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New Ways to Beat Malaria

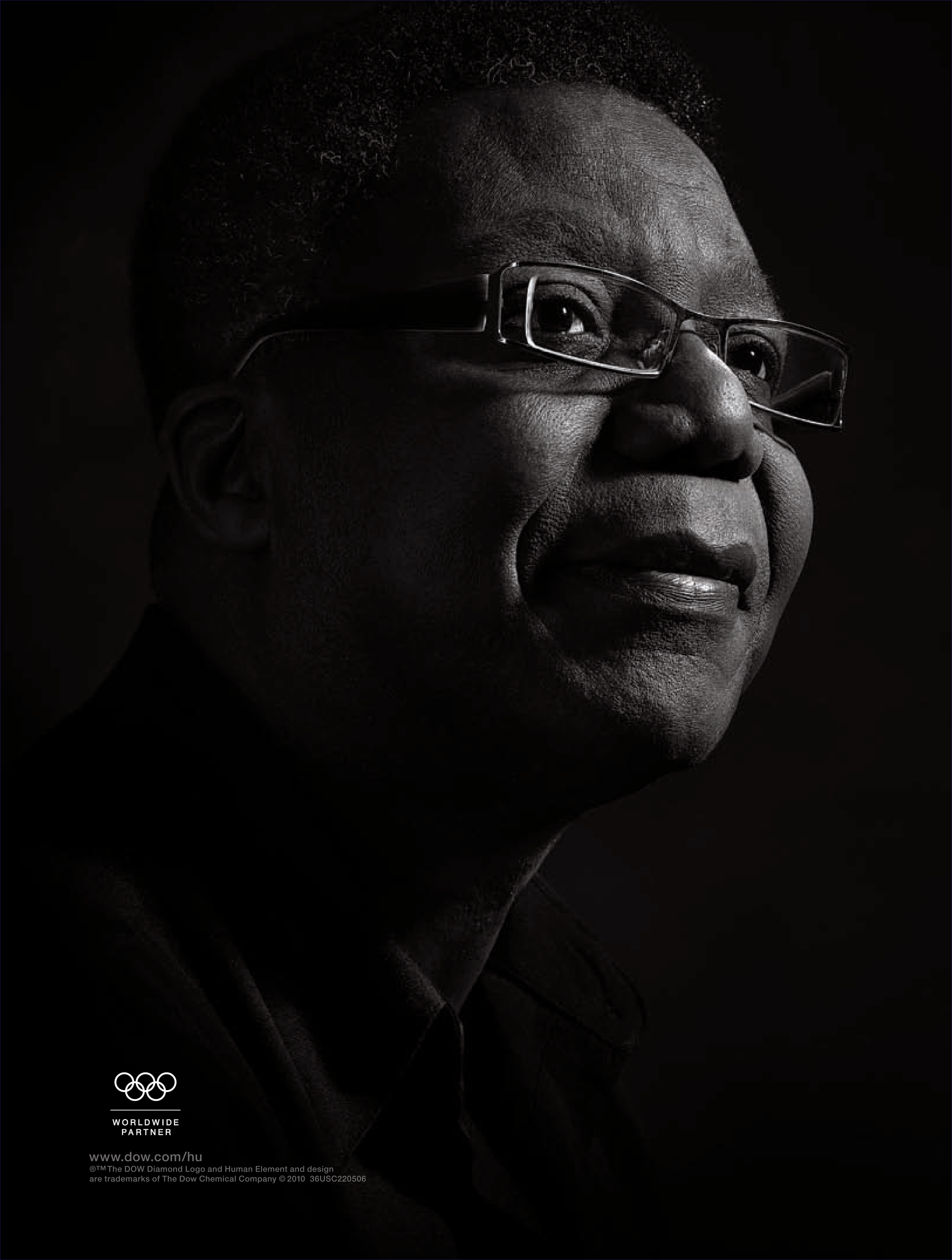
Neuroscience
Brain Control with Light

Climate Critic
What Science Gets Wrong

Energy
How to Build the Supergrid

Hidden Worlds of Dark Matter

An entire universe may be interwoven silently with our own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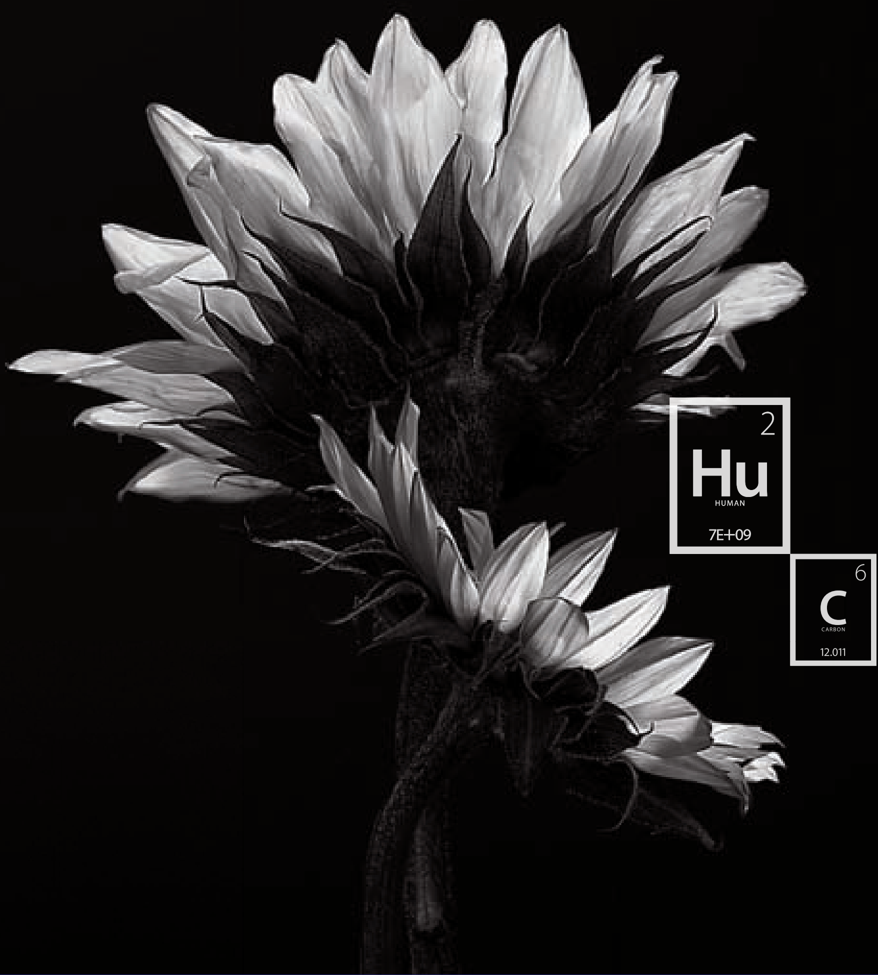


NOT
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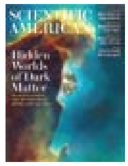
YESTERDAY.

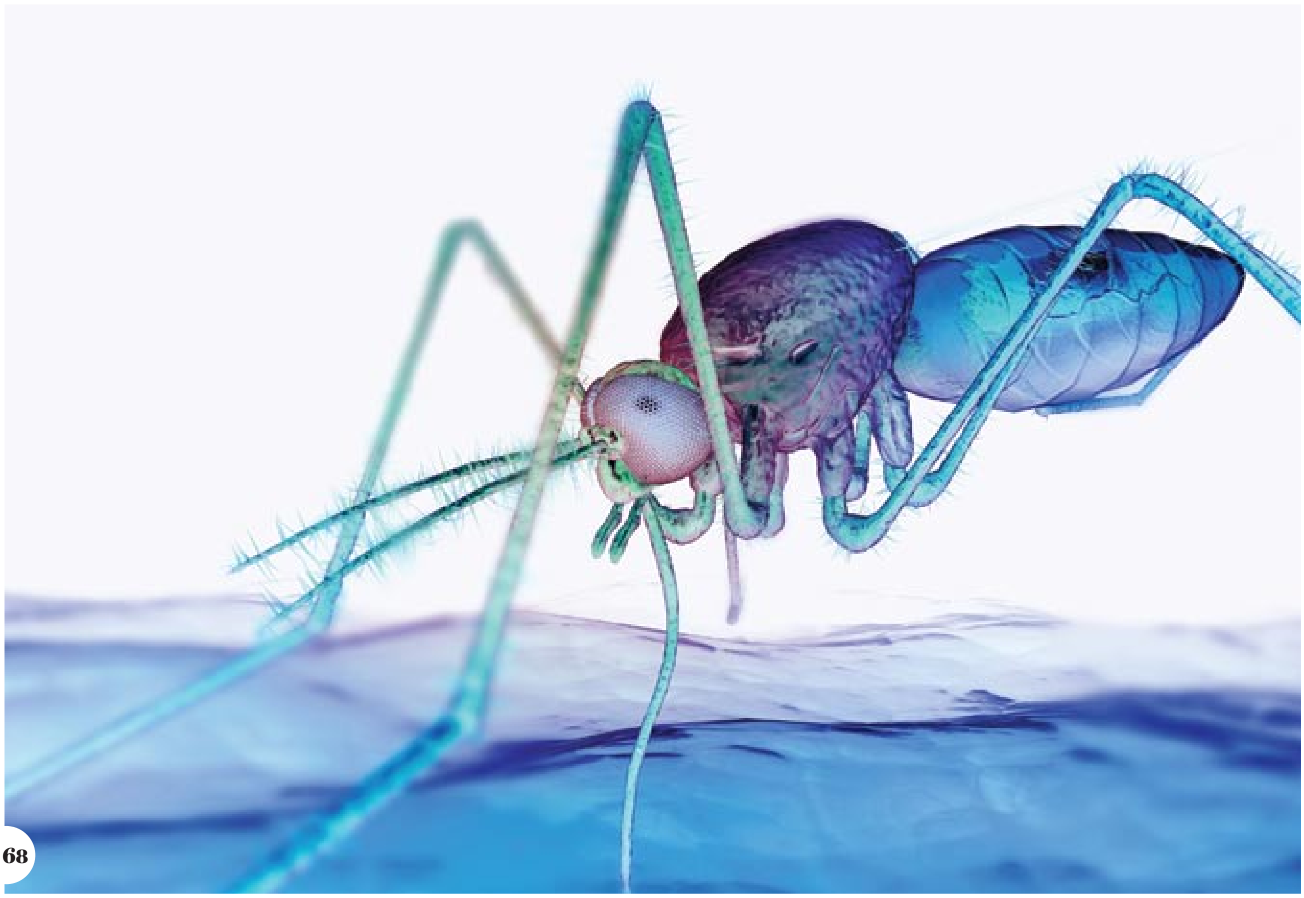
SCIENTIFIC AMERICAN

November 2010 Volume 303, Number 5

ON THE COVER



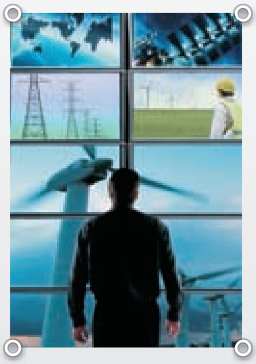
The famous Hubble Space Telescope image of the "Pillars of Creation" in the Eagle Nebula, superposed on an image of Earth, evokes the idea of the invisible world of dark matter and the forces it exerts on our own. Image by Kenn Brown, Mondolithic Studios.



FEATURES

PHOTO RESEARCHERS, INC. *(mosquito)*; JEFF HESTER AND PAUL SCOWEN *University of Arizona* AND NASA/ESA *(Eagle Nebula)*


A GRID THAT'S MORE THAN SMART.



LOCKHEED MARTIN

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SCIENTIFIC AMERICAN

DEPARTMENTS

ON THE WEB

The 2010 Nobel Prizes
Learn all about the achievements that netted the latest crop of laureates the most prestigious prize in science.
Go to www.ScientificAmerican.com/nov2010

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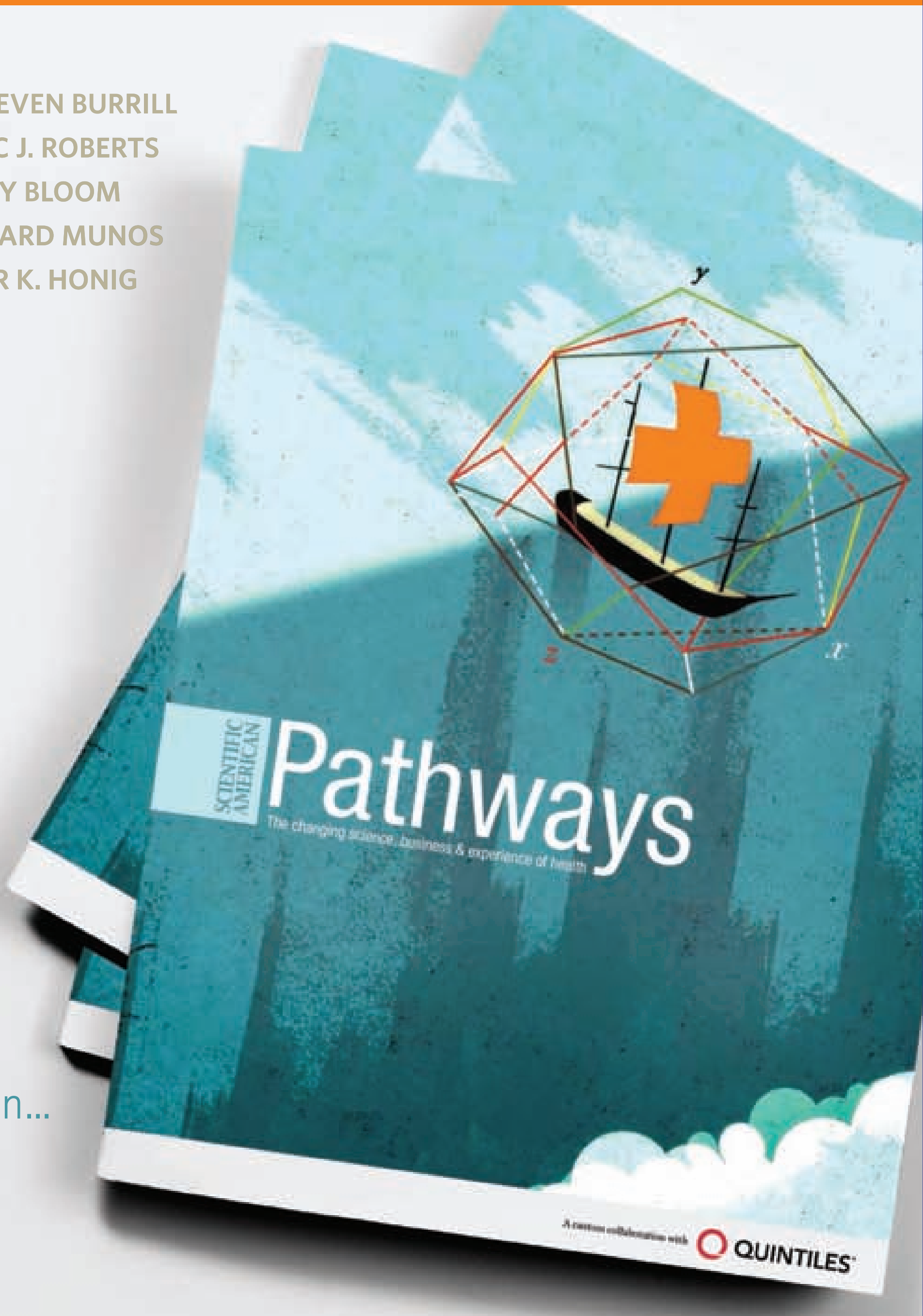

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Has the post-genome world delivered on its promises?

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Join the conversation at www.sa-pathways.com

Mariette DiChristina is editor in chief of *Scientific American.*

Teachable Moment

This page often focuses on the fascinating science featured inside the magazine, but this month I also want to tell you about what we are doing for science outside of our pages.

As a *Scientific American* reader, you are most likely concerned about the sliding performance of U.S. students in science and math. Fostering learning in general is important, of course. (For more on that, see "Hearing the Music, Honing the Mind," Science Agenda, on page 16.) But as President Barack Obama put it in September: "Our nation's success depends on strengthening America's role as the engine of discovery and innovation."

Toward that end, Nature Publishing Group (NPG), *Scientific American*'s parent company, has joined Change the Equation, part of the White House's Educate to Innovate efforts to boost teaching in science, technology, engineering and math (STEM). NPG's Bridge to Science activities include Scitable learning guides, teacher training, and development of a model for understanding science education's return on investment. And in early 2011 look for these programs from *Scientific American:*

BRING SCIENCE HOME. As a mom of two school-age daughters who think science is cool, I know the vital role parents play in cultivating a love of the subject. So each day for a month www.ScientificAmerican.com will offer simple experiments that parents and kids can do together at home.

Arno Penzias (Nobel Prize in Physics, 1978, *left*) and **George Smoot** (Nobel Prize in Physics, 2006, *right*) with DiChristina at Lindau in Germany.

CITIZEN SCIENCE. We plan a digital platform, including a Web site page and apps, for parents and kids to learn about and participate in ongoing scientific research.

1,000 SCIENTISTS IN 1,000 DAYS. We will recruit researchers to volunteer time in the classroom or to participate in activities such as National Lab Day.

A different kind of instruction takes place at the Lindau Nobel Laureate Meetings in Germany, but it, too, has a profound effect on the future of science. Laureates share wisdom with young scientists in talks and casual conversation. I blogged from the 60th anniversary meeting, and now you can see more in videos on www.ScientificAmerican.com.

Last, this issue itself is rife with mind-expanding opportunities for students, scientists and nonscientists alike. Just to name two, see "Dark Worlds," by Jonathan Feng and Mark Trodden, on page 38, for an armchair journey into the invisible universe. And "Climate Heretic," by Michael D. Lemonick, offers a challenging but important lesson about keeping lines of communication—and minds—open while discussing climate science; turn to page 78. SA

C. FLEMMING *Nobel Laureate Meetings*

Illustration by Nick Higgins

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July 2010

DIRTY HYBRIDS

"The Dirty Truth about Plug-in Hybrids," by Michael Moyer, failed to present an accurate and complete picture of the environmental benefits of plug-in and all-electric vehicles. The "regions" that the article cites are subject to significant local variation, especially for communities where increased use of these vehicles might be targeted by local planners. For example, Virginia, which is lumped in with the rest of the Southeast, actually has an electricity production profile much closer to the Mid-Atlantic. Because more than one million folks in the state live within 30 miles of the nation's capital, increased use of all-electric vehicles would give a reduction in emissions from electrics, not an increase. But even plug-in hybrids would likely decrease local ozone levels, which has been among the most elusive of the targets of the Clean Air Act ever since the act was passed.

All-electrics also do not use oil or coolants. Depending on the model, they may not use brake fluid, either. All this would bring additional local and national environmental benefits.

R. Steven Brown
Executive director
Environmental Council of the States
Washington, D.C.

Is there a second "dirty truth" about plug-in cars? With a switch to electric motors, energy now delivered over the "gas station grid" would be delivered over the electric power grid instead. The increase in capacity required by such a change would not come cheaply.

Disaster preparedness and recovery also need to be considered. Before a hurricane, the power grid will have to be large enough to handle a surge as people charge up their cars in anticipation of losing power. Further, because highways often suffer less damage than power lines in a disaster, gas stations can reopen relatively quickly if they have generators to power their pumps. Plug-in cars cannot be refueled until the electric power grid is restored. Switching to electric cars means putting all our eggs in one basket instead of relying on two largely separate grids.

Although plug-in cars and hybrids may well be part of a greener future, I suspect that driving less—reining in suburban sprawl and promoting mass transit—will be key to bringing transportation-based carbon emissions under control.

Stephen J. Schnably
Coral Gables, Fla.

> **"Children learn about the world much as scientists do—smashing things to smithereens."**
> MICHAEL JACOB *OAKLAND, CALIF.*

WAR OF THE MACHINES

P. W. Singer's "War of the Machines" reminded me of the 1967 *Star Trek* episode "A Taste of Armageddon." In this show the *Enterprise* has encountered two planets at war, although there is no evidence of death, maiming, destruction, fire, and so on. Turns out the two planets have been waging their war by computer. The computers designate certain areas "hit," but there is no resulting physical damage to the environment. The people in "hit" areas have to report to a "disintegration center" for voluntary suicide.

Captain Kirk's solution is to blow up the war computers on one of the planets because, he says, "Death, destruction, disease, horror. That's what war is all about … that's what makes it a thing to be avoided. You've made it neat and painless. So neat and painless, you've had no reason to stop it.… I've given you back the horrors of war … you have a real war on your hands. You can either wage it with real weapons, or you might consider an alternative.… Make peace."

Although Singer's article does not go this far, it seems a not unreasonable step from war by robots to war by computers. A reviewer of the *Star Trek* episode quoted General Robert E. Lee: "It is well that war is so terrible, or we should grow too fond of it." I am not fond of war. Would that robots would negotiate peace.

Lila Porterfield
Clarkesville, Ga.

NUCLEAR SQUARE-OFFS

In "No Country Is an Island" [Critical Mass], Lawrence M. Krauss describes the probable apocalyptic effects of a postulated nuclear war between India and Pakistan. After tensions escalated in the late 1990s, the two countries set up a "hotline" and various dialogues aimed at avoiding catastrophe. And despite much mutual animosity, neither India nor Pakistan denies each other the right to exist, in principle and a priori.

Yet many do not appreciate the far greater threat now looming between Israel and Iran. Israel is believed to have hundreds of warheads, with second-strike capability. Moreover, it faces explicit existential threats from Iran and other extremist entities, which are edging closer to nuclear capability. Alone of all peoples, those of Israel have faced attempted extermination in recent history and believe themselves to be under a renewed threat. There exists no logical route whereby dialogue or hotlines could be set up between two enemies in a conflict where one side refuses point-blank to recognize the other's right to exist per se. Nor would Israel, if faced with certain genocide, have any reason not to take the rest of humanity with it to the funeral pyre.

Whereas there are many reasons to dislike Israel's obdurate and often ham-fisted foreign policy, the wider interests of humankind are ill served by demands for Israel to be isolated or removed from the planet.

Michael Martin-Smith
Hull, England

TIMOTHY ARCHIBALD

HOW BABIES REALLY THINK

In the Key Concepts for Alison Gopnik's "How Babies Think," the wording and perspective are not quite correct: "Children learn about the world much as scientists do—in effect, conducting experiments, analyzing statistics and forming theories to account for their observations." I believe you meant to say: "Children learn about the world much as scientists do—smashing things to smithereens, staring in wonder at the results and then breaking out in giggles."

Michael Jacob
Oakland, Calif.

CLARIFICATIONS

In Michael Shermer's "When Scientists Sin" [Skeptic], the quote attributed to David Goodstein was actually Goodstein quoting from the "Federal Research Misconduct Policy," published in the *Federal Register* in 2000.

Some readers objected that the analysis in Michael Moyer's "The Dirty Truth about Plug-In Hybrids" included no renewable power sources. The article was based on a study of what effects a fleet of plug-in vehicles would have on regional power generation. It examined the difference between the status quo and a scenario where many vehicles drew energy from the grid in the years 2020 and 2030. It found that the additional power would come from on-demand sources, which are now mostly fossil-fuel-based. In California, for example, 99 percent would have to come from natural gas (barring significant additions to the state's portfolio of renewables) even though natural gas is not the main source of that state's total energy consumption.

LETTERS TO THE EDITOR

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Letters may be edited for length and clarity. We regret that we cannot answer each one. Post a comment on any article at ScientificAmerican.com/nov2010

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WENDY McMURDO

Hearing the Music, Honing the Mind

Music produces profound and lasting changes in the brain. Schools should add classes, not cut them

Nearly 20 years ago a small study advanced the notion that listening to Mozart's *Sonata for Two Pianos in D Major* could boost mental functioning. It was not long before trademarked "Mozart effect" products appealed to neurotic parents aiming to put toddlers on the fast track to the Ivy League. Georgia's governor even proposed giving every newborn there a classical CD or cassette.

The evidence for Mozart therapy turned out to be flimsy, perhaps nonexistent, although the original study never claimed anything more than a temporary and limited effect. In recent years, however, neuroscientists have examined the benefits of a concerted effort to study and practice music, as opposed to playing a Mozart CD or a computer-based "brain fitness" game once in a while. Advanced monitoring techniques have enabled scientists to see what happens inside your head when you listen to your mother and actually practice the violin for an hour every afternoon. And they have found that music lessons can produce profound and lasting changes that enhance the general ability to learn. These results should disabuse public officials of the idea that music classes are a mere frill, ripe for discarding in the budget crises that constantly beset public schools.

Studies have shown that assiduous instrument training from an early age can help the brain to process sounds better, making it easier to stay focused when absorbing other subjects, from literature to tensor calculus. The musically adept are better able to concentrate on a biology lesson despite the racket in the classroom or, a few years later, to finish a call with a client when a colleague in the next cubicle starts screaming at an underling. They can attend to several things at once in the mental scratch pad called working memory, an essential skill in this era of multitasking.

Discerning subtleties in pitch and timing can also help children or adults in learning a new language. The current craze for high school Mandarin classes furnishes an ideal example. The difference between *mā* (a high, level tone) and *mà* (falling tone) represents the difference between "mother" and "scold." Musicians, studies show, are better than nonmusicians at picking out easily when your *mā* is *mà*ing you to practice. These skills may also help the learning disabled improve speech comprehension.

Sadly, fewer schools are giving students an opportunity to learn an instrument. In *Nature Reviews Neuroscience* this summer, Nina Kraus of Northwestern University and Bharath Chandrasekaran of the University of Texas at Austin, who research how music affects the brain, point to a disturbing trend of a decline of music education as part of the standard curriculum. A report by the advocacy organization Music for All Foundation found that from 1999 to 2004 the number of students taking music programs in California public schools dropped by 50 percent.

Research of our brains on music leads to the conclusion that music education needs to be preserved—and revamped, as needed, when further insights demonstrate, say, how the concentration mustered to play the clarinet or the oboe can help a problem student focus better in math class. The main reason for playing an instrument, of course, will always be the sheer joy of blowing a horn or banging out chords. But we should also be working to incorporate into the curriculum our new knowledge of music's beneficial effect on the developing brain. Sustained involvement with an instrument from an early age is an achievable goal even with tight budgets. Music is not just an "extra." SA

COMMENT ON THIS ARTICLE www.ScientificAmerican.com/nov2010

Commentary on science in the news from the experts

Scott O. Lilienfeld is a clinical psychologist and professor of psychology at Emory University. His specialties include evidence-based practices in psychology and the challenges posed by pseudoscience to clinical psychology.

Fudge Factor

Did Marc Hauser know what he was doing?

As of this writing, the precise nature of Marc Hauser's transgressions remains murky. Hauser is Harvard's superstar primate psychologist—and, perhaps ironically, an expert on the evolution of morality—whom the university recently found guilty of eight counts of scientific misconduct. Harvard has kept mum about the details, but a former lab assistant alleged that when Hauser looked at videotapes of rhesus monkeys, in an experiment on their capacity to learn sound patterns, he noted behavior that other people in the lab couldn't see, in a way that consistently favored his hypothesis. When confronted with these discrepancies, the assistant says, Hauser asserted imperiously that his interpretation was right and the others' wrong.

Hauser has admitted to committing "significant mistakes." In observing the reactions of my colleagues to Hauser's shocking comeuppance, I have been surprised at how many assume reflexively that his misbehavior *must* have been deliberate. For example, University of Maryland physicist Robert L. Park wrote in a Web column that Hauser "fudged his experiments." I don't think we can be so sure. It's entirely possible that Hauser was swayed by "confirmation bias"—the tendency to look for and perceive evidence consistent with our hypotheses and to deny, dismiss or distort evidence that is not.

The past few decades of research in cognitive, social and clinical psychology suggest that confirmation bias may be far more common than most of us realize. Even the best and the brightest scientists can be swayed by it, especially when they are deeply invested in their own hypotheses and the data are ambiguous. A baseball manager doesn't argue with the umpire when the call is clear-cut—only when it is close.

Scholars in the behavioral sciences, including psychology and animal behavior, may be especially prone to bias. They often make close calls about data that are open to many interpretations. Last year, for instance, Belgian neurologist Steven Laureys insisted that a comatose man could communicate through a keyboard, even after controlled tests failed to find evidence. Climate researchers trying to surmise past temperature patterns by using proxy data are also engaged in a "particularly challenging exercise because the data are incredibly messy," says David J. Hand, a statistician at Imperial College London.

Two factors make combating confirmation bias an uphill battle. For one, data show that eminent scientists tend to be more arrogant and confident than other scientists. As a consequence, they may be especially vulnerable to confirmation bias and to wrong-headed conclusions, unless they are perpetually vigilant. Second, the mounting pressure on scholars to conduct single-hypothesis-driven research programs supported by huge federal grants is a recipe for trouble. Many scientists are highly motivated to disregard or selectively reinterpret negative results that could doom their careers. Yet when members of the scientific community see themselves as invulnerable to error, they impede progress and damage the reputation of science in the public eye. The very edifice of science hinges on the willingness of investigators to entertain the possibility that they might be wrong.

The best antidote to fooling ourselves is adhering closely to scientific methods. Indeed, history teaches us that science is not a monolithic truth-gathering method but rather a motley assortment of tools designed to safeguard us against bias. In the behavioral sciences, such procedures as control groups, blinded designs and independent coding of data are essential methodological bulwarks against bias. They minimize the odds that our hypotheses will mislead us into seeing things that are not there and blind us from seeing things that are. As astronomer Carl Sagan and his wife and co-author Ann Druyan noted, science is like a little voice in our heads that says, "You might be mistaken. You've been wrong before." Good scientists are not immune from confirmation bias. They are aware of it and avail themselves of procedural safeguards against its pernicious effects. SA

COMMENT ON THIS ARTICLE www.ScientificAmerican.com/nov2010

Illustration by Christian Northeast

It's hefty. It's gold.
It's a great price. What a country.

Shown larger than actual size of 27 mm in diameter

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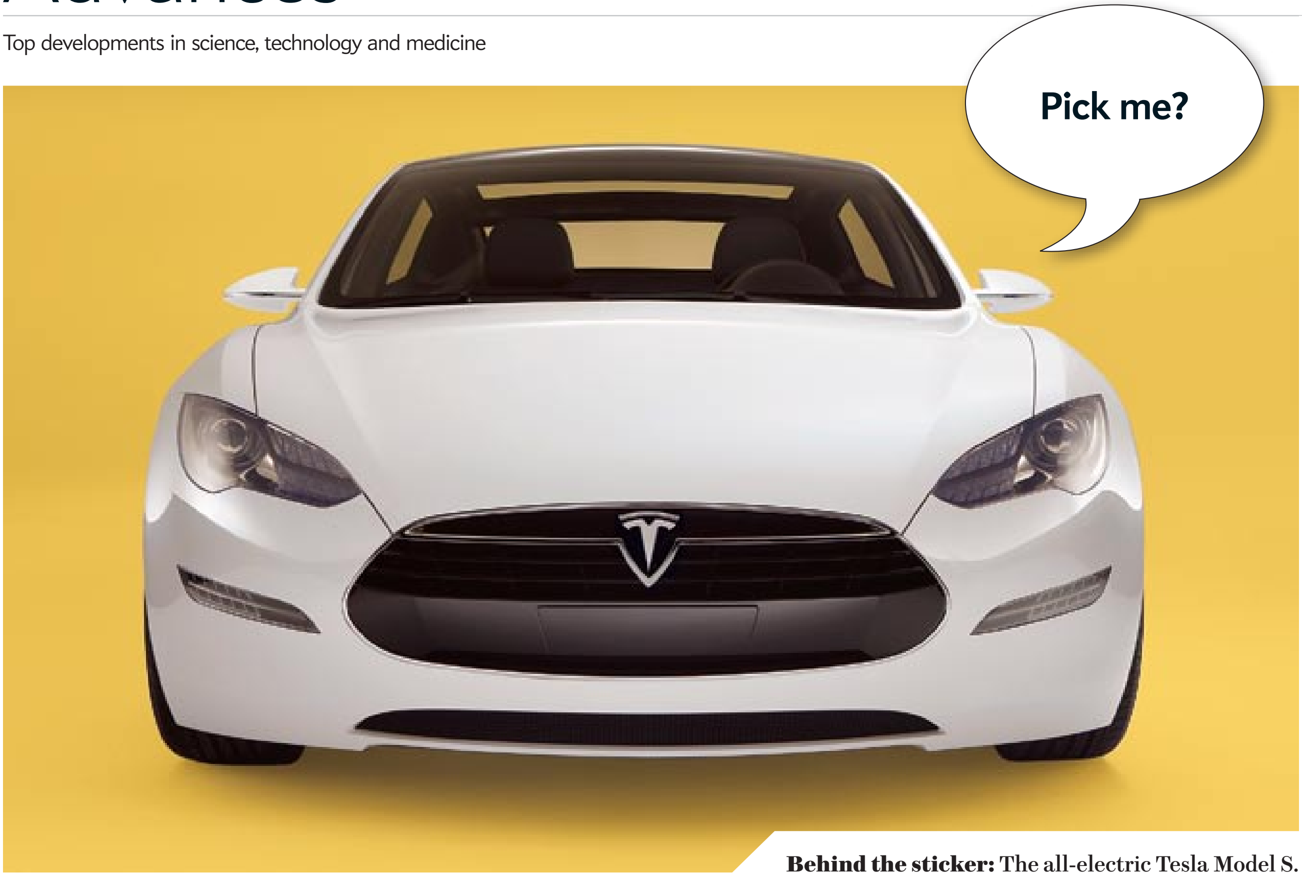


Behind the sticker: The all-electric Tesla Model S.

Energy Efficiency

Window Shopping for Electric Cars

How consumers can compare plug-in vehicles with their gasoline-powered cousins

The U.S. Environmental Protection Agency has an electric car problem. Federal law requires that new cars be sold with a label that includes the vehicle's fuel efficiency as measured in miles per gallon. Yet beginning next year, gallons will start to give way to watts, prompting the EPA to redesign their window stickers.

In an attempt to smooth the transition, the EPA has adopted a new unit called miles per gallon of gasoline-equivalent (MPGe). Basically, it is a conversion factor that measures the electricity required to run the car (usually expressed in kilowatt-hours) in another unit of energy: gallons of gasoline. An all-electric vehicle should get somewhere north of 100 MPGe, even though it will never use a drop of gas.

