less than 180 degrees.

GRAVITY COMES FROM CURVATURE

According to general relativity, concentrations of mass and energy curve the spacetime around them. This curvature causes objects, such as Earth orbiting the sun, to follow curved trajectories and to fall toward one another. Under most circumstances, the trajectories are very similar to those predicted by Newton’s law of gravity computed in a flat spacetime. Illustrations often depict the concept by showing space as a curved rubber sheet (*below*), but this picture is incomplete; it does not represent how time is warped along with space. This warping causes time to pass slightly more slowly deeper into a gravity well. Knowing how time is warped is essential for determining the correct trajectories.



can of foam and all the other items on his utility belt directly away from his spacecraft. In accord with the principle of momentum conservation, with each throw he recoiled a little in the opposite direction—toward his ship. He even unharnessed his jet pack and shoved that dead weight away as forcefully as he could. Alas, when he had nothing left to hurl, he found he had done only enough to counteract his initial motion away from the ship. He was now floating motionless with respect to his ship but still far away from it. His situation may have seemed hopeless: his high school physics teacher had impressed on him that it is not possible to accelerate a body without an external force or some kind of mass ejection.

Fortunately for our adrift friend, he had earlier established that he was in a curved space, and he was wise enough to know that some conservation laws in physics work differently in a curved space than in the flat (uncurved), Newtonian space of his school years. In particular, he remembered reading a 2003 physics paper in which planetary scientist Jack Wisdom of the Massachusetts Institute of Technology showed that an astronaut could move through curved space in ways that would be impossible according to Newton’s laws of motion—simply by making the right movements with his arms and legs. In other words, he could swim. It did not require any fluid to push against; he could dog-paddle through the vacuum.

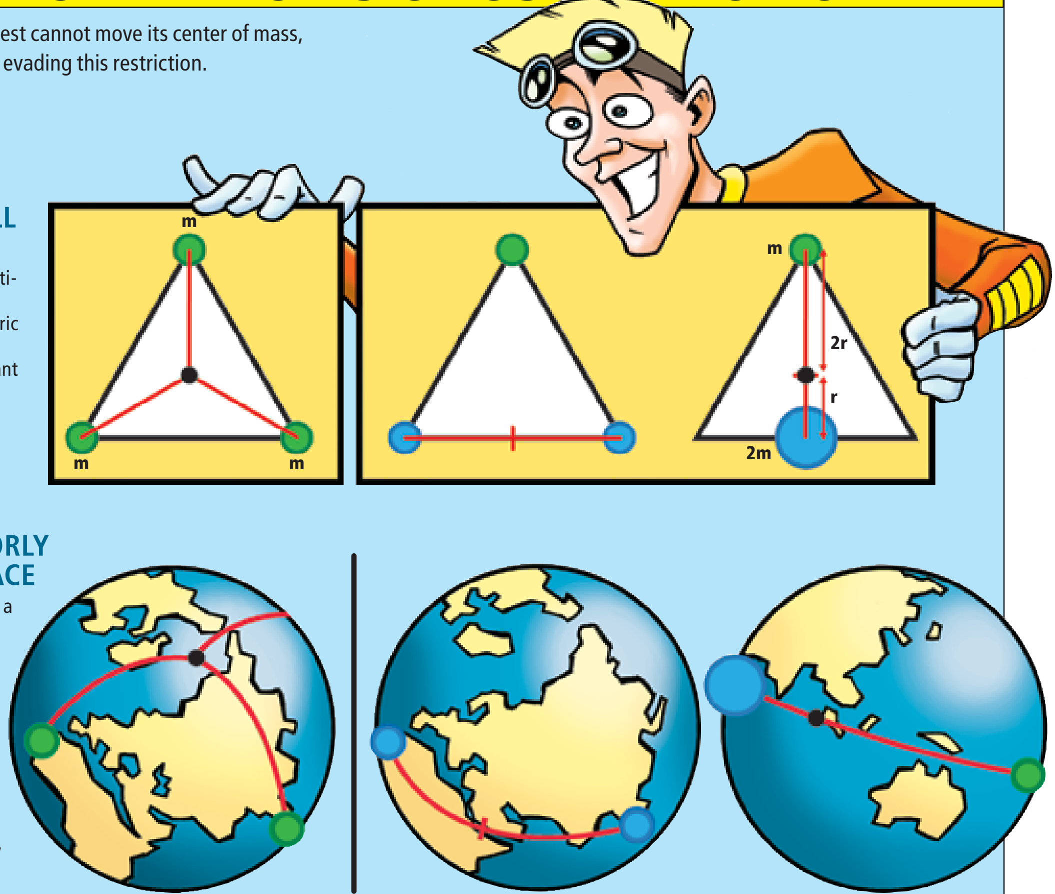
Wisdom’s trick is rather like how a cat, dropped upside down, can twist its body and retract and extend its legs so that it flips over and lands on its feet. The laws of Newtonian mechanics permit the cat to change its orientation, but not its velocity, without needing to push on anything or be pushed by anything.

Astronauts such as those onboard the International Space Station use a version of the cat-twisting trick to turn around in weightlessness without needing to grab onto a handhold. In the curved spacetime of general relativity, a cat or an astronaut can pull off more impressive stunts. Our hero covered the distance back to his spacecraft in somewhat more than an hour—no Olympic record but certainly quick enough

[A LOOPHOLE]

WHY CURVATURE ALLOWS UNUSUAL MOTION

In flat space, an isolated system at rest cannot move its center of mass, but curved space has a loophole for evading this restriction.



CENTER OF MASS IS WELL DEFINED IN FLAT SPACE

Three balls of equal mass, *m*, at the vertices of an equilateral triangle have their center of mass at the triangle's geometric center (*black dot*). This position can be calculated as the point that is equidistant from all three corners (*left*), but it may also be calculated in two steps (*right*).

CENTER OF MASS IS POORLY DEFINED IN CURVED SPACE

Now imagine that the three balls are in a space curved like a surface of a sphere and are at locations corresponding to Dakar, Singapore and Tahiti on Earth. Computing the balls' center of mass by finding an equidistant point produces a location near the North Pole (*left*). Computing the center of mass in two steps, however, yields a spot near the equator (*right*). This ambiguity about the center of mass makes it possible to "swim" through a curved space.

to ensure that he would live to undertake more adventures.

Swimming Lessons

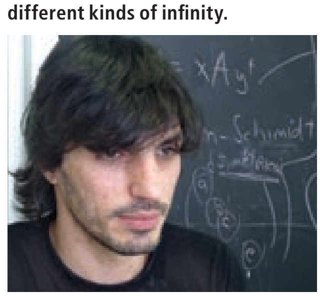
How exactly does Wisdom's phenomenon work? How is it an adventurer such as Mr. Everard can swim in space? In a flat space—the kind assumed by Newtonian mechanics and also special relativity—the center of mass of an isolated system (for example, astronaut plus dead jet pack) never accelerates. Suppose Mr. Everard had tied a long cord to his jet pack before he shoved it away and then reeled it back in. Throughout the entire exercise, as the jet pack and astronaut first moved farther apart and later came together again, the center of mass of the two would be unchanged. At the end, he and his jet pack would be back at their initial position. More generally, Mr. Everard cannot move merely by cyclically changing his shape or structure and then restoring it again.

In curved space, the situation is different. To understand why, imagine an alien creature with two arms and a tail, all of which it can extend and retract [*see box on page 43*]. To simplify the discussion, imagine that virtually all of the alien's mass is concentrated at the ends of its three limbs, a quarter of it in each hand and the other half at the tip of the tail. Floating in *flat* space, this alien is helpless. If it extends its tail by, say, two meters, the hands move forward one meter and the tail tip moves back one meter, maintaining the center of mass. Retracting the tail again brings the whole alien back to its starting position, just as with Mr. Everard and his inert jet pack. Similar things happen if the alien tries extending its arms. Whatever combination or sequence of limb extensions and retractions the alien carries out, its center of mass stays the same. The best it can do is use the cat trick (extend limbs, swing them around, retract them, swing them back again) to change the direction it is pointing.

But now imagine that this alien lives in a curved space, shaped like the surface of a sphere. To help you picture it, I will use geo-

[THE AUTHOR]

Eduardo Guéron is associate professor of applied mathematics at the Federal University of ABC in Brazil (the "ABC Region" borders on the city of São Paulo). Guéron earned his Ph.D. at the State University of Campinas in Brazil in 2001, and he was a visiting scientist at the Massachusetts Institute of Technology from 2003 to 2004. He studies gravitation, dynamical systems and fundamental problems in general physics. Guéron also enjoys playing with his four-year-old daughter and trying to teach her that there are different kinds of infinity.

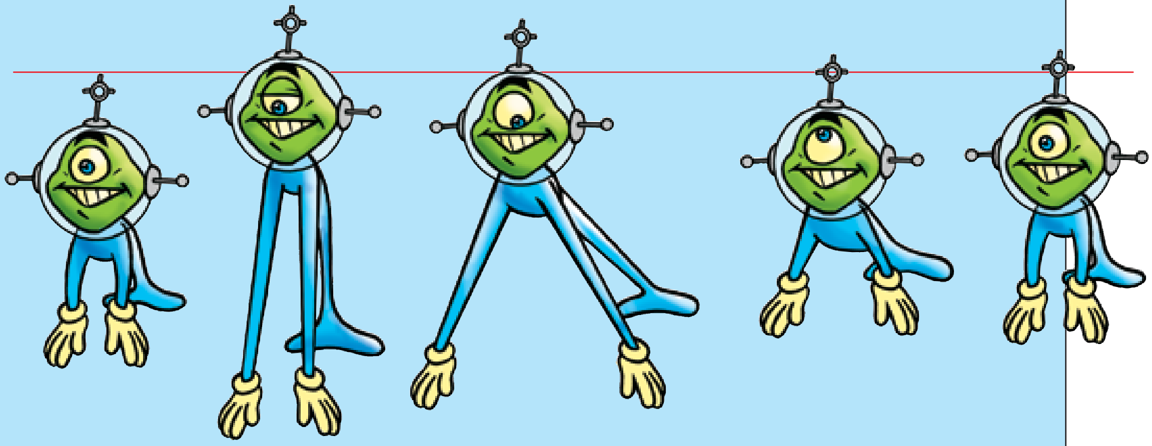


COURTESY OF EDUARDO GUÉRON (*Guéron*)

[HOW TO SWIM]

A SWIMMER IN CURVED SPACETIME

A tripodlike machine or alien creature could swim through empty but curved spacetime by cyclically extending, opening, retracting and closing its legs. Each cycle of four actions moves the tripod through space—here a small distance up the page—even though it ejects no propellant and no external force acts on it.



graphical terms to describe positions and directions on the sphere. The alien starts on the sphere's equator, its head pointing west and its arms and tail all retracted. It extends both arms, one to the north and one to the south. It then lengthens its tail while keeping its arms extended at right angles to its body. As in flat space, if the mass-laden tail tip moves one meter to the east, the hands move one meter west. Here is the crucial difference on the sphere: the alien keeps its arms aligned with the sphere's lines of longitude and the distance between those lines is greatest at the equator. Thus, when the alien's hands (nearer the north and south poles of the sphere) move one meter westward, its shoulders (on the equator) move more than one meter. Now when the alien retracts its arms, along the lines of longitude, it ends up with its hands more than one meter west. When it retracts its tail, restoring its original body configuration, it finds itself a short distance westward along the equator from its original position!

By cyclically repeating these movements, the alien crawls along the equator. The unusually heavy tail tip and hands are not essential to the swimming; it is just easier to see how far the arms move in response to the tail stretching if all the mass is concentrated at those three points. And, as it happens, if the alien species depended on the curved-space swimming for its survival, it might evolve heavy knobs at its extremities to improve the efficiency of its swimming. After all, mass located at its elbows will not reach so far around the curvature of the sphere as its hands do and therefore will not produce as much extra movement of the body.

A sphere is a two-dimensional surface, but the same principle works in curved four-dimensional spacetime. Cyclic changes in the configuration of a system can lead to a net displacement. Wisdom's proposed swimmer was a tripod with telescoping legs. The legs can be retracted or extended in length, and the angle between them can be widened or narrowed. The tripod swims by extending its legs, spreading them, retracting them and closing them. The greater the curvature of spacetime where the tripod is, the farther it gets displaced by this sequence of moves.

Spacetime is only very slightly curved, except near a black hole. So in practice you would be swimming for billions of years before you moved a millimeter.

Moving Violations?

Though surprising at first, swimming is a direct consequence of basic conservation laws, not a violation of them. Swimming works because the very concept of a center of mass is not well defined in a curved space. Suppose we have three one-kilogram balls located at the vertices of an equilateral triangle. On a flat surface, their center of mass is the geometric center of the triangle. You can calculate where the center of mass is located in a number of different ways, and each method gives the same result. You can find the point that is an equal distance from all three balls. Or you can replace two of the balls with a single two-kilogram ball located halfway between them and then calculate the center of mass of that ball and the third ball (the point one third of the way along the line to the third ball). The result will be the same. This geometric fact carries over into the dynamics of the system: the center of mass of an isolated system never accelerates.

On a curved surface, however, different computations may not give the same result. Consider a triangle formed by three equal-mass balls in Singapore, Dakar and Tahiti—all near the equator. A point equidistant to the three balls is near the North Pole. But if you replace the balls in Singapore and Dakar with a heavier one in between them and then calculate the position that is one third of the way along the great circle from that ball to the one in Tahiti, your answer will lie close to the equator. Thus, the "center of mass" on a curved surface is ambiguous. This geometric fact ensures that a system in a curved space can move even when it is isolated from any outside influences.

Other subtleties also arise. A standard physics homework assignment involves adding up the forces on a body to determine the net force. Physics students express forces as vectors, which are drawn as arrows. To add two vectors, they slide the arrows around so that the base of one arrow meets the tip of the other. In a curved space, this procedure has pitfalls: the direction of a vector can change when you slide it around a closed path. The procedure for calculating the total force on a body in curved space is therefore considerably more complicated and can result in oddities such as swimming.

Some effects in Newtonian gravitation may seem similar to spacetime swimming at first glance. For instance, an astronaut orbiting Earth could alter his orbit by stretching tall and curling into a ball at different stages. But these Newtonian effects are distinct from spacetime swimming—they occur because the gravitational field varies from place to place. The astronaut must time his actions, like a person on a swing does to swing faster. He cannot change his Newtonian orbit by rapidly repeating very small motions, but he *can* swim through curved spacetime that way.

That the possibility of spacetime swimming went unnoticed for nearly 90 years reminds us that Einstein's theories are still incompletely understood. Although we are unlikely to construct a swimming rocket anytime soon, Nobel laureate physicist Frank Wilczek, also at M.I.T., has argued that Wisdom's work raises profound questions about the nature of space and time.

In particular, Wisdom's findings bear on the age-old question of whether space is a material

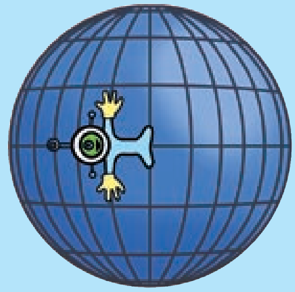
[WHY IT WORKS]

PADDLING ACROSS A SPHERE

Swimming through curved spacetime can be understood by considering a simpler two-dimensional alien swimmer that lives on the surface of a sphere.

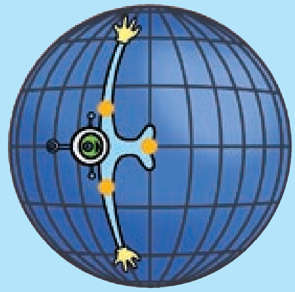
ON YOUR MARKS

The swimmer is facing west, with its arms pointing north and south and its tail pointing east. To simplify the discussion, imagine all of the swimmer's mass is concentrated at the end of its limbs—a quarter in each hand and a half in the tip of its tail.



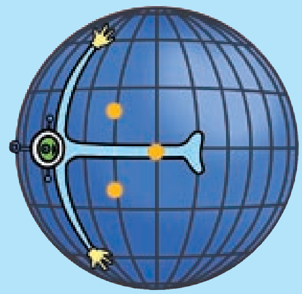
ARMS OUT

The arms stretch north and south (orange balls mark where the hands started). The equal and opposite movement keeps momentum balanced.



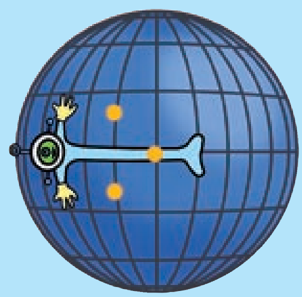
EXTEND TAIL

Now the tail stretches eastward. To balance momentum, the hands move west. Being near the poles of the sphere, the hands cross several lines of longitude to travel the same distance as the heavy tail tip, and the "shoulders" move a long way west along the equator.



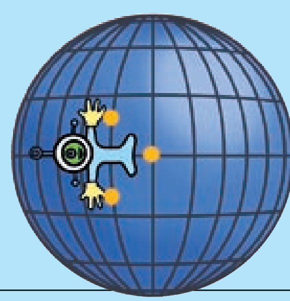
ARMS IN

The arms retract along the lines of longitude (which are the equivalent of straight lines on the sphere). The hands are now much farther west of their starting points than the tail tip is east of its starting point.



RETRACT TAIL

When the tail retracts again, the hands move back toward the east to balance momentum. The cycle of actions has moved the swimmer as a whole a short distance to the west because of the "extra" distance that the hands have traveled.



On a saddle shape, which has negative curvature, the same actions would move a swimmer eastward. See http://physics.technion.ac.il/~avron for animations of both examples.

"You cannot lift yourself by pulling on your bootstraps, but you can lift yourself by kicking your heels."
—Jack Wisdom, M.I.T.

object in its own right (a position known as substantivalism) or merely a convenient conceptual device to express the relations among bodies (a position known as relationalism) [see "A Hole at the Heart of Physics," by George Musser; SCIENTIFIC AMERICAN, September 2002].

To illustrate these viewpoints, imagine that Mr. Everard is floating in an otherwise empty universe. He would have no stars or galaxies to serve as reference points to judge his motion. Physicist and philosopher Ernst Mach, a relationalist, argued in 1893 that motion would be meaningless in this situation. Yet even a completely empty space can be curved, in which case Mr. Everard could swim through it. It therefore seems that spacetime acts as a virtual fluid against which the motion of an isolated body can be defined. Even completely empty space has a specific geometric structure—another point in favor of substantivalism. At the same time, though, matter (or any other form of energy) is what gives spacetime its geometric structure, so spacetime is not independent of its contents—a point in favor of relationalism. This debate, which crops up in the attempts to develop a unified theory of physics, remains unresolved.

On the Wings of Time

Worn out by the effort to swim back to his spaceship, Mr. Everard was resting inside the cabin and letting the autopilot plot a course back home. Suddenly, the alarm went off and the red lights started flashing, indicating that the spaceship was falling onto a massive planet. Mr. Everard was delighted by this opportunity for new and interesting discoveries, but landing on this planet would be a challenge. The ship had too little fuel for a powered descent, and the planet lacked an atmosphere, making a parachute useless.

