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SCIENTIFIC AMERICAN

How to Save Millions of Children from **Rotavirus**

APRIL 2006
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BIZARRE PARTICLES AND SPACETIME BRAIDS SOLVE IMPOSSIBLE PROBLEMS

COMPUTING WITH QUANTUM KNOTS

Cultured Apes and **Evolving Intelligence**

Magnetic Triggers of **Solar Flares**

Plugged-In **Hybrid Cars**

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Cover image by Jean-Francois Podevin; photograph at left by Madhuri Dass, CARE; image on preceding page by Ron Miller

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The Collider Calamity

For decades, the big guns of American science have been the U.S. Department of Energy's particle colliders, which investigate the nature of matter by accelerating subatomic particles and smashing them together. Colliders at the Fermi National Accelerator Laboratory (Fermilab), Stanford Linear Accelerator Center (SLAC) and Brookhaven National Laboratory have discovered exotic particles such as the top quark and revealed phenomena that hint at new laws of physics. But this great American enterprise, like so many others, is now moving overseas. While the Europeans and Japanese build new particle accelerators, the U.S. is poised to shut down its premier colliders at Fermilab and SLAC over the next few years. And funding for Brookhaven's Relativistic Heavy Ion Collider (RHIC) is so tight that the lab could not have run its full slate of experiments this year without $13 million raised by a New York billionaire.

FERMILAB, home of the Tevatron.

The sad story began in 1993, when Congress canceled the $11-billion Superconducting Super Collider, the intended successor to Fermilab's Tevatron. CERN, the European laboratory for particle physics near Geneva, then started work on the Large Hadron Collider (LHC), which would produce impacts with energies seven times higher than the Tevatron's. Because the greater energies could enable researchers to discover hypothesized particles such as the Higgs boson, American physicists flocked to the LHC, which is expected to begin operating next year.

Some scientists realized, however, that they could continue to do experiments at American colliders that would complement the research at the LHC. One group designed a device called BTeV that would study the decay of B mesons emanating from collisions in the Tevatron. BTeV employed such sophisticated technology that it could have outperformed a similar detector at the LHC. But last year the Department of Energy canceled BTeV. Without that experiment, most physicists see no compelling reason to keep the Tevatron running after the LHC comes online. SLAC plans to shut down its linear collider when that lab concludes its own B-meson study by 2008. And the National Science Foundation recently killed an experiment called RSVP that would have used Brookhaven's accelerator to investigate rare particle decays that could not be observed at the LHC.

Besides depriving researchers of potential discoveries, these cuts threaten to make the U.S. less economically competitive. The development of high-energy accelerators has led to advances in medicine and electronics, and American expertise in this field will wither if the U.S. ceases to build and operate colliders. Moreover, although American scientists will participate in the research at the LHC, the Europeans will get most of the educational benefits of the facility, which will inspire and train the next generation of physicists. To stem the damage, the DOE has proposed a budget for 2007 that would restore funding for RHIC and bolster neutrino research at Fermilab.

But America's physicists yearn to work on the high-energy frontier, and their last great hope is the International Linear Collider, which would probe the new particles revealed by the LHC. The design, expense and location of this facility have not yet been determined, but the U.S. should do everything in its power to ensure that it is built, preferably on American soil. Although the project's price tag might ultimately rival that of the Super Collider, the cost of *not* doing the science would be even higher.

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Join host Steve Mirsky each week as he explores the latest developments in science and technology through interviews with leading scientists and journalists.

"10th Planet" Proves Bigger Than Pluto

When astronomers announced the discovery of 2003UB313, the so-called 10th planet, a little more than a year ago, they had a hunch it might be bigger than Pluto because of its brightness. But despite several attempts to observe more closely the mysterious object orbiting the sun at a distance of more than 14 billion kilometers, accurate estimates of its size remained elusive. Recently scientists determined that 2003UB313 has a diameter of roughly 3,000 kilometers—roughly 700 kilometers larger than Pluto's.

RYAN REID

Study Strengthens Link between Virus and Weight Gain

New study results bolster the controversial hypothesis that certain cases of obesity are contagious. Over the past 20 years, some research has suggested that specific strains of human and avian adenoviruses—responsible for ailments ranging from chest colds to pinkeye—actually make individuals build up more fat cells. Now researchers have identified another strain of adenovirus that makes chickens plump.

Ask the Experts

Why do bubbles form if a glass of water is left alone for a while?

Rick Watling, a meteorologist with the National Oceanic and Atmospheric Administration, explains.

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Letters

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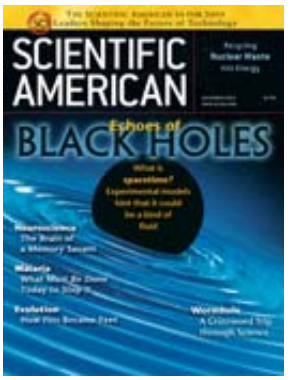


LETTERS ABOUT the December 2005 issue included a down-to-earth query about unearthly black holes for the authors of "An Echo of Black Holes," Theodore A. Jacobson and Renaud Parentani, and a report of research data complementing Darold A. Treffert and Daniel D. Christensen's anatomical exploration of savant Kim Peek, "Inside the Mind of a Savant." Responding to "Running on Empty" [SA Perspectives], letter writers pitched ideas on how the U.S. can kick its oil "addiction" (the now presidentially sanctioned term).

As a holiday treat, readers (savant and nonsavant alike) were invited to test their recollection of the year's articles when they took on Patrick Merrell's "Wormhole" puzzle. Apparently they appreciated the challenge, for there was not a cross word about it. In fact, Mike Abbott via e-mail suggested with alacrity: "Great crossword puzzle—do it again!"

PEEKING INTO A SAVANT'S MIND

We were intrigued by Darold A. Treffert and Daniel D. Christensen's research on Kim Peek in "Inside the Mind of a Savant." It has long been suspected that savants are less conceptual than nonsavants. Perhaps because of a cortex that is functioning suboptimally, they process, censor and edit incoming information far less than most of us, thereby paradoxically enhancing their perception and memory for trifles. We devised three simple experiments for testing the theory on Peek. First we gave him a paragraph of English text and asked him to find all the "f"s in it. Normal controls miss about 15 percent of the "f"s, because they edit out those that sound like "v" (as in "of"). In four trials, Peek missed less than 2 percent—the first direct evidence that savants may have a shallower depth of processing than normal subjects.

In experiment two, we showed Peek phrases such as

PARIS
IN THE
THE SPRING

Again, nonsavants miss the repetition of "the" because they focus on the *meaning*, but Peek immediately noticed it.

In the third experiment we read aloud a list of words for him to remember: ice, snowman, winter, North Pole, chill, Kool-Aid. Tested after a minute, if a normal person is asked, "Was the word 'cold' in the list?" he or she usually says yes. Peek, though, was immune to this illusion, perhaps because of his shallow depth of processing.

Thus, at least some savants may owe their skills to some degree of failure in higher-level perceptual and conceptual encoding of incoming sensory information. The technique we have introduced provides a simple, low-tech approach to testing the idea on other savants.

V. S. Ramachandran, Lindsey Oberman, S. Azoulai and L. Williams
Center for Brain and Cognition
University of California, San Diego

THE CHURCH OF ST. DARWIN

I would appreciate it if Steve Mirsky did not jam his religion of evolution down our throats. He just cannot get off touting his religion as the only true religion, repeating his mantra again in "The Trials of Life" [Anti Gravity]. Thank you for reprimanding Mirsky about proselytizing his personal religion, instead of reporting on science.

Bob Langenbach
SeaTac, Wash.

MIRSKY REPLIES: Langenbach's faith in his conclusion that I have been reprimanded is unfounded. He causes one to ponder, however, the benefits of decreeing evolu-

tion to be a religion—biologists could tap the vast amount of research funding suddenly available through the White House Office of Faith-Based and Community Initiatives, and academic departments would receive tax-exempt status. Alas, evolution remains science.

THE X FACTOR

In "The Scientific American 50," the editors announce 50 scientific achievements for 2005—only one woman is included. How can this be?

Women are scientists, make significant contributions, win Nobel Prizes, are members of the National Academy of Sciences, and hold professorial and high-ranking administrative positions at major scientific institutions, including governmental funding agencies and academic centers. A review of scientific publications for 2005 reveals that virtually all top-ranking journals for the biological sciences and the majority in many other scientific disciplines include women as authors. Hence, there is not a paucity of significant contributions at all levels by women.

Apparently the SA 50 editors relied on an advisory board that also excluded women. Publishing a list of achievements that systematically ignores those by women is a serious editorial lapse. It impacts the careers of women scientists at all levels, decreasing the attractiveness of science to young women and preventing senior women from reaching full potential. *Scientific American* is in a position to change this.

Elaine L. Bearer
Brown University

PETROLEUM 12-STEP

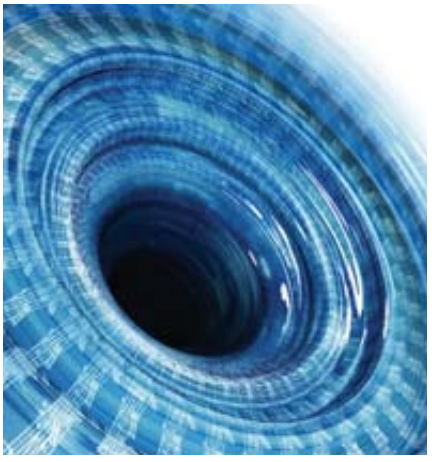
In "Running on Empty" [SA Perspectives], you propose a gasoline tax to wean Americans from their gas guzzlers. As with all value-added or sales taxes, this is regressive, disproportionately impacting low-income individuals.

Instead why not tack on to the annual registration fee a surtax based on the inability of a vehicle to meet a specified mileage? For every mpg below that, the vehicle owner would pay $100. Additionally, this specified mileage standard should increase yearly by, say, 1 mpg, until it reaches 60. Vehicles that exceed the target would receive a rebate, decreasing through time as the mileage goal increases. The revenue should be earmarked to the construction and operation of renewable energy sources.

Luis Messina
Prunedale, Calif.

SOUNDING OUT BLACK HOLES

In "An Echo of Black Holes," Theodore A. Jacobson and Renaud Parentani explain Hawking radiation as one member of a pair of virtual particles that is stranded outside a black hole while the other is trapped inside. I've read that explanation in many articles, and always,



GIANT SUCKING SOUND: A fluid flow can act on sound the way a black hole acts on light.

the effect is said to drain away the black hole's mass. But if one member is trapped, hasn't the hole's mass increased?

Richard Dexheimer
Dallas, Tex.

JACOBSON AND PARENTANI REPLY: One source of confusion in descriptions of the Hawking effect is how the energy balance is accounted for in the process and what is happening with the "virtual pairs" that are the origin of the radiation. In the effect, a pair of photons, for example, emerges from the vacuum, one outside the horizon with positive energy and the other inside with opposite, negative energy. (The members of a virtual pair must always have opposite values of energy, because the total energy is conserved.) Negative-energy particles cannot exist outside the horizon, because the vacuum is by definition the lowest energy state. Therefore, only a positive-energy photon can escape, whereas its negative-energy partner is trapped inside, lowering the total energy—and therefore the mass—of the black hole.

If a negative-energy photon cannot exist outside the horizon, how can it exist inside? Would not that violate the definition of the vacuum, too? No, because what we are calling here "energy" is actually momentum inside the horizon! The usual concept of conserved energy is related to time-shift symmetry, whereby the laws of physics are the same at all times. Conserved momentum is related to space-shift symmetry. In a black hole spacetime, the symmetry that is a temporal shift outside the horizon becomes a spatial shift inside. Therefore, the single conserved quantity corresponds to energy outside and momentum inside. Because nothing prohibits adding momentum to the vacuum, negative-energy partners can exist inside the horizon, as long as their locally measured energy is positive.

In the fluid analogue of a black hole, the energy for the sonic Hawking radiation comes from the kinetic energy of the bulk flow of fluid. A sound wave going upstream saps energy from the flow, but the energy of the wave itself makes up for this, so the total energy is higher—as long as the flow speed is less than the speed of sound. Inside the sonic horizon, however, the flow speed is greater than the speed of sound. There the wave saps more energy from the flow than it carries itself, so the total energy is less than that of the undisturbed flow. Such a wave can be thought of as containing negative energy.

ERRATUM In "An Echo of Black Holes," it was misstated that fluid flow in a Laval nozzle reaches and exceeds the speed of sound at the narrowest point. The fluid reaches the speed of sound at the narrowest point and is supersonic beyond it.

KENN BROWN

50, 100 & 150 Years Ago

FROM *SCIENTIFIC AMERICAN*

Nuclear Gamble ▪ Aeroplane Assertion ▪ Early Forensics

APRIL 1956

URANIUM SPREAD—"The U.S. will release 88,000 pounds of fissionable uranium 235 for research and development and for fueling nuclear power reactors, President Eisenhower announced last month. Half of the uranium will be sold or leased to approved groups in the U.S.; the rest will be available to foreign nations. The U.S.S.R. and its satellites are excluded from the plan; so are Britain and Canada, which already make nuclear fuel. The 88,000 pounds of U-235 represent enough fuel to generate four million kilowatts of electric power, or the combined explosive charge of some 3,000 atomic bombs."

APRIL 1906

WRIGHT AEROPLANE—"According to the statement sent to the Aero Club of America recently by Messrs. Orville and Wilbur Wright (which statement is, by the way, the first authoritative one made by the brothers in their own country), they have already solved the problem of the century, mechanical flight, with their motor-driven, man-carrying aeroplane. During the past three years in which they have been experimenting with it, they have made 150 flights averaging a mile each, but not until the machine had been changed and improved many times. The final flight of 24 1/5 miles on October 5 last was longer than the 105 flights of 1904 taken together."

WRIGHT VERIFICATION—"I visited Dayton in November, 1905, and verified the absolute accuracy of the statements which the Wrights have since made, over their own signatures, to the Aérophile of Paris and to the Aero Club of New York. There is no question in my mind that they have solved the problem of man-flight by dynamic means. Believing this solution had a money value, they have, until recently, preserved whatever secrecy they could. —[Octave] Chanute"

VESUVIUS CATACLYSM—"The present eruption is unquestionably one of the most violent of modern times and already has shown a most destructive nature. The flow of lava has not been of remarkable magnitude, though, but the fall of lapilli and stones has been almost unprecedented. The great loss of life can be laid at its door alone, for the people, terror-stricken by the violence of the volcanic detonations and the murky yellow gloom, huddle together in buildings, many of which collapse under the weight of the accumulated material which has fallen upon them."

MOTORIZED SKATES in Paris, 1906

SAN FRANCISCO EARTHQUAKE—"The full horror of the devastation which last week swept San Francisco and adjacent cities, burst upon us before we had even fairly concluded that the Neapolitan disaster had reached its full extent. The earthquake which was the ultimate cause of the destruction of the greatest American city on the Pacific coast was incomparably the severest ever recorded in the United States, and was accompanied by the loss of hundreds, if not thousands of lives, and the destruction of property valued at hundreds of millions. The earth tremor destroyed almost the entire water system of the city, and at the present writing San Francisco is the scene of a conflagration."

MOTOR ROLLER—"The new motor skate which has been lately brought out at Paris by M. Constantini, a well-known inventor of carburetors for automobiles, is attracting considerable attention owing to its novelty [*see illustration*]. On the back of the leather belt is fixed a small gasoline tank. Three sportswomen equipped with the skates are to have a race from the Place de la Concorde to the Maillot Gate."

APRIL 1856

CSI PRUSSIA—"Recently, on one of the Prussian railroads, a barrel which should have contained silver coin was found, on arrival at its destination, to have been emptied of its precious contents and refilled with sand. Professor Ehrenberg, of Berlin, sent for samples of sand from all the stations along lines of railway that the specie had passed, and by means of his microscope, identified the station from which the sand must have been taken. The station once fixed upon, it was not difficult to hit upon the culprit from the few employees on duty."

ECONOMICS

The Check Is in the Mail

DOES THE MONEY IMMIGRANTS SEND HOME DO ANY GOOD? **BY GEORGE MUSSER**

If there is any political issue that could use a dose of scientific rigor, it is migration. U.S. immigration policy is widely regarded as a total mess, the European melting pot produces pelting mobs, and all over the world tall fences have been constructed to keep facts from entering the debate. One of the most far-reaching aspects of migration often gets ignored altogether: remittances—the money and gifts that migrants send back to families and friends. Studies have chronicled what individual beneficiaries do with the largesse, but the broader effect is only dimly understood. "No one has worked on it seriously," says social anthropologist Jorge Durand of the University of Guadalajara in Mexico.

SENDING A LITTLE SOMETHING: Filipinos wire money back home at the Philippine National Bank in central Hong Kong. Remittances have become a huge factor in the global economy: in the Philippines's case, they accounted for 13.5 percent of the gross domestic product in 2004 and have been growing at roughly 20 percent a year.

TED ALJIBE *AFP/Getty Images*

That is finally starting to change. In December remittances were the topic of a special conference in Mexico City organized by the country's National Population Council and several U.N. agencies, and the World Bank highlights them in its flagship annual report, the 2006 *Global Economic Prospects*. Politicians have perked up, too. Mexican president Vicente Fox has called migrants—one in 10 of his citizens—"heroes" for their generosity.

The reason for all the attention is simple. Even though the average migrant sends back just a couple of hundred dollars a month, it adds up to serious money. The World Bank estimates that developing countries received $167 billion last year—twice as much as they got in foreign aid. Mexico's intake has quintupled in a decade, to $18 billion; labor is now the country's biggest export after oil. And that is just the amount flowing through official channels.

To be showered with money seems like a

news SCAN

TAPPING THE FLOW

Migrants send billions of dollars back to their home countries, and governments are now casting about for ways to tap the inflow to stimulate growth. The ideas include taxing it, providing matching funds for development projects, and enticing migrants who have made it good to move back home. They are also working to lower the exorbitant fees for transferring money and to persuade international lenders to count remittances when assessing a nation's credit rating. In the end, though, the most effective policy may simply be for governments to build infrastructure, ensure stability and generally pull their economic act together. "If an area is primed for an economic takeoff, remittances can help," says labor economist Philip Martin of the University of California, Davis. "If not, remittances can prolong the agony of people staying in areas that cannot support them."

happy arrangement for the receiving country. Yet in the 1980s remittances acquired a reputation among social scientists as "easy money" that, like an oil windfall, can rot out an economy. Case studies have found that recipients invest little of the money in farm equipment or business start-ups, preferring instead to go on shopping sprees. People grow dependent on the MoneyGram in the mail, and all that cash sloshing around pushes up inflation. Those not so lucky to have relatives abroad fall behind, worsening social inequality, and exporters' costs rise, making it harder for them to compete in global markets.

In the 1990s, though, Durand and others argued that case studies do not track the full effect of remittances as they ripple through an economy. Even if families do not invest the money, the businesses they buy from do, so remittances can jump-start growth. In one widely cited model, $1 of remittances boosts GDP by $3. The infusion of money makes a real difference in places where entrepreneurs have no other access to capital. Compared with alternatives to catalyze economic development, such as government programs or foreign aid and investment, remittances are more accurately targeted to families' needs and more likely to reach the poor.

Today the debate has settled into a "both sides are right" mode. Some towns achieve prosperity aided by remittances; others get trapped in a cycle of dependency. A number of cross-country analyses, such as one last year by economist Nikola Spatafora of the International Monetary Fund and his colleagues, have concluded that nations that rake in more remittances have a lower poverty rate—but only barely. A larger effect is to smooth out the business cycle, because migrants increase their giving during economic downturns in their homelands and scale it back during upswings. Averting the disruptive extremes of boom and bust can help bring about long-term growth.

One burning question is whether immigrants who sink roots into their adopted countries send less money. "Some people are actually saying that in Mexico remittances might stop in 10 years' time," says World Bank economist Dilip Ratha. Meanwhile his institution and others are working to procure good data. "When these flows are as large as they are and as important as they are," Ratha says, "it would be worth investing in a better database."

SOLAR POWER

Lifting the Winter Dark

MIRRORS TO REFLECT LIGHT INTO A TOWN THAT GETS NO SUN **BY MICHAEL DUMIAK**

Springtime light may lift the spirits, but in Rattenberg, residents have a long memory for shadows. From late fall to midwinter, this tiny Austrian town, famous for its glassblowing, gets no sun at all. And it has been that way for centuries. Next time, though, the villagers may finally see the light—thanks to giant rotating mirrors known as heliostats.

Bartenbach Light Laboratory in the Austrian Tyrol plans to begin construction of the heliostats this August. "The idea is not just to light the village," says Silvia Pezzana, an engineer at the firm. "The idea is to give them the impression they have sun."

Some 600 years ago Rattenberg's founders settled between the river Inn and the 3,000-foot-tall Stadtberg and Rat mountains, sheltering the village in the shadow of the rock as a measure of security against bandits and wartime fighting. (A civil war broke out at the time between supporters of the Austrian duke Frederick the Handsome and the Bavarian duke Louis of Wittelsbach.) Raids and plundering ended; the shade remains. To this day, when the cold months come the daylight stays below the horizon, blocked by the mountains. "The sun left us at the beginning of December," says Gundi Schmidt, a social worker born

and raised in Rattenberg. She's lucky: shadows creep over other parts of town starting in November.

Bartenbach's answer will be a set of 15 mirrors about a quarter of a mile away, across the Inn River in a sunny field. Pezzana says they will be set on poles, and each will measure about six feet across, tracking the sun using custom software running remotely from Rattenberg. On days when the sun is out, light will be reflected to a mirror-covered tower standing next to the ancient stone fort that once protected the village. "Those secondary mirrors point the light to small mirrors on buildings in the village, which takes the light down into the street," Pezzana says. The small mirrors will also diffuse the light, minimizing fire hazards and preventing glare. On the street, the effect will seem to be more of a dappling than full sun.

HERE COMES THE SUN: Scale model of a street in Rattenberg, an Alpine village that gets no winter sun, shows what residents will see when reflectors called heliostats bounce light into town. Bartenbach Light Laboratory plans to install the heliostats this summer.

BARTENBACH LICHTLABOR GMBH

All the necessary measurement and calibration have added up in the past to price tags that have kept heliostats from being an everyday proposition. But the Bartenbach project will cost an affordable $2 million or so to develop and install. What is making the heliostats cheaper these days are big improvements in measuring and manufacturing glass mirrors, resulting in a less

SUNNY CUBICLES

Heliostats for lighting are rare; when it comes to lighting workplaces in the U.S., most are found on top of biotech outfit Genzyme's corporate offices in Cambridge, Mass. "There are eight heliostats in the U.S., seven of which are on Genzyme's roof," company spokesperson Erin Emlock says. The firm's heliostats reflect light through the open shaft of its 12-story headquarters, enabling many employees to work using natural light alone, Emlock remarks. The resulting energy savings, along with other green features, such as the use of waste steam from a nearby power plant and innovative insulation, means Genzyme's monthly power bill is about 40 percent cheaper than that of a comparable office building.

flawed and more reflective plane surface. The development of dust- and weather-resistant materials has also helped, as has increased software processing power, which allows the mirrors to be more precisely positioned.

Schmidt is a little skeptical about the project—her solution, only half in jest, is to take down the mountains—but there is no joking when she says the town has been losing population. Old-timers are dying off, and young people, given the choice of building a cheaper new house in the sun, are leaving. The town burghers are also hoping a more pleasant winter environment will boost overnight stays and improve daily commerce during the winter months, when tourism dips and Rattenberg's crystal flowers sit unsold on the shelves.

Whether light can make such a difference is not known, but about 60 other Alpine towns face similar gloom, so heliostats may become more common. Cheaper heliostats might also cut office lighting costs—Bartenbach uses one to reflect natural light into basement offices and to power special solar lamps. More such applications may overcome long-disappointed expectations for everyday use of solar power. For the town of Rattenberg it may be enough to chase six centuries of winter blues into the past.

Michael Dumiak is based in Berlin.

IMMUNITY

Turning Yellow

MAKING THE YELLOW FEVER VACCINE FIGHT OTHER GERMS

BY CHRISTINE SOARES

A personal ad seeking the perfect vaccine might read: "Must confer strong immunity, quickly, with a single dose and minimal side effects. Should offer lasting protection, preferably for a lifetime." Unfortunately, few vaccines would measure up. Many of them require multiple doses to get the immune system's attention or periodic booster shots to refresh its memory. Others may elicit a partial immune response but fail to activate T cells, the powerful search-and-destroy soldiers of the immune system.

Hence vaccine designers' fascination with one of the oldest vaccines around. The yellow fever shot has been fulfilling the perfect vaccine wish list since the 1930s, when it was first created at what is today the Rockefeller University. "It is perhaps the safest and most effective vaccine ever developed," according to Raul Andino of the University of California, San Francisco, one of several researchers hoping to transfer its successful traits to modern vaccines against other problematic pathogens.

Andino and the others are working to piggyback the immune-stimulating features of various vaccines onto the yellow fever shot. The scientists hope that by riding yellow fever's coattails, those vaccines will provoke a more potent and lasting immunity than they are able to muster on their own. "I think using a tried-and-true vaccine such as yellow fever will be very successful. I really like the idea," says immunology specialist Peter Palese of the Mount Sinai School of Medicine.

Based on a strain called YF17D, the yellow fever vaccine is a live but weakened form of the wild virus. Charles M. Rice, head of the Laboratory of Virology and Infectious Disease at

MEAN VACCINE: Yellow fever shot confers long-lasting immunity, a trait that medical researchers hope to transfer to other kinds of vaccines.

EMILY HARRISON (*photoillustration*); NATION WONG *zefa/Corbis* (*syringe*); CDC/PHOTO RESEARCHERS, INC. (*yellow fever TEM*)

NEED TO KNOW: ONE-SHOT DEAL?

Along with mosquito-control measures, the yellow fever vaccine has worked so well that the disease, once a terrifying killer, is now a dim memory in much of the world. Most people, unless they have traveled to a few enclaves in Africa or South America where yellow fever still thrives, have never even been exposed to the vaccine, which could be another point in favor of a chimera approach. They represent a broad "naive" population likely to respond to a combination shot. But the yellow fever vaccine is so good at creating enduring immunity, effectively to itself, that the chimera trick might only work once. Viruses such as influenza, whose antigens evolve so often that frequent new immunizations are needed, would therefore probably not be ideal candidates for chimeric vaccines.

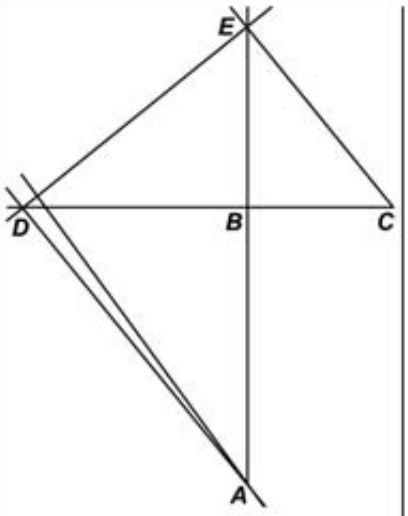
Rockefeller, has shown in mice that a component of malaria vaccine inserted into YF17D elicited malaria-targeted T cells and gave the mice long-lasting protection against the infection. In similar experiments with mice and monkeys, Andino has used YF17D to deliver HIV antigens—immune-provoking bits of viral protein. The chimeric YF17D/HIV vaccine prompted a 1,000-fold higher T cell response than the same HIV proteins delivered with different vectors. Andino has also caused melanoma tumors in mice to regress with a YF17D vaccine carrying a tumor-specific antigen.

Chimeric YF17D vaccines developed by Acambis, a biotech firm in Cambridge, Mass., are already showing promise in early human trials, but they are all combinations of yellow fever and its close relatives in the so-called flavivirus family, including the dengue, Japanese encephalitis and West Nile viruses. Making chimeras containing proteins from unrelated pathogens is trickier. The main challenge is to insert the foreign protein into the yellow fever virus without disabling the vaccine. For that, it helps to know how the yellow fever vaccine stimulates such potent immunity to begin with, which has been a long-standing mystery.

The answer may lie with dendritic cells, immune system sentinels whose normal job is to digest sick cells infected by pathogens. The dendritic cells then alert immune warrior cells to the presence of an intruder by presenting them with its distinctive antigens. Rice recently showed that YF17D directly infects dendritic cells. A few other viruses, including HIV, herpes simplex and measles, infect them as well, but they either kill or incapacitate the cells. He found that YF17D lets them live and continue to fulfill their antigen-presenting function.

Something about being infected themselves might give extra urgency to the dendritic cells' communication with the other immune cells, Rice speculates. Or it could be just that the vaccine strain "is in the optimal antigen-presenting cells to begin with," he says, thereby accounting for the powerful immune response. Either way, the findings suggest a possible vaccine-design tip from nature.

"We know that dendritic cells are a crucial and central mechanism for making long-lasting immunity," Palese says. "It's a must." As researchers continue exploring ways to make yellow fever vaccine protect against other pathogens, it seems that the 70-year-old perfect vaccine still has some tricks to teach the scientists as well.



To with straightedge and compass double a cube, to draw with these instruments the edge of a cube double in volume of a cube with a given edge, is one of the ancient problems determined insoluble.

In the diagram above, if right angle ***ABC*** has ***AB*** twice as long as ***BC***, and with these two lines extended and right-angled ***ADEC*** placed as shown, it is known that if ***BC*** is the edge of a cube then ***BE*** is the edge of a cube double the volume.

But he problem is the construction. One has to make sure shape ***ADEC*** not only meets points ***A*** and ***C***, but also that its right-angle vertices lie on perpendiculars ***AE*** and ***CD***.

For this the ancients fashioned a laborious mechanical device, with a part like a carpenter's square for such as angle ***ADE***, and a moving crossbar for a ***CE***. The whole was then manipulated until all the above placements were reached. These accordingly involved the indirect "sliding" described previously here.

Offered presently is again a greatly simplified use of sliding, with only straightedge and compass, and a single placement to be reached:

With *AB* and *BC* extended as before, turn a line *AD* on *A* until on drawing at meeting point *D* a perpendicular *DE*, and at *E* a perpendicular *EC*, *EC* meets *C*. Only the last result is the aim.

Much more work by the author, Paul Vjecsner, is in his book and on his website, http://vjecsner.net. His insertions in *Scientific American* were in November and December 2005, and March 2006.

NEUROSCIENCE

Taking Sides

IS BEING RIGHT-HANDED ALL FOR THE GREATER GOOD? BY SANDRA UPSON

Ask why most people are right-handed, and the answer might fall along the same lines as why fish school. Two neuroscientists suggest that social pressures drive individuals to coordinate their behaviors so that everyone in the group gets an evolutionary edge.

Approximately 85 percent of people prefer their right hand, which is controlled by the left hemisphere of the brain. One theorized benefit of locating a particular function in one hemisphere is that it frees the other to deal with different tasks. But that idea does not explain why population-wide trends for handedness exist in the first place. Moreover, evidence gleaned in recent years has overturned the long-held belief that human handedness is a unique by-product of brain specialization attributable to language. A suite of studies has revealed brain lateralization in species from fish to primates. Last August, for instance, scientists discovered that in the wild, chimpanzees show hand preferences.

The presence of lateralization throughout the animal kingdom suggests some benefit from it, contend neuroscientists Giorgio Vallortigara of the University of Trieste and Lesley Rogers of the University of New England in Australia. Also, last August, in the journal *Behavioral and Brain Sciences*, the two presented evidence to support their idea that social constraints force individuals toward asymmetry in the same direction. They noted, for example, that baby chickens attack more readily when a threat appears on their left. And Rogers has found that chicks with more asymmetrical brains form more stable social groups: perhaps by approaching each other on the right, she hypothesizes, the chicks fight one another less and are more likely to notice predators.

Lateralization seems to confer an advantage for some fish as well. In certain species, the majority tend to swim left when a predator attacks, whereas other species head right. The potential benefits of such patterns may not seem intuitive: a predator could learn that attacking a fish on one particular side is more effective. But Vallortigara and Rogers's idea fits with the conventional explanation of why fish school at all. When threatened, fish turning in the same direction have a greater chance of survival than if they scatter to become a darting swarm of head-butting fish.

Nevertheless, the bird and fish data do not explain human handedness. "The issue then becomes: maybe this lateralization long predates the rise of the mammals," speculates Robin Dunbar, an evolutionary psychologist at the University of Liverpool in England.

EVOLUTIONARY PRESSURE to conform may explain why righties outnumber lefties six to one.

RANDY FARIS *Corbis*

"And mammals are lateralized as they are in the brain simply because their ancestors were, going back to the origins of the fish."

Research on chimpanzees supports that idea. Elizabeth V. Lonsdorf of the Lincoln Park Zoo in Chicago and William D. Hopkins of the Yerkes National Primate Research Center at Emory University recently published data showing that wild chimpanzees display heritable population-wide hand preferences in certain tool-aided tasks—for instance, two thirds of the chimpanzees they observed in the wild preferred holding a stick in the left hand to dig termites out of a hole. Previously, primates had exhibited right-hand preferences in captivity but no handedness in the wild, leading scientists to speculate that they became lateralized through interacting with humans.

The chimpanzee findings fill in what had been a troublesome missing link between lower vertebrates and humans. "Getting away from the human uniqueness argument has really been good," Hopkins says. "It has made people really rethink some of their ideas."

Other explanations for lateralization exist—for instance, that it was passed down as part of a larger genetic package that improved its possessor's chance of survival in a way unrelated to a specific lateralization. "I would take exception to the idea that there's one definitive approach, because it is such a slippery question and one that requires inference," says neuroscientist Jeffrey Hutsler of the University of Michigan at Ann Arbor.

Given possible evolutionary reasons to conform to the norm, what about the lefties, the outliers, those who zig when all others zag? Safety from predators increases with group size, but so does competition, Vallortigara notes, making different behavior beneficial. Studies of left-handedness in some one-on-one sports, such as boxing, suggest the same. So relax, all you nonconformists.

Sandra Upson is a freelance writer based in New York City.

ECOLOGY

Survival of the Smallest

RETURNING THE BIG ONES TO KEEP FISHERIES HEALTHY **BY SARAH SIMPSON**

Any commercial fisher or weekend angler knows to "throw the little ones back." The idea is to give small fish time to grow up and make babies. But that strategy may actually be harming fish stocks.

Ongoing experiments on captive fish reveal that harvesting only the largest individuals can actually force a species to evolve undesirable characteristics that diminish an overfished stock's ability to recover, says David O. Conover, director of the Marine Sciences Research Center at Stony Brook University. The results may explain why many of the world's most depleted stocks do not rebound as quickly as expected.

SHRINK-FIT: Harvesting the largest fish drives fifth-generation Atlantic silversides to be smaller (*left third*) than fish from populations that were harvested at random (*middle third*) or from which only small fish were harvested (*right third*).

STEPHAN MUNCH *Stony Brook University*

The genetic effects appeared in Atlantic silversides, a small, usually fast-growing fish. Conover brought a batch of wild silversides to his laboratory in 1998. He and his students then reared six generations, each time removing the largest 90 percent from one group, the smallest 90 percent from another group, and a random 90 percent from a third.

By 2002 it was plain to see that killing off the largest fish had a dramatic effect. Individuals in that group were only about 70 percent the average weight of their randomly harvested counterparts; they were only 55 percent the weight of survivors in the group where only the largest individuals were spared. Because the compared fish were the same age, the scientists could attribute the shrinkage to selection of genes for slower growth.

Even more alarming, the slower growth came with a suite of deficiencies. Detailed examinations of the fifth- and sixth-generation fish, led by Matthew R. Walsh, now a doctoral student at the University of California, Riverside, revealed that members of the large-harvested group were less willing to forage for food and less able to outwit predators. They also produced smaller and fewer eggs, and a lesser portion of those eggs grew into healthy offspring.

These results are not entirely a surprise, Walsh notes. Historical records confirm that cod and other popular food fishes were bigger in the past, and "it is well known in many fish species that fecundity increases with body size," he says. Now, though, human-induced evolution will be more difficult for biologists and fisheries managers to ignore. "This work is a good example of how evolution can work against the long-term fitness of the population—and against our interests," says U.C.R. fish biologist David N. Reznick.

Whether weaker fish are making it to the dinner table now is not at all clear, Conover admits. But letting some big fish go along with the little ones is probably a smart strategy nonetheless. Meanwhile Conover's team has halted all size-selective harvesting and is waiting to see whether subsequent generations will recuperate—and how long it takes to do so.