The new figure doesn't clear up the apples-to-oranges problem, however. Consumers tend to use the old-fashioned MPG metric as shorthand for many things—including how green the car is and the cost of driving—that don't jibe neatly with MPGe. For example, the carbon footprint of an electric vehicle strongly depends on local electricity sources [see "The Dirty Truth about Plug-in Hybrids," by Michael Moyer; SCIENTIFIC AMERICAN, July].

With so many factors to consider, the EPA created two sticker prototypes. One throws together all the information a consumer could possibly want to know in one place. The other takes the opposite approach. It is dominated by a single letter grade—A+ through D (there are no failures here)—which encapsulates all those factors in one score. Unfortunately, this simple measure would score 88 percent of all vehicles between a B and a C. "You need sufficient resolution to allow customers who say 'I want a minivan' or 'I want a midsize SUV' to meaningfully cross-shop vehicles that are similar," says John M. DeCicco, a senior lecturer at the University of Michigan's School of Natural Resources and Environment. "Letter grades fail on that score."

A closer look at that sticker reveals a more important figure: how much the car will cost to operate compared with the average vehicle. Critically, the EPA adds up five years' worth of driving. "It takes differences that are small and that you might ignore and makes them substantial but not in a misleading way—five years is an amount of time you're likely to spend with your car," says Richard Larrick of Duke University's Fuqua School of Business. Larrick and his colleagues have shown that simply scaling up numbers influences consumer choice. For example, students, offered an option of two movie rental plans, were more likely to choose an extended plan when the number of movies in the plan was tallied by the year, not the month. Similarly, the EPA stickers should have the effect of promoting vehicles that are less expensive to operate, like electric cars. Good-bye gallons, and good riddance. *—Michael Moyer*

COURTESY OF TESLA MOTORS

COMMENT ON THESE ARTICLES www.ScientificAmerican.com/nov2010

Influenza

Finding a Killer's Achilles' Heel

The 1918 flu genome may help fight future outbreaks

It has been five years since a team of scientists resurrected the 1918 influenza virus from the lungs of a long-frozen victim. At the time, the Jurassic Park–like feat was both widely celebrated and sharply criticized. Opponents worried about the risk of an accidental (or intentional) release of the revived killer, which claimed between 50 million and 100 million lives in about 15 months and has been dubbed the worst plague in human history. Proponents insisted that the insights gained from a fully reconstructed virus would be instrumental in fighting the next pandemic.

A paper published in the November issue of the journal *Microbe* cites a potential new drug target, among other findings, as evidence that the risk was not taken in vain. Terrence Tumpey of the Centers for Disease Control and Prevention and his colleagues have closed in on a protein called PB1 that enables the virus to copy itself. When researchers substituted the PB1 protein in a normal flu virus with the 1918 version of that same protein, the normal virus morphed into a superkiller: it replicated and spread through its rodent host eight times faster, killing more mice as a result. It turns out that all 20th-century pandemic viruses, among them the 2009 swine flu, have avian flu PB1 genes. Most seasonal flu viruses have human flu PB1 genes.

Scientists are now working to develop new drugs that target PB1. Small molecules that bind to the protein's receptors could prevent the virus from replicating and might greatly reduce virulence. The need for new antiflu drugs is increasingly urgent, as several recent flu strains, including the swine flu, have developed resistance to currently available treatments such as Tamiflu. When combined with the older antivirals, PB1-targeted drugs could drastically reduce the spread of resistance, making the approach of the annual flu season a little less worrisome for everyone.

—Jeneen Interlandi

QUOTABLE

"If you want to get people to believe something really, really stupid, just stick a number on it."

Author Charles Seife in his new book,
Proofiness: The Dark Arts of Mathematical Deception

PHOTO RESEARCHERS, INC. *(flu ward)*; FRANK ZAURITZ *Redux Pictures (Hawking)*

Science in Society

Hawking vs. God

The battle for eternity is fought on *Larry King Live*

Has Stephen Hawking overreached? The publication in September of *The Grand Design,* a book the British physicist co-authored with Leonard Mlodinow of Caltech, raised hackles as some saw it as denying the existence of God based on scientific arguments.

Physics, the book states, can now explain where the universe came from and why the laws of nature are what they are. The universe arose "from nothing" courtesy of the force of gravity, and the laws of nature are an accident of the particular slice of universe we happen to inhabit. "It is possible to answer these questions purely within the realm of science, and without invoking any divine beings," the authors wrote. (An adaptation of the book appeared in the October *Scientific American.*)

Theologians were incensed, saying that the existence of a creator is by definition outside science's domain. Some, including Reverend Robert E. Barron, a theology professor at the University of St. Mary of the Lake near Chicago, also complained that the book is philosophically naive. For example, Barron says, the existence of the laws that caused the appearance of the universe must have predated the big bang. "The 'laws of gravity' seem to be something other than nothing."

As the media frenzy spread from bloggers and tweeters to prime-time television, the authors countered that they never meant to claim that science proved that there is no God. "God may exist," Hawking told CNN's Larry King, adding, "but science can explain the universe without the need for a creator."

"We don't say we've proved that God doesn't exist." Mlodinow says. "We don't even say we've proved that God hasn't created the universe." As for the laws of physics, he says, some may choose to call those God. "If you think that God is the embodiment of quantum theory, that's fine."

On the other hand, the scientific account of the origin of the universe may not be as complete as Hawking represents. It is based on string theory and on an even more mysterious—and just as untested—version of it called M-theory, as well as on Hawking's own cosmological thoughts. "The theories that Hawking and Mlodinow use to base their arguments on have as much empirical evidence as God," wrote cosmologist Marcelo Gleiser on an NPR.org blog. Moreover, Gleiser added, "because we don't have instruments capable of measuring all of nature, we cannot ever be certain that we have a final theory."

Stanford University theoretical physicist Leonard Susskind, whose 2006 book *The Cosmic Landscape* also questioned the need for a creator in the account of creation, agrees. "Not all physicists think the quest for a complete theory is over," he says. "I don't think we are anywhere near it." Whether or not there is a God, his or her handiwork is certainly not easy to understand.

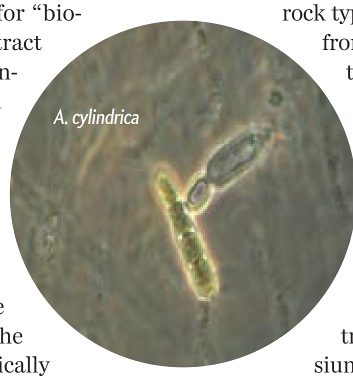
—Davide Castelvecchi

Astrobiology

Bugs in Space

Microscopic miners could help humans thrive on other planets

Mining companies use microbes to recover metals such as gold, copper and uranium. Now researchers suggest bacteria could be enlisted for "biomining" in space, to extract oxygen, nutrients and minerals from the moon and Mars for use by future colonists.



COURTESY OF KAREN OLSSON-FRANCIS

More than a quarter of the world's copper is harvested from ores using microorganisms, which separate the desired material from the rock to which it is chemically bound. Geomicrobiologists Karen Olsson-Francis and Charles S. Cockell of the Open University in Milton Keynes, England, reasoned that microbes could be drafted for use on other planets as well. "It would be a way of living off the land in space," Cockell says.

The researchers experimented with a variety of cyanobacteria, often known as blue-green algae, on analogues of lunar and Martian regolith (loose surface rock). These photosynthetic bacteria have adapted to live in some of the most extreme environments on Earth, from the cold, hyperarid Antarctic McMurdo Dry Valleys to the hot, dry Atacama Desert in Chile, suggesting they might be capable of surviving the rigors of outer space.

To test the microbes' mettle, Olsson-Francis and Cockell launched several species 300 kilometers into low Earth orbit and exposed them in succession to vacuum, cold, heat and radiation. The bacteria were then grown with water on different rock types, including anorthosite from South Africa (analogous to lunar highland regolith) and basalt from an Icelandic volcano (similar to lunar and Martian regolith). The scientists detail their findings in a recent issue of *Planetary and Space Science.*

The microbes all extracted calcium, iron, potassium, magnesium, nickel, sodium, zinc and copper from the rocks. But *Anabaena cylindrica,* which is used as a fertilizer in rice paddies, grew the fastest, extracted the most elements, and could withstand both lunar and Martian conditions, potentially making it the best cyanobacterium to use in space.

Using microbes for biomining has many advantages, Cockell says. Although chemicals can extract minerals from extraterrestrial regolith, microbes catalyze this extraction at much faster rates. Purely chemical systems also require large amounts of energy, which early extraterrestrial outposts will likely lack. "We will not be able to colonize the moon or Mars without development of cyanobacterial biotechnologies," says astrobiologist Igor Brown, who did not take part in the study. Space colonization is not just for humans anymore. *—Charles Q. Choi*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It seems like we've been waiting a long time for the electric car, but maybe the electric car was waiting for this. Introducing the WattStation from GE. Learn more about electric vehicle charging at: ecomagination.com/wattstation.
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COURTESY OF DISNEY

Computer Graphics

Fit for a Princess

How the laws of physics helped style Disney's newest star

When the animators at Walt Disney Studios first dressed up Rapunzel, the long-haired star of the forthcoming movie *Tangled,* and had her spin around in front of a mirror, she froze mid-turn, and the folds in her multilayered purple dress turned stiff as shells. The filmmakers had run up against a challenge that has long plagued sartorially inclined animators.

"From very early on, we knew we wanted to get more elaborate clothing than had been done so far in [computer graphics]," says Rasmus Tamstorf, a senior research scientist at Walt Disney Animation Studios Research. "But when a character wearing free-flowing, multiple layers of clothing moves, it can create a lot of contact between the different layers, especially in the way they slide on top of one another. And that can cause problems."

Rather than scaling back his sartorial ambitions or deploying armies of animators to illustrate complicated scenes by hand—solutions traditionally employed by ambitious animators to get around the challenge—Tamstorf and his team decided it was time to find a new way to solve the problem.

They got in touch with a computer scientist who has made a specialty of studying how materials respond to collisions. Eitan Grinspun of Columbia University's school of engineering had become fascinated with this area of research in 2002, when he filmed a cowboy hat hitting and bouncing off the floor. He studied the film for hours in slow motion and found the simplest equation that expressed the interaction of variables affecting the hat's bounce. These included friction, the hat's "bendiness" (elasticity) and the momentum with which it hit the ground. Then he translated that equation into simple computer code that could be used to predict the movement of any "flexy, bendy material," including rubber, fabric, even sheets of metal.

But depicting the movement of Rapunzel's fancy gown posed a larger challenge. With multilayered clothing, a computer must account for potentially thousands of collisions at once. When an animation program becomes overwhelmed with data, it resorts to a "fail-safe," a backup program that prevents the layers of fabric from creating new collisions. Previous fail-safes continued to move the fabric forward in space but did not allow the layers of material to move relative to one another, creating a rigid, shell-like appearance. After months, Grinspun and Tamstorf's team came up with a solution. They accepted the need for a collision-stopping fail-safe, but theirs allows the layers of fabric to slide against one another, and it accounts for friction, which affects the speed with which the fabric moves. The result is far more lifelike. Now Grinspun has moved on to a new challenge—developing a program that accurately predicts the movement of hair, which collides in even more complex ways than clothing. He expects his solutions to appear in another animated feature next year. —*Adam Piore*

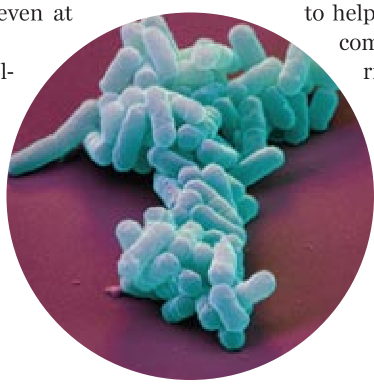
Microbiology

Nice Germs Finish Last

Resistant bacteria help their kin survive antibiotics, but at a cost

The world is full of Good Samaritans; you'll find many of them in your own body. James J. Collins, a biologist at Boston University, has found that small numbers of drug-resistant bacteria help their vulnerable counterparts survive antibiotic onslaughts, even at a cost to themselves.

Collins and his colleagues exposed one culture of *Escherichia coli*—some strains of which colonize the human and animal gut; others of which are notorious for causing disease outbreaks—to increasing amounts of an antibiotic over time. When they periodically analyzed the levels of drug resistance in the colony, they saw something unexpected: although the entire population was thriving in the presence of the drug, only a few individual bacteria were actually resistant. "We were really surprised to see that the levels of resistance of the individual isolates were considerably lower than the population as a whole," explains Collins, who published his results recently in *Nature*. (*Scientific American* is part of Nature Publishing Group.) Further analysis revealed that the resistant mutants were secreting a molecule called indole that thwarts their own growth but helps the rest of the population survive by activating drug-export pumps on the bacterial cell membranes.



Altruists: The discovery that some *E. coli* (*shown*) protect others may lead to smarter, more potent drugs.

The findings could spur scientists to develop better antibiotics. If indole allows pathogenic bacteria to withstand antibiotics, it may be possible to thwart drug resistance by blocking indole signaling with small molecules, Collins says. Alternatively, "the findings suggest the possibility that scientists could one day use indole or an indole-based therapeutic, if proven safe, to help beneficial bacteria outcompete pathogenic bacteria in the urinary tract or intestinal system," says Mark Anderson, chief scientific officer of Emeryville, Calif.–based NovaBay Pharmaceuticals, which develops drugs for antibiotic-resistant infections.

The results may also change the way doctors track infections in their patients. If a bacterial population can become antibiotic-resistant even when only a small number of individuals have the appropriate genetic mutations, doctors who collect and analyze small bacterial specimens from patients may underestimate just how resistant the infection is as a whole, Collins notes. "These unicellular organisms can function as a multicellular organism of sorts," he says. Thus, isolated samples may not be representative of the big picture. *—Melinda Wenner Moyer*

PHOTO RESEARCHERS, INC.

QUOTABLE

"28 percent of the world cannot change anything."

Alexander Bedritsky, Russian president Dmitry Medvedev's top climate change adviser, arguing to replace the Kyoto Protocol with a wider treaty that brings in poorer nations. The question of whether to scrap or extend Kyoto will be taken up in December at the next round of climate talks in Cancún, Mexico.

Buried? Ötzi the Iceman may not have died where hikers found him in 1991.

COURTESY OF SOUTH TYROL MUSEUM OF ARCHAEOLOGY (WWW.ICEMAN.IT)

Archaeology

The Iceman's Last Stand

The story of a famous corpse gets a surprising twist

It is one of the most evocative ancient corpses ever discovered: a 46-year-old man with an arrow wound in his left shoulder, whose body and belongings came to rest in a high mountain pass some 5,000 years ago. Ever since hikers first spotted the remains of Ötzi the Iceman, as he is known, emerging from the melting ice in the Ötztal Alps near the Austrian-Italian border in 1991, scientists have been working to determine how he died and what he was doing in such a remote spot. The leading theory holds that he had fled there and froze to death after being shot with a bow and arrow during a skirmish with members of a rival tribe. A new study challenges this disaster scenario and suggests instead that the Iceman died in a fight in the valley below and was later transported to the lofty locale for a grand ceremonial send-off.

A team of Italian and American researchers reached this conclusion after analyzing the distribution of the Iceman's personal effects, which include a backpack and other items traditionally construed as mountaineering equipment. They reasoned that if he died in or near the place where he was found and had been carrying his possessions when he died, then the melting and freezing cycles should have distributed the artifacts in a random pattern all around his body. In fact, the distribution pattern they found showed two distinct clusters of artifacts, one near some stone slabs, which they interpret as the remnants of a burial platform, and another in the nearby depression where the hikers found the Iceman's body. The study suggests that his body and bulky accoutrements were deposited precisely on the small stone platform and later borne by flowing water to the depression. Furthermore, the unfinished weapons and grass mat that accompanied the Iceman are better explained as grave goods and a funeral shroud than as mountaineering gear. Earlier pollen analyses also indicated a delay between the time of death and burial. Taking this evidence together, the investigators propose that the Iceman passed away at low altitude in the spring and that his clansmen packed his body in ice until late summer, when they carried him up the mountain for a final farewell. Luca Bondioli of the National Museum of Prehistory and Ethnology in Rome and his colleagues described the results of their study in the journal *Antiquity*.

Not everyone is so sure about these conclusions. Klaus Oeggl of the University of Innsbruck in Austria notes that the team has not supplied convincing evidence that the stone slabs represent a burial platform and that subsequent pollen tests have failed to uphold the original signal indicating a late summer burial. He agrees that a ritual of some kind would explain the presence of unfinished artifacts at the site but maintains that the disaster theory remains the best explanation. Still, he remarks, the new study is stimulating because it is the first to discuss the burial hypothesis extensively. *—Kate Wong*

Just the Facts

Getting It Right on Stem Cells

Why hundreds of embryonic stem cell lines aren't enough

This fall funding for embryonic stem cell research once again faces uncertainty. In August a federal district court judge blocked the use of federal funds for any project that would destroy embryos. In September a higher court restored funding temporarily, while it considers an appeal by the Justice Department. We offer a guide to the facts behind the controversy:

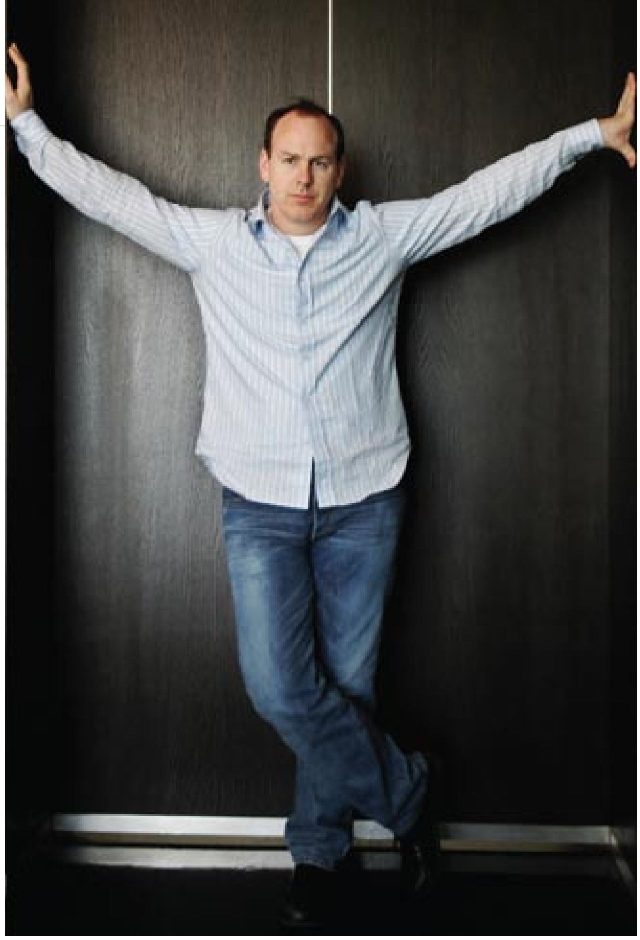
Where do the embryos used for stem cell lines come from?
All stem cell lines come from discarded IVF embryos. Currently there are around 400,000 embryos stored at fertility clinics around the country.

How many stem cell lines are there?
A stem cell line is a family of constantly dividing cells produced from a group of parent cells that were harvested from a single embryo. M. William Lensch, a scientist at the Harvard Stem Cell Institute, estimates there are 800 lines around the world.

Why isn't this enough?
In theory, one stem cell line can supply an infinite number of researchers indefinitely. But despite their omnipotent potential, embryonic stem cells are a finicky lot. Some have a tendency to grow into liver cells, others into blood, and others into nerve, pancreas or heart tissue. Sometimes the differences are caused by known factors, such as embryo age or protein contamination, but more frequently they are not understood. "For some projects, existing lines work very well, but for others, not at all," Lensch says.

Why aren't more unused embryos made into cell lines?
Whereas some 60 percent of infertility patients would like to donate their unused embryos to research, a dearth of funding and an uncertain regulatory environment have muddied the process. "Everything is at a standstill right now," says Elena Gates, director of the IVF tissue bank at the University of California, San Francisco.

—Jeneen Interlandi



Scientist in the Field

Darwin Was a Punk

Evolutionary biologist and musician Greg Graffin explains why there are no good songs about science and how evolution can be a guide to life

PROFILE

NAME:
Greg Graffin

TITLE:
Lead singer, Bad Religion
Lecturer in life sciences and paleontology at U.C.L.A.

LOCATION:
Ithaca, N.Y.
Los Angeles

How are evolution and punk rock related? The idea with both is that you challenge authority, you challenge the dogma. It's a process of collective discovery. It's debate, it's experimentation, and it's verification of claims that might be false.

In your new book,* Anarchy Evolution: Faith, Science and Bad Religion in a World without God, *you talk about the "anarchic exuberance of life." What do you mean by that? The trick is: How do you talk about natural selection without implying the rigidity of law? We use it as almost an active participant, almost like a god. In fact, you could substitute the word "god" for "natural selection" in a lot of evolutionary writings, and you'd think you were listening to a theologian. It's a routine we know doesn't exist, but we teach it anyway: genetic mutation and some active force choose the most favorable one. That simply isn't a complete explanation of what's going on. We need to stop thinking about lawlike behaviors and embrace the surprises.

Was Darwin a punk? He was very straight-laced because of English Victorian culture, but he sure did like to hobnob with the radicals. There are punk fans who kind of stand in the back and never in their lives go slam dancing but love the music and what it represents. Darwin may have been that kind of contemplative and pensive antiauthoritarian.

Are there any good songs about science? No, I don't know of a single one. Most songwriters who have been lucky enough to have their song on the radio or be heard widely don't know anything about science. The best songs have a strong dose of metaphor. Most songs about science don't have that. Like *She Blinded Me with Science.* It's a stupid song, no offense to Thomas Dolby.

How can evolution be a guide to life? When you win the lottery, no one's asking you to justify it. If you have a tragedy, everyone wants to know why. Everybody wants you to justify it. The way you do that, the story or narrative you tell, is your worldview. The fossil record gives me a great deal of comfort in difficult times. It helps me recognize that this current drama going on on the planet is one of a series of episodes. Ultimately, life goes on even after a catastrophe. That gives me comfort. Don't ask me why.

—David Biello

Genomics

To Breed a Better Bird

A quick and cheap way of mapping the turkey genome may lead to more precise livestock farming methods

Geneticists are working hard to grow a tastier, more healthful Thanksgiving bird. Scientists at the U.S. Department of Agriculture have mapped nearly 90 percent of the domestic turkey genome, which could help breeders produce improved meat in greater, cheaper quantities. Within the next three to five years the new map will allow farmers to take blood samples from young birds, extract DNA, and screen it for desirable genes, such as those for high fertility, resistance to disease, reduced fat and greater proportion of white meat. The genome-aided process would be more efficient than natural selection, which farmers practice now and which requires them to wait until turkeys mature to observe these characteristics and select for them.

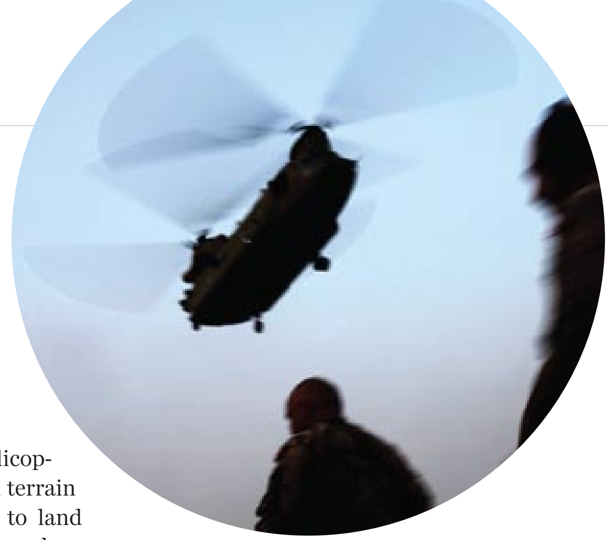
The mapping team was the first to combine two next-generation platforms that allowed for the analysis of short fragments and long strands of DNA simultaneously, saving time and money. The breakthrough heralds genome maps for more farm animals in the future. *—John H. Tucker*

MICHAEL KAPPELER *Getty Images (Graffin)*; ARTHUR MORRIS *Corbis (turkey)*

Military Technology

Laser Tag

Off-the-shelf technology could ward off missile attacks on military helicopters



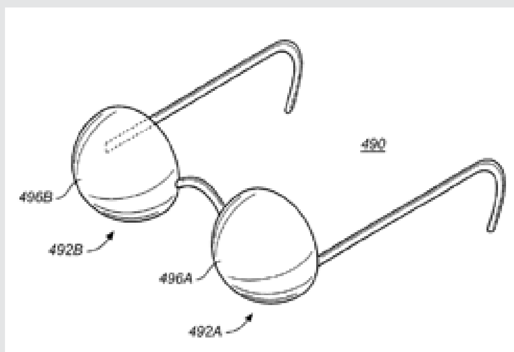
The military relies heavily on helicopters in Afghanistan, where rough terrain can make it hard for airplanes to land and for troops and vehicles to travel on the ground. Unfortunately, the U.S. armed forces' roughly 3,000 helicopters, which fly relatively slow and low to the ground, are easy targets for enemies with shoulder-launched missiles.

Current state-of-the-art missile defenses, built originally for airplanes, cannot withstand the vibrations helicopters generate. But Mohammed N. Islam, a laser and fiber-optics scientist at the University of Michigan at Ann Arbor, and his colleagues are now developing a way to thwart missile attacks with off-the-shelf lasers rugged enough for helicopters. The lasers jam the sensors on the missiles' heat seekers by shining infrared beams at them, buying the helicopters enough time to make a getaway.

The new technology, which Islam plans to commercialize, comes from telecommunications providers, who rely on multiple-wavelength lasers to create lanes for data signals to travel within fiber-optic cables. These "midinfrared supercontinuum lasers" give off a much broader range of wavelengths than typical lasers, ranging from the visible (800 nanometers) to the midinfrared (4.5 microns). "It's a clever way of using lasers that you can essentially buy off the shelf," says laser scientist Anthony M. Johnson of the University of Maryland, Baltimore County, who did not take part in this research.

Helicopters probably face the greatest need for such laser-based protection against missiles, but, Islam says, the technology is potentially applicable to all aircraft. *—Charles Q. Choi*

PATENT WATCH



***When 3-D movies** returned to theaters five years ago with the opening of* Chicken Little, *they came with new specs. The old 3-D glasses that relied on red/cyan lenses went the way of Godzilla. Instead the new eye gear used a variety of more sophisticated methods to bring a sharp, full-color, three-dimensional image to viewers' eyes without limiting the spectrum of colors they could see. Dolby, one of the major players in the 3-D movie market, just received a patent for its glasses, which offers a close-up look at how they work.*

The Dolby glasses (Patent No. 7,784,938) rely on a phenomenon called spectral separation. A projector breaks up each of the three primary colors into multiple spectra and beams two different images—one meant for the left eye, one meant for the right eye—to the screen in rapid succession, one right after the other. (The images are projected at a rate of 144 frames per second, so you don't notice the trick.) Multilayer filters on Dolby's glasses allow the left eye to see shorter wavelength bands of blue, green and red than the right eye. "Both eyes get a full spectrum of color, but it's not the exact same frequency that the other eye is getting," says Martin Richards, a principal staff engineer in Dolby's image technology group. The filters in each lens are made up of 70 to 80 layers of titanium oxide or silicon oxide, each with a different index of refraction; they either reflect or allow light to pass through, depending on its wavelength.

Dolby designed its glasses with curved lenses to correct for cross talk (when the right eye's image leaks into the left eye's field of vision), color shift, and reflections at the edge of the field of view. It also allows for light to hit the glasses from any angle without distortion. The actual glasses are not as bug-eyed as in the original sketch (above) and come enclosed in black frames. —Anna Kuchment

CHRISTOPH BANGERT *Redux Pictures (helicopter)*; U.S. PATENT AND TRADEMARK OFFICE *(3-D glasses)*

Physics

Going with the Flow

Could electrical transformers have a gravitational analogue?

If the sign of a successful scientific theory is that you get more out of it than you put in, then the most successful of all must be Einstein's general theory of relativity. Starting from a few simple principles and earthy thought experiments, such as what would happen if you got stuck in a falling elevator, general relativity predicts everything we know about gravity and much we never suspected. In the latest example, John Swain of Northeastern University suggests that it might be possible to build a gravitational transformer that transfers kinetic energy just as an electrical transformer transfers electrical energy.

The idea is based on the uncanny resemblance between the equations of general relativity and those of electricity and magnetism. The gravitational attraction that makes apples fall is analogous to an electric field, with mass playing the role of electric charge. And just as the motion of electric charges gives rise to a magnetic field, so the motion of mass gives rise to a "gravitomagnetic" field. Earth's spin, for instance, tugs on satellites in an effect known as frame dragging.

A steady flow of mass is analogous to DC electric power; an unsteady flow, to AC power. If you juxtapose two wires carrying AC power, the current in one creates an oscillating magnetic field that in turn generates, or "induces," current in the other wire, thereby transferring power—voilà, a transformer. So why shouldn't the same work for mass flows? Gravitomagnetism could then convey power from one flow to a nearby one.

Physicist and futurist Robert L. Forward made an offhand remark about this possibility in a 1961 paper, and Swain proposes that the process occurs naturally during, for example, the formation of black holes. Scientists might even pull it off in the lab. "There are lots of situations where one would expect these transformerlike effects," Swain says.

Any time someone talks about manipulating gravity in the lab, though, it blows some physicists' fuses. Claims even by the most reputable of researchers have fizzled [see "A Philosopher's Stone," by George Musser; News Scan, Scientific American, June 2002]. Swain's idea strikes relativity experts as vague and probably unobservable. "I notice that Swain never puts in actual numbers to calculate the size of anything," says Clifford M. Will of Washington University in St. Louis.

The analogy between gravitation and electromagnetism is only approximate, adds Giovanni Modanese of the University of Bolzano in Italy. Theorists have yet to prove that gravitomagnetism can induce currents; if anything, he suspects it can't. But it is remarkable that a century-old theory still remains a topic of such lively debate. *—George Musser*

DAN SAELINGER *Getty Images*

Psychology

Status Update: "I'm So Glamorous"

A study of Facebook users shows how narcissism and low self-esteem can be interrelated

Are you a narcissist? Check your recent Facebook activity.

Social-networking sites offer users easy ways to present idealized images of themselves, even if those ideals don't always square with their real-world personalities. Psychology researcher Soraya Mehdizadeh has discovered a way to poke through the offline-online curtain: she has used Facebook to predict a person's level of narcissism and self-esteem.

Mehdizadeh, who conducted the study as an undergraduate at Toronto's York University, gained access to the Facebook accounts of 100 college students and measured activities like photo sharing, wall postings and status updates; she also studied how frequently users logged on and how often they remained online during each session. Her findings were published recently in *Cyberpsychology, Behavior and Social Networking*.

After measuring each subject using the Narcissism Personality Inventory and Rosenberg Self-Esteem Scale, Mehdizadeh, who graduated from York this past spring, discovered narcissists and people with lower self-esteem were more likely to spend more than an hour a day on Facebook and were more prone to post self-promotional photos (striking a pose or using Photoshop, for example). Narcissists were also more likely to showcase themselves through status updates (using phrases like "I'm so glamorous I bleed glitter") and wall activity (posting self-serving links like "My Celebrity Look-alikes").

Self-esteem and narcissism are often interrelated but don't always go hand in hand. Some psychologists believe that narcissists—those who have a pervasive pattern of grandiosity, a need for admiration, as well as a lack of empathy—unconsciously inflate their sense of self-importance as a defense against feeling inadequate. Not enough empirical research has been produced to confirm that link, although Mehdizadeh's study seems to support it. Because narcissists have less capacity to sustain intimate or long-term relationships, Mehdizadeh thinks that they would be more drawn to the online world of virtual friends and emotionally detached communication.

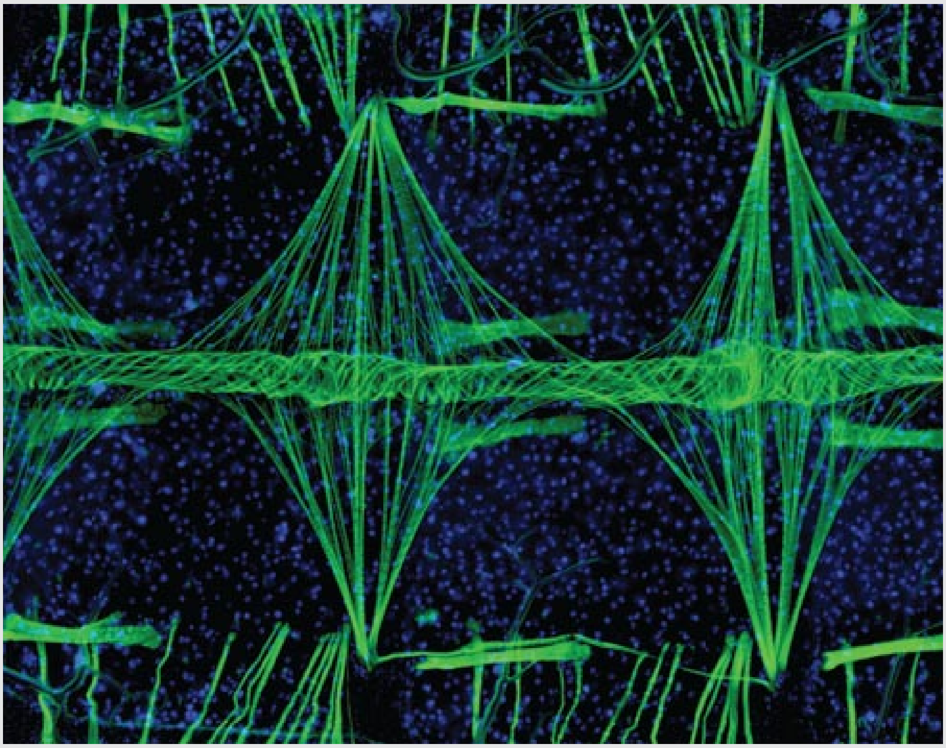
Although it seems that Facebook can be used by narcissists to fuel their inflated egos, Mehdizadeh stops short of proclaiming that excessive time spent on Facebook can turn regular users into narcissists. She also notes that social-networking sites might ultimately be found to have positive effects when used by people with low self-esteem or depression.

"If individuals with lower self-esteem are more prone to using Facebook," she says, "the question becomes, 'Can Facebook help raise self-esteem by allowing patients to talk to each other and help each other in a socially interactive environment?' I don't think it's necessarily a bad thing that people with low self-esteem use Facebook." —*John H. Tucker*

WHAT IS IT?