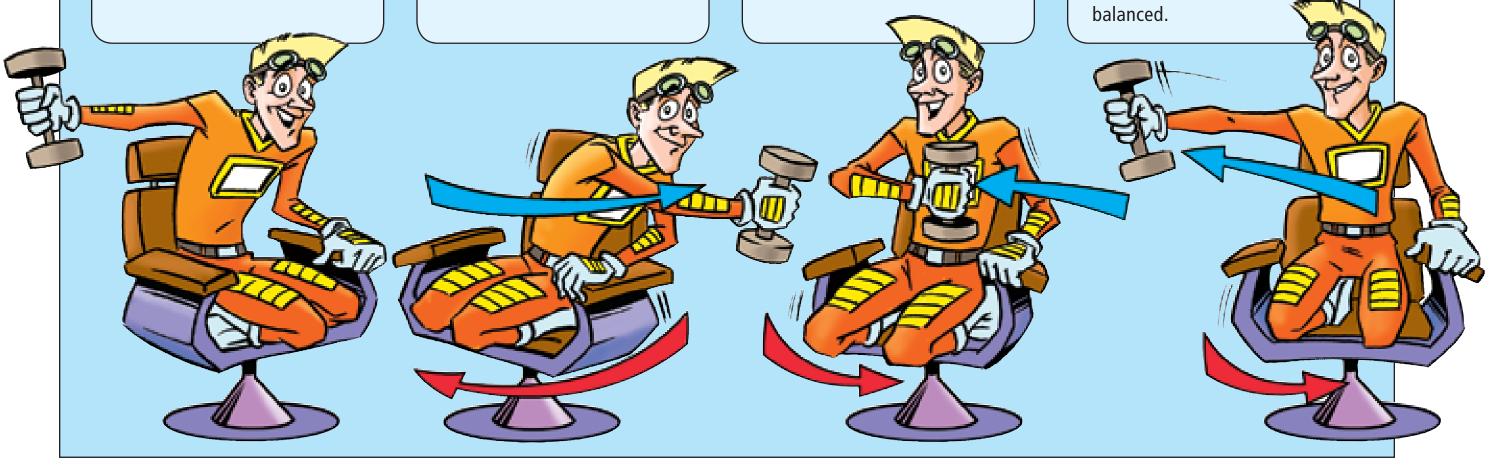
Fortunately, he remembered the 2007 paper that my colleague, mathematical physicist Ricardo A. Mosna of the State University of Campinas in Brazil and I wrote. Inspired by Wisdom's example, we came up with another way to exploit general relativity to control motion. Our analysis indicates that an object can slow its descent toward, say, a planet by repeat-

[DO-IT-YOURSELF]

TAKING IT FOR A SPIN

Near Earth, spacetime is so very close to being flat that you cannot "swim" through it to change your location. Yet you can change your orientation without needing an outside force (much like a falling cat twists to land on its feet). Here is one way to try it out. See www.ScientificAmerican.com for a video.

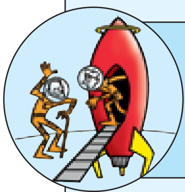
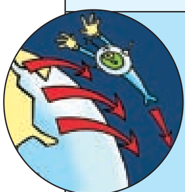
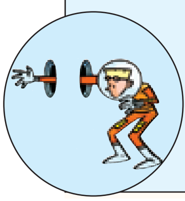
1. Kneel or sit on a swivel chair, preferably one that does not also rock. Hold a weight out to your side (the weight will increase the effect).
2. Swing the weight around to your other side, keeping your arm outstretched all the way. To conserve angular momentum, the chair (and you on it) should swivel in the opposite direction.
3. Now bring the weight back across you, keeping it as much as possible on a path going through the axis of the chair.
4. The chair will turn back part of the way to where it began, but you should end up rotated from your original position. Repeating the move can turn you full circle if you and the chair are well balanced.



[OTHER ODDITIES]

BEYOND NEWTON

General relativity has long predicted several effects that have no analogue in Newtonian gravitation, in addition to the recently uncovered phenomena of spacetime swimming and gliding.

EFFECT	EXAMPLE	EXPLANATION	THEORY	STATUS
 Gravitational time dilation	A person travels near a black hole; she returns younger than her stay-at-home twin	Time passes more slowly in a strong gravitational field	Inferred by Albert Einstein while developing general relativity	Used in technology: the Global Positioning System (GPS) has to allow for gravitational time dilation in the timing of its signals to compute accurate positions
 Gravitational waves	Waves of gravity propagating out from a binary star system at the speed of light	Gravitational waves are traveling oscillations of spacetime geometry, as if spacetime itself were undergoing vibrations of compression and expansion	General relativity's equations clearly permit waves, but the waves are hard to analyze exactly	Observed indirectly in the late 1970s: the orbital period of a pulsar and a neutron star forming a binary system became shorter over time as predicted to occur because of gravitational wave emission. LIGO and other experiments are seeking direct observations of gravitational waves
 Lense-Thirring effect	A satellite near Earth feels a force pulling it in the direction of Earth's rotation	Like a ball spinning in molasses, a rotating mass drags spacetime itself around a small amount	Predicted by Joseph Lense and Hans Thirring in 1918	In February 2009 researchers announced that results from the Gravity Probe B satellite matched the prediction within an experimental uncertainty of 15 percent
 Wormholes	A hypothetical shortcut connecting two different regions of the universe	Extraordinary hypothetical kinds of energy would provide negatively curved spacetime, which is required to form a wormhole structure	Discussed as early as 1916; researchers showed that general relativity's equations permit traversable wormholes in 1988	Still very speculative; most physicists believe that they will never be found

edly stretching and contracting in an asymmetric fashion—meaning the extending motion is faster than the retracting. A ship equipped with a device moving in that fashion could act as a glider even in the absence of air.

In this case, the effect has to do with the temporal rather than spatial qualities of the motion, which brings to light one of the deepest aspects of Einstein's theories: the connection between space and time. In Newtonian mechanics, physicists can specify the location of events using three coordinates for spatial position and one for the time, but the concepts of space and time are still distinct. In special relativity, they are inextricably intertwined. Two observers with different velocities may not agree on their measurements of the distance or time interval between two events, but they do agree on a certain amalgam of space and time. Thus, the observers see time and space, considered separately, differently—yet see the same spacetime.

In general relativity, the structure of spacetime becomes distorted (that is, curved), producing what we perceive as the force of gravity. Whereas Newtonian gravity involves only space, relativistic gravity also involves time. This distortion of both space and time leads to effects such as one known as frame dragging: a rotating body (such as Earth) exerts a slight force in the direction of its rotation on other nearby objects (such as orbiting satellites). Loosely speaking, the spinning Earth drags spacetime itself around slightly. More generally, the velocity of motion of a mass influences the gravitational field it produces. Frame dragging and the glider are both examples of this phenomenon.

The swimming effect arises from non-Euclidean geometry, and the relativistic glider is a consequence of indissolubility of space and time. Other such phenomena may remain to be recognized and understood within the inscrutable equations of general relativity. Mr. Everard and other disciples surely have more adventures in store. ■

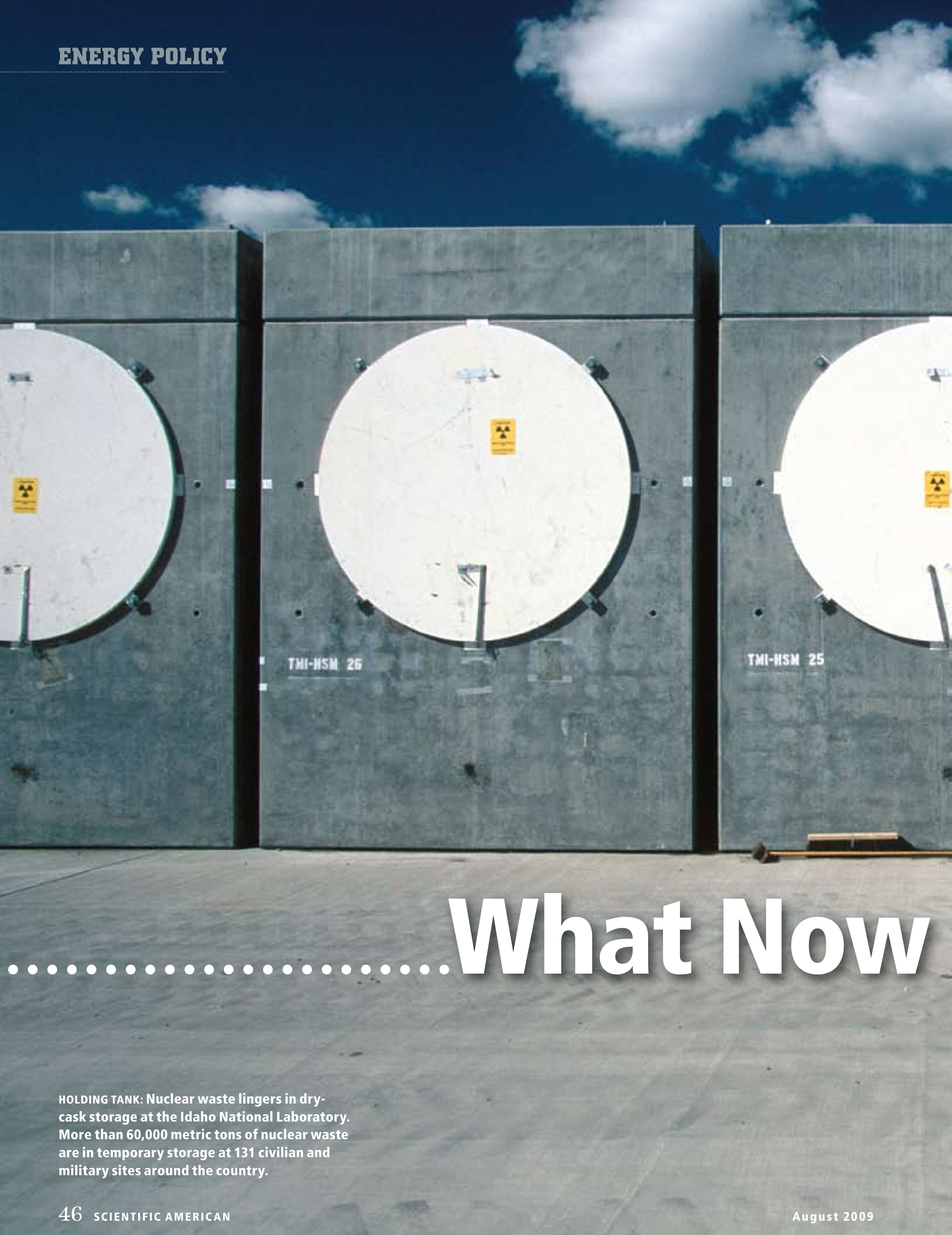
MORE TO EXPLORE

Space, Time, and Gravity: The Theory of the Big Bang and Black Holes. Robert M. Wald. University of Chicago Press, 1992.

Swimming in Spacetime: Motion in Space by Cyclic Changes in Body Shape. Jack Wisdom in *Science*, Vol. 299, pages 1865–1869; March 21, 2003.

Swimming versus Swinging Effects in Spacetime. Eduardo Guéron, Clóvis A. S. Maia and George E. A. Matsas in *Physical Review D*, Vol. 73, No. 2; January 25, 2006.

Relativistic Glider. Eduardo Guéron and Ricardo A. Mosna in *Physical Review D*, Vol. 75, No. 8; April 16, 2007.



What Now

HOLDING TANK: Nuclear waste lingers in dry-cask storage at the Idaho National Laboratory. More than 60,000 metric tons of nuclear waste are in temporary storage at 131 civilian and military sites around the country.

for Nuclear Waste?

Yucca Mountain was supposed to be the answer to the U.S.'s nuclear waste problem, but after 22 years and $9 billion, that vision is dead. Now some say that doing nothing in the near term may be the smartest solution • BY MATTHEW L. WALD

KEY CONCEPTS

- The Obama administration has effectively canceled the plan to store nuclear waste at Yucca Mountain.
- Spent fuel will for the foreseeable future continue to be stored onsite at 131 locations around the country.
- The end of Yucca means that all options for waste disposal are now in play, including recycling, use in advanced reactors and burial at other sites.

—The Editors

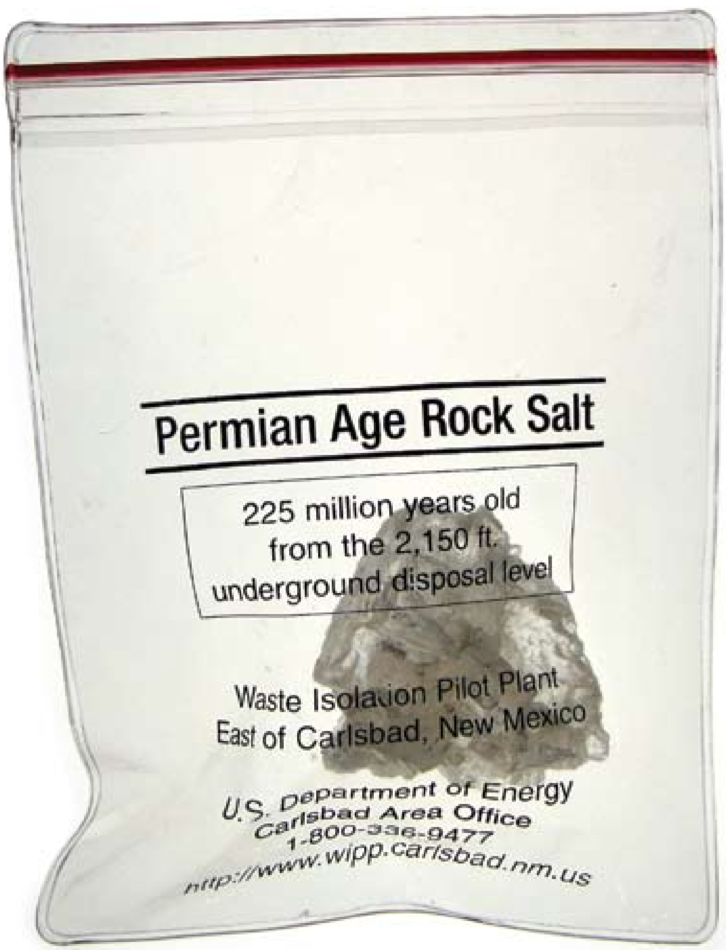
Two weeks after President Barack Obama pulled the plug on Yucca Mountain, the site near Las Vegas where the federal government has been trying for 22 years to open a repository for nuclear waste, geochemist James L. Conca came to Washington, D.C., with an idea in his pocket.

Conca has been assigned by the state of New Mexico to monitor the environment around a different federal nuclear dump, one used for defense-related plutonium, and where others see problems, he sees opportunity.

The long battles over nuclear waste have produced much study and argument, epic legal wrangling and one mass-produced souvenir: a plastic bag labeled "Permian Age Rock Salt" that holds clear hunks of crystal mined from the Waste Isolation Pilot Plant 2,150 feet under the Chihuahuan Desert outside of Carlsbad, N. M. Conca, director of the Carlsbad Environmental Monitoring and Research Center at New Mexico State University, delights in giving away the little bags, telling recipients to hold the crystals up to the sunlight and peer through the translucent salt as if they were candling an egg.

Inside the chunks are little bubbles of water—what geologists call inclusions—that have been trapped for 225 million years, traces of a long-gone sea. They look a bit like bubbles trapped in Jell-O. Inclusions indicate how fast water, the vector for spreading waste, can move through the rock; in this case, Conca says, the timeline is encouraging. The salt naturally creeps in to close any cracks, so the water remains trapped. "Permeability is not just very low but zero," he says. When it comes to a place to put something that will be hazardous for a million years—the wastes that were to go to Yucca, for example—"you couldn't engineer something this good," he observes.

Conca's position is not shared by the elected leaders of New Mexico—if it were, the arguing would be over by now. But it is an indication that while the problem of nuclear waste remains unsolved, there are a number of reasonable candidate solutions. Some, like Carlsbad, resemble Yucca in kind if not location—find a quiet area and bury the stuff. Others rely on increasingly complex recycling schemes. But until elected officials implement an alternative plan—a process, if Yucca is any guide, that could take decades—the waste will languish at 131 storage sites around the country [*see box on page 52*].



The Collapse

This delay may not be an entirely bad thing. So far, at least, the interim waste being stored onsite at power plants is well inventoried and managed. It does not cascade from storage lagoons, as a billion gallons of toxic coal wastes did from a Tennessee Valley Authority power plant in December 2008. And unlike carbon dioxide, it does not disperse into the atmosphere to be counted in worrisome parts per million, an index of climate sickness akin to the white blood cell count of an infected patient. It does, however, accumulate and linger, in some cases longer than the reactor that produced it. The waste debate has gone on so long that there are now 10 "orphan" sites, radioactive mausoleums where the power plant is gone but the waste remains.

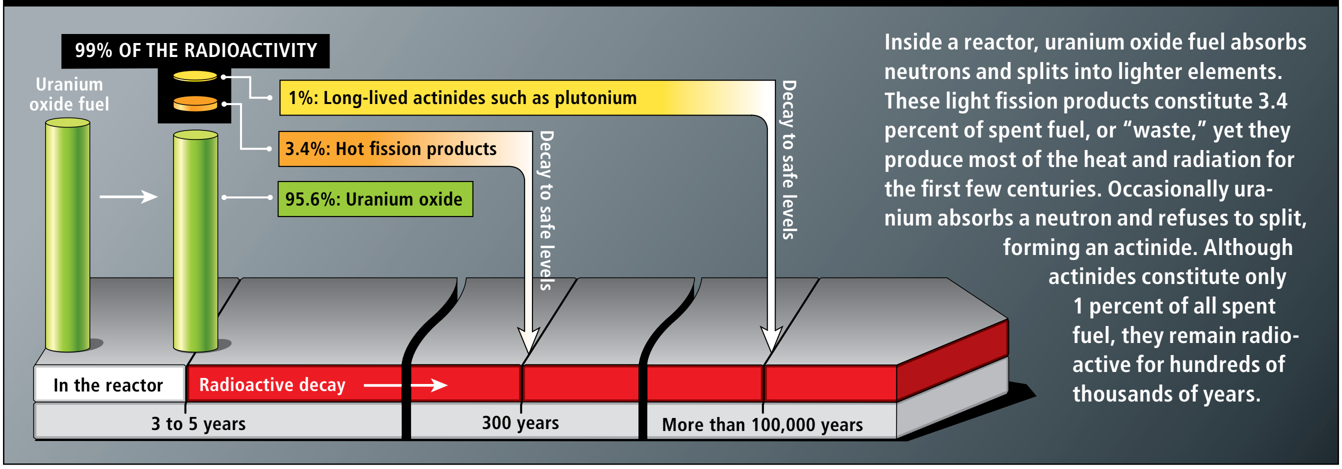
"Waste" might not be quite the right word;

A HARD PLACE: Geochemist James L. Conca argues that the best place to store nuclear waste is inside salt deposits deep under the New Mexican desert. The salt (*left*) naturally adjusts to fill any cracks that develop in the crystal, so anything buried within will remain trapped.

PETER ESSICK *Getty Images (preceding pages)*; SCIENTIFIC AMERICAN *(this page)*

[NUCLEAR ANATOMY]

THE COMPONENTS OF NUCLEAR WASTE



Inside a reactor, uranium oxide fuel absorbs neutrons and splits into lighter elements. These light fission products constitute 3.4 percent of spent fuel, or "waste," yet they produce most of the heat and radiation for the first few centuries. Occasionally uranium absorbs a neutron and refuses to split, forming an actinide. Although actinides constitute only 1 percent of all spent fuel, they remain radioactive for hundreds of thousands of years.

technically, the term for the bulk of the material to be buried is "spent nuclear fuel." The civilian stuff starts out as a fuel assembly—a bundle of thin-walled metal tubes, each filled with ceramic pellets of uranium oxide the size of pencil erasers. In the absence of free neutrons, this uranium is extremely stable. Power plant technicians handle the fresh fuel wearing nothing more than white gloves—and the gloves are for the protection of the fuel, not the workers.

After it arrives on site, the fuel is lowered into the outermost regions of a circular reactor vessel, which is sealed up and run for one to two years. Then the vessel is opened, the innermost, oldest fuel is removed, and the younger fuel moved toward the center. Usually a given fuel assembly will stay in the vessel for three cycles, which can last a total of anywhere from three to six years.

When a fuel assembly comes out, highly radioactive fission products such as strontium 90 and cesium 137 are generating tens of kilowatts of heat. If the assembly were cooled merely by air, the metal surrounding the nuclear material would melt; it might even burn. So the assemblies are kept submerged in a spent-fuel pool, a steel-lined concrete pool with water so clean that a drop of tap water would pollute it. These fission products burn hot but relatively quickly. Their half-life—the time it takes for half the material to transmute into more stable elements and release radiation—is measured in mere years. Heat production falls by 99 percent in the first year. It falls by another factor of five by the time the fuel is five years old and by another 40 percent by year 10.

After a few years the rods no longer need to be stored in water. They are transferred into steel sleeves, then drained, dried, pumped full of an inert gas and sealed. The sleeves are loaded into giant concrete casks and put into on-site storage near the reactor. Inside its concrete-and-steel silo, the fuel produces so little heat that it can be cooled by the natural circulation of air.