NANOTECH

Crystal Steer

SAPPHIRE PLAYS SUPPORTING ROLE FOR NANOTUBES **BY CHARLES Q. CHOI**

Carbon nanotubes would make ideal connecting wires in advanced circuits if not for the painstaking effort required to line up each tiny, sticky, floppy strand. Now scientists have found that crystalline sapphire can automatically help guide nanotubes into the patterns needed to build transistors and to make flexible electronics.

Electrical signals can flow more quickly through carbon nanotubes than through silicon, which in principle could lead to faster computers, explains Chongwu Zhou, an electrical engineer at the University of Southern California. Moreover, nanotubes

NANOTUBE HOOKUP

Molecular electronics strives to employ single organic molecules as the tiniest of computing or sensor elements, but these molecules often have unstable connections with their electrodes. Organic chemist Colin Nuckolls and his colleagues at Columbia University have developed a method that more robustly wires these molecules to carbon nanotubes. The technique, described in the January 20 *Science*, cuts molecule-size gaps in the nanotubes using oxygen plasma. It leaves their ends chemically receptive to the kind of linkages found in proteins, which are significantly more durable than ones formed by the gold and sulfurous compounds typically used to attach molecules to electrodes.

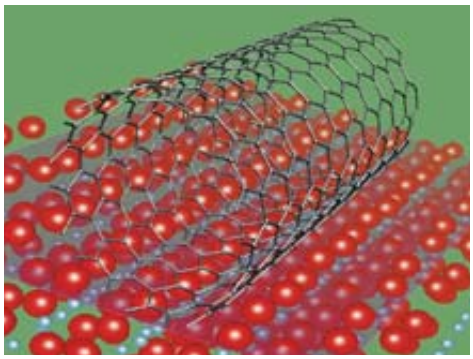
can be as small as one-fifth the theoretical minimum size of conventional silicon circuitry.

To make nanotube circuits, scientists scatter nanotubes randomly and attach electrodes wherever they can, or else they try to grow nanotubes toward one another and later fabricate electrodes on them. Such efforts, though, are slow and inefficient, leading scientists to wonder if substrates existed that could naturally orient the tubes. After more than a year of experiments on various crystals, Zhou and his colleagues discovered that sapphire could achieve just that. Sapphire crystal is hexagonal, rising from a flat base, and the researchers found that most vertical slices of sapphire apparently expose constituent aluminum and oxygen atoms in layouts that promote the formation of nanotubes in orderly rows.

In the January *Nano Letters*, Zhou's team reported the creation of transistors with such aligned nanotubes. The researchers coated commercially available artificial sapphire with a cagelike protein called ferritin and flowed hydrocarbon gas over it while baking it. Iron within the protein catalyzed the growth of single-walled nanotubes from carbon supplied by the gas. Once the sapphire was covered with nanotubes, they could place the metal electrodes of the transistors wherever they wanted and remove the unwanted nanotubes with highly ionized oxygen gas.

Past carbon nanotube transistors were typically constructed atop silicon composites common in the electronics industry. The drawback was that the metal electrodes and the silicon interacted to suck up electrical charge, slowing down performance and raising power consumption. Zhou's strategy eliminates the parasitic drain because sapphire is electrically insulating, not semiconducting like silicon. The method is closely related to the so-called silicon-on-sapphire approach that IBM and other chipmakers have used to build specialized high-performance circuitry, "so we can borrow a lot of knowledge from the semiconductor industry," Zhou remarks.

When compared with other carbon nanotube electronics, these findings display the



TUBE TOP: A substrate of sapphire, which consists of aluminum (*light blue*) and oxygen (*red*) atoms, can orient carbon nanotubes naturally.

SONG HAN, XIAOLEI LIU, DIAHUA ZHANG AND CHONGWU ZHOU *University of Southern California*

highest density of aligned nanotubes, at up to 40 per micron. Other methods manage only one to five, Zhou states. Nanotube density is crucial, because the more there are between electrodes, the more signals will be conducted. The scientists can control nanotube density by varying how much iron they employ within the ferritin.

The researchers could readily create flexible electronics from their nanotube transistors by baking a plastic film onto the nanotube transistors and then peeling off the strips, which hold on to the transistors. Carbon nanotube flexible electronics could "relatively easily" outperform the silicon-based versions currently used by industry, Zhou says, and he foresees its use in applications such as large flat-panel displays, vehicle windshields and smart cards. He also notes that such aligned nanotubes could act as sensors: attached molecules could send an electrical signal across the nanotubes if they reacted with cancer markers or other compounds.

These findings are "a very important result in resolving one of the most difficult problems related to carbon nanotube manufacture for integrated circuits," says Kang Wang, director of the Center on Functional Engineered Nano Architectonics at the University of California, Los Angeles. He points to one crucial hurdle to overcome: ensuring that all nanotubes made by this technique are semiconducting, because it currently produces a mix of metallic (fully conducting) and semiconducting ones.

Charles Q. Choi is a frequent contributor.

BY THE NUMBERS

Lady Luck

MORE AMERICANS CANNOT RESIST ROLLING THE DICE **BY RODGER DOYLE**

In 1970 casino gambling was confined to Nevada; New Hampshire, New Jersey and New York were the only states with lotteries. Today either casinos or lotteries—usually both—are legal in 47 states, as shown on the map. In addition, widespread but illegal gambling thrives on the Internet.

Because of its potential for addictive behavior, casino gambling has aroused the interest of health professionals. The activity is pervasive: A 1998 survey found that 29 percent of Americans had taken their chances at a casino in the previous 12 months. More probably do so now, because several other states have legalized casinos since then. Health concerns also swirl around state lotteries, particularly those that sell high-price instant games for $20 or more. Internet gambling is troubling, too, because it is a solitary activity that can be pursued uninterrupted for hours and so may prove uniquely addictive. Available from numerous overseas Web sites, it is illegal under federal law and the laws of six states yet is widely practiced and rarely prosecuted.

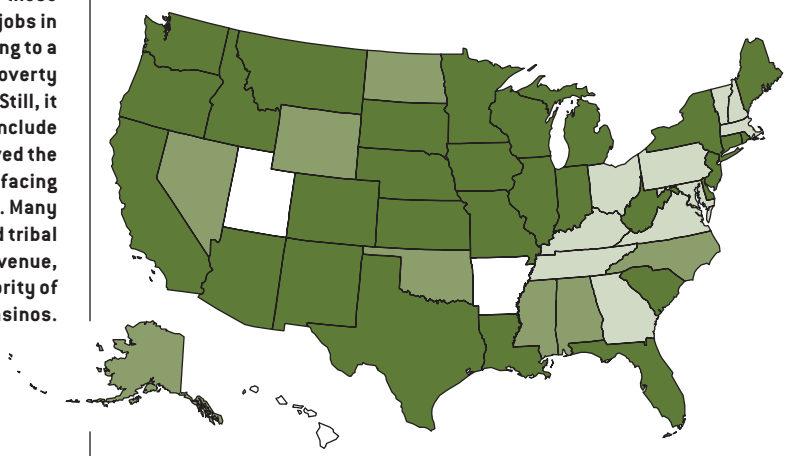
Increasing opportunities to visit casinos, buy lottery tickets and engage in Internet gambling may have led in recent years to a rise in pathological gambling, which the American Psychiatric Association (APS) defines as a persistent and recurrent behavior "that disrupts personal, family, or vocational pursuits." Pathological gambling raises the chances of bankruptcy, divorce and suicide. Another category—problem gambling—is not defined by the APS but is commonly used to describe a less severe degree of addiction.

The annual prevalence of pathological gambling is estimated at 1.2 percent of the adult population; for problem gambling, the estimate is at least 2.8 percent. Thus, some 2.4 million Americans are afflicted with pathological gambling and at least 6.1 million with problem gambling. The social cost, including that for treatment of gambling addiction, bankruptcy, divorce and crime, is significant; however, it has not been adequately measured, because addicted gamblers tend to have other problem behaviors, such as substance abuse, antisocial personality disorder and depression. Such behaviors are difficult to separate from gambling addiction.

Despite the social ills, substantial arguments can be made in favor of legal gambling. For most people, it is a pleasant diversion. For older people, it is a social pastime that may enhance memory, problem solving, concentration and coordination. Furthermore, legalization may help limit the participation of organized crime. Against these positive elements must be balanced the human toll from pathological and problem gambling. The incommensurability of these conflicting claims explains in part why gambling remains such a contentious issue.

Rodger Doyle can be reached at rodgerpdoyle@verizon.net

WHERE STATE LOTTERIES AND GAMBLING CASINOS ARE LEGAL



RODGER DOYLE; SOURCE: MELISSA S. KEARNEY, 2005. CASINOS INCLUDE THOSE RUN BY NATIVE AMERICANS AND BY COMMERCIAL INTERESTS; THEY INCLUDE RACINOS—RACETRACK CASINOS—AND RIVERBOAT CASINOS

ROULETTE ON RESERVATIONS

In the late 1980s changes in the law made it far easier for Native American tribes to open casinos, leading to widespread proliferation of gambling on reservations. By 2003 these casinos provided 240,000 jobs in the U.S., thus leading to a significant diminution of poverty on those reservations. Still, it would be a mistake to conclude that gambling has solved the socioeconomic issues facing Native Americans. Many geographically isolated tribal casinos generate little revenue, and a substantial minority of tribes have not adopted casinos.

FURTHER READING

Gambling: An Addictive Behavior with Health and Primary Care Implications. Marc N. Potenza et al. in *Journal of General Internal Medicine,* Vol. 17, No. 9, pages 721–732; September 2002.

The Social and Economic Impact of Native American Casinos. William N. Evans and Julie H. Topoleski in *National Bureau of Economic Research,* Working Paper 9198; September 2002.

A Review of Research on Aspects of Problem Gambling. Max Abbott, Rachel Volberg, Maria Bellringer and Gerda Reith. Auckland University of Technology Gambling Research Center, October 2004. Available at www.rigt.org.uk/downloads/Auckland_report.pdf

The Economic Winners and Losers of Legalized Gambling. Melissa S. Kearney in *National Bureau of Economic Research,* Working Paper 11234; March 2005.

DATA POINTS: CANCER DEATHS

The American Cancer Society reports a drop in total cancer deaths from 2002 to 2003, the first decrease since nationwide record keeping began in 1930. Total cancer deaths for 2006 are expected to rise because of the growing and aging population. The death rate, however, will continue its fall, which began in 1991.

Cancer deaths in 2002: 557,271
In 2003: 556,902

Expected cancer cases in 2006: 1,399,790

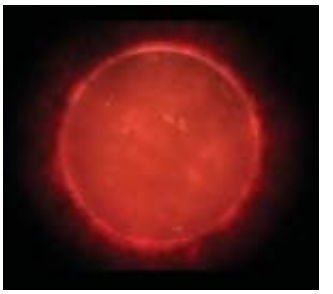
Deaths expected from:
Lung cancer: 162,460
Colorectal cancer: 55,170
Breast cancer: 40,970
Prostate cancer: 27,350
Percent of all cancer deaths from these four types: 51

Odds of developing cancer by age 39:
Men: 1 in 70
Women: 1 in 50
Between ages 40 and 59:
Men: 1 in 12
Women: 1 in 11
Between ages 60 and 69:
Men: 1 in 6
Women: 1 in 9

SOURCE: Cancer Facts & Figures 2006.

ASTRONOMY

Singular Is the New Binary



RED DWARF (*artist's conception*) is the most common type of star and tends to come single.

Astronomy textbooks have long told neophyte stargazers that three of every five points of light in the night sky are waltzing pairs of stars called binary systems. The statistic is based on counts of visible stars begun at the turn of the 20th century, when telescopes were less powerful. Brighter stars are relatively rare, though: in our galaxy, they account for 15 to 20 percent of the stellar systems. In the past five years, more sensitive instruments have surveyed red dwarf systems, which are dimmer and much more common. So far only a quarter of these systems were found to be binary, which would mean that two thirds of stellar systems are actually single red dwarfs. The result should help researchers make sense of star-formation theories, says Charles Lada of the Harvard-Smithsonian Center for Astrophysics, who reports the tally in an upcoming *Astrophysical Journal Letters*. "Many of the current theories find it a lot easier to form single stars," Lada says. —*JR Minkel*

FOOD

Fat Chance

Cutting back on fat per se does not protect against cancer and heart disease, at least in the short run. That conclusion comes from the latest results from the ongoing Women's Health Initiative, which has followed nearly 49,000 women aged 50 to 79 for the past eight years. One group reduced fat consumption 8 to 10 percent over the duration of the trial compared with a control group. Overall, the two groups had statistically indistinguishable rates of colon cancer and heart disease and just a marginal reduction in breast cancer risk of 9 percent, although chance could have accounted for that outcome. Researchers report the findings in three studies published February 8 in the *Journal of the American Medical Association*. Continued follow-up might yet bump the marginal findings into the statistically significant range, says Ross Prentice of the Fred Hutchinson Cancer Research Center in Seattle, lead author of the breast cancer study. —*JR Minkel*

FIELD BIOLOGY

Finding a Lost World

BIG BLOOM: Largest rhododendron flower was one of several new species discovered in a pristine New Guinea forest.

On an expedition to one of Asia's most isolated jungles in the misty Foja Mountains of western New Guinea, scientists uncovered a vast trove of new species, giant flowers and rare wildlife. The December 2005 voyage revealed nearly two dozen previously unknown species of frogs, four new butterflies, what may be the largest rhododendron flower on record (at nearly six inches across), and a novel breed of honeyeater, the first new bird discovered on the island in almost 70 years. Also seen were the golden-mantled tree kangaroo, formerly known from only a single mountain in neighboring Papua New Guinea, and little-known long-beaked echidnas, a primitive egg-laying mammal. These discoveries suggest the nearly 2.5 million acres of the Foja jungle could be the largest essentially pristine tropical forest in Asia, announced expedition co-sponsor Conservation International on February 7. —*Charles Q. Choi*

WALT FEIMER *NASA (top)*; WAYNE TAKEUCHI; COURTESY OF CONSERVATION INTERNATIONAL *(bottom)*; ILLUSTRATION BY MATT COLLINS

INVASIVE SPECIES

Musseling In

ZEBRA MUSSELS could face a weapon of encapsulated chlorine.

A new weapon against the invasive zebra mussel, still wreaking havoc in the Great Lakes, could soon be deployed: microcapsules of a chlorinated salt. Chlorination is the widespread method for attacking zebra mussels. The problem is that the mollusks can detect chlorine and seal their valves for up to three weeks, necessitating prolonged dosing, which poisons the water. Instead University of Cambridge researchers took potassium chloride, a salt especially toxic to zebra mussels but at low doses harmless to most organisms, and wrapped it in 105-micron-wide capsules made of vegetable oil and other ingredients. These match the size of particles that zebra mussels filter from the water. Aquarium findings reported in the February 1 *Environmental Science & Technology* show that the capsules killed 60 percent of zebra mussels with one dose while leaving native mussels apparently unscathed. —*Charles Q. Choi*

BRIEF POINTS

■ **Ball lightning in the lab: Physicists concentrated the energy from a household microwave into a cubic centimeter and piped it into a ceramic, creating a hot spot. Withdrawing the pipe brought out the hot spot, which formed a buoyant, three-centimeter-wide fireball that lived for a few tens of milliseconds.**

Physical Review Letters, February 3

■ **Mice lacking the *Runx1* gene feel no pain or discomfort from heat or cold. The gene appears to be a master switch for neuropathic pain, or chronic pain that outlasts an injury and is associated with nervous system changes.**

Neuron, February 2

■ **What is the best throwing angle to achieve distance? A study of soccer throw-ins reveals it to be 30 degrees, because a person can release the soccer ball faster there than at 45 degrees, the conventionally assumed angle.**

Sports Biomechanics (in press)

■ **Prions of chronic-wasting disease, a relative of mad cow disease, have been found in the muscles of infected deer, posing a new source of prion exposure for venison eaters.**

Science online, January 26

MIMICRY

When a Fungus Has a Ball

Move over, cuckoo. The new master designer of impostor eggs is a genus of fungus called *Athelia,* some species of which trick termites into nurturing their young. Sclerotia, or "termite balls," are tough, filamentous orbs that can sprout into fungal colonies when dropped into piles of termite excreta, where competition for resources is lacking. As they do for any ball of similar diameter and scent as their eggs, termites assiduously smear fungal balls with their saliva, a moisturizer and antibiotic. For their part, the fungal spheres neither benefit nor harm eggs tended in petri dishes, reports Okayama University entomologist Kenji Matsuura in a *Proceedings of the Royal Society B* paper published online January 24. He concludes that the fungus cuckolds termites for its sole gain in this unusual example of egg mimicry. —*JR Minkel*

EGG TRICK: To termites, fungal balls (*dark orange*) can look like eggs (*white*).

STRESS

Genetic Changes from Bullying

Neuroscientists have uncovered genes underlying the fear of bullies in rodents. Mice constantly menaced by larger mice become loners, scared even of more docile mice. Bullying evidently triggers an upheaval in gene expression within the so-called mesolimbic dopamine pathway, a brain circuit linked with feelings of reward and desire. The result was the boosted expression of 309 genes and a stifling of 17, with many of these changes persisting for weeks afterward. A key regulator of the pathway is brain-derived neurotrophic factor, a chemical linked with antidepressant activity. Olivier Berton of the University of Texas Southwestern Medical Center and his colleagues knocked out the circuit's production of this factor, thereby reversing most of the bullying-inspired gene expression. The mice then accepted strangers despite repeated harassment. These findings, in the February 10 *Science,* could help treat depression and post-traumatic stress disorder, of which social withdrawal is a prominent symptom. —*Charles Q. Choi*

ED RESCHKE *Peter Arnold, Inc.* (*top*); KENJI MATSUURA *Okayama University* (*bottom*)

As Luck Would Have It

Are some people really luckier than others, or is it all in their heads? Both

By MICHAEL SHERMER

Amyotrophic lateral sclerosis (ALS) is a neuromuscular disease that attacks motor neurons until muscle weakness, atrophy and paralysis lead inexorably to death. Victims of this monstrous malady could be forgiven for feeling unlucky.

How, then, can we explain the attitude of the disease's namesake, baseball great Lou Gehrig? He told a sellout crowd at Yankee Stadium: "For the past two weeks you have been reading about the bad break I got. Today I consider myself the luckiest man on the face of this earth." The Iron Horse then recounted his many blessings and fortunes, a list twice punctuated with "I'm lucky" and "That's something."

Lucky people expect good things to happen.

Clearly, luck is a state of mind. Is it more than that? To explore this question scientifically, experimental psychologist Richard Wiseman created a "luck lab" at the University of Hertfordshire in England. Wiseman began by testing whether those who believe they are lucky are actually more likely to win the lottery. He recruited 700 subjects who had intended to purchase lottery tickets to complete his luck questionnaire, which is a self-report scale that measures whether people consider themselves to be lucky or unlucky. Although lucky people were twice as confident as the unlucky ones that they would win the lottery, there was no difference in winnings.

Wiseman then gave subjects a standardized "life satisfaction" scale, which asks individuals to rank themselves on how satisfied they are with their family life, personal life, financial situation, health and career. The results were striking. "Lucky people are far more satisfied with all areas of their lives than unlucky or neutral people," Wiseman reveals in his charming and insightful book, *The Luck Factor* (Miramax Books, 2003). Does this satisfied state of mind translate into actual life outcomes that someone might call lucky? It does. Here's how.

Wiseman gave subjects the "big five" personality scale, which measures "agreeableness," "conscientiousness," "extroversion," "neuroticism" and "openness." Although there were no differences between lucky and unlucky people on agreeableness and conscientiousness, Wiseman found significant differences for extroversion, neuroticism and openness.

Lucky people score significantly higher than unlucky people on extroversion. "There are three ways in which lucky people's extroversion significantly increases the likelihood of their having a lucky chance encounter," Wiseman explains: "meeting a large number of people, being a 'social magnet' and keeping in contact with people." Lucky people, for example, smile twice as often and engage in more eye contact than unlucky people do, which leads to more social encounters, which generates more opportunities.

The neuroticism dimension measures how anxious or relaxed someone is, and Wiseman found that the lucky ones were half as anxious as the unlucky ones—that is, "because lucky people tend to be more relaxed than most, they are more likely to notice chance opportunities, even when they are not expecting them." In one experiment, Wiseman had volunteers count the number of photographs in a newspaper. Lucky subjects were more likely to notice on page two the half-page ad with the message in large bold type: STOP COUNTING—THERE ARE 43 PHOTOGRAPHS IN THIS NEWSPAPER.

Wiseman discovered that lucky people also score significantly higher in openness than unlucky people do. "Lucky people are open to new experiences in their lives.... They don't tend to be bound by convention and they like the notion of unpredictability," he notes. As such, lucky people travel more, encounter novel prospects and welcome unique opportunities.

Expectation also plays a role in luck. Lucky people expect good things to happen, and when they do they embrace them. But even in the face of adversity, lucky people turn bad breaks into good fortune. Consider the example set by one of the longest ALS sufferers in history, Stephen W. Hawking, who writes: "I was lucky to have chosen to work in theoretical physics, because that was one of the few areas in which my condition would not be a serious handicap." Unable to move and confined to a wheelchair, Hawking has capitalized on his fate by using it as a chance to transform our understanding of the universe, which he has. That's something. SA

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

BRAD HINES

The Prostitutes' Union

Among the poor and most vulnerable, Smarajit Jana has found a way to slash the incidence of HIV—by organizing sex workers as any other labor collective By MADHUSREE MUKERJEE

Blanching at the stench of urine, I stumble up pitch-black, uneven steps to the top floor, which seems to be a rooftop on which someone has constructed shacks out of brick, asbestos and plastic. A shaft of light from a street lamp falls past tenuous bamboo railings onto a figure in a glittering white sari. She crouches on the bare brick floor by the roof's edge, holding a mirror in one hand and a lipstick in another, using the light to make up. Older residents of the brothel, who expect no clients, crowd into a tiny room to tell me their stories. "I've spent my life in this hell," says Pushpa Adhikari, an ancient woman with sad eyes who was sold into sexual slavery at the age of nine. The others demur: thugs used to terrorize the brothels with nightly rapes and murders, but now that the prostitutes are united the hoodlums keep their distance. "It used to be hell—now it's heaven," corrects one woman, and even Adhikari nods.

MADHUSREE MUKERJEE

SMARAJIT JANA: COLLECTIVE REASONING

- Delhi-based public health scientist who founded India's Sonagachi project, in which sex workers form a collective to ensure condom use.
- His first love: occupational medicine, because the combination of science, politics and economics appealed to him.
- What he said to prostitutes that helped them feel socially and morally empowered: "I sell services, so do you."

Freeing the brothels from terror is merely a side effect of the Sonagachi project, an HIV intervention program named after the red-light district of Kolkata (formerly Calcutta) where it began. Rural poverty forces millions of Indian men to migrate to urban centers in search of a livelihood; there they visit brothels, pick up the AIDS virus and take it back to their wives. Truck drivers also infect prostitutes along the major highways. India already harbors at least five million cases of HIV—the most in the world after South Africa—but it is too poor, and its health infrastructure too weak, to permit reliance on drugs. Only if prostitutes cease to acquire and transmit the virus can the epidemic be contained, and Smarajit Jana, a public health scientist, has found a way to accomplish that.

"I strongly believe that for a program to succeed, the subjects have to adopt its goals as their own," he explains. They have: the sex workers run the HIV program themselves. Jana persuaded them to form a growing collective that now includes 60,000 members pledged to condom use. It offers bank loans, schooling for children, literacy training for adults, reproductive health care and cheap condoms—and has virtually eliminated trafficking of women in the locale. Best of all, the project has kept the HIV prevalence rate among prostitutes in Sonagachi down to 5 percent, whereas in the brothels of Mumbai (Bombay) it is around 60. Other sexually transmitted diseases are down to 1 percent. Jana now works with CARE in Delhi, assisting other social workers in similarly transferring their HIV prevention programs to the people they serve. Such community-led interventions have become inte-

gral to the Bill and Melinda Gates Foundation in its five-year, $200-million effort to combat AIDS in India.

An unassuming man with flyaway hair and a ready smile, Jana, who is now 53, went through medical school in Kolkata in the 1970s. There he organized students to collect leftover medicines and visit slums to treat the inhabitants. Medical school in India is highly subsidized, so "we felt very strongly that we were morally responsible" to give something back, Jana recalls. They campaigned and litigated against hazardous medical products, getting two dozen of them recalled. When, instead of aiming for a lucrative private practice, Jana specialized in public health and went off to run a rural clinic, his parents were horrified.

At the clinic, Jana observed that if a woman had undergone a tubectomy, for which she had received money from a population-control program, she invariably blamed any subsequent health problems on it. Circumstances having forced her into the operation, she resented it and influenced others against it. "In the short term, you can get results with such coercive methods," Jana realized, "but in the long term, the program will fail"—as, indeed, the sterilization effort did. To truly succeed, one needed not only informed consent but heartfelt consent, which meant that one first had to understand what made someone tick.

SELF-EMPOWERING EFFORTS by sex workers, such as giving out condoms, have cut HIV rates in India.

SAVITA KIRLOSKAR *Reuters*

Jana would apply this insight in 1991, when an official from the World Health Organization asked him to survey the brothels of Sonagachi for HIV. By then, Jana had found his niche in occupational medicine, establishing precedents for compensating factory workers and protecting tea-garden laborers from pesticides. Jana agreed to the WHO request only after the official used the phrase "sex worker": the concept intrigued him. He opened a clinic in the area, and when patients finally trickled in, he treated and listened. The prostitutes' lives turned out to revolve around their children, which suggested how to make HIV relevant. Jana in turn explained to the women that he saw them simply as workers earning a living: "I sell services, so do you." To the prostitutes, who despised themselves no less than everyone else did, the idea was mind-boggling. "Many others came to ask if I had indeed said this. It had a ripple effect," Jana remembers. Gaining a measure of self-respect became the first step in a long process of empowerment.

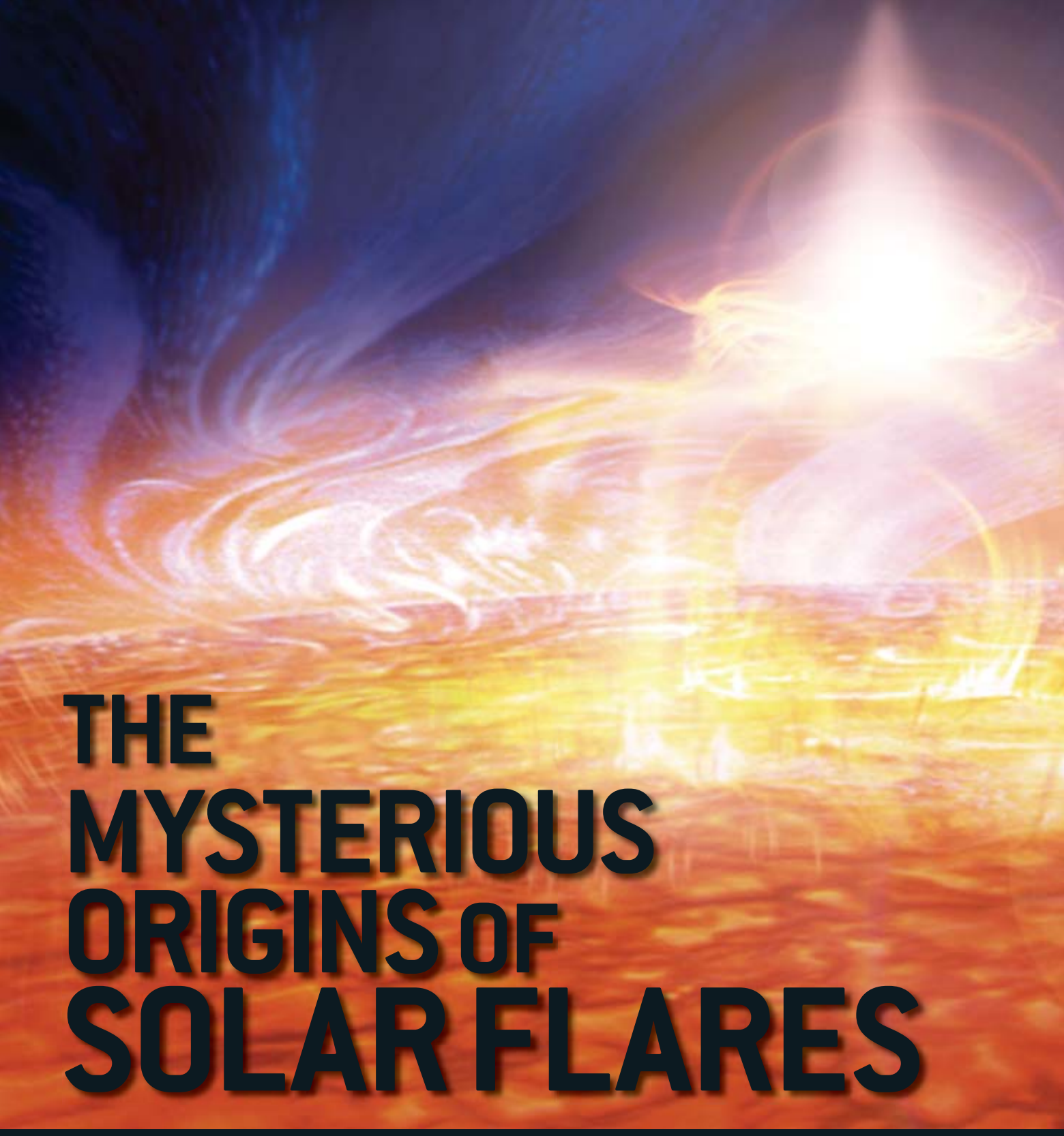
Following the survey, Jana undertook to ensure that the women protected themselves against HIV. He trained a few sex workers to go around the brothels talking about the virus and distributing condoms, and he sent researchers along to take notes on everything. It transpired that if a prostitute insisted on condom use, her customer just went to someone else. Unlike AIDS, starvation posed an immediate threat, and the program seemed doomed. "Counseling, educating—it just doesn't work," Jana states. "Higher up in the social hierarchy, people are able to act on the information given to them. Not so in the lower levels."

Thinking of HIV as an occupational hazard gave him the solution: a workers' collective. "The outcome of a negotiation depends on the relative power between the two parties," Jana explains. "When an individual sex worker deals with a client, she is weak. To change the power equation, she needs the support of other sex workers."

That was not enough, however: Jana also had to loosen several layers of coercion that perpetuated unsafe sex. He persuaded the brothel madams that keeping HIV down was in their interest. To reduce the depredations of gangsters, he invited their bosses—often local politicians—to tour the area and converted them to the cause. He lobbied the police to stop raiding brothels, because if a prostitute lost a day's earnings she was less likely to insist on condom use. He argued with syndicate leaders who controlled the pimps and who ultimately conceded to his economic logic. And finally, because society's revulsion left the sex workers feeling worthless and therefore less able to protect themselves, Jana pitted them against Kolkata's intellectuals in impassioned, face-to-face debates about morality. As the women grew in confidence, he removed himself from the scene: Jana's greatest achievement is his planned obsolescence.

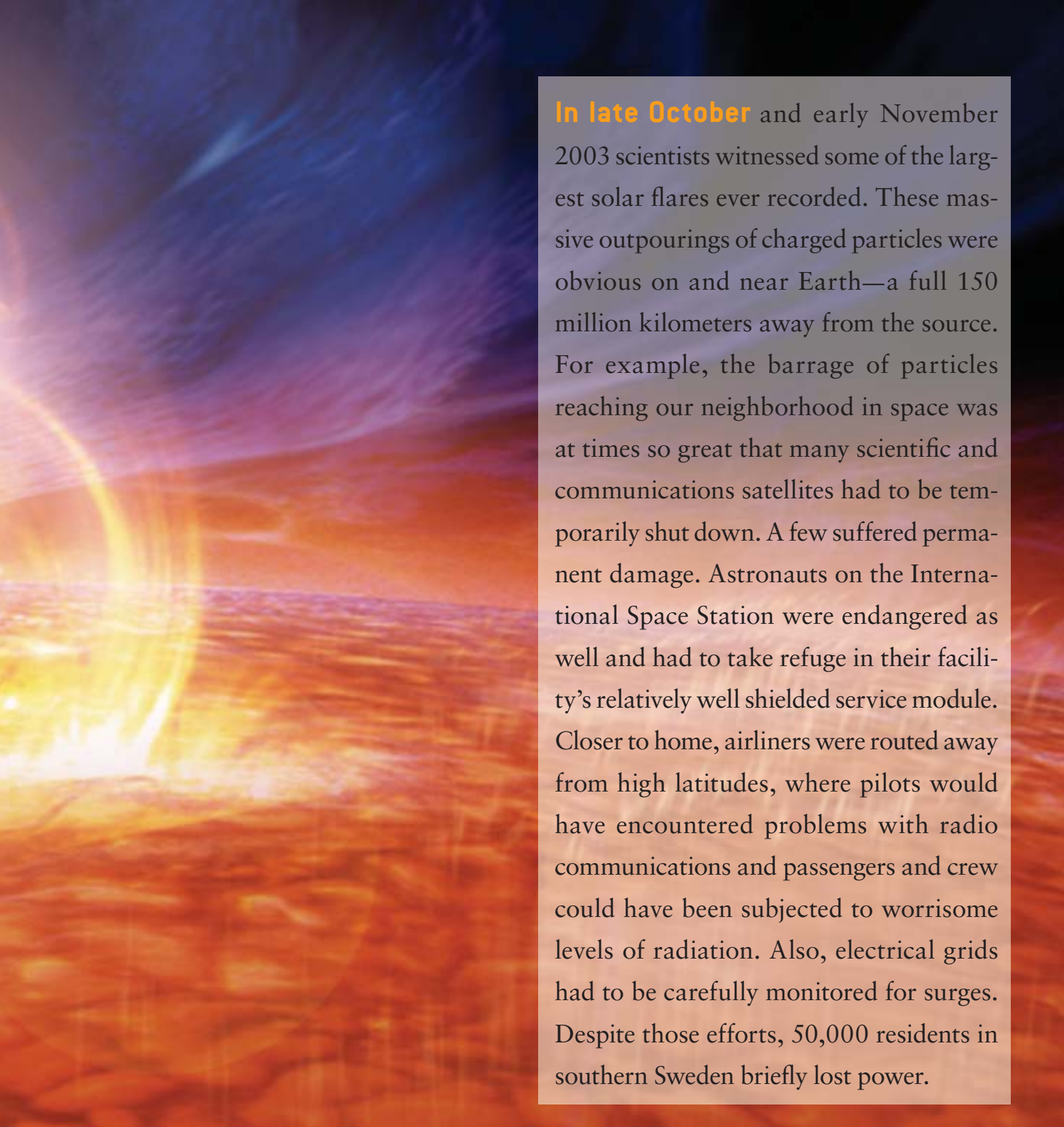
Jana has added community empowerment to the known spectrum of structural interventions—that is, programs that seek to alter the forces that maintain harmful behavior, explains public health scientist Michael Merson of Yale University. The United Nations's AIDS effort holds the Sonagachi project up as a "best practice" model. Still, how well it can be reproduced remains to be seen. Meanwhile the collective has hosted three conferences, attended by sex workers from around the world (including the U.S.) who hope to learn its secret. And while I interview Jana during one of his visits to Kolkata, hundreds of women wait patiently outside, each for her turn to meet him. In their eyes, this man who reached down to help them up wears the halo of a modern-day savior. SA

Madhusree Mukerjee, a former editor at Scientific American, *is researching the origins of Indian poverty for a book.*



THE MYSTERIOUS ORIGINS OF SOLAR FLARES

New observations are beginning to reveal what triggers these huge explosions of the sun's atmosphere



In late October and early November 2003 scientists witnessed some of the largest solar flares ever recorded. These massive outpourings of charged particles were obvious on and near Earth—a full 150 million kilometers away from the source. For example, the barrage of particles reaching our neighborhood in space was at times so great that many scientific and communications satellites had to be temporarily shut down. A few suffered permanent damage. Astronauts on the International Space Station were endangered as well and had to take refuge in their facility's relatively well shielded service module. Closer to home, airliners were routed away from high latitudes, where pilots would have encountered problems with radio communications and passengers and crew could have been subjected to worrisome levels of radiation. Also, electrical grids had to be carefully monitored for surges. Despite those efforts, 50,000 residents in southern Sweden briefly lost power.

SUDDEN EXPLOSIONS of the solar atmosphere release the energy equivalent of billions of atomic bombs within the span of just a few minutes. The cause is an abrupt rearrangement of solar magnetic fields, which arch upward from the surface of the sun and can be traced by the glowing gas they hold.