A small, small world: *Each year Nikon solicits entries from thousands of scientists who use cameras and light microscopes to capture images of phenomena invisible to the naked eye. This year's winner, announced October 13, is Jonas G. King, a Ph.D. candidate in biological sciences at Vanderbilt University. King and his lab's principal investigator, Julián F. Hillyer, study the circulatory system of mosquitoes as it relates to malaria. [Also see "Halting the World's Most Lethal Parasite," on page 68.] Their winning picture is of a mosquito heart, a two-millimeter-long tube, part of which is visible in the center of this micrograph.*

To capture the image, King and Hillyer sliced through the abdomen of Anopheles gambiae, *the most important carrier of malaria. (The parasite becomes infective to humans as it travels from a mosquito's midgut to its salivary glands.) The team unfolded the abdomen's outer walls, scooped out the internal organs but left the heart in place. They then stained the tissue using fluorescent dyes. The green in the photo reveals the heart musculature; the blue shows the cell nuclei. The image helps scientists see how mosquitoes pump blood and, by extension, the malaria parasite through their bodies.* —Anna Kuchment



COURTESY OF JONAS G. KING

Thomas Kirkwood is director of the Institute for Ageing and Health at Newcastle University in England and is author of *Time of Our Lives: The Science of Human Aging.*

Why Women Live Longer

Stress alone does not explain the longevity gap

KENDRICK BRINSON *Luceo*

If there are any men left who still believe that women are the weaker sex, it is long past time for them to think again. With respect to that most essential proof of robustness—the power to stay alive—women are tougher than men from birth through to extreme old age. The average man may run a 100-meter race faster than the average woman and lift heavier weights. But nowadays women outlive men by about five to six years. By age 85 there are roughly six women to every four men. At age 100 the ratio is more than two to one. And by age 122—the current world record for human longevity—the score stands at one-nil in favor of women.

So why do women live longer than men? One idea is that men drive themselves to an early grave with all the hardship and stress of their working lives. If this were so, however, then in these days of greater gender equality, you might expect the mortality gap would vanish or at least diminish. Yet there is little evidence that this is happening. Women today still outlive men by about as much as their stay-at-home mothers outlived their office-going fathers a generation ago. Furthermore, who truly believes that men's work lives back then were so much more damaging to their health than women's home lives? Just think about the stresses and strains that have always existed in the traditional roles of women: a woman's life in a typical household can be just as hard as a man's. Indeed, statistically speaking, men get a much better deal out of marriage than their wives—married men tend to live many years longer than single men, whereas married women live only a little bit longer than single women. So who actually has the easier life?

It might be that women live longer because they develop healthier habits than men—for example, smoking and drinking less and choosing a better diet. But the number of women who smoke is growing and plenty of others drink and eat unhealthy foods. In any case, if women are so healthy, why is it that despite their longer lives, women spend more years of old age in poor health than men do? The lifestyle argument therefore does not answer the question either.

As an experimental gerontologist, I approach this issue from a wider biological perspective, by looking at other animals. It turns out that the females of most species live longer than the males. This phenomenon suggests that the explanation for the difference within humans might lie deep in our biology.

Many scientists believe that the aging process is caused by the gradual buildup of a huge number of individually tiny faults—some damage to a DNA strand here, a deranged protein molecule there, and so on. This degenerative buildup means that the length of our lives is regulated by the balance between how fast new damage strikes our cells and how efficiently this damage is corrected. The body's mechanisms to maintain and repair our cells are wonderfully effective—which is why we live as long as we do—but these mechanisms are not perfect. Some of the damage passes unrepaired and accumulates as the days, months and years pass by. We age because our bodies keep making mistakes.

Fountain of youth: Not only is she likely to live longer than he does, but she will help him live longer, too.

We might well ask why our bodies do not repair themselves better. Actually we probably could fix damage better than we do already. In theory at least, we might even do it well enough to live forever. The reason we do not, I believe, is because it would have cost more energy than it was worth when our aging process evolved long ago, when our hunter-gatherer ancestors faced a constant struggle against hunger. Under the pressure of natural selection to make the best use of scarce energy supplies, our species gave higher priority to growing and reproducing than to living forever. Our genes treated the body as a short-term vehicle, to be maintained well enough to grow and reproduce, but not worth a greater investment in durability when the chance of dying an accidental death was so great. In other words, genes are immortal, but the body—what the Greeks called *soma*—is disposable.

Or at least that's the idea I proposed in the late 1970s. Since then, the evidence to support this disposable soma theory has grown significantly—something I wrote about in *Scientific American* in September ["Why Can't We Live Forever?"]. In my own laboratory some years ago we showed that longer-lived animals have better maintenance and repair systems than short-lived animals do. The longer-lived animals are also the smarter ones, or the bigger ones, or the ones like birds and bats that evolved adaptations such as wings to make their lives safer. If you can avoid the hazards of the environment for a bit longer by flying away from danger or being cleverer or bigger, then the body is correspondingly a bit less disposable, and it pays to spend more energy on repair.

Could it be that women live longer because they are less disposable than men? This notion, in fact, makes excellent biological sense. In humans, as in most animal species, the state of the female body is very important for the success of reproduction. The fetus needs to grow inside the mother's womb, and the infant needs to suckle at her breast. So if the female animal's body is too much weakened by damage, there is a real threat to her chances of making healthy offspring. The man's reproductive role, on the other hand, is less directly dependent on his continued good health.

It is too extreme to say that for all biology cares, males need only to attract a mate and then can pretty much die. A study of children in Tanzania, for example, showed that children who lost a father before the age of 15 tended to be a little shorter than their peers, and height is a reasonably good proxy for health. But children who lost a mother fared even worse—they were shorter, poorer and did not live as long as fatherless orphans. From an evolutionary point of view, however, the drivers of mating success for males are generally not the drivers of longevity. In fact, high levels of testosterone, which boost male fertility, are quite bad for long-term survival.

Women may still struggle to achieve equality in many spheres of life. To be less disposable, however, is a blessing that offers some compensation. There is evidence from studies in rodents that cells in a female body do repair damage better than in the body of a male and that surgical removal of the ovaries eliminates this difference. As many dog and cat owners can attest, neutered male animals often live longer than their intact counterparts. Indeed, the evidence supports the notion that male castration might be the ticket to a longer life.

Might the same be true of humans? Eunuchs were once members of the elite in many societies. In China, boys were castrated to enable them to serve the emperor without the risk of impregnating his concubines. In Europe, such extreme practices were used to retain the singing qualities of boys as they moved into adolescence.

The historical record is not good enough to determine if eunuchs tend to outlive normal healthy men, but some sad records suggest that they do. A number of years ago castration of men in institutions for the mentally disturbed was surprisingly commonplace. In one study of several hundred men at an unnamed institution in Kansas, the castrated men were found to live on average 14 years longer than their uncastrated fellows. Nevertheless, I doubt that many men—myself included—would choose such a drastic remedy to buy a few extra years. SA

COMMENT ON THIS ARTICLE www.ScientificAmerican.com/nov2010

KENDRICK BRINSON *Luceo*

David Pogue is the personal-technology columnist for the *New York Times* and an Emmy Award–winning correspondent for *CBS News.*

The Trouble with E-Readers

Electronic books are still far too crude to replace ink and paper

This past summer Amazon made a shocking announcement: for the first time (and ever since), it sold more electronic books than hardcover ones.

Now, that headline should have had half a page of footnotes. Amazon provided only the relative proportions of sales, not the actual quantities. It didn't mention that its e-books of most best sellers cost a flat $10, compared with, for example, $25 for the same book in hardback. And it didn't say anything at all about paperback sales (which sell the most of all).

Otherwise, though, the news sure sounded as though printed books are dying, right along with a slice of our cultural souls. We would lose the satisfaction of holding a sturdy bound volume, the pleasure of turning physical pages, even the beautiful covers that let us see what someone else on the subway is reading. But a funeral for the printed book is premature, for three reasons.

First, it's human to underestimate the time it takes for fanciful technologies to arrive. We're way past the 2001 of the movie *2001: A Space Odyssey,* but we're still not bopping nonchalantly among the stars. According to *The Terminator,* the government's Skynet computer should have had control over our nukes for 13 years by now. And if the dark 2019 dystopia of *Blade Runner* is really going to happen, it had better hurry up.

Second, when these tech changes do occur, they tend not to wipe out the existing technologies; instead they just add on. Television didn't kill radio as everyone expected. E-mail didn't wipe out paper mail, either; the paperless office may never arrive. For the same reason, e-books won't kill paper books.

For the moment, there's a third problem: the crudeness of e-book technology itself.

Today you can buy e-book readers from more than a dozen companies: Amazon, Barnes & Noble, Sony, and so on. The prices have plummeted—a 2007 Kindle would have cost you $400; today an improved model goes for as low as $140.

But they're still pricey enough that you'll kick yourself if yours is lost or stolen. They're much more fragile than books. They run out of power, leaving you with nothing to read.

Furthermore, most are built around e-ink screens. E-ink looks like black ink on light gray paper. There's no backlight, no glare—and no need ever to turn it off, because e-ink draws power only when you actually turn a page. At that point, a brief electronic charge draws millions of particles into a pattern of letters. There they remain forever, even if you remove the battery.

But e-ink is also slow. With each page turn, there's a distracting black-white-black flashing as the screen obliterates one page to prepare for the next. On some readers, that interruption takes a full second. That's maddening when your current page ends with "He ripped the detonator from the flaming wreckage. Only one thing could save mankind now: a"

The biggest problem of all, though, is the e-books themselves. The publishers insist that e-books must be copy-protected. Predictably, each company uses a different protection scheme. You can't read a Kindle book on a Barnes & Noble Nook or a Sony Reader book on an iPad.

You can still read a 200-year-old printed book. But the odds of being able to read one of today's e-books in 200 years, or even 20, is practically zero.

No, you won't be giving a well-worn e-book to your children. But you won't be giving one to your friend, either; you can't resell or even give away an e-book. It doesn't seem right. Why shouldn't you be able to pass along an e-book just the way you'd pass on a physical one? You paid for it, haven't you?

Make no mistake: e-book sales will continue to climb. Screen technology will improve, and prices will fall. It's theoretically possible, in fact, that the publishers' Luddite lawyers will even relax a little bit about the copy protection.

For the moment, however, the headline "Printed Books Are Dead" was published much, much too early. SA

FOUR MONEY-SAVING E-BOOK TIPS www.ScientificAmerican.com/nov2010/ebook

Illustration by Gary Taxali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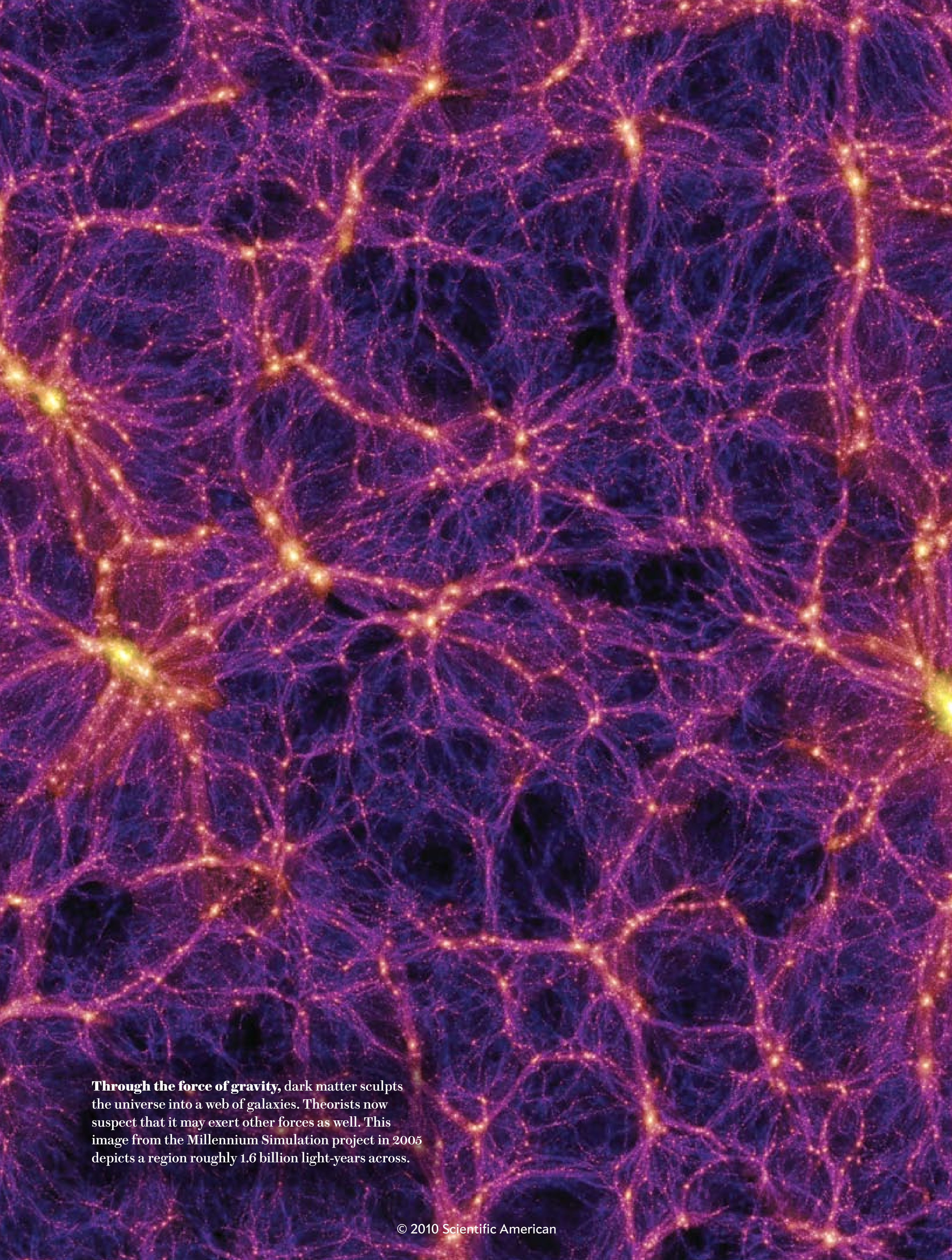
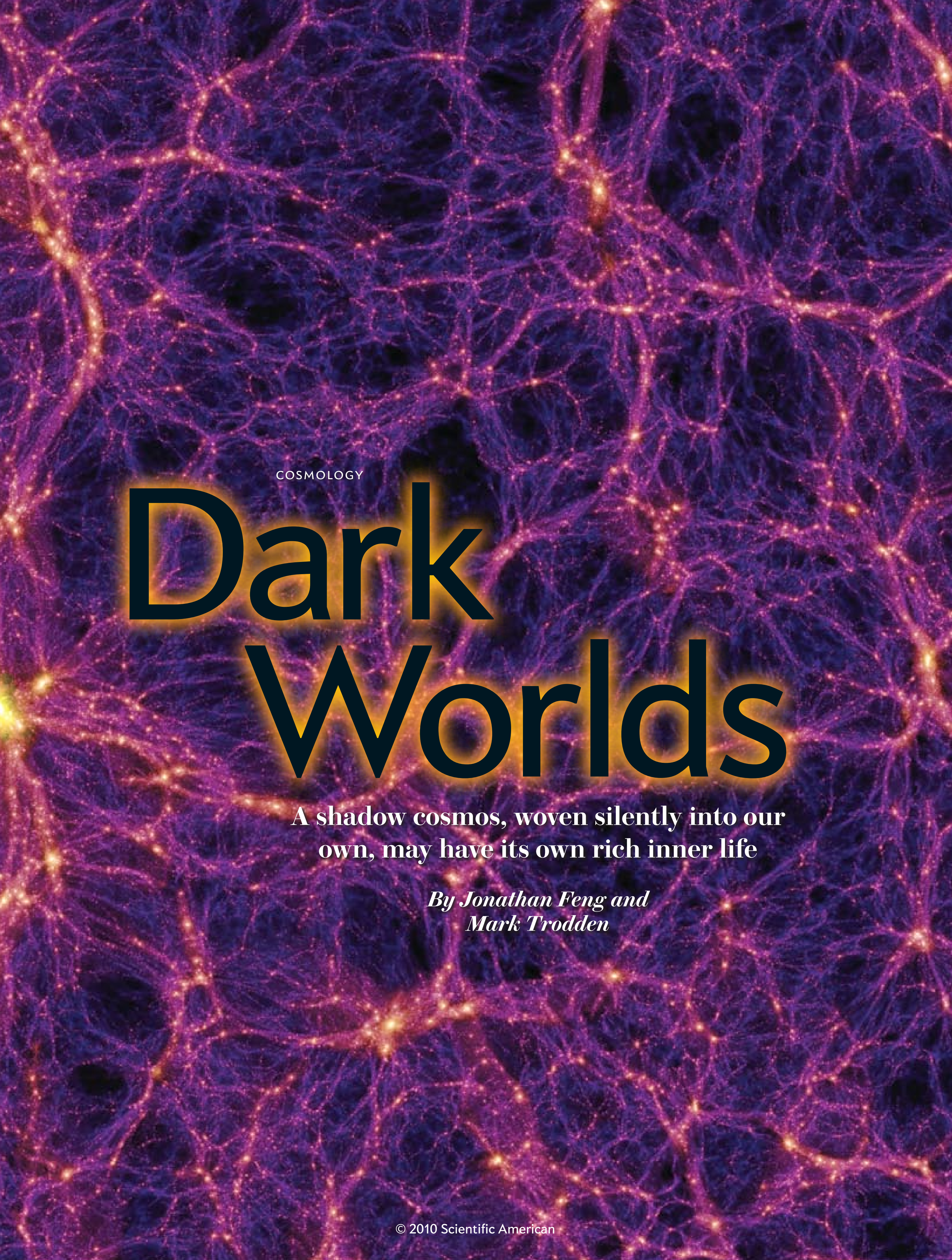


Through the force of gravity, dark matter sculpts the universe into a web of galaxies. Theorists now suspect that it may exert other forces as well. This image from the Millennium Simulation project in 2005 depicts a region roughly 1.6 billion light-years across.



COSMOLOGY

Dark Worlds

A shadow cosmos, woven silently into our own, may have its own rich inner life

By Jonathan Feng and Mark Trodden

Jonathan Feng is a theoretical physicist working at the intersection of particle physics and cosmology, with a focus on dark matter. Currently a professor of physics and astronomy at the University of California, Irvine, he played the trumpet in a former life.

Mark Trodden studies particle physics and cosmology. He is co-director of the Center for Particle Cosmology at the University of Pennsylvania and an author of Cosmic Variance, a leading physics blog. When not pondering the cosmos, he can often be found sipping wine in a busy kitchen.

On September 23, 1846, Johann Gottfried Galle, director of the Berlin Observatory, received a letter that would change the course of astronomical history. It came from a Frenchman, Urbain Le Verrier, who had been studying the motion of Uranus and concluded that its path could not be explained by the known gravitational forces acting on it. Le Verrier suggested the existence of a hitherto unobserved object whose gravitational pull was perturbing Uranus's orbit in precisely the way required to account for the anomalous observations. Following Le Verrier's directions, Galle went to his telescope that night and discovered the planet Neptune.

A similar drama—in which astronomers observe anomalous cosmic motions, deduce the presence of new matter and go out to hunt for it—is playing out again today in modern cosmology. In the role of Uranus, we see stars and galaxies moving in ways they should not; in the role of Neptune, we deduce the existence of hitherto unobserved substances, provisionally called dark matter and dark energy. From the types of anomalies we see, we can glean a few basic facts about them. Dark matter seems to be a sea of invisible particles that fills space unevenly; dark energy is spread out uniformly and acts as if it is woven into the fabric of space itself. Scientists have yet to repeat Galle's accomplishment of pointing an instrument at the sky and glimpsing the unseen players definitively, but tantalizing inklings, such as blips in particle detectors, continue to accumulate.

From its discovery as a shadowy force on Uranus, Neptune proved to be a fascinating world in its own right. Might the same be true of dark matter and dark energy? Scientists are increasingly considering the possibility that dark matter, in particular, is not just a contrivance to account for the motion of visible matter but a hidden side of the universe with a rich inner life. It may consist of a veritable zoo of particles interacting through novel forces of nature—an entire universe interwoven silently with our own.

THE DARK SIDE

These ideas are a shift from the long-held assumption that dark matter and dark energy are the most antisocial substances in the cosmos. Since astronomers first inferred the existence of dark matter in the 1930s, they have considered inertness its defining property. Observations suggest it outweighs ordinary matter by a factor of 6 to 1. Galaxies and galaxy clusters are embedded in giant balls, or "halos," of dark matter. For such a mass of material to elude direct detection, astronomers reason that it has to consist of particles that scarcely interact with ordinary matter or, indeed, with one another. All they do is provide the gravitational scaffolding for luminous matter.

Astronomers think the halos formed early on in cosmic history and then drew in ordinary matter, which, being capable of a rich range of behaviors, developed into intricate structures, while dark matter, being inert, remained in its primitive state. As for dark energy, its only role appears to be to accelerate cosmic expansion, and the available evidence indicates it has remained completely unchanged over the life of the cosmos.

The prospect that dark matter might be rather more interesting is driven not so much by the field of astronomy but by detailed investigations of the inner workings of atoms and the world of subatomic particles. Particle physicists have a tradition of seeing glimmers of unknown forms of matter in the behavior of known matter, and their evidence is completely independent of cosmic motions.

In the case of dark matter, the train of thought began with the discovery of radioactive beta decay in the early 1900s. Italian theorist Enrico Fermi sought to explain the phenomenon

IN BRIEF

Scientists have two independent reasons for thinking that the cosmos is filled with some unknown form of matter, dark matter. Not only do stars, galaxies and gas clouds move as if they are being tugged by the gravity of hidden material, but processes such as radioactivity present puzzles that can be solved by the existence of hitherto unknown particles.

Dark matter is usually assumed to consist of WIMPs, a kind of particle that scarcely interacts with the visible world. Boringness is its sine qua non.

Or at least that is the usual assumption. Might dark matter in fact have a rich inner life? Particle physicists striving to understand what makes up dark matter think it could interact through a full range of forces, including a form of light to which our eyes are totally blind.

COURTESY OF VOLKER SPRINGEL *Max Planck Institute for Astrophysics and Heidelberg Institute for Theoretical Studies (preceding pages)*

What Lurks in the Shadows

Modern scientific instruments have revealed the existence of unseen mass and energy in the universe but have barely scratched the surface of the types of stuff that might make it up.

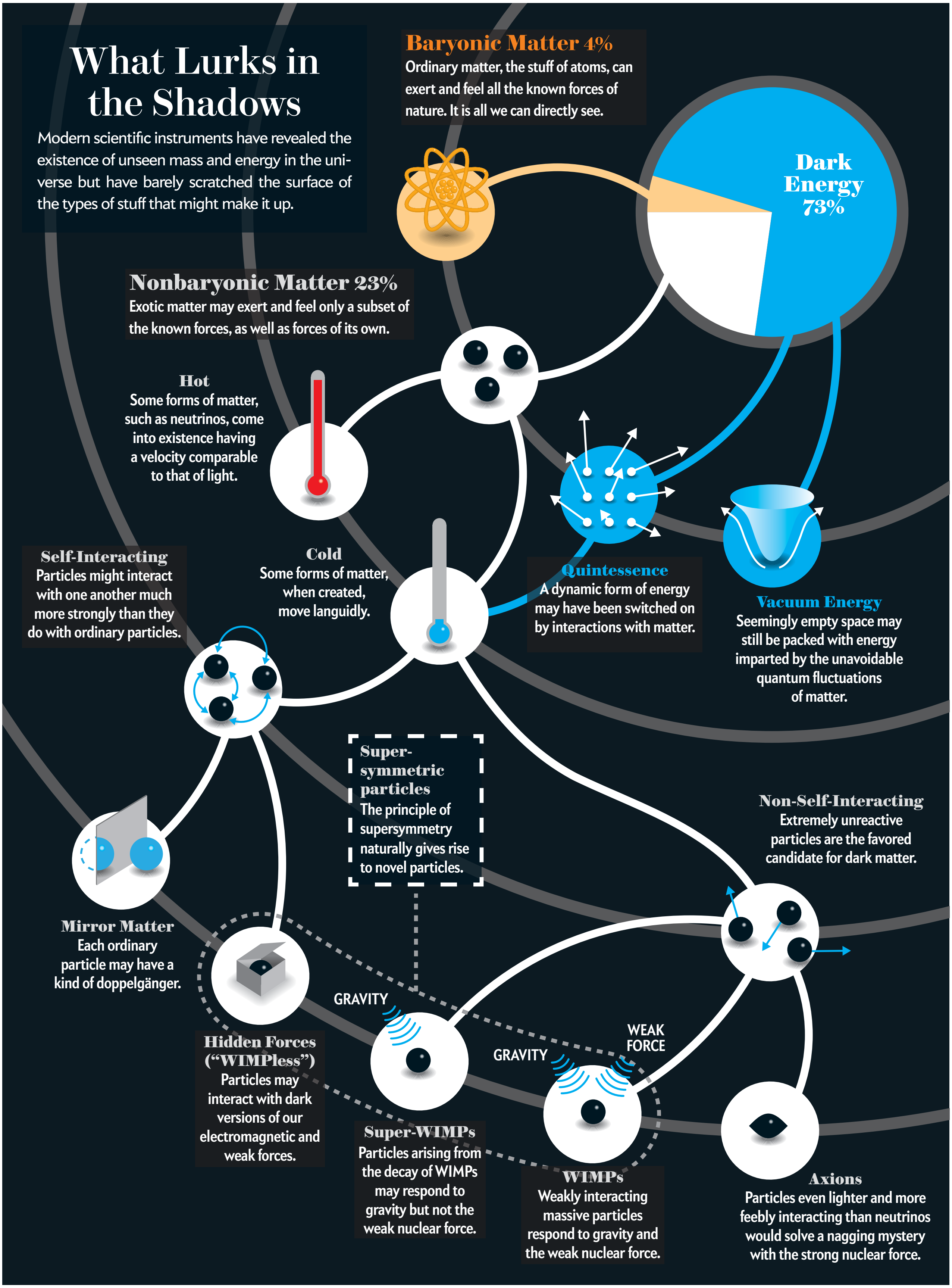
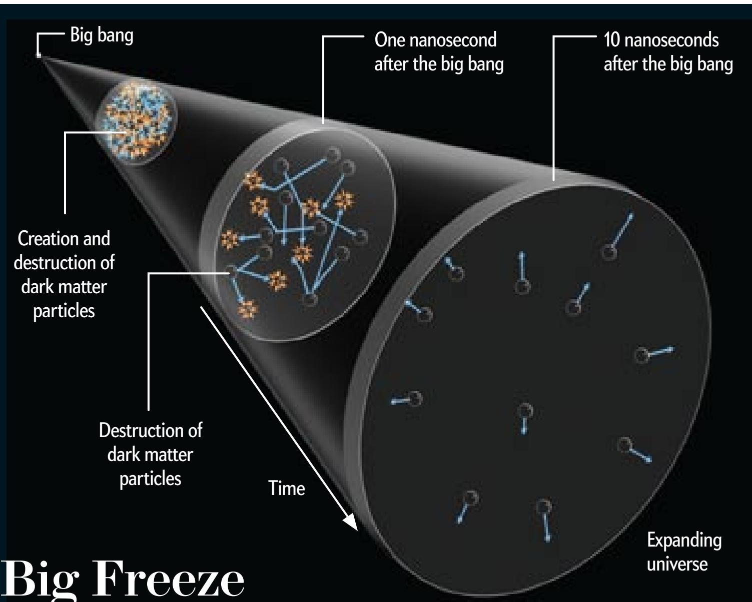


Illustration by Bryan Christie

WHERE DARK MATTER CAME FROM



Big Freeze

In the hot, dense early universe, dark matter particles such as WIMPs were created and destroyed in a dynamic equilibrium. As the cosmos expanded, it cooled and eventually was no longer able to create new particles. Those left over became so spread out that they ceased colliding and getting destroyed. For WIMPs, theory makes a firm prediction for the amount of material that survived, which is consistent with observations.

by postulating a new force of nature and new force-carrying particles that caused atomic nuclei to decay. This new force was similar to electromagnetism and the new particles to photons, the particles of light—but with a key twist. Unlike photons, which are massless and therefore highly mobile, Fermi argued that the new particles had to be heavy. Their mass would limit their range and account for why the force causes nuclei to fall apart but otherwise goes unnoticed. To reproduce the observed half-life of radioactive isotopes, they had to be quite heavy—around 100 times that of the proton, or about 100 giga-electron-volts, in the standard units of particle physics.

The new force is now known as the weak nuclear force and the hypothesized force-carrying particles are the *W* and *Z* particles, which were discovered in the 1980s. They are not dark matter themselves, but their properties hint at dark matter. A priori, they should not be so heavy. Their high mass suggests that something is acting on them—novel particles that cause them to take on mass like a friend who encourages you to give into temptation and eat another slice of cake. One goal of the Large Hadron Collider is to look for those particles, which should have masses comparable to those of the *W* and *Z*. Indeed, physicists think dozens of types of particles may be waiting to be discovered—one for each of the known particles, paired off in an arrangement known as supersymmetry.

These hypothetical particles include some collectively known as weakly interacting massive particles, or WIMPs. The name arises because the particles interact only by means of the weak nuclear force. Being immune to the electric and magnetic forces that dominate the everyday world, they are totally invisible and have scarcely any direct effect on normal particles. Therefore, they make the perfect candidate for cosmic dark matter.

Whether they can truly explain dark matter, though, depends on how many of them there are. Here is where the particle physics argument really gains traction. Like any other breed of particle, WIMPs would have been produced in the fury of the big bang. High-energy particle collisions back then both created and destroyed WIMPs, allowing a certain number of them to exist at any given moment. This number varied with time depending on two competing effects driven by the expansion of the universe. The first was the cooling of the primordial soup, which reduced the amount of energy available to create WIMPs, so that their number diminished. The second effect was the dilution of particles, which reduced the frequency of collisions until they effectively ceased to occur. At that point, about 10 nanoseconds after the big bang, the number of WIMPs became frozen in. The universe no longer had either the energy needed to create WIMPs or the dense concentrations of mass needed to destroy them.

Given the expected mass of WIMPs and the strength of their interactions, which govern how often they annihilate one another, physicists can easily calculate how many WIMPs should be left over. Rather amazingly, the number matches the number required to account for cosmic dark matter today, within the precision of the mass and interaction-strength estimates. This remarkable agreement is known as the WIMP coincidence. Thus, particles motivated by a century-old puzzle in particle physics beautifully explain cosmological observations.

This line of evidence, too, indicates that WIMPs are inert. A quick calculation predicts that nearly one billion of these particles have passed through your body since you started reading this article, and unless you are extraordinarily lucky, none has had any discernible effect. Over the course of a year you might expect just one of the WIMPs to scatter off the atomic nuclei in your cells and deposit some meager amount of energy. To have any hope of detecting such events, physicists set their particle detectors to monitor large volumes of liquid or other material for long periods. Astronomers also look for bursts of radiation in the galaxy that mark the rare collision and annihilation of orbiting WIMPs. A third way to find WIMPs is to try to synthesize them in terrestrial experiments [*see box on page 44*].

OUT-WIMPING THE WIMPS

THE EXTRAORDINARY EFFORT now being devoted to WIMP searches might leave the impression that these particles are the only theoretically plausible dark matter candidate. Are they? In fact, recent developments in particle physics have uncovered other possibilities. This work hints that the WIMP is just the tip of the iceberg. Lurking under the surface could be hidden worlds, complete with their own matter particles and forces.

One such development is the concept of particles even more wimpy than WIMPs. Theory suggests that WIMPs formed in the

Illustration by Bryan Christie

first nanosecond of cosmic history might have been unstable. Seconds to days later they could have decayed to particles that have a comparable mass but do not interact by the weak nuclear force; gravity is their only connection to the rest of the natural world. Physicists, tongue in cheek, call them super-WIMPs.

The idea is that these particles, rather than WIMPs, constitute the dark matter of today's universe. Super-WIMPs would elude direct observational searches but might be inferred from the telltale imprint they would leave on the shapes of galaxies. When created, super-WIMPs would have been moving at a significant fraction of the speed of light. They would have taken time to come to rest, and galaxies could not have begun forming until they did. This delay would have left less time for matter to accrete onto the centers of galaxies before cosmic expansion diluted it. The density at the center of dark matter halos should therefore reveal whether they are made of WIMPs or super-WIMPs; astronomers are now checking. In addition, the decay from WIMP to super-WIMP should have produced photons or electrons as a by-product, and these particles can smash into light nuclei and break them apart. There is some evidence that the universe has less lithium than expected, and the super-WIMP hypothesis is one way to explain the discrepancy.

The super-WIMP scenario also inspires fresh possibilities for what experimental physicists might observe. For instance, the original WIMP need not have been either dark or wimpy; it could have had an electric charge. Any charge it had would not have affected the evolution of the cosmos, because the particle decayed so quickly. It would, however, mean that WIMPs would be extremely conspicuous if experimentalists were able to recreate them. Particle detectors would register them as electrons on steroids; having the same charge as an electron but 100,000 times more mass, such a particle would barrel through the detectors, leaving spectacular tracks in its path.

DARK FORCES, HIDDEN WORLDS

THE MAIN LESSON of super-WIMP models is that there is no reason, either theoretically or observationally, that dark matter should be as boring as astronomers tend to presume. Once one admits the possibility of hidden particles with properties that go beyond the standard WIMP scenario, it is natural to consider the full range of possibilities. Could there be a whole sector of hidden particles? Could there be a hidden world that is an exact copy of ours, containing hidden versions of electrons and protons, which combine to form hidden atoms and molecules, which combine to form hidden planets, hidden stars and even hidden people?

The possibility that a hidden world could be identical to ours has been explored at length, beginning in 1956 with an offhand comment in a Nobel Prize–winning paper by Tsung-Dao Lee and Chen Ning Yang and more recently by many others, including Robert Foot and Raymond Volkas of the University of Melbourne in Australia. The idea is truly tantalizing. Could it be that what we see as dark matter is really evidence for a hidden world that mirrors ours? And are hidden physicists and astronomers even now peering through their telescopes and wondering what their dark matter is, when in fact their dark matter is us?