The long-term challenge is dealing with the actinides, materials created when uranium absorbs a neutron but refuses to split apart. These elements have half-lives in the hundreds of thousands of years. The Department of Energy originally set out to demonstrate that Yucca was safe for 10,000 years, yet it acknowledged that peak radiation releases would come after about 300,000 years. Opponents seized on that disparity, and in 2004 the U.S. Court of Appeals for the Federal Circuit ruled that the DOE had to demonstrate that the waste could be stored safely for one million years.

Yucca was never the leading candidate from a scientific point of view. A volcanic structure, it became the leading candidate when it was chosen in 1987 by the best geologists in the U.S. Senate. Before politicians stepped in, aiming to speed up the selection process and also to guarantee that the waste would not go anywhere else, Yucca was on a list of possible locations, along with sites in Texas and Washington State. The DOE and its predecessor agency put these sites on the list for their scientific promise and partly for reasons of convenience—in the case of Yucca Mountain, the federal government already owned the place, and it was adjacent to a nuclear weapons test site.

Yucca fell out of the running for pretty much the same reason: politics. In 1987 the speaker of the House was a Texan, Jim Wright, and so was the vice president, George H. W. Bush. The House majority leader was Tom Foley of Wash-

[THE AUTHOR]

Matthew L. Wald is a reporter for the *New York Times*, where he has covered energy topics since 1979. His most recent article for *Scientific American* was "The Power of Renewables" in the March issue.

JEN CHRISTIANSEN (*illustration*); COURTESY OF SUSAN ETHRIDGE (*Wald*)

Yucca became the leading candidate when it was chosen by the best geologists in the U.S. Senate.

ington State, and Harry Reid was a first-term senator from Nevada. Washington State and Texas dropped off the list. Now Reid is the majority leader, and the president won Nevada's four electoral votes partly by promising a new look at nuclear waste. The politics of geology has changed.

A purely scientific evaluation of competing geologies might find a better choice. "Salt is nice, in some senses, from a geologic perspective," says Allison M. Macfarlane, a geochemist and assistant professor of environmental science and policy at George Mason University and a frequently mentioned candidate for a vacant seat on the Nuclear Regulatory Commission. But if the salt is heated, the watery inclusions mobilize and flow toward the heat, she points out, so burying spent fuel there would require waiting until the hot waste products cool down a bit—somewhere around the second half of this century.

Macfarlane helped to organize a conference called "Toward a Plan B for U.S. High-Level Nuclear Waste Disposal" in July 2007, an event that mostly demonstrated that there was no plan B. The U.S. could find another solution, though, she says, if it used a more open, fair process for choosing sites—in other words, if it took the choice away from the politicians.

Plan B

It was never supposed to come to this. The Nuclear Waste Policy Act of 1982 specified that utilities had to pay into a government-administered Nuclear Waste Trust Fund a tenth of a cent for every kilowatt-hour of energy their reactors generated. The government, in turn, agreed to find a place to bury the waste. The DOE forced the utilities to sign contracts and promised to begin taking deliveries in January 1998.

Before President Obama submitted his 2010 budget, cutting funding for Yucca Mountain to a perfunctory $197 million, the official opening date was scheduled for 2017. And the department estimated that as of that date, it was liable for damages of $7 billion to the utilities, possibly the world's largest late fee. The price rises by $500 million every additional year of delay. If the science and engineering can come together, a fix is worth a lot of money.

Another possible solution revisits a decision made over three decades ago. By volume, about 95.6 percent of the spent fuel that comes out of a reactor is the same uranium oxide in the original fuel. The rest of the spent fuel is made of hot fission products (3.4 percent) and long-lived actinides such as plutonium (1 percent). At the start of the nuclear age, the plan was to recycle the uranium and plutonium into new fuel, discarding only the short-lived fission products. In theory, this would reduce the vol-

END OF AN ERA: Politics gave birth to Yucca, and politics contributed to its demise. While many other countries recycle their spent nuclear fuel, the process creates plutonium that could be stolen and used to construct a nuclear weapon; citing these fears, President Gerald Ford (1) banned recycling in 1976. That left burial as the only remaining option. A search for suitable sites turned up three: one in Texas, one in Washington State and Yucca in Nevada. At the time, Texas was home to Vice President George H. W. Bush (2) and Jim Wright (3), the speaker of the House. House Majority Leader Tom Foley (4) was from Washington. Nevada, politically weak, was saddled with the site over the strong objections of first-term Senator Harry Reid (5). Now Reid is Senate majority leader, and Nevada, a swing state, voted for Barack Obama last November. Earlier this year President Obama's secretary of energy, Steven Chu, (6) announced that Yucca (7) was now "off the table."

DIRCK HALSTEAD *Getty Images (Ford)*; JENNIFER LAW *Getty Images (Bush)*; DIANA WALKER *Getty Images (Wright)*; ROB LEWINE *Getty Images (Foley)* ume of waste by up to 90 percent. But President Gerald Ford banned recycling in 1976, and his successor, President Jimmy Carter, a former officer in the nuclear navy, concurred. The reason they gave was proliferation risk—the plutonium could also be used for bombs, so the reprocessing technology would be risky in Third World hands. (The economics have also been unfavorable.)

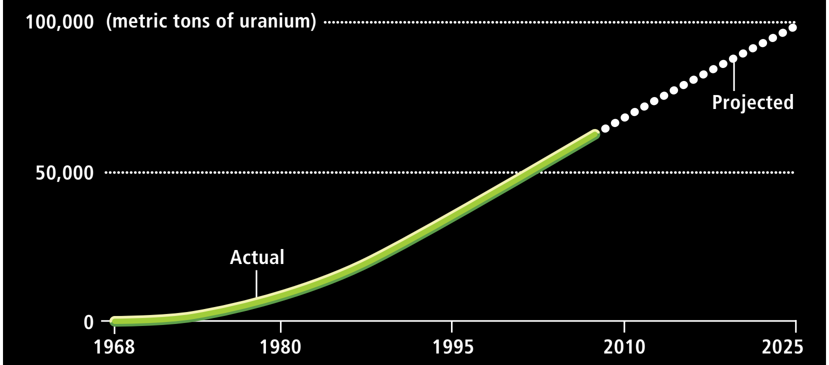
With the Ford decision, the U.S. committed itself to an "open" fuel cycle, meaning that the fuel would make a one-way trip—cradle to grave—as opposed to a "closed" cycle, where much of the fuel would have made a second or third pass through the reactor. It also made questions over waste a perennial part of the nuclear conversation. Various proposals have been floated over the years. Some have advocated shooting the stuff into space (a challenge, given its weight and the less-than-perfect success rate of launch vehicles). Others have suggested burying the waste at the borders of geologic plates and letting it slide over the eons back into the earth's mantle.

Instead it is filling up spent-fuel pools and then being shifted into dry casks, the steel-lined concrete silos. Although dry-cask storage might seem like a precarious and accidental solution, there is much to recommend it. Barring an accident such as dropping the sleeve on the racks of fuel in the pool, not much can go wrong. A terrorist attack could conceivably breach a cask, but the material inside is still a solid and is unlikely to go far. A terrorist group with a few rocket-propelled grenades and the talent to aim them well could find far more devastating targets than dry casks.

Storage space is also not an immediate concern. "There is enough capacity on our existing nuclear plants, if not for the rest of the century, then for a good portion of it," says Revis James, director of the Energy Technology Assessment Center at the Electric Power Research Institute, a utility consortium based in Palo Alto, Calif. "You could survive with aboveground storage for quite a while." Moreover, he says, "we're talking about a volume of waste that in the greater scheme of things is pretty small." (According to the International Atomic Energy Agency, a 1,000-megawatt reactor produces about 33 tons a year of spent fuel—enough to fill the bed of a large pickup

Where Will We Put It All?

Spent fuel from U.S. nuclear power reactors continues to accumulate



NUCLEAR DEBT: Before it was canceled, Yucca was to hold 70,000 metric tons of spent fuel. The U.S. is projected to reach that total by 2012. New approaches to the waste problem must contend with this multidecade backlog of waste.

SCOTT J. FERRELL *Getty Images* (*Reid and Chu*); JOE CAVARETTA *AP Photo* (*Yucca Mountain*); JEN CHRISTIANSEN (*illustration*); SOURCE: ENERGY INFORMATION ADMINISTRATION

Waste is a changing thing. The longer it is held in interim storage, the easier it is to deal with.

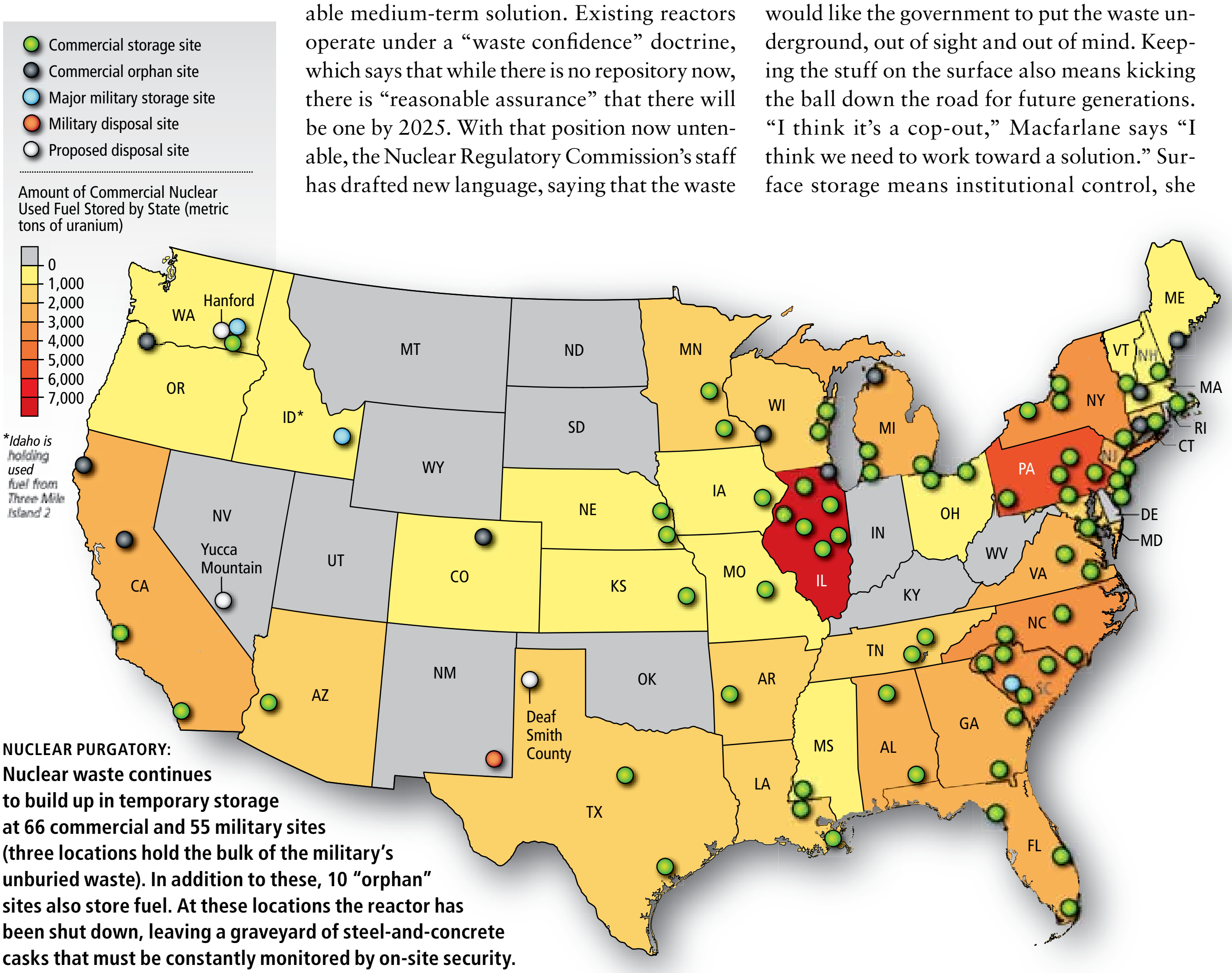
truck.) As we face the threat of global warming, it would be a mistake to dismiss nuclear energy—an energy source that produces no greenhouse gases—on the basis of waste, he argues.

In addition, waste is a changing thing. The longer it is held in interim storage, the more material decays and the easier it is to deal with. While existing federal law sets the capacity of Yucca in terms of tons of waste, the real limit is heat. If the fuel is hot enough and packed closely enough to boil the groundwater, it will create steam that can fracture the rock, increasing the speed with which waste can eventually escape. The older the fuel, the lower the heat output and the smaller the repository required. (Or rather the smaller the *number* of repositories required—by 2017 the U.S. will already have accumulated far more nuclear waste than Yucca was legally supposed to take.)

As a result, dry-cask storage has shifted from its original role as a short-term solution to a viable medium-term solution. Existing reactors operate under a "waste confidence" doctrine, which says that while there is no repository now, there is "reasonable assurance" that there will be one by 2025. With that position now untenable, the Nuclear Regulatory Commission's staff has drafted new language, saying that the waste can be stored in casks for decades at reactors with no environmental effect, until burial is available. The change should make it easier to construct new reactors even in the absence of a long-term plan for the waste they will produce.

Not everyone is so sanguine. Arjun Makhijani, president of the antinuclear group Institute for Energy and Environmental Research, filed dissenting language with the commission earlier this year. He argued that it is irresponsible to assume that acceptable burial sites will one day become available. "A scientific explanation of the term 'reasonable assurance' requires either physical proof that such a [long-term storage] facility exists," he wrote, or firm evidence that one could be built using existing technology. Yet there is no validated model of any facility that proves that the waste is highly likely to stay isolated for hundreds of thousands of years, he says.

Others object to long-term storage on the surface. Certainly the nuclear power industry would like the government to put the waste underground, out of sight and out of mind. Keeping the stuff on the surface also means kicking the ball down the road for future generations. "I think it's a cop-out," Macfarlane says "I think we need to work toward a solution." Surface storage means institutional control, she



NUCLEAR PURGATORY:
Nuclear waste continues to build up in temporary storage at 66 commercial and 55 military sites (three locations hold the bulk of the military's unburied waste). In addition to these, 10 "orphan" sites also store fuel. At these locations the reactor has been shut down, leaving a graveyard of steel-and-concrete casks that must be constantly monitored by on-site security.

JEN CHRISTIANSEN; SOURCES: NUCLEAR ENERGY INSTITUTE AND NUCLEAR REGULATORY COMMISSION

[THE OPTIONS]

WHAT CAN BE DONE WITH THE WASTE?

Secretary of Energy Steven Chu has appointed a study panel to examine the various options for dealing with nuclear waste. There are three major options, each with its proponents and detractors. In the end, these options are not mutually exclusive, and the U.S. can and probably will pursue a policy based on some combination of the three.

	ENVIRONMENTAL UNCERTAINTY	PROLIFERATION RISK	COST	VERDICT
BURIAL: Yucca-like underground storage at an undetermined location			$$	Money is in the bank, but science and politics have yet to align
SURFACE STORAGE: Concrete-and-steel casks at reactor sites			$	Not a long-term solution, although after 100 years the waste would be easier to bury
RECYCLING IN REACTORS: Turns waste into more power but at a cost			$$$$	Poses risk of pollution in reprocessing and requires a fleet of a new type of nuclear reactor

says: "We have no guarantee what the government is going to be 100 years from now or if there's going to be one."

Accelerated Breakdown

There is another alternative: hurrying up the decay chain. Although nuclear recycling facilities of the kind rejected by the U.S. in the 1970s can recycle only the plutonium in spent fuel, plutonium is just one of a dozen or so long-lived actinides. A broader solution is industrial-grade transubstantiation: using a new kind of reactor to break down the actinides [see "Smarter Use of Nuclear Waste," by William H. Hannum, Gerald E. Marsh and George S. Stanford; Scientific American, December 2005].

General Electric is promoting a "fast reactor" that breaks up actinides with high-energy neutrons—the same subatomic particles that sustain the chain reactions in the current generation of reactors, only moving at a much higher speed. "It reduces volume on the order of 90 percent and cuts the half-life to less than 1,000 years instead of hundreds of thousands of years," says Lisa Price, GE Hitachi Global's senior vice president of nuclear fuel. "That can change the characteristics of what the long-term disposal site ultimately has to be." (The calculation assumes reuse of the recovered uranium, too—something that is very difficult in conventional reactors.)

But this solution requires one new fast reactor for every three or four now running to process the spent fuel, a tough challenge at a time when the industry is having trouble simply resuming construction of the kind of reactor it built 30 years ago. One of the main arguments against such reactors is cost—a fast reactor is cooled by molten sodium rather than water, and the advanced design is estimated to cost anywhere from $1 billion to $2 billion more per reactor than a similarly sized conventional reactor [see "Rethinking Nuclear Fuel Recycling," by Frank N. von Hippel; Scientific American, May 2008]. Democrats in Congress blocked most funding for fast reactors late in the Bush administration, and President Obama does not favor them.

Finally, Yucca could always come back. "Thirty-nine states have high-level waste—either civilian spent nuclear fuel or Navy spent nuclear fuel or defense program high-level waste," says Edward F. Sproat III, who was the DOE official in charge of the Yucca project for the last two and a half years of the Bush administration. The waste is "all destined to go to Yucca, and there's no other place to send it." He and others argue that President Obama and Senator Reid have the political power to block funding but not to change the 1987 amendment to the Nuclear Waste Policy Act that targets Yucca exclusively. And if Congress debates where else to put it, he says, "everybody knows their state is going to be back in play." ■

➡ MORE TO EXPLORE

Nuclear Energy: Principles, Practices, and Prospects. David Bodansky. American Institute of Physics, 2004.

Department of Energy Office of Civilian Radioactive Waste Management, Yucca Mountain Repository: **www.ocrwm.doe.gov/repository**

Safety and Security of Commercial Spent Nuclear Fuel Storage: Public Report. Committee on the Safety and Security of Commercial Spent Nuclear Fuel Storage. National Research Council, 2006: **www.nap.edu/catalog/11263.html**

Surprises *from* Celiac Disease

Study of a potentially fatal food-triggered disease has uncovered a process that may contribute to many autoimmune disorders • BY ALESSIO FASANO

KEY CONCEPTS

- Celiac disease (CD) is an autoimmune disorder triggered by ingestion of gluten, a major protein in wheat, or of related proteins in other grains.
- Research into the root causes indicates that the disorder develops when a person exposed to gluten also has a genetic susceptibility to CD and an unusually permeable intestinal wall.
- Surprisingly, essentially the same trio—an environmental trigger, a genetic susceptibility and a "leaky gut"—seems to underlie other autoimmune disorders as well. This finding raises the possibility that new treatments for CD may also ameliorate other conditions.

—The Editors

My vote for the most important scientific revolution of all time would trace back 10,000 years ago to the Middle East, when people first noticed that new plants arise from seeds falling to the ground from other plants—a realization that led to the birth of agriculture. Before that observation, the human race had based its diet on fruits, nuts, tubers and occasional meats. People had to move to where their food happened to be, putting them at the mercy of events and making long-term settlements impossible.

Once humans uncovered the secret of seeds, they quickly learned to domesticate crops, ultimately crossbreeding different grass plants to create such staple grains as wheat, rye and barley, which were nutritious, versatile, storable, and valuable for trade. For the first time, people were able to abandon the nomadic life and build cities. It is no coincidence that the first agricultural areas also became "cradles of civilization."

This advancement, however, came at a dear price: the emergence of an illness now known as celiac disease (CD), which is triggered by ingesting a protein in wheat called gluten or eating similar proteins in rye and barley. Gluten and its relatives had previously been absent from the human diet. But once grains began fueling the growth of stable communities, the proteins undoubtedly began killing people (often children) whose bodies reacted abnormally to them. Eating such proteins repeatedly would have eventually rendered sensitive individuals unable to properly absorb nutrients from food. Victims would also have come to suffer from recurrent abdominal pain and diarrhea and to display the emaciated bodies and swollen bellies of starving people. Impaired nutrition and a spectrum of other complications would have made their lives relatively short and miserable.

If these deaths were noticed at the time, the cause would have been a mystery. Over the past 20 years, however, scientists have pieced together a detailed understanding of CD. They now know that it is an autoimmune disorder, in which the immune system attacks the body's own tissues. And they know that the disease arises not only from exposure to gluten and its ilk but from a combination of factors, including predisposing genes and abnormalities in the structure of the small intestine.