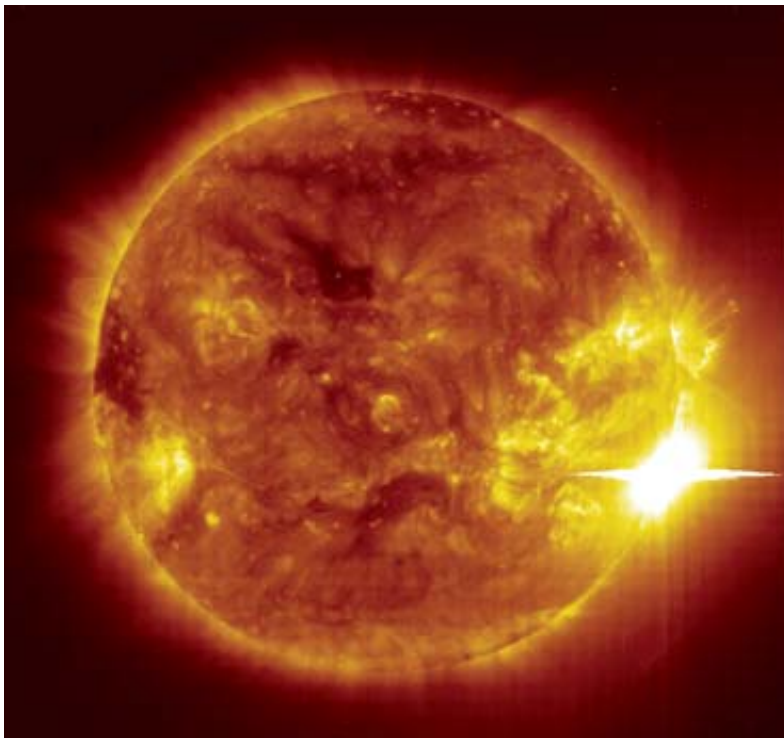
By Gordon D. Holman

Fortunately, Earth's magnetic field and atmosphere protect the overwhelming majority of people from the ravages of even the worst solar storms. But society's increasing reliance on technology makes nearly everyone vulnerable to some extent [see "The Fury of Space Storms," by James L. Burch; SCIENTIFIC AMERICAN, April 2001]. The greatest potential for damage during a large flare comes from material shot rapidly off the sun's outer atmosphere—coronal mass ejections, in space physicist lingo. Some of these events send huge quantities of ionized gas on a collision course with Earth, as was the case for more than one of the exceptionally large flares that occurred in 2003.

Although scientists have long sought to figure out what drives both flares and the coronal mass ejections that accompany many of them, only in the past decade or so have observations been good enough to reveal their intricacies and to elucidate the physical mechanism behind them, thanks to new technologies introduced during the 1990s. The key turns out to be a sudden rearrangement of magnetic field lines, a phenomenon called reconnection.

Fair and Mild, Highs of Two Million

THE WEATHER ON EARTH, complicated as it is, at least results from familiar processes: solar heating, differences in air pressure and shifting wind patterns. So most people have an intuitive grasp of why, for instance, the skies can be sunny one day and rainy the next. In contrast, solar flares and other aspects of "space weather" involve the interplay of magnetic fields and gas that is hot enough to become ionized (which is to say that the constituent atoms are stripped of their electrons). Such interactions cannot be seen directly and can be tricky to visualize, even for specialists. The leading idea for how these goings-on generate solar flares—magnetic reconnection—dates back to the 1950s and 1960s. Yet observational evidence for it has been slow in coming, so much so that some space physicists were beginning to have their doubts about the theory's merit.



RECORD-BREAKING FLARE erupted near the edge of the sun on November 4, 2003. The flash of radiation overwhelmed the detector on the Solar and Heliospheric Observatory's extreme-ultraviolet telescope, leaving a spurious horizontal line on this image (*left*). As with other such events, a sunspot—the site of particularly intense magnetic fields—was situated nearby (*right*).

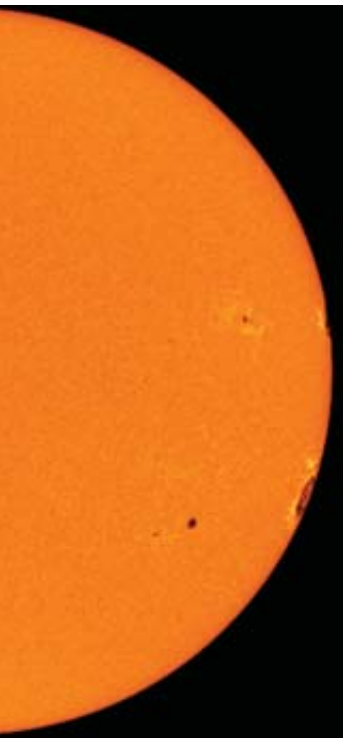
Scientists generally agree that the energy released in a flare must first be stored in the sun's magnetic fields. That surmise follows from the fact that flares erupt from parts of the sun called active regions, where solar magnetic fields are much stronger than average. These areas are most easily identified by the presence of sunspots—those dark-looking patches host the most intense magnetic fields on the sun. In these zones, the lines of force of the magnetic field extend from the surface into the corona, the outer layer of the solar atmosphere, arching upward in broad loops, which trap hot gas—and I do mean *hot:* several million kelvins. These temperatures are high enough to cause the contained gas to emit both extreme ultraviolet radiation and x-rays [see "The Paradox of the Sun's Hot Corona," by Bhola N. Dwivedi and Kenneth J. H. Phillips; SCIENTIFIC AMERICAN, June 2001]. The flares that occasionally burst forth from active regions emanate from such magnetic features, causing the gas in the loops to heat up more than usual—typically to between 10 million and 40 million kelvins.

Beyond the general association between flares and strong magnetic fields, the picture of how things work has long remained very fuzzy. For example, it has dawned only gradually on astronomers that the magnetic field loops and hot gas involved in flares may differ quite a bit from very similar-looking structures found elsewhere within active regions. The

Overview/*Physics of Flares*

- Solar flares can release the energy equivalent of billions of atomic bombs in the span of just a few minutes. These explosions give off a burst of x-rays and charged particles, some of which may later hit Earth, endangering satellites and causing power outages.
- The sun's tumultuous magnetic fields provide the fuel of flares. The sudden release of energy in a flare results from a process called reconnection, whereby oppositely directed magnetic field lines come together and partially annihilate each other.
- Although theoretical studies of magnetic reconnection on the sun have been carried out for decades, only recently have space probes uncovered observational evidence for this phenomenon. The telltale signs include pointed magnetic loops located below the spot where magnetic reconnection is taking place.

DON DIXON (*preceding pages*); SOHO/EIT (ESA AND NASA) (*flare and sunspot*) (*above*)



first signs of that distinction came nearly 14 years ago, from measurements carried out by the Japanese Yohkoh satellite, the first space probe to obtain pictures of solar flares at wavelengths that extend up to moderately high x-ray energies (making them useful in picking out very hot gas). For some of these events, the tops of the magnetic loops showed a curious cusp, giving them the pointed appearance of a Gothic arch, rather than presenting the usual rounded peak.

While examining the Yohkoh images, Satoshi Masuda, then a graduate student at the University of Tokyo, discovered that the cusp region of one 1992 flare emitted an unusually large dollop of relatively high energy (short-wavelength) x-rays. He concluded that the source was a pocket of exceptionally hot gas (about 100 million kelvins), which would be expected to glow brightly at short x-ray wavelengths. Alternatively, something could have accelerated electrons in this region to extremely high velocities, causing them to emit x-rays when they ran into ions in the surrounding gas and suddenly slowed down.

Either one of these possibilities was puzzling. If the gas was that scorching, how could it stay confined to such a small spot? And if instead the x-rays came from accelerated electrons bashing into ions, why was the radiation coming from a compact source near the top of the loop and not just from the bottom, where the density of gas is highest?

To solve these riddles, space physicists required measurements that could distinguish the effects of hot gas from those of accelerated electrons. And to understand when and where relevant activity was taking place, they needed frequent images of solar radiation in the full range of x-ray and gamma-ray energies. The lack of such information handicapped investigators for most of the next decade, but in 2002 NASA launched the Ramaty High Energy Solar Spectroscopic Imager (RHESSI), which has now captured detailed views of the cusp region in certain solar flares. In doing so, RHESSI has provided persuasive evidence—essentially a smoking gun—confirming that magnetic reconnection is responsible for both flares and coronal mass ejections.

Crossing the Lines

FOLLOWING WHAT EXACTLY HAPPENS during a reconnection event requires, first off, a general understanding of how invisible magnetic loops can trap hot gas in the solar atmosphere. Such gas is better termed plasma, because it consists mostly of electrons and protons separated from one another, which means that it is electrically conductive. An electric field can thus push these charge-carrying particles along it, creating electric currents. A magnetic field exerts forces on such charged particles, too, sending them twirling around magnetic field lines.

Although electrons and protons are constrained to circle magnetic field lines in this manner, they can move relatively freely along the length of those lines. I say "relatively" because charged particles will experience a retarding force if they travel along magnetic field lines that converge. So, for example, during its descent from the top of a loop toward the bottom, a particle will be slowed as it approaches one of the so-called foot points of the loop, where the field lines converge and the magnetic field is more intense. Eventually the increasingly strong field brings the electron or proton to a halt and then pushes it back up. This process is akin to throwing a cannonball against a mattress. Unlike the ball, however, which temporarily gives up its energy of motion to compress the mattress springs, charged particles on the sun do not transfer energy to the magnetic field. Rather the energy of their downward travel shifts to increase the frequency of their circular motion around magnetic field lines. In this way, the two foot points of a magnetic loop act like mirrors, reflecting protons and electrons back and forth in what is essentially a big trap for charged particles.

Surprisingly enough, the plasma itself can affect the magnetic field lines holding it. It does so because being a sea of charged particles, it can contain electric currents, which arise whenever there is a voltage difference present to drive them. In more familiar electric circuits—say, the one found in a flashlight—a battery provides the driving voltage. On the sun, nothing like a battery exists, but the shifting magnetic fields induce voltage differences (according to the same physical principles that operate an electric generator), thereby giving rise to electric currents. Making matters even more complicated, these currents produce new magnetic fields. This effect, combined with the tendency for magnetic foot points to move around erratically, results in an ever changing panoply of highly distorted

INTENSE AURORAL DISPLAY lit up the night sky over Alaska in October 2003 as a result of heightened solar activity. Outpourings of charged particles from the sun can spawn an aurora when they reach Earth and impinge on the upper atmosphere. These and other energetic particles travel downward along lines of force of the magnetic field.

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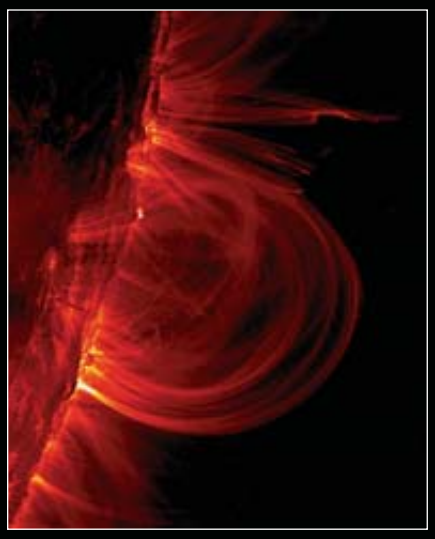
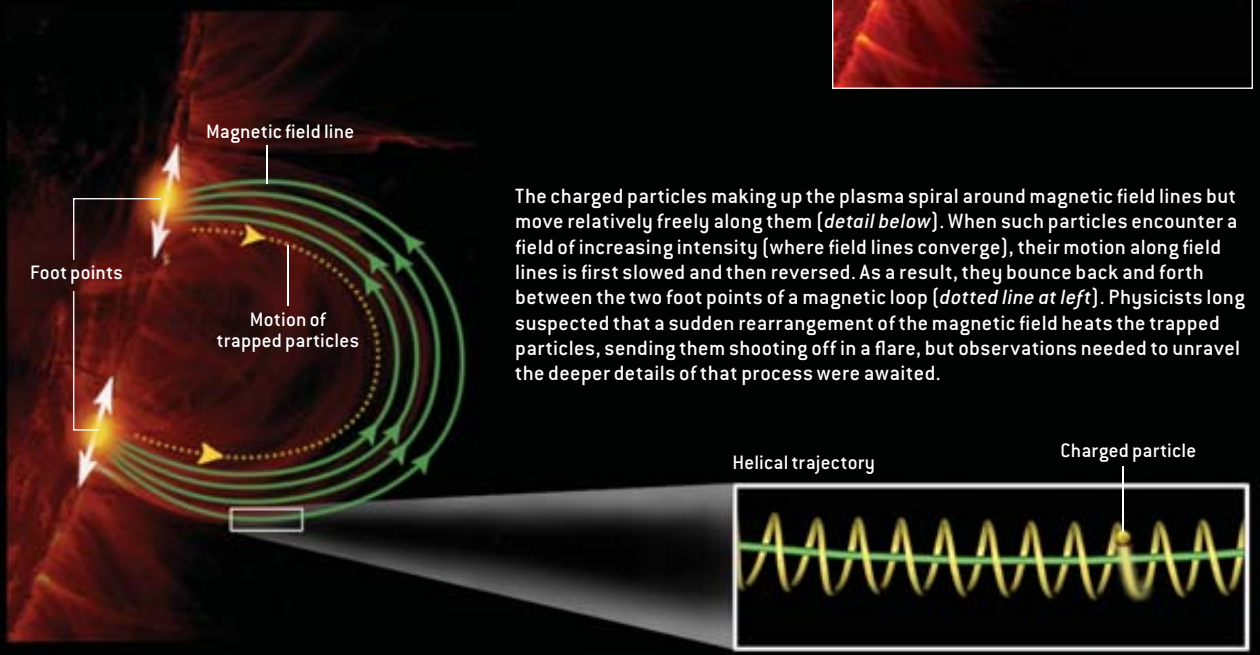
FLARE FODDER

Shifting magnetic fields and searingly hot plasma—gas in which the constituent atoms are stripped of their electrons—provide all the ingredients needed for a flare (*below*), although the recipe for how they come together to produce a flare has only recently been deciphered [*see box on page 44*].



Glowing loops of gas commonly jut from the solar surface, as seen in this extreme-ultraviolet image from the Transition Region and Coronal Explorer (TRACE) space probe. The luminous lines follow the local magnetic field, which changes over time as motion of the hot plasma near and just underneath the visible surface of the sun shifts the "foot points," the places where the field lines are anchored.



The charged particles making up the plasma spiral around magnetic field lines but move relatively freely along them (*detail below*). When such particles encounter a field of increasing intensity (where field lines converge), their motion along field lines is first slowed and then reversed. As a result, they bounce back and forth between the two foot points of a magnetic loop (*dotted line at left*). Physicists long suspected that a sudden rearrangement of the magnetic field heats the trapped particles, sending them shooting off in a flare, but observations needed to unravel the deeper details of that process were awaited.

magnetic fields in the solar atmosphere, ones that contain considerable magnetic field energy—the fuel of solar flares.

This part of the story describes just some of the basic physics at work, which scientists have understood for many decades. The problem arises when one tries to explain exactly how all this magnetic field energy is converted into heat, accelerated particles and ejected material. One possibility comes simply from a consideration of any electric circuit, which is characterized not just by the current it carries and the voltage driving the flow of charge but also by the electrical resistance present. The filament in a lightbulb, for example, offers resistance to the electric current flowing through it, dissipating electrical energy by turning it into light and heat. The solar atmosphere offers electrical resistance because the charged particles making up the electric currents sometimes collide with one another, impeding their motion and warming things up. Also, the voltage that drives the current has an electric field associated with it. If this electric field is strong enough, electrons and ions will be accelerated out of the hot plasma. Voilà: heating and high-energy particles, the components of a flare.

This neat explanation, alas, does not hold up very well under scrutiny. One reason is that the electrical resistance in the corona is typically quite low—too low to account for the explosive rate at which solar flares brighten. And even if the resistance were higher, explaining how the required amount of magnetic energy could be concentrated in one place and released in a sudden burst would still be difficult. Investigators concluded decades ago that the generation of a voltage driving a simple, single current could not heat the solar atmosphere quickly enough or produce a flux of accelerated particles that is sufficient to make a flare.

Over the years, space physicists have come up with various

TRACE (STANFORD-LOCKHEED INSTITUTE FOR SPACE RESEARCH/NASA SMALL EXPLORER PROGRAM) (*image*); DON DIXON (*illustration*)

ideas of greater complexity: perhaps, they reasoned, flares result from many different currents coming together or from a volume of turbulent plasma waves and the random electric fields associated with them. Such special arrangements are probably capable of bringing about a flare, but these mechanisms cannot account for all the observations, especially the tendency for coronal mass ejections to accompany large flares. A more promising theory involves the dynamics not just of the electric field but also of its magnetic counterpart. So let me describe the physics of such fields in greater detail.

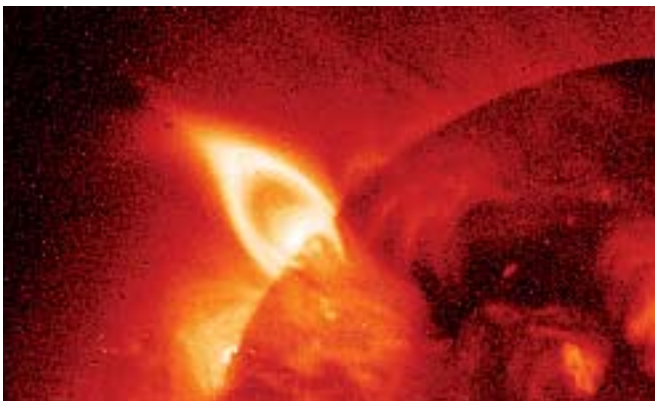
Magnetic fields have a direction associated with them. Around a bar magnet, for example, the lines of force point from the north pole to the south. If two parallel but oppositely directed magnetic fields are brought together in plasma, an electric current will form between them, taking the shape of a flat sheet. (Most people are used to thinking of current as flowing one-dimensionally—say, along a wire—but on the sun, where the entire atmosphere is conductive, nothing prevents it from flowing in two-dimensional sheets.) The energy contained in these oppositely directed magnetic fields would then decrease over time as resistance dissipated the electric current in the sheet.

In 1956 the late Peter Alan Sweet, who was then working at the University of London Observatory, realized that the energy in the magnetic field would decline much faster if the oppositely directed field lines actually broke apart and then rejoined, or reconnected, in the current sheet that formed between them. As a result, the two opposing fields would cancel each other in a burst of energy, almost like the annihilation of matter and antimatter. Adjacent magnetic fields and the plasma in which they were embedded could then flow into the sheet from both sides. The physics of this phenomenon is such that newly created magnetic fields, ones connecting the formerly separated lines of force, and plasma would be ejected out the ends of the sheet. In the late 1950s and early 1960s Eugene N. Parker of the University of Chicago worked out the mathematics describing this process, now called Sweet-Parker magnetic reconnection.

But such reconnection cannot be the full explanation of what goes on during a flare, because the rearrangement of magnetic field lines takes place too slowly to account for the dazzling rate of energy release. Realizing this shortcoming of the new model, in 1963 the late Harry E. Petschek of Avco-Everett Research Laboratory in Everett, Mass., turned his attention to the problem and determined that under certain circumstances reconnection takes place much faster than the Sweet-Parker rate. The phenomenon he analyzed is now referred to as Petschek or fast reconnection, in contrast to what Sweet and Parker first described, called slow reconnection.

Seeing Is Believing

IN BOTH FAST AND SLOW RECONNECTION, the thickness of the current sheet is tiny—just meters, which is too small for today's generation of instruments to resolve when observing the sun. Still, both processes give rise to an important phenomenon that can be detected: the creation of magnetic fields in distinct regions. Have the images from modern space probes revealed such telltale features? Perhaps.



POST-FLARE LOOPS sometimes show a distinct cusp at the top. This geometry of the glowing gas reflects a pinching of the local magnetic field. Such pinching can bring about the magnetic reconnection needed to power flares and sometimes remains in evidence for days afterward.

Although reconnection might well be ubiquitous on the sun, finding direct evidence for it has proved difficult. The RHESSI mission helped enormously in this regard. In 2003 Linhui Sui, then a graduate student from the Catholic University of America working with me at the NASA Goddard Space Flight Center, was analyzing RHESSI observations of a flare of moderate intensity that occurred on April 15, 2002. This event was of special interest because it gave off a coronal mass ejection at an angle that made it easy to view. Moreover, the flare had a simple loop structure. So for the most part, it appeared very normal. Sui noticed, however, a compact source of weak x-rays hovering above the magnetic loop, seemingly unconnected to it. Intrigued but uncertain of the reality of this detached source, we obtained a series of images from the beginning to the end of the flare, a sequence that covered about 10 minutes.

It was real all right. Early on, the enigmatic x-ray source sat near the top of the loop. As the flare began to give off higher-energy x-rays, the top of the loop moved downward, while the compact source remained stationary. At the climax of the flare, when the higher-energy x-rays reached their peak intensity, the loop abruptly changed direction and started upward. The mysterious source of x-rays began to shift upward as well, but it was going much faster. Within two minutes, this x-ray source faded and disappeared. No one had ever seen such

THE AUTHOR

GORDON D. HOLMAN conducts research in the Laboratory for Solar and Space Physics at the NASA Goddard Space Flight Center and is a co-investigator for the Ramaty High Energy Solar Spectroscopic Imager. He holds a Ph.D. in astrophysics from the University of North Carolina, Chapel Hill. His research is primarily concerned with the application of plasma physics to the interpretation of astrophysical observations. Holman also works closely with his NASA colleagues to make accessible descriptions of solar physics available through the World Wide Web.

YOHKOH (LOCKHEED MARTIN SOLAR AND ASTROPHYSICS LABORATORY/NATIONAL ASTRONOMICAL OBSERVATORY OF JAPAN/UNIVERSITY OF TOKYO/NASA/ISAS)

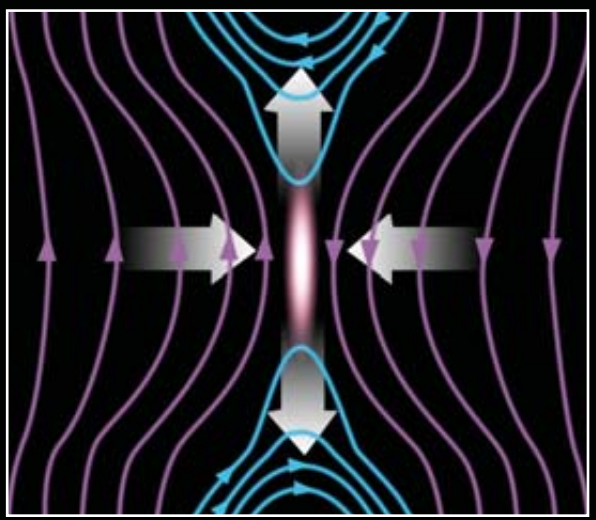
MAKING CONNECTIONS

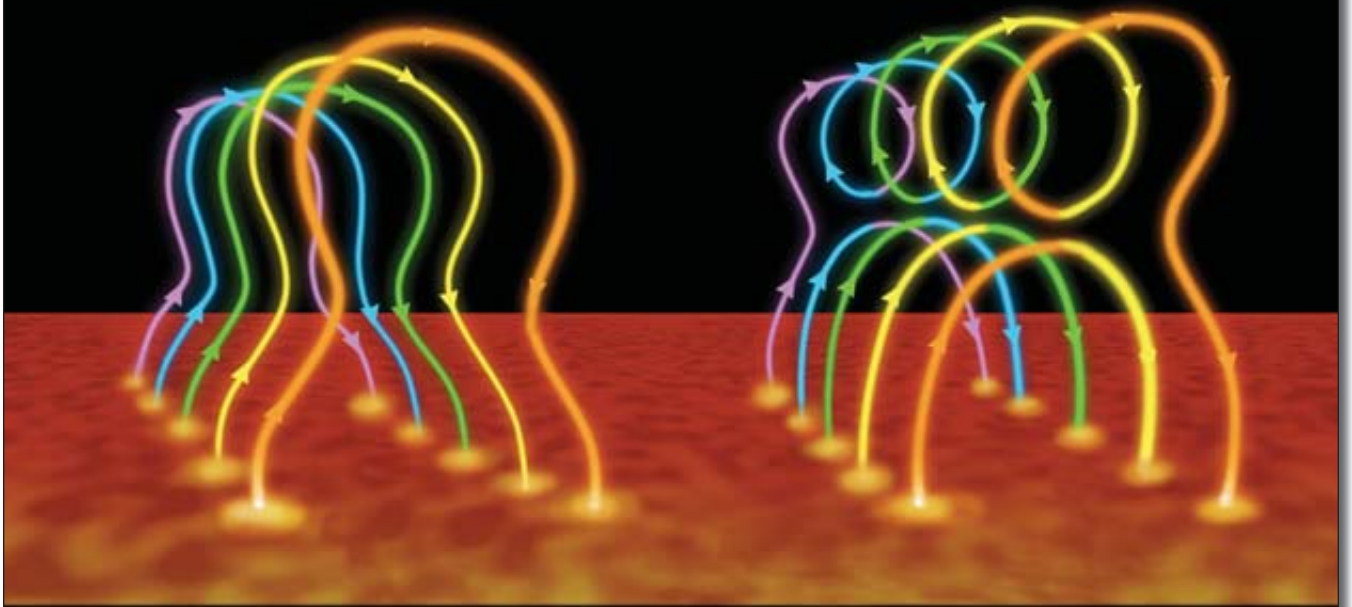
The energy source for solar flares is a phenomenon called magnetic reconnection, in which the sun's magnetic field lines join and quickly reconfigure themselves. Such reconnection events draw energy from the magnetic field, using it to heat the sun's atmosphere locally and to accelerate charged particles to high speeds.

REWIRING THE FIELD

In general, magnetic reconnection occurs when oppositely directed magnetic field lines are brought together. In the diagram at the right, up- and down-pointing field lines (*purple*) move toward the center. A vertically oriented sheet of electric current (*pink, seen here on edge*) then forms. Oppositely directed magnetic fields can merge within this current sheet, partially annihilating each other and releasing the magnetic energy they contain. New field lines (*blue*) form above and below the current sheet and move rapidly away from the site of reconnection.

On the sun (*below*), such reconnection events can get exceedingly complicated. There they sometimes reconfigure solar arcades, the series of arching field lines that often occur back to back. For example, a set of such lines can sometimes all pinch inward simultaneously (*below left*). If the process continues, it can result in wholesale reconnection, sparking a flare and leaving a helical magnetic field above a low arcade of loops below (*below right, spots where different colors meet mark where reconnection occurred*). The helical field and the material it contains may expand outward, becoming a coronal mass ejection.

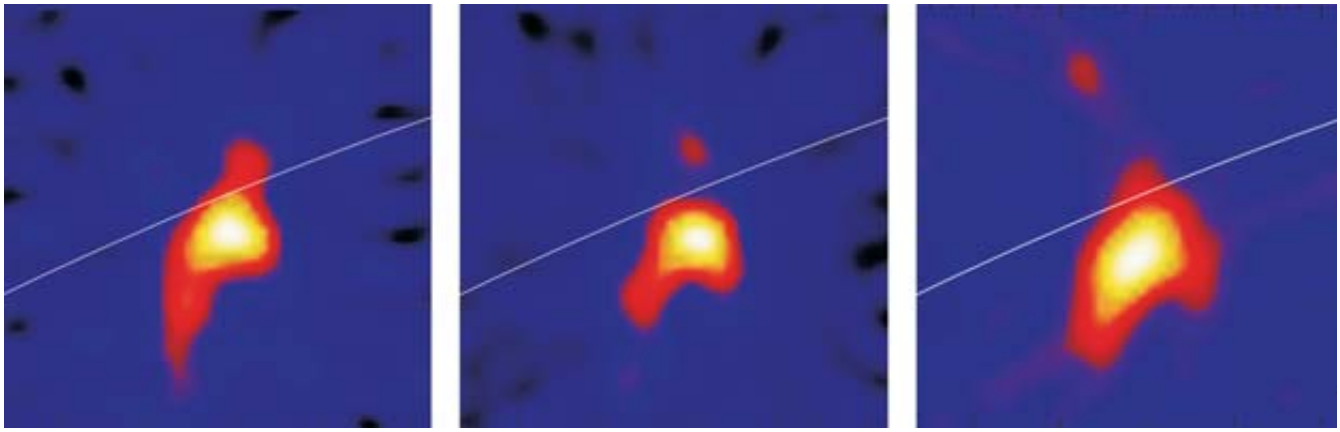




LINGERING EVIDENCE

Such reconnection events often leave telltale signs. The image at the left, obtained with the TRACE probe in September 2000, shows a tangled web of loops that were evident two hours after a solar flare took place in this locale. Although the configuration of the magnetic field before this flare occurred is unknown, the jumbled appearance of the loops in this image suggests that significant magnetic reconnection must have taken place, perhaps leaving parts of the magnetic field largely disconnected from the solar surface.

DON DIXON (*illustrations*); TRACE (*image*)



X-RAY SNAPSHOTS that were obtained by the Ramaty High Energy Solar Spectroscopic Imager depict the flare of April 15, 2002, which was accompanied by a coronal mass ejection. During this flare, a source of x-rays appears as a red bulge just above the main loop of hot gas (*left*) and above the visible edge of the sun (*white line*). This source remains stationary for some minutes as the top of the loop descends (*center*) but later shoots off rapidly into space (*right*). The sequence supports the idea that reconnection at the top of magnetic loops accounts for flares and coronal mass ejections, because the pattern is exactly what one would expect if the magnetic field were reconnecting above the loop, allowing half of the newly formed field lines to shift downward while the other half raced upward, powering a coronal mass ejection.

events unfold before. The x-ray source that at first seemed motionless ended up shooting outward from the sun at 300 kilometers a second—the speed at which the coronal mass ejection that accompanied this flare blasted off. Sui and I suspected that we had at last discovered the elusive origins of such explosive releases of material. Even better, measurements of the temperature pinpointed where the energy was coming from: between the top of the magnetic loop and the curiously behaving source of x-rays.

This pattern matches what one would expect to see if the magnetic field were reconnecting above the loop in a vertically oriented sheet of electric current. Coronal magnetic field and plasma presumably flowed horizontally into the current sheet from both sides. The oppositely directed magnetic fields reconnected there, and half of the newly formed field lines shifted rapidly downward, where they stacked up on existing magnetic loops. The other half of the reconnected magnetic field raced upward, building up a large, twisted magnetic loop, parts of which were unconnected to the sun. At least in some flares, these twisted magnetic field loops must become coronal mass ejections. Magnetic reconnection provides a way for the central part of such a loop (and the bubble of plasma in which it resides) to escape the sun—as if the tethers holding down a balloon were suddenly cut.

The picture that emerged from our study of this 2002 event also helps to elucidate the earlier Yohkoh observations. The cusp seen at the top of the 1992 flare loops must have sat just below an invisible current sheet, where newly reconnected magnetic field lines were continuously forming and collapsing onto the field below. The cusp shone brightly at x-ray wavelengths because of the constant injection of heated plasma and accelerated electrons from the current sheet above and, possibly, because of heating and electron acceleration in the cusp itself.

An explanation of how at least some solar flares and coronal mass ejections form now appears at hand, but many questions remain to be answered. For example: What is responsible for particle acceleration in flares? And what causes the sudden onset of magnetic reconnection? Space physicists hope to find answers to these questions soon as we continue to study flares using RHESSI and other solar observatories, including the soon-to-be-launched Solar B and STEREO probes. The Solar B mission will map solar magnetic fields in great detail. The STEREO mission (shorthand for *S*olar *TE*rrestrial *RE*lations *O*bservatory) will place two spacecraft into positions from which three-dimensional stereo image pairs of the sun can be obtained. Investigators hope that these views will provide more clues to the geometry of coronal mass ejections as they leave the sun and travel through interplanetary space.

Scientists' ability to anticipate violent space weather will no doubt improve in coming years. Gains will come from both a greater understanding of the mechanisms driving solar flares and the increasingly sophisticated tools available to monitor space around the sun and around Earth. Those of us studying space storms thus expect that many of our lingering mysteries may soon be solved. We look forward to the time when our forecasts of space weather become as commonplace as the predictions meteorologists routinely provide. SA

MORE TO EXPLORE

Magnetic Reconnection. Eric Priest and Terry Forbes. Cambridge University Press, 2000.

Evidence for Magnetic Reconnection in Three Homologous Solar Flares Observed by *RHESSI.* Linhui Sui, Gordon D. Holman and Brian R. Dennis in *Astrophysical Journal,* Vol. 612, pages 546–556; September 1, 2004.

Multiwavelength Analysis of a Solar Flare on 2002 April 15. Linhui Sui, Gordon D. Holman, Stephen M. White and Jie Zhang in *Astrophysical Journal,* Vol. 633, pages 1175–1186; November 10, 2005.

General information about solar flares can be found at **http://hesperia.gsfc.nasa.gov/sftheory/**

Information about the Ramaty High Energy Solar Spectroscopic Imager can be found at **http://hesperia.gsfc.nasa.gov/hessi/**

NASA

NEW HOPE FOR DEFEATING ROTAVIRUS

Although its name is unfamiliar to many, rotavirus is the leading cause of severe childhood diarrhea worldwide and a frequent killer of young children in developing nations. Now—after 30 years of investigation—vaccines that may well conquer it are ready for market

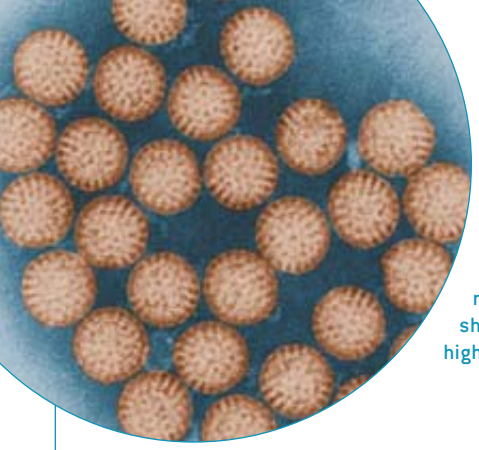
By Roger I. Glass

The thought of a murderous virus often conjures images of patients suffering from Ebola virus in Africa, SARS in Asia or hantavirus in the U.S. Yet those evildoers have taken far fewer lives than rotavirus, whose name is virtually unknown. This virus infects nearly all children in their first few years of life. It causes vomiting followed by diarrhea. The diarrhea is often so severe that, if left untreated, it can lead to shock from dehydration and then death. Worldwide, rotavirus kills an estimated 610,000 children every year, accounting for about 5 percent of all deaths among those younger than five years. In the U.S., few children perish from the virus, but as many as 70,000 require hospitalization for it annually, and several million suffer quietly at home.

Scientists, though, are now about to break the grip of this devastating disease. In January—some three decades after investigators first identified the pathogen—researchers reported that two rotavirus vaccines had proved successful in massive clinical trials. The process of developing rotavirus vaccines has been more difficult and complicated than anyone imagined, full of setbacks and surprises. But today both the World Health Organization and the Global Alliance for Vaccines and Immunization consider rotavirus vaccine a top priority, and the final battle to get immunizations to the young children who so desperately need them has begun.

INFANT ILL with severe diarrhea caused by rotavirus will be saved by rehydration therapy. But too many children in impoverished countries, where access to health care is limited, go untreated and die from the virus.

GEOFF WARD



ROTAVIRUS PARTICLES look wheellike (hence the Latin name *rota* for "wheel") through an electron microscope. The particles shown here are colorized and highly magnified.

Identifying the Contagion

ROTAVIRUS was first identified as a cause of human disease in 1973 by Ruth Bishop, a young microbiologist working on gastrointestinal diseases at the Royal Children's Hospital in Melbourne, Australia. At the time, investigators were perplexed by diarrhea in children. Although the disorder was common and frequently severe, the causative agent was rarely identified. Searching for clues, Bishop's group looked through an electron microscope at biopsied tissue from the duodenum, or small intestine, of acutely sick children. What they saw astounded them: an infestation of wheel-shaped viruses in the epithelial cells that form the intestinal lining.