Unfortunately, basic observations indicate that hidden worlds cannot be an exact copy of our visible world. For one, dark matter is six times more abundant than normal matter. For another, if dark matter behaved like ordinary matter, halos would have flattened out to form disks like that of the Milky Way—with dramatic

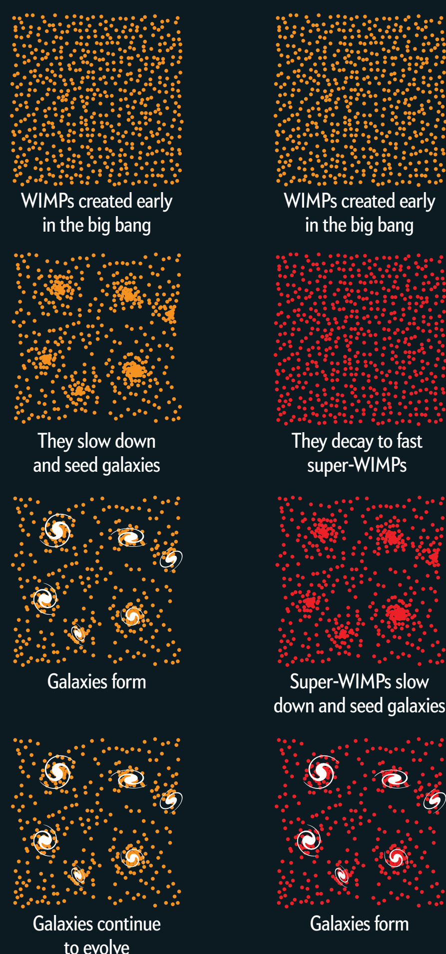
A NEW TYPE OF DARK MATTER

Varieties of Weaklings

Super-WIMPs were the first proposed type of particle that enriches the standard WIMP scenario for dark matter. The term is intentionally ironic: these particles are "super" not because they are mightier than WIMPs but because they are wimpier: they interact with ordinary matter only through the force of gravity.

	Baryonic	WIMP	Super-WIMP
Gravity	✓	✓	✓
Electromagnetic force	✓		
Weak nuclear force	✓	✓	
Strong nuclear force	✓		
Possible dark forces		✓	✓

In the WIMP scenario (*left column*), WIMPs seed galaxy formation directly. In the super-WIMP scenario (*right column*), they decay to super-WIMPs, which do the seeding—with a delay relative to the WIMP scenario.



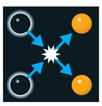
gravitational consequences that have not been seen. Last, the existence of hidden particles identical to ours would have affected cosmic expansion, altering the synthesis of hydrogen and helium in the early universe; compositional measurements rule that out. These considerations argue strongly against hidden people.

That said, the dark world might indeed be a complicated web of particles and forces. In one line of research, several investigators, including one of us (Feng) and Jason Kumar of the University of Hawaii at Manoa, have found that the same supersymmetric framework that leads to WIMPs allows for alternative scenarios that lack WIMPs but have multiple other types of particles. What is more, in many of these WIMP-less theories, these particles interact with one another through newly postulated dark forces. We found that such forces would alter the rate of particle

PHYSICS OBSERVATIONS

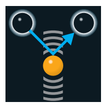
How to See the Unseeable

So far everything astronomers know about dark matter comes from its gravitational effects on visible matter. But they need to detect it directly if they are to find out what it is. That will not be easy: dark matter is elusive by definition. Nevertheless, motivated by the promise of discovering what a quarter of the universe is, thousands of researchers are looking. Most of their efforts have focused on WIMPs, and the three common search strategies are to look for the particles' annihilation, scattering and production.

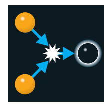


ANNIHILATION When two WIMPs meet, they obliterate each other and leave behind a clutch of other particles such as electrons, antielectrons (known as positrons) and neutrinos. Such annihilation cannot be very common, or else no WIMPs would be left by now. Fortunately, current experiments are sensitive enough to notice if even a tiny fraction of WIMPs are being annihilated.

Detectors on high-altitude balloons and satellites have sought electrons and positrons. In the coming year the space shuttle is scheduled to transport the Alpha Magnetic Spectrometer to the International Space Station, where it will sit docked, looking for positrons. Other observatories such as the Super-Kamiokande experiment in Japan and IceCube in Antarctica are watching for neutrinos.



DIRECT DETECTION Dark matter should be streaming through our planet as it travels through the galaxy. On rare occasions, a WIMP will bump into an atomic nucleus and cause it to recoil, just as a pool ball does when struck by the cue ball. The predicted recoil energies are almost imperceptible but may be within the range of sensitive detectors. Cryogenic technology slows the natural vibrations of atoms and makes it easier to notice any recoil. The energy deposited in the detector holds the key to pinning down the fundamental properties of dark matter. Two experiments, DAMA and CoGeNT, have claimed to detect a signal (*below*), but others, such as XENON and CDMS, have found nothing. These and other new experiments are improving their sensitivities rapidly, promising an exciting near future for this field.



PRODUCTION Dark matter might be created at particle colliders, such as the Large Hadron Collider at CERN near Geneva, a mammoth experiment that collides protons together at extremely high energies. Dark matter production is dark matter annihilation played backward: if dark matter can annihilate into normal particles, it can also be produced by the collisions of normal particles. The signature of dark matter production would be the observation of collisions in which energy and momentum seem to go missing, indicating that some unreactive particles have been produced and then escaped the detector without registering. These giant experiments, designed to tease out the secrets of the subatomic world, may wind up discovering the dominant form of matter in the universe.

Experiments That Claim to Have Detected Dark Matter Particles

EXPERIMENT	CDMS	DAMA	CoGeNT	PAMELA
What it stands for	Cryogenic Dark Matter Search	DArk MAtter	Coherent Germanium Neutrino Technology	Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics
Where it is	Soudan mine in Minnesota	Gran Sasso underground lab in Italy	Soudan mine	Attached to Russian satellite
What it has seen	Two recoil events	Annual variation in the number of recoil events	Recoil events	Excess of positrons
Why the signal might be real	Direct, expected signal of dark matter	Statistically significant	Sensitive to ultralow energy recoils	Direct, expected signal of dark matter annihilation
Why it might not be	Not statistically significant	Apparently excluded by other results	Normal nuclear events might be responsible	Could be explained by astrophysical sources
Which experiments will follow up	SuperCDMS, XENON	XENON, MAJORANA Demonstrator	XENON, MAJORANA Demonstrator	Alpha Magnetic Spectrometer

Illustration by Bryan Christie

creation and annihilation in the early universe, but again the numbers work out so that the right number of particles are left over to account for dark matter. These models predict that dark matter may be accompanied by a hidden weak force or, even more remarkably, a hidden version of electromagnetism, implying that dark matter may emit and reflect hidden light.

This "light" is, of course, invisible to us, and so the dark matter remains dark to our eyes. Still, new forces could have very significant effects. For example, they could cause clouds of dark particles to become distorted as they pass through one another. Astronomers have searched for this effect in the famous Bullet Cluster, which consists of two clusters of galaxies that have passed through each other. Observations show that the brief co-mingling of clusters left the dark matter largely unperturbed, indicating that any dark forces could not be very strong. Researchers are continuing to look in other systems.

Such forces would also allow dark particles to exchange energy and momentum with one another, a process that would tend to homogenize them and cause initially lopsided halos to become spherical. This homogenizing process should be most pronounced for small galaxies, also known as dwarf galaxies, where the dark matter is slow-moving, particles linger near one another and small effects have time to build up. The observation that small galaxies are systematically rounder than their larger cousins would be a telltale sign of dark matter interacting through new forces. Astronomers are only just beginning to undertake the requisite studies.

ASTRONOMICAL OBSERVATIONS

Silver Bullet

The famous Bullet Cluster is among astronomers' most persuasive evidence for dark matter. It is actually a pair of galaxy clusters that collided. The collision did not affect the galaxies' stars (*visible image*), because they present small targets on these scales, but interstellar gas clouds rammed into one another and emitted x-rays (*pink*). Dark matter (*blue*) betrayed its presence because its gravity distorted the light of background objects. It remained aligned with the stars—indicating that whatever particles make it up are highly unreactive.

COURTESY OF NASA

FROM ONE DARK THING TO ANOTHER

An equally intriguing possibility is that dark matter interacts with dark energy. Most existing theories treat the two as disconnected, but there is no real reason they must be, and physicists are now considering how dark matter and dark energy might affect each other. One hope is that couplings between the two might mitigate some cosmological problems, such as the coincidence problem—the question of why the two have comparable densities. Dark energy is roughly three times as dense as dark matter, but the ratio might have been 1,000 or a million. This coincidence would make sense if dark matter somehow triggered the emergence of dark energy.

Couplings with dark energy might also allow dark matter particles to interact with one another in ways that ordinary particles do not. Recent models allow and sometimes even mandate dark energy to exert a different force on dark matter than it does on ordinary matter. Under the influence of this force, dark matter would tend to pull apart from any ordinary matter it had been interlaced with. In 2006 Marc Kamionkowski of the California Institute of Technology and Michael Kesden, then at the Canadian Institute for Theoretical Astrophysics in Toronto, suggested looking for this effect in dwarf galaxies that are being torn apart by their larger neighbors. The Sagittarius dwarf galaxy, for example, is being dismembered by the Milky Way, and astronomers think its dark matter and ordinary matter are spilling into our galaxy. Kamionkowski and Kesden calculate that if the forces acting on dark matter are at least 4 percent stronger or weaker than the forces acting on the ordinary matter, then the two components should drift apart by an observable amount. At present, however, the data show nothing of the sort.

Another idea is that a connection between dark matter and dark energy would alter the growth of cosmic structures, which depends delicately on the composition of the universe, including its dark side. A number of researchers, including one of us (Trodden) with collaborators Rachel Bean, Éanna Flanagan and Istvan Laszlo of Cornell University, have recently used this powerful constraint to rule out a large class of models.

Despite these null results, the theoretical case for a complex dark world is now so compelling that many researchers would find it more surprising if dark matter turned out to be nothing more than an undifferentiated swarm of WIMPs. After all, visible matter comprises a rich spectrum of particles with multiple interactions determined by beautiful underlying symmetry principles, and nothing suggests that dark matter and dark energy should be any different. We may not encounter dark stars, planets or people, but just as we could hardly imagine the solar system without Neptune, Pluto and the swarm of objects that lie even farther out, one day we might not be able to conceive of a universe without an intricate and fascinating dark world. SA

MORE TO EXPLORE

Einstein's Telescope: The Hunt for Dark Matter and Dark Energy in the Universe. Evalyn Gates. W. W. Norton, 2009.

Approaches to Understanding Cosmic Acceleration. Alessandra Silvestri and Mark Trodden in *Reports on Progress in Physics*, Vol. 72, No. 9, Paper No. 096901; September 2009. **arxiv.org/abs/0904.0024**

Modern Cosmology and the Building Blocks of the Universe. Mark Trodden. Penn Alumni Weekend Lecture, May 15, 2010. **www.sas.upenn.edu/home/news/troddenandabbate/trodden.html**

What's the Matter? The Search for Clues in Our Cold, Dark Universe. Jonathan Feng. Pagels Memorial Public Lecture, July 14, 2010. **vod.grassrootstv.org/vodcontent/9251-1.wmv**

Dark Matter Candidates from Particle Physics and Methods of Detection. Jonathan L. Feng in *Annual Reviews of Astronomy and Astrophysics*, Vol. 48, pages 495–545; August 2010. **arxiv.org/abs/1003.0904**

COMMENT ON THIS ARTICLE **www.ScientificAmerican.com/nov2010**

COMETS

Speaker: **Mark Bailey, Ph.D.**

Meteors, Meteor Showers, and the Draconids — Meteors or shooting stars are fragments of dust from comets, burning up in the Earth's atmosphere. The time of this lecture coincides with a predicted outburst of the annual Draconid meteor shower. It is expected that activity will increase to a peak over a 2- to 3-hour period beginning around 8pm, with up to several hundred meteors per hour possibly being seen, depending on local weather conditions. After a brief introduction to meteors and meteor storms, we go up on deck to observe the "dragon's" fiery flame.

Comets and Concepts in History — Humans have a love-hate relationship with comets. We'll look at the oldest theories of the nature of comets and the role they played in astronomy's development. Blaze a trail with Dr. Bailey through the historic observations, arguments, and theories leading to the realization that comets are largely Oort cloud products, formed with the Sun and planets 4.5 billion years ago.

The Life, Times, and Persistent Puzzles of Comets —Broaden your horizons delving into 20 years' worth of discoveries on comets and their origins — whether in the Edgeworth-Kuiper belt just beyond Neptune, the trans-Neptunian disc, or the Oort cloud. Survey the natural history of comets in the inner solar system, and discover the persistent puzzles and uncertainties in this vibrant, active field of solar-system research.

Risks Posed by Comets and Asteroids — Comets occasionally descend on the Earth with catastrophic effect. At one extreme, such impacts can change the course of evolution disrupting the normal "Darwinian" process. At another extreme, relatively small impacts may have important implications for the development of civilization. Find out how the risk of rare, high-consequence events is assessed.

EVOLUTION

Speaker: **Mohamed Noor, Ph.D.**

What is "Evolution" Anyway and Why Should I Care? — The mere word "evolution" conjures images in the public ranging from movie dinosaurs to something vaguely half-human-half-gorilla. What does the word evolution actually mean in the biological sciences, what is the evidence that it is true, and why should the general public know and care? In fact, evolution affects your everyday life, from your health to your livelihood — come learn why!

On the Origin of Species, Really — Although Darwin's book title suggested that he defined the origin of species, in fact, he only focused on the process of divergence within species and assumed the same processes "eventually" led to something that could be called a new species. Dr. Noor will talk about how species are identified (in practice and in principle), how to modern evolutionary biologists use this type of information to get a handle on how species are formed, and what questions remain.

Genetics, Genomics, and You: Don't Fear Your Genotype! — The missing element to Darwin's theory was how it worked in terms of inheritance. Genetics answered that. Today "personal genomics" issues span medical, legal, ethical, and other areas and pose big question. Get ready for discussion and a lab exercise to help understand the lingo, opportunities, and issues associated with living in the genomics era.

Life in the US Academic Sciences — What happens behind closed doors in the "Ivory Tower" of an academic scientist? Scientists at universities juggle multiple roles. What do these people actually do all day? What are these scientists trained well to do and what are areas where they really are not trained well? What is a typical career trajectory in the sciences, and how are scientists evaluated? Get an inside look from a noted academic.

ATHENS' BEST

Visit the new Acropolis Museum and the National Archaeological Museum with our skilled guide who will add immeasurably to your experience. See the Parthenon frieze, exquisite sanctuary relics, and Archaic sculpture at the Acropolis Museum. Lunch, of course, is tucked away at a taverna favored by Athenian families. For dessert, we'll visit the richest array of Greek antiquities anywhere at the National Archaeological Museum.

EPHESUS

Many civilizations left their mark at Ephesus. It's a many layered, many splendored history, often oversimplified. Bright Horizons pulls together three important elements of Ephesus rarely presented together. Meander the Marble Road, visit the legendary latrines, check out the Library, and visit the centers of the city. A visit to the Terrace Houses enlivens your picture of Roman Ephesus. Lunch on Mediterranean cuisine in the countryside, and then visit the Ephesus Museum where you get a fuller look at local history, from the Lydians to the Byzantines.

GEOLOGY

Speaker: **Michael Wysession, Ph.D.**

Changing Climates, the Black Sea Flood, and the Rise of Civilization — The philosopher Will Durant said, "Civilization exists by geologic consent, subject to change without notice." The history of climate change illustrates this richly. Dr. Wysession lays out the factors controling the climate and how climate change has been the driving factor for the course of human history. You'll get a detailed look at the Black Sea Flood of 7500 years ago, and enrich your understanding of the impact of climate change.

Santorini and the History of Megatsunamis — 3600 years ago, Thera/Santorini saw one of most powerful volcanic eruptions known, leaving just the island ring we see today, burying the Minoan city of Akrotiri under 60 feet of ash, creating a megatsunami that devastated the entire Mediterranean. The the U.S. Northwest's 1700 M-9 earthquake, Lisbon's 1755 quake, Krakatoa's 1883 eruption, and the devastating Sumatra 2004 quake created similarly catastrophic tsunamis. Survey the terrain of megatsunamis, and learn potential future tsunami triggers.

The Eruption of Vesuvius and the Impact of Volcanoes — The term "Plinian volcanic eruptions" honors Pliny the Elder who chronicled the 79 CE eruption of Vesuvius. These eruptions eject ash high in the atmosphere, having their greatest impact through global climate change. From Peru to Russia, from eruptions 74,000 BCE to the French Revolution, you'll focus on the impact of volcanos on history. Time well spent with Dr. Wysession, who keeps his eye on the Yellowstone Caldera!

Fermi's Paradox and the Likelihood of Finding Another Earth — During a discussion on the likelihood of intelligent civilizations existing elsewhere, the physicist Enrico Fermi asked "Well, where is everybody?" Geologic research shows that the conditions required for life to exist continuously for nearly four billion years are stringent, and may rarely occur in the galaxy. Learn all of the factors that had to happen just right to produce Earth's spectacular and potentially unique diversity of geologic and biologic environments.

SCIENTIFIC AMERICAN TRAVEL
BRIGHT HORIZONS

ANCIENT ASTRONOMY

Speaker: **John Steele, Ph.D.**

Astronomy in Ancient Babylon —Cuneiform writing on thousands of clay tablets documents the astronomical activity of the ancient Babylonians. These texts circa the first millennium BC, include lists of astrological omens, astronomical observations, and calculations of the positions and phenomena of the moon and the planets. Join Dr. Steele to investigate the astronomical traditions of the ancient Babylonians and their invention of scientific astronomy.

Ancient Greek Astronomy — How could Ptolemy insist that the earth was the center of the Universe? The ancient Greeks didn't invent astronomy, but they were the first to combine philosophy with mathematics to model the motion of the heavens using geometry. Along the way they figured out the size of the Earth, the distance of the moon from the Earth, and developed geometrical methods for modeling planetary motion. Delve into the legacy of Greek astronomy, and trace its impact in the medieval Islamic world and Renaissance Europe.

The Antikythera Mechanism: An Ancient Mechanical Universe — In 1900 sponge divers off the tiny island of Antikythera discovered an ancient Roman shipwreck laden with works of art. Almost unnoticed were the poorly preserved remains of a small mechanical device — the Antikythera Mechanism. Through painstaking reconstruction and analysis over the past century, we now know the device was a mechanical astronomical computer of great ingenuity. Learn the story of research on the mechanism — and what it has revealed about ancient Greek science and technology.

Eclipses in History — Eclipses are one of the most awe-inspiring astronomical events. Throughout history eclipses were viewed with fear, excitement, astonishment, and scientific curiosity. Take a look at how eclipses have been observed, interpreted, and commemorated in different cultures around the world and discover how scientists today benefit from ancient eclipse records.

Karl Deisseroth is a member of the bioengineering and psychiatry faculties at Stanford University. He is the 2010 International Nakasone Award laureate for his development of microbial opsins and optogenetics.

NEUROSCIENCE

Controlling the Brain with Light

With a technique called optogenetics, researchers can probe how the nervous system works in unprecedented detail. Their findings could lead to better treatments for psychiatric problems

By Karl Deisseroth

EVERY DAY AS A PRACTICING PSYCHIATRIST, I CONfront my field's limitations. Despite the noble efforts of clinicians and researchers, our limited insight into the roots of psychiatric disease hinders the search for cures and contributes to the stigmatization of this enormous problem, the leading cause worldwide of years lost to death or disability. Clearly, we need new answers in psychiatry. But as philosopher of science Karl Popper might have said, before we can find the answers, we need the power to ask new questions. In other words, we need new technology.

Developing appropriate techniques is difficult, however, because the mammalian brain is beyond compare in its complexity. It is an intricate system in which tens of billions of intertwined neurons—with multitudinous distinct characteristics and wiring patterns—exchange precisely timed, millisecond-scale electrical signals and a rich diversity of biochemical messengers. Because of that complexity, neuroscientists lack a deep grasp of what the brain is really doing—of how specific activity patterns within specific brain cells ultimately give rise to thoughts,

IN BRIEF

Neuroscientists have long been frustrated by their inability to study how the brain works in sufficiently precise detail. Unexpectedly, a solution has emerged from basic genetic research on microorganisms that rely on light-responsive "opsin" proteins to survive.

By inserting opsin genes into the cells of the brain, scientists can now use flashes of light to trigger firing by specific neurons on command. This technology, optogenetics, permits researchers to conduct extremely precise, cell type–targeted experiments in the brains of living, freely moving animals—which electrodes and other traditional methods do not allow.

Although optogenetics is still in its infancy, it is already yielding potentially useful insights into the neuroscience underlying some psychiatric conditions.

Photograph by Darren Braun

memories, sensations and feelings. By extension, we also do not know how the brain's physical failures produce distinct psychiatric disorders such as depression or schizophrenia. The ruling paradigm of psychiatric disorders—casting them in terms of chemical imbalances and altered levels of neurotransmitters—does not do justice to the brain's high-speed electrical neural circuitry. Psychiatric treatments are thus essentially serendipitous: helpful for many but rarely illuminating.

Little wonder, then, that in a 1979 *Scientific American* article, Nobel laureate Francis Crick suggested that the major challenge facing neuroscience was the need to control one type of cell in the brain while leaving others unaltered. Electrical stimuli cannot meet this challenge, because electrodes are too crude a tool: they stimulate all the cells at their insertion site without distinguishing between different cell types, and their signals also cannot turn neurons off with precision. Crick later speculated in lectures that light could serve as a control tool because it could be delivered in precisely timed pulses in a range of colors and locations, but at the time no one had any idea about how specific cells could be made to respond to light.

Meanwhile, in a realm of biology as distant from the study of the mammalian brain as might seem possible, researchers were working on microorganisms that would only much later turn out to be relevant. At least 40 years ago biologists knew that some microorganisms produce proteins that directly regulate the flow of electric charge across their membranes in response to visible light. These proteins, which are produced by a characteristic set of "opsin" genes, help to extract energy and information from the light in the microbes' environments. In 1971 Walther Stoeckenius and Dieter Oesterhelt, both then at the University of California, San Francisco, discovered that one of these proteins, bacteriorhodopsin, acts as a single-component ion pump that can be briefly activated by photons of green light—a remarkable all-in-one molecular machine. Later identification of other members of this family of proteins—the halorhodopsins in 1977 and the channelrhodopsins in 2002—continued this original theme from 1971 of single-gene, all-in-one control.

What excites neuroscientists about optogenetics is that it provides control over defined events within defined cell types at defined times.

In 20/20 hindsight, the solution to Crick's challenge—a strategy to dramatically advance brain research—was therefore available in principle even before he articulated it. Yet it took more than 30 years for the concepts to come together in the new technology of optogenetics.

Optogenetics is the combination of genetics and optics to control well-defined events within any specific cells of living tissue (not just those of the nervous system). It includes the discovery and insertion into cells of genes that confer light responsiveness; it also includes the associated technologies for delivering light into the brain, directing the light's effect to genes and cells of interest, and assessing readouts, or effects of this optical control. What excites neuroscientists about optogenetics is that it provides control over defined events within defined cell types at defined times—a level of precision that is not only fundamentally new but most likely crucial to biological understanding.

The significance of any event in a cell is understandable only in the context of the other events occurring around it in the rest of the tissue, the whole organism or even the larger environment. Even a shift of a few milliseconds in the timing of a neuron's firing, for example, can sometimes completely reverse the effect of its signal on the rest of the nervous system. Thousands of scientists are now wielding optogenetics to learn how specific activity patterns within select sets of neurons lead to complex physiology and behavior in worms, flies, fish, birds, mice, rats and monkeys. The work has already yielded important insights into human problems, including depression, disordered sleep, Parkinson's disease and schizophrenia.

CASTING LIGHT ON LIFE

Biology has a tradition of using light to intervene in living systems. Researchers have long employed a light-based method called CALI to destroy, and thus inhibit, selected proteins; lasers have also been used to destroy specific cells, for example, in the worm *Caenorhabditis elegans*. Conversely, Richard L. Fork of Bell Laboratories (in the 1970s) and Rafael Yuste of Columbia University (in 2002) reported ways to stimulate neurons with lasers that partially disrupted cell membranes. In the past decade the laboratories of Gero Miesenböck, while at Memorial Sloan-Kettering Cancer Center, and of Ehud Isacoff, Richard H. Kramer and Dirk Trauner, then all at the University of California, Berkeley, have employed multicomponent systems for modulating targeted cells with light. They introduced, for example, both a protein that regulates neurons and a chemical that would spur the protein into action when triggered by ultraviolet light.

Yet destroying proteins or cells of interest obviously limits one's experimental options, and methods that depend on multiple components, though elegant and useful, entail practical challenges and have not had broad applicability or utility in mammals. A fundamental shift to a single-component strategy was necessary. As it turned out, this single-component strategy was not able to build on any of the parts or methods from earlier approaches but instead employed the remarkable all-in-one light-activated proteins from microbes: bacteriorhodopsins, halorhodopsins and channelrhodopsins.

In 2000, well after bacteriorhodopsin and halorhodopsin had become known to science, the Kazusa DNA Research Institute in Japan posted online thousands of new gene sequences from the green algae *Chlamydomonas reinhardtii*. While reviewing them, Peter Hegemann, then at Regensburg University in Berlin, who had predicted that *Chlamydomonas* would have a light-activated ion channel, noticed two long sequences similar to those for bacteriorhodopsin, obtained copies of them from Kazusa and asked Georg Nagel (then a principal investigator in Frankfurt) to test if they indeed coded for ion channels. In 2002 Hegemann and Nagel described their finding that one of these sequences encoded a single-protein membrane channel responsive to blue light: when hit by blue photons, it regulated the flow of positively charged ions. The protein was consequently dubbed channelrhodopsin-1, or ChR1. The following year Nagel and Hegemann (along with their colleagues, including Ernst Bamberg in Frankfurt) explored the other sequence and named the encoded protein channelrhodopsin-2, or ChR2. Almost simulta-

The Humble Origins of Light-Sensitive Proteins

Some types of algae and other microbes depend for their survival on so-called opsin proteins that respond to visible light. When illuminated, these protein channels regulate the flow of electrically charged ions across membranes, which allows the cells to extract energy from their environments. Opsins of different types can vary in their light sensitivity and behavior. The opsin genes that make these proteins are the foundation for the optogenetic technology that neuroscientists are now using to control the activity patterns in targeted neurons.

Microbe

Chlamydomonas reinhardtii is a single-cell, motile alga equipped with a pair of flagella that allow it to swim through freshwater.

Volvox carteri is an alga closely related to *Chlamydomonas* that consists of hundreds of cells living together as a globular colony.

Natronomonas pharaonis is an archaebacterium that can live only in waters with extremely high salt concentrations.

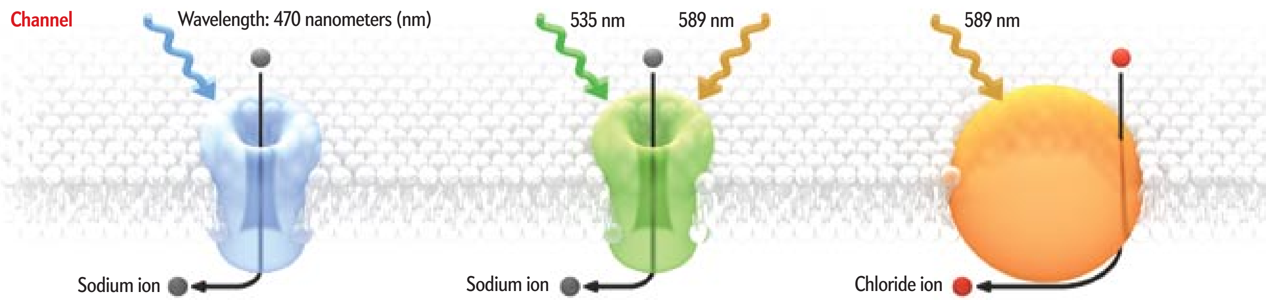
Habitat

Soil and bodies of freshwater worldwide

Ponds, lakes, pools and water-filled ditches

Highly saline soda lakes in Egypt and Kenya

Channel

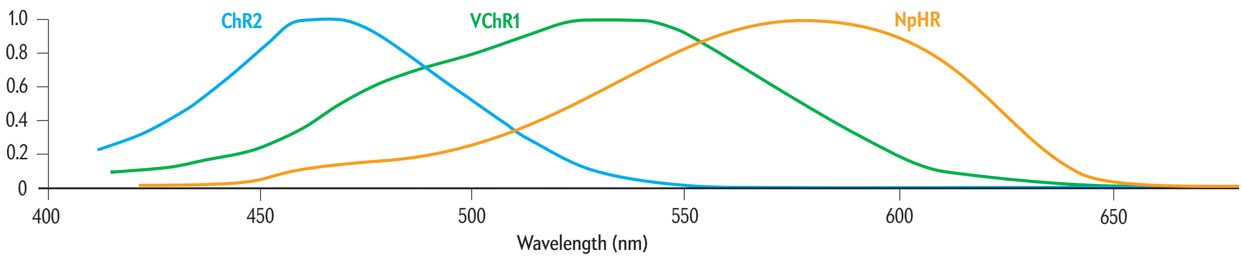


ChR2 channelrhodopsin allows positive sodium ions to pass in response to blue light.

VChR1 channelrhodopsin responds to some wavelengths of green and yellow light.

NpHR halorhodopsin regulates the flow of negative chloride ions in response to yellow light.

Relative Response to Light



TONI ANZENBERGER *Redux Pictures* (dirt); ERIC STRIFFLER *New York Times/Redux Pictures* (pond); ULRICH DOERING *Alamy* (lake); SOURCE: "OPTOGENETIC INTERROGATION OF NEURAL CIRCUITS: TECHNOLOGY FOR PROBING MAMMALIAN BRAIN STRUCTURES," BY F. ZHANG ET AL., IN *NATURE PROTOCOLS*, VOL. 5 NO. 3; FEBRUARY 18, 2010 (*channels and light sensitivity curves*)

Illustrations by Bryan Christie

neously, John L. Spudich of University of Texas Medical School at Houston separately provided evidence that those genes were important to the light-dependent responses of *Chlamydomonas*. Yet the discovery of these channelrhodopsins—a third type of single-component light-activated ion-conductance protein—did not immediately translate into an advance in neuroscience any more than the discoveries of bacteriorhodopsins and halorhodopsins in previous decades had.

A number of scientists have confided to me that they had considered inserting bacterial or algal opsin genes in neurons and trying to control the altered cells with light but had abandoned the idea. Animal cells were unlikely to manufacture the microbial proteins efficiently or safely, and the proteins were virtually certain to be too slow and weak to be effective. Furthermore, to function, the proteins would require an additional cofactor—a vitamin A–related compound called all-*trans* retinal to absorb the photons. The risk of wasting time and money was far too great.

Nevertheless, for the bioengineering research team I had assembled at Stanford University, the motivation to improve understanding in clinical psychiatry was more than enough to justify the extremely high risk of failure. During my psychiatric residency, I had witnessed firsthand the weaknesses and side effects of medications and treatments such as electroconvulsive therapy. This experience contributed to my willingness to take the plunge, and so as a principal investigator at Stanford in 2004 I formed a team that included graduate students Edward S. Boyden and Feng Zhang to address this challenge. I introduced channelrhodopsin-2 into mammalian neurons in culture by the well-established techniques of transfection—that is, by splicing the gene for ChR2 and a specific kind of on switch, or promoter, into the genes of a vector (such as a benign virus) that ferried the added genetic material into the cells. Promoters can ensure that only selected kinds of neurons (such as only those able to secrete the neurotransmitter glutamate) will express, or make, the encoded opsin proteins.

Against all odds, the experiment worked—and worked surprisingly well. Using nothing more than safe pulses of visible light, we attained reliable, millisecond-precision control over the cells' patterns of firing of action potentials—the voltage blips, or impulses, that enable one neuron to convey information to another. In August 2005 my team published the first report that by introducing a single microbial opsin gene into mammalian neurons, we could make the cells precisely responsive to light. Channelrhodopsins (and, eventually as we found, the bacteriorhodopsin from 1971 and the halorhodopsins, too) all proved able to turn neurons on or off, efficiently and safely in response to light. They worked in part because, in an unexpected gift from nature, mammalian tissues happen to contain naturally robust quantities of all-*trans* retinal—the one chemical cofactor essential for photons to activate microbial opsins—so nothing beyond an opsin gene needs to be added to targeted neurons.

Our initial report appeared in 2005, and a year later my Stanford colleague Mark Schnitzer and I named the approach "optogenetics" in a review paper. By then, laboratories across the world were employing it, using versions of these genes that my team had synthesized to work optimally in mammalian cells. As of today, we have sent those genes to around 700 labs.

IMPROVING ON NATURE

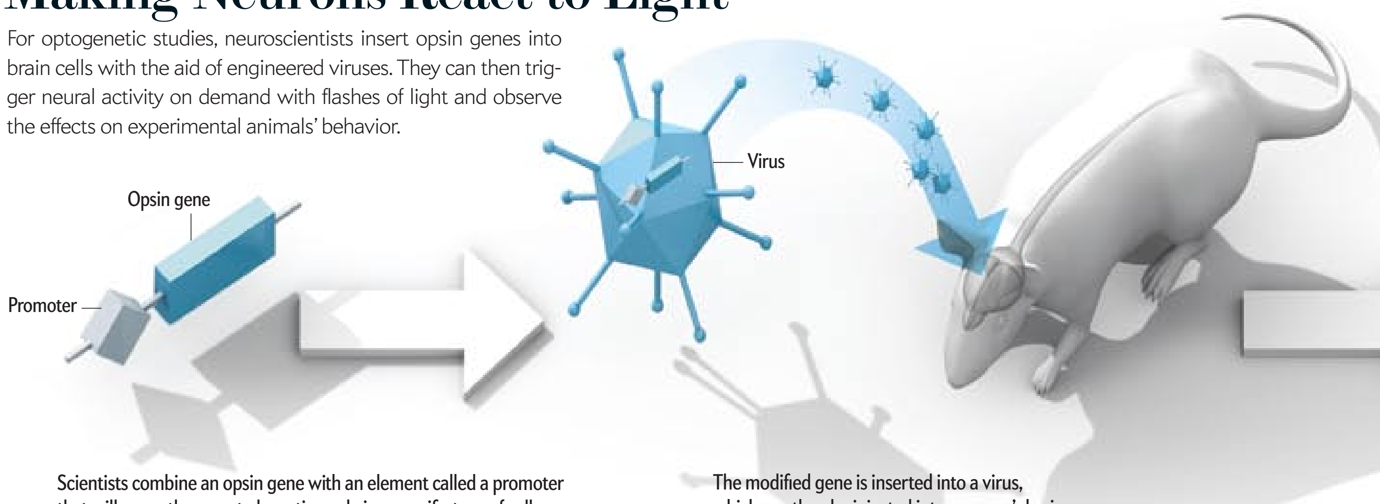
The number of optogenetic tools, along with the variety of their capabilities, has expanded rapidly because of an astonishing convergence of ecology and engineering. Investigators are adding new opsins to their tool kit by scouring the natural world for novel ones; they are also applying molecular engineering to tweak the known opsins to make them even more useful for diverse experiments in a wider range of organisms.