What is more, CD provides an illuminating example of the way such a triad—an environmental trigger, susceptibility genes and a gut abnormality—may play a role in many autoimmune disorders. Research into CD has thus sug-

gested new types of treatment not only for the disease itself but also for various other autoimmune conditions, such as type 1 diabetes, multiple sclerosis and rheumatoid arthritis.

Early Insights

After the advent of agriculture, thousands of years passed before instances of seemingly well-fed but undernourished children were documented. CD acquired a name in the first century A.D., when Aretaeus of Cappadocia, a Greek physician, reported the first scientific description, calling it *koiliakos,* after the Greek word for "abdomen," *koelia*. British physician Samuel Gee is credited as the modern father of CD. In a 1887 lecture he described it as "a kind of chronic indigestion which is met with in persons of all ages, yet is especially apt to affect children between one and five years old." He even correctly surmised that "errors in diet may perhaps be a cause." As clever as Gee obviously was, the true nature of the disease escaped even him, as was clear from his dietary prescription: he suggested feeding these children thinly sliced bread, toasted on both sides.

Identification of gluten as the trigger occurred after World War II, when Dutch pediatrician Willem-Karel Dicke noticed that a war-related shortage of bread in the Netherlands led to a significant drop in the death rate among children affected by CD—from greater than 35 percent to essentially zero. He also reported that once wheat was again available after the conflict, the mortality rate soared to previous levels. Following up on Dicke's observation, other scientists looked at the different components of wheat, discovering that the major protein in that grain, gluten, was the culprit.

Turning to the biological effects of gluten, investigators learned that repeated exposure in

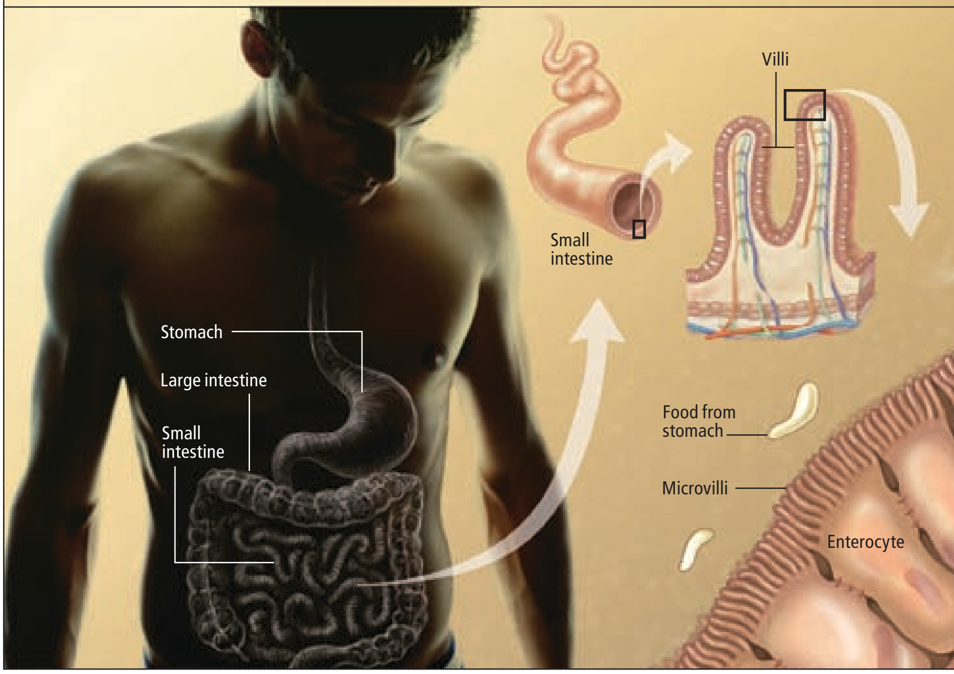
FOODS CONTAINING wheat, rye or barley trigger an autoimmune reaction (against the body's own tissues) in people afflicted with celiac disease. The response harms the intestinal lining and impairs the body's absorption of nutrients. Chronic exposure to those foods can also lead to cancer and other ill effects in such individuals.

JUPITERIMAGES (*photograph*); JEN CHRISTIANSEN (*photoillustration*)

[BASICS]

NORMAL DIGESTION

In the normal digestive tract, partly processed food from the stomach enters the small intestine, which is lined with fingerlike projections called villi (*below left*). Enzymes from the pancreas and on the surface of the villi's constituent epithelial cells (enterocytes) break down most of the food to its smallest components—such as glucose and amino acids (*below right*). Then these nutrients pass into the bloodstream to fuel tissues throughout the body. Celiac disease disrupts the absorption of nutrients by damaging enterocytes and by flattening the villi, which reduces the surface area available to interact with food (*micrographs*).



CD patients causes the villi, fingerlike structures in the small intestine, to become chronically inflamed and damaged, so that they are unable to carry out their normal function of breaking food down and shunting nutrients across the intestinal wall to the bloodstream (for delivery throughout the body). Fortunately, if the disease is diagnosed early enough and patients stay on a gluten-free diet, the architecture of the small intestine almost always returns to normal, or close to it, and gastrointestinal symptoms disappear.

In a susceptible person, gluten causes this inflammation and intestinal damage by eliciting activity by various cells of the immune system. These cells in turn harm healthy tissue in an attempt to destroy what they perceive to be an infectious agent.

A Diagnostic Discovery

Fuller details of the many mechanisms through which gluten affects immune activity are still being studied, but one insight in particular has already proved useful in the clinic: a hallmark of the aberrant immune response to gluten is production of antibody molecules targeted to an enzyme called tissue transglutaminase. This enzyme leaks out of damaged cells in inflamed areas of the small intestine and attempts to help heal the surrounding tissue.

Discovery that these antibodies are so common in CD added a new tool for diagnosing the disorder and also allowed my team and other researchers to assess the incidence of the disease in a new way—by screening people for the presence of this antibody in their blood. Before then, doctors had only nonspecific tests, and thus the most reliable way to diagnose the disease was to review the patient's symptoms, confirm the intestinal inflammation by taking a biopsy of the gut, and assess whether a gluten-free diet relieved symptoms. (Screening for antibodies against gluten is not decisive, because they can also occur in people who do not have CD.)

For years CD was considered a rare disease outside of Europe. In North America, for example, classic symptoms were recognized in fewer than one in 10,000 people. In 2003 we published the results of our study—the largest hunt for people with CD ever conducted in North America, involving more than 13,000 people. Astoundingly, we found that one in 133 apparently healthy subjects was affected, meaning the disease was nearly 100 times more common than had been thought. Work by other researchers has confirmed similar levels in many countries, with no continent spared.

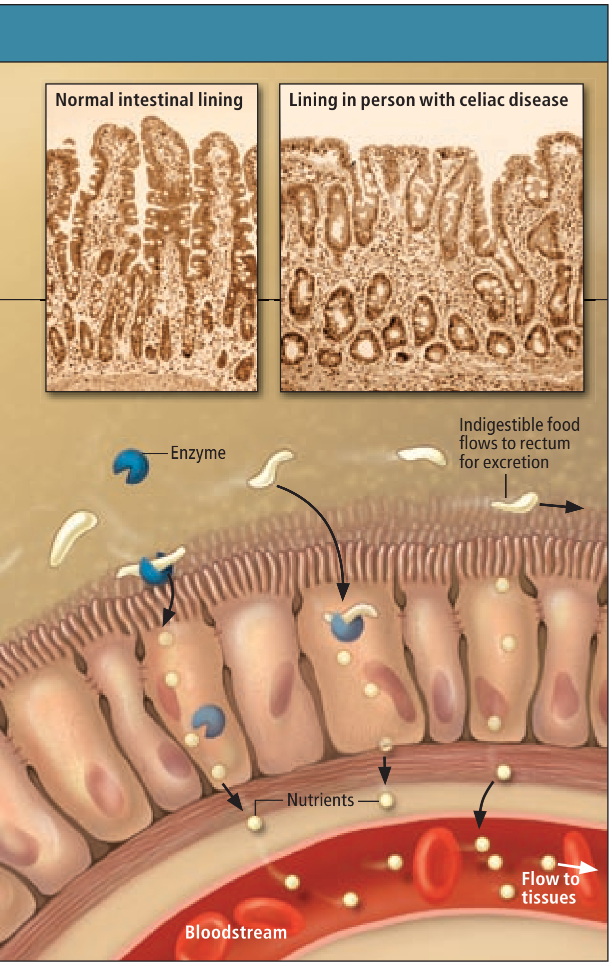
How did 99 percent of cases escape detection for so long? The classical outward signs—persistent indigestion and chronic diarrhea—appear only when large and crucial sections of the intestine are damaged. If a small segment of the intestine is dysfunctional or if inflammation is fairly mild, symptoms may be less dramatic or atypical.

It is also now clear that CD often manifests in a previously unappreciated spectrum of symptoms driven by local disruptions of nutrient absorption from the intestine. Disruption of iron absorption, for example, can cause anemia, and poor folate uptake can lead to a variety of neurological problems. By robbing the body of particular nutrients, CD can thus produce such symptoms as osteoporosis, joint pain, chronic fatigue, short stature, skin lesions, epilepsy, dementia, schizophrenia and seizure.

Because CD often presents in an atypical fashion, many cases still go undiagnosed. This new ability to recognize the disease in all its

We found that the disease was nearly 100 times more common than had been thought.

GETTY IMAGES (*digestive system*); JEN CHRISTIANSEN (*photoillustration*); KIM MOSS *Electronic Publishing Services, Inc. (intestinal illustration)*



forms at an early stage allows gluten to be removed from the diet before more serious complications develop.

From Gluten to Immune Dysfunction

Celiac disease provides an enormously valuable model for understanding autoimmune disorders because it is the only example where the addition or removal of a simple environmental component, gluten, can turn the disease process on and off. (Although environmental factors are suspected of playing a role in other autoimmune diseases, none has been positively identified.)

To see how gluten can have a devastating effect in some people, consider how the body responds to it in most of the population. In those without CD, the body does not react. The normal immune system jumps into action only when it detects significant amounts of foreign proteins in the body, reacting aggressively because the foreigners may signal the arrival of disease-causing microorganisms, such as bacteria or viruses.

A major way we encounter foreign proteins and other substances is through eating, and immune soldiers sit under the epithelial cells that line the intestine (enterocytes), ready to pounce and call in reinforcements. One reason our immune system typically is not incited by this thrice-daily protein invasion is that before our defenses encounter anything that might trouble them, our gastrointestinal system usually breaks down most ingested proteins into standard amino acids—the building blocks from which all proteins are constructed.

Gluten, however, has a peculiar structure: it is unusually rich in the amino acids glutamine and proline. This property renders part of the molecule impervious to our protein-chopping machinery, leaving small protein fragments, or peptides, intact. Even so, in healthy people, most of these peptides are kept within the gastrointestinal tract and are simply excreted before the immune system even notices them. And any gluten that sneaks across the gastrointestinal lining is usually too minimal to excite a significant response from a normally functioning immune system.

CD patients, on the other hand, have inherited a mix of genes that contribute to a heightened immune sensitivity to gluten. For example, certain gene variants encoding proteins known as histocompatibility leukocyte antigens (HLAs) play a role. Ninety-five percent of people with CD possess the gene either for HLA-DQ2 or for HLA-DQ8, whereas just 30 to 40 percent of the general population have one of those versions. This finding and others suggest that the HLA-DQ2 and HLA-DQ8 genes are not the sole cause of immune hyperactivity but that the disease, nonetheless, is nearly impossible to establish without one of them. The reason these genes are key becomes obvious from studies of the function of the proteins they specify.

The HLA-DQ2 and HLA-DQ8 proteins are made by antigen-presenting cells. These immune sentinels gobble up foreign organisms and proteins, chop them, fit selected protein fragments into grooves on HLA molecules, and display the resulting complexes on the cell surface for perusal by immune system cells called helper T lymphocytes. T cells that can recognize and bind to the displayed complexes then call in reinforcements.

In patients with CD, tissue transglutaminase released by intestinal epithelial cells attaches to undigested gluten and modifies the peptides in a way that enables them to bind extremely strongly to DQ2 and DQ8 proteins. In conse-

FAST FACTS

- Roughly 1 percent of the global population has celiac disease, although most do not know it.
- More than two million people in the U.S. are afflicted with the disease.
- Some common symptoms in infants and children are abdominal pain, bloating, constipation, diarrhea, weight loss and vomiting.
- About half of adults with the condition do not suffer from diarrhea at diagnosis.
- Other signs that may occur in adults are anemia, arthritis, bone loss, depression, fatigue, infertility, joint pain, seizures, and numbness in the hands and feet.

[THE AUTHOR]

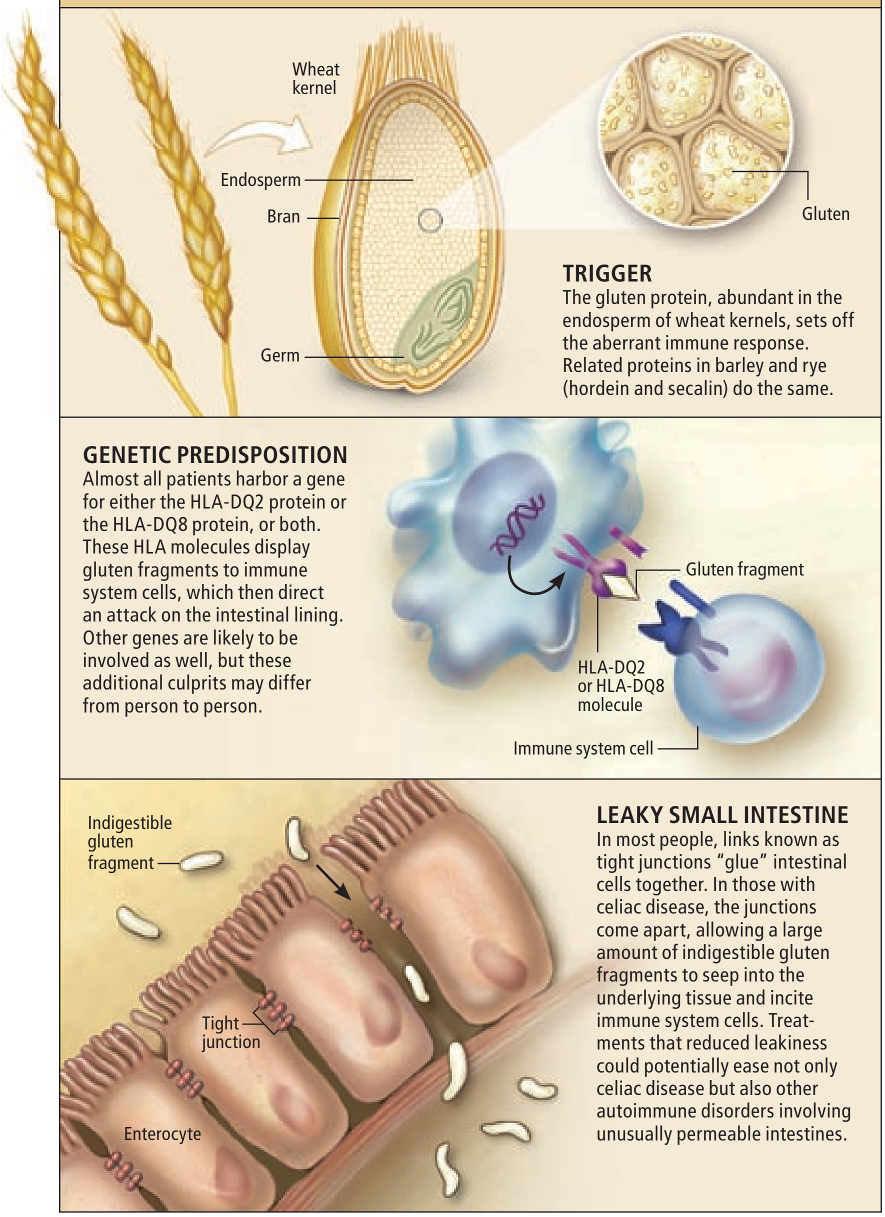
Alessio Fasano is professor of pediatrics, medicine and physiology and director of the Mucosal Biology Research Center and the Center for Celiac Research at the University of Maryland School of Medicine. Much of his basic and clinical research focuses on the role of intestinal permeability in the development of celiac disease and other autoimmune disorders.

CENTER FOR CELIAC RESEARCH, UNIVERSITY OF MARYLAND SCHOOL OF MEDICINE (*micrographs*); UNIVERSITY OF MARYLAND (*Fasano*)

[OVERVIEW]

A TRIO OF CAUSES

Three factors underlie celiac disease: an environmental trigger, a genetic susceptibility and, according to the author's research, an unusually permeable gut (*below*). The author suspects that the same basic triad contributes to other autoimmune diseases, although each disorder will have its own triggers and genetic components.



quence, when antigen-presenting cells under intestinal epithelial cells take up the complexes of tissue transglutaminase and gluten, the cells join the gluten to the HLAs and dispatch them to the cell surface, where they activate T cells, inducing the T cells to release cytokines and chemokines (chemicals that stimulate further immune activity). These chemicals and enhancement of immune defenses would be valuable in the face of a microbial attack, but in this instance they do no good and harm the intestinal cells responsible for absorbing nutrients.

CD patients also tend to have other genetic predispositions, such as a propensity for overproducing the immune stimulant IL-15 and for harboring hyperactive immune cells that prime the immune system to attack the gut in response to gluten.

Guilt by Association

What role might antibodies to tissue transglutaminase play in this pathological response to gluten? The answer is still incomplete, but scientists have some idea of what could happen. When intestinal epithelial cells release tissue transglutaminase, B cells of the immune system ingest it—alone or complexed to gluten. They then release antibodies targeted to the enzyme. If the antibodies home in on tissue transglutaminase sitting on or near intestinal epithelial cells, the antibodies might damage the cells directly or elicit other destructive processes. But no one yet knows whether they, in fact, cause such harm.

In the past nine years my colleagues and I have learned that unusual intestinal permeability also appears to participate in CD and other autoimmune diseases. Indeed, a growing body of evidence suggests that virtually the same trio of factors underpins most, and perhaps all, autoimmune diseases: an environmental substance that is presented to the body, a genetically based tendency of the immune system to overreact to the substance, and an unusually permeable gut.

Finding the Leak

It is fair to say that the theory that a leaky gut contributes to CD and autoimmunity in general was initially greeted with great skepticism, partly because of the way scientists thought of the intestines. When I was a medical student in the 1970s, the small intestine was described as a pipe composed of a single layer of cells connected like tiles with an impermeable "grout," known as tight junctions, between them. The tight junctions were thought to keep all but the smallest molecules away from the immune system components in the tissue underlying the tubes. This simple model of the tight junctions as inert, impermeable filler did not inspire legions of researchers to study their structure, and I was among the unenthused.

It was only an unexpected twist of fate, and one of the most disappointing moments of my career, that drew me to study tight junctions. In the late 1980s I was working on a vaccine for

KIM MOSS *Electronic Publishing Services, Inc.*

cholera. At that time, the cholera toxin was believed to be the sole cause of the devastating diarrhea characteristic of that infection. To test this hypothesis, my team deleted the gene encoding the cholera toxin from the bacterium *Vibrio cholerae*. Conventional wisdom suggested that bacteria disarmed in this way would make an ideal vaccine, because the remaining proteins on a living bacterial cell would elicit a strong immune response that would protect against diarrhea.

But when we administered our attenuated bacteria to volunteers, the vaccine provoked enough diarrhea to bar its use. I felt completely disheartened. Years of hard work were literally down the toilet, and we were faced with two unattractive options: giving up and moving on to another research project or persevering and trying to understand what went wrong. Some intuition that there was more to this story prompted us to choose the latter path, and this decision led us to discover a new toxin that caused diarrhea by a previously undescribed mechanism. It changed the permeability of the small intestine by disassembling those supposedly inert tight junctions, an effect that allowed fluid to seep from tissues into the gut. This "grout" was interesting after all.