My own involvement with rotavirus began in 1979, when my wife and I moved to Bangladesh to work at the International Center for Diarrheal Disease Research. Young and idealistic, we were drawn by the prospect of helping children in a country where severe diarrhea was a leading cause of death. The center's hospital in Dhaka admitted so many patients with unspecified "intestinal" flu annually that some had to be cared for in hallways and in tents outside. Believing the cause of their diarrhea to be bacterial, we were surprised to find many of the children were suffering not from cholera, salmonella, shigella or *Escherichia coli* but from rotavirus, about which we knew little. With the help of a simple test, we determined that rotavirus was responsible for the admittance of between 25 and 40 percent of all children younger than five to our hospital for diarrhea.

Overview/*Rotavirus Victory*

- Almost every child in the world contracts a rotavirus infection at least once, yet the disease has poor name recognition. Often it is dismissed as stomach or intestinal flu, even by health care workers.
- The disease exacts a devastating toll on young children, every year hospitalizing tens of thousands of them in the U.S. and killing more than 600,000 in poorer countries.
- Since the virus's discovery some 30 years ago, researchers have unraveled many of its secrets, in the process realizing that only a vaccine is likely to curb it.
- Today, after many snafus and false starts, the race to find a vaccine is almost won: several rotavirus vaccines have now proved safe and effective.

Studies from around the globe yielded similar results. What is more, they revealed that rotavirus was not only widespread but a major cause of death in the poorest nations. By 1985 such data compelled the Institute of Medicine to put rotavirus infection atop a list of diseases for which vaccines were urgently needed in the developing world.

At the same time, surprisingly little was known about the incidence and distribution of rotavirus in the U.S. In 1986, when I returned to the U.S. Centers for Disease Control, the disease was rarely diagnosed and, in fact, was not even listed in the *International Classification of Diseases*. Having seen the impact of the disease overseas, my co-workers and I were intent on finding out whether it was affecting many people in the states.

But how does one assess the burden of a disease that is rarely diagnosed, is never listed as the cause of hospitalization in discharge records, and goes unrecognized by a majority of pediatricians who commonly treat it? My colleague, Mei-Shang Ho, began by looking at U.S. data on childhood hospitalizations. She found that diarrhea was a common cause of hospital stays, accounting for 12 percent of hospitalizations in children younger than five, and that most cases were coded as being of unknown etiology. Further studies revealed that a lion's share of the undiagnosed cases were attributable to rotavirus. Three other interesting facts about rotavirus in the U.S. emerged as well. First, infection follows a distinctly seasonal pattern, peaking from December to March; second, the vast majority of children hospitalized for this virus are younger than five years; and third, regardless of season, rotavirus causes most cases of severe diarrhea in young children.

Epidemiologists now know that rotavirus is far and away the leading cause of childhood diarrhea worldwide, infecting virtually all children between the ages of three months and five years. Unlike bacteria that spread via contaminated food and water and thus disproportionately affect people in poor regions, rotavirus shows no regard for geographic borders. Indeed, the very ubiquity of the pathogen—with Americans facing the same risk of infection as Bangladeshis—suggests the virus is highly contagious, spreading as easily as, say, a cold virus. And, as is true of cold viruses, sanitation and clean drinking water have little power to block transmission.

Molecular and clinical studies bear witness to its virulence. Just 10 virus particles can start trouble in a young child. A virus-laden droplet landing on a baby's thumb or toy is all it takes. Popped into the mouth, the virus makes its way to the epithelial cells lining the small intestine, where it replicates at astonishing speed: within 24 hours, 10 viruses become millions, filling and killing the cells with their proteins, toxins and newly made particles. Soon the gut epithelium sloughs, and a flood of fluids and electrolytes exits the body in diarrheal bursts. Without rehydration therapy, a child can lose as much as 10 percent of his or her body weight and go into shock in just one or two days.

Fortunately, children who survive their first infection suffer no long-term consequences, and few ever experience an-

CHARLES D. HUMPHREY *U.S. Centers for Disease Control and Prevention*

other bout of rotavirus diarrhea. They have natural immunity—that is, their immune system has become primed to quickly recognize and prevent replication of rotavirus when it next invades. But because so many children become severely ill with the first infection, scientists consider a vaccine that could mimic this natural immunity to be the best hope for saving lives.

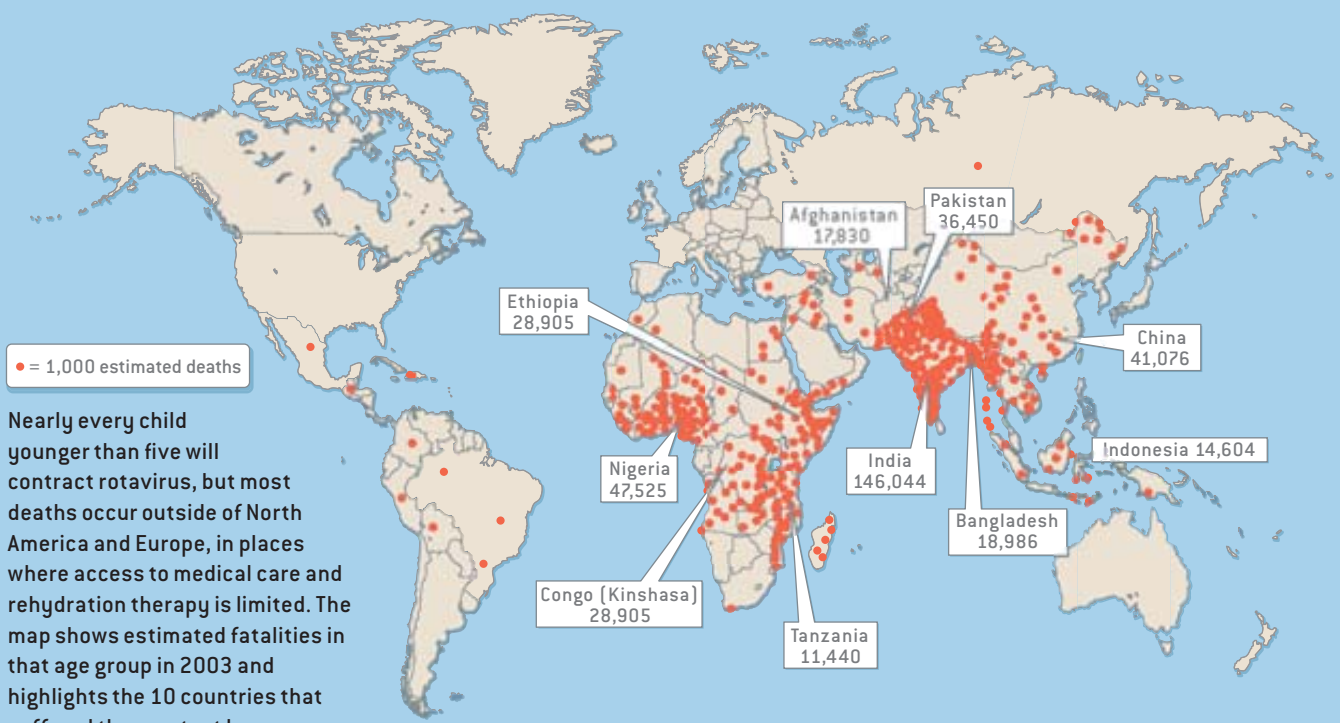
Quest for a Vaccine Begins

VACCINES are powerful weapons in the human arsenal against infectious disease and among the most effective interventions in public health. Made from either live or killed microorganisms or from their key proteins, vaccines trick a recipient's immune system into believing it is under attack. In response, the immune system produces antibodies against the vaccine (which poses no biological threat), just as it would against the virus itself. And as in natural immunity, should the disease-causing agent ever invade, the immune system is fully primed, ready to pump out antibodies to immobilize it.

Twenty years ago several pharmaceutical companies became interested in developing a vaccine against rotavirus. With a potential market both large in size and global in scope, the high costs of vaccine development appeared reasonable. In addition, distribution would be easy even in remote places: rotavirus vaccine could be added to the Universal Program for Childhood Immunization, which under the auspices of the WHO and UNICEF already delivers routine vaccines to about 80 percent of the world's children.

Although different approaches to vaccines have been considered—human versus animal strains, live versus killed viruses, whole virus or protein subunits—rotavirus researchers followed the lead of Albert Sabin, creator of the oral poliomyelitis vaccine. Sabin believed that live vaccines, which can replicate somewhat but are too weak to trigger disease, best mimic the protection acquired through natural infection. Also, in the case of rotavirus, oral vaccines would prompt an immune response where it is most desirable—in the gastrointestinal tract. Vaccine developers quickly focused on live but weakened, or attenuated, strains of rota-

Global Distribution of Deaths from Rotavirus



Nearly every child younger than five will contract rotavirus, but most deaths occur outside of North America and Europe, in places where access to medical care and rehydration therapy is limited. The map shows estimated fatalities in that age group in 2003 and highlights the 10 countries that suffered the greatest losses.

Bangladesh falls near the bottom of that group but has the highest per capita death rate from the disease. Rural inhabitants there often have to travel far, by slow means (*left photograph*), to get help. Babies with profuse diarrhea who reach a hospital in Dhaka are placed on cots that drain directly into buckets meant to catch the watery excrement. In the right photograph, a mother at the hospital is feeding a rehydration solution to her infant.

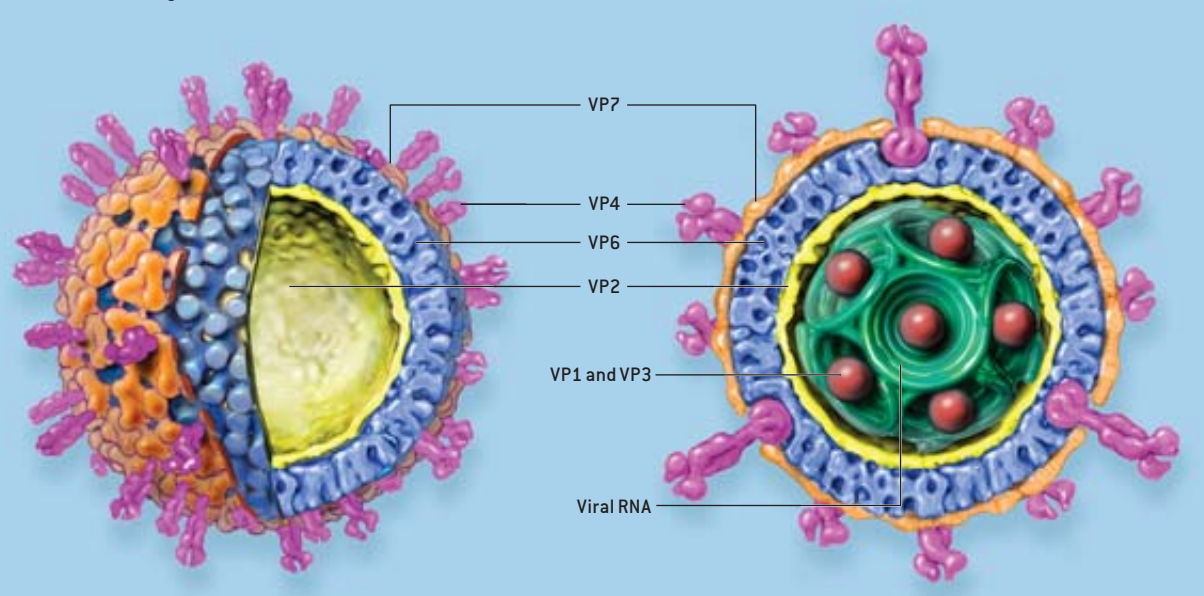
LUCY READING-IKKANDA; SOURCE: UMESH D. PARASHAR *CDC (map)*; ASEM ANSARI *International Center for Diarrheal Diseases Research, DHAKA, BANGLADESH (left photograph)*; JEAN C. SACK *ICDDR (right photograph)*

Rotavirus Up Close

Structural studies reveal that rotavirus, shown below in two cutaway views, consists of three protein layers that encase the genome. Its structural proteins—those present in particles that spread from person to person—are called VPs and are denoted by numbers.

VP7 forms the outer surface and is studded with VP4 spikes. These two proteins elicit a host's disease-fighting immune response and thus play a central role in vaccines. VP4 also facilitates viral entry into cells, as do VP5 and VP8 (*not shown*), which result from cleavage of VP4 in a host's body. VP6 composes the middle layer and is required for gene transcription, a process essential to the synthesis of viral proteins in infected cells. VP2 makes up the inner shell, and VP1 and VP3 are enzymes involved in copying viral genes.

The genome comprises 11 segments of double-stranded RNA tightly coiled and packed together. These segments code for the VPs as well as for nonstructural proteins (NSPs), including a toxin called NSP4 that is made after the virus enters cells.



virus that could be administered by mouth, without needles.

In 1983 the first rotavirus vaccine was ready for testing. Francis Andre of Smith Kline-RIT (now GlaxoSmithKline Biologicals) in Rixensart, Belgium, and Timo Vesikari, a pediatrician at the University of Tampere in Finland, prepared and tested a vaccine derived from a rotavirus strain found in cows. They chose a bovine rotavirus because it grew well in culture and was thought to be naturally attenuated in humans.

From all vantages, the first trial, conducted in Finland, was a landmark success: the vaccine reduced the chances that a vaccinated child would get severe rotavirus by 88 percent, demonstrating that immunity could be induced with a live oral vaccine. Moreover, the vaccine had no troubling side effects.

THE AUTHOR

ROGER I. GLASS is chief of the Viral Gastroenteritis Section at the Centers for Disease Control and Prevention and adjunct professor of pediatrics and international health at Emory University. A leading epidemiologist whose research emphasizes the role of vaccines in disease prevention, he advises the World Health Organization, the Global Alliance for Vaccines and Immunization, and the Program for Appropriate Technology in Health. In 1998 he received the Pasteur Award from the Children's Vaccine Initiative for his work on behalf of rotavirus vaccine. The author thanks Philip R. Dormitzer of Harvard Medical School for generously assisting in the development of the artwork for this article.

Encouraged, Smith Kline-RIT launched trials in other countries, and by the late 1980s the end of rotavirus-related deaths seemed at hand. But then results from trials in Africa and Peru proved inconsistent and disappointing. Lacking certainty about the reasons for the troubles—although poor health, untreated infections, malnutrition and parasites are known to affect a child's immune response to vaccines—the company put its rotavirus program on hold.

Back to the Drawing Board

RESEARCHERS at the National Institutes of Health and the Wistar Institute in Philadelphia sought to explain the failure of the RIT vaccine. Possibly, the bovine strain was overattenuated—that is, it was too weak to replicate and elicit a good immune response under challenging conditions. They began looking for new formulations. Albert Kapikian of the NIH, for example, identified a rhesus strain of virus, and Fred Clark and Stanley Plotkin of Wistar identified another bovine strain that might replicate more vigorously. The strains were prepared for clinical trials, but these, too, showed both success and failure. Several more years were needed to rethink the science.

Meanwhile other researchers were unraveling the virus's molecular structure. Though wheellike in cross section, rotavirus is actually a three-layered sphere containing 11 seg-

ANDREW SWIFT; SOURCE: "EMERGING THEMES IN ROTAVIRUS CELL ENTRY, GENOME ORGANIZATION, TRANSCRIPTION AND REPLICATION," BY HARIHAN JAYARAM, M. K. ESTES AND B. V. VENKATARM PRASAD IN *VIRUS RESEARCH*, VOL. 101; 2004

ments of double-stranded RNA, each of which consists of a single gene encoding a protein. The proteins fall into two basic types: ones that are structural (composing the virus) and ones that are nonstructural (made within infected cells). The structural viral proteins, or VPs, are numerically named: VP1, VP2 and so on, as are the nonstructural proteins, or NSPs, which participate in viral replication and in deranging intestinal function.

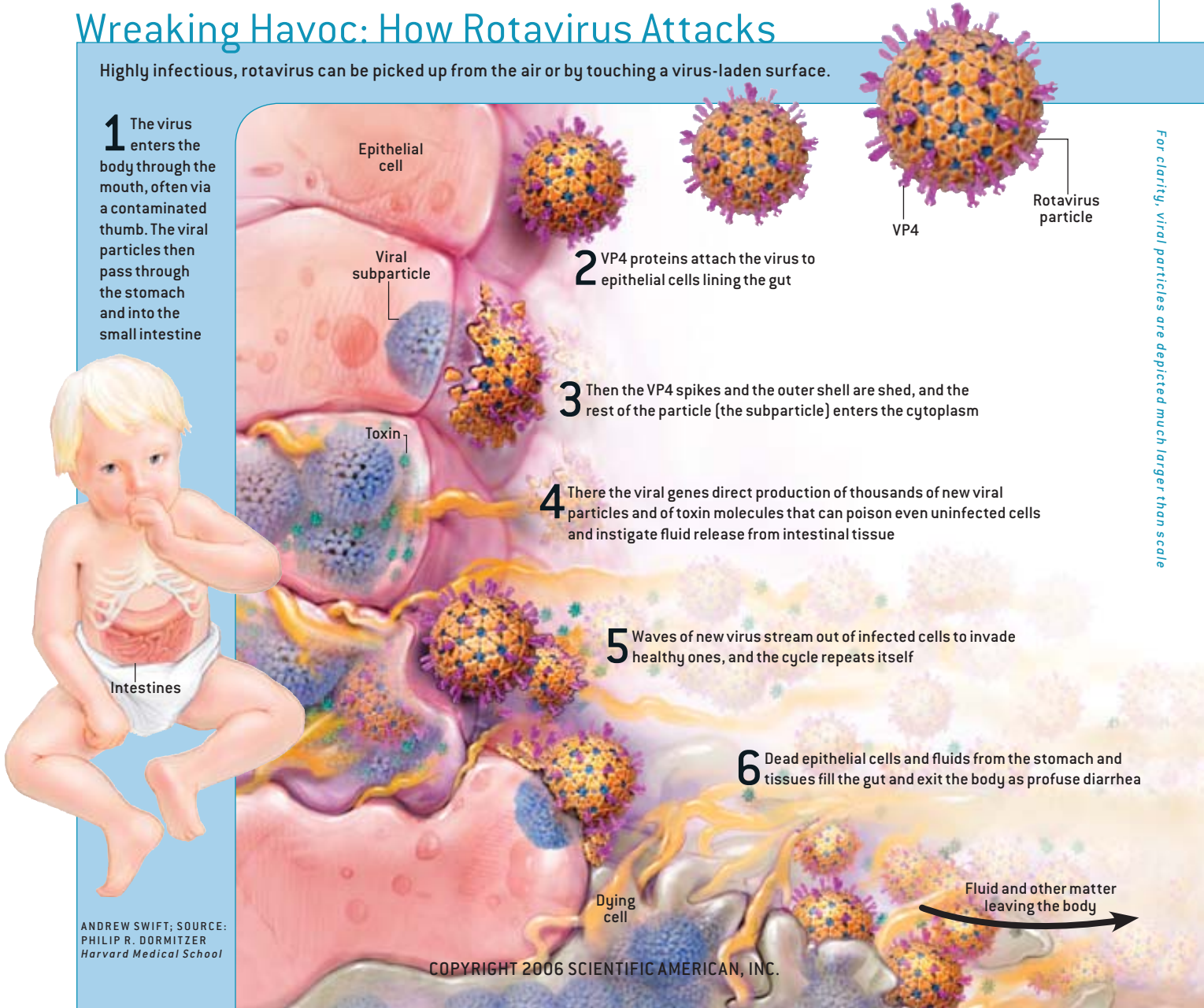
The outermost shell, important in eliciting the host's immune response, has been a focus of attention in vaccine development. VP7 fashions its lumpy surface, and the VP4 protein forms the spikes on the outside of the "wheel." VP6, the most abundant protein in the virus, sits underneath VP7 and participates in producing viral proteins in infected cells. A nonstructural molecule called NSP4 is a toxin that may play a role in triggering profuse diarrhea.

The proteins come in several varieties, and separate strains sport different mixes of proteins. When two viral strains infect the same cell, their gene segments can reassort just like figures on a slot machine, forming new combinations and thus novel versions of the virus. New reassortant viruses arise constantly, but as is true of most mutations, few offer survival advantages to the virus. Consequently, of the 42 unique rotavirus strains identified to date based on their combinations of VP7 and VP4 varieties, only four or five account for more than 90 percent of rotavirus disease worldwide.

Exploiting the natural ability of rotavirus to reassort its genes, Kapikian and his NIH colleague Harry Greenberg developed a laboratory method to create reassortants that had features useful for vaccines but would not cause disease in humans. They began by making a reassortant virus that combined 10 genes from a monkey rotavirus—giving it the property of attenuation—with one gene encoding a surface protein, VP7, from a human strain. They made three such reassortants, each displaying a different human version of VP7, and one purely rhesus virus, displaying a fourth VP7 found in both monkey and human rotaviruses. They mixed all four into a cocktail called a tetravalent vaccine intended to offer

Wreaking Havoc: How Rotavirus Attacks

Highly infectious, rotavirus can be picked up from the air or by touching a virus-laden surface.



For clarity, viral particles are depicted much larger than scale

ANDREW SWIFT; SOURCE: PHILIP R. DORMITZER *Harvard Medical School*

protection against the four most prevalent human strains of rotavirus.

In 1991 the Food and Drug Administration granted the pharmaceutical company Wyeth Ayerst (later Wyeth Pharmaceuticals) permission to make and test this vaccine, which they named RotaShield. Over the next five years it launched large-scale clinical trials in the U.S., Finland and Venezuela, verifying RotaShield's safety, ability to induce a protective immune response, and lasting efficacy. In 1998 RotaShield was licensed by the FDA and recommended by the CDC's Advisory Committee on Immunization Practices and the American Academy of Pediatrics for routine immunization of all American children. Over the next nine months more than 600,000 children received an estimated 1.2 million doses of RotaShield.

These were heady times. The vaccine still had to be tested on undernourished children in developing nations, where live oral vaccines for other diseases—including polio and cholera—were known to be less effective than elsewhere. Also, the price per dose was still high for most developing nations. But for the first time, the world had a tool with which to combat rotavirus, and many of us were jubilant.

Then disaster struck. In 1999 several infants suffered a serious complication within two weeks of receiving the vaccine: a segment of the intestine folded into a nearby region (like a part of a telescope collapses into another), creating a blockage called intussusception. The condition can be excruciatingly painful and must be quickly reversed with either an air or fluid enema or fixed surgically. In rare cases, the intestine perforates and the infant dies. The CDC, which was monitoring experience with RotaShield, called for an immediate halt to the immunization program, thereby sinking a vaccine that had taken 15 years and several hundred million dollars to launch.

The agency initially estimated the risk to be one intussusception in 2,500 vaccine recipients, which was considered unacceptable. Later studies pegged the probability at only one in 11,000. Then Lone Simonsen of the NIH correlated risk with age: infants younger than three months were in less danger than older ones. If the vaccine were given only to young babies, the likelihood of intussusception could drop 10-fold, to perhaps one in 30,000.

The new data raised new questions. Was this risk acceptable in the U.S., where children are often hospitalized but rarely die of rotavirus? Were the odds more palatable in the developing world, where one child in 200 dies of rotavirus? If 150 lives could be saved for each complication from intussusception, might the risk be justified? Given these statistics, was it unethical, in fact, to withhold a vaccine that might save half a million lives a year? Or no matter what the risk-benefit analysis showed, was it unethical to market a vaccine in the developing world that had been withdrawn from use in the U.S.?

The CDC and the WHO called a meeting of policymakers from developing countries. After heated discussion, science bowed to politics. As a high-ranking Indian official said, "I know this vaccine would save 100,000 children in my country. But when the first case of intestinal blockage occurred, I would not be forgiven for allowing a vaccine that had been withdrawn in the United States to be used in my country."

Back on Track

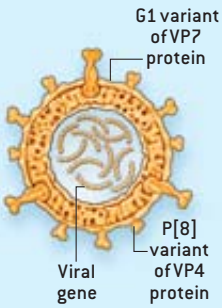
RESEARCHERS continued to study the link between vaccination and intussusception. Children who contracted rotavirus naturally had no greater incidence of blockage than other children, so why should vaccination per se raise their risk? Some began to suspect the problem was specific to the rhesus strains, not an effect common to all live oral rotavirus vaccines.

Making a Rotavirus Vaccine

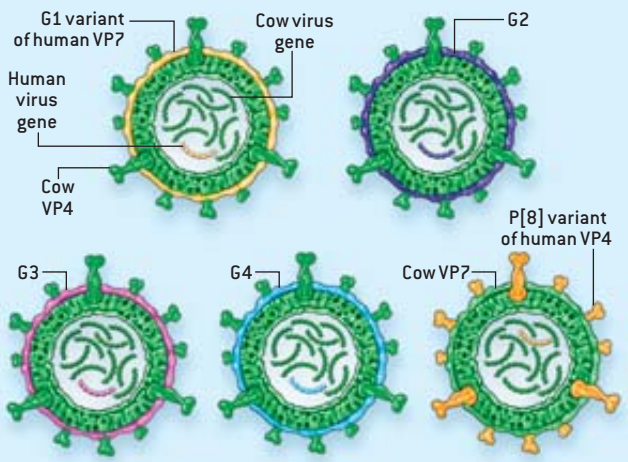
Two rotavirus vaccines that recently proved highly effective in large clinical trials are depicted schematically below.

ROTARIX

Made by GlaxoSmithKline, Rotarix consists of a single strain of a human-infecting rotavirus that provides protection against many strains. The vaccine features common variants of VP7 and VP4—G1 and P[8], respectively. Because such a human virus could potentially cause disease if it were fully functional, the manufacturer weakened it through a standard cell culture method that prevents it from causing symptoms but enables it to replicate enough to trigger an immune response.



ROTATEQ



Made by Merck, RotaTeq contains five genetically distinct viruses called reassortants. These reassortants are produced by combining 10 cow (*green*) rotavirus genes with one of five human (*other colors*) rotavirus genes, thereby generating mainly cow viruses that display a protein from the human virus on the surface. Four of the reassortants have a gene that codes for a variant of human VP7 (either G1, G2, G3 or G4), and one reassortant carries a gene for the P[8] form of the human VP4 spike. The end result is a pentavalent vaccine, which specifically protects against the four most prevalent human strains of rotavirus yet has too many cow genes to cause disease in people.

ANDREW SWIFT

Betting the intussusception problem could be overcome, two vaccine makers renewed their interest in rotavirus. GlaxoSmithKline dusted off its program and pressed forward with a new monovalent vaccine derived entirely from a single attenuated human strain. Because natural rotavirus infection was not associated with intussusception, they reasoned their vaccine would similarly not increase the risk of this complication. In addition, the company would select for study only infants who were six weeks to 13 weeks old, a stage when natural intussusception is rare. At the same time, Merck developed a pentavalent vaccine derived from five human-bovine reassortant strains that together would target the major strains of rotavirus. Merck scientists knew bovine strains did not grow or replicate as well as the rhesus strain and also did not cause the low-grade fever many children developed after being immunized with the rhesus vaccine. Also, the company would limit eligibility in its clinical trials exclusively to infants six to 12 weeks old.

Both companies conferred with the FDA on their plans to conduct clinical trials. The FDA, wanting to ensure that the next generation of rotavirus vaccines would be safer than RotaShield, insisted that the trials be large enough to detect any risks, however small, that might be associated with the vaccine. An initial target of 60,000 participants per trial was set, making these the largest and most expensive safety trials of any vaccine ever tested before licensing. Not only would the trials be costly, but the undertaking itself was risky—each one would instantly collapse if the rate of intussusception among vaccinated babies exceeded that of nonvaccinated ones. The developers pressed on with some trepidation.

Now, six years after the intussusception debacle, the rotavirus gamble is paying off. GlaxoSmithKline and Merck have completed their clinical trials, and the results for both vaccines are encouraging. They offer from 85 to 98 percent protection against severe rotavirus diarrhea. Moreover, the vaccinated children showed no more cases of intussusception than did nonvaccinated children.

The GlaxoSmithKline vaccine, Rotarix, was tested primarily in Latin America. Since 2004, it has won approval from more than 20 countries and, most recently, from the European Union; it is under review in the U.S. Merck, in contrast, targeted the U.S. market first, wanting to prove that its vaccine, RotaTeq, is safe here before introducing it elsewhere. The company has gained approval in Mexico and the U.S. and expects to have it for Europe this year; such approvals are a prelude to introducing the vaccine to many countries.

Vaccine manufacturers in the developing world are also interested in rotavirus. Unlike those that require sophisticated bioengineering techniques, a rotavirus vaccine, like that for polio, can be made using traditional tissue culture methods and so is within the reach of smaller companies. Today more than 10 makers in India, China, Indonesia and Brazil are preparing live oral rotavirus vaccines; a Chinese firm has already gained approval to sell its product.

BABY ANDREW was a subject in the large-scale study that evaluated the safety and effectiveness of the RotaTeq vaccine.

Future Challenges

THE PROSPECT of new vaccines fuels hope that rotavirus's grip may soon be broken. Still, hurdles remain. Because many policymakers in developing countries have not heard of rotavirus, they fail to understand its dire consequences. Surveillance efforts in more than 40 countries—being conducted by Joseph Bresee and Umesh D. Parashar of the CDC, with the WHO and the Program for Appropriate Technology in Health—are just beginning to provide data that decision makers will need before welcoming the vaccines into their nations. In addition, confirmation that live oral vaccines are safe and effective in the poorest areas is still lacking. Moreover, the vaccines, which cost several hundred million dollars each to develop, must be affordable to those responsible for the 135 million children born worldwide every year.

Yet momentum is building, and many of us hope that within a decade, this major cause of diarrhea and principal killer of children in the developing world will be eliminated by the most cost-effective public health measure we have today: immunization. With help from a committed global community, rotavirus will soon join such microorganisms as polio, smallpox and diphtheria, which have been vanquished by vaccines and are now sidelined and obscure. Epidemiologists hope the anonymity that has historically characterized this disease will define it once again, its regained obscurity a true testament to the power of vaccination. SA

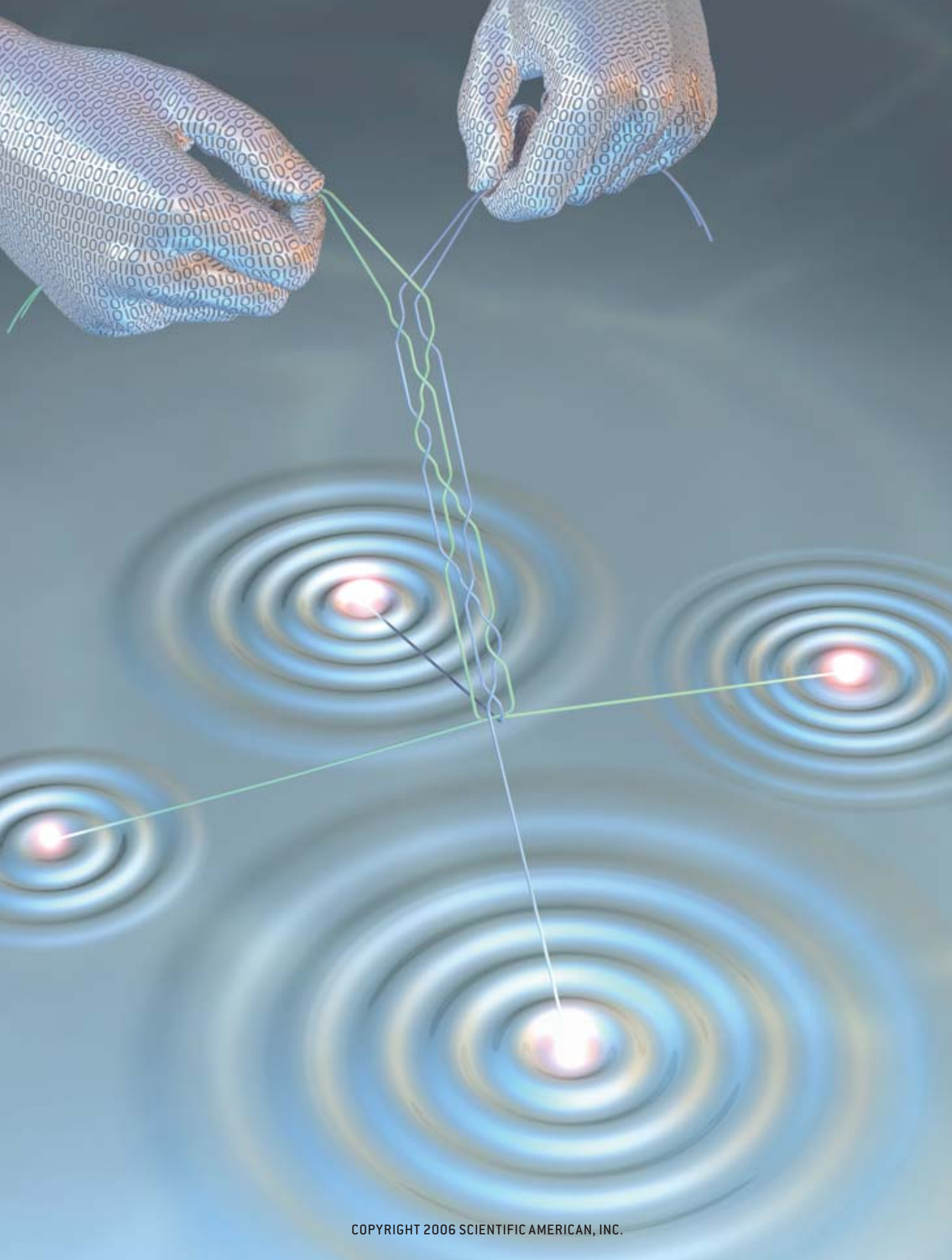
MORE TO EXPLORE

Global Illness and Deaths Caused by Rotavirus Disease in Children. U. D. Parashar et al. in *Emerging Infectious Diseases,* Vol. 9, No. 5, pages 565–572; May 2003.

The Future of Rotavirus Vaccines: A Major Setback Leads to New Opportunities. Viewpoint. R. Glass et al. in *Lancet,* Vol. 363, Issue 9420, pages 1547–1550; May 2004.

Safety and Efficacy of an Attenuated Vaccine against Severe Rotavirus Gastroenteritis. G. Ruiz-Palacios et al. in *New England Journal of Medicine,* Vol. 354, pages 11–22; January 5, 2006.

Safety and Efficacy of a Pentavalent Human-Bovine (WC3) Reassortant Rotavirus Vaccine. T. Vesikari et al. in *New England Journal of Medicine,* Vol. 354, pages 23–32; January 5, 2006.



BY BRAIDING WORLD LINES (trajectories) of special particles, one can perform a quantum computation that is impossible for any ordinary (classical) computer. The particles live in a fluid known as a two-dimensional electron gas.

Computing with Quantum Knots

A machine based on bizarre particles called anyons that represents a calculation as a set of braids in spacetime might be a shortcut to practical quantum computation

By Graham P. Collins

GEORGE RETSECK

Quantum computers promise to perform calculations believed to be impossible for ordinary computers. Some of those calculations are of great real-world importance. For example, certain widely used encryption methods could be cracked given a computer capable of breaking a large number into its component factors within a reasonable length of time. Virtually all encryption methods used for highly sensitive data are vulnerable to one quantum algorithm or another.

The extra power of a quantum computer comes about because it operates on information represented as qubits, or quantum bits, instead of bits. An ordinary classical bit can be either a 0 or a 1, and standard microchip architectures enforce that dichotomy rigorously. A qubit, in contrast, can be in a so-called superposition state, which entails proportions of 0 and 1 coexisting together. One can think of the possible qubit states as points on a sphere. The north pole is a classical 1, the south pole a 0, and all the points in between are all the possible superpositions of 0 and 1 [see "Rules for a Complex Quantum World," by Michael A. Nielsen; Scientific American, November 2002]. The freedom that qubits have to roam across the entire sphere helps to give quantum computers their unique capabilities.

Unfortunately, quantum computers seem to be extremely difficult to build. The qubits are typically expressed as certain quantum properties of trapped particles, such as individual atomic ions or electrons. But their superposition states are ex-

ceedingly fragile and can be spoiled by the tiniest stray interactions with the ambient environment, which includes all the material making up the computer itself. If qubits are not carefully isolated from their surroundings, such disturbances will introduce errors into the computation.

Most schemes to design a quantum computer therefore focus on finding ways to minimize the interactions of the qubits with the environment. Researchers know that if the error rate can be reduced to around one error in every 10,000 steps, then error-correction procedures can be implemented to compensate for decay of individual qubits. Constructing a functional machine that has a large number of qubits isolated well enough to have such a low error rate is a daunting task that physicists are far from achieving.