In 2008, for instance, our genome searches led by Feng Zhang on a different algal species, *Volvox carteri,* revealed a third channelrhodopsin (VChR1), which responds to yellow light instead of blue, as we showed with Hegemann. Using VChR1 and the

PROCEDURES

Making Neurons React to Light

For optogenetic studies, neuroscientists insert opsin genes into brain cells with the aid of engineered viruses. They can then trigger neural activity on demand with flashes of light and observe the effects on experimental animals' behavior.



Scientists combine an opsin gene with an element called a promoter that will cause the gene to be active only in a specific type of cell.

The modified gene is inserted into a virus, which can then be injected into a mouse's brain.

Illustration by Bryan Christie

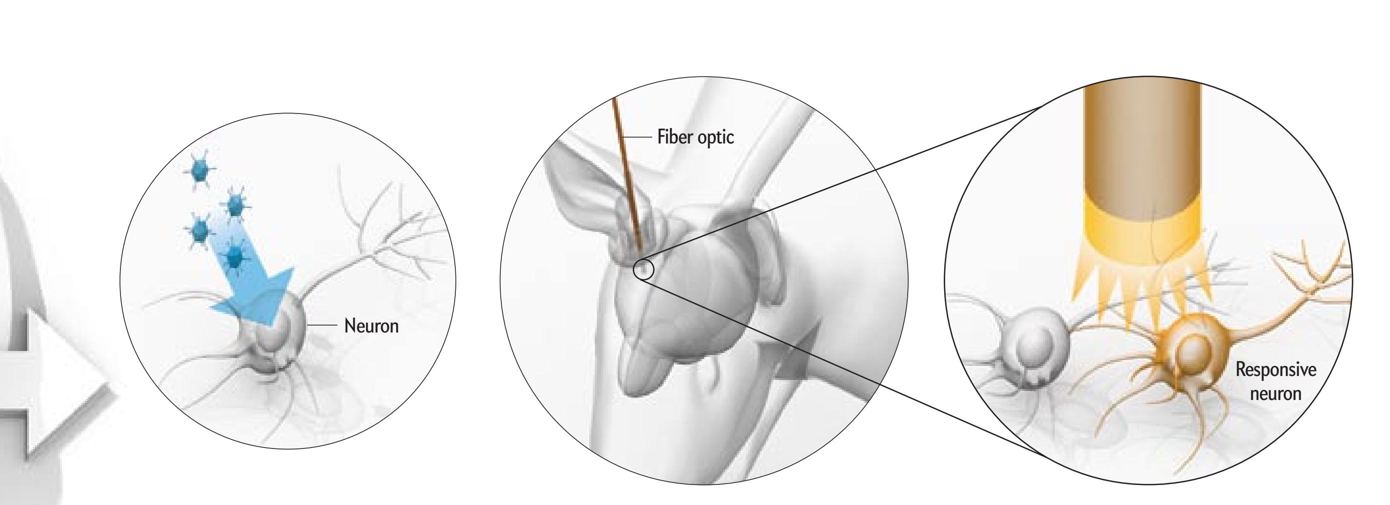
other channelrhodopsins together, we can simultaneously control mixed populations of cells, with yellow light exerting one type of control over some of them and blue light sending a different command to others. And we now have found that the most potent channelrhodopsin of all is actually a hybrid of VChR1 and ChR1 (with no contribution at all from ChR2). Our other modified opsins (created with Ofer Yizhar, Lief Fenno, Lisa Gunaydin, and Hegemann and his students) now include "ultrafast" and "ultraslow" channelrhodopsin mutants that offer exquisite control over the timing and duration of action potentials: the former can drive action potentials more than 200 times per second, whereas the latter can push cells into or out of stable excitable states with single pulses of light. Our newest opsins can also now respond to deep red light bordering on the infrared, which stays more sharply focused, penetrates tissues more easily and is very well tolerated.

Molecular engineering has also extended optogenetic control beyond cells' electrical behaviors to their biochemistry. A large fraction of all approved medical drugs act on a family of membrane proteins called G-protein-coupled receptors. These proteins sense extracellular signaling chemicals, such as epinephrine, and respond by changing the levels of intracellular biochemical signals, such as calcium ions, and thus the activity of the cells. By adding the light-sensing domain from a rhodopsin molecule to G-protein-coupled receptors, Raag D. Airan and others in my laboratory developed a set of receptors called optoXRs that respond rapidly to green light. When viruses insert genetic constructs for optoXRs into the brains of lab rodents, the optoXRs provide us with control over biochemical events in the animals while they are moving freely within a cage. Fast and cell type–specific optical control over biochemical pathways is now therefore possible, both in laboratory dishes and in untethered mammals; this control over biochemistry opens the door to optogenetics in essentially every cell and tissue in biology.

Many of the natural opsin genes now being discovered in various microbes' genomes encode proteins that mammalian cells do not make well. But Viviana Gradinaru in my group has developed a number of general-purpose strategies for improving their delivery and expression. For example, pieces of DNA can be bundled with the opsin genes to act as "zip codes" to ensure the genes are transported to the correct compartments within mammalian cells and translated properly into functional proteins. And with fiber-optic tools we developed in 2006 and 2007, investigators can now deliver light for optogenetic control to any area of the brain—whether surface or deep—in freely moving mammals. And to enable simultaneous readouts of the dynamic electrical signals elicited by optogenetic control, we have developed millisecond-scale instruments that are integrated hybrids of fiber optics and electrodes (which we call "optrodes").

The motivation to improve understanding in clinical psychiatry was more than enough to justify the extremely high risk of failure.

A beautiful synergy can emerge between optical stimulation and electrical recording because the two can be set up to not interfere with each other. We can now, for instance, directly observe the changing electrical activity in the neural circuits involved in motor control at the same time as we are optically controlling those circuits with microbial opsins. The more rich and complex the optogenetic inputs and electrical outputs of neural circuits become, the more we will be able to move toward a form of reverse engineering for neural circuitry: we will be able to infer the computational and informational roles of neural circuits from how they transform our signals. Reverse-engineering healthy neural circuits will offer wonderful opportunities for determining which properties and activities differ in psychiatric and neurological disease states. That knowledge, in turn, should



The virus infects many nerve cells, but because of the promoter only one type of neuron makes the opsin protein.

Fiber-optic probes inserted into the animal's brain can flash light on the brain to control specific patterns of neural activity.

help guide efforts to find interventions able to restore normalcy in those circuits.

REVERSE-ENGINEERING THE MIND

The importance of optogenetics as a research tool, particularly in conjunction with other technologies, continues to grow rapidly. In recent years neuroscience has made many advances based on the brain-scanning technique called functional magnetic resonance imaging (fMRI). These scans are usually billed as providing detailed maps of neural activity in response to various stimuli. Yet strictly speaking, fMRI only shows changes in blood-oxygen levels in different areas of the brain, and those changes are just a proxy for actual neural activity.

Some nagging uncertainty has therefore always surrounded the question of whether these complex signals can be triggered by increases in local excitatory neural activity. This past May, however, my laboratory used a combination of optogenetics and fMRI (ofMRI) to verify that the firing of local excitatory neurons is fully sufficient to trigger the complex signals detected by fMRI scanners. In addition, the pairing of optogenetics and fMRI can map functional neural circuits with an exactness and completeness not previously possible with electrodes or drugs. Optogenetics is thereby helping to validate and advance a wealth of scientific literature in neuroscience and psychiatry.

Indeed, the impact of optogenetics has already been felt directly on some questions of human disease. In animals, we have employed optogenetics on a kind of neuron (hypocretin cells) deep in a part of the brain previously implicated in the sleep disorder narcolepsy. Specific types of electrical activity in those neurons, we have found, set off awakening. Finding a way to induce that neural activity clinically might therefore offer a treatment someday, but most important is the scientific insight that specific kinds of activity in specific cells can produce complex behaviors.

Optogenetics is also helping to determine how dopamine-making neurons may give rise to feelings of reward and pleasure. My team optogenetically induced differently timed bursts of activity in well-defined sets of dopamine neurons in freely moving mice. We identified the stimulus patterns that appeared to drive a sense of reward for the animals. In the absence of any other cue or reward, mice chose to spend more time in places where they had received particular kinds of bursts of activity in their dopamine neurons. This information is useful for teasing out the cellular activity underlying both the normal reward process and the pleasure-system pathologies involved in depression and substance abuse.

The optogenetic approach has also improved our understanding of Parkinson's, which involves a disturbance of information processing in certain motor-control circuits of the brain. Since the 1990s some Parkinson's patients have received a measure of relief from a therapy called deep-brain stimulation, in which an implanted device similar to a pacemaker applies carefully timed oscillating electric stimuli to certain areas far inside the brain, such as the subthalamic nucleus.

Yet the promise of this technique for Parkinson's (and indeed for a variety of other conditions) is partially limited because electrodes stimulate nearby brain cells unselectively and medical understanding of what stimuli to apply is woefully incomplete. Recently, however, we have used optogenetics to study animal models of Parkinson's and gained fundamental insight into the nature of the diseased circuitry and the mechanisms of action of therapeutic interventions.

We have found, for example, that deep-brain stimulation may be most effective when it targets not cells but rather the

MOLECULAR ASSETS

An Expanding Tool Kit of Useful Genes

Scientists continue to expand the capabilities of optogenetics by tinkering with the genes of known opsins and by searching for those of additional light-responsive proteins in nature. New opsins with desirable characteristics, used alone or in combination, enable researchers to solve biological mysteries through once impossible experiments. Below are some valued categories of opsins and their uses.

OPSIN	MICROBE SOURCE	WAVELENGTH SENSITIVITY	USES
Ultrafast channelrhodopsin (ChR2) mutants	*Chlamydomonas reinhardtii* alga	470 nanometers (maximum activation)	For rapid on/off activation of firing in neurons with millisecond precision, up to 200 times per second
Step function opsins (ultraslow ChR2 mutants)	*Chlamydomonas reinhardtii* alga	470 nm for switching on; 546 nm for switching off some mutants	For switching cells in and out of excitable states with only brief flashes of light. Because of their light sensitivity, they are particularly useful for experiments in which light must penetrate through substantial volumes of tissue (as in the brains of mammals)
VChR1 channelrhodopsin	*Volvox carteri* alga	535 and 589 nm	For activating neural firing. Because VChR1 responds to yellow light and ChR2 responds to blue, both types of opsins can be used together to simultaneously and independently control firing in co-mingled populations of neurons
OptoXRs	Synthetic, based on rhodopsin and G-protein-coupled receptors	500 nm	For fast and cell type–specific control over biochemical pathways, rather than electrical signals, in targeted cells. Can be used in free-roaming experimental animals

MORALITY

Does Optogenetics Challenge Ethics?

Optogenetics now joins the ranks of brain-modulation technologies, such as psychoactive drugs and surgical interventions, that are strong enough to raise ethical and philosophical questions. Yet if we look at it one way, optogenetics is actually safer and less fraught with ethical considerations than those older strategies. The increased power and specificity of optogenetics are coupled to its technological complexity: it would be virtually impossible to use optogenetics on an unwitting or unwilling patient.

More subtle (and perhaps more interesting) new issues arise from the precision of optogenetics, however. At some level, all aspects of our personalities, priorities, capabilities, emotions and memories arise from electrical and biochemical events within particular sets of neurons in particular temporal patterns. Controlling those key components of the mind would raise challenging philosophical questions, ranging from when it is appropriate or justifiable to make such modifications to more abstract questions about the very nature and modifiability of the self and the will.

Neural interventions based on surgery, drugs or electrodes have historically been so coarse that those important philosophical issues have been more theoretical than practical; ethicists and the law have only partially addressed them. The psychiatrist is no stranger to this type of question, given even our current medical capabilities to influence human emotions and the psychological construction of reality.

But times change, as the stunning rapidity of developments in optogenetics over the past few years exemplifies. Quantum leaps in the temporal and cellular precision of our interventions require ongoing and thoughtful consideration by society, as all advanced technologies do. Neuroscientists must therefore be prepared to explain carefully to the interested layperson what optogenetics experiments mean (and do not mean) for our understanding and treatment of the human mind. *—K.D.*

connections between cells—affecting the flow of activity between brain regions. And with our colleague Anatol Kreitzer of U.C.S.F., we functionally mapped two pathways in brain movement circuitry: one that slows movements and one that speeds them up and can counteract the parkinsonian state.

We have also learned how to prod one kind of cell, neocortical parvalbumin neurons, to modulate 40-cycles-per-second rhythms in brain activity called gamma oscillations. Science has known for some time that schizophrenic patients have altered parvalbumin cells and that gamma oscillations are abnormal in both schizophrenia and autism—but the causal meaning of these correlations (if any) was not known. Using optogenetics, we showed that parvalbumin cells serve to enhance gamma waves and that those waves in turn enhance the flow of information through cortical circuits.

In my patients with schizophrenia, I see what clearly appear to be information-processing problems, in which mundane random events are incorrectly viewed as parts of larger themes or patterns (an informational problem perhaps giving rise to paranoia and delusions). These patients also suffer from some failure of an internal "notification" mechanism that informs us when thoughts are self-generated (an informational problem perhaps underlying the frightening phenomenon of "hearing voices"). In my patients with autism spectrum disease, rather than inappropriately broad linkages in information, I see overly restricted information processing: they miss the big picture by focusing too narrowly on just parts of objects, people, conversations, and so on. These failures of information processing may lead to failures in communication and social behavior; better understanding of gamma oscillations may therefore provide insights into these complex diseases.

As a physician, I find this work thrilling because we are bringing engineering principles and quantitative technology to bear on devastating, seemingly "fuzzy" and intractable psychiatric diseases. Optogenetics is thus helping to move psychiatry toward a network-engineering approach, in which the complex functions of the brain (and the behaviors it produces) are interpreted as properties of the neural system that emerge from the electrochemical dynamics of the component cells and circuits. It thus fundamentally changes our understanding of how electrically excitable tissues function in health and disease. It has indeed been a long (and unpredictable) journey from marveling at the way a strange bacterial protein—bacteriorhodopsin—reacts to light.

BOUNTY OF THE UNEXPECTED

At meetings of the Society for Neuroscience and some other very large conferences, I have occasionally heard colleagues suggest that it would be more efficient to focus tens of thousands of scientists on one massive and urgent project at a time—for example, Alzheimer's disease—rather than pursue more diverse explorations. Yet the more directed and targeted research becomes, the more likely we are to slow overall progress, and the more certain it is that the distant and untraveled realms of nature, where truly disruptive ideas can arise, will be utterly cut off from our common scientific journey.

The lesson of optogenetics is that the old, the fragile and the rare—even cells from pond scum or from harsh Saharan salt lakes—can be crucial to comprehension of ourselves and our modern world. The story behind this technology underscores the value of protecting rare environmental niches and the importance of supporting true basic science. We should never forget that we do not know where the long march of science is taking us or what will be needed to illuminate our path. SA

MORE TO EXPLORE

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FIND AN EXPANDED VERSION of this article at **www.ScientificAmerican.com/optogenetics**

Matthew L. Wald is a reporter in the Washington bureau of the *New York Times,* where he writes about energy and the environment.

ENGINEERING

How to Build the Supergrid

The U.S. needs a new electric transmission system to deliver cleaner, more reliable power nationwide. Four steps could clear hurdles

By Matthew L. Wald

THE TRANSMISSION GRID THAT DELIVERS ELECTRICITY from power plants is a vital piece of America's infrastructure. It is also good at hiding its flaws. People may notice the towers and wires marching across the landscape or the local substations that step down the voltage so electricity can be distributed to homes and businesses, but the transmission grid does not show congestion like highways do or flooding like burst water mains do. Nevertheless, the grid needs a major upgrade. If the U.S. is going to switch from dirty fossil fuels to cleaner, more renewable wind and solar power—or even nuclear—the transmission system must be vastly expanded to reach the remote deserts and high plains where the sun shines most and the wind blows hardest. Furthermore, if the country wants to protect itself against increasingly large blackouts, which cost tens of billions of dollars or more a year, it needs to modernize the grid as well.

So how do we build this supergrid? After years of debate, most engineers agree that a modern overlay should be added on top of the old, piecemeal, overtaxed system, creating a backbone that has greater capacity by using higher voltages and reaching more remote locations. The Obama administration's 2009 stimulus package allocated $6.5 billion in credit for federal agencies to build power lines and $2 billion in loan guarantees for private companies, so money is available to get started. Constructing the supergrid will require several big technical steps, and one political.

IN BRIEF

An upgraded U.S. transmission system could make electricity cheaper, reduce blackouts, and bring remote wind and solar power to distant cities.

Building this supergrid would likely involve four steps: more transmission lines, higher voltages, direct-current lines spanning the longest distances and short, direct-current ties linking the nation's three isolated transmission regions.

Federal authority to determine the routes of new lines might be needed to overcome resistance by state and local governments, as well as citizens and utility companies. Renewable energy mandates could spur privately funded lines.

TOM GRISCOM *Gallery Stock*

BUILD, BABY, BUILD

THE FIRST STEP is simply to erect more transmission lines, especially extending from potential hotbeds of renewable energy to growing cities where demand is met now with coal-fired plants. New lines would also help regional utilities sell surplus power, when they have it, to utilities that are far away.

Large-scale construction is long overdue. As the country's Investor in Chief Barack Obama said about the current system in October 2009: "Just imagine what transportation was like in this country back in the 1920s and 1930s before the Interstate Highway System was built. It was a tangled maze of poorly maintained back roads that were rarely the fastest or the most efficient way to get from point A to point B."

During the past decade, only a little more than 1,000 miles of high-voltage transmission lines were built each year. But a National Renewable Energy Laboratory study released in January concluded that supplying 20 percent of the country's power with wind would require 22,700 miles of new interstate electrical highways, on top of the more than 160,000 miles of existing high-voltage lines. The sight of workers erecting power lines would be more common than the sight of crews building roads.

In addition to connecting renewables, more lines would solve a vexing surplus problem. In a growing number of markets today, even when demand for electricity is low, certain power plants must run to keep voltage stable across the system, yet there is no demand for the actual power they are producing. At night, when winds are often high, there may be no place to send the electricity they create. In these situations, some transmission managers, such as the California Independent System Operator, are forced to pay power generators such as wind farms to cut their output. And if that still outpaces demand, "you pay people to take [the power]," laments Yakout Mansour, CEO of the California operator.

This imbalance can make clean, renewable energy awfully expensive. Forcing wind turbines to stop producing when the wind is blowing can quickly make them uneconomical. Electric highways can dilute the surplus, sending it to customers who do need power but are far away. More lines can also help spread out voltage surges and dips across a larger area of suppliers and consumers, so the fluctuations can be absorbed without creating dangerous voltage spikes or meddlesome blackouts or brownouts.

More lines would also make storage facilities for mass energy more feasible. Surplus wind energy at night could be stored by any number of technologies that can generate power during the next day when needed: big batteries, flywheels, compressed air chambers, water pumped uphill so it can later fall through turbines, molten salt tanks heated to later drive steam turbines, and so on. But the power needs to reach those facilities in the first place.

PUMP IT UP

MORE TRANSMISSION LINES will better connect generators and users. But transmitting power at higher voltages—the second step to a supergrid—will reduce losses along the wires, saving money and lessening the footprint of power lines running over hill and dale.

Power is lost along a transmission line primarily as heat, yet losses drop significantly as voltage rises. James A. Muntz, manager of transmission at Northeast Utilities, which wants to import more electricity from Canada, has calculated the large loss reductions for a 100-mile line loaded with 800 megawatts (MW), roughly the output of a large coal plant. If the line is operating at 345 kilovolts (kV)—the level used along many backbone wires today—19.8 MW of power is lost. At 765 kV, the highest voltage operated in the U.S. (though not widely used), only 3.45 MW is lost—about one sixth of the losses at 345 kV. For a 1,100-kV line, the loss is a mere 1.91 MW. The Soviet Union once operated a 1,150-kV line, Japan has a similar line and China is building several.

In addition to saving utilities money daily, higher voltages could help regional planners reduce the land and construction costs required for power lines. One 765-kV line can carry as much energy as six 345-kV lines, according to Michael Heyeck, a transmission executive at American Electric Power, which is the largest U.S. operator of such lines. A 765-kV line requires a footprint along the ground that is 200 feet wide, but the six 345-kV lines require 900 feet. The standard 765-kV power line tower is 135 to 150 feet high, however, significantly taller than 345-kV towers, which typically reach 110 to 125. As voltage rises, the lines need more clearance above the ground, yet the public generally looks on higher towers as more visually intrusive.

Transmitting power at higher voltages—the second step to a supergrid—will reduce losses along the wires, saving money and lessening the footprint of power lines running over hill and dale.

In January 2008 American Electric Power and the U.S. Department of Energy unveiled one possible plan to lay a nationwide 765-kV backbone over the existing transmission system—the way interstate highways overlay local roads—to greatly expand the grid's capacity and lower its losses. The backbone would require 22,000 miles of 765-kV lines, of which 3,000 miles already exist. The network would cost about $60 billion. But billions of dollars could be saved every year because of significantly lower losses and because expensive local power could more readily be displaced with inexpensive power from places the grid does not now reach.

GO DIRECT

TO FURTHER REDUCE LOSSES, engineers recommend that lines along the most heavily traveled corridors use direct current, instead of the standard alternating current supplied to virtually all homes and businesses. Muntz calculates that the same 100-mile line loaded with the same 800 MW, but operating at 500 kV of direct current, would lose 3.82 MW, less than half the alternating-current losses at the same voltage. Push the line up to 800 kV, and losses drop to 1.5 MW, also less than half for a 765-kV alternating-current line.

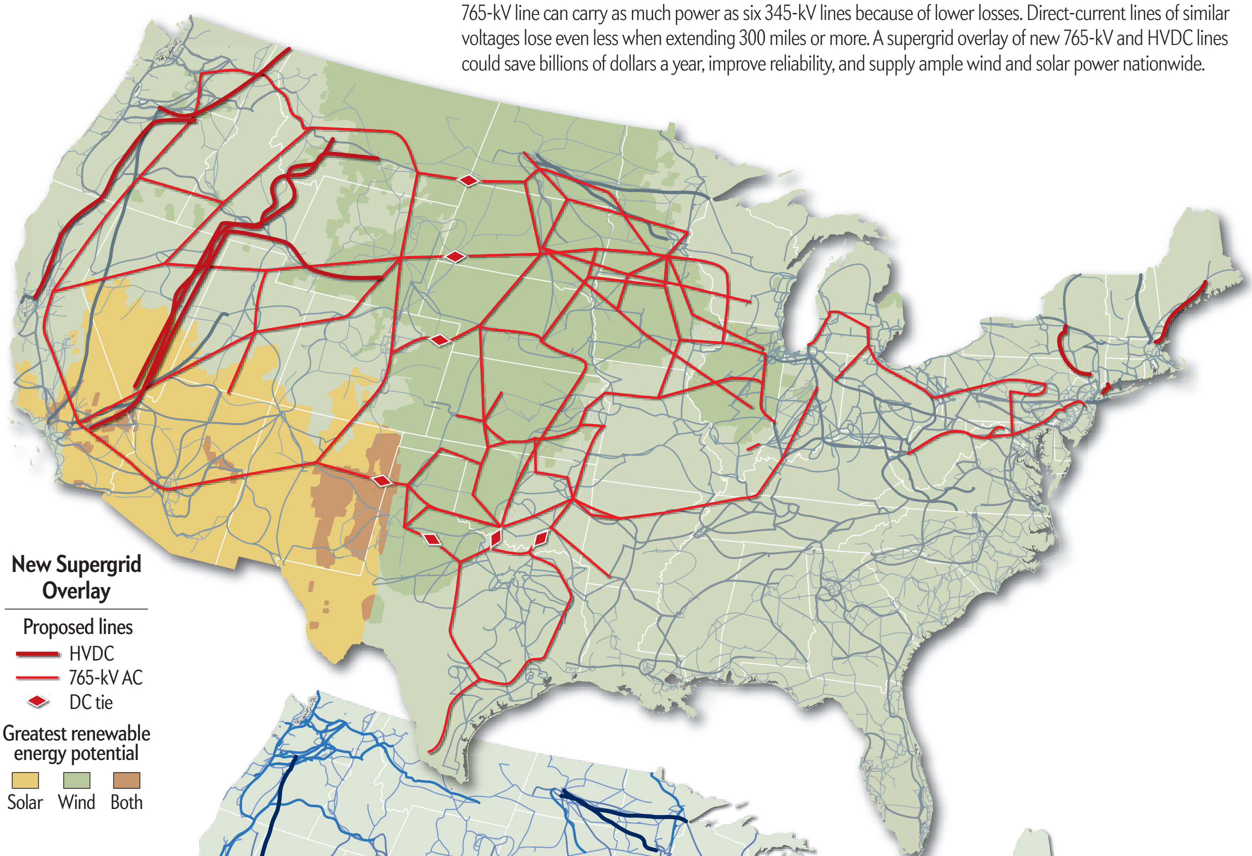
Direct current is desirable for point-to-point transmission, with no stops in between. It is already used between hydroelectric dams in northern Quebec and New England and between dams on Oregon's Columbia River and southern California. In these cases, direct current was selected because it is efficient and is controllable. Alternating current follows the path of least resistance, buzzing along random wires like water on a mountaintop trickling down various streams to a pool at the base. A

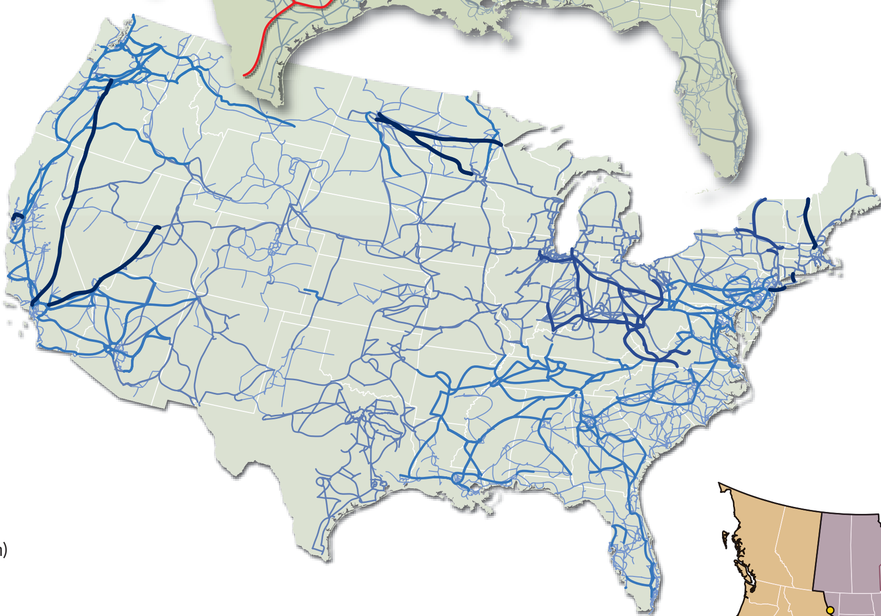
Future Highways for Electricity

The U.S. transmission system (*middle map*), which brings electricity from power plants to neighborhood substations, does not adequately reach areas rich in wind and solar power and is prone to outages. Overlaying a robust backbone of high-voltage lines (*top*) could solve both problems. At a minimum, the nation's three regional grids could be tied together (*bottom*) to improve reliability for all.

Bulking Up Transmission

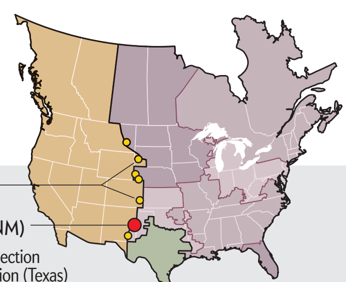
Today's system has few 765-kilovolt alternating-current (AC) and high-voltage direct-current (HVDC) lines. One 765-kV line can carry as much power as six 345-kV lines because of lower losses. Direct-current lines of similar voltages lose even less when extending 300 miles or more. A supergrid overlay of new 765-kV and HVDC lines could save billions of dollars a year, improve reliability, and supply ample wind and solar power nationwide.





Three Regions Become One

The three grids that serve the U.S. and Canada are joined by only a few weak links. Weaving them together with more direct-current (DC) ties would counteract instabilities and help utilities sell surplus power. One company, Tres Amigas, is planning an alternative: a massive hub that would integrate the grids with superconducting cables.



SOURCES: PLATTS, A DIVISION OF MCGRAW-HILL (*transmission lines*); NATIONAL RENEWABLE ENERGY LABORATORY (*potential solar and wind energy regions*)

Maps by XNR Productions

direct-current line is like a pipe from top to bottom, with a pump that can be adjusted in real time.

Control is important because of the balkanized nature of the power grid, made of hundreds of local networks with separate owners. When a seller sends electricity to a buyer far away, the power will flow along whichever wires it chooses, potentially causing overloads in various places between the end points that have no commercial relation to the deal.

Direct-current cables have been opened in the past few years between the New Jersey coast and the southern side of New York's Long Island and across Long Island Sound to Connecticut. In both cases, finding an acceptable underwater route was much easier than it would have been across the heavily congested metropolitan areas, and the lines provided express power flows. The 53-mile Trans Bay Cable was recently opened along the bottom of San Francisco Bay, carrying 400 MW. Control is so smooth that utility officials closed old, relatively dirty generating stations in San Francisco that had been operated to improve the voltage and frequency stability of the area's alternating-current networks.

Despite the advantages, direct-current lines are worthwhile only if installed over long distances. That is because special converter stations are needed at each end to change alternating current to direct current and back again. The conversion requires massive electronics that eat up around 1 percent of the electricity at each end. According to Andrew Phillips, director of transmission at the Electric Power Research Institute, with declining costs, the break-even point has moved down to about 300 to 350 miles, compared with 500 miles 15 years ago.

If configured smartly, long direct-current lines could form a backbone across the continent that would differ from American Electric Power's 765-kV plan, which employs direct current sparingly. The National Renewable Energy Laboratory study calls for 10 massive, 800-kV east-west direct-current connections from the Plains states to the Atlantic coast, although it did not specify routes. At a conference on building Midwest wind farms to supply the East Coast, Dale Osborn, transmission technical director of the Midwest Independent System Operator, said that direct current is the only technology that would guarantee that the power would get to exactly where it was needed. The complication is that tapping into a line at a midpoint, the equivalent of a highway interchange, is extremely expensive.

KNIT THE NATION TOGETHER

MORE LONG-DISTANCE transmission lines, at higher voltages, whether alternating or direct current, could form a supergrid that strengthens and extends the existing transmission system. Such lines would have to be built at a scale greater than planning has traditionally been practiced, however. The challenge is particularly acute with direct-current wires: an alternating-current line can be lengthened in increments, like extending a road a few miles at a time, but a direct-current line is like a bridge, with a fixed beginning and end.

Transmission has almost always been built piecemeal, within the territory of one utility or two neighboring utilities. The siting of new lines and obtaining rights-of-way always face bureaucratic hurdles and usually public opposition. A third challenge arises nationally, because the Lower 48 states are divided into three giant power grids: the Eastern Interconnection from the Rockies eastward, the Western Interconnection from the Rockies westward, and Texas. The three grids have largely functioned as independent islands for decades, and the eastern network is also subdivided like a jigsaw puzzle into regional pieces.

In an effort to modernize, regional operators in the Eastern Interconnection unveiled a plan in 2009 for a systemwide upgrade that would enable wind power to meet 20 percent of the grid's energy needs by 2024. The plan called for 15,000 miles of overlaid transmission lines, half of which would be direct current. The map did not specify routes, but the lines could run along existing utility rights-of-way or along railroad lines or even highways.

The plan got stymied in part over how cost would be apportioned. One option would be "merchant" lines, the equivalent of toll roads built by private companies, a few of which exist today. But this arrangement works only when the buyer and seller can be precisely linked, meaning, only for direct current. An option for alternating-

Massive electronics convert alternating current to direct current for Trans Bay Cable's 53-mile, high-voltage line that runs along the bottom of San Francisco Bay.

COURTESY OF TRANS BAY CABLE LLC

current lines is to split the cost among the generators and consumers who will be served; however, some regional transmission organizations that have tried this scheme have had long arguments about the formula. The Southwest Power Pool proposed a cost-allocation system, approved by the Federal Energy Regulatory Commission in June, under which higher-voltage lines are treated as highways and costs are divided among all utilities in the area. Lower-voltage lines are treated as byways; like local streets, their costs are borne locally. Costs for lines with intermediate voltage would be shared.

A plan to upgrade the Northeast fell apart when New York and New England claimed the plan favored tapping wind energy on the Great Plains and not the Atlantic coast.

But that arrangement will not work for direct current, because the lines provide no benefit for anybody who is not at either end. A line that began in the Dakotas and ended in Chicago would be useless to Minnesota, Wisconsin and Iowa. For such a line, the cost of transmission might be built into the cost of electricity, a technique that Hydro Quebec is trying in a new line that will serve New England.

The troubled plan for the Eastern Interconnection finally fell apart when New York and New England states claimed that the plan had a bias toward tapping wind energy on the Great Plains and sending it to the eastern seaboard. The eastern states said the plan would preclude developing wind resources off the Atlantic coast, and they walked out.

A different attempt to integrate the three giant power grids is under way in New Mexico, in a spot close to where the three large interconnections touch. The region also happens to have plentiful wind and solar resources.

The three systems are not connected now, because their alternating currents are not synchronized. In each grid, the electrons alternate direction 60 times a second, at precisely the same moment, like Rockettes dancing in a chorus line. But the three sets of currents do not dance together; they are timed to different drummers.

Swapping energy among them requires switching the alternating current from one region to direct current, tying it to an adjacent region, then switching it to alternating current at the correct synchrony. Eight direct-current ties exist among the three interconnects, but they can transfer only a modest 1,500 MW of power, the equivalent of two large coal plants.