Indeed, at nearly the same time, a series of seminal discoveries clarified that a sophisticated meshwork of proteins forms the tight junctions; however, little information was available on how these structures were controlled. Therefore, the discovery of our toxin, which we called the "*zonula occludens* toxin," or Zot (*zonula occludens* is Latin for "tight junction"), provided a valuable tool for clarifying the control process. It revealed that a single molecule, Zot, could loosen the complex structure of the tight junctions. We also realized that the control system that made this loosening possible was too complicated to have evolved simply to cause biological harm to the host. *V. cholerae* must cause diarreha by exploiting a preexisting host pathway that regulates intestinal permeability.

Five years after the formulation of this hypothesis, we discovered zonulin, the protein that in humans and other higher animals increases intestinal permeability by the same mechanism as the bacterial Zot. How the body uses zonulin to its advantage remains to be established. Most likely, though, this molecule, which is secreted by intestinal epithelial tissue as well as by cells in other organs (tight junctions have important roles in tissues throughout the body), performs several jobs—including regulating the movement of fluid, large molecules and immune cells between body compartments.

Discovery of zonulin prompted us to search the medical literature for human disorders characterized by increased intestinal permeability. It was then that we first learned, much to my surprise, that many autoimmune diseases—among them, CD, type 1 diabetes, multiple sclerosis, rheumatoid arthritis and inflammatory bowel diseases—all have as a common denominator aberrant intestinal permeability. In many of these diseases, the increased permeability is caused by abnormally high levels of zonulin. And in CD, it is now clear that gluten itself prompts exaggerated zonulin secretion (perhaps because of the patient's genetic makeup).

This discovery led us to propose that it is the enhanced intestinal permeability in CD patients that allows gluten, the environmental factor, to seep out of the gut and to interact freely with genetically sensitized elements of the immune system. That understanding, in turn, suggests that removing any one factor of the autoimmunity-causing trinity—the environmental trigger, the heightened immune reactivity or the intestinal permeability—should be enough to stop the disease process.

Therapies to Topple the Trinity

As I mentioned before, and as this theory would predict, removing gluten from the diet ends up healing the intestinal damage. Regrettably, a lifelong adherence to a strict gluten-free diet is not easy. Gluten is a common and, in many countries, unlabeled ingredient in the human diet. Further complicating adherence, gluten-free products are not widely available and are more

[MYSTERY]

A Clue to Delayed Onset

People with celiac disease are born with a genetic susceptibility to it. So why do some individuals show no evidence of the disorder until late in life? In the past, I would have said that the disease process was probably occurring in early life, just too mildly to cause symptoms. But now it seems that a different answer, having to do with the bacteria that live in the digestive tract, may be more apt.

These microbes, collectively known as the microbiome, may differ from person to person and from one population to another, even varying in the same individual as life progresses. Apparently they can also influence which genes in their hosts are active at any given time. Hence, a person whose immune system has managed to tolerate gluten for many years might suddenly lose tolerance if the microbiome changes in a way that causes formerly quiet susceptibility genes to become active. If this idea is correct, celiac disease might one day be prevented or treated by ingestion of selected helpful microbes, or "probiotics." —*A.F.*

WHY REPLACING WHEAT IS HARD

Gluten is a major reason that wheat-based baked goods are light and airy. During baking, gluten strands trap water and carbon dioxide gas (from yeast and other leavening agents) and expand. To make gluten-free items, bakers generally combine several flours (as well as starches and additives), because no single variety mimics the properties of wheat flour. This demand adds significantly to the cost of the resulting product. It also explains why gluten-free foods have a hard time rivaling their gluten-containing counterparts for taste and texture. —*A.F.*

JIM McKNIGHT *AP Photo*

The theory that a leaky gut contributes to CD and autoimmunity in general was initially greeted with skepticism.

expensive than their gluten-containing counterparts. In addition, sticking perfectly over years to any diet for medical purposes is notoriously challenging. For such reasons, diet therapy is an incomplete solution.

Consequently, several alternative therapeutic strategies have been considered that disrupt at least one element of the three-step process. Alvine Pharmaceuticals in San Carlos, Calif., has developed oral protein-enzyme therapies that completely break down gluten peptides normally resistant to digestion and has an agent in clinical trials. Other investigators are considering ways to inhibit tissue transglutaminase so that it does not chemically modify undigested gluten fragments into the form where they bind so effectively to HLA-DQ2 and HLA-DQ8 proteins.

No one has yet come up with safe and ethical ways to manipulate the genes that make people susceptible to disease. But researchers are busy developing therapies that might dampen some of the genetically controlled factors that contribute to the immune system's oversensitivity. For example, the Australian company Nexpep is working on a vaccine that would expose the immune system to small amounts of strongly immunogenic forms of gluten, on the theory that repeated small exposures would ultimately induce the immune system to tolerate gluten.

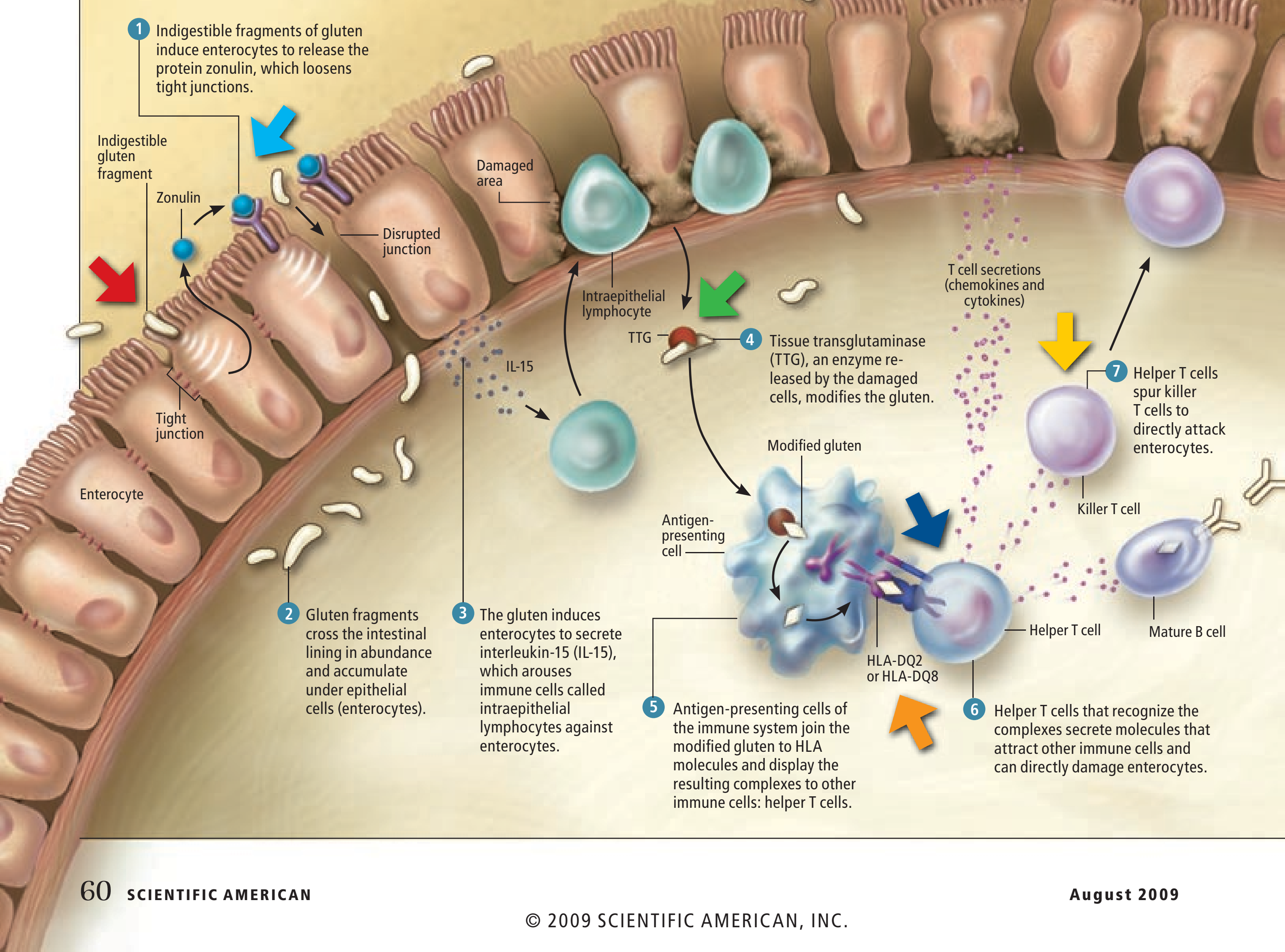
With an eye toward blocking the intestinal

KIM MOSS *Electronic Publishing Services, Inc.*

[MECHANISMS OF DISEASE]

THE INSIDE STORY

Investigators do not know every detail of how the immune system wreaks havoc with the intestinal lining of celiac patients, but they have identified a number of likely processes (*below*). Colored arrows indicate events that might be blocked by interventions now being investigated [*see table on opposite page*].



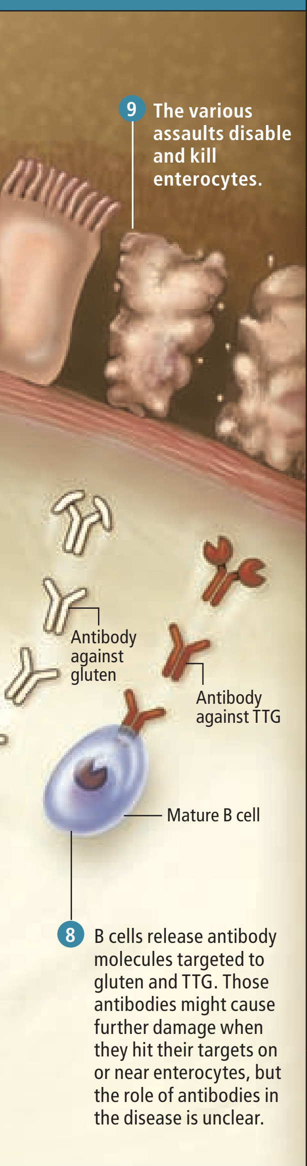
barrier defect, I co-founded Alba Therapeutics to explore the value of a zonulin inhibitor named Larazotide. (I am now a scientific adviser for Alba and hold stock options, but I no longer participate in making decisions for the company.) Larazotide has now been tested in two human trials examining safety, tolerability and signs of efficacy in celiac patients who ate gluten. These were gold-standard trials—randomized, placebo-controlled tests in which neither the drug deliverers nor the patients know who receives treatment and who receives a sham, until the trial is over.

Together the tests showed no excess of side effects in patients given Larazotide rather than the placebo. More important, the first, smaller study demonstrated that the agent reduced gluten-induced intestinal barrier dysfunction, production of inflammatory molecules and gastrointestinal symptoms in celiac patients. And the second, large study, reported at a conference in April, showed that CD patients who received a placebo produced antibodies against tissue transglutaminase but that the treated group did not. As far as I know, this result marks the first time a drug has halted an autoimmune process, interfering specifically with an immune response against a particular molecule made by the body. Other drugs that suppress immune activity act less specifically. Recently Alba received approval from the U.S. Food and Drug Administration to expand studies of Larazotide to other autoimmune disorders, including type 1 diabetes and Crohn's disease.

These new prospects for therapy do not mean that CD patients can abandon dietary restrictions anytime soon. Diet could also be used in a new way. Under the leadership of Carlo Catassi, my team at the University of Maryland has begun a long-term clinical study to test whether having infants at high risk eat nothing containing gluten until after their first year can delay the onset of CD or, better yet, prevent it entirely. "High risk," in this case, means infants possess susceptibility genes and their immediate family has a history of the disorder.

We suspect the approach could work because the immune system matures dramatically in the first 12 months of life and because research on susceptible infants has implied that avoiding gluten during the first year of life might essentially train that developing immune system to tolerate gluten thereafter, as healthy people do, rather than being overstimulated by it. So far we have enrolled more than 700 potentially genetically susceptible infants in this study, and preliminary findings suggest that delaying gluten exposure reduces by fourfold the likelihood that CD will develop. It will be decades, however, until we know for certain whether this strategy can stop the disease from ever occurring.

Given the apparently shared underpinning of autoimmune disorders in general, researchers who investigate those conditions are eager to learn whether some therapeutic strategies for CD might also ease other autoimmune conditions that currently lack good treatments. And with several different approaches in the pipeline to treat CD, we can begin to hope that this disease, which has followed humanity from the dawn of civilization, is facing its last century on earth. ■



[LOOKING AHEAD]

TREATMENT IDEAS

Today patients with celiac disease have one therapeutic option: avoid all foods that contain gluten. But because following a restricted diet can be difficult, investigators are exploring other options for patients, such as those listed below. These are early days in the process; no drug in the table has yet reached the advanced clinical trials needed to gain marketing approval.

THERAPY	DRUG NAME (INVESTIGATOR/STATUS)
Avoid gluten in the diet of infants through their first year of life	No drug (University of Maryland and, separately, Marche Polytechnic University, Italy/in human trials)
Degrade otherwise indigestible gluten fragments so they cannot evoke an immune response	ALV003 (Alvine and, separately, AN-PEP at VU University Medical Center, the Netherlands/in human trials)
Block zonulin from making the gut permeable	Larazotide (Alba Therapeutics/in human trials)
Keep tissue transglutaminase from modifying gluten fragments in ways that stimulate the immune system	No name (Numerate and Stanford University/under study in the laboratory)
Stop HLA-DQ2 from attaching to gluten peptides and displaying them to helper T cells	Mimics of gluten (Leiden University, the Netherlands, and, separately, Stanford University/under study in the laboratory)
Vaccinate patients with selected gluten fragments to induce helper T cells to tolerate, rather than reacting to, gluten displayed by HLA-DQ2 molecules	Nexvax2 (Nexpep, Australia/in human trials)
Block migration of killer T cells into the intestinal lining	CCX282-B (Chemocentryx/in human trials)
Start a hookworm infection (the parasites dampen a host's immune responses in the gut)	Hookworm parasites (Princess Alexandra Hospital, Australia, and collaborators/in human trials)

SOURCES: WWW.CLINICALTRIALS.GOV; "DIAGNOSIS AND TREATMENT OF CELIAC DISEASE," BY L. M. SOLLID AND K.E.A. LUNDIN, IN *MUCOSAL IMMUNOLOGY*, VOL. 2, NO 1; JANUARY 2009

➡ MORE TO EXPLORE

Mechanisms of Disease: The Role of Intestinal Barrier Function in the Pathogenesis of Gastrointestinal Autoimmune Diseases. Alessio Fasano and Terez Shea-Donohue in *Nature Clinical Practice Gastroenterology & Hepatology,* Vol. 2, No. 9, pages 416–422; September 2005.

Diagnosis and Treatment of Celiac Disease. L. M. Sollid and K.E.A. Lundin in *Mucosal Immunology,* Vol. 2, No. 1, pages 3–7; January 2009.

An Iron Key to High-Temperature Superconductivity?

KEY CONCEPTS

- Conventional superconductors carry electric currents without energy losses but only when cooled to near absolute zero. Copper oxide, or cuprate, superconductors shattered a long-standing temperature barrier in the late 1980s, but adapting them for industry has been challenging.
- The cuprates seemed to be unique until 2008, when physicists found that compounds known as pnictides (pronounced "nik-tides") also superconduct well above absolute zero.
- Study of the pnictides might help scientists to finally understand how the cuprates work and to perhaps learn how to make room-temperature superconductors.

—The Editors

The discovery that compounds known as iron pnictides can superconduct at 50 degrees above absolute zero has reignited physicists' quest for better high-temperature superconductors and may offer clues to unlocking a 20-year mystery

By Graham P. Collins

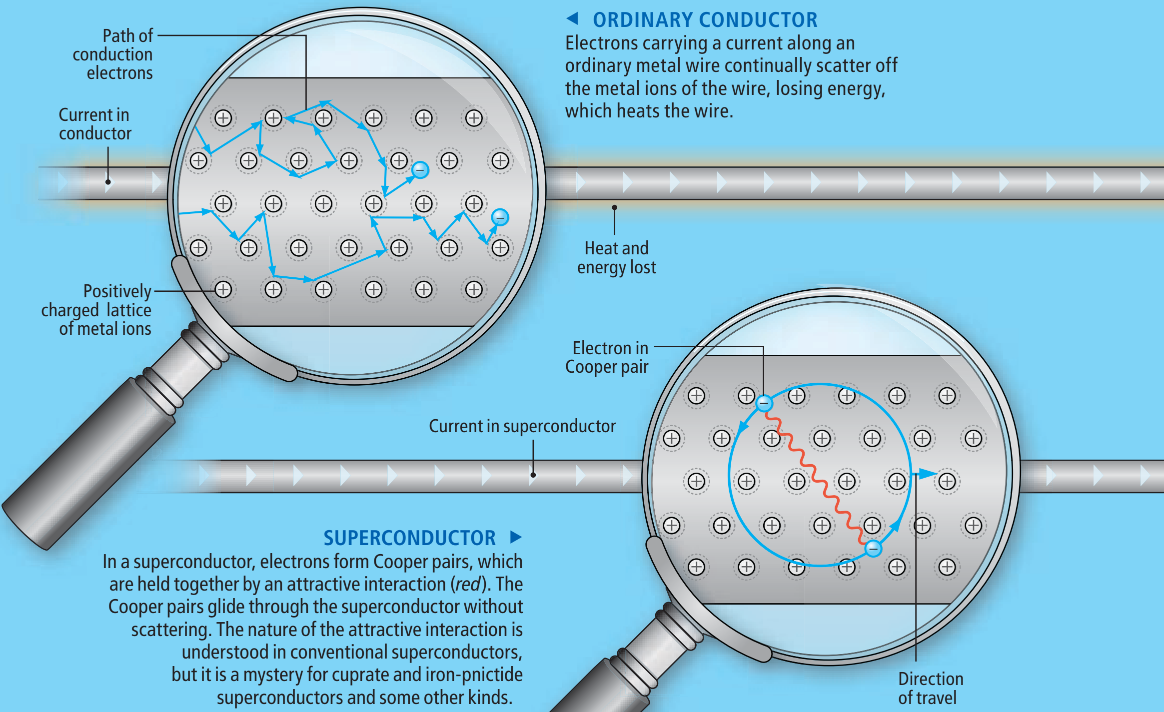
Hideo Hosono's research group at the Tokyo Institute of Technology was not looking for a superconductor in 2006. Rather the team was trying to create new kinds of transparent semiconductors for flat-panel displays. But when the researchers characterized the electronic properties of their new substance—a combination of lanthanum, oxygen, iron and phosphorus—they found that below four kelvins, or –269 degrees Celsius, it lost all resistance to carrying an electric current; that is, it superconducted.

Although 4 K is far below the current laboratory record of 138 K (let alone the holy grail of "room temperature," or about 300 K), experimentalists with a new superconductor are like yachtsmen with a new boat design. The sailors want to know how fast they can make it go; the physicists, how hot any variant of the material can superconduct. Superconductors' uses in industry are hobbled by the need for expensive, complicated, space-hogging cooling systems. Any increase in operating temperature could ease those drawbacks for existing devices and make completely fresh applications technically and economically viable. Engineers envisage, for instance, lossless power

[BASICS]

What Makes a Conductor Super

An ordinary conductor drains energy from an electric current because the electrons carrying the current collide with the metal ions of the conductor (*top*). In a superconductor, in contrast, the electrons form “Cooper pairs” (*bottom*), all of which collect in a single quantum state of lowest energy, a process known as Bose-Einstein condensation. This sea of Cooper pairs moves as one entity. To dislodge a Cooper pair from this flow requires boosting it to a higher-energy quantum state, and a collision with a metal ion does not involve enough energy to do so. The current therefore flows without energy losses.



ORDINARY CONDUCTOR Electrons carrying a current along an ordinary metal wire continually scatter off the metal ions of the wire, losing energy, which heats the wire.

SUPERCONDUCTOR In a superconductor, electrons form Cooper pairs, which are held together by an attractive interaction (*red*). The Cooper pairs glide through the superconductor without scattering. The nature of the attractive interaction is understood in conventional superconductors, but it is a mystery for cuprate and iron-pnictide superconductors and some other kinds.