A few researchers are pursuing a very different way to build a quantum computer. In their approach the delicate quantum states depend on what are known as topological properties of a physical system. Topology is the mathematical study of properties that are unchanged when an object is smoothly deformed, by actions such as stretching, squashing and bending but not by cutting or joining. It embraces such subjects as knot theory. Small perturbations do not change a topological property. For example, a closed loop of string with a knot tied in it is topologically different from a closed loop with no knot [*see box on opposite page*]. The only way to change the closed loop into a closed loop plus knot is to cut the string, tie the knot and then reseal the ends of the string together. Similarly, the only way to convert a topological qubit to a different state is to subject it to some such violence. Small nudges from the environment will not do the trick.

At first sight, a topological quantum computer *does not seem much like a computer at all.*

At first sight, a topological quantum computer does not seem much like a computer at all. It works its calculations on braided strings—but not physical strings in the conventional sense. Rather, they are what physicists refer to as world lines, representations of particles as they move through time and space. (Imagine that the length of one of these strings represents a particle's movement through time and that its thickness represents the particle's physical dimensions.) Moreover, even the particles involved are unlike the electrons and protons that one might first imagine. They are instead quasiparticles—excitations in a two-dimensional electronic system that behave a lot like the particles and antiparticles of high-energy physics. And as a further complication, the quasiparticles are of a special type called anyons, which have the desired mathematical properties.

Here is a what a computation might look like: first, create pairs of anyons and place them along a line [*see box on page 60*]. Each anyon pair is rather like a particle and its corresponding antiparticle, created out of pure energy.

Next, move pairs of adjacent anyons around one another in a carefully determined sequence. Each anyon's world line forms a thread, and the movements of the anyons as they are swapped this way and that produce a braiding of all the threads. The quantum computation is encapsulated in the particular braid so formed. The final states of the anyons, which embody the result of the computation, are determined by the braid and not by any stray electric or magnetic interaction. And because the braid is topological—nudging the threads a little bit this way and that does not change the braiding—it is inherently protected from outside disturbances. The idea of using anyons to carry out computations in this fashion was proposed in 1997 by Alexei Y. Kitaev, now at Microsoft.

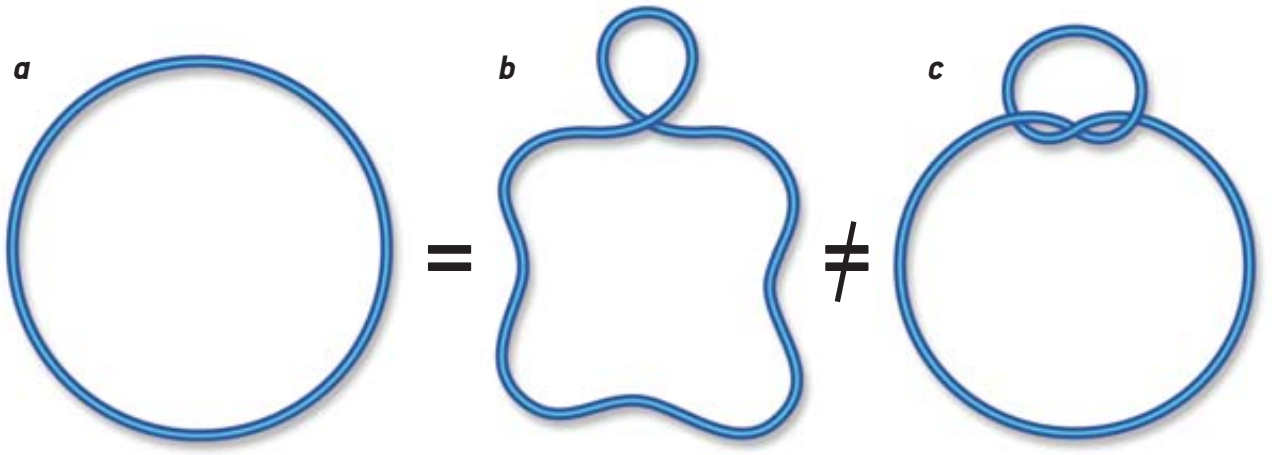
Michael H. Freedman, now at Microsoft, lectured at Harvard University in the fall of 1988 on the possibility of using quantum topology for computation. These ideas, published in a research paper in 1998, built on the discovery that certain mathematical quantities known as knot invariants were associated with the quantum physics of a two-dimensional surface evolving in time. If an instance of the physical system could be created and an appropriate measurement carried out, the knot invariant would be approximately computed automatically instead of via an inconvenient-

Overview/*Quantum Braids*

- Quantum computers promise to greatly exceed the abilities of classical computers, but to function at all, they must have very low error rates. Achieving the required low error rates with conventional designs is far beyond current technological capabilities.
- An alternative design is the so-called topological quantum computer, which would use a radically different physical system to implement quantum computation. Topological properties are unchanged by small perturbations, leading to a built-in resistance to errors such as those caused by stray interactions with the surrounding environment.
- Topological quantum computing would make use of theoretically postulated excitations called anyons, bizarre particlelike structures that are possible in a two-dimensional world. Experiments have recently indicated that anyons exist in special planar semiconductor structures cooled to near absolute zero and immersed in strong magnetic fields.

TOPOLOGY AND KNOTS

Topology of a closed loop (*a*) is unaltered if the string is pushed around to form another shape (*b*) but is different from that of a closed loop with a knot tied in it (*c*). The knot cannot be formed just by moving around the string. Instead one must cut the string, tie the knot and rejoin the ends. Consequently, the topology of the loop is insensitive to perturbations that only push the string around.



ly long calculation on a conventional computer. Equally difficult problems of more real-world importance would have similar shortcuts.

Although it all sounds like wild theorizing quite removed from reality, recent experiments in a field known as fractional quantum Hall physics have put the anyon scheme on firmer footing. Further experiments have been proposed to carry out the rudiments of a topological quantum computation.

Anyons

AS PREVIOUSLY MENTIONED, a topological quantum computer braids world lines by swapping the positions of particles. How particles behave when swapped is one of the many ways that quantum physics differs fundamentally from classical physics. In classical physics, if you have two electrons at locations A and B and you interchange their positions, the final state is the same as the initial state. Because the electrons are indistinguishable, so, too, are the initial and final states. Quantum mechanics is not so simple.

The difference arises because quantum mechanics describes the state of a particle with a quantity called the wave function, a wave in space that encapsulates all the properties of the particle—the probability of finding it at various locations, the probability of measuring it at various velocities, and so on. For example, a particle is most likely to be found in a region where the wave function has a large amplitude.

A pair of electrons is described by a joint wave function, and when the two electrons are exchanged, the resulting joint wave function is minus one times the original. That changes peaks of the wave into troughs, and vice versa, but it has no effect on the amplitude of the oscillations. In fact, it does not change any measurable quantity of the two electrons considered by themselves.

What it does change is how the electrons might interfere with other electrons. Interference occurs when two waves are added together. When two waves interfere, the combination has a high amplitude where peaks of one align with peaks of the other ("constructive interference") and has a low amplitude where peaks align with troughs ("destructive interference"). Multiplying one of the waves by a phase of minus one interchanges its peaks and troughs and thus changes constructive interference, a bright spot, to destructive interference, a dark spot.

It is not just electrons that pick up a factor of minus one in this way but also protons, neutrons and in general any particle of a class called fermions. Bosons, the other chief class of particles, have wave functions that are unchanged when two particles are swapped. You might say that their wave functions are multiplied by a factor of plus one.

Deep mathematical reasons require that quantum particles in three dimensions must be either fermions or bosons. In two dimensions, another possibility arises: the factor might be a complex phase. A complex phase can be thought of as an angle. Zero degrees corresponds to the number one; 180 degrees is minus one. Angles in-between are complex numbers. For example, 90 degrees corresponds to i, the square root of minus one. As with a factor of minus one, multiplying a wave function by a phase has absolutely no effect on the measured properties of the individual particle, because all that matters for those properties are the amplitudes of the oscillations of the wave. Nevertheless, the phase can change how two complex waves interfere.

Particles that pick up a complex phase on being swapped are called anyons because *any* complex phase might appear, not just a phase of plus or minus one. Particles of a given species, however, always pick up the same phase.

Electrons in Flatland

ANYONS EXIST ONLY in a two-dimensional world. How can we produce pairs of them for topological computing when we live in three dimensions? The

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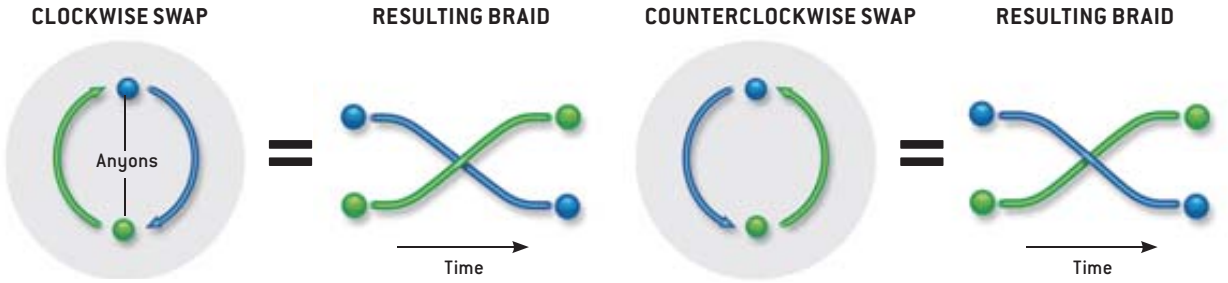
HOW TOPOLOGICAL QUANTUM COMPUTING WORKS

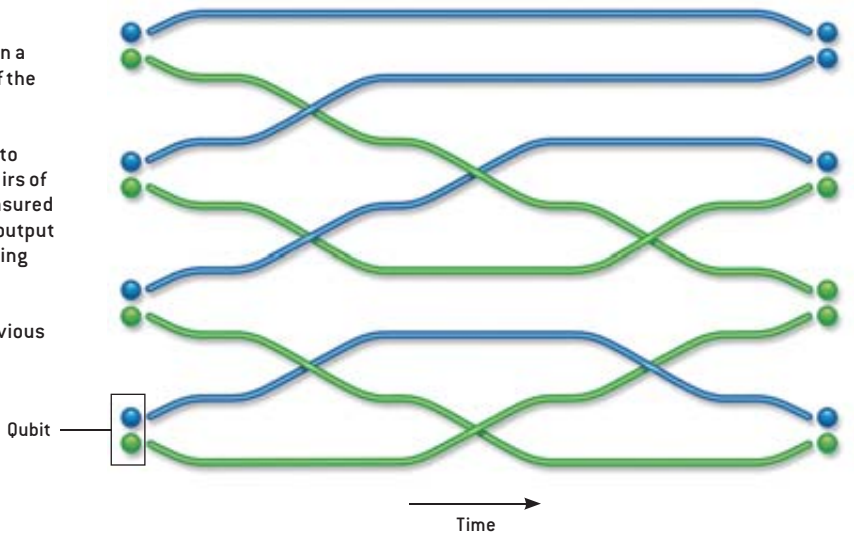
BRAIDING

Just two basic moves in a plane—a clockwise swap and a counterclockwise swap—generate all the possible braidings of the world lines (trajectories through spacetime) of a set of anyons.

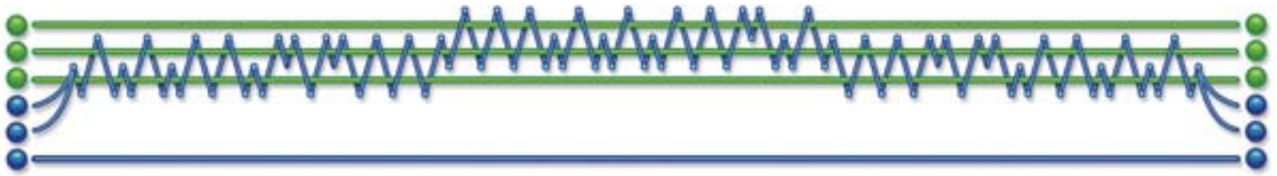


COMPUTING

First, pairs of anyons are created and lined up in a row to represent the qubits, or quantum bits, of the computation. The anyons are moved around by swapping the positions of adjacent anyons in a particular sequence. These moves correspond to operations performed on the qubits. Finally, pairs of adjacent anyons are brought together and measured to produce the output of the computation. The output depends on the topology of the particular braiding produced by those manipulations. Small disturbances of the anyons do not change that topology, which makes the computation impervious to normal sources of errors.



BUILDING A LOGIC GATE



A logic gate known as a CNOT gate is produced by this complicated braiding of six anyons. A CNOT gate takes two input qubits and produces two output qubits. Those qubits are represented by triplets (*green* and *blue*) of so-called Fibonacci anyons. The particular style of braiding—leaving one triplet in place and moving two anyons of the other triplet around its anyons—simplified the calculations involved in designing the gate. This braiding produces a CNOT gate that is accurate to about 10^{-3}.

answer lies in the flatland realm of quasiparticles. Two slabs of gallium arsenide semiconductor can be carefully engineered to accommodate a "gas" of electrons at their interface. The electrons move freely in the two dimensions of the interface but are constrained from moving in the third dimension, which would take them off the interface. Physicists have intensely studied such systems of electrons, called two-dimensional electron gases, particularly when the systems are immersed in high transverse magnetic fields at extremely low temperatures, because of the unusual quantum properties exhibited under these conditions.

For example, in the fractional quantum Hall effect, excitations in the electron gas behave like particles having a fraction of the charge of the electron. Other excitations carry units of the magnetic flux around with them as though the flux were an integral part of the particle. In 2005 Vladimir J. Goldman, Fernando E. Camino and Wei Zhou of Stony Brook University claimed to have direct experimental confirmation that quasiparticles occurring in the fractional quantum Hall state are anyons, a crucial first step in the topological approach to quantum computation. Some researchers, however, still seek in-

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dependent lines of evidence for the quasiparticles' anyonic nature because certain nonquantum effects could conceivably produce the results seen by Goldman and his colleagues.

In two dimensions, an important new issue arises in the swapping of two particles: Do the particles follow clockwise tracks or counterclockwise tracks as they are interchanged? The phase picked up by the wave function depends on that property. The two alternative paths are topologically distinct, because the experimenter cannot continuously deform the clockwise paths into counterclockwise paths without crossing the paths and having the particles collide somewhere.

To build a topological quantum computer requires one additional complication: the anyons must be what is called nonabelian. This property means that the order in which particles are swapped is important. Imagine that you have three identical anyons in a row, at positions A, B and C. First swap the anyons at positions A and B. Next swap the anyons now located at B and C. The result will be the original wave function modified by some factor. Suppose instead that the anyons at B and C are swapped first, followed by swapping those at A and B. If the result is the wave function multiplied by the same factor as before, the anyons are called abelian. If the factors differ depending on the order of the swapping, they are nonabelian anyons. (The nonabelian property arises because for these anyons, the factor that multiplies the wave function is a matrix of numbers, and the result of multiplying two matrices depends on the order in which they are multiplied.)

The experiment by Goldman's team involved abelian anyons. Nevertheless, theorists have strong reason to believe that certain fractional quantum Hall quasiparticles are indeed nonabelian. Experiments have been proposed to settle that question. One was suggested by Freedman, along with Sankar Das Sarma of the University of Maryland at College Park and Chetan Nayak of Microsoft, with important refinements proposed by Ady Stern of the Weizmann Institute in Israel and Bertrand Halperin of Harvard University; the second was presented by Kitaev, Parsa Bonderson of the California Institute of Technology and Kirill Shtengel, now at the University of California, Riverside.

Braids and Gates

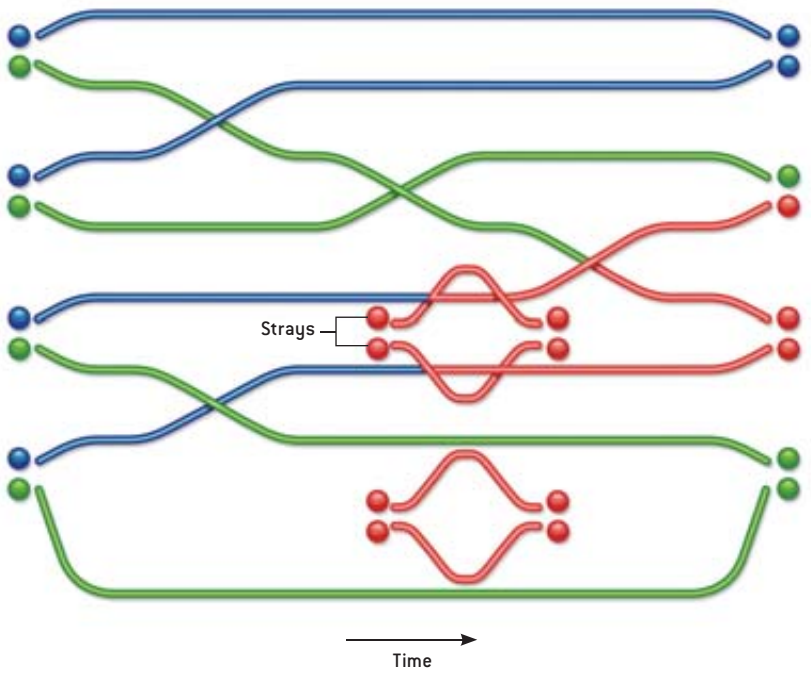
ONCE YOU HAVE nonabelian anyons, you can generate a physical representation of what is called the braid group. This mathematical structure describes all the ways that a given row of threads can be braided together. Any braid can be built out of a series of elementary operations in which two adjacent threads are moved, by either a clockwise or a counterclockwise motion. Every possible sequence of anyon manipulations corresponds to a braid, and vice versa. Also corresponding to each braid is a very complicated matrix, the result of combining all the individual matrices of every anyon exchange.

Now we have all the elements in place to see how these braids correspond to a quantum computation. In a conventional computer, the state of the computer is represented by the combined state of all its bits—the particular sequence of 0s and 1s in its register. Similarly, a quantum computer is represented by the combined state of all its qubits. In a topological quantum computer, the qubits may be represented by groups of anyons.

In a quantum computer, the process of going from the initial state of all the qubits to the final state is described by a matrix that multiplies the joint wave function of all the qubits. The similarity to what happens in a topological quantum computer is obvious: in that case, the matrix is the one associated with the particular braid corresponding to the sequence of anyon manipulations. Thus, we have verified that the operations car-

PREVENTING RANDOM ERRORS

Errors will occur in a topological computation if thermal fluctuations generate a stray pair of anyons that intertwine with the braid of the computation before they self-annihilate. Those strays will then corrupt (*red lines*) the computation. The probability of this interference drops exponentially with the distance that the anyons travel, however. The error rate can be minimized by keeping the computation anyons sufficiently far apart (*bottom pair*).



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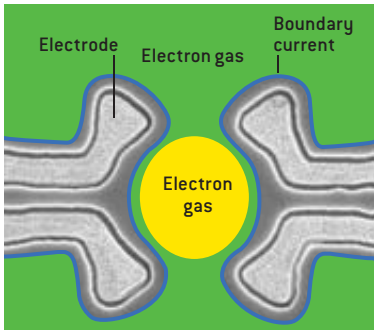
TOPOLOGICAL ERRORS

ANYON DETECTOR

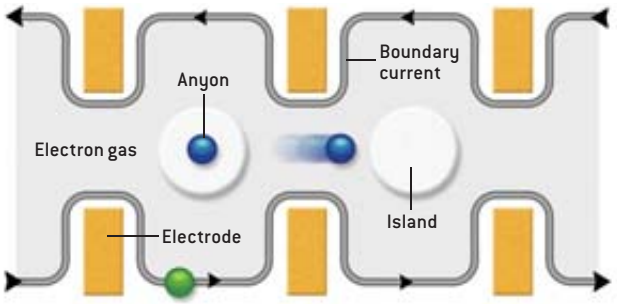
The device in this colorized micrograph was used by Vladimir J. Goldman and his co-workers to demonstrate that certain quasiparticles (excitations in the quantum Hall state) behave as anyons. The device was cooled to 10 millikelvins and put in a strong magnetic field. A two-dimensional electron gas formed around the four electrodes, with different types of quasiparticles present in the yellow and green areas. Characteristics of the current flowing along the boundary confirmed that the quasiparticles in the yellow island were anyonic.



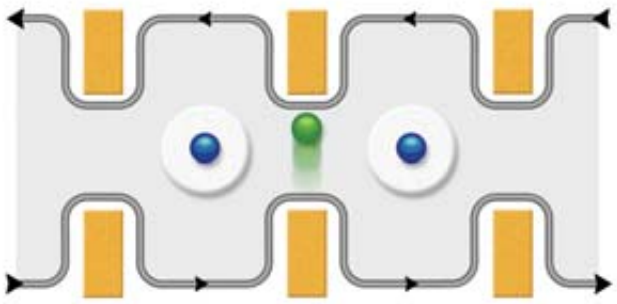
NOT GATE

This proposed anyonic NOT gate is based on a fractional quantum Hall state involving anyons having one-quarter the charge of an electron. Electrodes induce two islands on which anyons can be trapped. Current flows along the boundary but under the right conditions can also tunnel across the narrow isthmuses.

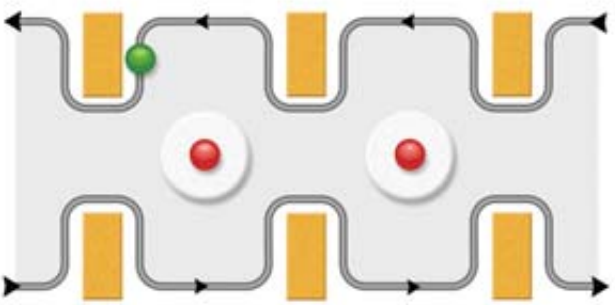
1 Initialize the gate by putting two anyons (*blue*) on one island and then applying voltages to transfer one anyon to the other island. This pair of anyons represents the qubit in its initial state, which can be determined by measuring the current flow along the neighboring boundary.



2 To flip the qubit (the NOT operation), apply voltages to induce one anyon from the boundary (*green*) to tunnel across the device.



3 The passage of this anyon changes the phase relation of the two anyons so that the qubit's value is flipped to the opposite state (*red*).



ried out on the anyons result in a quantum computation.

Another important feature must be confirmed: Can our topological quantum computer perform *any* computation that a conventional quantum computer can? Freedman, working with Michael Larsen of Indiana University and Zhenghan Wang, now at Microsoft, proved in 2002 that a topological quantum computer can indeed simulate any computation of a standard quantum computer, but with one catch: the simulation is approximate. Yet given any desired accuracy, such as one part in 10^4, a braid can be found that will simulate the required computation to that accuracy. The finer the accuracy required, the greater the number of twists in the braid. Fortunately, the number of twists required increases very slowly, so it is not too difficult to achieve very high accuracy. The proof does not, however, indicate *how* to determine which actual braid corresponds to a computation—that depends on the specific design of topological quantum computer, in particular the species of anyons employed and their relation to elementary qubits.

The problem of finding braids for doing specific computations was tackled in 2005 by Nicholas E. Bonesteel of Florida State University, along with colleagues there and at Lucent Technologies's Bell Laboratories. The team showed explicitly how to construct a so-called controlled NOT (or CNOT) gate to an accuracy of two parts in 10^3 by braiding six anyons. A CNOT gate takes two inputs: a control bit and a target bit. If the control bit is 1, it changes the target bit from 0 to 1, or vice versa. Otherwise the bits are unaltered. Acting on qubits, any computation can be built from a network of CNOT gates and one other operation—the multiplication of individual qubits by a complex phase. This result serves as another confirmation that topological quantum computers can perform any quantum computation.

Quantum computers can perform feats believed to be impossible for classical computers. Is it possible that a topological computer is more powerful than a conventional quantum computer? An-

GEORGE RETSECK (*illustration*); FROM F. E. CAMINO ET AL. IN *PHYSICAL REVIEW LETTERS*, VOL. 95; 2005 (*micrograph*)

other theorem, proved by Freedman, Kitaev and Wang, shows that is not the case. They demonstrated that the operation of a topological quantum computer can be simulated efficiently to arbitrary accuracy on a conventional quantum computer, meaning that anything that a topological quantum computer can compute a conventional quantum computer can also compute. This result suggests a general theorem: any sufficiently advanced computation system that makes use of quantum resources has exactly the same computational abilities. (An analogous thesis for classical computing was proposed by Alonzo Church and Alan Turing in the 1930s.)

Particles In, Answers Out

I HAVE GLOSSED OVER two processes that are crucial to building a practical topological quantum computer: the initialization of the qubits before the start of the computation and the readout of the answer at the end.

The initialization step involves generating quasiparticle pairs, and the problem is knowing what species of quasiparticle has been created. The basic procedure is to pass test anyons around the generated pairs and then measure how the test anyons have been altered by that process, which depends on the species of the anyons that they have passed. (If a test anyon is altered, it will no longer be cleanly annihilated with its partner.) Anyon pairs not of the required type would be discarded.

The readout step also involves measuring anyon states. While the anyons are widely separated, that measurement is impossible: the anyons must be brought together in pairs to be measured. Roughly speaking, it is like checking to see if the pairs annihilate cleanly, like true antiparticles, or if they leave behind residues of charge and flux, which reveals how their states have been altered by braiding from the exact antiparticle relation in which they began their lives.

Also, it is not true that a topological computer is totally immune to errors. The main source of error is thermal fluctuations in the substrate material, which can generate an extra pair of anyons. Both the anyons then intertwine themselves with the braid of the computation, and finally the pair annihilates again [*see box on page 61*]. Fortunately, the thermal generation process is suppressed at the low temperature at which a topological computer would operate. Furthermore, the probability of the entire bad process occurring decreases exponentially as the distance traveled by the interlopers increases. Thus, one can achieve any required degree of accuracy by building a sufficiently large computer and keeping the working anyons far enough apart as they are braided.

Topological quantum computing remains in its infancy. The basic working elements, nonabelian anyons, have not yet been demonstrated to exist, and the simplest of logic gates has yet to be built. The previously mentioned experiment of Freedman, Das Sarma and Nayak would achieve both those goals—if the anyons involved do turn out to be nonabelian, as expected, the device would carry out the logical NOT operation on the qubit state. The trio estimated that the error rate for the process would be 10^{-30} or less. Such a tiny error rate occurs because the probability of errors is exponentially suppressed as the temperature is lowered and the length scale increased. That exponential factor is the essential contribution of topology, and it has no analogue in the more traditional approaches to quantum computing.

The promise of extraordinarily low error rates—many orders of magnitude lower than those achieved by any other quantum computation scheme to date—is what makes topological quantum computing so attractive. Also, the technologies involved in making fractional quantum Hall devices are mature, being precisely those of the microchip industry; the only catch is that the devices have to operate at extremely low temperatures—on the order of millikelvins—for the magical quasiparticles to be stable.

If nonabelian anyons actually exist, topological quantum computers could well leapfrog conventional quantum computer designs in the race to scale up from individual qubits and logic gates to fully fledged machines more deserving of the name "computer." Carrying out calculations with quantum knots and braids, a scheme that began as an esoteric alternative, could become the standard way to implement practical, error-free quantum computation. SA

The trio estimated that the error rate for their *NOT gate would be 10^{-30} or less.*

Graham P. Collins is a staff writer and editor, with a Ph.D. in physics from Stony Brook University. *He wishes to thank Michael H. Freedman, the director of Project Q at Microsoft, for contributions in the preparation of this article.*

MORE TO EXPLORE

Topologically Protected Qubits from a Possible Non-Abelian Fractional Quantum Hall State. Sankar Das Sarma, Michael Freedman and Chetan Nayak in *Physical Review Letters,* Vol. 94, pages 166802-1–168802-4; April 29, 2005.

Devices Based on the Fractional Quantum Hall Effect May Fulfill the Promise of Quantum Computing. Charles Day in *Physics Today,* Vol. 58, pages 21–24; October 2005.

Anyon There? David Lindley in *Physical Review Focus,* Vol. 16, Story 14; November 2, 2005. **http://focus.aps.org/story/v16/st14**

Topological Quantum Computation. John Preskill. Lecture notes available at **www.theory.caltech.edu/~preskill/ph219/topological.pdf**

WHY ARE SOME ANIMALS

THE UNUSUAL BEHAVIOR OF ORANGUTANS IN A SUMATRAN SWAMP

PERRY VAN DUIJNHOVEN FROM *AMONG ORANGUTANS: RED APES AND THE RISE OF HUMAN CULTURE,* BY CAREL VAN SCHAIK. THE BELKNAP PRESS OF HARVARD UNIVERSITY PRESS,

SO SMART?

SUGGESTS A SURPRISING ANSWER

ORANGUTAN mother and infant in Sumatra.

BY CAREL VAN SCHAIK

Even though we humans write the textbooks and may justifiably be suspected of bias, few doubt that we are the smartest creatures on the planet. Many animals have special cognitive abilities that allow them to excel in their particular habitats, but they do not often solve novel problems. Some of course do, and we call them intelligent, but none are as quick-witted as we are.

What favored the evolution of such distinctive brainpower in humans or, more precisely, in our hominid ancestors? One approach to answering this question is to examine the factors that might have shaped other creatures that show high intelligence and to see whether the same forces might have operated in our forebears. Several birds and nonhuman mammals, for instance, are much better problem solvers than others: elephants, dolphins, parrots, crows. But research into our close relatives, the great apes, is surely likely to be illuminating.

Scholars have proposed many explanations for the evolution of intelligence in primates, the lineage to which humans and apes belong (along with monkeys, lemurs and lorises). Over the past 13 years, though, my group's studies of orangutans have unexpectedly turned up a new explanation that we think goes quite far in answering the question.

Incomplete Theories

ONE INFLUENTIAL ATTEMPT at explaining primate intelligence credits the complexity of social life with spurring the development of strong cognitive abilities. This Machiavellian intelligence hypothesis suggests that success in social life relies on cultivating the most profitable relationships and on rapidly reading the social situation—for instance, when deciding whether to come to the aid of an ally attacked by another animal. Hence, the demands of society foster intelligence because the most intelligent beings would be most successful at making self-protective choices and thus would survive to pass their genes to the next generation. Machiavellian traits may not be equally beneficial to other lineages, however, or even to all primates, and so this notion alone is unsatisfying.

One can easily envisage many other forces that would promote the evolution of intelligence, such as the need to work hard for one's food. In that situation, the ability to figure out how to skillfully extract hidden nourishment or the capacity to remember the perennially shifting locations of critical food items would be advantageous, and so such cleverness would be rewarded by passing more genes to the next generation.

My own explanation, which is not incompatible with these other forces, puts the emphasis on social learning. In humans, intelligence develops over time. A child learns primarily from the guidance of patient adults. Without strong

social—that is, cultural—inputs, even a potential wunderkind will end up a bungling bumpkin as an adult. We now have evidence that this process of social learning also applies to great apes, and I will argue that, by and large, the animals that are intelligent are the ones that are cultural: they learn from one another innovative solutions to ecological or social problems. In short, I suggest that culture promotes intelligence.

I came to this proposition circuitously, by way of the swamps on the western coast of the Indonesian island of Sumatra, where my colleagues and I were observing orangutans. The orangutan is Asia's only great ape, confined to the islands of Borneo and Sumatra and known to be something of a loner. Compared with its more familiar relative, Africa's chimpanzee, the red ape is serene rather than hyperactive and reserved socially rather than convivial. Yet we discovered in them the conditions that allow culture to flourish.

Technology in the Swamp

WE WERE INITIALLY attracted to the swamp because it sheltered disproportionately high numbers of orangutans—unlike the islands' dryland forests, the moist swamp habitat supplies abundant food for the apes year-round and can thus support a large population. We worked in an area near Suaq Balimbing in the Kluet swamp [*see map at left*], which may have been paradise for orangutans but, with its sticky mud, profusion of biting insects, and oppressive heat and humidity, was hell for researchers.

One of our first finds in this unlikely setting astonished us: the Suaq orangutans created and wielded a variety of tools. Although captive red apes are avid tool users, the most striking feature of tool use among the wild orangutans observed until then was its absence. The animals at Suaq ply their tools for two major purposes. First, they hunt for ants, termites and, especially, honey (mainly that of stingless bees)—more so than all their fellow orangutans elsewhere. They often cast discerning glances at tree trunks, looking for air traffic in and out of small holes. Once discovered, the holes become the focus of visual and then manual inspection by a poking and picking finger. Usually the finger is not long enough, and the orangutan prepares a stick tool. After carefully inserting the tool, the ape delicately moves it back and forth, and then withdraws it, licks it off and sticks it back in. Most of this "manipulation" is done with the tool clenched between the teeth; only the largest tools, used primarily to hammer chunks off termite nests, are handled.

The second context in which the Suaq apes employ tools involves the fruit of the *Neesia*. This tree produces woody, five-angled capsules up to 10 inches long and four inches wide. The capsules are filled with brown seeds the size of lima beans, which, because they contain nearly 50 percent fat, are highly nutritious—a rare and sought-after treat in a natural habitat without fast food. The tree protects its seeds by growing a very tough husk. When the seeds are ripe, however, the husk begins to split open; the cracks gradually widen, exposing neat rows of seeds, which have grown nice red attachments (arils) that contain some 80 percent fat. To discourage seed predators further, a mass of razor-sharp needles fills the husk. The orangutans at Suaq strip the bark off short, straight twigs, which they then hold in their mouths and insert into the cracks. By moving the tool up and down inside the crack, the animal detaches the seeds from their stalks. After this maneuver, it can drop the seeds

KLUET SWAMP provides an unusually lush habitat for orangutans. The author and his colleagues discovered that in such a productive setting, the apes, generally known to live solitary lives, are surprisingly sociable.

Overview/*The Orangutan Connection*

- The author has discovered extensive tool use among orangutans in a Sumatran swamp. No one has observed orangutans systematically using tools in the wild before.
- This unexpected finding suggests to the author a resolution to a long-standing puzzle: Why are some animals so smart?
- He proposes that culture is the key. Primatologists define culture as the ability to learn—by observation—skills invented by others. Culture can unleash ever increasing accomplishments and can bootstrap a species toward greater and greater intelligence.

JEN CHRISTIANSEN (*map*); PERRY VAN DUIJNHOVEN FROM *AMONG ORANGUTANS: RED APES AND THE RISE OF HUMAN CULTURE*, BY CAREL VAN SCHAIK. THE BELKNAP PRESS OF HARVARD UNIVERSITY PRESS, © 2004 BY THE PRESIDENT AND FELLOWS OF HARVARD COLLEGE (*photographs above and opposite page*)

MOST ORANGUTANS spend their lives without making or using tools. The red apes at Suaq are an exception; they create a variety of tools. One of the most common is a stick (*above right*) they prepare for gathering ants, termites and, especially, honey. Without the tool (*far left*), attempts to retrieve honey from a hole in a tree, by biting the hole, for example, often fail. The Suaq apes, in contrast, insert the tool into the hole and, holding it in their mouth (*arrow at right*), move it delicately back and forth. They then withdraw it to lick off the honey (*far right*).

straight into its mouth. Late in the season, the orangutans eat only the red arils, deploying the same technique to get at them without injury.

Both these methods of fashioning sticks for foraging are ubiquitous at Suaq. In general, "fishing" in tree holes is occasional and lasts only a few minutes, but when *Neesia* fruits ripen, the apes devote most of their waking hours to ferreting out the seeds or arils, and we see them grow fatter and sleeker day by day.

Why the Tool Use Is Cultural

WHAT EXPLAINS this curious concentration of tool use when wild orangutans elsewhere show so little propensity? We doubt that the animals at Suaq are intrinsically smarter: the observation that most captive members of this species can learn to use tools suggests that the basic brain capacity to do so is present.

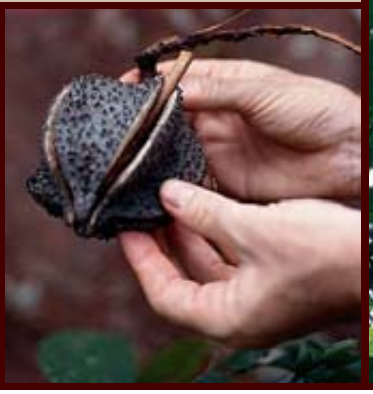
So we reasoned that their environment might hold the answer. The orangutans studied before mostly live in dry forest, and the swamp furnishes a uniquely lush habitat. More insects make their nests in the tree holes there than in forests on dry land, and *Neesia* grows only in wet places, usually near flowing water. Tempting as the environmental explanation sounds, however, it does not explain why orangutans in several populations outside Suaq ignore altogether these same rich food sources. Nor does it explain why some populations that do eat the seeds harvest them without tools (which results, of course, in their eating much less than the orangutans at Suaq do). The same holds for tree-hole tools. Occasionally, when the nearby hills—which have dryland forests—show massive fruiting, the Suaq orangutans go there to indulge, and while they are gathering fruit they use tools to exploit the contents of tree holes. The hill habitat is a dime a dozen throughout the orangutan's geographic range, so if tools can be used on the hillsides above Suaq, why not everywhere?