A private venture called Tres Amigas proposes a single transfer station in Clovis, N.M., that would move power among all three interconnects on a larger scale. Silicon-based power electronics—not the fingernail-size chips in a computer but hunks of semiconductor the size of a stack of dinner plates—would chop the flow of alternating current into tiny pieces and reassemble it as direct current. The current would then move through superconducting cables, with extremely low losses, to another terminal where more semiconductors would reassemble the power into alternating current. The transfer station, estimated to cost $1 billion, could handle 5,000 MW of power flows and could be expanded to 30,000 MW if more robust power electronics were devised. The huge tie would act as an anchor for the three systems, transferring power and counteracting voltage instabilities.

Tres Amigas would make money by charging for power transfers and possibly by facilitating a market for selling and buying power, as the New York Stock Exchange does for stocks. It could also sell its stabilization of voltage and frequency as a service.

Hurdles loom, though. For example, Texas is not now regulated by the Federal Energy Regulatory Commission, and companies there do not want to be. Yet the state could benefit. “Texas has built all this wind and is up against the wall” with not enough local customers to buy it, says Phillip G. Harris, chief executive of Tres Amigas and a former president of the nation’s largest independent system operator, PJM. Other locations with extensive renewable energy would have a way to ship it, too.

ACTION OR OBSTRUCTION

ONE OF THE GREATEST HURDLES facing a truly national supergrid is the geographical and financial scale. For the federal government to organize and fund it, as it did for interstate highways, a strong national mandate for renewable energy would probably be needed. Another pathway would be setting a dependable price on carbon-based fuels or carbon dioxide emissions that either creates a pot of money or gives renewable energy an edge, which could spur private-sector funding of a supergrid to deliver it.

At the moment, though, the prospects are uncertain. Transmission planning remains a state-level exercise, because states generally control land-use decisions. Without a strong push from a renewable energy mandate or a carbon charge, “there does not appear to be a great deal of stomach for a national plan for transmission,” concludes Jay Apt, executive director of Carnegie Mellon University’s Electricity Industry Center.

Indeed, in March a newly formed Coalition for Fair Transmission Policy, made up of giant investor-owned utilities, public power cooperatives, congressional Democrats and Republicans, and state energy officials, voiced opposition to a strong national electric grid, centrally planned and broadly financed, that would promote renewable energy. The group is trying to block the Federal Energy Regulatory Commission from approving a series of major transmission pathways from wind-rich areas in the middle of the continent to load centers across the nation. Other critics question whether the commission even has the authority to approve such lines. Senator Ron Wyden of Oregon, a coalition member, compares the proposed power lines to gas pipelines that would carry fuel between New York and northern California but might pass through Oregon, “with no direct benefit to the people in my state.” A modern network could benefit people in all states, however, by bringing more efficient, less expensive power to interconnected grids everywhere and reducing the likelihood of blackouts. SA

MORE TO EXPLORE

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A plan to connect North America’s three separate grids: **www.tresamigasllc.com**

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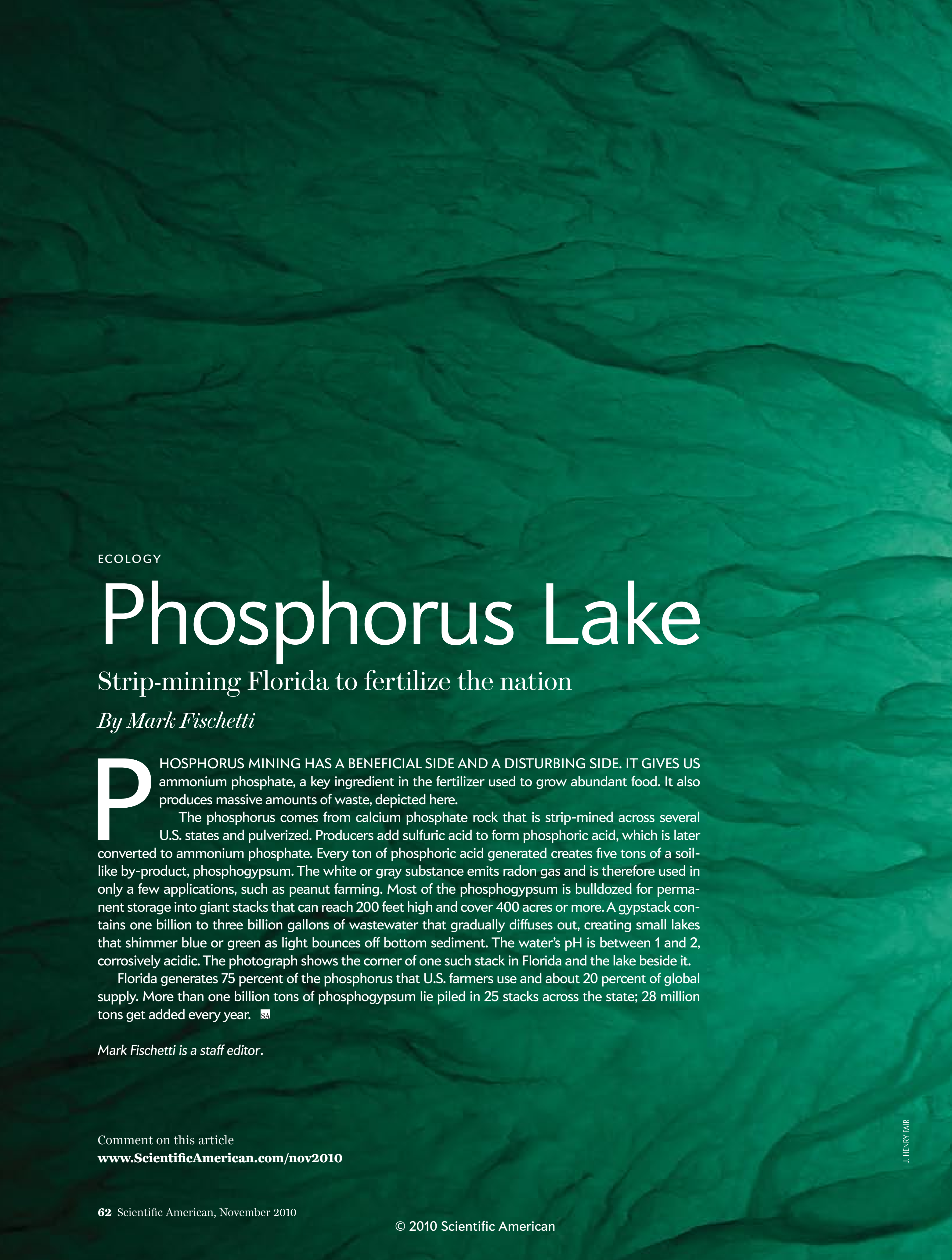

ECOLOGY

Phosphorus Lake

Strip-mining Florida to fertilize the nation

By Mark Fischetti

PHOSPHORUS MINING HAS A BENEFICIAL SIDE AND A DISTURBING SIDE. IT GIVES US ammonium phosphate, a key ingredient in the fertilizer used to grow abundant food. It also produces massive amounts of waste, depicted here.

The phosphorus comes from calcium phosphate rock that is strip-mined across several U.S. states and pulverized. Producers add sulfuric acid to form phosphoric acid, which is later converted to ammonium phosphate. Every ton of phosphoric acid generated creates five tons of a soil-like by-product, phosphogypsum. The white or gray substance emits radon gas and is therefore used in only a few applications, such as peanut farming. Most of the phosphogypsum is bulldozed for permanent storage into giant stacks that can reach 200 feet high and cover 400 acres or more. A gypstack contains one billion to three billion gallons of wastewater that gradually diffuses out, creating small lakes that shimmer blue or green as light bounces off bottom sediment. The water's pH is between 1 and 2, corrosively acidic. The photograph shows the corner of one such stack in Florida and the lake beside it.

Florida generates 75 percent of the phosphorus that U.S. farmers use and about 20 percent of global supply. More than one billion tons of phosphogypsum lie piled in 25 stacks across the state; 28 million tons get added every year. SA

Mark Fischetti is a staff editor.

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J. HENRY FAIR

PHYSICS

Dr. Unification

For years the cosmos and the atom have been at odds with one another. If any physicist can reconcile them, it's Steven Weinberg

Interview by Amir D. Aczel

STEVEN WEINBERG CAME UP WITH A GOOD IDEA ONE DAY while driving his red Camaro. The paper he wrote, "A Model of Leptons," was just two and a half pages long—including references and acknowledgments. When it came out in 1967, it was largely ignored. But it became one of the most quoted physics papers ever and helped to earn Weinberg the 1979 Nobel Prize, shared with Abdus Salam and Sheldon Glashow.

In those two and a half pages, Weinberg showed that two of the four forces of nature, electromagnetism and the weak nuclear force, which outwardly seem completely different, could be different aspects of a single unified set of "electroweak" forces. This theory predicted the existence of a new neutral particle among those that carry out the action of the weak force, known as the weak bosons. And he showed how the innate symmetry of the electroweak forces becomes hidden or, as physicists say, "spontaneously broken," so that we perceive electromagnetism and the weak force as dissimilar. This symmetry-breaking process endows particles such as quarks with mass.

Weinberg also contributed to a theory of a third force of nature, the strong nuclear force. Together these theories form the prevailing explanation of the material world, the Standard Model of particle physics.

Since then, Weinberg has continued to plumb the depths of nature, proposing theories that go beyond the Standard Model and hold hope of creating a fully unified theory—one that includes not only electromagnetism and nuclear forces but also gravity. Weinberg did early work on the leading candidate for a unified theory, string theory. He also has written books for general readers, most recently *Lake Views,* a collection of essays. SCIENTIFIC AMERICAN asked physicist Amir D. Aczel of Boston University to speak with Weinberg about the prospects of these theories, now that the Large Hadron Collider (LHC), the mammoth particle accelerator at CERN near Geneva, is hunting for the Higgs and other particles.

SCIENTIFIC AMERICAN: The Large Hadron Collider has been running for six months now, and there is a lot of

IN BRIEF

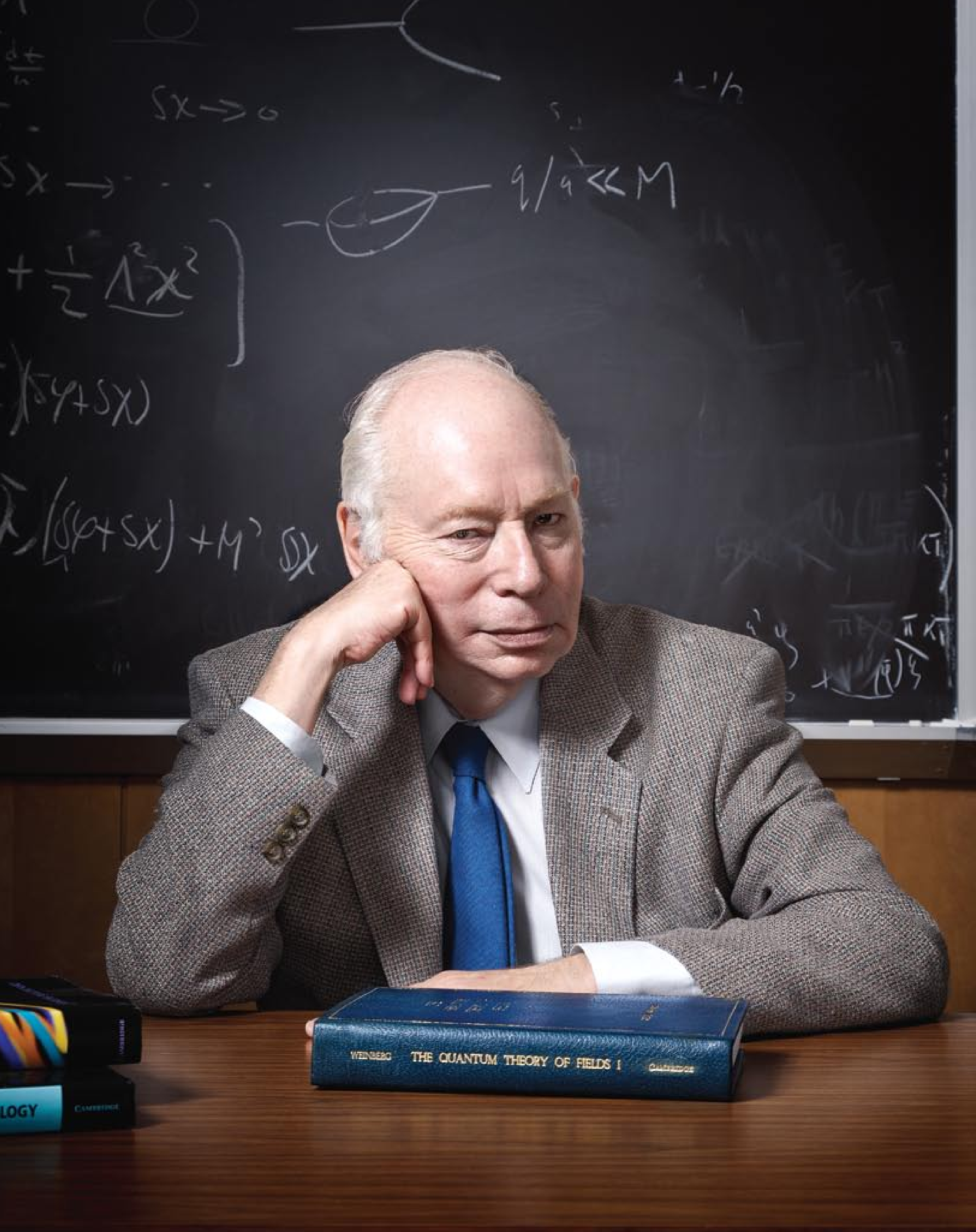
Creating a unified theory of nature is the highest goal of modern physics, and few have contributed as much to achieving it as Steven Weinberg of the University of Texas at Austin.

In the 1960s Weinberg helped to develop two pillars of the Standard Model: the unification of electromagnetism and the weak nuclear force, and the theory of the strong nuclear force.

Since then, he has contributed to efforts to complete the unification, such as string theory, by including the only force of nature that the Standard Model does not cover: gravity.

Weinberg has also applied particle physics to cosmology. His model explaining dark energy in terms of parallel universes is the most widely cited argument in favor of a multiverse.

Photograph by Jeff Wilson


WEINBERG
THE QUANTUM THEORY OF FIELDS I
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excitement about it. Some people have even compared its expected results with the quantum and relativity revolutions of the first third of the 20th century. What is your view?
WEINBERG: I think that it is exciting. Conceivably, it could produce a revolution in our thinking about physics comparable to the great revolutions of the early 20th century, but there is no reason to expect that. A revolution like that would be through something completely unanticipated—and so I can't anticipate it!

In the near term, we're trying to take the next steps beyond the Standard Model and also get to the point where we can confidently say something about what was going on in the early universe. That's going to take a while. Beyond that, we look forward to tying it all up—to having a theory that accounts for all particles and forces. We don't know what it will look like.

I do think that when we have a really comprehensive understanding of nature at the most fundamental level, it will percolate out into society in general. It will probably be very mathematical, and it will be a long time before the general public understands it, just as it took a long time before even scientists understood Newton's theory. Eventually, though, the Newtonian picture of the world had a profound influence on the way people in general thought about the world and human life. It had effects on economics, biology, politics and religion. I think something like that may happen if we come to a really comprehensive theory of nature.

When we have a really comprehensive understanding of nature at the most fundamental level, it will percolate out into society in general.

I think that our picture of nature is getting more and more all-embracing, and things that previously seemed very puzzling, like the nature of the force that holds particles together inside the atom, are now understood perfectly well—only to be replaced by other mysteries, like why the particles in the Standard Model have the properties they have. And the process of explaining things that have seemed puzzling, while discovering new puzzles, will go on for a long time. It's just a guess, but I think that we'll get to the point where there are no puzzles of this sort. And that will be really quite a remarkable turning point in the intellectual history of the human race.

The Higgs particle is often described as the LHC's first big target, assuming the Tevatron collider at Fermilab does not find it first. How dependent are the electroweak unification and the Standard Model on the Higgs particle?
I would say they're completely dependent on the idea that there is a broken electroweak symmetry. But if you then ask why the symmetry is broken, that's open to question. The symmetry-breaking mechanism that appears in [Salam's and my] electroweak theory requires the existence of a new particle, which has come to be known as the Higgs particle. Our simple picture led to the prediction of the ratio of the masses of the weak bosons, which seems to work beautifully.

But there is also another possibility, that the symmetry is broken instead by new strong forces and that there is no Higgs particle. These new forces have to be very strong, stronger than the ordinary strong force. Lenny Susskind and I independently worked out a theory we agreed to call Technicolor. It would give the same predictions for the masses of the weak bosons as the original electroweak theory, but it has trouble explaining quark masses. Some theorists continue to work on Technicolor and believe it's a viable theory. And it may be true. If it is, the LHC should find it. Those Technicolor forces lead to a whole zoo of new particles.

So even if the LHC doesn't find the Higgs, it can find something that plays an equivalent role, like Technicolor. You can actually show that without any new particles at all, you get into mathematical inconsistencies.

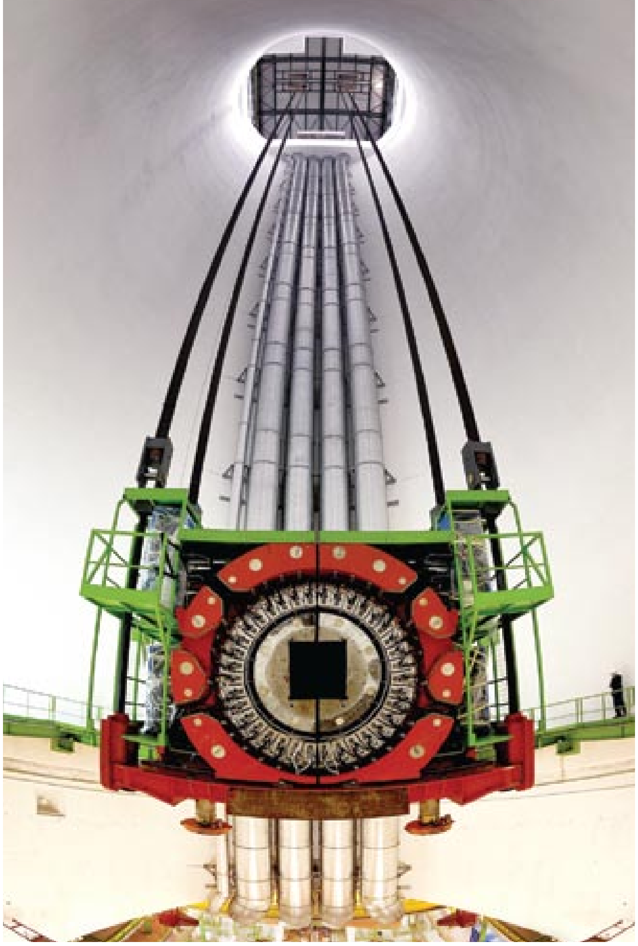
Another principle that physicists hope to confirm at the LHC is supersymmetry, the idea that particles of force, like the weak bosons, and particles of matter, like electrons and quarks, are deeply related. Some physicists are as confident about supersymmetry as Einstein was about relativity—so compelling it must be true. Do you feel the same way?
No, I don't. Special relativity fit in so well with what was already known theoretically and experimentally—with Maxwell's theory of electricity and magnetism, with the fact that nobody could discover effects of the "ether" that people had thought existed. If I were fortunate enough to have invented special relativity in 1905, I would have felt, as Einstein did, that that theory just had to be right.

I don't have that feeling about supersymmetry. It has a number of minor successes. It improves the prediction for a crucial parameter of the Standard Model. It provides a natural candidate for dark matter particles [see "Dark Worlds," by Jonathan Feng and Mark Trodden, on page 38]. It has a beautiful feature—that it's the only conceivable symmetry that could unify particles like weak bosons with particles like electrons. But none of that is impressive enough to convince you that it has to be right.

You've worked on the anthropic principle—the idea that aspects of our universe have no deeper explanation other than that we live in a peculiarly habitable piece of a larger domain. In particular, you've argued that the anthropic principle is our best explanation for the density of dark energy, the mysterious stuff that is causing the expansion of the universe to accelerate. Can you tell us about it?
We speculate a lot about things we see as fundamental, like the masses of the particles, the different varieties of forces, the fact that we live in three space dimensions and one time dimension. But maybe all this is not fundamental but environmental. The universe may be much more extensive than we've imagined, with much more than just the big bang that we see around us. There may be different parts of the universe—where "parts" could mean various things—that have very different properties and in which what we normally call the laws of nature may be different and even the dimensionalities of space and time are different. There has to be some underlying law that describes the whole thing, but we may be much further from it than we now imagine.

When I first wrote about this in 1987—and this is still true—I was pretty open-minded about the various ways in which one could imagine that the universe had different parts, with properties like the density of dark energy varying from one part to another. One way is Andrei Linde's chaotic inflation, in which there are many big bangs, occurring episodically here and there, each having different values of things like the density of dark energy.

As Stephen Hawking has described [see "The (Elusive) Theo-



COURTESY OF CERN

Compact muon solenoid, one of the Large Hadron Collider's detectors, seeks the Higgs particle that Weinberg postulated.

ry of Everything," by Stephen Hawking and Leonard Mlodinow; Scientific American, October], the universe may be in a quantum-mechanical superposition of different states, like Schrödinger's famous cat. Just as it is possible for the cat to be in two states at the same time, in one of which he's alive, in the other of which he is dead, so may the universe. In the state in which the cat is alive, the cat knows he's alive, and in the other state he doesn't know anything. In the same way, there are states of the universe where there are scientists exploring what looks to them like the whole universe, and there are other states where perhaps the universe is too small or goes through its history too rapidly, and there are no scientists and no one to notice what it's like.

Anthropic arguments predict that the dark energy density will be small enough to allow galaxies to form, but not much smaller, because universes in which it is much smaller are rare. Through a calculation I did in 1998 with two astrophysicists at the University of Texas at Austin, Hugo Martel and Paul R. Shapiro, we came to the conclusion that any dark energy had to be big enough to be discovered pretty soon. Soon after, astronomers discovered it.

You bridge two different communities of physicists: those who do cosmology and general relativity and those who do particle physics and quantum theory. Do you think your dual expertise helps you see how to unify these two areas?

I don't see a direction of unification yet. I certainly would like to. I have ideas about possible paths to unification that come out of experience in elementary particle physics. But whether those ideas have anything to do with the real world, it's much too early to say.

String theory is often supposed to be the only way of dealing with infinities in the quantum theory of gravitation, but there is an alternative that's based on quantum field theories of the same general sort as used in the Standard Model, and that I call asymptotic safety. The strength of forces goes to a finite value at high energy. They are prevented from—safe from—going to infinity.

For a long time the idea went nowhere because it's hard to show that theories are or are not asymptotically safe. I did some preliminary calculations, which I thought were encouraging, but it got too hard, and I worked on other things. Then, starting a little before 2000, the subject was picked up by a number of people in Europe, who verified asymptotic safety in various approximations and showed that they are mathematically as well defined as the Standard Model.

How is this approach different from string theory?

It's the opposite of string theory. In string theory you give up on the standard quantum field theory, and you invent something really new. String theory is a big step in a new direction. Asymptotic safety says that good old quantum field theory, of the kind we've been working with for 60 or 70 years, is all you need.

I'm not going to make a big pitch that asymptotic safety is the way to go. If it turned out that the truth is string theory, I wouldn't be surprised. It's beautiful mathematically, and it may really be the right answer. Asymptotic safety is just a possibility that is also worth exploring seriously.

So far neither approach has led to any great breakthrough, such as calculating the mathematical parameters of the Standard Model, the numbers that the model takes as a given, with no real explanation. That would be the real test—for instance, that you understand why particle masses have the ratios they have. Looking at these masses has been a bit like looking at documents in an ancient script like Linear A. We have all this text, but we don't know what it's telling us.

How do you find time to write on things other than physics?

I love physics—I really wouldn't want to go back in time and choose any other career than the one I've chosen. But it's a rather cold and lonely profession, especially for a theorist like me who doesn't work much in collaborations. The work I do has nothing to do with human affairs; human interests and emotions don't enter into it. It can only be understood by a limited number of fellow professionals.

To get out of the ivory tower, I like to think about other things and write about them. Also, like most scientists, I am keenly aware our work is supported by the public and that if we don't try to explain to the public what we're doing and what we hope to do, it's hard to make a case that we deserve their support. SA

Amir D. Aczel *is a research fellow at the Center for Philosophy and History of Science at Boston University, a Guggenheim Fellow and the author of 17 books. His latest,* Present at the Creation: The Story of CERN and the Large Hadron Collider, *came out last month.*

MORE TO EXPLORE

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COMMENT ON THIS ARTICLE **www.ScientificAmerican.com/nov2010**

Mary Carmichael is a senior writer at *Newsweek* covering health and science. She has received various awards, including the Casey Medal for Meritorious Journalism. She has also worked at PBS's *Frontline* and *Mental Floss* magazine and is a co-author of two books. Carmichael is currently a Knight Science Journalism Fellow.

GLOBAL HEALTH

Halting the World's Most Lethal Parasite

A new malaria vaccine, a plan to immunize mosquitoes and other "crazy" ideas have brightened prospects for vanquishing this killer

By Mary Carmichael

RIGHT NOW, SOMEWHERE IN THE WORLD—IN A petri dish in Baltimore, maybe, or in the salivary glands of a laboratory-bred mosquito in Seattle, or in the bloodstream of a villager in Ghana—resides a chemical compound that could help eradicate human history's biggest killer. Scientists have many promising malaria vaccine candidates in the works, and for the first time one has reached advanced human trials. If it or another candidate is even partly effective in people, it could save the lives of millions of children and pregnant women. It would be the only vaccine yet developed against a human parasite, an achievement of Nobel caliber. And it could, in its first-generation form, be distributed in Africa as soon as 2015.

"If all goes well, five years from today, a vaccine could start being implemented in a wide way in six- to 12-week-old children," says Joe Cohen, a scientist who is leading some of the most promising research. "It is a fantastic achievement. We are all very proud of that." This is an extraordinary moment for malaria vaccine research. So why isn't Regina Rabinovich singing from the rooftops?

Rabinovich is a formidable dark-haired woman with an M.D., an M.P.H. and a résumé that includes a stint as director of the PATH Malaria Vaccine Initiative, as well as her current job as head of infectious disease programs at the Bill & Melinda Gates Foundation. But ask her about all the progress that scientists have made in the past few years, and she pauses.

Rabinovich administers one of the world's largest funding

IN BRIEF

Vaccines against malaria have encountered repeated failures. New technological approaches have revived the push for an agent that would provide lifelong immunity.

Late-stage clinical trials will finish this winter on a vaccine that has been under development since the 1980s. It could reduce cases of the most lethal form of malaria by half.

Even as this work moves forward, researchers are proceeding with other strategies for new vaccines, such as a weakened form of the parasite that is cultured in mosquitoes.

Because malaria has been so hard to fight in the past, researchers must moderate outsize expectations to keep hopes from being dashed yet another time if new vaccine candidates fail.

EVA-MARIA PASIEKA *Corbis*

Deadly cargo: The *Anopheles* mosquito carries the malaria parasite responsible for disease and death in much of the tropics.

programs for malaria vaccine R&D, but she will go only as far as to say there are "some things percolating." Pressed about those things, she cautions that some of them, especially the ones that are still in the early stages of research, are "just doomed to break your heart." Her painstaking caution makes sense. For all the challenges malaria researchers have overcome, a new one looms now. As they move closer to the first vaccine for the disease, they must prevent their hopes from tipping over into hype.

The malaria community is all too accustomed to cycles of excitement and heartbreak. In the 1960s an enormous campaign wiped out the disease in many parts of the world and drove its numbers down in others. But that success ultimately bred its own end. As malaria came to be perceived as less of a threat, global health agencies became complacent; their chief tool, DDT, was found to be toxic to birds, and they largely abandoned their efforts. Malaria numbers roared back more fiercely than before. Meanwhile scientists left the field, and vaccine research stagnated.

It is surprising—and shameful—that for so long malaria was neglected by funders and thus by scientists who could not get grants to study it. On the other hand, it is easy to see why people lost hope. Malaria was, after all, a particularly tough organism to fight. Its complex parasitic life cycle—which starts in the salivary glands of mosquitoes, moves to the human bloodstream, shifts to the human liver for a sort of adolescence, comes *back* to the human bloodstream, and finally moves back into the body of a new mosquito—was not well understood until recently. A small group of researchers at GlaxoSmithKline (GSK) made a serious attempt to start up momentum for a vaccine in the mid-1980s, working with a protein from the surface of the common and deadly *Plasmodium falciparum* strain of the parasite. But their first try failed, and the parasite kept on killing a million people every year.

The circumstances could not be more different today. Thanks to a string of innovations and a huge infusion of cash (largely from the Gates Foundation, which has given $4.5 billion to general vaccine development since 1994 and recently upped its pledge to $10 billion for the next 10 years), dozens of malaria vaccine-related projects are now under way, albeit mostly in early stages. And GSK scientists kept reinventing the candidate that began in the 1980s until they got something more promising that has now reached late-stage human trials. It has been proved safe and is now being tested in a large series of randomized clinical trials at 11 sites in Africa in which one group will receive the vaccine and another will be injected with a placebo only. This is the only vaccine to get this far—ever—but promising preliminary clinical research is moving forward on other candidates.

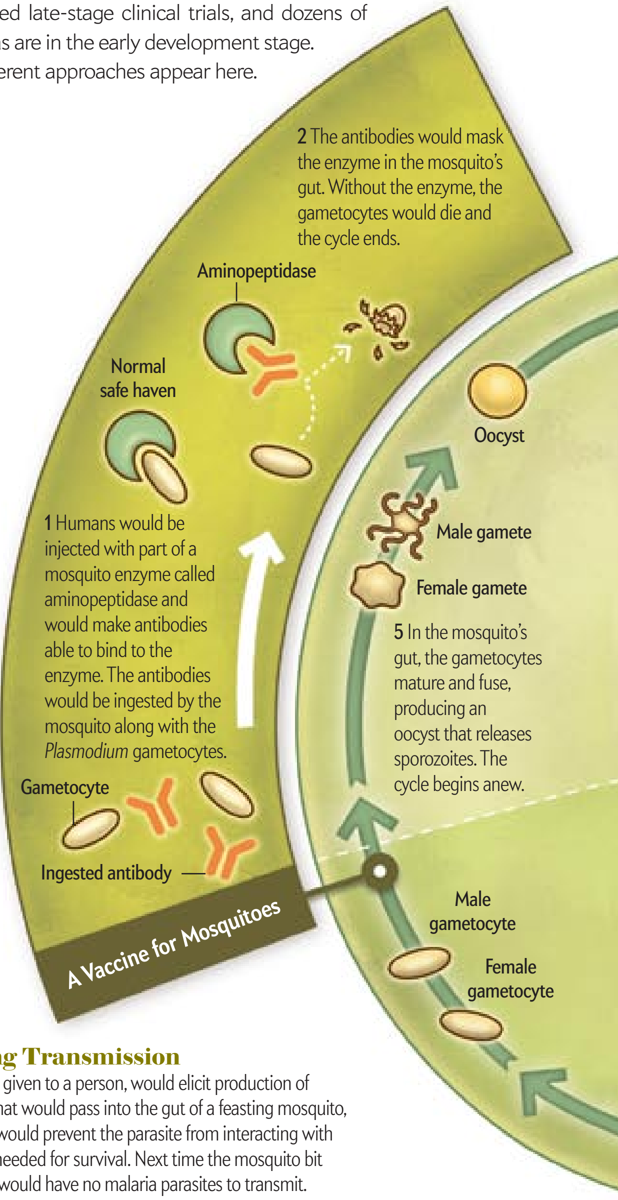
Some researchers are pursuing an unorthodox strategy in phase I (which mostly involves safety testing): culturing genetically weakened parasites inside the bodies of mosquitoes and delicately dissecting the creatures out of the insects' spit glands to fashion them into a vaccine. A third category of vaccines would immunize the mosquitoes that transport the malaria parasite to its human victims, using the human body to deliver antibodies. "We're talking about using people to passively immunize insects," says Rhoel Dinglasan, one of the pioneers of this approach. "It's a bit crazy."

"Crazy," of course, given enough time and luck and hard work, can turn into something "innovative." But for any of these

A NEW ERA

Three Promising Vaccine Strategies

For decades the public health community has tried to devise a vaccine that would confer lifetime immunity against the malaria parasite and help stamp out disease. Yet the effort has always been an exercise in frustration. The complex life cycle of the parasite makes it challenging to know the best way to create an effective vaccine. But the advent of new funding and a spate of innovative ideas have changed the outlook dramatically in recent years. For the first time, a vaccine has reached late-stage clinical trials, and dozens of other ideas are in the early development stage. Three different approaches appear here.