IMPORTANCE OF TEMPERATURE

Most superconductors in use today rely on the same coolant as Heike Kamerlingh Onnes did when he discovered the phenomenon nearly a century ago: liquid helium, which boils at 4.2 kelvins and adds considerable expense and complexity to a system. The most widely used superconductors remain niobium alloys that can superconduct as high as 18 K—in the absence of a magnetic field. In devices involving magnetic fields or high current densities, superconductors require extra chilling to maintain the superconductivity. The very strong niobium alloy magnets of the Large Hadron Collider, for instance, operate at 2.9 K. New materials that can function well above liquid-helium temperatures would revolutionize superconductor applications.

cables carrying huge currents and compact superstrong magnets—for magnetic resonance imaging, levitated trains, particle accelerators and other wonders—all without the exorbitant expense and trouble of the liquid-helium cooling systems required by the old, cold, conventional superconductors.

So the Japanese group set about doping its material—adding a sprinkling of foreign atoms to the recipe—to try to raise the transition temperature. Replacing some of the oxygen atoms with fluorines brought on superconductivity at 7 K. Swapping arsenic for phosphorus resulted in superconduction up to 26 K, a temperature high enough to get physicists’ attention all around the world and to spark a flurry of research when the group’s arsenic paper appeared in late February 2008. By the end of March, groups in China had similar compounds superconducting just above 40 K. A month later, 56 K.

Although these impressive results were not close to challenging the records set over the past two decades by the copper oxide, or cuprate, superconductors, physicists were excited for several reasons. First, who knew where the rising temperatures would end? Second, they suspected that the iron compounds would be easier to work into technological applications than the cuprates, which are brittle and require complicated techniques to fashion into long wires such as for power cables or magnets.

Next, iron was a peculiar element to have in a superconductor because its atoms are strongly magnetic, and magnetism generally inhibits superconductivity. Indeed, along with perfect conduction, a defining characteristic of a superconductor is that it forces an applied magnetic field to skirt around it instead of passing through its interior. A field strong enough to enter the superconductor destroys the superconductor. Why was the magnetism of the iron atoms right inside the material not spoiling things? That puzzle remains unanswered.

But perhaps most interesting of all, the new iron compounds knocked the cuprates off their pedestal as a seemingly unique class of high-temperature superconductors. For more than 20 years the cuprates had resisted all attempts by researchers to formulate a theory explaining all of their properties, most particularly their high transition temperatures. Now with two species to compare and contrast, experimenters might finally uncover the vital clues that theorists could use to solve the mystery of high-temperature superconductivity.

PHOTOGRAPH BY JAMIE CHUNG AND STYLING BY BRIAN BRYN (*preceding page*); LUCY READING-IKKANDA (*this page*)

Layered Structures

Hope that the iron superconductors can offer clues about the cuprates is bolstered by the many similarities of the two kinds of compound. Both classes of material superconduct at warmer temperatures than all other known superconductors do. In both classes, each compound has a particular optimum level of doping that maximizes its transition temperature (the temperature below which the material becomes superconducting, also called the critical temperature). The temperature is lower for "underdoped" and "overdoped" samples, eventually falling to absolute zero when far enough from the optimum—in other words, a sample that is doped lightly or heavily enough does not superconduct at all [*see box on page* 67].

The most obvious similarity, however, is that both the cuprates and the iron pnictides are made of alternating layers of atoms. Where cuprates feature copper oxide (CuO_2) sheets, the new materials have sheets of an iron pnictide (pronounced "nik-tide")—iron bound to an element from nitrogen's group in the periodic table, such as phosphorus, arsenic or antimony. In Hosono's 26 K material, for instance, layers of lanthanum oxide (LaO) alternate with iron arsenide (FeAs).

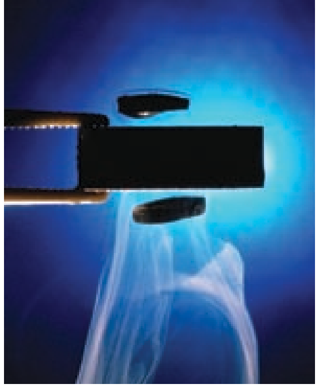
The copper oxide and iron pnictide layers are the meat of these crystalline club sandwiches. They are where physicists believe superconductivity is produced. The "bread" layers merely contribute additional electrons to the meat or remove some electrons from it. With fluorine-doped LaOFeAs, for instance, each fluorine atom begins with one more electron than the oxygen it replaced, and these surplus electrons move to the FeAs layers, altering their electrical properties.

Viewed from above, the atoms in an FeAs layer would appear to be positioned on a nanoscale chessboard; one iron atom on each black square and an arsenic atom on every white one. The cuprates' CuO_2 layers are similar but with only half the black squares occupied by a copper atom. Each CuO_2 layer is essentially flat; all the atoms lie in the same plane. In contrast, the arsenic atoms in an FeAs layer sit above and below the level of the iron atoms, four of them surrounding each iron atom at the vertices of a tetrahedron. As with almost every feature of the materials, whether it is the similarity or dissimilarity of the structures that is more important remains to be unraveled.

The layered structure profoundly affects the cuprate superconductors' properties, making them behave differently depending on whether a superconducting current, or supercurrent, is flowing parallel to the layers or perpendicular to them. For instance, the effect of a magnetic field on a supercurrent in a cuprate crystal depends on the direction of the field. The superconductivity can withstand a much stronger field when the field is aligned with the cuprate sheets than when it is perpendicular to them. That property has important ramifications because many applications of superconductivity involve generation of strong magnetic fields. These kinds of effects also serve as possible clues to deciphering why the cuprates superconduct.

Theorists took these clues deeply to heart and for 20 years they have largely focused on developing an explanation of how superconductivity could develop within a single cuprate sheet. That is, they have viewed the two-dimensionality as a crucial feature. This idea is reasonable from a theoretical standpoint because throughout mathematics and physics examples abound of systems that exhibit properties and phenomena unique to the two-dimensional case and absent or far more complicated in three dimensions. And in the specific case of the cuprates, many experiments have produced results that single out the CuO_2 plane as being very special.

The first research on the iron pnictides seemed to be telling the same story, but in late July 2008, two groups of researchers—one led by Nan-Lin Wang of the Chinese Academy of Sciences, the other led by Paul C. Canfield of



LEVITATION

As well as having zero electrical resistance, a superconductor does not allow magnetic fields in its interior, a property called perfect diamagnetism. This effect can levitate a superconductor over a magnet (*uppermost disk, above*) or a magnet over a superconductor. So-called type 2 superconductors enable magnetic flux to pierce them in thin tubes that may become pinned at defects in the material. Such a superconductor can also be suspended below a magnet (*bottom disk*).

CHARLES O'REAR *Corbis (superconductor and magnets)*; LUCY READING-IKKANDA *(iron tile)*

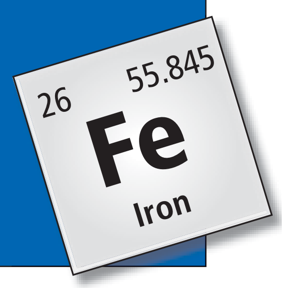
[NEW EXCITEMENT]

Another Iron in the Fire

Physicist's excitement over the discovery of the copper oxide, or cuprate, high-temperature superconductors in 1986 is legendary. A session on the cuprates at an American Physical Society conference in early 1987 was dubbed the "Woodstock of Physics" after thousands of researchers overflowed the room and presentations continued past 3 a.m.

But after that frenzied beginning, work to understand the cuprates' properties turned out to be a long, frustrating slog. Over two decades experimenters marshaled a veritable arsenal of techniques to investigate the materials, including neutron scattering, electron spectroscopy and scanning superconducting quantum interference device microscopy. Yet the puzzle of what physical process produced the high-temperature superconductivity remained unsolved.

Thus, the iron pnictides rekindled the old excitement when they appeared on the scene, with transition temperatures second only to those of the cuprates and with somewhat similar structures. Physicists are rapidly recapitulating 20 years of cuprate experiments on the iron materials, hoping to see vital clues in the similarities and differences of the two compounds. A solution to the mystery could open the door to room-temperature superconductors, which would transform technology in unimagined ways.



MATERIAL PROGRESS

In the 98-year history of superconductivity, researchers have discovered a diverse assortment of materials that superconduct.

1911 Mercury 4.2 kelvins
The first superconductor was discovered by Heike Kamerlingh Onnes when he used liquid helium to cool mercury below its superconducting transition temperature of 4.2 K.

1941 Niobium alloys 16–23 K
Industrial use of superconductors took off only after 1961, when researchers discovered that niobium tin (Nb_3Sn), which superconducts at 18.3 K, could carry high currents and withstand large magnetic fields.

1971 Niobium germanium 23 K
This material (Nb_3Ge) held the record for highest transition temperature from 1971 to 1986.

1979 Heavy fermions 0.5–1.0 K
Heavy-fermion superconductors such as uranium platinum (UPt_3) are remarkable by also having electrons that effectively have hundreds of times their usual mass. Conventional theory cannot explain these materials' superconductivity.

1986 Cuprates 35–138 K
The first high-temperature superconductors, these ceramic materials were the first that could be cooled with liquid nitrogen, which boils at 77 K.

1991 Fullerenes 18–33 K
Solid crystals made of buckyballs (C_{60}) superconduct when doped with alkali metal atoms such as potassium, rubidium and cesium.

1995 $HgBa_2Ca_2Cu_3O_8$ 138 K
Doped with thallium, this cuprate has the highest-known transition temperature at atmospheric pressure. At high pressure it superconducts up to 164 K.

2001 Magnesium diboride 39 K
The unusually high transition temperature of magnesium diboride turns out to be an exceptional case of conventional superconductivity.

2006 Iron pnictides 4–56 K
Hideo Hosono (*right*) discovered the first of these compounds, which form only the second kind of high-temperature superconductor.

Iowa State University, with both groups including collaborators at Los Alamos National Laboratory—independently found that a particular iron pnictide superconductor responds very similarly to strong magnetic fields pointing in different directions. That is, this material, which has potassium-doped barium layers interleaved with FeAs and which can superconduct up to about 38 K, seems to have three-dimensional superconductivity.

In the words of Jan Zaanen, a theorist at Leiden University in the Netherlands, if the cuprates and the iron pnictides share the same "secret of high-temperature superconductivity," this experimental result implies that "two-dimensionality has been a red herring all along, causing theorists to look in wrong directions."

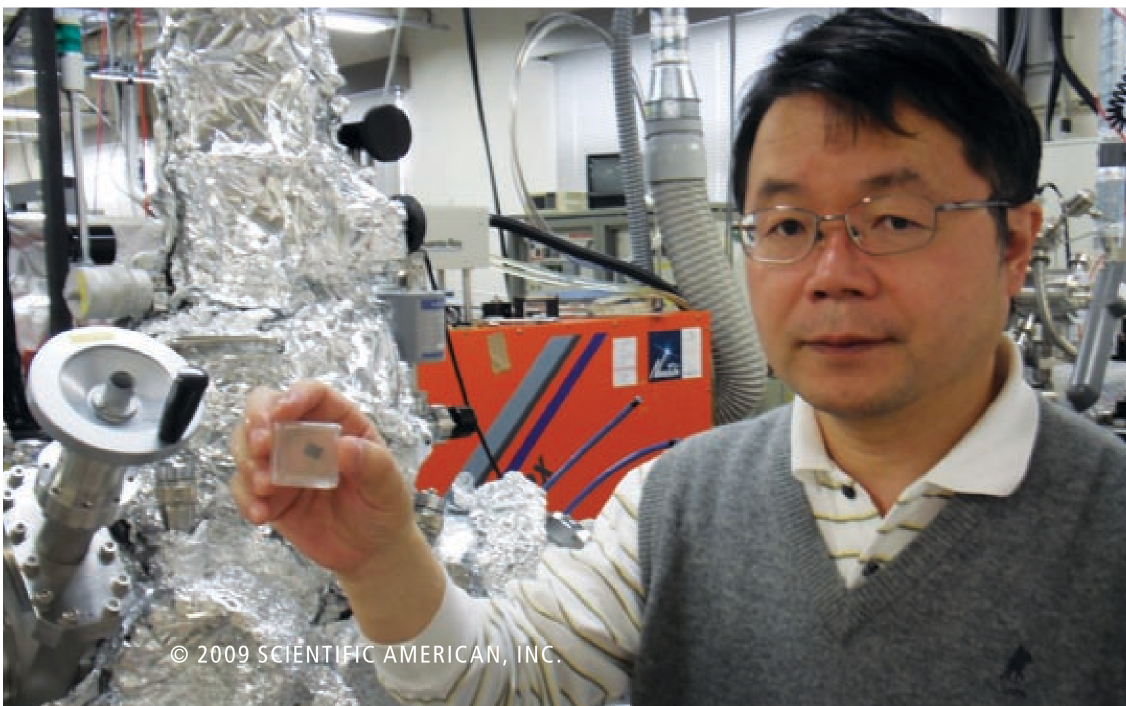
Quanta of Sound

The "secret of high-temperature superconductivity" that Zaanen and other physicists want to extract by interrogating the cuprates and pnictides is a quite specific piece of information about what makes these materials superconduct. In particular, they want to know what interaction between the electrons involved leads to the superconducting state. An electric current in an ordinary metal is carried by the so-called conduction electrons, which are free to move through the material. These electrons, however, constantly collide with the positively charged metal ions, which saps the energy of the current and heats the metal—this effect is the metal's electrical resistance.

Superconductivity occurs when conduction electrons become linked together in pairs, which are known as Cooper pairs. The Cooper pairs gather en masse in a single quantum state, a process known as Bose-Einstein condensation. This swarm of charged particles is able to move through the material in lockstep without losing energy in collisions with the metal ions; the resistance drops to zero. Measurements confirm that in both cuprate and iron pnictide superconductors, the carriers of electric current have twice the charge of an electron—the carriers are Cooper pairs. But theory must also explain the mechanism that forms these Cooper pairs. According to the classic explanation of conventional superconductivity—the BCS theory, developed by John Bardeen, Leon N. Cooper and J. Robert Schrieffer in 1957—a very prosaic entity plays this role: sound.

Sound is made of vibrations. The quantum of vibration in a solid is the phonon, named by analogy with the photon, the quantum of light (or, if you like, the quantum of electromagnetic vibrations). An interaction between two conduction electrons, mediated by phonons, can be visualized as follows: the first electron's electric field tugs on the metal's positively charged ions as it passes near them. The electron leaves in its wake a temporary region of distorted lattice—the very stuff of phonons. A second electron will experience a small attractive force toward the momentarily distorted region because of the slightly increased density of positive charge there. This small, indirect attractive force is enough to produce Cooper pairs and superconductivity, so long as the temperature is low enough that thermal vibrations do not overwhelm the effect. The BCS theory puts this ap-

COURTESY OF HIDEO HOSONO



proximate heuristic picture on a firm mathematical basis that allows calculation of a material's transition temperature based on the material's other properties.

One of the classic verifications of the BCS theory is the observation that transition temperatures of two isotopes of a superconducting material are different by about the right proportion. Thus, mercury 198 superconducts when it is colder than 4.18 K, but mercury 202 only does so below 4.14 K. The slightly heavier mercury 202 atoms vibrate less and at a lower pitch, and thus in mercury 202 the electron-phonon force is weaker, the Cooper pairs are more fragile and less thermal energy suffices to overwhelm the superconductivity.

Studies of cuprates, however, revealed virtually no isotope effect—phonons could not be the principal binder of Cooper pairs in those materials. In many respects this result was no surprise because the cuprates superconducted far above 30 K and theorists had long ago computed that the electron-phonon interaction described by the BCS model would not be strong enough to hold Cooper pairs together at such high temperatures in any plausible material.

An exception to this 30 K rule did come along in 2002, in the form of magnesium diboride, which superconducts at 39 K [see "Low-Temperature Superconductivity Is Warming Up," by Paul C. Canfield and Sergey L. Bud'ko; Scientific American, April 2005]. Magnesium diboride does show the isotope effect and is understood to be a BCS superconductor, albeit a peculiar variant of the theme. Its unusually high transition temperature results from exceptionally strong coupling between certain electrons and lattice vibrations and from it managing to have two populations of electrons that each form a distinct condensate of Cooper pairs.

What of the new iron-based superconductors? Only a few weeks after Hosono's discovery that fluorine-doped LaOFeAs superconducts at 26 K was published on the Web, theorists released a preprint calculating that the electron-phonon coupling in that material, acting in the manner described by the BCS theory, could not be the glue holding the Cooper pairs together. Lilia Boeri of the Max Planck Institute of Solid State Physics in Stuttgart, Germany, and her co-workers calculated that the transition temperature would be below 1 K if phonons were responsible in the conventional way.

Remarkably, however, researchers have seen

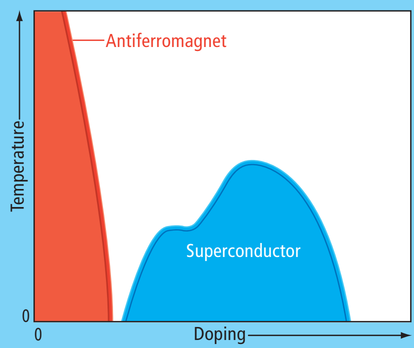
[COMPARISON]

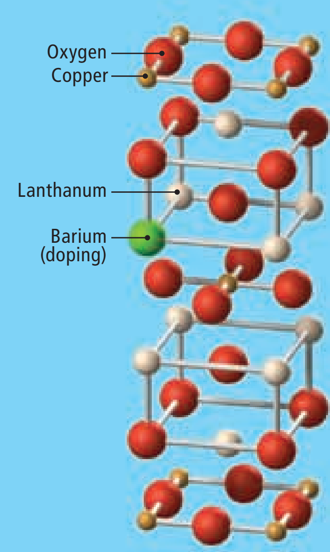
Anatomy of Two Materials

The cuprate superconductors and the iron pnictides share many similarities but also differ in certain ways. Physicists are still coming to grips with determining which characteristics are most important to superconductivity. Both materials consist of alternating layers of atoms, as shown here for the cuprate La_2CuO_4 and the iron pnictide LaOFeAs (*below right*). In both cases, the materials' properties depend on the level of doping, or inclusion of impurity atoms—barium atoms replace some lanthanums in the cuprate, and fluorine atoms replace some oxygens in the pnictide. Physicists map out how a material's properties vary with doping and temperature in phase diagrams (*below left*) analogous to diagrams of the pressures and temperatures at which water vaporizes or forms various kinds of ice.

CUPRATES ▸

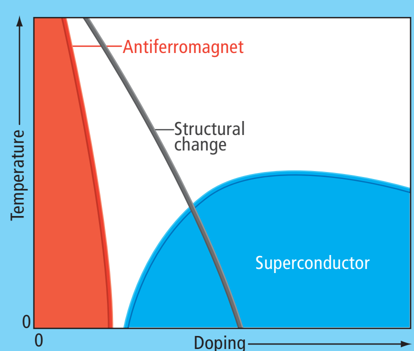
At very low doping, the cuprates are insulators and antiferromagnetic (*below, red*)—in each copper oxide layer the copper atoms, which are like tiny magnetic compass needles, line up in the opposite direction to their nearest neighbors. Increased doping eliminates the antiferromagnetism and the material becomes conducting (*white*). It superconducts (*bright blue*) below a transition temperature that depends on the level of doping. Not shown here are many exotic phases within the "normal" conductor that a theory must explain along with the superconductivity.