Another suggestion we considered, captured in the old adage that necessity is the mother of invention, is that the Suaq animals, living at such high density, have much more competition for provisions. Consequently, many would be left without food unless they could get at the hard-to-reach supplies—that is, they *need* tools in order to eat. The strongest argument against this possibility is that the sweet or fat foods that the tools make accessible sit very high on the orangutan preference list and should therefore be sought by these animals everywhere. For instance, red apes in all locations are willing to be stung many times by honeybees to get at their honey. So the necessity idea does not hold much water either.

A different possibility is that these behaviors are innovative techniques a couple of clever orangutans invented, which then spread and persisted in the population because other individuals learned by observing these experts. In other words, the tool use is cultural. A major obstacle to studying culture in nature is that, barring experimental introductions, we can never demonstrate convincingly that an animal we observe invents some new trick rather than simply applying a well-remembered but rarely practiced habit. Neither can we prove that one individual learned a new skill from another group member rather than figuring out what to do on its own. Although we can show that orangutans in the lab are capable of observing and learning socially, such studies tell us nothing about culture in nature—neither what it is generally about nor how much of it exists. So field-workers have had to develop a system of criteria to demonstrate that a certain behavior has a cultural basis.

First, the behavior must vary geographically, showing that it was invented somewhere, and it must be common where it is found, showing that it spread and persisted in a population. The tool uses at Suaq easily pass these first two tests. The second step is to eliminate simpler explanations that produce the same spatial pattern but without involv-

FRUIT OF THE *NEESIA* TREE (*below left*) has inspired another important tool in the repertoire of the orangutans at Suaq. The highly nutritious seeds are surrounded by razor-sharp needles that serve to keep out mammalian seed predators. To circumvent the painful needles, the Suaq apes strip the bark off short, straight twigs, which they then hold in their mouth and insert into cracks in the ripening fruit (*right*). By moving the tool up and down inside the crack, the ape detaches the seeds without getting injured. The photograph in the center shows a small fruit with the tool still sticking out.



ing social learning. We have already excluded an ecological explanation, in which individuals exposed to a particular habitat independently converge on the same skill. We can also eliminate genetics because of the fact that most captive orangutans can learn to use tools.

The third and most stringent test is that we must be able to find geographic distributions of behavior that can be explained by culture and are not easily explained any other way. One key pattern would be the presence of a behavior in one place and its absence beyond some natural barrier to dispersal. In the case of the tool users at Suaq, the geographic distribution of *Neesia* gave us decisive clues. *Neesia* trees (and orangutans) occur on both sides of the wide Alas River. In the Singkil swamp, however, just south of Suaq and on the same side of the Alas River [*see map on opposite page*], tools littered the floor, whereas in Batu-Batu swamp across the river they were conspicuously absent, despite our numerous visits in different years. In Batu-Batu, we did find that many of the fruits were ripped apart, showing that these orangutans ate *Neesia* seeds in the same way as their colleagues did at a site called Gunung Palung in distant Borneo but in a way completely different from their cousins right across the river in Singkil.

Batu-Batu is a small swamp area, and it does not contain much of the best swamp forest; thus, it supports a limited number of orangutans. We do not know whether tool use was never invented there or whether it could not be maintained in the smaller population, but we do know that migrants from across the river never brought it in because the Alas is so wide there that it is absolutely impassable for an orangutan. Where it is passable, farther upriver, *Neesia* occasionally grows, but the orangutans in that area ignore it altogether, apparently unaware of its rich offerings. A cultural interpretation, then, most parsimoniously explains the unexpected juxtaposition of knowledgeable tool users and brute-force foragers living practically next door to one another, as well as the presence of ignoramuses farther upriver.

Tolerant Proximity

WHY DO WE SEE these fancy forms of tool use at Suaq and not elsewhere? To look into this question, we first made detailed comparisons among all the sites at which orangutans have been studied. We found that even when we excluded tool use, Suaq had the largest number of innovations that had spread throughout the population. This finding is probably not an artifact of our own interest in unusual behaviors, because some other sites have seen far more work by researchers eager to discover socially learned behavioral innovations.

We guessed that populations in which individuals had more chances to observe others in action would show a greater diversity of learned skills than would populations offering fewer learning opportunities. And indeed, we were able to confirm that sites in which individuals spend more time with others have greater repertoires of learned innovations—a relation, by the way, that also holds among chimpanzees [*see illustration on page 70*]. This link was strongest for food-related behavior, which makes sense because acquiring feeding skills from somebody else

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requires more close-range observation than, say, picking up a conspicuous communication signal. Put another way, those animals exposed to the fewest educated individuals have the smallest collection of cultural variants, exactly like the proverbial country bumpkin.

When we looked closely at the contrasts among sites, we noticed something else. Infant orangutans everywhere spend over 20,000 daylight hours in close contact with their mothers, acting as enthusiastic apprentices. Only at Suaq, however, did we also see adults spending considerable time together while foraging. Unlike any other orangutan population studied so far, they even regularly fed on the same food item, usually termite-riddled branches, and shared food—the meat of a slow loris, for example. This unorthodox proximity and tolerance allowed less skilled adults to come close enough to observe foraging methods, which they did as eagerly as kids.

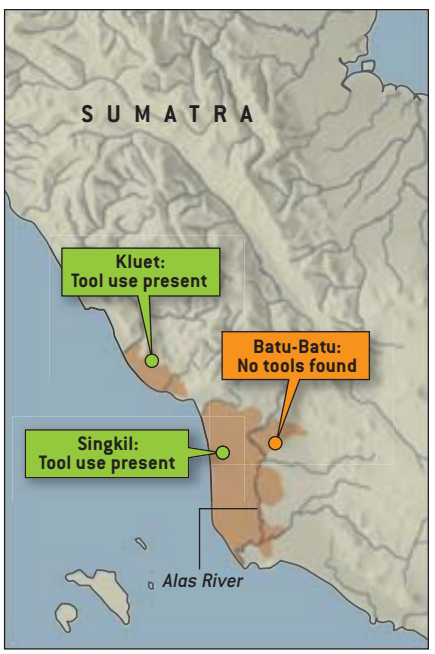
Acquisition of the most cognitively demanding inventions, such as the tool uses found only at Suaq, probably requires face time with proficient individuals, as well as several cycles of observation and practice. The surprising implication of this need is that even though infants learn virtually all their skills from their mothers, a population will be able to perpetuate particular innovations only if tolerant role models other than the mother are around; if mom is not particularly skillful, knowledgeable experts will be close at hand, and a youngster will still be able to learn the fancy techniques that apparently do not come automatically. Thus, the more connected a social network, the more likely it is that the group will retain any skill that is invented, so that in the end tolerant populations support a greater number of such behaviors.

Our work in the wild shows us that most learning in nature, aside from simple conditioning, may have a social component, at least in primates. In contrast, most laboratory experiments that investigate how animals learn are aimed at revealing the subject's ability for individual learning. Indeed, if the lab psychologist's puzzle were presented under natural conditions, where myriad stimuli compete for attention, the subject might never realize that a problem was waiting to be solved. In the wild, the actions of knowledgeable members of the community serve to focus the attention of the naive animal.

The Cultural Roots of Intelligence

OUR ANALYSES of orangutans suggest that not only does culture—social learning of special skills—promote intelligence, it favors the evolution of greater and greater intelligence in a population over time. Different species vary greatly in the mechanisms that enable them to learn from others, but formal experiments confirm the strong impression one gets from observing great apes in the wild: they are capable of learning by watching what others do. Thus, when a wild orangutan, or an African great ape for that matter, pulls off a cognitively complex behavior, it has acquired the ability through a mix of observational learning and individual practice, much as a human child has garnered his or her skills. And when an orangutan in Suaq has acquired more of these tricks than its less fortunate cousins elsewhere, it has done so because it had greater opportunities for social learning throughout its life. In brief, social learning may bootstrap an animal's intellectual performance onto a higher plane.

IMPASSABLE RIVERS may have halted the spread of tool use. *Neesia* trees and orangutans, for example, occur on both sides of the wide Alas River (*photograph*), but in the Singkil swamp (*map*), tools abound on the forest floor, whereas in Batu-Batu swamp across the river the resident orangutans use a simpler technique to detach *Neesia* seeds that does not involve tools. Migrants are not able to bring tool use to Batu-Batu, because the Alas is too wide there for an orangutan to cross.



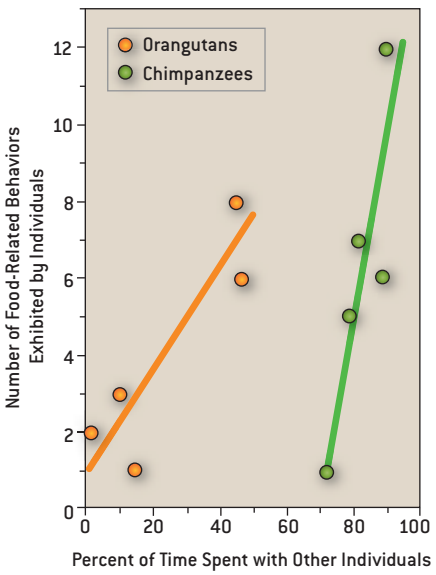
BASE MAP SOURCE: PERRY VAN DUIJNHOVEN; ADAPTED BY JEN CHRISTIANSEN; PERRY VAN DUIJNHOVEN (*photograph*)

To appreciate the importance of social inputs to the evolution of ever higher intelligence, let us do a thought experiment. Imagine an individual that grows up without any social inputs yet is provided with all the shelter and nutrition it needs. This situation is equivalent to that in which no contact exists between the generations or in which young fend for themselves after they emerge from the nest. Now imagine that some female in this species invents a useful skill—for instance, how to open a nut to extract its nutritious meat. She will do well and perhaps have more offspring than others in the population. Unless the skill gets transferred to the next generation, however, it will disappear when she dies.

Now imagine a situation in which the offspring accompany their mother for a while before they strike out on their own. Most youngsters will learn the new technique from their mother and thus transfer it—and its attendant benefits—to the next generation. This process would generally take place in species with slow development and long association between at least one parent and offspring, but it would get a strong boost if several individuals form socially tolerant groups.

We can go one step further. For slowly developing animals that live in socially tolerant societies, natural selection will tend to reward a slight improvement in the ability to learn through observation more strongly than a similar increase in the ability to innovate, because in such a society, an individual can stand on the shoulders of those in both present and past generations. We will then expect a feed-forward process in which animals can become more innovative and develop better techniques of social learning because both abilities rely on similar cognitive mechanisms. Hence, being cultural predisposes species with some innovative capacities to evolve toward higher intelligence. This, then, brings us to the new explanation for cognitive evolution.

This new hypothesis makes sense of an otherwise puzzling phenomenon. Many times during the past century people reared great ape infants as they would human children. These so-called enculturated apes acquired a surprising set of skills, effortlessly imitating complex behavior—understanding pointing, for example, and even some human language, becoming humorous pranksters and creating drawings. More recently, formal experiments such as those performed by E. Sue Savage-Rumbaugh of Georgia



POPULATIONS in which individuals have more chances to observe others in action show a greater diversity of learned skills than populations offering fewer learning opportunities. The relation holds for both chimpanzees and orangutans.

State University, involving the bonobo Kanzi, have revealed startling language abilities [see "The Emergence of Intelligence," by William H. Calvin; Scientific American, October 1994]. Though often dismissed as lacking in scientific rigor, these consistently replicated cases reveal the astonishing cognitive potential that lies dormant in great apes. We may not fully appreciate the complexity of life in the jungle, but I guess that these enculturated apes have truly become overqualified. In a process that encapsulates the story of human evolution, an ape growing up like a human can be bootstrapped to cognitive peaks higher than any of its wild counterparts.

The same line of thinking solves the long-standing puzzle of why many primates in captivity readily use—and sometimes even make—tools, when their counterparts in the wild seem to lack any such urges. The often-heard suggestion that they do not need tools is belied by observations of orangutans, chimpanzees and capuchin monkeys showing that some of this tool use makes available the richest food in the animals' natural habitats or tides the creatures over during lean periods. The conundrum is resolved if we realize that two individuals of the same species can differ dramatically in their intellectual performance, depending on the social environment in which they grew up.

Orangutans epitomize this phenomenon. They are known as the escape artists of the zoo world, cleverly unlocking the doors of their cages. But the available observations from the wild, despite decades of painstaking monitoring by dedicated field-workers, have uncovered precious few technological accomplishments outside Suaq. Wild-caught individuals generally never take to being locked up, always retaining their deeply ingrained shyness and suspicion of humans. But zoo-born apes happily consider their keepers valuable role models and pay attention to their activities and to the objects strewn around the enclosures, learning to learn and thus accumulating numerous skills.

The critical prediction of the intelligence-through-culture theory is that the most intelligent animals are also likely to live in populations in which the entire group routinely adopts innovations introduced by members. This prediction is not easily tested. Animals from different lineages vary so much in their senses and in their ways of life that a single yardstick for intellectual performance has traditionally been hard to find. For now, we can merely ask whether lineages that show incontrovertible signs of intelligence also have innovation-based cultures, and vice versa. Recognizing oneself in a mirror, for example, is a poorly understood but unmistakable sign of self-awareness, which is taken as a sign of high intelligence. So far, despite widespread attempts in numerous lineages, the only mammalian groups to pass this test are great apes and dol-

JEN CHRISTIANSEN; SOURCE: CAREL VAN SCHAIK

phins, the same animals that can learn to understand many arbitrary symbols and that show the best evidence for imitation, the basis for innovation-based culture. Flexible, innovation-based tool use, another expression of intelligence, has a broader distribution in mammals: monkeys and apes, cetaceans, and elephants—all lineages in which social learning is common. Although so far only these very crude tests can be done, they support the intelligence-through-culture hypothesis.

Another important prediction is that the propensities for innovation and social learning must have coevolved. Indeed, Simon Reader, now at Utrecht University in the Netherlands, and Kevin N. Laland, currently at the University of St. Andrews in Scotland, found that primate species that show more evidence of innovation are also those that show the most evidence for social learning. Still more indirect tests rely on correlations among species between the relative size of the brain (after statistically correcting for body size) and social and developmental variables. The well-established correlations between gregariousness and relative brain size in various mammalian groups are also consistent with the idea.

Although this new hypothesis is not enough to explain why our ancestors, alone among great apes, evolved such extreme intelligence, the remarkable bootstrapping ability of the great apes in rich cultural settings makes the gap seem less formidable. The explanation for the historical trajectory of change involves many details that must be painstakingly pieced together from a sparse and confusing fossil and archaeological record. Many researchers suspect that a key change was the invasion of the savanna by tool-wielding, striding early *Homo*. To dig up tubers and deflesh and defend carcasses of large mammals, they had to work collectively and create tools and strategies. These demands fostered ever more innovation and more interdependence, and intelligence snowballed.

Once we were human, cultural history began to interact with innate ability to improve performance. Nearly 150,000 years after the origin of our own species, sophisticated expressions of human symbolism, such as finely worked nonfunctional artifacts (art, musical instruments and burial gifts), were widespread [see "The Morning of the Modern Mind," by Kate Wong; Scientific American, June 2005]. The explosion of technology in the past 10,000 years shows that cultural inputs can unleash limitless accomplishments, all with Stone Age brains. Culture can indeed build a new mind from an old brain. SA

ORANGUTANS near Sumatra's western coast are much more gregarious than red apes living elsewhere. Juveniles seek one another's company at every possible opportunity.

HERMAN D. RIJKSEN FROM *AMONG ORANGUTANS: RED APES AND THE RISE OF HUMAN CULTURE*, BY CAREL VAN SCHAIK. THE BELKNAP PRESS OF HARVARD UNIVERSITY PRESS, © 2004 BY THE PRESIDENT AND FELLOWS OF HARVARD COLLEGE

MORE TO EXPLORE

A Model for Tool-Use Traditions in Primates: Implications for the Coevolution of Culture and Cognition. C. P. van Schaik and G. R. Pradhan in *Journal of Human Evolution,* Vol. 44, pages 645–664; 2003.

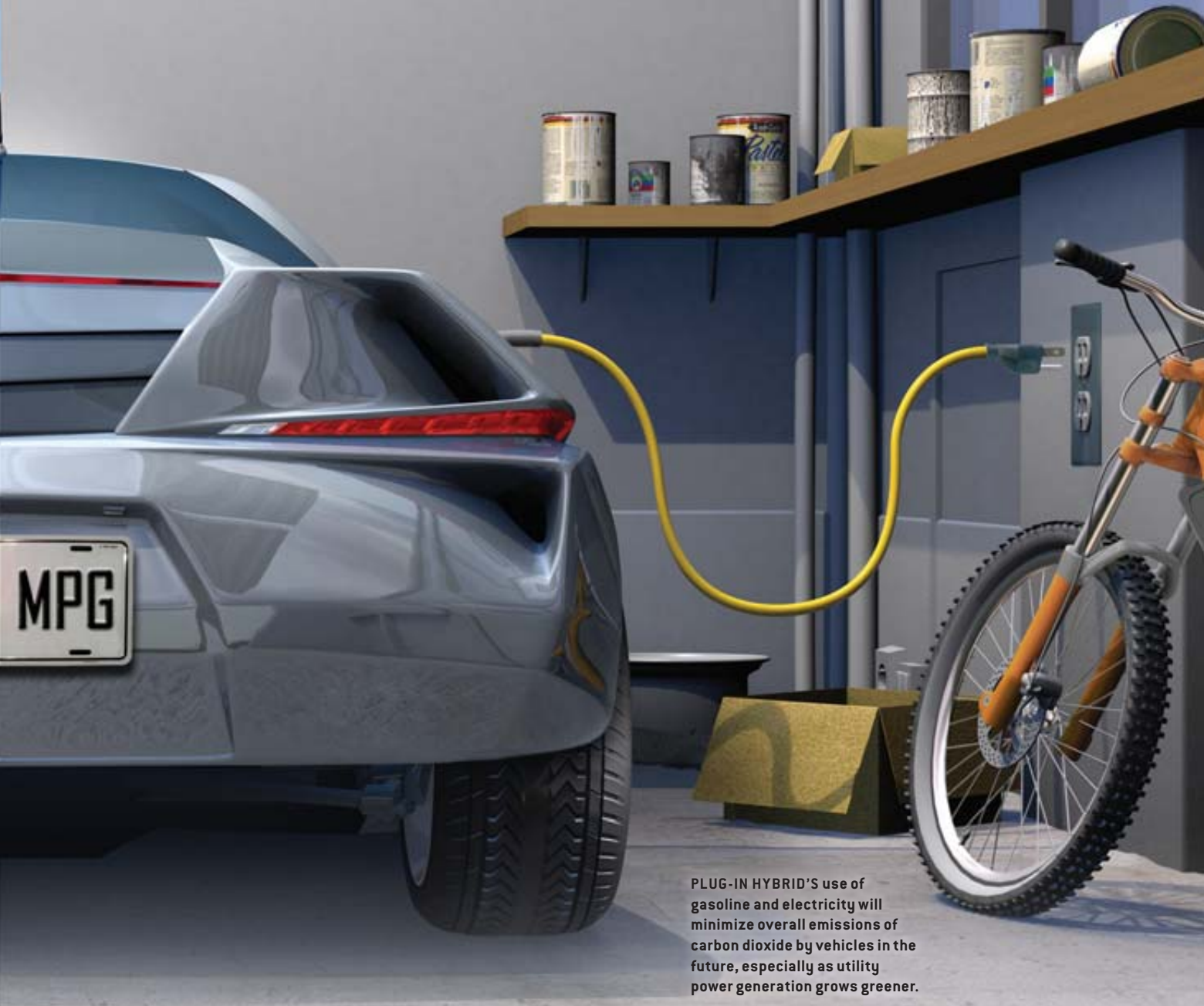
Orangutan Cultures and the Evolution of Material Culture. C. P. van Schaik, M. Ancrenaz, G. Borgen, B. Galdikas, C. D. Knott, I. Singleton, A. Suzuki, S. S. Utami and M. Y. Merrill in *Science,* Vol. 299, pages 102–105; 2003.

Conformity to Cultural Norms of Tool Use in Chimpanzees. Andrew Whiten, Vicky Horner and Frans de Waal in *Nature* online; August 2005.

HYBRID VEHICLES

By Joseph J. Romm and Andrew A. Frank

As car buyers turn to fuel-sipping gasoline-electric hybrid vehicles, a new generation of greener hybrids is just coming over the horizon



PLUG-IN HYBRID'S use of gasoline and electricity will minimize overall emissions of carbon dioxide by vehicles in the future, especially as utility power generation grows greener.

GAIN TRACTION

When gasoline prices climbed to $3 a gallon last summer, hybrid vehicles—which combine a conventional engine and a battery-powered electric motor to achieve improved fuel economy and performance—began racing out of showrooms. Whereas the average U.S. car goes about 23 miles on a gallon of gas, a full-fledged hybrid car such as a Toyota Prius travels about twice as far on the same amount, depending on how it is driven. Annual U.S. sales of hybrids from 2004 to 2005 doubled to 200,000 and are expected to swell to more than half a million by 2010. By 2020 most new car models ought to offer a hybrid power-train option.

By then, next-generation technology, called plug-in hybrids, will offer motorists still better fuel efficiency as well as other perks: low-cost battery recharging overnight by simply connecting a 120-volt plug to an electrical outlet at home or work, very few trips to the gas station each year, and even the chance to sell surplus power back to the electric grid. Beyond the consumer benefits, the new plug-ins would help reduce the release of greenhouse gases by displacing emissions from millions of tailpipes to utility power plants. Today these facilities burn domestically supplied coal or natural gas, and in the future they should generate cleaner electricity from energy sources such as wind, solar or even advanced fossil fuel–based systems that capture carbon dioxide for underground storage.

To see where the hybrid vehicle is going, one needs to look back to where the automobile has been. For 100 years, nearly every car has been powered by an internal-combustion engine running on gasoline or diesel fuel. Automotive engineers pursued the idea of matching an engine and a battery-powered electric motor to achieve greater horsepower and better fuel economy early in the 20th century but abandoned the concept as engines grew ever more potent and thus needed no boost. Fuel was cheap and widely available, so a gas-hungry power plant was no real problem. By the oil crises of the 1970s, common wisdom among drivers held that to get good gas mileage one had to sacrifice size, weight and performance. Although downsizing came into brief vogue, cars soon grew bigger and their appetite for gasoline expanded apace. When oil prices started their recent ascent, better fuel economy once again became a highly desirable feature.

Today's hybrids marry advanced power electronics and computer controls with conventional and electric drivetrains to achieve improved fuel economy and reduced emissions, together with superior acceleration and greater range. A hybrid vehicle can get by with a smaller internal-combustion engine than a conventional automobile because the battery and electric-motor system provides additional power when it is needed for acceleration or hill-climbing maneuvers.

Any technology that can raise fuel economy can be used instead to increase horsepower. So far hybrid drivetrains provide enough efficiency improvement and their electric motors develop such high acceleration that automakers have used the technology to raise both horsepower and fuel economy simultaneously. The Ford Escape Hybrid, for instance, gets significantly better mileage with almost the same power output. Others, such as the Toyota Highlander Hybrid 4x4 sport utility vehicle, exploit hybrid systems to achieve moderate increases in both categories [*see box on page 77*].

The extra expense of the large battery and motor and the associated power electronics means that a hybrid inevitably costs more than a regular car. The premiums for current hybrids range from $3,000 to $7,000, with $4,000 being the average. The electric-motor and battery package adds a weight penalty: about 5 percent in Honda's Accord Hybrid, for example. This extra burden cuts fuel efficiency slightly.

For a vehicle traveling 15,000 miles a year burning gasoline priced at $2.50 a gallon, hybrid technology that raises mileage from 20 to 30 miles a gallon can save the consumer around $600 a year. Thus, at present hybrid prices, together with the newly enhanced federal tax credit for hybrids, payback can take several years, assuming that one assigns no value to benefits such as increased range.

As fuel prices mount, however, hybrid efficiency will cut payback times substantially. Meanwhile rising manufacturing levels and improved battery technology are expected to lower production costs. From 1997 to 2004, for example, the price tag for the nickel metal hydride batteries used in hybrids dropped by half, as did their weight. Even so, the batteries still represent more than 50 percent of the extra cost of today's hybrids. Toyota alone plans to offer hybrid versions of almost all its models and sell a million hybrid vehicles a year worldwide during the next decade, efforts that will spur production volumes and an associated fall in costs.

Overview/*Hybrid Vehicles*

- A small but growing number of hybrid cars and trucks combine electric motors with conventional petroleum-burning engines to reduce fuel consumption. The technology is now starting to evolve rapidly.
- Hybrid power trains currently add several thousand dollars to a vehicle's price tag; owners must operate the vehicle for a few years to gain back their additional initial investment in savings from the lower fuel costs. But as battery technology improves and manufacturing production volumes rise, the premiums for hybrid vehicles are expected to drop significantly.
- Better batteries should also spur the commercialization of plug-in hybrid vehicles, which can recharge overnight via the electric grid to take advantage of lower, off-peak rates. Because power plants generate electricity overwhelmingly from domestic sources such as coal, nuclear energy and hydropower, the shift would reduce reliance on foreign oil imports for transportation.

Hybrid Types

HYBRID DESIGNS come in several flavors, depending on the degree of fuel economy that engineers want to achieve. A "full" hybrid takes advantage of multiple techniques to economize on gas; a "mild" hybrid employs fewer gas-saving strategies to avoid extra systems costs; and a "micro" hybrid merely shuts down the engine during stops to gain a modest efficiency improvement.

A full hybrid, such as the Toyota Prius, can provide a fuel-economy improvement of 60 percent or more. The biggest fuel savings achieved by a full hybrid vehicle derives from regenerative braking, a technology that captures as electrical power much of the energy normally lost as frictional heat. Just as a

KENN BROWN (*preceding pages*)

HOW HYBRIDS GET GREEN

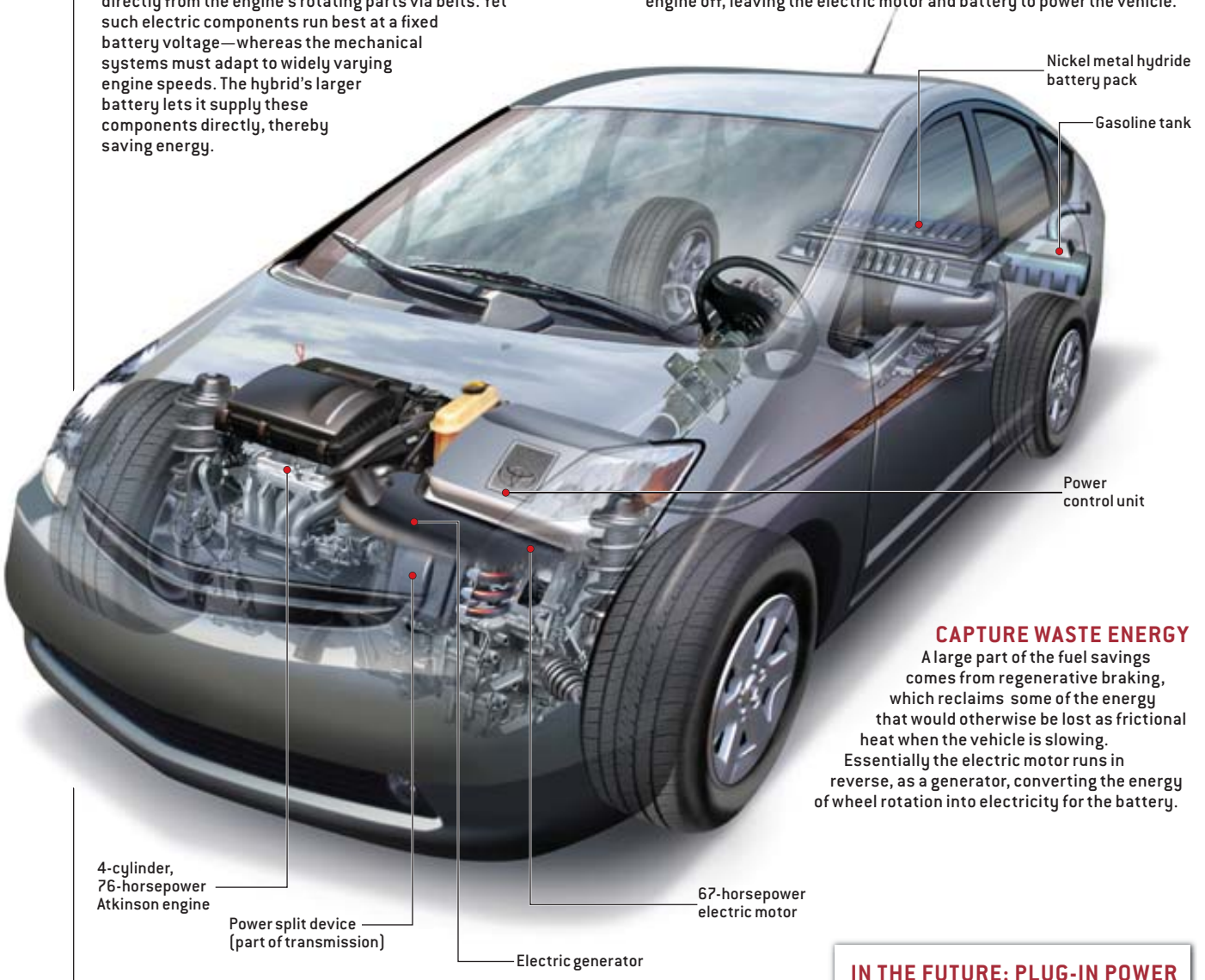
Engineers employ several strategies to save energy in hybrid electric vehicles, which combine a gasoline engine and an electric motor. Here is a breakdown for "full" hybrids, such as the Toyota Prius, which employ all these techniques. Full hybrids can achieve fuel-economy savings of 60 percent or more, whereas mild hybrids get up to 35 percent savings and micro hybrids about 10 percent [*see text on opposite page for further explanation*].

USE ENERGY-SAVING ELECTRICAL COMPONENTS

In conventional cars, the air-conditioning, power steering, water and oil pumps, and fans draw mechanical power directly from the engine's rotating parts via belts. Yet such electric components run best at a fixed battery voltage—whereas the mechanical systems must adapt to widely varying engine speeds. The hybrid's larger battery lets it supply these components directly, thereby saving energy.

DESIGN ENGINE TO SHUT DOWN AT STOPS

Conventional engines run inefficiently when idling at stoplights or working under light loads. Hybrids trim the losses by shutting the engine off, leaving the electric motor and battery to power the vehicle.



CAPTURE WASTE ENERGY

A large part of the fuel savings comes from regenerative braking, which reclaims some of the energy that would otherwise be lost as frictional heat when the vehicle is slowing. Essentially the electric motor runs in reverse, as a generator, converting the energy of wheel rotation into electricity for the battery.

SWITCH ENGINE TYPE

Some car makers replace the conventional Otto cycle gasoline engine with the Atkinson cycle, which burns fuel much more efficiently but has not been widely used because of its lower power production. The hybrid's electric motor makes up for the lost brawn.

REDUCE ENGINE SIZE

Engines run best at a few high-efficiency speeds and torque levels, but standard cars must operate over a wide range of power outputs in everyday driving. The ability of the electric motor to boost vehicle power during acceleration or uphill climbs allows hybrid designers to downsize engines.

IN THE FUTURE: PLUG-IN POWER

In a next-generation hybrid design, the addition of a larger battery plus an electrical cable with an outlet plug would let the vehicle recharge overnight, when utilities produce cheaper, off-peak power. More than half of a typical American's driving needs could thus be accomplished on less costly (and increasingly cleaner) centrally generated electricity alone.

TONY RANDAZZO

motor can transform electrical energy stored in a battery into torque (the force that produces wheel rotation and hauling power), the process can run in reverse so that the torque created by slowing a moving car generates electricity that can be accumulated in a battery.

Stop-and-go city driving offers the greatest opportunity for braking energy regeneration, but the process also transpires while riding up and down hilly country. Today's hybrid vehicles collect on average about half the total braking energy. In the future, better batteries and more sophisticated systems will enable cars to collect even more of the available energy.

Like all engines, internal-combustion power plants run most efficiently in a narrow range of torque and speeds. Because a hybrid's battery and motor can provide the boost required for acceleration or hill climbing, engineers can both downsize the car's engine and optimize it to run only at high-efficiency operating points that burn much less gas. The vehicle can then electronically engage the electric motor to kick in the extra power when needed.

Some makers of full hybrids, such as Toyota and Ford, have replaced the standard Otto cycle engine used in most gasoline-powered cars with a more fuel-thrifty configuration based on the Atkinson cycle. A modern Atkinson cycle engine uses electronic controls and intake-valve timing to achieve greater expansion of the fuel/air mixture burning in the cylinder, thereby allowing the power plant to make more efficient use of the fuel. Engineers had only rarely used the Atkinson cycle before because its greater fuel economy comes at the expense of power output; however, in a hybrid, the electric motor can make up for the lost power. In highway driving, the Atkinson engine, combined with the energy savings from braking regeneration, can yield an overall hybrid system efficiency better than that of the modern diesel engine—the leading internal-combustion engine in this regard.

DIESEL-ELECTRIC HYBRIDS, such as this Ford Reflex concept car, can achieve even better mileage than gasoline-electric vehicles. The Reflex prototype is expected to deliver up to 65 miles per gallon of diesel fuel and also features solar panels in the headlights and taillights to generate auxiliary power for the battery.

Hybrid vehicles can avoid yet another inefficiency of conventional car designs, which typically run the air-conditioning, power steering, water, oil pump, fan and other power-sapping systems directly off the gasoline engine. The large hybrid battery combines with new low-cost power electronics to run these fully electric, high-efficiency components. On a hot summer day, an electrically powered air-conditioning unit can consume 20 percent less energy than an engine-driven system.

Another major fuel-economy advantage in a full hybrid stems from its ability to use its electric motor and batteries to power the vehicle without the engine. Thus, fuel can be saved by running the car as an electric vehicle when the engine would otherwise be burning fuel while idling or traveling at low speeds.

Mild hybrid power trains, such as the integrated motor-assist system in Honda's Insight, Civic and new Accord models, provide up to a 35 percent fuel-economy gain. In addition to the start-stop function, the electric motor in a mild hybrid gives the engine a boost during acceleration and captures some braking energy.

In a micro hybrid or a start-stop hybrid, such as those being introduced by General Motors, the engine shuts down when the car comes to a halt, and an integrated starter-generator fires up the engine instantly when the driver steps on the gas pedal. This kind of vehicle, which uses electric motors to drive the accessories but not the wheels, produces a 10 percent efficiency improvement in city driving but little gain on the highway.

Plug-In Hybrids Rule

HYBRIDS OFFER one benefit that will most likely become more valuable with time; their more efficient use of gasoline results in lower emissions of carbon dioxide, the primary greenhouse gas. Future federal transportation policy may well be driven by concerns about climate change. Many industrial countries have already tightened fuel-economy standards to reduce the release of carbon dioxide. In the U.S.,

THE AUTHORS

JOSEPH J. ROMM and *ANDREW A. FRANK* have advocated the adoption of hybrid vehicle technology for many years. Romm, who received his doctorate in physics from the Massachusetts Institute of Technology, is a principal with Capital E, a clean-energy consulting firm. His latest book is *The Hype about Hydrogen: Fact and Fiction in the Race to Save the Climate* (Island Press, 2004). As an acting assistant secretary of the U.S. Department of Energy in the late 1990s, Romm helped to manage the agency's efforts to develop and use advanced energy technology. Frank earned a Ph.D. from the University of Southern California. He was professor of electrical engineering at the University of Wisconsin–Madison for 18 years and is now professor of mechanical and aeronautical engineering at the University of California, Davis. His research interests include the engineering of advanced hybrid vehicles, including plug-ins.

FORD MOTOR COMPANY

2006 Hybrid Model Lineup

An array of cars, sport utility vehicles and pickups now on dealership floors offer hybrid electric systems. Some get very good fuel economy; others trade some savings for performance, and still others offer little mileage benefit at all. Estimates are based on a 45 percent highway, 55 percent city driving cycle, 15,000 annual miles, and $2.50 a gallon for regular gasoline.