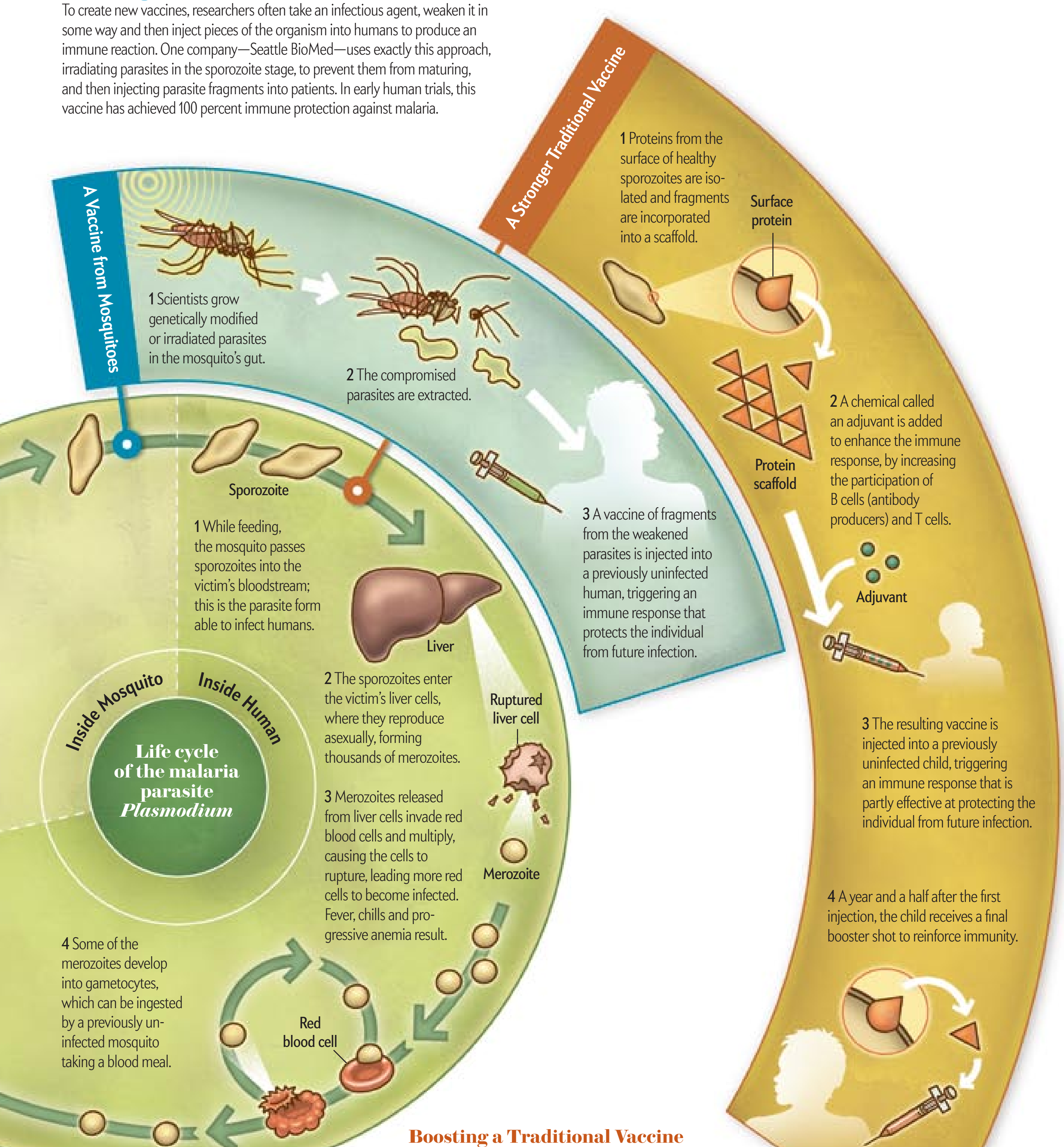
Blocking Transmission

The vaccine, given to a person, would elicit production of antibodies that would pass into the gut of a feasting mosquito, where they would prevent the parasite from interacting with an enzyme needed for survival. Next time the mosquito bit someone, it would have no malaria parasites to transmit.

Illustration by Peter and Maria Hoey

Culturing Weak Parasites

To create new vaccines, researchers often take an infectious agent, weaken it in some way and then inject pieces of the organism into humans to produce an immune reaction. One company—Seattle BioMed—uses exactly this approach, irradiating parasites in the sporozoite stage, to prevent them from maturing, and then injecting parasite fragments into patients. In early human trials, this vaccine has achieved 100 percent immune protection against malaria.

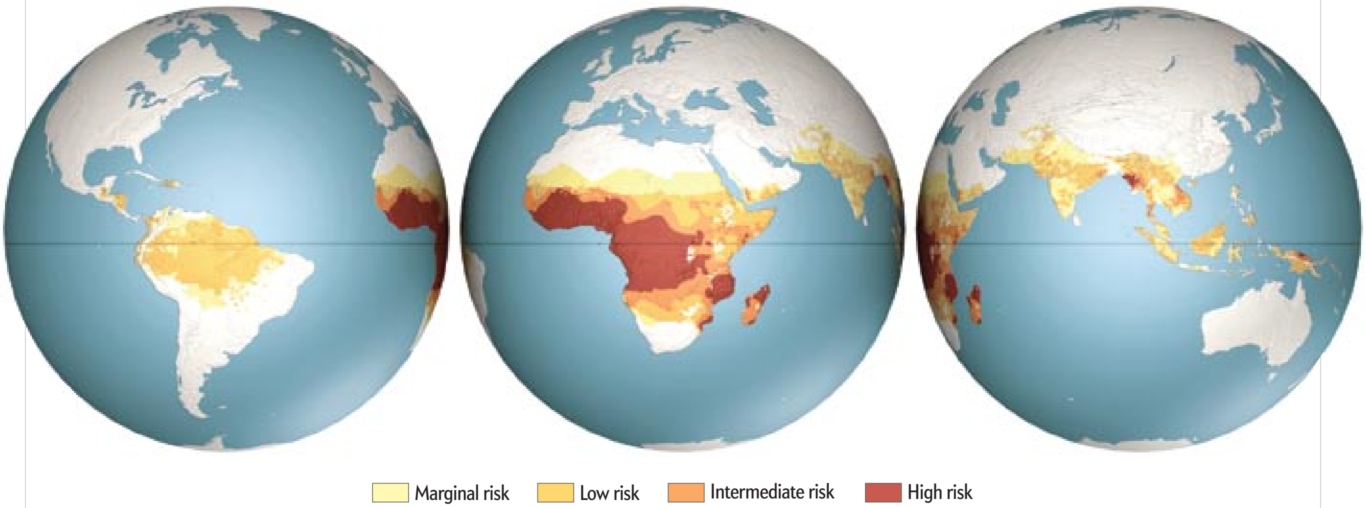


Boosting a Traditional Vaccine

A vaccine from GlaxoSmithKline has entered late-stage clinical trials against *Plasmodium falciparum,* a deadly species of the parasite. An earlier version of the vaccine failed in clinical trials, but it was reformulated with a chemical, an adjuvant, that enhances the immune response. The newer version appears to reduce an individual's chance of getting the severe form of the disease by about half, an unprecedented statistic for a malaria vaccine this close to commercial availability.

Where the Risks Are

A global antimalaria campaign that relies on vaccines to eradicate disease or diminish its incidence must target the populations that face the greatest risk. To update epidemiological data that were decades out-of-date, the Malaria Atlas Project, a collaboration of the University of Oxford, Kenya Medical Research Institute and the Wellcome Trust, compiled thousands of local reports of parasite prevalence to estimate the risk of contracting the disease. The maps below show regions vulnerable to the most deadly form of the parasite, *Plasmodium falciparum*. (*P. vivax* is generally milder but may still cause extreme illness. The parasite is more widespread, affecting 2.85 billion people.) Measures of risk are derived from the percentage of people that harbor the parasite, whether or not they are actually sick.



vaccine candidates—or the many others in even earlier stages of development—to succeed, it will have to meet a number of challenges first. The time has arrived to take those challenges on, Rabinovich says: "You don't progress by hiding your head in the sand."

YES, IT WORKS. BUT HOW WELL?

THE CANDIDATE made by GSK, called RTS,S, still relies on the same *P. falciparum* protein as before. But now it has a helper. If all had gone as hoped in the 1980s, this so-called circumsporozoite, or CS, protein, would have served alone as an antigen, the part of a vaccine that provokes the immune system to produce antibodies or other immune responses that attempt to kill the parasite. The approach had worked with a similarly constructed vaccine for hepatitis B. The immune system, however, did not react as planned to the CS protein, and researchers embarked on a 20-year quest to reformulate the vaccine. To elicit a strong enough response from the body, they first had to assemble many copies of the protein onto a chemical scaffold with the aim of eliciting the production of sufficient antibodies. "The idea was to make it look more like the actual pathogen," says GSK's Cohen, the scientist who has spearheaded the work on RTS,S.

The body did respond more robustly to this reformulation but still not strongly enough to yield any real protection against the disease (a common problem with many vaccine candidates for all kinds of diseases). Boosting the response further required another breakthrough. After 15 years, investigators succeeded in adding a chemical that increased the numbers of antibody-making B cells. This adjuvant also roped in T cells, which play many important roles in maintaining the body's defenses against disease.

Today researchers are injecting that formulation in late-stage trials, constituting the largest test of a malaria vaccine ever conducted. A target group of 16,000 children—some between six and 12 weeks old and some a little older, at five to 17 months—have started to receive their vaccinations. By December the researchers will have completed all their injections, and results will begin to roll in during the middle of next year. If those data and a follow-up set seem promising, says Christian Loucq, current director of the PATH Malaria Vaccine Initiative, which is a key organizer of new studies, it will be time to see "the impact of the vaccine in real life."

That impact could be enormous, saving hundreds of thousands of lives every year—provided that the vaccine is widely distributed. But two possible hurdles exist. The first is expense. All told, developing RTS,S and getting it to market will end up costing hundreds of millions of dollars, so it could be too pricey for practical use in the developing world. But GlaxoSmithKline has said that it will set the price very low, with a small profit of 5 percent and that it hopes that international consortia and organizations such as UNICEF and the Global Alliance for Vaccines and Immunization will buy the vaccine and distribute it to developing countries in Africa where it is most needed.

Second, it is exceedingly unlikely that RTS,S will work as well as most vaccines for other diseases, which generally need to be at least 80 percent effective before they are approved for wide use. So far the best data from phase II suggest that RTS,S reduces cases of malaria by as much as half. Most vaccines with that kind of statistic would never be considered effective enough for widespread use. But malaria is enough of a killer, and the vaccine is so far advanced compared with other candidates, that 50

SOURCE: "A WORLD MALARIA MAP: *PLASMODIUM FALCIPARUM* ENDEMICITY IN 2007," BY SIMON I. HAY ET AL., IN *PLOS MEDICINE*, VOL. 6, NO. 3; MARCH 2009

Maps by George Retseck

percent actually looks pretty good—that is still 500,000 lives potentially saved every year.

Very young children face the greatest susceptibility to severe malaria. They have little natural protection against the disease, unlike older victims, who acquire some level of immunity after repeated infections and tend to get milder cases as they age. Unprotected, children may be left with lifelong neurological disabilities. Even if some youngsters become infected after being vaccinated, they may contract milder, nonfatal cases.

The World Health Organization and UNICEF already immunize African infants against other diseases such as polio and diphtheria around the same very young age (three months, give or take) that they would ideally get RTS,S. "We want the malaria vaccine to be integrated into that delivery system," Cohen says. "We can piggyback on the fact that they're already giving other vaccines." That built-in delivery infrastructure might speed up the process of getting the vaccine from bench to bedside—and it would mean that the costs of delivering injections would be fairly low, because it would be possible to forgo new distribution networks. Still, Cohen says, "we need to make sure now that preparedness on the ground is ready. It's not going to be a trivial thing." And it is as yet unclear how often those kids would need to come back to the clinic to get booster shots.

The vaccine has other drawbacks, too. First, RTS,S is designed to work in African strains of *P. falciparum,* not the other malarial strains that circulate around the rest of the globe. Second, that 50 percent efficacy statistic means the vaccine could never be used by itself to completely wipe out malaria—and eradication is the rationale for developing a vaccine in the first place.

To use RTS,S for eradication, researchers will ultimately have to reformulate it—again—or else administer it alongside a different compound. GSK scientists are now contemplating a "prime boost" approach—the two-stage strategy that has shown some hints of effectiveness in early HIV vaccine trials—for their next iteration of RTS,S. Both the "prime" and the "boost" arms of this new vaccine would present the CS protein to the body, but in different ways, possibly yielding a stronger immune response. At least that is how the thinking goes. But the research has taken place only in lab animals so far. If this new attempt to reformulate RTS,S lasts as long as the previous one did, it could be another 15 years before a fully effective version of RTS,S becomes a fixture of public health. "In that time," Cohen asks, "who knows what else scientists will find?"

Public health first: GlaxoSmithKline is vaccinating children in Africa for late-stage clinical trials.

KAREL PRINSLOO *AP Photo*

MOSQUITOES AS LIVING LABS

SHORT OF TAKING RTS,S and being in the lucky 50 percent for whom it works, there is just one other well-established way to make yourself immune to malaria without actually catching the disease: First, find a swarm of mosquitoes that are carrying weak, genetically damaged parasites. Then let 1,000 or more of them bite you. The parasites may sail down your bloodstream into your liver, but instead of developing into their adult form as they usually would, they will get stuck there and die, unable to mature past adolescence. Meanwhile your body will manufacture antibodies against them, and you will be set for life. U.S. Navy researchers discovered this phenomenon in the 1970s, and two decades later several scientists picked it up and ran with it. Two of them—Stefan H. Kappe of Seattle BioMed and Stephen L. Hoffman, chief executive of Sanaria in Rockville, Md.—now operate mosquito-breeding labs where gloved technicians sit all day extracting weakened parasites from the spit glands of mosquitoes and crushing them into a solution that may be suitable for a vaccine.

Researchers can injure the malaria parasite's DNA before culturing the microorganism in the bodies of mosquitoes in two different ways. Seattle BioMed's approach is a precise one: it deletes only the genes that help the parasite mature past adolescence in the human liver. Without these genes, the parasite does not develop further. "It can check into the liver, but it can't check out," Kappe says.

Currently Kappe's team knocks out only two genes, which normally help the parasite build a membrane around itself while it takes up residence in the liver cells. The membrane seems to somehow keep the liver cells from realizing they are infected. Parasites without membranes promptly cause a liver cell to commit suicide rather than playing host to it. In many hundreds of mice, including some genetically engineered to carry human liver cells. Kappe's team has administered its parasite vaccine and shown 100 percent protection against malaria. There is no damage to the liver in the process—only 10,000 or so parasites enter the body, so even if they all make it to the liver, the maximum amount of lost cells is fairly small compared with the many millions of cells that make up the organ (which, of course, can also regenerate).

This spring, as part of an early-stage clinical trial, 20 people who have received multiple doses of the vaccine will roll up their sleeves and offer their arms to five mosquitoes apiece—all of them infected with what Kappe calls "real malaria," a strain that would probably need treating if it took hold in the body. Then they will go about their daily lives for a week, checking into a hotel on the seventh day to be thoroughly examined by a clinical team. If they are malaria-free, Kappe says, the team will consider it a sign that the vaccine has worked. If instead they have the parasites in their bloodstream, researchers will remove them by giving them antimalarial medications. "It's a very powerful tool to be able to actually give people malaria," Kappe says. "This is a very unique model. You obviously cannot do it with HIV or anything else that is untreatable. But even in the worst-case scenario [if patients get sick], we can treat the infection. How enthusiastic people are to participate in these studies is truly amazing. They are not scared at all."

The other way to wreck a malaria parasite's DNA and make it safe fodder for a vaccine is the old-fashioned one: irradiate it. This is the approach taken by Sanaria, Hoffman's biotech company. It may have advantages, he says. Because radiation scram-

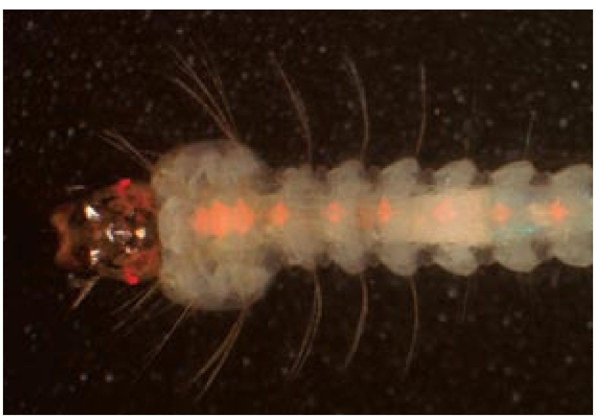
PLAN B

Vaccine Alternatives

Malaria vaccines might not work. Researchers have never succeeded in creating a successful human vaccine against parasites of any kind. So the public health establishment has always pursued a range of alternative approaches in tandem with vaccine development. Unfortunately, none of them, whether bed nets or preventive medications, offers lasting immunity against the virus.

DDT, the banned chemical, is making a comeback indoors, where it poses less harm. It can rid mosquitoes from an inhabited area without causing environmental devastation.

Bed nets that ward off mosquitoes offer an attractive solution because of their low-cost simplicity and their proven effectiveness in lowering incidence of the disease.



Mosquito larvae, in tests, have been engineered to block parasite transmission; if such insects outcompeted other mosquitoes, malaria could fade from the scene.

bles the genetic code in many more sites than two, it may be a safer, more complete way to ensure that the parasite cannot reproduce once it gets to the liver. But Hoffman remains unconvinced that radiation can outdo the precise approach of knocking out specifically targeted genes, and he is experimenting with the latter, too. He will not know which is better until both approaches are "empirically tested," he says. "There's no substitute for that."

Hoffman knows all too well the value of empirical testing. This past summer, during a phase I trial of his irradiated-sporozoite vaccine, he got a reality check. The Food and Drug Administration had given Sanaria the signal to run a trial with 100 subjects. At the time he obtained approval, Hoffman believed that a mosquito transmitting malaria to a human injected somewhere between five and 10 parasites. He based the strength of his doses—how many parasites his vaccine would contain—on that figure. It was only later that scientists realized the mosquito injects a lot more parasites when it bites, somewhere between 300 and 500. "What all that means is by the time we got into the trial, we were probably 10-fold low with our dose," Hoffman says. "We figured this out in the middle of the study. You can't really change your design at that point." Even the too-low doses provided some protection against malaria, Hoffman says, but they were not as effective as RTS,S.

Hoffman, like Rabinovich, remains a realist. For a while, he became depressed, until he talked to vaccinologists and biotechnology mavens, all of whom reacted with enthusiasm. "This is fantastic what you've done," they told Hoffman. "Did you think you were a magician, that you could come in and put this stuff into people and walk out with 100 percent protection? It doesn't work that way in real life." Hoffman now hopes to start a new phase I trial. He has increased the concentration of parasites in his vaccine and changed the way it is administered.

THE "IMMUNOLOGICAL BED NET"

IF IT DOES PROVE TOO DIFFICULT to immunize people against malaria, what about vaccinating the third organism in this unholy trinity: the mosquito? Any vaccine needs to break the cycle of transmission, and until now one step in that cycle has been largely ignored: the point at which the mosquito bites an infected human, picks up the malaria parasite from its victim's bloodstream and becomes infected itself. If the parasite's development could be halted at that point, inside the mosquito's body, it would die, unable to infiltrate a human host. Case numbers would plummet. Dinglasan, a young molecular biologist at Johns Hopkins University (and a native of the Philippines who has seen plenty of malaria in his homeland), has an idea for how to make that happen. He is working in mice only thus far and is appropriately circumspect. "I'm not going to be like a car salesman about it if it doesn't work," he says. If it does, though, it will mark a genuine shift in combating malaria.

When the malaria parasite enters a mosquito's body, it immediately tries to make itself at home in the insect's gut by seeking out a specific enzyme in the digestive tissue, an aminopeptidase. If it does not find that enzyme to establish a beachhead in the gut in the first 24 hours, it gets digested, and the mosquito fails to become an incubator for the parasite. (At least people assume that is what happens, adds Dinglasan with a laugh: "No one's really looked at the mosquito poo to check.") If mosquitoes receive a meal of antibodies against the aminopeptidase, they

JOHN STANMEYER VII (top); PER-ANDERS PETTERSSON *Getty Images* (middle); COURTESY OF M. RIEHLE *University of Arizona* (bottom) come away with protection against malaria. The theory: the antibodies mask the enzyme, hanging around and preventing the parasite from targeting it. Dinglasan has isolated a specific fragment of the enzyme unique to mosquitoes and injected mice with that fragment only, causing them to make antibodies against it. Mosquitoes that bite those mice then pick up the antibodies, which do not appear to degrade significantly in the digestive tract. The insects, in effect, become immunized by unwittingly eating a vaccine—and because the parasite dies inside of them, it does not get transmitted to mammalian hosts. If the concept works in humans, too, voilà, Loucq says: "It's like an immunological bed net."

The approach has downsides, of course, chief among them the challenge of getting people to accept a vaccine that protects mosquitoes but not people—not directly, anyway. (You could get the vaccine and still be infected by a mosquito that first picked up malaria from someone who was not immunized.) Yes, eventually, the disease burden will drop as there are fewer infected vectors buzzing around, but at first a lot of people might get vaccinated and still get sick, and there could be side effects in people who had previously felt fine. That would in some sense violate the first rule of medicine: "do no harm."

Still, precedent exists for taking vaccines to protect other people (such as men who get immunized against the human papillomavirus: their risk of catching it is low to begin with, but by getting the vaccine, they protect their sexual partners). And in the long term, a transmission-blocking vaccine could be equally or more effective than a traditional one that immunizes the person to whom it is given. "People say there's no direct benefit," Dinglasan says. "The fact of the matter is that there is a benefit. It's just delayed."

The aminopeptidase approach also has benefits that no other vaccination strategy can boast. For technical reasons, it would probably be more "scalable"—translation, cheaper to mass-produce—than RTS,S or the mosquito-cultivated vaccines at Sanaria and Seattle BioMed. The antigen, it turns out, shows up in all 40-some mosquito species that transmit malaria, so the vaccine should work in all of them. ("Is that lucky?" Dinglasan says. "Yes. Completely lucky.") And the antibodies seem to work against both *P. falciparum,* the common African type of malaria parasite, and *P. vivax,* more commonly found in Asia. RTS,S does not work against *P. vivax,* because the CS protein targeted by the vaccine differs between the two parasite species.

Tests by Dinglasan so far against *P. falciparum* in mice have shown 100 percent effectiveness and a tally of 98 percent in combating the *P. vivax* found in Thailand. That matters for practical reasons, because ideally, a malaria vaccine needs to be universally useful. "The truth of the matter is, it's too expensive to make many separate vaccines," Dinglasan points out. "The coffers of the donors, the Warren Buffets and the Bill Gateses—people may think they're infinite, but they're not."

Dinglasan has a long way to go yet before the coffers open wide for him. At the moment, he is only in the "feasibility stage," trying to see how much antigen his lab can make. He says he should have some solid results by February. Then he will allow himself to think about practical applications. Could this vaccine be used in combination with RTS,S? How much of it would a mosquito need to suck from the human bloodstream to become immunized? How long might it take to move it from mice to people?

A vaccine that protects mosquitoes, not people (at least not directly), challenges our traditional public health notions of how to confer broad-based immunity from a major illness.

Dinglasan will be answering these questions as a much larger one looms: What, really, is needed to eradicate malaria around the world, once and for all? Without a strong vaccine, it is already possible to control the disease with bed nets and medications that can either prevent or treat it, such as chloroquine, artemisinin and malarone. But it is probably impossible to eliminate it entirely. Bed nets fail; mosquitoes may develop resistance to the insecticides the nets are treated with, and users may not want to sleep under a malaria-resistant curtain all the time. "The bed net story is beautiful, and if they're used in a highly controlled environment, they can prevent transmission," Dinglasan says. "But humans tend to be poor at following directions. Have you ever lived in these countries? I have. Yes, most of the kids are under the bed nets. But the adults are drinking outside of the hut, and alcohol makes you more attractive to mosquitoes. We've also seen that the insecticide-treated nets kill the indoor mosquitoes, but then the outdoor mosquitoes take over the niche."

As for preventive meds, they are better for travelers than they are for people in the developing world: they can be unpleasant and expensive, and they would have to be taken constantly. Some other steps that helped to rid the developed world of malaria—draining swamps, for instance, or widespread spraying of DDT—would be impractical in the developing world.

Then again, those are only the options on the table today. Scientists are busy studying the malaria parasite's genome and certain aspects of the human genome that may offer some resistance; new and surprising leads may well come from those projects. And there is even talk of malaria-control strategies that sound outlandish now, such as releasing genetically engineered, malaria-resistant mosquitoes into nature to compete with the wild type. Ten years ago, of course, the idea that we would be this close to even a partly effective malaria vaccine would have sounded outlandish, too.

The key, Dinglasan says, is making sure that the global health community stays engaged for the long haul. "The current leaders of the malaria community have told me they don't even know if my generation will see [the vaccination effort] through," he says. "It might be the next generation. That's how long we're thinking. Will the world stay interested? Will it hang in there for that long?" One thing, at least, is sure—the malaria parasite will. SA

MORE TO EXPLORE

The Fever: How Malaria Has Ruled Humankind for 500,000 Years. Sonia Shah. Sarah Crichton Books, 2010.

Malaria Nexus provides access to a selection of relevant journal articles from Elsevier. Available at **www.malarianexus.com**

The Centers for Disease Control and Prevention's malaria page offers a variety of educational resources: **www.cdc.gov/malaria**

FOR ADDITIONAL RESOURCES click this article's link at **www.ScientificAmerican.com/nov2010**

Fiorenzo Omenetto and **David Kaplan** are professors of biomedical engineering at Tufts University. They have been reinventing silk for high-technology applications together for nearly four years.

TECHNOLOGY

From Silk Cocoon to Medical Miracle

Scientists are crafting arteries, ligaments, circuitry and holograms from worm yarn

By Fiorenzo Omenetto and David Kaplan

FOR A MILLENNIUM, TRADERS BROUGHT SILK FABRICS FROM THE FAR EAST along the Silk Road to Europe, where the beautiful yet tough material was fashioned into dazzling clothes. Today bioengineers are infusing the natural protein fibers spun by silkworms with enzymes and semiconductors. They are processing the modified strands under varying temperature, shear and acidic conditions to create novel materials with remarkable properties [*see illustration on opposite page*].

Physicians like silk sutures because they are strong and compatible with human tissue, meaning the body's immune system doesn't reject them. Our laboratory at Tufts University has recently extended those traits to make thin tubes that can be used as grafts to replace sections of clogged arteries, which could eliminate the need to extract a vein for that purpose from a patient's leg for a coronary bypass, the usual procedure. James Goh and his colleagues at the National University of Singapore have regenerated an anterior cruciate ligament in a live pig's knee using stem cells implanted in silk scaffolding.

Biocompatibility also gives engineers a way to devise interesting sensors. Engineers at Tufts and elsewhere have crafted electronic and photonic materials by patterning metals or thin films onto silk's surface. Doctors might one day slip such films deep into the brain to treat epilepsy or spinal cord injuries. Silk implants in animals have already demonstrated the slow release of medication to control seizures.

Scientists can foresee implanted sensors that electronically monitor nutrients, drug doses, or cells in blood or tissue and that optically record and transmit the information along silk fibers. They could design such devices to degrade at the end of their lifetimes, so they do not need to be surgically removed. We can program silk to dissolve over a specific amount of time by adjusting the size and arrangement of the protein's crystalline structure (which gives silk cloth its shimmering sheen).

Genetic advances are at hand, too. In September, Kraig Biocraft Laboratories in Lansing, Mich., announced it had genetically altered silkworms to produce spider silk, which has greater tensile strength than worm silk and could improve artificial ligaments or even bulk products such as bulletproof vests. SA

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CARY WOLINSKY *Aurora Images* (*cocoon*)

WOLFGANG KAEHLER *Corbis* (*silk thread*); COURTESY OF FIORENZO OMENETTO (*artery, sponges, thin film, fiber optics*); FROM "DISSOLVABLE FILMS OF SILK FIBROIN FOR ULTRATHIN CONFORMAL BIO-INTEGRATED ELECTRONICS," BY DAE-HYEONG KIM ET AL., IN *NATURE MATERIALS*, VOL. 9; JUNE 2010 (*brain*)

Michael D. Lemonick is senior science writer at Climate Central, a nonprofit, nonpartisan climate change think tank. For 21 years he was a science writer for *Time* magazine.

ENVIRONMENT

Climate Heretic

Why can't we have a civil conversation about climate?

By Michael D. Lemonick

In trying to understand the Judith Curry phenomenon, it is tempting to default to one of two comfortable and familiar story lines.

For most of her career, Curry, who heads the School of Earth and Atmospheric Sciences at the Georgia Institute of Technology, has been known for her work on hurricanes, Arctic ice dynamics and other climate-related topics. But over the past year or so she has become better known for something that annoys, even infuriates, many of her scientific colleagues. Curry has been engaging actively with the climate change skeptic community, largely by participating on outsider blogs such as Climate Audit, the Air Vent and the Blackboard. Along the way, she has come to question how climatologists react to those who question the science, no matter how well established it is. Although many of the skeptics recycle critiques that have long since been disproved, others, she believes, bring up valid points—and by lumping the good with the bad, climate researchers not only miss out on a chance to improve their science, they come across to the public as haughty. "Yes, there's a lot of crankology out there," Curry says. "But not all of it is. If only 1 percent of it or 10 percent of what the skeptics say is right, that is time well spent because we have just been too encumbered by groupthink."

She reserves her harshest criticism for the Intergovernmental Panel on Climate Change (IPCC). For most climate scientists the major reports issued by the United Nations–sponsored body every five years or so constitute the consensus on climate science. Few scientists would claim the IPCC is perfect, but Curry thinks it needs thoroughgoing reform. She accuses it of "corruption." "I'm not going to just spout off and endorse the IPCC,"

IN BRIEF

If people and governments are going to take serious action to reduce carbon emissions, the time pretty much has to be now, because any delay will make efforts to stave off major changes more difficult and expensive to achieve.

In the wake of "Climategate" and attacks on policy makers, the public is more confused than ever about what to think, particularly when it comes to talk of uncertainty in climate science. Climate policy is stalled.

The public needs to understand that scientific uncertainty is not the same thing as ignorance, but rather it is a discipline for quantifying what is unknown.

Climate scientists need to do a better job of communicating uncertainty to the public and responding to criticism from outsiders.

Critic: Judith Curry has traded harsh words with many of her colleagues in climate science.

Photograph by Gregory Miller

she says, "because I think I don't have confidence in the process."

Whispered discreetly at conferences or in meeting rooms, these claims might be accepted as part of the frequently contentious process of a still evolving area of science. Stated publicly on some of the same Web sites that broke the so-called Climategate e-mails last fall, they are considered by many to be a betrayal, earning Curry epithets from her colleagues ranging from "naive" to "bizarre" to "nasty" to worse.

All of which sets up the two competing story lines, which are, on the surface at least, equally plausible. The first paints Curry as a peacemaker—someone who might be able to restore some civility to the debate and edge the public toward meaningful action. By frankly acknowledging mistakes and encouraging her colleagues to treat skeptics with respect, she hopes to bring about a meeting of the minds.

The alternative version paints her as a dupe—someone whose well-meaning efforts have only poured fuel on the fire. By this account, engaging with the skeptics is pointless because they cannot be won over. They have gone beyond the pale, taking their arguments to the public and distributing e-mails hacked from personal computer accounts rather than trying to work things out at conferences and in journal papers.

Which of these stories is more accurate would not matter much if the field of science in question was cosmology, say, or paleontology, or some other area without any actual impact on people's lives. Climate science obviously is not like that. The experts broadly agree that it will take massive changes in agriculture, energy production, and more to avert a potential disaster.

In this context, figuring out how to shape the public debate is a matter of survival. If people and governments are going to take serious action, it pretty much has to be now, because any delay will make efforts to stave off major climate change much more expensive and difficult to achieve. But the COP15 climate negotiations in Copenhagen last December ended in a watered-down policy document, with no legally binding commitments for countries to reduce greenhouse gas emissions. Following Copenhagen, the U.S. Senate was unable to pass even a modest "cap and trade" bill that would have mandated reductions. And in the wake of Climategate a year ago and widespread attacks on the IPCC and on climate science in general, the public may be more confused than ever about what to think. Is Curry making things worse or better?

OVER TO THE DARK SIDE

CURRY'S SAGA began with a *Science* paper she co-authored in 2005, which linked an increase in powerful tropical cyclones to global warming. It earned her scathing attacks on skeptical climate blogs. They claimed there were serious problems with the hurricane statistics the paper relied on, particularly from before the 1970s, and that she and her co-authors had failed to take natural variability sufficiently into account. "We were generally aware of these problems when we wrote the paper," Curry says, "but the critics argued that these issues were much more significant than we had acknowledged."

She did not necessarily agree with the criticisms, but rather than dismissing them, as many scientists might have done, she began to engage with the critics. "The lead author on the paper, Peter J. Webster, supports me in speaking with skeptics," Curry says, "and we now have very cordial interactions with Chris Landsea (whom we were at loggerheads with in 2005/2006), and we have had discussions with Pat Michaels on this subject."

In the course of engaging with the skeptics, Curry ventured onto a blog run by Roger Pielke, Jr., a professor of environmental studies at the University of Colorado who is often critical of the climate science establishment, and onto Climate Audit, run by statistician Steve McIntyre. The latter, Curry adds, "became my blog of choice, because I found the discussions very interesting and I thought, 'Well, these are the people I want to reach rather than preaching to the converted over at [the mainstream climate science blog] RealClimate.'"

It was here that Curry began to develop respect for climate outsiders—or at least, some of them. And it made her reconsider her uncritical defense of the IPCC over the years. Curry says, "I realize I engaged in groupthink myself"—not on the hurricane paper per se but more broadly in her unquestioning acceptance of the idea that IPCC reports represent the best available thinking about climate change.

She says she always trusted the IPCC to gather and synthesize all the disparate threads in this complex and multifaceted area of science. "I had 90 to 95 percent confidence in the IPCC Working Group 1 report," she states, referring to the basic-science section of the three-part report. But even then, she harbored some doubts. In areas where she had some expertise—clouds and sea ice, for example—she felt that the report's authors were not appropriately careful. "I was actually a reviewer for the IPCC Third Assessment Report," Curry says, "on the subject of atmospheric aerosols [that is, particles such as dust and soot that affect cloud formation]. I told them that their perspective was far too simplistic and that they didn't even mention the issue of aerosol impacts on the nucleation of ice clouds. So it's not so much as finding things that were wrong, but rather ignorance that was unrecognized and confidence that was overstated." In retrospect, she laughs, "if people expert in other areas were in the same boat, then that makes me wonder."

Apparently few others felt the same way; of the many hundreds of scientists involved in that report, which came out in 2001, only a handful have claimed their views were ignored—although the Third Assessment Report could not possibly reflect any one scientist's perspective perfectly.

Still, once Curry ventured out onto the skeptic blogs, the questions she saw coming from the most technically savvy of the outsiders—including statisticians, mechanical engineers and computer modelers from industry—helped to solidify her own uneasiness. "Not to say that the IPCC science was wrong, but I no longer felt obligated in substituting the IPCC for my own personal judgment," she said in a recent interview posted on the Collide-a-Scape climate blog.

Curry began to find other examples where she thought the IPCC was "torquing the science" in various ways. For example, she says, "a senior leader at one of the big climate-modeling institutions told me that climate modelers seem to be spending 80 percent of their time on the IPCC production runs and 20 percent of their time developing better climate models." She also asserts that the IPCC has violated its own rules by accepting nonpeer-reviewed papers and assigning high-status positions to relatively untested scientists who happen to feed into the organization's "narrative" of impending doom.

Climate skeptics have seized on Curry's statements to cast doubt on the basic science of climate change. So it is important to emphasize that nothing she encountered led her to question the science; she still has no doubt that the planet is warming, that human-generated greenhouse gases, including carbon dioxide, are in large part to blame, or that the plausible worst-case scenario could be catastrophic. She does not believe that the Climategate e-mails are evidence of fraud or that the IPCC is some kind of grand international conspiracy. What she does believe is that the mainstream climate science community has moved beyond the ivory tower into a type of fortress mentality, in which insiders can do no wrong and outsiders are forbidden entry.