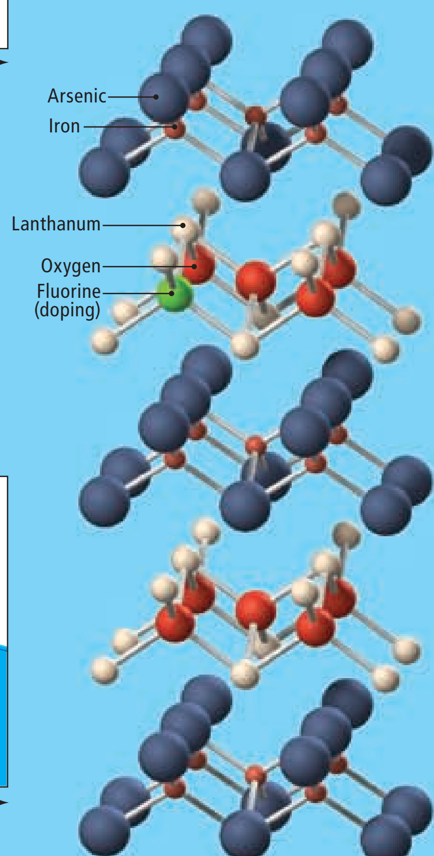




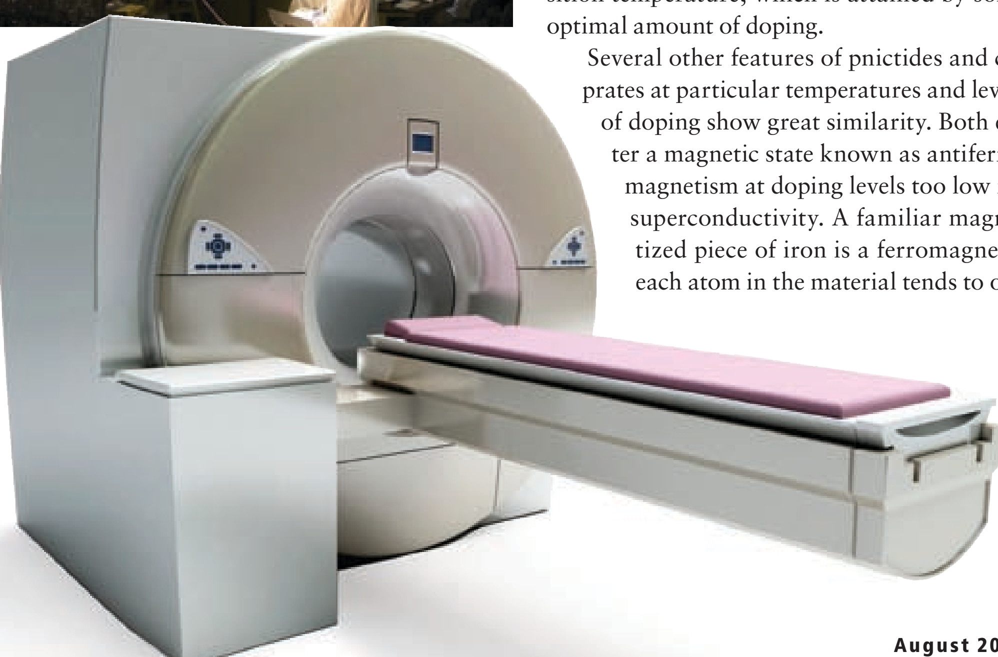
PNICTIDES ▸

The pnictides at low doping are also antiferromagnetic (*red*) but are poorly conducting metals rather than insulators in that state. As in the cuprates, the superconducting phase (*bright blue*) takes over at low temperatures within a range of doping levels. The materials also typically undergo a structural change (*gray line*), going from a very symmetrical pattern of iron atoms at low doping and temperatures to a stretched arrangement at higher doping and temperatures. Some experiments suggest that this structural distortion, and not the doping per se, is what controls the pnictides' behavior.





KENNETH EWARD *BioGrafx* (*molecular structures*); LUCY READING-IKKANDA (*graphs*); SOURCE: "IRON-BASED SUPERCONDUCTORS: UNITY OR DIVERSITY?" BY STEVEN A. KIVELSON AND HONG YAO, IN *NATURE MATERIALS*, VOL. 7; DECEMBER 2008



▲ **CONVENTIONAL superconductors have found applications ranging from particle accelerators such as the Relativistic Hadron Ion Collider (RHIC) (*top*) and the Large Hadron Collider, to superconducting gyroscopes and magnetic field detectors in the Gravity Probe B satellite (*above*) to magnetic resonance imaging (*right*).**

some isotope effects, just as the BCS theory would predict. This past May, Xian Hui Chen of the University of Science and Technology of China and his collaborators reported observing a strong effect on the transition temperature of iron arsenide superconductors made with two different isotopes of iron. Thus, the electron-phonon coupling seems to play a role, but other interactions, not included in the BCS theory or the calculations by Boeri and her co-workers, must also be important. Those other interactions could also be behind the cuprates' Cooper pairs and thus might be "the shared secret" of high-temperature superconductivity.

Competing Processes

Clues to the additional physical processes important for high-temperature superconductivity may come from studying how the transition temperature varies with the level of doping for each iron pnictide and from examining the properties the material exhibits when it is not superconducting. Physicists map this information in so-called phase diagrams, which are analogous to the phase diagrams that record how a substance such as water changes its physical state when the temperature and pressure vary [*see box on preceding page*].

With the amount of doping plotted along the horizontal axis, the superconducting state of a cuprate or an iron pnictide forms a roughly semicircular region at the bottom of the graph. The limits of that region show that if the doping is too low or too high, the material does not superconduct even at absolute zero. The highest part of the semicircle shows the maximum transition temperature, which is attained by some optimal amount of doping.

Several other features of pnictides and cuprates at particular temperatures and levels of doping show great similarity. Both enter a magnetic state known as antiferromagnetism at doping levels too low for superconductivity. A familiar magnetized piece of iron is a ferromagnet—each atom in the material tends to ori-

RUSS UNDERWOOD *Lockheed Martin Corporation*; SOURCE: NASA (*Gravity Probe B*); SCIENCE SOURCE *Photo Researchers, Inc.* (*RHIC*); MEDICALRF.COM *Corbis* (*MRI*) ent its individual magnetic moment, its individual little "compass needle" of magnetism, in the same direction as its nearest neighbors. All of these magnetic moments thus combine to produce the field of the magnet as a whole. In an antiferromagnet, in contrast, the nearest neighbor atoms tend to point their magnetic moments in opposite directions and the material as a whole produces no magnetic field.

For the cuprates, the undoped materials are typically antiferromagnetic up to temperatures well above the highest superconducting transition temperature of the doped material. But as the doping level increases, the temperature for antiferromagnetism plunges to zero before superconductivity appears. Physicists interpret this as a sign that these two different kinds of ordering—antiferromagnetic alignment of the atoms' magnetic moments and the formation of a condensate of Cooper pairs—are incompatible and competing. The interaction that generates superconductivity in these materials has to overcome the antiferromagnetism.

The pnictides show similar behavior, with the undoped materials exhibiting an antiferromagnetism that is not present in the superconducting state. In December a collaboration of researchers at several laboratories in the U.S. and China found that the antiferromagnetism in the iron pnictide that they studied—cerium oxygen iron arsenide (CeOFeAs) doped with fluorine—disappeared rapidly with increasing doping, much as in the cuprates.

The group also looked at a structural transition that occurred. In the FeAs planes, each Fe atom is surrounded by four As atoms arranged at the vertices of a tetrahedron. At low doping and low temperatures, those tetrahedrons are distorted. At the amount of doping yielding the highest transition temperature, the distortion completely disappeared, suggesting that the good tetragonal symmetry could be important for the pnictide's superconductivity. Tetragonal symmetry is not a factor in the cuprates' CuO_2 planes, which at most deviate only slightly from being completely flat.

In the cuprates, the antiferromagnetic state is an electrical insulator, but for the pnictides it is a conductor, albeit a poorer conductor than a typical metal. Which is more important in understanding these two materials: the similarity of the antiferromagnetism or the dissimilarity of the conductivity of that state? As with so many features, a conclusive answer to that question remains hidden.

Catching Waves

Another issue of great importance for efforts to unravel the cause or causes of high-temperature superconductivity is the symmetry of the Cooper pairs. In BCS materials, the Cooper pairs have so-called spherical symmetry—a shape that, like a sphere, looks the same in all directions. Also termed s-wave symmetry, it is analogous to the perfectly symmetrical shape of a hydrogen atom in its ground state. (Both examples involve two fermions bound together—two electrons in the case of the Cooper pairs, a proton and an electron in the case of a hydrogen atom.)

The type of symmetry in cuprate Cooper pairs was long a controversial subject, and only after many years did experiments finally resolve it as a kind of symmetry called d-wave with some s-wave mixed in as well. The d-wave symmetry somewhat resembles a four-leaf clover, but with two colors of leaves (actually, "positive" and "negative" lobes) alternating around the stalk.Early experiments on pnictides pointed to s-wave symmetry, leaving open the possibility that those materials really do behave, somehow, as BCS superconductors. Results reported in December and January, however, show that the pnictide's s-wave has an unconventional feature, with positive regions on the opposite side of negative regions instead of the whole sphere being the same sign. Thus, once again the pnictides and cuprates seem to be similar but different.

These studies of the iron pnictides continue at a frenetic pace—in their 20 years of investigating the cuprates, experimenters have built up a veritable arsenal of techniques to bring to bear on the new materials. But the picture emerging from experiments so far is at least as puzzling as that of the cuprates. How much the two puzzles are related and how the commonalities might lead to insights that could be useful for developing room-temperature superconductivity may not be clear for some time.

Meanwhile the instigator of the field, Hosono, has added another curiosity to be explained. In March he reported finding that strontium iron arsenide ($SrFe_2As_2$) superconducts not only when doped with cobalt but also when the undoped compound is exposed to water vapor. Furthermore, differences in the features of the two cases suggest to him that a different superconducting mechanism is at work in each.

If the history of the cuprates is any guide, expect researchers to keep uncovering more puzzles than answers for some years to come. ■

FUTURE PROSPECTS

As cuprate wire fabrication processes improve, the cuprates' so far limited repertoire is expanding. Companies are developing large systems such as turbines in wind power generators (*below*) and ship propulsion engines, in both cases providing more power in a less huge device. Physicists hope that study of the pnictides will open the way to new materials with higher transition temperatures or better mechanical properties than the cuprates.

WIND POWER TURBINE

KEVIN HAND

➥ MORE TO EXPLORE

Iron-Based Layered Superconductor La[$O_{1-x}F_x$]FeAs (x = 0.05–0.12) with T_c = 26 K. Yoichi Kamihara, Takumi Watanabe, Masahiro Hirano and Hideo Hosono in *Journal of the American Chemical Society,* Vol. 130, No. 11, pages 3296–3297; March 19, 2008.

Condensed Matter Physics: The Pnictide Code. Jan Zaanen in *Nature,* Vol. 457, pages 546–547; January 29, 2009.

Iron Arsenide Superconductors: What Is the Glue? D. G. Hinks in *Nature Physics,* Vol. 5, No. 6, pages 386–387; June 2009.

A New Kind of DRUG TARGET

An emerging class of medicines works its magic by targeting unusual sites on biological molecules

By Melinda Wenner

KEY CONCEPTS

- A new drug discovery approach focuses on a property known as allosterism.
- Allosteric drugs attach to biological molecules at binding sites distinct from those usually targeted by medications.
- Instead of activating or inhibiting the bound molecules, as classic drugs do, allosteric types can act more like dimmer switches and might, at times, cause fewer side effects.
- Such agents may be able to treat disorders that lack drug therapies today.

—The Editors

Despite what the overcrowded, overpriced shelves of your pharmacy might suggest, pharmaceutical companies struggle to find new drugs these days. The low-hanging fruit is long gone, and the main discovery method that served so well in past decades is generating far fewer hits today. But a fresh strategy, focused on a property called allosterism, is now invigorating many investigators. Some predict it will revolutionize drug discovery and could deliver treatments for diseases that so far remain intractable.

Historically, scientists have developed drugs by finding molecules that mimic the behavior of our body's signaling molecules, such as hormones and neurotransmitters. The pharmaceutical doppelgangers of such endogenous substances latch onto cell-surface receptor molecules exactly where the native substances bind. If a mimic fits snugly into the binding pocket, known as the "active" site, it will activate the receptor, triggering a biochemical cascade within the cell. If the mimic has a slightly different shape, it will do the opposite, impeding the cascade. Most drugs on the market today—allergy medicines, beta blockers, antipsychotic drugs—act in one of those ways.

Problem is, such drugs have an all-or-nothing effect. They stimulate or repress physiological pathways, leaving no room for normal fluctuations in activity. And because the body has evolved to use the same chemicals for multiple purposes, one endogenous molecule often binds to a range of receptor subtypes, each responsible for different tasks—so drugs intended to replicate the action of, say, a given neurotransmitter on just one subtype may end up affecting many subtypes, leading to side effects. These limitations have made it impossible for scientists to find safe therapies for some diseases.

Thanks to a few serendipitous discoveries arising from an upgrade in technology, pharmaceutical companies are now moving beyond mimicry drugs. They are on the hunt for agents

THERAPEUTIC AGENTS known as allosteric ("other site") modulators take aim at targets outside of where classic drugs, and the body's own substances, normally hit selected molecules in the body.

SLIM FILMS

that interact with receptor regions that are geographically distinct from where a body's chemicals bind. These allosteric drugs, as they are called—allosteric means "other site"—can interact with unique domains on receptor subtypes, thus limiting side effects by affecting only a narrow set of receptors possessing those domains. And the new agents are not mere on-off switches; they can have nuanced effects, ramping up or down the activity of a signaling pathway as needed.

Spearheading the allosteric effort is Swiss biotechnology firm Addex, the first company to devote its entire pipeline to allosteric drugs. In collaboration with several pharmaceutical makers, Addex is testing certain of its drugs in patients. Other companies are pursuing the approach, too: allosteric drugs made by Pfizer and Amgen have earned approval from the U.S. Food and Drug Administration to treat HIV and chronic kidney failure.

Order from Chaos

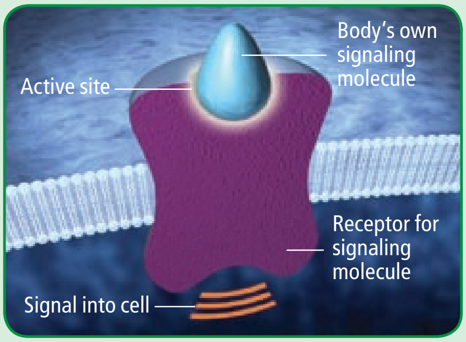
Allosterism is not a new concept. Since the early 20th century scientists studying enzymes, proteins that drive biochemical reactions forward,

[BASICS]

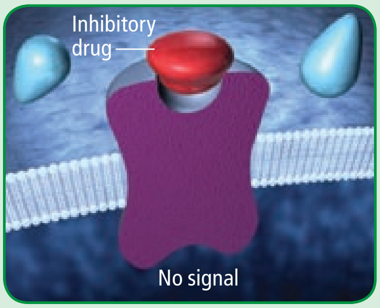
WHAT'S THE DIFFERENCE?

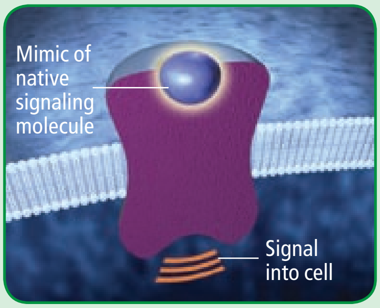
When one of the body's own molecules, such as a neurotransmitter, attaches to the so-called active site of its receptor on a cell (*right*)—something like a key fitting into a lock—the receptor sets off an intracellular signaling cascade that ultimately causes the cell to change its activity. Many drugs inhibit or enhance such signaling.

NORMAL CELLULAR ACTIVITY



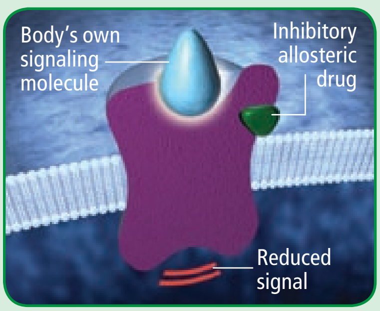
HOW CLASSIC DRUGS ACT

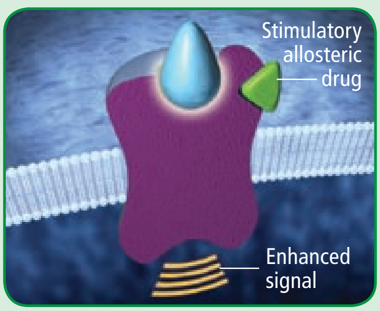




Typical pharmaceuticals bind to the active site in place of the native substance and either block the endogenous molecule's signaling (*left*) or mimic its effects (*right*).

HOW ALLOSTERIC DRUGS ACT





Allosteric drugs do not go to the active site. Instead they bind to other areas, altering the receptor's shape in a way that decreases (*left*) or increases (*right*) the receptor's response to the native substance. Allosteric agents might, for instance, cause the active site to grasp a neurotransmitter less or more effectively than usual.

have known it well: small molecules often bind to various locations on an enzyme and change its shape and function. It was not until the 1990s, however, that scientists started conceiving of allosterism in the context of drug development—and even then, the possibility arose unexpectedly.

Pharmaceutical companies have long focused most of their efforts on a class of cell-surface molecules called G-protein coupled receptors (GPCRs for short). These snakelike proteins weave through the cell's membrane seven times, initiating intracellular responses to events that occur outside the cell. When a ligand, a molecule that targets a receptor, binds to the active site of a GPCR on the outside of the cell, the receptor changes shape to activate a second molecule known as a G protein, which in turn initiates a biochemical cascade inside. The body produces more than 800 types of GPCRs, and about 100 types sit on any cell's surface. But drugs on the market target only one eighth of all our GPCRs. "We're only still touching the tip of the GPCR iceberg," says Arthur Christopoulos, a pharmacologist at Monash University in Australia.

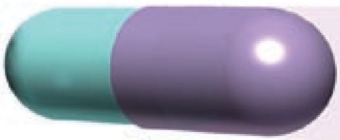
In the 1980s and early 1990s pharmacologists hunted for new GPCR drugs by using what were called radioligand assays. They identified the receptor they wanted to affect—perhaps a receptor linked to a disease pathway—and bound it to a known ligand that had been labeled radioactively. They then flooded the bound receptors with potential drug candidates to see which ones knocked the labeled ligands off. The more ligands a drug candidate kicked off, the better the "hit."

These assays were designed to find drugs that bound to the active site, which is also known in the business as the "orthosteric" site. They did not find allosteric drugs that affected the receptor's function in other ways, but at that point, scientists had no interest in doing so—orthosteric drugs were the obvious first choice. Unfortunately, for reasons not entirely clear, that approach stopped yielding good numbers of promising drug candidates after a while.

As a response, in the mid-1990s companies began trying a new, more physiological approach. They used "functional" assays that monitored how drug candidates affected the behavior of real, intact cells bearing receptors of interest, rather than looking at receptor binding alone. "This is where the interesting stuff started to happen," Christopoulos says. Sometimes a molecule increased a receptor's function; other times it inhibited the receptor. Orthosteric drugs should have been consistent in this regard. Some investigators realized that allosterism was responsible for the varied effects, but most saw allosterism not as a boon but as problematic.

Then, in 1999, a small La Jolla, Calif.–based biotechnology company called SIBIA Neurosciences, in collaboration with Novartis, reported discovering one of the first selective allosteric modulators: a molecule that toned down the activity of the metabotropic glutamate 5 recep-

KENNETH EWARD



The new agents are not mere on-off switches; they can have nuanced effects, ramping up or down the activity of a signaling pathway.

tor, or mGlu5—one of more than 30 receptor subtypes for the neurotransmitter glutamate. SIBIA had been looking for a selective modulator of mGlu5 because the receptor plays an important role in neurological disorders, including epilepsy.

It was the first time that a drugmaker had found such a molecule, recalls P. Jeffrey Conn, a pharmacologist at Vanderbilt University. Even so, Conn notes, most companies remained wary of pursuing allosteric agents, with their frequently unpredictable effects. “I don’t know if heretical is too strong a word,” he recalls, but the notion “was not a well-received idea in the GPCR field.”

SIBIA’s mGlu5 antagonist did not itself pan out as a drug, although it got a number of scientists thinking. One was Vincent Mutel, then a pharmacologist at Roche and now CEO of Addex. In 2001 he and his colleagues discovered, by chance, an allosteric molecule that enhanced the activity of the metabotropic glutamate receptor 1, or mGlu1. This subtype was not tied to any particular disease, but the finding convinced Mutel that allosteric molecules might serve not only as antagonists of receptor activity but also as enhancers. And he suspected that allosteric modulators for other glutamate receptors could be found. Some of those receptors were known to be involved in schizophrenia and anxiety disorders.

Mutel was so inspired that he left Roche at the end of 2001 and, along with colleagues from GlaxoSmithKline, Roche and PricewaterhouseCoopers, founded Addex to pursue the idea. “We put together all this energy and said, ‘Can we address the GPCR in a different way? Why not allosteric modulation?’ ” he says.