	MAKE, MODEL AND TYPE	POWER TRAIN	COMBINED MPG	RANGE	ANNUAL FUEL COST	ANNUAL CO_2 EMISSIONS
	**HONDA INSIGHT: TWO-SEATER**	3-cylinder, 1.0-liter engine with automatic continuously variable transmission (CVT)	56	530 miles	$670	3.5 tons
	**HONDA CIVIC HYBRID: COMPACT CAR**	4-cylinder, 1.3-liter engine with automatic CVT	50	550 miles	$750	3.9 tons
	**TOYOTA PRIUS: MIDSIZE CAR**	4-cylinder, 1.3-liter engine with automatic CVT	55	590 miles	$680	3.5 tons
	**HONDA ACCORD HYBRID: MIDSIZE CAR**	6-cylinder, 3.0-liter engine with automatic transmission	28	430 miles	$1,340	6.8 tons
	**FORD ESCAPE HYBRID: SPORT UTILITY VEHICLE**	4-cylinder, 2.3-liter engine with CVT transmission, 4-wheel drive (4WD)	31	420 miles	$1,210	6.2 tons
	**LEXUS RX 400H: SPORT UTILITY VEHICLE**	6-cylinder, 3.3-liter engine with automatic CVT, 4WD	29	450 miles	$1,290	6.6 tons
	**MERCURY MARINER HYBRID: SPORT UTILITY VEHICLE**	4-cylinder, 2.3-liter engine with automatic CVT, 4WD	31	420 miles	$1,210	6.2 tons
	**TOYOTA HIGHLANDER HYBRID: SPORT UTILITY VEHICLE**	6-cylinder, 3.3-liter engine with automatic CVT, 4WD	29	500 miles	$1,290	6.6 tons
	**CHEVROLET SILVERADO HYBRID: PICKUP TRUCK**	8-cylinder, 5.3-liter engine with automatic transmission, 4WD	19	450 miles	$1,970	9.9 tons
	**GMC SIERRA HYBRID: PICKUP TRUCK**	8-cylinder, 5.3-liter engine with automatic transmission, 4WD	19	450 miles	$1,970	9.9 tons

These calculations are based on EPA mileage ratings. Actual fuel-economy numbers may be somewhat lower [see box on page 79].

AMERICAN HONDA MOTOR CO., INC. (*Insight*, *Civic* and *Accord*); TOYOTA MOTOR SALES USA, INC. (*Prius* and *Highlander*); FORD MOTOR COMPANY (*Escape* and *Mercury Mariner*); LEXUS, A DIVISION OF TOYOTA MOTOR SALES USA, INC. (*Lexus*); GENERAL MOTORS CORPORATION (*Silverado* and *Sierra*)

California passed legislation in 2002 to cut the vehicular emissions of greenhouse gases 30 percent by model year 2016, and a group of other states have followed suit (although car makers are challenging the effort in court).

Plug-in hybrid electric vehicles combine the best of electric- and hybrid-drive technologies. They can be fully functional in either electric or hybrid mode and make possible even larger emissions and oil savings. These vehicles run partly on electricity generated at local power plants, which can lessen the nation's reliance on oil, while offering utilities a robust market for their off-peak power and drivers a cleaner, much lower-cost transportation fuel option. And like the straight hybrid, the plug-in can burn liquid fuel to afford a long driving range with rapid refueling. What is more, these plug-in hybrids should not be much more complex, heavy or pricey than present hybrid models. First, their internal-combustion engines will shrink as their electric motors and batteries grow. Second, batteries and electronic components have been steadily dropping in price.

A conventional auto costs about 12 cents a mile to operate at current gasoline prices. A plug-in hybrid could run on electrons at three cents a mile using electricity costing about eight cents a kilowatt-hour, the current average residential rate. And given that half of American cars travel only 25 miles a day or less, a plug-in with a battery capable of providing power for a 20-mile range could cut petroleum-based fuel consumption by as much as 60 percent. Even a long-distance commuter driving a plug-in hybrid could go most of a typical day on less expensive electricity stored in an advanced battery that was topped up overnight via a conventional wall socket and partially recharged at work during the day.

The larger battery of a plug-in hybrid, coupled with a higher-powered electric motor, allows significant downsizing of the gasoline engine and other related mechanical systems. Researchers at the University of California, Davis, have built plug-in hybrid prototypes that can travel 60 miles on electricity alone with engines that are less than half the size of standard engines. Their eight sedans and full-size SUVs are now undergoing testing. In 2005 DaimlerChrysler brought out the first plug-in hybrid prototype vehicles built by a major automaker, a hybrid version of its Mercedes-Benz Sprinter Van [*see illustration above*]. The modified Sprinter features a 143-horsepower combustion engine and a 120-horsepower electric motor. It can travel 20 miles in all-electric mode and has 40 percent lower gasoline consumption and better acceleration than a conventional Sprinter Van. Only a few such plug-in hybrid Sprinters have been operated to date.

As battery technology advances, engineers should be able to develop plug-in hybrids that consume far less gasoline than conventional vehicles. Urban driving range when operating on a single tank of gasoline and a full battery charge could be from 600 to 1,000 miles. The actual size of the different power systems in each car will depend on the driving needs of the car buyer. Long-distance commuters might purchase a plug-in with a bigger battery, for instance, although we expect that a 20-mile all-electric range will satisfy most consumers.

PLUG-IN HYBRID TECHNOLOGY from a major automaker debuted in 2005 with the rollout of the Mercedes-Benz Hybrid Sprinter Van prototype (*top*). A door opens to reveal the electrical socket for connecting the battery to a power source and charging it overnight (*bottom*).

The lower fuel bills for a plug-in hybrid would offset its higher price, assuming that steady progress in battery technology continues and costs drop. Extended-range electrochemical batteries currently run as much as $10,000 apiece. We believe nickel metal hydride or lithium ion batteries with affordable price tags of $3,000 or less will eventually provide enough energy for ranges of 20 miles or more. In time, engineers are expected to extend the operational lifetimes of these batteries to more than 15 years and 150,000 miles.

With modified internal-combustion engines, plug-in hybrids could also run on a mixture of 15 percent gasoline and 85 percent biofuel, such as cellulosic ethanol (from noncorn sources such as agricultural waste and dedicated energy crops). These kinds of vehicles could travel 500 miles on one gallon of gasoline blended with five gallons of ethanol and thus constitute a long-term strategy for dealing with the inevitable peak and subsequent decline in world oil supplies.

Plug-in hybrids offer other unique benefits. Because they can connect to the grid, they can take advantage of off-peak power rates that are far lower than typical residential ones. Utilities have excess power capacity, especially at night, because the peak load comes from summer air-conditioning. Plug-in hybrids could charge up at night and feed voltage-regulation services or electric power back to the grid at peak power times during the day. Vehicle owners may be able to get a rebate or revenue stream from electric utilities for this service. According to researchers at the University of Delaware, the potential value of such services is significant, as much as $3,000 annually, which could subsidize the cost of purchasing

DAIMLERCHRYSLER

Hybrids in the Real World

Some car buyers have been disappointed because their hybrid vehicles have failed to achieve the lofty mileage promised by the U.S. Environmental Protection Agency ratings. Like most cars, hybrids often post mileage results significantly lower than their EPA rating. Several factors explain the shortfall. (The EPA announced revisions to its testing procedure earlier this year that should address some of these problems.)

Flawed EPA testing procedures. The driving cycle used during the government mileage tests does not reflect actual experience or road conditions, because it is based on unrealistic assumptions about typical driving practices. The test's top highway speed is 60 miles an hour, for example, whereas the average driver often exceeds that velocity.

Larger seasonal mileage drops. In hybrids such as the Toyota Prius, computer software decides when to run the engine, when to run the electric motor and when to recharge the battery. Wintertime heating demands interfere with the software's optimization of the power system operations by forcing the engine to run more often, with the result that hybrids experience a larger decline in fuel efficiency than conventional vehicles do.

Owners of hybrids in northern climes inevitably see a sharp fall in fuel economy compared with the EPA rating, which is measured at temperatures ranging from 68 to 86 degrees Fahrenheit.

Inherent hybrid design. Because hybrids rely on regenerative braking systems, their mileage is much more sensitive to how they are driven. Motorists who optimize their driving for hybrids—by coasting to stops, for instance—report fuel-economy figures close to the EPA ratings. Aggressive driving can cause the fuel efficiency of hybrid vehicles to decrease more than 30 percent, whereas such driving has a much smaller impact on conventional vehicles. In general, full hybrids get the best mileage in stop-and-go traffic and offer fewer benefits on the highway.

STICKER SHOCK: New gasoline-electric hybrid vehicles can fall short of the fuel-economy levels promised by EPA test ratings. The authors explain why.

a plug-in hybrid or its battery. One can speculate that a utility might lease a plug-in hybrid to a consumer or business willing to leave the vehicle connected when it was not on the road and to permit the utility to control when the vehicle's battery was charged and discharged depending on its generation or voltage-regulation needs. Such an arrangement would help utilities with load balancing, for instance.

For policymakers concerned about global warming, plug-in hybrids hold an edge over another highly touted green vehicle technology—hydrogen fuel-cell cars. Plug-ins would be better at utilizing zero-carbon electricity because the overall hydrogen fueling process is inherently costly and inefficient. Any effective hydrogen economy would require an infrastructure that could use zero-carbon power to electrolyze water into hydrogen, convey this highly diffuse gas long distances, and pump it at high pressure into the car—all for the purpose of converting the hydrogen back to electricity in a fuel cell to drive an electric motor. The entire process of electrolysis, transportation, pumping and fuel-cell conversion would leave only about 20 to 25 percent of the original zero-carbon electricity to drive the motor. In a plug-in hybrid, the process of electricity transmission, charging an onboard battery and discharging that battery would leave 75 to 80 percent of the original electricity to drive the motor. Thus, a plug-in should be able to travel three to four times farther on a kilowatt-hour of renewable electricity than a hydrogen fuel-cell vehicle could.

If current trends in fuel costs and concerns about climate change continue, we expect a broad market transition around the year 2020, when hybrids are likely to become an option for most models. Relatively soon thereafter, we believe plug-in hybrids will probably become the dominant alternative-fuel vehicle, with the speed of that progress determined primarily by oil price rises and government policy on climate change and energy security. Whenever the world's transportation system finally moves to replace oil as its main power source, the most plausible car design would be a flexible-fuel, plug-in hybrid vehicle running on a combination of zero-carbon electricity and a biofuel blend. If the performance of batteries were to improve substantially at some point, drivers might then gradually switch to all-electric cars. It makes sense for us to adopt this highly practical personal transportation technology as expeditiously as possible. SA

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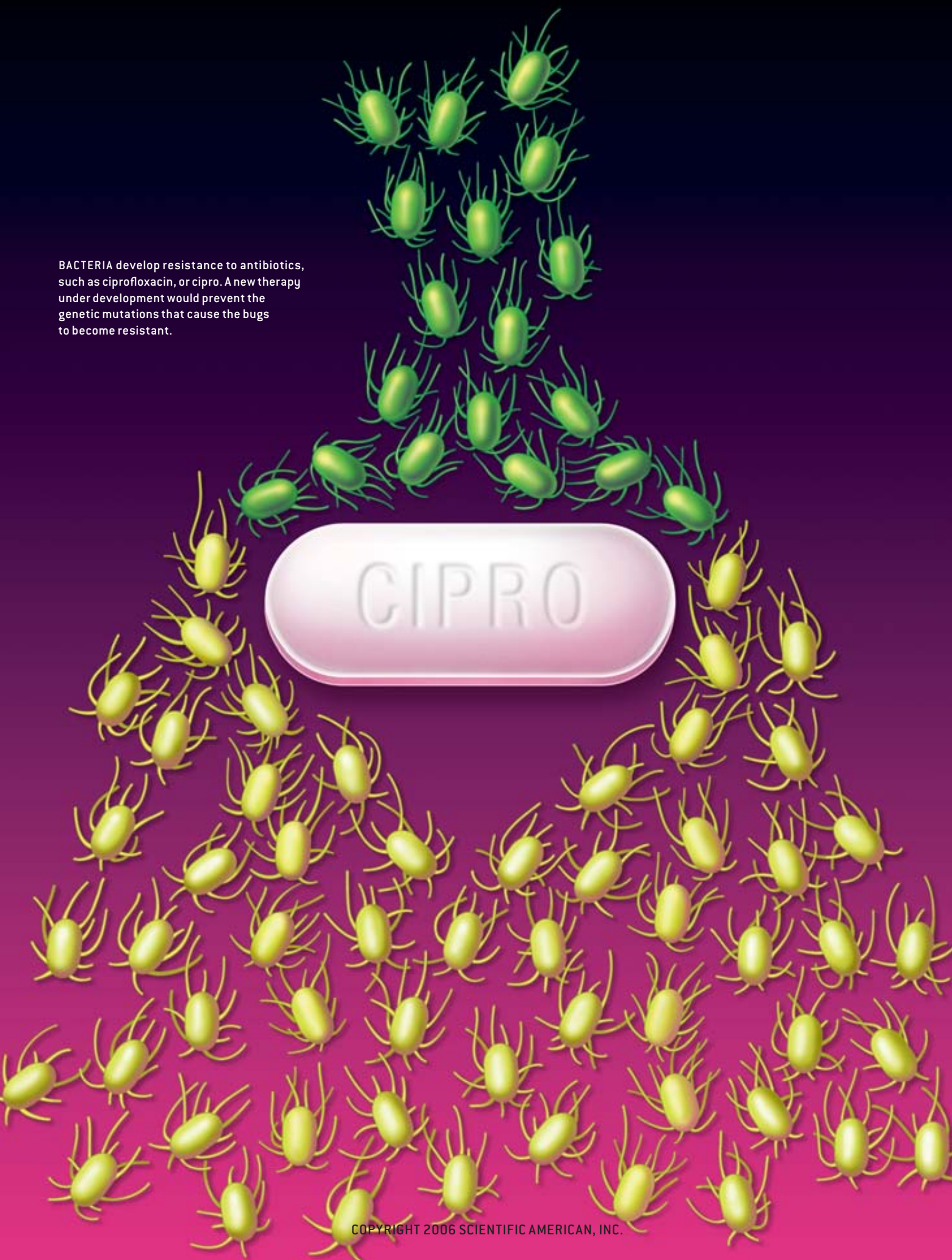
Driving the Solution: The Plug-In Hybrid Vehicle. Lucy Sanna in *EPRI Journal;* Fall 2005. Available at **mydocs.epri.com/docs/CorporateDocuments/EPRI_Journal/2005-Fall/1012885_PHEV.pdf**

To learn more about plug-ins, visit **www.calcars.org**

To learn more about hybrids, visit **www.hybridcars.com**

Andrew A. Frank's technical articles on plug-ins can be found at **www.team-fate.net**

TOYOTA MOTOR SALES USA, INC.



BACTERIA develop resistance to antibiotics, such as ciprofloxacin, or cipro. A new therapy under development would prevent the genetic mutations that cause the bugs to become resistant.

A compound that tweaks a pivotal protein may quell development of antibiotic resistance

an antibiotic resistance fighter

By Gary Stix

Floyd E. Romesberg received his doctorate from Cornell University in 1994, a degree granted for the study of salts called lithium dialkylamides. Synthetic chemists routinely use these compounds to remove protons from substances. Romesberg, the son of a chemist, spent his days looking at how these chemicals react and the rate at which the reactions took place. "It wasn't so much that the project was interesting," Romesberg says. "As a matter of fact, the project was pretty boring."

As soon as he finished his degree, he changed course, heading straight for postdoctoral studies in a different field at the University of California, Berkeley. There he extracted a promise from his prospective adviser—noted biochemist Peter G. Schultz—that he would be able to say good-bye to physical chemistry and immerse himself entirely in immunology. Although Romesberg harbors no regrets about his initial decision to study something rudimentary and dull, he remarks that going directly into biology would probably have been a mistake. The complexity of the field ensures that all too many graduate projects end up with only desultory results. "At Cornell, I was fortunately able to work on a small system that was amenable to a complete description. It was something that was actually solvable and allowed me to worry about fundamental questions," he concedes. "I always have this tendency to reduce things to basic molecular-, chemical-level questions, and I think that has served me very well."

Laboring in Schultz's group on antibodies, Romesberg became intrigued by the molecular processes that underlie evolution. Today his laboratory at the Scripps Research Institute in La Jolla, Calif., consisting of 19 researchers (12 graduate students and seven postdocs), has been organized into separate teams that are each tackling different questions related to evolution. One group is using high-powered lasers to look at how antibodies

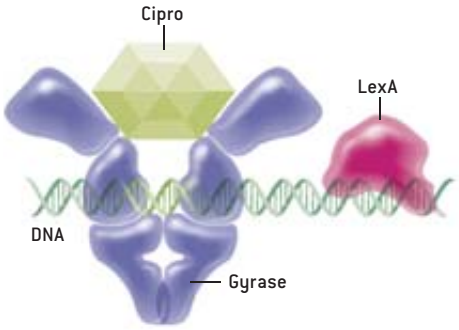
JEN CHRISTIANSEN

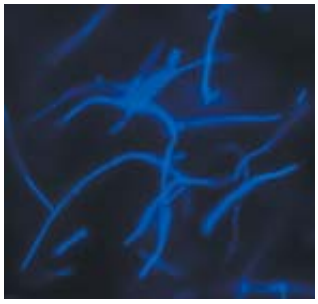
PRESERVING ANTIBIOTIC POTENCY

Rapid-fire mutations in *Escherichia coli* bacteria can undermine the effectiveness of ciprofloxacin (cipro), an antibiotic that is increasingly being prescribed by physicians.

Cipro's Action

Cipro usually harms bacteria by binding to an enzyme called gyrase and preventing it from functioning properly

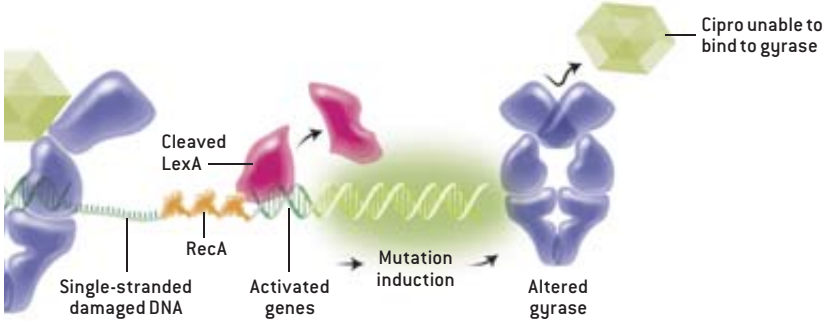




DNA of *E. coli* (*shown above*) cannot replicate when it is exposed to cipro.

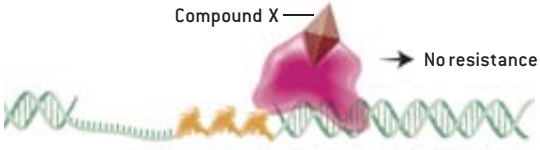
How Resistance Arises

Resistance is initiated when *E. coli* responds by generating single-stranded DNA. Individual molecules of another protein, RecA, then line up in a chain and attach to the single-stranded DNA. RecA facilitates cleavage of a regulatory protein, LexA. This change frees a set of formerly repressed genes to induce mutations elsewhere. The mutations end up blocking cipro's binding to gyrase, thereby preventing the drug from working



A Possible Solution

Drugs that bound to LexA and prevented its cleavage—such as the hypothetical compound X detected here—would stall that sequence and thus could overcome resistance and restore effectiveness to the antibiotic



evolve. Another hopes to determine how DNA would function in the presence of an unnatural nucleotide, or letter, added to the genetic code. The research with perhaps the most immediate practical importance attempts to examine how evolution sometimes goes into overdrive. Using this knowledge to block a fundamental process that allows a bacterium to undergo rapid mutation could provide a never-before-tried approach to overcoming bacterial resistance to antibiotics.

Sending Out an SOS

GENETIC MUTATIONS usually result from errors that occur when a cell reproduces itself. Often mutations hurt cells, and thus they have generally evolved to make as few as possible. Cells come equipped with their own built-in proofreaders and repair equipment to make sure that DNA is copied with as few mistakes as possible. Still, at times a cell may actually embrace the process of genetic mutation—in essence, evolution in fast-forward.

Since the 1970s scientists have known of a process—the SOS response—that occurs in bacteria and actually takes advantage of mutation as a form of self-defense. When bacteria are under extreme stress, they try various means of fixing the damage as an initial step. They then switch on genes whose protein products precipitate a spate of mutations that occur 10,000 times as fast as those arising during normal cell replication. In essence, the cells undergo a quick identity change. The bacterium *Escherichia coli,* for instance, responds to sustained DNA damage induced by ciprofloxacin (commonly shortened to cipro) and other antibiotics by sending out an SOS. The mutations prevent ciprofloxacin from binding to its target, a protein called gyrase, which is required for DNA replication. If the bacterium did not protect gyrase, the antibiotic would link to the protein, impede normal replication and cause breaks in DNA that would lead to the bacterial cell's death.

Having read about SOS, Romesberg hypothesized that switching off the system—shutting down hyperevolution—could prevent the cascade of mutations that allows antibiotic resistance to develop in *E. coli*. In experiments—published last June in the online journal *PLoS Biology*—Romesberg and

ALICE Y. CHEN (*illustration*); SCRIPPS RESEARCH INSTITUTE (*photograph*)

his co-workers Ryan T. Cirz, Jodie K. Chin and their collaborators at the University of Wisconsin–Madison found that ciprofloxacin induced SOS hypermutation in *E. coli* by triggering the clipping of a protein called LexA that keeps the SOS response repressed. Once cleaved, the repressor protein allowed three enzymes, DNA polymerases, to start producing mutations. Resistance quickly developed.

The researchers then created a strain of *E. coli* in which LexA could not be cut and found that the SOS response did not materialize. Mice infected with the pathogenic *E. coli* and given ciprofloxacin did not develop resistance. The group has achieved similar results for another antibiotic, rifampicin. And it is now testing whether blocking LexA cleavage in *E. coli* might prevent resistance to still other antibiotics and whether it might undermine drug effectiveness in other microbes. Ciprofloxacin, however, is by itself an important drug. Some strains of the bacterium that causes epidemic dysentery—*Shigella dysenteriae*—have become resistant to all antibiotics but ciprofloxacin. Dysentery is capable of causing tens of thousands of deaths in developing countries.

When his laboratory first started getting these results in 2002, Romesberg immediately saw the potential for a pharmaceutical—a small molecule that could be administered orally along with an antibiotic. The drug would function as an off switch for LexA cleavage. He and two partners had little difficulty raising more than $15 million to start a company called Achaogen. ("Achao" means "against chaos"—the "gen" was added by one partner, Ned David, because companies that incorporate this suffix in their name have sometimes flourished.)

Venture capitalists have turned cautious about funding early-stage start-ups. But they were open to a novel approach to antibiotic resistance—most solutions to date have involved new types of antibiotics—and the company is now testing several leads. But, as always, the ingenuity of the microbe could turn a lot of hard work into an exercise in futility. Stuart B. Levy, an expert on antibiotic resistance at Tufts University, commented that Romesberg's work provides new insight but added that its effect may be circumscribed. "We are always looking for novel approaches, especially those that counteract resistance," he says. "This finding suggests one, but it is focused on a limited genetic mechanism of drug resistance—that is, chromosomal mutation." Levy added that other types of resistance can crop up to directly attack the antibiotic. They can be acquired by transferring resistance genes from one species of bacterium to another and also within the same species.

Romesberg and his researchers, however, made their decision to focus on fluoroquinolones because resistance to them develops only through chromosomal mutations (the SOS response) and because they are predicted to become the largest-selling class of antibiotics by 2011. An unexpected—and undesired—aside to the publication of the *PLoS Biology* paper emerged when the intelligent-design community embraced the results as confirmation of its unorthodox worldview. The frenzied mutations in Romesberg's experiments were not random, its members contend, but were set off under deliberate direction of the bacterium: "Life takes *control* of its fate. Living things are not passive participants of the interplay between stochastic events and environmental pressures," writes the pseudonymous Mike Gene on the Web site idthink.net, while adding, "That evolution may be under some form of intrinsic control is only a piece of the teleological [design in nature] puzzle. But it is a significant piece, in that the ability to adapt, at least to these two antibiotics, is under control."

An unexpected aside to the Scripps lab's paper emerged when the INTELLIGENT-DESIGN COMMUNITY embraced the results for its own purposes.

Romesberg has avoided immersion in this debate but dismisses any basis for these assertions. The SOS response "says nothing about religion," he says. "It does speak to how successful and creative evolution can be. But there's nothing magic about it. It's totally mechanistic."

As with his choice of a seemingly mundane graduate project, Romesberg says he decided to explore antibiotic resistance because the steps to drug development were straightforward and relatively simple: "If we win, then we will be better equipped to handle the next level of complexity." That next level is cancer, a disease for which drug resistance is also a daunting problem. Both his research team and his company plan to craft a treatment that might supplement chemotherapy to prevent the mutations that lead to resistance to cancer drugs. Romesberg's gradualism—evolving from a salt's stripping of protons to the imposing challenge of cancer—may take longer than a headlong push for cures. But this measured path to scientific advance may lead more surely to success. SA

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Does Globalization Help

By Pranab Bardhan

Globalization and the attendant concerns about poverty and inequality have become a focus of discussion in a way that few other topics, except for international terrorism or global warming, have. Most people I know have a strong opinion on globalization, and all of them express an interest in the well-being of the world's poor. The financial press and influential international officials confidently assert that global free markets expand the horizons for the poor, whereas activist-protesters hold the opposite belief with equal intensity. Yet the strength of people's conviction is often in inverse proportion to the amount of robust factual evidence they have.

As is common in contentious public debates, different people mean different things by the same word. Some interpret "globalization" to mean the global reach of communications technology and capital movements, some think of the outsourcing by domestic companies in rich countries, and others see globalization as a byword for corporate capitalism or American cultural and economic hegemony. So it is best to be clear at the outset of this article that I shall primarily refer to economic globalization—the expansion of foreign trade and investment. How does this process affect the wages, incomes and access to resources for the poorest people in the world? This question is one of the most important in social science today.

For a quarter century after World War II, most developing countries in Africa, Asia and Latin America insulated their economies from the rest of the world. Since then, though, most have opened their markets. For

OR Hurt the World's Poor?

The answer is: both. The real question is how to maximize the help and minimize the hurt

JEAN-FRANCOIS PODEVIN

instance, between 1980 and 2000, trade in goods and services expanded from 23 to 46 percent of gross domestic product (GDP) in China and from 19 to 30 percent in India. Such changes have caused many hardships for the poor in developing countries but have also created opportunities that some nations utilize and others do not, largely depending on their *domestic* political and economic institutions. (The same is true for low-wage workers in the U.S., although the effects of globalization on rich countries are beyond the scope of this article.) The net outcome is often quite complex and almost always context-dependent, belying the glib pronouncements for or against globalization made in the opposing camps. Understanding the complexities is essential to taking effective action.

Neither Plague nor Panacea

THE CASE FOR FREE TRADE rests on the age-old principle of comparative advantage, the idea that countries are better off when they export the things they are best at producing, and import the rest. Most mainstream economists accept the principle, but even they have serious differences of opinion on the balance of potential benefits and actual costs from trade and on the importance of social protection for the poor. Free traders believe that the rising tide of international specialization and investment lifts all boats. Others point out that many poor people lack the capacity to adjust, retool and relocate with changing market conditions. These scholars argue that the benefits of specialization materialize in the long run, over which people and resources are assumed to be fully mobile, whereas the adjustments can cause pain in the short run.

Rice field, Jiangxi Province, China, early 1990s

GREG BAKER *AP Photo*

The debate among economists is a paragon of civility compared with the one taking place in the streets. Antiglobalizers' central claim is that globalization is making the rich richer and the poor poorer; proglobalizers assert that it actually helps the poor. But if one looks at the factual evidence, the matter is rather more complicated. On the basis of household survey data collected by different agencies, the World Bank estimates the fraction of the population in developing countries that falls below the $1-a-day poverty line (at 1993 prices)—an admittedly crude but internationally comparable level. By this measure, extreme poverty is declining in the aggregate [*see bottom illustration on opposite page*].

The trend is particularly pronounced in East, South and Southeast Asia. Poverty has declined sharply in China, India and Indonesia—countries that have long been characterized by massive rural poverty and that together account for about half the total population of developing countries. Between 1981 and 2001 the percentage of rural people living on less than $1 a day decreased from 79 to 27 percent in China, 63 to 42 percent in India, and 55 to 11 percent in Indonesia.

But although the poorest are not, on the whole, getting poorer, no one has yet convincingly demonstrated that improvements in their condition are mainly the result of globalization. In China the poverty trend could instead be attributed to internal factors such as the expansion of infrastructure, the massive 1978 land reforms (in which the Mao-era communes were disbanded), changes in grain procurement prices, and the relaxation of restrictions on rural-to-urban migration. In fact, a substantial part of the decline in poverty had already happened by the mid-1980s, before the big strides in foreign trade or investment. Of the more than 400 million Chinese lifted above the international poverty line between 1981 and 2001, three fourths got there by 1987.

Similarly, rural poverty reduction in India may be attributable to the spread of the Green Revolution in agriculture, government antipoverty programs and social movements—not the trade liberalization of the 1990s. In Indonesia the Green Revolution, macroeconomic policies, stabilization of rice prices and massive investment in rural infrastructure played a substantial role in the large reduction of rural poverty. Of course, globalization, by expanding employment in labor-intensive manufacturing, has helped to pull many Chinese and Indonesians out of poverty since the mid-1980s (though not yet as much in India, for various domestic institutional and policy reasons). But it is only one factor among many accounting for the economic advances of the past 25 years.

The sharp DECLINE IN EXTREME POVERTY in China may have more to do with the 1978 land reforms and other internal factors than with foreign trade or investment.

Overview/*Globalization and Poverty*

- The expansion of international trade and investment is one of the dominant trends of our time, but policymakers and advocates tend to discuss it without carefully examining the evidence available in social science.
- Because the modern era of globalization has coincided with a sustained reduction in the proportion of people living in extreme poverty, one may conclude that globalization, on the whole, is not making the poor poorer. Equally, however, it cannot take much credit for the decrease in poverty, which in many cases preceded trade liberalization.
- Countries that get the economic basics right—improving infrastructure, ensuring political stability, carrying out land reform, providing social safety nets, addressing market failures such as impeded access to credit—tend to succeed at reducing poverty. Although globalization can help, it is only one factor among many.

The Bund, Shanghai, 1999

Those who are dubious of the benefits of globalization point out that poverty has remained stubbornly high in sub-Saharan Africa. Between 1981 and 2001 the fraction of Africans living below the international poverty line increased from 42 to 47 percent. But this deterioration appears to have less to do with globalization than with unstable or failed political regimes. If anything, such instability reduced their extent of globalization, as it scared off many foreign investors and traders. Volatile politics amplifies longer-term factors such as geographic isolation, disease, overdependence on a small number of export products, and the slow spread of the Green Revolution [see "Can Extreme Poverty Be Eliminated?" by Jeffrey D. Sachs; SCIENTIFIC AMERICAN, September 2005].

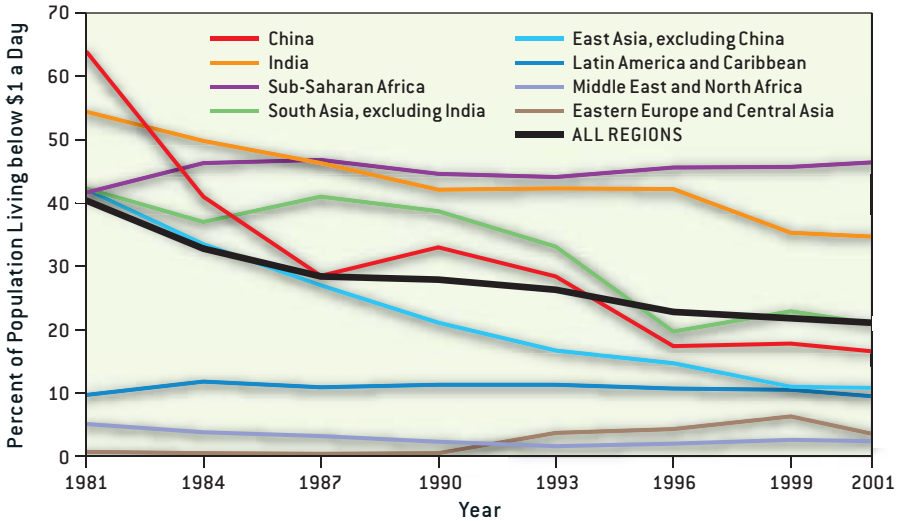
Sweatshops

GLOBAL MARKET competition in general rewards people with initiative, skills, information and entrepreneurship in all countries. Poor people everywhere are handicapped by their lack of access to capital and opportunities to learn new skills. Workers in some developing countries—say, Mexico—are losing their jobs in labor-intensive manufacturing to their counterparts in Asia. At the same time, foreign investment has also brought new jobs. Overall, the effect appears to be a net improvement. In Mexico, low-wage poverty is declining in the regions that are more involved in the international economy than others—even controlling for the fact that skilled and enterprising people migrate to those regions, improving incomes there independently of what globalization accomplishes. A recent study by Gordon H. Hanson of the University of California, San Diego, which took into account only people born in a particular region (thus leaving out migrants), found that during the 1990s average incomes in the Mexican states most affected by globalization increased 10 percent more than those least affected.

In poor Asian economies, such as Bangladesh, Vietnam and Cambodia, large numbers of women now have work in garment export factories. Their wages are low by world standards but much higher than they would earn in alternative occupations. Advocates who worry about exploitative sweatshops have to appreciate the relative improvement in these women's conditions and status. An Oxfam report in 2002 quoted Rahana Chaudhuri, a 23-year-old mother working in the garment industry in Bangladesh:

> This job is hard—and we are not treated fairly. The managers do not respect us women. But life is much harder for those working outside. Back in my village, I would have less money. Outside of the factories, people selling things in the street or carrying bricks on building sites earn less than we do. There are few other options. Of course, I want better conditions. But for me this job means that my children will have enough to eat and that their lives can improve.

In 2001 Naila Kabeer of the University of Sussex in England and Simeen Mahmud of the Bangladesh Institute of Development Studies did a survey of 1,322 women workers in Dhaka. They discovered that the average monthly income of workers in garment-export fac-



EXTREME POVERTY has become less prevalent over the past two decades—including the period during which globalization has taken hold. Therefore, it is simply incorrect to claim, as many do, that globalization makes the poor poorer. Regions that have stagnated (notably Africa) are largely cut off from the global economy, so their plight must have other causes.

EUGENE HOSHIKO *AP Photo (top)*; JANA BRENNING; SOURCE: WORLD BANK *(bottom)*

Burmese refugees in textile factory, Mae Sot, Thailand, 1990s

ALISON WRIGHT *Corbis*

tories was 86 percent above that of other wage workers living in the same slum neighborhoods.

Another indication of this relative improvement can be gauged by what happens when such opportunities disappear. In 1993, anticipating a U.S. ban on imports of products made using child labor, the garment industry in Bangladesh dismissed an estimated 50,000 children. UNICEF and local aid groups investigated what happened to them. About 10,000 children went back to school, but the rest ended up in much inferior occupations, including stone breaking and child prostitution. That does not excuse the appalling working conditions in the sweatshops, let alone the cases of forced or unsafe labor, but advocates must recognize the severely limited existing opportunities for the poor and the possible unintended consequences of "fair trade" policies.

The Local Roots of Poverty

INTEGRATION INTO the international economy brings not only opportunities but also problems. Even when new jobs are better than the old ones, the transition can be wrenching. Most poor countries provide very little effective social protection to help people who have lost their jobs and not yet found new ones. Moreover, vast numbers of the poor work on their own small farms or for household enterprises. The major constraints they usually face are domestic, such as lack of access to credit, poor infrastructure, venal government officials and insecure land rights. Weak states, unaccountable regimes, lopsided wealth distribution, and inept or corrupt politicians and bureaucrats often combine to block out the opportunities for the poor. Opening markets without relieving these domestic constraints forces people to compete with one hand tied behind their back. The result can be deepened poverty.

Conversely, opening the economy to trade and long-term capital flows need not make the poor worse off if appropriate domestic policies and institutions are in place—particularly to help shift production to more marketable goods and help workers enter new jobs.