UNCERTAINTY AND SCIENCE

CURRY IS NOT ALONE in criticizing the IPCC and individual climate scientists; in the wake of Climategate, an error about glacial melting in an IPCC report, and accusations of conflicts of interest involving IPCC chair Rajendra K. Pachauri, bodies ranging from the U.N. to the British government to individual universities on both sides of the Atlantic launched investigations. None found evidence of fraudulent science—including, most important, a probe by the InterAcademy Council (IAC)—a network of the U.S. National Academies of Science and its counterparts around the world. Although it found no major errors or distortions, it reported that the IPCC's procedures have failed to change adequately with the times and that in some cases the body has not enforced its own standards rigorously.

Stripped of incendiary words, the central issue that concerns Curry also happens to be the key problem in translating climate science into climate policy. The public at large wants to know whether or not climate is warming, by how much and when, and they want to know how bad the effects are going to be. But the answers scientists give in papers and at conferences come couched in a seemingly vague language of confidence intervals and probabilities. The politically charged nature of the issue seems to have made some scientists reluctant to even mention anything to the public about "uncertainty" for fear that the likes of Oklahoma's Senator James "greatest hoax ever perpetrated on the American people" Inhofe and other politically motivated skeptics will continue to use the word as a blunt instrument against the whole enterprise of climate science—that because the scientists do not know everything, they know nothing.

The uncertainty lies in both the data about past climate and the models that project future climate. Curry asserts that scientists haven't adequately dealt with the uncertainty in their calculations and don't even know with precision what's arguably the most basic number in the field: the climate forcing from CO_2—that is, the amount of warming a doubling of CO_2 alone would cause without any amplifying or mitigating effects from melting ice, increased water vapor or any of a dozen other factors.

Things get worse, she argues, when you try to add in those feedbacks to project likely temperature increases over the next century, because the feedbacks are rife with uncertainty as well: "There's a whole host of unknown unknowns that we don't even know how to quantify but that should be factored into our confidence level." One example she cites is the "hockey stick" chart showing that current temperatures are the warmest in hundreds of years. If you are going to say that this year or that decade is the hottest, you had better have a good idea of what temperatures have actually been over those hundreds of years—and Curry, along with many skeptics, does not think we have as good a handle on that as the scientific community believes.

Many climate scientists find these complaints unfair. They say the IPCC has been upfront about uncertainties all along—

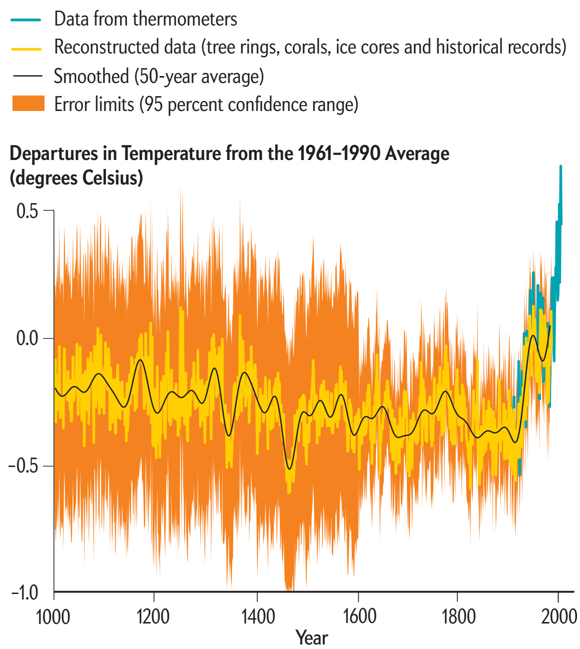
BEHIND THE NUMBERS

Making Sense of Trends

Some big questions in climate science are problematic because the answers often depend in part on proxy measurements or incomplete data. Scientists routinely spell out the extent of their uncertainty, but the very fact of uncertainty often leads to public confusion over the validity of the results. The graphics below illustrate two examples of data sets that have elicited controversy.

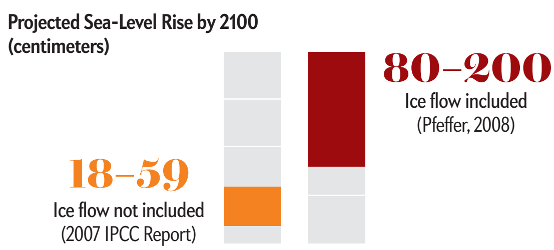
Reconstructing the Past

The IPCC's Third Assessment Report, published in 2001, includes a graph of temperature going back 1,000 years, rising steeply in recent decades, known as the hockey stick. Error bars (*orange*) are greater for the values calculated for the distant past because temperature measurements in that period were not available; instead scientists derived them from proxies such as tree rings, coral growth, ice hole bores and other data. (The yellow indicates the actual data plot.) The likelihood of true temperature falling between the error bars is considered to be 95 percent.



Predicting the Future

When the IPCC issued its Fourth Assessment Report in 2007, it included an estimate for future sea-level rise, which, because of a lack of data about ice dynamics, excluded this particular factor. The IPCC gave a range within which levels were "likely" to rise (with likely defined as 66 percent probability). Subsequently, scientists came up with revised estimates, based on new data, that more than doubled the projected sea-level rise.



SOURCES: THE IPCC THIRD ASSESSMENT REPORT, 2001 (*temperature graph*); THE IPCC THIRD ASSESSMENT REPORT, SUMMARY FOR POLICY MAKERS, 2007; "KINEMATIC CONSTRAINTS ON GLACIER CONTRIBUTIONS TO 21ST-CENTURY SEA-LEVEL RISE," BY W. T. PFEFFER ET AL., IN *SCIENCE*, VOL. 321; 2008 (*projected sea level*) that the reports explicitly cite areas where knowledge is lacking. It would be scientifically irresponsible to give flat answers to questions such as "How much will it warm?" or "How much will sea level rise?" Instead the experts give ranges and confidence intervals and the like. More important, other scientists part ways with Curry over how significant those uncertainties are to the final calculation. Yes, the most basic number in climate science is not known with absolute precision, agreed Stanford University's Stephen H. Schneider in a conversation shortly before he died in July. But it is only uncertain by a few percent, which simply is not enough to skew the projections significantly. Other effects, such as whether clouds will accelerate or retard warming, are much less certain—but here people like Schneider point out that the lack of precision is laid out by the IPCC. (Schneider was the one who persuaded the IPCC to systematize its discussion of uncertainty a decade ago.) For that reason, Curry's charges are misleading, her critics say. "We've seen a lot of strawmen from Judy lately," Schneider said. "It is frankly shocking to see such a good scientist take that kind of a turn to sloppy thinking. I have no explanation for it."

The sloppiness is not one-sided, however. While the IAC panel came out of its investigation with respect for the IPCC overall, it had issues with how the organization deals with uncertainty. "We looked very carefully at the question of how they communicate the level of uncertainty to policy makers," says Harold Shapiro, a former president of Princeton University and head of the IAC panel. "We found it was a mix. Sometimes they do it well, sometimes not so well. There were statements made where they expressed high confidence in a conclusion where there was very little evidence, and sometimes there were statements made that could not be falsified." A statement that cannot be proven false is generally not considered to be scientific.

In at least one respect, however, Curry is in harmony with her colleagues. The public needs to understand that in science un-

POLICY

How to Cope with an Uncertain Fate

It's time to abandon the fantasy that all nations must first agree on a master climate plan

BY M. GRANGER MORGAN

People make decisions in the face of irreducible uncertainty all the time. We choose where to go to college, what job to take, whom to marry, and whether to have children—all with limited and uncertain information. Governments do the same thing. They subsidize transportation networks, change regulatory policies, implement social programs, declare war and sue for peace, even though they can't know for certain how things will work out.

Although many details of climate science are uncertain, we know much more about how the climate system will respond to a dramatic increase in atmospheric carbon dioxide than we know about many of the choices we face in private life and in policy. Human actions over the past couple of centuries have placed our planet at great risk. If we do not act soon to change our energy systems and reduce emissions of greenhouse gases, later this century our children and grandchildren will witness profound changes to the planet's ecosystems and regional climates that may put at risk the livelihood and lives of billions of people in the developing world. The people who do climate science and assessment should be more careful and open in their communication with the public, but uncertainty about the science is not what is preventing progress on policy.

The first thing we should do is put aside the idea that all nations must agree before any of them can get serious about reducing carbon emissions. Otherwise we are likely to face decades of delay. We should continue to work on international agreements but focus more on getting individual nations and regions to take action. We should develop international strategies to coalesce different kinds of emission-control regimes into larger agreements and develop strategies for getting laggards onboard either through moral suasion or through policies such as high tariffs on imports from noncomplying regions.

We also need to end the us-versus-them mind-set. Yes, the developed world has benefited from a few hundred years of development based on unconstrained emissions of greenhouse gases. But have you been to Brazil, China or India lately? All their aircraft, cell phones, automobiles and computers are also the consequence of those years of development. The developed nations, because they can afford to, have an obligation to take the lead in controlling emissions. Yet responsibility is not as clear-cut as many think. Millions of well-to-do people in the developing world leave carbon footprints that are as large as anyone's. They should not get a free ride.

Finally, we need to help people understand the basics. In a study my colleagues and I published in the journal *Risk Analysis* more than 15 years ago and replicated just this year, we found that many Americans do not understand the difference between climate and weather and that a majority still do not identify burning coal, oil and natural gas as the primary cause of climate change. Education will not be easy, because lobby groups continue to spend millions of dollars every year to protect their short-term economic interests by keeping the public confused. "Climategate" has been used to prolong this confusion.

It took decades to overcome the doubt that lobbyists cast on the link between cigarettes and cancer. If we don't act soon to reduce carbon emissions dramatically, a few more decades may commit us to a course that could lead to global catastrophe. We're not certain about that, of course. But the risk is real, and the odds are not in our favor.

M. Granger Morgan is head of engineering and public policy at Carnegie Mellon University and director of its Center for Climate Decision Making.

GETTY IMAGES

certainty is not the same thing as ignorance; rather it is a discipline for quantifying what is unknown. Curry has sought to begin a conversation on one of the most important and difficult issues in climate policy: the extent to which science can say something valid despite gaps in knowledge. "If we can't talk the language of probability theory and probability distributions," says Chris E. Forest, a statistician at Pennsylvania State University, "we have to resort to concepts like odds, rolls of the dice, roulette wheels." And because climate is complex, he adds, the terms "likely" and "very likely" in the IPCC reports represent lots of wheels or lots of dice rolling at once, all interacting with one another. When scientists translate statistical jargon into comprehensible language, they necessarily oversimplify it, giving the impression of glossing over nuance. The public gets cartoon versions of climate theories, which are easily refuted.

A crucial lesson for the public is that uncertainty cuts both ways. When science is uncertain, it means that things could turn out to be much rosier than projections would indicate. It also means things could turn out to be much worse. Sea-level-rise projections are a case in point. Glaciologists can easily estimate how quickly the thick blankets of ice covering Greenland and Antarctica should melt as temperatures rise and how much that extra water should raise sea level. Warming, though, could also affect the rate at which glaciers flow from the ice sheets down to the sea to dump icebergs, which raises sea level independently. Predicting the latter effect is tougher. In fact, Curry says, "we don't know how to quantify it, so we don't even include it in our models. But it's out there, and we know it probably has an impact."

Rather than sweeping that uncertainty about ice sheets under the rug, as Curry's overall critique might lead one to assume, the IPCC's 2007 Fourth Assessment Report flags this uncertainty. Specifically, the report projects 0.18 to 0.59 meter of sea-level rise by the end of the century but explicitly excludes possible increases in ice flow. The reason, as the report explains, is that while such increases are likely, there was insufficient information at the time to estimate what they might be. Since the report came out, new research has given a better sense of what might happen with ice dynamics (although the authors caution that considerable uncertainty remains about the projections). It turns out that the original projections may have been too benign [*see box on page 81*].

The same could be true for other aspects of climate. "The plausible worst-case scenario could be worse than anything we're looking at right now," Curry says. The rise in temperature from a doubling of CO_2 "could be one degree. It could be 10 degrees. Let's just put it out there and develop policy options for all the scenarios and do a cost-benefit analysis for all of them, and then you start to get the things that make sense."

DOING DAMAGE

THERE IS NO QUESTION Curry has caused a stir; she is frequently cited by some of the harshest skeptics around, including Marc Morano, the former aide to Senator Inhofe and founder of the Climate Depot skeptic blog. It is not just the skeptics: Andrew C. Revkin, the *New York Times*'s longtime environment reporter has treated her with great respect on his Dot Earth blog more than once. So has Keith Kloor, who runs the militantly even-handed Collide-a-Scape blog.

What scientists worry is that such exposure means Curry has the power to do damage to a consensus on climate change that has been building for the past 20 years. They see little point in trying to win over skeptics, even if they could be won over. Says Gavin A. Schmidt, a climate scientist at the NASA Goddard Institute for Space Studies in New York City and proprietor of the RealClimate blog: "Science is not a political campaign. We're not trying to be everyone's best friend, kiss everyone's baby."

Uncertainty cuts both ways. When science is uncertain, it means things could turn out to be much rosier than projections indicate. It also means things could turn out much worse.

To Curry, the damage comes not from the skeptics' critiques themselves, most of which are questionable, but from the scientific community's responses to them—much as deaths from virulent flu come not from the virus but from the immune system's violent overreaction. Curry remarks that she has been a victim of this herself, spurned by her colleagues for her outreach efforts (although she adds that she has not been damaged professionally and continues to publish). "She's been hugely criticized by the climate science community," McIntyre says, "for not maintaining the fatwa [against talking to outsiders]."

Some disinterested commentators agree. One is S. Alexander Haslam, an expert in organizational psychology at the University of Exeter in England. The climate community, he says, is engaging in classic black sheep syndrome: members of a group may be annoyed by public criticism from outsiders, but they reserve their greatest anger for insiders who side with outsiders. By treating Curry as a pariah, Haslam says, scientists are only enhancing her reputation as some kind of renegade who speaks truth to power. Even if she is substantially wrong, it is not in the interests of climate scientists to treat Curry as merely an annoyance or a distraction. "I think her criticisms are damaging," Haslam says. "But in a way, that's a consequence of failing to acknowledge that all science has these political dynamics."

In a sense, the two competing storylines about Judith Curry—peacemaker or dupe?—are both true. Climate scientists feel embattled by a politically motivated witch hunt, and in that charged environment, what Curry has tried to do naturally feels like treason—especially since the skeptics have latched onto her as proof they have been right all along. But Curry and the skeptics have their own cause for grievance. They feel they have all been lumped together as crackpots, no matter how worthy their arguments. The whole thing has become a political potboiler, and what might be the normal insider debates over the minutiae of data, methodology and conclusions have gotten shrill. It is perhaps unreasonable to expect everyone to stop sniping at one another, but given the high stakes, it is crucial to focus on the science itself and not the noise. SA

MORE TO EXPLORE

The Intergovernmental Panel on Climate Change makes its four assessment reports available in their entirety on its Web site: **www.ipcc.ch**

RealClimate.org bills itself as "a commentary site on climate science by working climate scientists for the interested public and journalists." Gavin A. Schmidt is one of the moderators.

Climate Audit.org is a skeptic's blog run by Steve McIntyre, an amateur climatologist.

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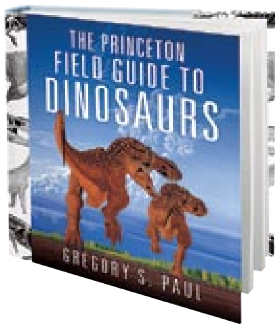

Caudipteryx zoui

The Princeton Field Guide to Dinosaurs

by Gregory S. Paul. Princeton University Press, 2010 ($35)

Artist and researcher Gregory S. Paul describes hundreds of dinosaur species in this richly illustrated compendium. Learn how beasts ranging from *Allosaurus* to *Zuniceratops* grew, moved and reproduced—and how they eventually went extinct.

EXCERPT

Massive: The Missing Particle That Sparked the Greatest Hunt in Science

by Ian Sample. Basic Books, 2010 ($25.95)

Journalist *Ian Sample chronicles the search for a particle known as the Higgs boson—the key to explaining how the universe got its mass. Here he talks about the moments leading up to a 1987 meeting between Alvin Trivelpiece, then director of the Office of Energy Research, and President Ronald Reagan about the development of a machine to find the Higgs.*

"Trivelpiece had been granted 15 minutes to win the president's support for the largest and most costly atom smasher ever conceived. A green light, the advocates said, would guarantee American dominance at the forefront of high-energy physics for decades to come. Without his backing for the project, the nation's historic leadership in unraveling the nature of matter was sure to fade as other countries pushed on.

"The Superconducting Supercollider sounded like the kind of diabolical weapon a comic-book super-villain might build in his (or her) lair to hold the world to ransom. In practice, it was the world's first particle accelerator to be designed specifically to look for the Higgs boson. . . .

"The supercollider wasn't the only machine that had a chance of discovering the Higgs boson. At Fermilab, [physicist Leon M. Lederman's] Tevatron had been colliding protons and antiprotons since 1985, though at energy levels too low to prove the existence of the Higgs particle. At CERN, engineers were building a new machine, the Large Electron Positron (LEP) collider, and were expecting to switch it on within two years. Both machines would need major upgrades before the scientists would have a realistic shot at discovering the Higgs boson, but at least they were up and running. In the particle accelerator business, that is no trivial achievement....

"Trivelpiece had set off early for the meeting, but along the way fell into conversation with William Martin, the deputy secretary of energy. Martin wasted no time reminding him that a lot of time and money had been spent arranging the meeting. He went on to add that all of Alvin's friends and colleagues were relying on him to win the president over. 'Now don't be nervous,' Martin said, as he turned to leave. Right up to that moment, Trivelpiece hadn't been nervous at all."

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ALSO NOTABLE

BOOKS

The Music Instinct: How Music Works and Why We Can't Live without It, by Philip Ball. Oxford University Press, 2010 ($29.95)

Selling the Fountain of Youth: How the Anti-Aging Industry Made a Disease Out of Getting Old—and Made Billions, by Arlene Weintraub. Basic Books, 2010 ($29.95)

Galileo: Watcher of the Skies, by David Wootton. Yale University Press, 2010 ($35)

Creeping Failure: How We Broke the Internet and What We Can Do to Fix It, by Jeffrey Hunker. McClelland & Stewart, 2010 ($25.95)

Chasing the Sun: The Epic Story of the Star That Gives Us Life, by Richard Cohen. Random House, 2010 ($35)

Honeybee Democracy, by Thomas D. Seeley. Princeton University Press, 2010 ($29.95)

The Wave: In Pursuit of the Rogues, Freaks, and Giants of the Ocean, by Susan Casey. Doubleday, 2010 ($27.95)

Moon: A Brief History, by Bernd Brunner. Yale University Press, 2010 ($25)

Preparing for Climate Change, by Michael D. Mastrandrea and Stephen H. Schneider. MIT Press, 2010 ($14.95)

White Coat, Black Hat: Adventures on the Dark Side of Medicine, by Carl Elliott. Beacon Press, 2010 ($24.95)

EXHIBITS

Brain: The Inside Story, at the American Museum of Natural History in New York City from November 20, 2010, through August 14, 2011

Cyprus: Crossroads of Civilizations, at the Smithsonian National Museum of Natural History in Washington, D.C., through May 1, 2011

MASSIVE JACKET DESIGN BY ARIANA ABUD

Michael Shermer is publisher of *Skeptic* magazine (www.skeptic.com). He is author of *Why Darwin Matters* and blogs at BigQuestionsOnline.com.

The Skeptic's Skeptic

In the battle for ideas, scientists could learn from Christopher Hitchens

Science values data and statistics and champions the virtues of evidence and experimentation. Those of us "viewing the world with a rational eye" (as the new descriptor for this column reads) also have another, underutilized tool at our disposal: rapier logic like that of Christopher Hitchens, a practiced logician trained in rhetoric. Hitchens—who is "leaving the party a bit earlier than I'd like" because of esophageal cancer, as he lamented to Charlie Rose in a recent PBS interview—has something deeply important to offer on how to think about unscientific claims. Although he has no formal training in science, I would pit Hitchens against any of the purveyors of pseudoscientific claptrap because of his unique and enviable skill at peeling back the layers of an argument and cutting to its core.

We would all do well to observe and emulate his power to detect and dissect baloney through pure thought. To wit, after watching a quack medicine man fleecing India's poor one Sunday afternoon, the belletrist scowled in a 2003 *Slate* column, "What can be asserted without evidence can also be dismissed without evidence." The observation is worthy of elevation to a dictum.

Of course, as scientists we prefer to tether evidence, when it is available, to logical analysis in support of a claim or to proffer counterevidence that disputes a claim. A radiant example of Hitchens's insightful thinking, coupled to the effective employment of counterevidence, is his reaction to an episode of the television series *Planet Earth*. As he watched, he had a revelation of creationism's profound flaws. The episode was on life underground, during which Hitchens noticed that the blind salamander had "eyes" that "were denoted only by little concavities or indentations," as he recounted in a 2008 *Slate* commentary. "Even as I was grasping the implications of this, the fine voice of Sir David Attenborough was telling me how many millions of years it had taken for these denizens of the underworld to lose the eyes they had once possessed."

Creationists make a big deal about the eye, insisting that the gradual stepwise process of natural selection could not have sculpted such a complex instrument because of "irreducible complexity," meaning that the removal of any part would render it useless. Even Charles Darwin fretted about the eye in *On the Origin of Species:* "To suppose that the eye, with all its inimitable contrivances for adjusting the focus to different distances, for admitting different amounts of light, and for the correction of spherical and chromatic aberration, could have been formed by natural selection, seems, I freely confess, absurd in the highest possible degree."

If God created the eye, then how do creationists explain the blind salamander? "The most they can do is to intone that 'the Lord giveth and the Lord taketh away,'" Hitchens mused. "Whereas the likelihood that the postocular blindness of underground salamanders is another aspect of evolution by natural selection seems, when you think about it at all, so overwhelmingly probable as to constitute a near certainty." To confirm his instincts, Hitchens queried evolutionary biologist Richard Dawkins, who agreed: "Why on earth would God create a salamander with vestiges of eyes? If he wanted to create blind salamanders, why not just create blind salamanders? Why give them dummy eyes that don't work and that look as though they were inherited from sighted ancestors?"

Hitchens's point is even deeper, however, when he applies the counterfactual argument of regression to the cosmos itself, noting that "there is a dialectical usefulness to considering the conventional arguments in reverse, as it were. For example, to the old theistic question, 'Why is there something rather than nothing?' we can now counterpose the findings of Professor Lawrence Krauss and others, about the foreseeable heat death of the universe.... So, the question can and must be rephrased: 'Why will our brief 'something' so soon be replaced with nothing?' It's only once we shake our own innate belief in linear progression and consider the many recessions we have undergone and will undergo that we can grasp the gross stupidity of those who repose their faith in divine providence and godly design."

The dialectical usefulness of clear logic, coupled to elegant prose (layered on top of the usual dollop of data), cannot be overstated and should be considered by scientists as another instrument of persuasion in the battle for ideas. SA

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Illustration by Thomas Fuchs

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The ongoing search for fundamental farces

Steve Mirsky has been writing the Anti Gravity column for 100 years, within an order of magnitude. He also hosts the *Scientific American* podcast Science Talk.

Oh, We Have Liftoff All Right

NASA and astronauts face the dirty reality of slipping the surly bonds of Earth

In space, as was first noted in the ad campaign for the movie *Alien,* no one can hear you scream. What prompts that screaming in the *Alien* franchise and other space opera sci-fi is typically terror, dismemberment or larval-monster intestinal occupation. But more mundane issues make real-life astronauts want to scream. Because in space, everybody can smell your gas.

Space, when done with people living together in close quarters, stinks. Best-selling author Mary Roach catalogues the rank unpleasantness of space travel in her new book *Packing for Mars: The Curious Science of Life in the Void* (W. W. Norton, 2010). Her introduction's first words encapsulate, if you will, the situation: "To the rocket scientist, you are a problem. You are the most irritating piece of machinery he or she will ever have to deal with."

We humans are incredibly demanding because of our hunger and thirst—and the messy, odoriferous products of our satiety. Humans are the reason the space shuttle needs toilets. And humans in zero gravity are the reason the toilets have rearview mirrors. (You can find the details in Roach's book or spend a moment to think about the various ramifications of weightless evacuation.)

The *Mercury, Gemini* and *Apollo* spacecraft didn't even have toilets—rudimentary devices were used for docking and capture, ruling out the chances of anybody boldly going. Showers are also too tricky to deal with out there. So it's no surprise that the interior of your average spaceship quickly winds up smelling very, very bad. Think of a car ride with three immature guys for whom "pull my finger" is considered a droll example of classic wit. Now imagine spending a week in the car with the windows rolled up.

In an interview, Roach recounted her gentle interrogation of *Apollo 13* hero James A. Lovell about the stank: "So when the capsule came down and those frogmen came and they opened the hatch, what was that like for them?" she asked him. "And he said, 'Well, it was …'—then his gentlemanly instincts took over, and he said, 'It was quite different than the fresh ocean breezes outside.' But elsewhere I saw him describe it as like living in a Porta Potty."

On shorter jaunts into space, some of the stuff humans produce is simply chucked from the ship. The physiologically confusing term of art for one such action is the "urine dump." And, believe it or not, space pee is pretty. "A number of astronaut memoirs mentioned how these flash-frozen droplets, illuminated, would look like this silvery snowstorm," Roach told me. "I think three different astronauts mentioned how beautiful the urine dump was."

For manned Mars voyages, however, recycling is mandatory. As on the International Space Station now, treated urine would be a treat, sort of. "Once the salt is taken care of and the distasteful organic molecules have been trapped in an activated charcoal filter," Roach writes in the book, "urine is a restorative and surprisingly drinkable lunchtime beverage. I was about to use the word unobjectionable, but that's not accurate. People object. They object a lot."

Nevertheless, urine is the easy part. On a Mars trip, the captain's log, if you will, presents a whole different set of problems—and possibilities. "Hydrocarbons are good radiation shielding," Roach told an audience at a Manhattan bookstore just before our conversation. "So the thinking is that on the way to Mars, you would use your food to line the interior of the module that you're living in. And at NASA, they have this device where you could make tiles that would contain fecal material. It's like an Easy-Bake Oven. And on the way back, you would line the capsule with the new tiles. So you'd fly to Mars in a can of food, and then you'd fly home in a can of poop." Only she didn't say "poop." SA

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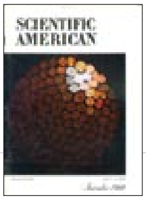
Illustration by Matt Collins

Innovation and discovery as chronicled in *Scientific American*



November 1960

Radical Husbandry

"Disastrous experience has shown that the habitats afforded by Africa are brittle and susceptible to ruin. The monumental failure of the earthnut (peanut) project in Tanganyika—a megalomaniac pipe-dream advanced in ignorance of the plainest facts about African soils—is well known. Where the vegetation of the great African plateau is replaced by crop plants, many soils either set rock-hard or erode, and carrying capacity declines. The record supports one radical conclusion. Only under the natural communities of game animals can a high biological capture and turnover of solar energy be maintained. This conclusion calls for the management of game to produce protein in the food supply."

NOTE: *This article is available in full on the Web at www.ScientificAmerican.com/nov2010*

Fiber Optics Light Up

"Recently, light conductors of a special type have been transformed from trivial curiosities to important optical devices. In this form they are made of bundles of very thin and therefore flexible, glass fibers, usually coated with a layer of glass of a different kind. Such bundles can not only transport an optical image over a tortuous path, but can also transform it in a number of useful ways. As the technology advances, fiber optics will no doubt find wider applications in various areas of research and engineering. —Narinder S. Kapany"

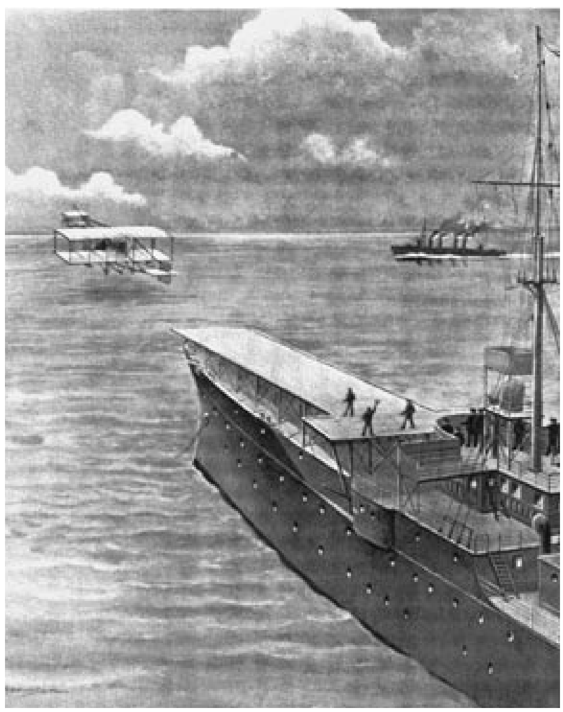
November 1910

First Navy Flier

"The services of Eugene Ely, with his Curtiss biplane, were secured for the making of this first attempt to fly from the deck of a naval vessel to a designated spot ashore. As our image shows, a platform was erected upon the bow of the 'Birmingham.' Despite squalls of wind and rain, Ely decided to attempt a flight. Between squalls, he had his engine started. As the machine left the platform, it settled rapidly till it struck the water with a splash, which the spectators supposed marked the termination of the flight. Instead, however, the machine rose again and continued on its way. It traveled straight for the nearest land, where it descended without a mishap."

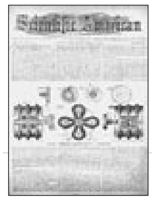
Growing Cells

"Dr. Alexis Carrel and his assistant in the Rockefeller Institute, Dr. Montrose T. Burrows, have logically observed that it is the part of science to develop methods which permit the discovery of physiological laws. These workers have begun the systematic investigation of one such method, namely, the cultivation of adult tissues outside the body from which they are taken. Their experiments have demonstrated that adult tissues and organs grow very easily outside the body. Carrel and Burrows, who are so scientific and so conservative in their work, consider it can at any rate thus far be assumed that the perfection of the method of cultivating adult tissues of mammals outside of the body will be helpful in the exploration of unknown fields of human pathology—wherein investigation bids fair to be most momentous to human existence."



First flight from a U.S. Navy ship: Eugene Ely in his Curtiss biplane soars into history, 1910

SCIENTIFIC AMERICAN, VOL. CIII, NO. 22; NOVEMBER 26, 1910



November 1860

Brazilian Progress

"We learn from a correspondent of the Philadelphia Ledger that the Don Pedro Railroad is progressing favorably in the hands of the active American engineer engaged in its construction. The emperor [Pedro II of Brazil], who is a friend to progress in the arts and science, has recently visited the road attended by a party who rode through one of the tunnels, and the Emperor descended several shafts, being determined to inspect closely this gigantic undertaking. On descending the main shaft of the grand tunnel, Major Ellison was selected to sit opposite his majesty, as being near his size and weight. The ministers present endeavored to persuade him from the attempt, but as he was satisfied with the security of the arrangements, he determined to gratify his curiosity and set them an example. Since his Majesty's visit to the road all opposition to the tunneling has ceased. The route will be from Rio de Janeiro to the Parahiba river." SA

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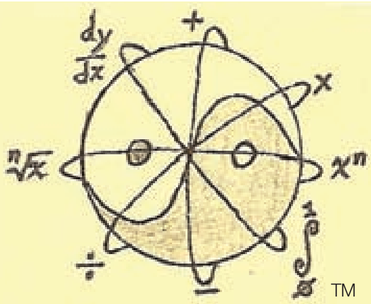

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● Chemicals used by U.S. consumers and industry: 50,000 ● Tested: 300 ● Restricted: 5

Experts guesstimate that about 50,000 chemicals are used in U.S. consumer products and industrial processes. Why the uncertainty? The 1976 Toxic Substances Control Act does not require chemicals to be registered or proven safe before use. Because the Environmental Protection Agency must show, after the fact, that a substance is dangerous, it has managed to require testing of only about 300 substances that have been in circulation for decades. It has restricted applications of five.

The House Toxic Chemicals Safety Act of 2010 and the Senate Safe Chemicals Act of 2010 would require manufacturers to prove that existing and new chemicals meet specific safety criteria. Stricter scrutiny in Europe and Canada suggests that "10 to 30 percent of U.S. chemicals would need some additional level of control," says Richard Denison, a molecular biochemist at the Environmental Defense Fund. That would be 5,000 to 15,000 chemicals, not five.

—Mark Fischetti

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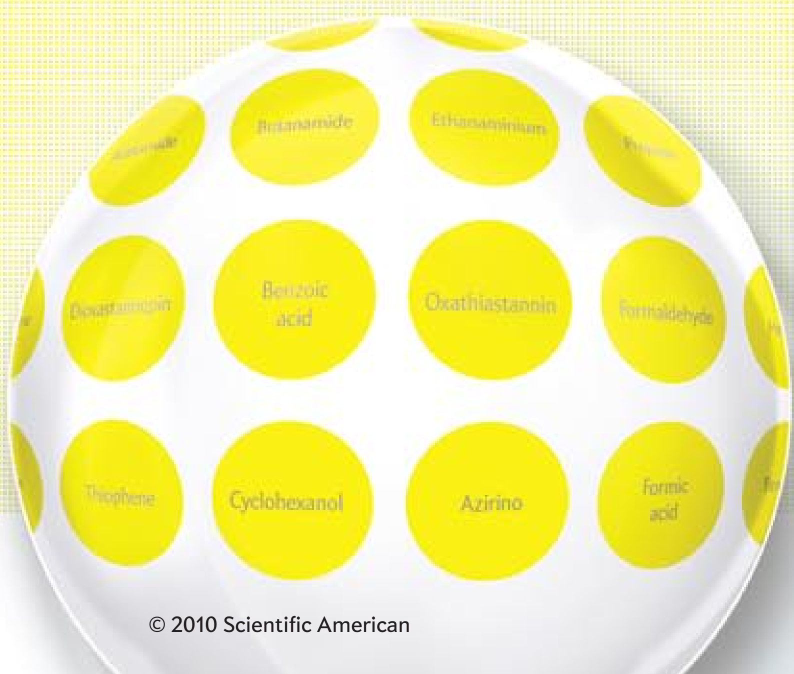

SOURCES: U.S. ENVIRONMENTAL PROTECTION AGENCY AND ENVIRONMENTAL DEFENSE FUND; RESEARCH ASSISTANCE BY NICHOLETTE ZELIADT

Graphic by Don Foley and Jen Christiansen