Small Changes, Big Payoffs

Allosteric drugs may have an edge over traditional orthosteric molecules because of what they cannot do as well what they can do. When allosteric molecules bind, they subtly change the receptor’s shape, which changes how easily the natural ligand can connect to the active site. This helping role means that allosteric modulators usually do not have a noticeable effect unless the natural ligand is present. “If you put it on the receptor, it does nothing,” Mutel explains. If a disease develops because a chemical is produced normally but does not bind as well as it should to its receptor, an ideal drug would help it bind better—but just when the chemical is around. Only an allosteric drug can do that; an orthosteric drug would activate the receptor as soon as it entered the body, which would not conform to natural dynamics.

The tendency to induce an effect only in the presence of the natural ligand could also make allosteric drugs safer than some orthosteric drugs. Although no one understood how Valium worked when it was discovered, scientists now know it is an allosteric modulator that “turns up” the activity of the receptor for GABA, the body’s main inhibitory neurotransmitter. Other central nervous system depressants, such as phenobarbitol, are deadly if taken in large quantities, but Valium “just sits on the receptor and does nothing until the brain releases GABA, and then when GABA binds, its actions are boosted five- to 10-fold,” Christopoulos explains. Typically a person who takes too much Valium simply sleeps it off, he says.

On the “can do” side of the ledger, the ability of allosteric molecules to interact with receptors beyond the active site means they can bind specifically to individual subtypes. Many receptors evolved to respond to the same orthosteric ligand, explains Darryle Schoepp, a senior vice president at Merck & Co. One neurotransmitter might act on a dozen receptor subtypes, each responsible for initiating a different biochemical cascade. Nature, though, has not had a strong need to keep other parts of the receptors identical. Consequently, an allosteric modulator might bind to a nonorthosteric spot on subtype mGlu2 but not find any anchor in mGlu3 or other subtypes—thereby avoiding acting unnecessarily on receptor variants whose altered activity could potentially cause side effects.

These drugs can also have nuanced effects because they can influence a receptor’s shape in a number of ways. Administering them would be akin to replacing on-off light switches with dimmer switches, allowing for a range of outcomes—

[THE AUTHOR]

COURTESY OF MELINDA WENNER

Melinda Wenner is a science writer in Brooklyn, N.Y. Her latest feature for *Scientific American* addressed efforts to develop taste enhancers [“Magnifying Taste,” August 2008].

Allosteric drugs may have an edge over traditional drug molecules because of what they cannot do as well as what they can do.

a receptor could be tuned to be barely active, mostly active or highly active. Because so many diseases are marked by subtle disruptions in biochemistry or signal processing, notes Terry Kenakin, a principal research investigator at GlaxoSmithKline, it would be very useful to drug developers to be able to "tweak" the body back to normalcy.

From Concept to Clinic

With so many advantages, allosterism is now a common word among pharmacologists. "The area now has just expanded tremendously," Conn says.

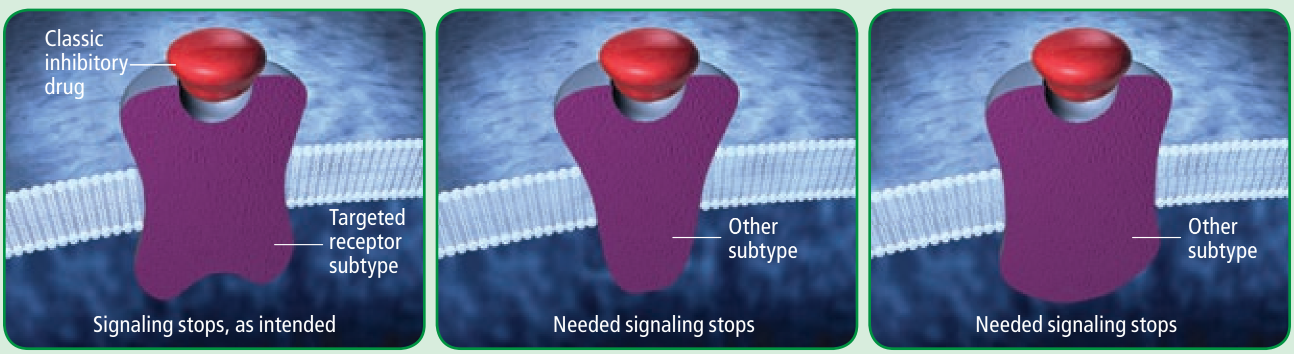
Addex has 60,000 potential allosteric modulators in its library and is screening them for effects on a number of GPCRs as well as on other types of receptors and ion channels. Its compound ADX10059, which tones down the ability of the mGlu5 receptor to bind glutamate, is now in human trials for efficacy in migraine and heartburn associated with gastrointestinal reflux disorder (GERD). Another of Addex's mGlu5 antagonists, intended to treat involuntary movements resulting from Parkinson's disease, has recently completed safety tests in patients. The company is also collaborating with Merck and Johnson & Johnson to develop allosteric modulators for schizophrenia and anxiety disorders.

[ALLOSTERIC ADVANTAGE]

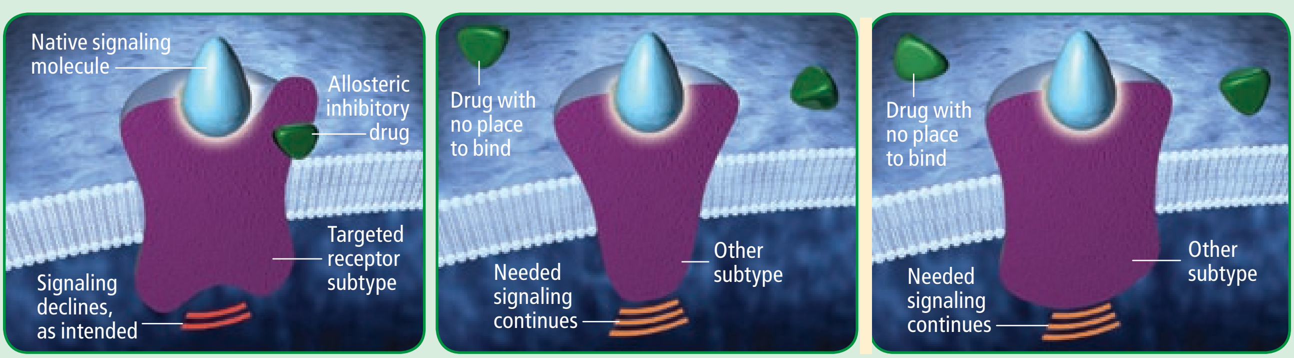
A WAY TO LIMIT SIDE EFFECTS

If a receptor comes in multiple forms, a classic drug aimed at the active site of one subtype will also likely affect its kin, because the subtypes of a given receptor have a similar active site. An inhibitor delivered to shut down one subtype (*left in top panel*), then, may also inhibit relatives needed by a patient (*top center* and *right*), potentially causing side effects. But an allosteric drug can bind to a site that is specific to a single subtype (*left in bottom panel*), leaving other subtypes unaffected (*bottom center* and *right*) and thereby potentially limiting side effects.

TYPICAL DRUG AFFECTS TOO MANY RECEPTORS



ALLOSTERIC DRUG CAN ACT ON A SPECIFIC RECEPTOR SUBTYPE



KENNETH EWARD

[ALLOSTERIC EXAMPLES]

ON THE MARKET AND ON TAP

Two new allosteric drugs entered the market in the past few years, and a number of others are in, or close to, human testing for a range of disorders; the list below offers a sampling. All the agents below that are under study affect receptors for neurotransmitters and are in relatively early phases of trials (phase I or phase II, as opposed to very large phase III tests).

DISORDER	AGENT (MAKER)	ACTION	STATUS
Chronic kidney failure	Cinacalcet (Amgen)	Enhances activity of calcium receptors	On the market
Cognitive deficits of Alzheimer's disease	XY4083 (Xytis)	Enhances activity of alpha7 subtype of nicotinic acetylcholine receptor	First human trial expected to start this year
Cognitive deficits of schizophrenia	GSK729327 (GlaxoSmithKline)	Enhances activity of AMPA-type ionotropic glutamate receptors	In early trials
Gastroesophageal reflux disease (GERD)	ADX10059 (Addex); AZD2066 (AstraZeneca); AFQ056 (Novartis)	Inhibit metabotropic glutamate receptor 5	In early trials
HIV	Maraviroc (Pfizer)	Acts on CCR5 receptor to interfere with HIV entry into cells	On the market
Pain	Xen2174 (Xenome)	Inhibit norepinephrine transporter	In early trials
Parkinson's disease	ADX48621 (Addex); AFQ056 (Novartis)	Inhibit metabotropic glutamate receptor 5	In early trials

The two allosteric drugs that have already made it to market are Amgen's cinacalcet (sold in the U.S. as Sensipar), which was approved in 2004 to activate calcium receptors as a treatment for chronic renal failure, and Pfizer's maraviroc (marketed as Selzentry), which was approved in 2007 for the treatment of HIV. Maraviroc gains access to cells by attaching to a receptor called CCR5, which normally binds an immune chemical called a chemokine; CCR5 likewise grasps HIV and helps it into the cell. Selzentry changes the shape of the CCR5 receptor in a way that bars HIV from binding to it. Unfortunately, Kenakin says, the drug also blocks the chemokine from binding, and chemokines help cells fight HIV. Future compounds, he says, may be able to block HIV without impeding the chemokine.

Allosteric agents do present challenges. What initially frustrated scientists about them—that they have one effect in one experiment and another in a second experiment—is still a major headache. GPCRs "are in every cell type, and they couple to G proteins, and there are lots of different types of G proteins," Christopoulos says. A single GPCR can have multiple ligands and be paired to different biochemical pathways in the body, depending, among other things, on which tissue the receptor is in. Scientists therefore have to test allosteric drug candidates in multiple assays and tissue systems to make sure the compounds are doing the right things in the right places.

Finally, Mutel points out, "a chemical is a chemical, and it will have a certain toxicity." Allosteric drugs may, on average, be safer than orthosteric drugs because they can be taken in smaller concentrations—they do not have to compete with the natural ligand—and because most do not affect a receptor unless the natural ligand is already present. Even so, not all allosteric drugs will be safe, and some could have side effects by binding to and affecting unrelated receptors.

Nevertheless, pharmaceutical scientists are confident that allosterism has far-reaching promise for future drug development. "There's a lot of negative press out there about inefficiency in drug discovery and how things aren't going very well," Merck's Schoepp says. Allosterism breathes new life into the field. "We can do things that we couldn't do before," he notes. "This approach could really transform drug discovery." ■

➥ MORE TO EXPLORE

New Bull's-Eyes for Drugs. Terry Kenakin in *Scientific American*, Vol. 293, No. 4, pages 50–57; October 2005.

Allosteric Modulation of G Protein-Coupled Receptors. L. T. May, K. Leach, P. M. Sexton and A. Christopoulos in *Annual Review of Pharmacology and Toxicology*, Vol. 47, pages 1–51; 2007.

Allosteric Modulators of GPCRs: A Novel Approach for the Treatment of CNS Disorders. P. Jeffrey Conn, Arthur Christopoulos and Craig W. Lindsley in *Nature Reviews Drug Discovery*, Vol. 8, No. 1, pages 41–54; January 2009.

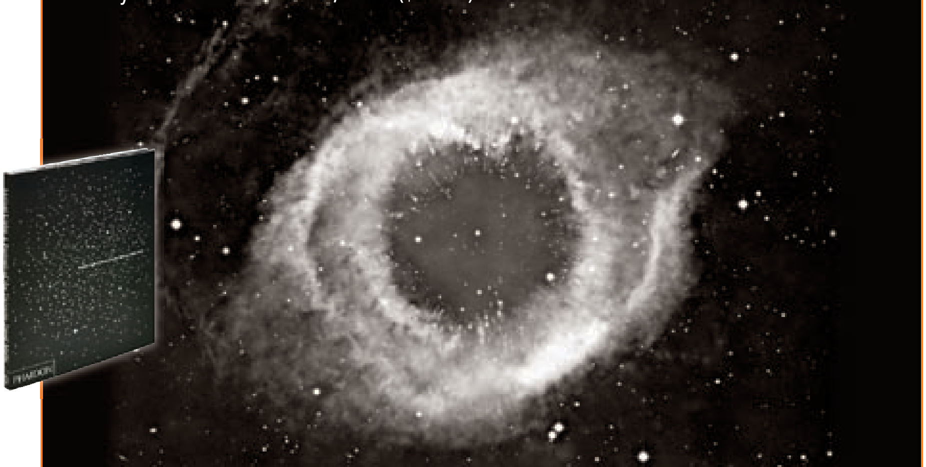
Promise of mGluR2/3 Activators in Psychiatry. P. Jeffrey Conn and Carrie K. Jones in *Neuropsychopharmacology*, Vol. 34, No. 1, pages 248–249; January 2009.

Celestial Views ■ Bigfoot Pursuits ■ Scientific Twitterers

BY KATE WONG

➜ ANCIENT LIGHT: A PORTRAIT OF THE UNIVERSE

by David Malin. Phaidon, 2009 ($49.95)



Celebrated astronomical photographer David Malin takes readers on a memorable tour of the night sky with this collection of 60 large-format black-and-white photographs. Platinum prints capture galaxies, nebulae (such as the Helix nebula, *above*), star clusters and other phenomena in stellar detail.

EXCERPT

➜ COLD: ADVENTURES IN THE WORLD'S FROZEN PLACES

by Bill Streever. Little, Brown, 2009 ($24.99)

Biologist Bill Streever, chair of the North Slope Science Initiative's Science Technical Advisory Panel in Alaska, spent a year seeking out the remaining chilly places in our warming world. The result is a natural history of cold and how it has shaped the planet and its inhabitants. Here the author describes a July visit to northern Alaska.

"The mercury rises to fifty-two degrees here on Narwhal Island, ten miles north of Alaska's North Slope. Nothing but water and ice separates me from the North Pole. . . .

"Occasionally, a chunk of ice strands next to the shore, hard aground. Another chunk butts up against the first. They grind. Water drips from their tops continuously. Pieces of ice break off, dropping into the Beaufort Sea with splashes that sound remarkably similar to those produced by bass jumping in a still pond. I wade into the sea, break off a piece of ice, and pop it into my mouth. It tastes as fresh as spring water. The molecules in ice are packed in an orderly fashion, forming crystals. There is little space between the molecules for salt ions.

"Farther out, between here and the horizon, the ice is more densely packed and in places continuous. Fog banks hover over the ice like plumes of smoke. Occasionally, maybe once each half hour, the pack ice cracks under the pressure of movement, of collisions, of one body striking another. The cracking sounds like distant cannon fire."

ALSO NOTABLE

BOOKS

- ➜ **Wicked Plants: The Weed That Killed Lincoln's Mother & Other Botanical Atrocities**
  by Amy Stewart. Algonquin Books of Chapel Hill, 2009 ($18.95)
- ➜ **The End of the Long Summer: Why We Must Remake Our Civilization to Survive on a Volatile Earth**
  by Dianne Dumanoski. Crown, 2009 ($24.95)
- ➜ **Wetware: A Computer in Every Living Cell**
  by Dennis Bray. Yale University Press, 2009 ($28)
- ➜ **One Hundred Essential Things You Didn't Know You Didn't Know: Math Explains Your World**
  by John D. Barrow. W. W. Norton, 2009 ($25.95)
- ➜ **The Fallen Sky: An Intimate History of Shooting Stars**
  by Christopher Cokinos. Tarcher/Penguin, 2009 ($27.95)
- ➜ **Greenhouse of the Dinosaurs: Evolution, Extinction, and the Future of Our Planet**
  by Donald R. Prothero. Columbia University Press, 2009 ($29.50)
- ➜ **Why Evolution Works (and Creationism Fails)**
  by Matt Young and Paul K. Strode. Rutgers University Press, 2009 ($21.95)
- ➜ **Anatomy of a Beast: Obsession and Myth on the Trail of Bigfoot**
  by Michael McLeod. University of California Press, 2009 ($24.95)
- ➜ **On the Origin of Stories: Evolution, Cognition and Fiction**
  by Brian Boyd. Belknap Press of Harvard University Press, 2009 ($35)

FOLKS WE FOLLOW ON TWITTER

carlzimmer, science writer Carl Zimmer

phylogenomics, evolutionary biologist Jonathan Eisen of the University of California, Davis

seanmcarroll, theoretical physicist Sean Carroll of the California Institute of Technology

RebeccaSkloot, science writer Rebecca Skloot

Astro_Mike, NASA astronaut Mike Massimino

BadAstronomer, astronomer and writer Phil Plait

Carl Zimmer

COURTESY OF DAVID MALIN AND PHAIDON PRESS (*nebula*); COURTESY OF BEN STECHSHULTE (*Zimmer*)

Q *How do marine mammals avoid **freezing to death**? Do they ever feel cold?*

—"Disputatore" via Twitter

D. Ann Pabst, a marine zoologist at the University of North Carolina Wilmington, bundles up a reply (as told to Coco Ballantyne):

Marine mammals maintain a warm core temperature in frigid water with two broad types of responses: behavioral and physiological. A typical behavioral response is migration—in the winter, for instance, pregnant right whales migrate from waters off Canada and New England to the warmer coastal waters of Georgia and Florida to birth their young. Physiological adaptations, on the other hand, include having a large body size, as most marine mammals do, which means a relatively low ratio of surface area to volume. (As size increases in a three-dimensional object, the object's volume grows at a faster rate than does its surface area.) By having a small area of skin, across which heat is exchanged with the environment, as compared with a large volume of heat-generating body tissue, big mammals can retain their heat more effectively.

Marine mammals also have excellent insulation in the form of fur or blubber, or both. The sea otter has the densest hair of any mammal known: 130,000 hairs per square centimeter of skin, by one count. Fur insulates most efficiently when it is dry because it traps still air, an excellent insulator, against the skin surface. Water, in contrast, is highly conductive; it removes heat from the body 25 times faster than air at the same temperature. The otter's fur is so dense that it can trap a layer of air at the skin surface even when the animal is submerged.

Mammals that spend most or all of their life in water rely on blubber—a specialized layer of the skin containing fat as well as the proteins collagen and elastin—which provides, among other things, insulation and energy storage much as human fat does. The amount of blubber varies from one animal to the next. Newborn harbor porpoises pack the most; some 43 percent of their total body mass is blubber.

In some circumstances, marine mammals suffering from poor nutrition or health might have trouble maintaining a healthy blubber supply, both in terms of quantity and quality. These animals may ultimately die from exposure to extreme temperatures. Alternatively, if they find themselves displaced from their natural habitats, they might succumb under the strain of conditions to which they are not suited.

The skin of marine mammals is innervated with temperature-sensing nerve cells just as is the skin of any mammal. These specialized creatures certainly have the ability to sense temperature, and they clearly respond to temperature stimuli, but how that translates into what they feel—whether they experience discomfort, for example—is a difficult question to answer.

SEA OTTERS, Alaska

PATRICK ENDRES *Getty Images*

Q *How does **bathwater** well below the boiling point give off steam?*

Herman Merte, a professor emeritus of mechanical engineering at the University of Michigan at Ann Arbor, explains:

What one sees drifting above a hot bath—often called "steam"—is in fact tiny drops of liquid water that have coalesced out of the gaseous mixture of air and water vapor above the fluid's surface. The vapor, itself an invisible gas, arises from evaporation, whereby water molecules escape from a liquid. Evaporation is a slower process than boiling but is accelerated when water heats up (gaining increased energy).

The conditions under which invisible water vapor condenses into visible mist depend on the ambient temperature and the amount of water vapor in the air. Compared with cold air, warm air can hold more water vapor before becoming so saturated that condensation occurs. This property explains why a bath—or a cup of tea—emits more visible steam on a cold winter morning than on a hot summer afternoon. ■

HAVE A QUESTION?... *Send it to experts@SciAm.com or go to* **www.ScientificAmerican.com/asktheexperts**

your own perfect world: priceless

Your World MasterCard® comes with rewards, offers and perks that matter to you. Whether it's tee time reservations at premier golf courses or preferred seats at the big game, you decide what's in your perfect world. Offers may vary. Go to priceless.com/world and register for more details.

WORLD MASTERCARD®

MasterCard