Contrasting case studies of countries make this quite apparent. Although the island economies of Mauritius and Jamaica had similar per capita incomes in the early 1980s, their economic performance since then has diverged dramatically, with the former having better participatory institutions and rule of law and the latter mired in crime and violence. South Korea and the Philippines had similar per capita incomes in the early 1960s, but the Philippines languished in terms of political and economic institutions (especially because power and wealth were concentrated in a few hands), so it remains a developing country, while South Korea has joined the ranks of the developed. Botswana and Angola are two diamond-exporting countries in southern Africa, the former democratic and fast-growing, the latter ravaged by civil war and plunder.

The experiences of these and other

THE AUTHOR

PRANAB BARDHAN is an economics professor at the University of California, Berkeley. He has done theoretical research and field studies on rural institutions in poor countries, on the political economy of development policies, and on international trade. He is perhaps best known for showing that economic efficiency and social justice are not antithetical goals; indeed, they are often complementary. Bardhan was editor in chief of the *Journal of Development Economics* from 1985 to 2003 and is currently co-chair of a MacArthur Foundation–funded international research network on inequality and economic performance.

Brothel near Mahim train station, Mumbai, India, 2002

ALEX MAJOLI *Magnum Photos*

countries demonstrate that antipoverty programs need not be blocked by the forces of globalization. There is no "race to the bottom" in which countries must abandon social programs to keep up economically; in fact, social and economic goals can be mutually supportive. Land reform, expansion of credit and services for small producers, retraining and income support for displaced workers, public-works programs for the unemployed, and provision of basic education and health can enhance the productivity of workers and farmers and thereby contribute to a country's global competitiveness. Such programs may require a rethinking of budget priorities in those nations and a more accountable political and administrative framework, but the obstacles are largely domestic. Conversely, closing the economy to international trade does not reduce the power of the relevant vested interests: landlords, politicians and bureaucrats, and the rich who enjoy government subsidies. Thus, globalization is not the main cause of developing countries' problems, contrary to the claim of critics of globalization—just as globalization is often not the main solution to these problems, contrary to the claim of overenthusiastic free traders.

What about the environment? Many conservationists argue that international integration encourages the overexploitation of fragile natural resources, such as forests and fisheries, damaging the livelihoods of the poor. A common charge against transnational companies is that they flock to poor countries with lax environmental standards. Anecdotes abound, but researchers have done very few statistical studies. One of the few, published in 2003 by Gunnar Eskeland of the World Bank and Ann Harrison of the University of California, Berkeley, considered Mexico, Morocco, Venezuela and Ivory Coast. It found very little evidence that companies chose to invest in these countries to shirk pollution-abatement costs in rich countries; the single most important factor in determining the amount of investment was the size of the local market. Within a given industry, foreign plants tended to pollute less than their local peers.

Like persistent poverty, lax environmental standards are ultimately a domestic policy or institutional failure. A lack of well-defined or well-enforced property rights or regulation of common property resources often leads to their overuse. Responding to pressure from powerful political lobbies, governments have deliberately kept down the prices of precious environmental resources: irrigation water in India, energy in Russia, timber concessions in Indonesia and the Philippines. The result, unsurprisingly, is resource depletion. To be sure, if a country opens its markets without dealing with these distortions, it can worsen the environmental problems.

Wages and conditions in GARMENT FACTORIES are poor by world standards but better than those in alternative occupations such as domestic service or street prostitution.

When Talk Gives Way to Action

FORTUNATELY, the two sides of the globalization debate are—slowly—developing some measure of agreement. In many areas, advocates in both camps see the potential for coordination among transnational companies, multilateral organizations, developing country governments and local aid groups on programs to help the poor. Going beyond the contentious debates and building on the areas of emerging consensus and cooperation, international partnerships may be able to make a dent in the poverty that continues to oppress the lives of billions of people in the world. Here are some measures under discussion.

Capital controls. The flow of international investment consists both of long-term capital (such as equipment) and of speculative short-term capital (such as shares, bonds and currency). The latter, shifted at the click of a mouse, can stampede around the globe in herdlike movements, causing massive damage to fragile economies. The Asian financial crisis of 1997 was an example. Following speculators' run on the Thai currency, the baht, the poverty rate in rural Thailand jumped 50 percent in just one year. In Indonesia, a mass withdrawal of short-term capital caused real wages in manufacturing to drop 44 percent. Many economists (including those who otherwise support free trade) now see a need for some form of control over short-term capital flows, particularly if domestic financial institutions and banking standards are weak. It is widely believed that China, India and Malaysia escaped the brunt of the Asian financial crisis because of their stringent controls on capital flight. Economists still disagree, though, on what form such control should take and what effect it has on the cost of capital.

Polling station, Gaborone, Botswana, 2004

THEMBA HADEBE *AP Photo*

Reduced protectionism. The major hurdle many poor countries face is not too much globalization but too little. It is hard for the poor of the world to climb out of poverty when rich countries (as well as the poor ones themselves) restrict imports and subsidize their own farmers and manufacturers. The annual loss to developing countries as a group from agricultural tariffs and subsidies in rich countries is estimated to be $45 billion; their annual loss from trade barriers on textile and clothing is estimated to be $24 billion. The toll exceeds rich countries' foreign aid to poor countries. Of course, the loss is not equally distributed among poor countries. Some would benefit more than others if these import restrictions and subsidies were lifted.

Trust-busting. Small exporters in poor nations often lack the marketing networks and brand names to make inroads into rich-country markets. Although transnational retail companies can help them, the margins and fees they charge are often very high. Restrictive business practices by these international middlemen are difficult to prove, but a great deal of circumstantial evidence ex-

Globalization does not explain the differing fates of Botswana and Angola, both diamond exporters, one democratic, the other RAVAGED BY CIVIL WAR.

Teenage government soldier, Benguela, Angola, 1993

ARMANDO FRANCA *AP Photo*

ists. The international coffee market, for example, is dominated by four companies. In the early 1990s the coffee earnings of exporting countries were about $12 billion, and retail sales were $30 billion. By 2002 retail sales had more than doubled, yet coffee-producing countries received about half their earnings of a decade earlier. The problem is not global markets but impeded access to those markets or depressed prices received by producers, as a result of the near-monopoly power enjoyed by a few retail firms. In certain industries, companies may actively collude to fix prices. Some economists have proposed an international antitrust investigation agency. Even if such an agency did not have much enforcement power, it could mobilize public opinion and strengthen the hands of antitrust agencies in developing countries. In addition, internationally approved quality-certification programs can help poor-country products gain acceptance in global markets.

Social programs. Many economists argue that for trade to make a country better off, the government of that country may have to redistribute wealth and income to some extent, so that the winners from the policy of opening the economy share their gains with the losers. Of course, the phrase "to some extent" still leaves room for plenty of disagreement. Nevertheless, certain programs stir fairly little controversy, such as assistance programs to help workers cope with job losses and get retrained and redeployed. Scholarships allowing poor parents to send their children to school have proved to be more effective at reducing child labor than banning imports of products.

Research. The Green Revolution played a major role in reducing poverty in Asia. New international private-public partnerships could help develop other products suitable for the poor (such as medicines, vaccines and crops). Under the current international patent regime, global pharmaceutical companies do not have much incentive to do costly research on diseases such as malaria and tuberculosis that kill millions of people in poor countries every year. But research collaborations are emerging among donor agencies, the World Health Organization, groups such as Doctors Without Borders and private foundations such as the Bill & Melinda Gates Foundation.

Immigration reform in rich countries. A program to permit larger numbers of unskilled workers into rich countries as "guest workers" would do more to reduce world poverty than other forms of international integration, such as trade liberalization, can. The current climate, however, is not very hospitable to this idea.

Simplistic antiglobalization slogans or sermons on the unqualified benefits of free trade do not serve the cause of alleviating world poverty. An appreciation of the complexity of the issues and an active interweaving of domestic and international policies would be decidedly more fruitful. SA

MORE TO EXPLORE

Moving to Greener Pastures? Multinationals and the Pollution Haven Hypothesis. G. S. Eskeland and A. H. Harrison in *Journal of Development Economics,* Vol. 70, No. 1, pages 1–24; February 2003.

The Impact of Globalization on the Poor. Pranab Bardhan in *Globalization, Poverty, and Inequality.* Edited by S. M. Collins and C. Graham. Brookings Institution Press, Washington, D.C., 2004.

Globalization, Gender and Poverty: Bangladeshi Women Workers in Export and Local Markets. N. Kabeer and S. Mahmud in *Journal of International Development,* Vol. 13, No. 1, pages 93–109; January 2004.

How Have the World's Poorest Fared Since the Early 1980's? Shaohua Chen and Martin Ravallion in *World Bank Research Observer,* Vol. 19, No. 2, pages 141–170; Fall 2004.

Globalization and Labor Income in Mexico. G. H. Hanson. National Bureau of Economic Research Working Paper No. 11027. Cambridge, Mass. January 2005.

JET ENGINES

Big Squeeze

You run to your connecting flight, flash your ticket just in time and scramble into your seat. The plane pushes away from the gate, and the engines power up. As you breathe a sigh of relief, you peer out the window and wonder: Just what will be propelling me into the troposphere? For virtually all commercial airliners today, the answer is "turbofan engines," the latest in a decades-long evolution. First came the turbojet, now obsolete, then the turboprop, which is still found onboard small planes. The big advance for turbofans is that the propeller is traded for a fan inside the nacelle (housing), and much of the incoming air bypasses the guts of the engine, providing thrust simply by being compressed by the fan's shape [*see illustration on opposite page*].

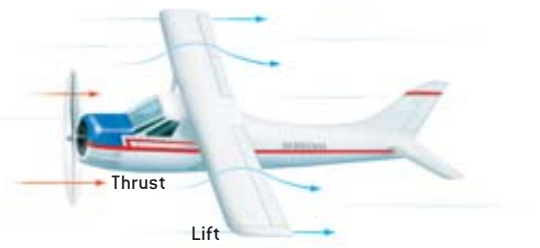
A jet engine exploits famous physics principles. According to Newton's third law of motion—for every action there is an equal and opposite reaction—air streaming out the back faster than the aircraft's speed will thrust the plane forward. The fan adds energy to the airstream, increasing velocity.

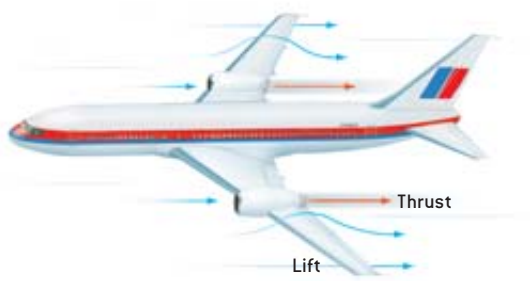
In the newest so-called high-bypass turbofans, six to eight pounds of air flows around the engine core for every pound of air that flows through it. The higher this bypass ratio, the more fuel-efficient and quieter the engine. Raising the ratio requires incremental improvements. "There are sweet spots in optimizing the mix of engine performance, emissions and noise," says Dale Carlson, manager of advanced technology at GE Aviation in Evendale, Ohio. The emphasis today is on systems design to maximize those sweet spots.

As the financially troubled airlines face skyrocketing fuel prices, improving economy has become paramount. "If we can raise engine fuel efficiency by 5 percent, that's a big deal," states Gary Roberge, director of advanced technology at Pratt & Whitney in East Hartford, Conn. Engineers are testing thermoplastic housings and aluminum engine parts to reduce weight and nickel alloys and ceramic matrix composites that can withstand higher temperatures for more efficient fuel burns. Some radical engine designs are always on the boards as well, but Roberge believes turbofans will still dominate "for the next 10 or 20 years."

—Mark Fischetti

TURBOFAN draws in air with a rotating fan. The air separates into two streams. The fan raises the pressure of the "bypass air" to about twice ambient pressure, accelerating it and creating thrust out the back. "Core air" passes through rotating compressor blades, which step up its pressure by roughly 30 to 40 times and its temperature by 1,000 degrees Fahrenheit or more. The air enters a combustor, where it mixes with fuel and ignites. The superheated output blasts through turbines, turning them. The still-pressurized exhaust exits through a narrowing nozzle that accelerates it, supplying added thrust. The high-pressure turbine spins the high-pressure compressors; the low-pressure turbine spins the low-pressure compressors and front fan.





PROPELLER AND JET ENGINES generate thrust by pushing air backward. In both cases, because the wing top is curved, air streaming over it must travel farther and thus faster than air passing underneath the flat bottom. According to Bernoulli's principle, the slower air below exerts more force on the wing than the faster air above, thereby lifting the plane.

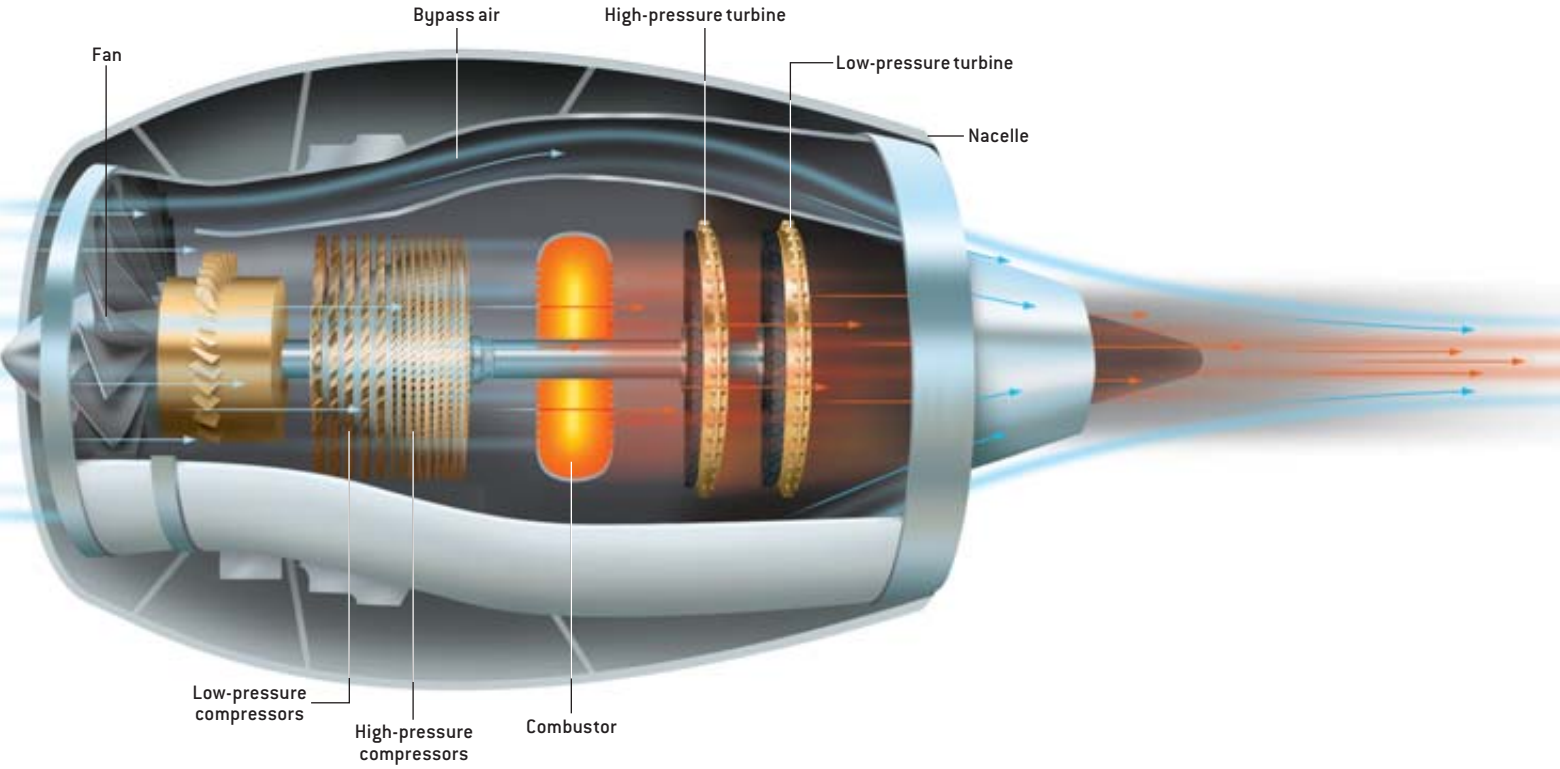
KENT SNODGRASS *Precision Graphics*

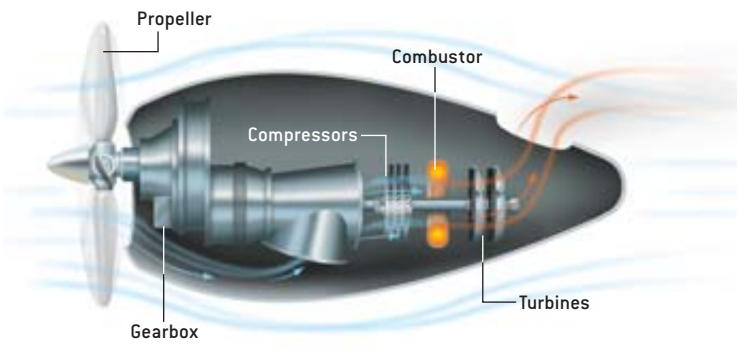
DID YOU KNOW...

GEARING UP: Raising the ratio of bypass air to core air improves engine efficiency and reduces acoustic noise. But more bypass air requires a larger fan and rear turbine—and when rotating fast the fan blade tips can reach high supersonic speed, which creates noise associated with shock waves. Pratt & Whitney is working on a gear turbofan—essentially, a turbofan engine with a gearbox inserted right behind the fan. The gears would allow very high bypass ratios yet keep fans at slower, quieter speeds.

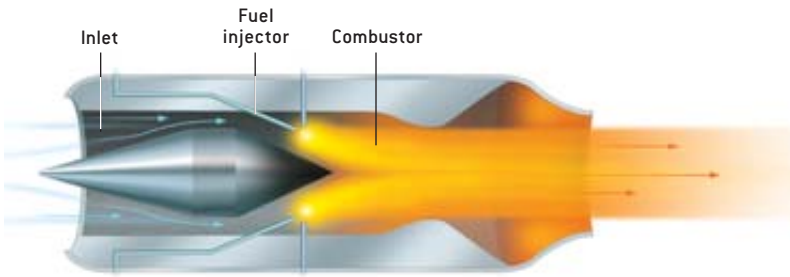
SCRAMJET: A supersonic combustion ramjet, or scramjet, operates similarly to a ramjet, except the incoming air is not slowed to subsonic speeds. Ramjets become very inefficient beyond Mach 5, but in principle scramjets can go much faster. The leading U.S. prototype plane, the X-43 operated by NASA, flew at nearly Mach 10 in November 2004, but work has been scaled back because of budget changes. Russia has also flown prototype vehicles.

TOAST: Turbofans and props belong to an engine class called turboshaft. Variations power military helicopters, M1 tanks and high-power boat propellers. Industrial gas turbines, used by power utilities, closely resemble turbofan jet engines, without the bypass air. High-pressure exhaust gas spins a turbine added at the back end, which turns a shaft in an electric generator that creates the electricity consumed in your kitchen to burn your toast.





TURBOPROP has a propeller instead of a fan. Compressors raise the incoming air's pressure, and the combustor ignites fuel and air, driving the mixture through the turbines, which turn the propeller. The propeller generates most of the thrust, rather than the exhaust flow.



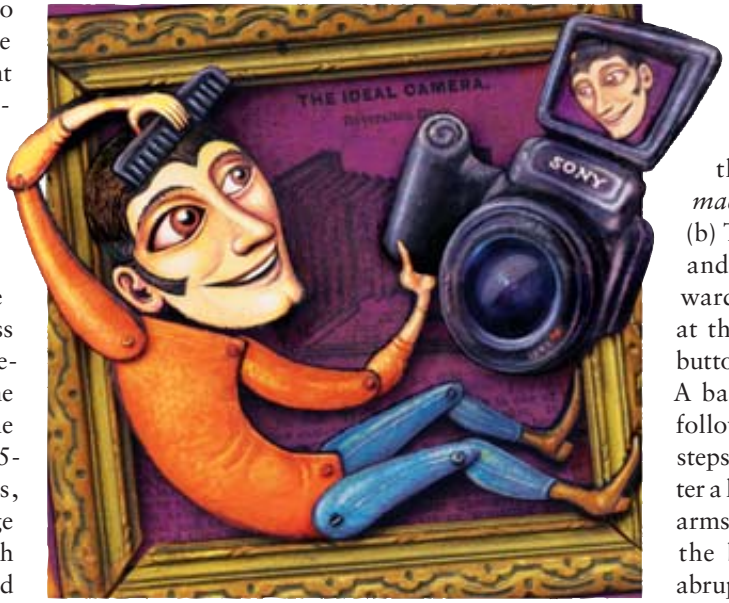
RAMJET has few moving parts. It propels fighter planes and missiles between speeds of Mach 2 and Mach 4. A separate jet engine or rocket must accelerate the craft beyond the speed of sound, starting the ramjet by forcing supersonic air inside the inlet. The inlet then slows the air. The combustor ignites the subsonic air and fuel, and the expanding gas creates thrust. Flaps on the inlet plug move to alter airflow, varying the thrust as desired.

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

Sharp Shooter

SONY'S R1 COMBINES NEAR PRO-QUALITY IMAGES WITH LIVE PREVIEW **BY STEVEN ASHLEY**

Digital cameras come in two basic flavors. Most people are familiar with the convenient point-and-shoot—the electronic descendant of the cheap, compact and once ubiquitous Kodak Brownie. These cameras let shutterbugs preview shots on a tiny screen and cost a couple of hundred dollars each. Less common are digital single-lens reflex (D-SLR) units—the computerized versions of the classic through-the-lens, 35-millimeter-film cameras, which offer far higher image resolution, along with much loftier prices. (They can exceed several thousand dollars.)



WELL-POSED SELF-PORTRAITS are a snap with the new Sony Cybershot DSC R1 digital camera. Merely rotate the real-time LCD monitor forward, compose the frame and shoot away.

Now comes Sony's Cybershot DSC R1 digital still camera, the first of a new category of reasonably affordable ($999), all-in-one electronic picture-takers that combines some of the best features of existing high- and low-end digital designs. I have been interested in purchasing a D-SLR for some time but have been waiting for prices to fall before dropping a bundle on one. Could the R1 be a useful alternative? I tried it to find out.

The first thing you notice about the R1 is its considerable bulk and heft. At around two pounds, it is clearly a two-hander. But the zoom lens, which extends all the way from an effective 24mm (wide angle) to 120mm (short telephoto), makes left-hand adjustments pretty much standard procedure anyway—especially if you often shoot entire rooms, big-group photographs or expansive landscapes. So when this slick package of high-tech optical design slips readily into your grip and handles smoothly enough thereafter, you don't complain too much about the weight.

The second thing you notice is the R1's stalk-mounted, live-view screen sitting topside. Like a point-and-shoot's monitor, the R1's two-inch-wide, high-brightness liquid-crystal display (LCD) presents the photograph before you snap it. But it also raises up, tilts and swivels to accommodate the photographer's vantage point, whichever way the lens points. Once I realized the implications of this unique feature, the next step was obvious: a series of arm's-length self-portraits.

The procedure goes something like this: (a) Face the screen fully front so *il maestro* can compose the frame. (b) Trust the automatic settings and adjust the mug in the forward-rotated, live display, stare at the lens, depress the shutter button to focus and then punch it. A barely audible "click" sound follows immediately. (c) Repeat steps a and b as necessary. (d) Enter a less well-lit room, assume the arms-extended position and mash the button; a red laser probe abruptly ranges across your cheekbone, a pop-up flashlamp blinks open, and blinding strobes flare. Minor shutter lag … then muted click. (e) Repeat step d as desired.

As your vision slowly recovers, you can see that the unique all-angle, real-time display could finally enable photographers to appear properly positioned and posed in timed shots of small groups, for example. And for less common camera perspectives, such as the low-angle, pet-level scan I later took of my neighbor's new puppy, the flexible monitor can be invaluable. In the latter case, the R1 became a view camera.

But what is truly surprising about the R1 is the outstanding quality of those initial impromptu head shots (all vanity aside, of course). When scrolled across the LCD screen (and later printed out on paper), the images are all fine detail

LEAH PALMER PREISS

and nicely rendered color and contrast. Sans insidious red eye, as well. Automatic imaging mode notwithstanding, the results are considerably better than those from any pocket digicam. In fact, the photographs look to be nearly on a par with those produced by professional-grade D-SLRs.

At this point, the reason for the R1's almost inaudible click finally hits home. The new camera is not an SLR; it lacks a shutter altogether. The SLR's clicking shutter mechanism—the moving mirror and prism device that momentarily redirects the light passing through the lens from the viewfinder and into your eye to the 35mm film (in nondigital models) or the large-scale silicon imaging array sensor (in their digital counterparts)—seems absent. A glance into the R1's viewfinder confirms this suspicion; rather than showing a bright optical field, the camera has a miniature electronic screen that displays what the lens sees.

LIVE PREVIEW SCREEN and the high-resolution, low-power image sensor place the Sony R1 digital camera into a category of its own.

"Much of the R1's novel design derives from our choice of sensor," says Mark Weir, Sony's product manager for digital cameras. "As far as we know, never before has a camera been built around a large-scale sensor—one with big pixels that can grab a lot more light than the smaller pixels used in point-and-shoot sensors—that can generate a continuously, and rapidly updated, image for the live-preview display." Large-scale sensors, which are sometimes called advanced photo systems (APS) or APS-class systems, are many times the size of the devices used in point-and-shoots.

Weir explains that existing D-SLRs need traditional shutter mechanisms because their multimegapixel image sensors can produce an "exposure" for only a brief period (when the shutter engages). These imagers must operate intermittently because they run very hot and hungry for battery power. During the rest of the time, the D-SLR user sees an actual, optical scene in the viewfinder—one that only generally relates to the forthcoming photographic image, which is determined by the camera settings. In this case, what you see is not necessarily what you get.

SONY ELECTRONICS

Developing a suitable, always-on APS sensor was the key to the new design approach, Weir continues. Sony engineers chose to base the R1's big, 10.3-megapixel (21.5mm-by-14.4mm) sensor on improved complementary metal oxide semiconductor (CMOS) technology rather than on the charge-coupled device (CCD) sensors often used in D-SLRs. Beyond the broad dynamic range, low signal-to-noise ratio and extraordinary light sensitivity that all APS sensors provide, the advanced CMOS array in the new camera affords several exclusive benefits: significantly reduced power consumption to ensure reasonable battery life and, especially, lower operating temperatures. "Heat is the enemy of electronic imaging," Weir declares.

Once the new image sensor was perfected, Sony engineers matched it with a high-performance Carl Zeiss zoom lens, which takes up the space vacated by the shutter mechanism. This relatively fast (with a maximum aperture of F2.8 to F4.8) 35mm-equivalent lens complements the big sensor well. For instance, the lens is designed to ably distinguish fine gradations of tonal contrast.

As with a point-and-shoot digicam, the lens is a fixed or dedicated optical system; the R1 does not support easily interchangeable lenses. The broad zoom capability compensates for that disadvantage somewhat, as do the strap-on long-telephoto and macro (close-up) lenses one can buy as accessories. The upside of the nonremovable lens, Weir says, is that the sensor system can be specially tailored to the optical characteristics of the Zeiss zoom, which greatly improves the photographic results.

There are a few other drawbacks. Close-in shots are limited to a range of about a foot, and a video-capture mode is not included. The high-speed burst-shooting mode, which is useful for unpredictable, fast-moving subjects such as uncooperative kids or pets, is limited to a paltry three shots maximum.

But add in a very capable digital image-processing system, and the R1 offers pretty much all the amateur photo enthusiast could want, at a price that won't break the bank. And although the hybrid approach leads to some compromises, the new R1 seems a distinctive take on the digital camera—one that should spawn followers. For now, however, the Cyber-shot DSC R1 is in a class of its own. SA

Beyond the Standard Model

THEORETICAL PHYSICISTS ARE NOT YET AT THE END OF THEIR STRING **BY JIM HOLT**

WARPED PASSAGES: UNRAVELING THE MYSTERIES OF THE UNIVERSE'S HIDDEN DIMENSIONS
by Lisa Randall
Ecco (HarperCollins), 2005 ($27.95)

THE COSMIC LANDSCAPE: STRING THEORY AND THE ILLUSION OF INTELLIGENT DESIGN
by Leonard Susskind
Little, Brown and Company, 2005 ($24.95)

HIDING IN THE MIRROR: THE MYSTERIOUS ALLURE OF EXTRA DIMENSIONS, FROM PLATO TO STRING THEORY AND BEYOND
by Lawrence M. Krauss
Viking, 2005 ($24.95)

What are theoretical physicists up to these days? Judging from the titles of the popularizations they are turning out, one might be forgiven for thinking that they are eating psychedelic mushrooms or chewing on lotus leaves. *Warped Passages, Hiding in the Mirror, The Cosmic Landscape*—sounds like a trilogy by Carlos Castaneda.

Well, what *should* theoretical physicists be up to? It's been three decades since the so-called Standard Model was hammered out. Thanks to this remarkable achievement, the behavior of all known particles can be described with exquisite precision, right down to the 11th decimal place. The only force the Standard Model leaves out is gravity, and that is handled very nicely by Einstein's theory of general relativity. Considering that the Standard Model and general relativity together account for any conceivable observation we might make, further theorizing can, without prejudice, be dismissed as metaphysics—which, of course, literally means "after physics."

Needless to say, the authors of these books—accomplished theoretical physicists, all three—don't buy this characterization. Theory has a future, they think, and it will probably involve a fairly extravagant addition to what we think of as reality. Beyond that, however, they don't see eye to eye.

Lisa Randall of Harvard University takes a cautious "bottom-up" approach: she wants to keep her theorizing firmly rooted in the actual observation of elementary particles. And what worries her most is a rather specific flaw in the theoretical status quo: our inability to explain why gravity is so absurdly weak compared with the other forces of nature. To solve this "hierarchy problem," she and her collaborator, Raman Sundrum, have posited the existence of a hitherto unnoticed dimension of space—not a little curled-up dimension, like those of string theory, but a large, possibly infinite dimension. As she explains in *Warped Passages,* our 3-D world may inhabit this 4-D space the way a shower curtain inhabits a bathroom. The particles in our world are like the water droplets running over the surface of the shower curtain. Only gravitons can escape the curtain into the larger space, and such leakage may account for the observed weakness of gravity compared with the other forces.

Leonard Susskind of Stanford University is very much a "top-down" fellow. In fact, he is one of the creators of string theory. In the four decades of its existence, string theory has not generated any novel predictions that can be tested. Nor have the legions of physicists who pursue string theory been able to find a mathematically unique version of it. At present, there is an enormous "landscape" of theoretical possibilities, numbering something like 1 followed by 500 zeros. Each version corresponds to a different universe with what might be called its own local weather: vacuum energy, number of dimensions, elementary particle masses, coupling constants, and so on. In *The Cosmic Landscape,* Susskind tries to make a virtue of this seeming embarrassment. Invoking inflationary cosmology, he submits that each of these theoretical possibilities has actually bubbled into existence as a "pocket universe." Together all these

UNWEAVING the debates about string theory.

DUSAN PETRICIC

pocket universes make up what he calls the "megaverse" (other physicists prefer "multiverse"). Among this enormous multiplicity of pocket universes, Susskind further contends, there is bound to be one with just the right vacuum energy to permit the emergence of intelligent beings. No wonder we observe ourselves to be living in such a miraculously fine-tuned universe, he concludes, unabashedly embracing the notorious anthropic principle.

Lawrence Krauss of Case Western Reserve University admits that he finds both Randall's and Susskind's arguments seductive. Yet at the end of *Hiding in the Mirror,* his masterly survey of higher-dimensional theorizing, he remains a skeptic—even though, like the *X-Files*'s Fox Mulder, he "wants to believe."

Each of these books is superb in its own way, but reading them together is especially rewarding, as subtle tensions emerge that illustrate the dilemmas faced by theoretical physicists today. Take the anthropic principle. Susskind almost rejoices in it. "Given a megaverse, endlessly filled with pocket universes," he writes, "the Anthropic Principle is an effective tool to weed out and eliminate most of them as candidates for our universe." Both Randall and Krauss, in contrast, find the anthropic approach rather a letdown. Edward Witten agrees. "I'd be happy if it is not right," he has commented. "I would be happy to have a more unique understanding of the universe."

It is easy to sympathize. Suppose you want to explain why the observable world has three spatial dimensions. You might approach the matter anthropically, arguing that if there were some other number of dimensions, we would not be here to wonder about it. In a world with more than three dimensions, there would be no stable orbits for electrons—hence no chemistry, hence no chemically based life-forms, hence no us. In a two-dimensional world, signals would not propagate cleanly—hence no information processing, hence no intelligence, hence no us. (Proving the impossibility of intelligent life in a one-dimensional world is left as an exercise for the reader.) But by falling back on such anthropic reasoning we might be giving up too early. Indeed, string theorists have come up with more fundamental explanations for why only three of the nine spatial dimensions the theory posits should have expanded to observably large size—explanations that make no reference to the possibility or impossibility of creatures like us being around. The anthropic explanation looks embarrassingly lightweight in comparison, not to say parochial.

Even if the current generation of theoretical physicists can sort out such differences among themselves, they will still have to contend with those who deny that their enterprise is meaningful at all. Susskind writes that "no serious theoretical physicist today is content with two apparently incompatible theories," by which he means quantum mechanics and general relativity. But Freeman Dyson, who decades ago played an important role in tidying up the mathematics of the Standard Model, has declared that he, for one, is happy with the status quo. General relativity explains big things, quantum mechanics explains little things, he points out, and if the twain meet, it is on a scale that is physically undetectable and hence empirically irrelevant.

The question of testability raised by Dyson clearly vexes all three authors. Krauss, in particular, writes that unless the theorizing about extra dimensions and megaverse landscapes ultimately helps to "resolve fundamental physical questions, it *is* all just mathematics." But that hardly means it will have been a waste of time. Even if Witten's string-theoretical investigations never yield testable consequences, they have nonetheless greatly advanced the area of pure mathematics called knot theory—which is why Witten has been awarded the most prestigious of mathematical prizes, the Fields Medal. No one expects mathematics to be testable.

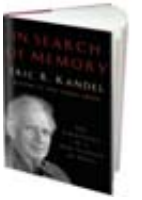
Still, a little humility on the part of theoretical physicists might be advisable, especially toward their experimental colleagues. "Most really good theoretical physicists don't pay much attention to what experimenters think," Susskind writes. "They build their theories based on their own instincts and go where intuition leads them." Hardworking experimental physicists, for their part, have been known to grumble about the leisurely life of their theorizing counterparts. The experimenters say—facetiously, for all I know—that theoretical physicists will never schedule a meeting on Wednesday, because that would spoil two weekends. SA

Jim Holt writes about science and philosophy for the New Yorker *and the* New York Times Magazine.

THE EDITORS **RECOMMEND**

IN SEARCH OF MEMORY: THE EMERGENCE OF A NEW SCIENCE OF MIND

by Eric R. Kandel. W. W. Norton & Company, 2006 ($27.95)



Kandel, who received the Nobel Prize in 2000, traces advances in understanding learning and memory. His own groundbreaking findings showed that learning produces changes in behavior by modifying the strength of connections between nerve cells. He conveys his immense grasp of the science beautifully, but it is his personal recollections that make the book especially compelling. He begins with his searing childhood memories of the German annexation of Austria and his family's escape to the U.S. when he was nine. And he ends with a conference he organized in Vienna to examine the strange reluctance of Austria (unlike Germany) to acknowledge its role in the Holocaust. One comes away in awe of the scientific advances—and of a life well and fully lived.

Short Takes

ONLY A SCIENTIST WOULD BRAG, "I ONCE CAUGHT A FISH THIS SMALL . . ." BY STEVE MIRSKY

In late January a Brobdingnagian battle erupted over a Lilliputian water dweller. Okay, the battle wasn't really all that huge. And we're *not* talking about the Benihana shrimp toss case, a lawsuit that started in January. That ballyhoo *was* big and concerned a chef who flung sizzling shrimp into the mouths of his patrons. Hey, it's not just dinner, it's a show. Anyway, one guy dodged the shrimp, hurt his neck, went into a general health decline and eventually died. His widow sued for $16 million, which is a lot of clams. (In February the jury let Benihana off the hook, finding the restaurant not at fault.)

No, the fight in question concerns competing claims by scientists over the smallest of fry: the world's tiniest fish, which also makes them the world's shortest vertebrates. A multi-institutional research team reported that it had discovered adult fish just 7.9 millimeters long. The species, *Paedocypris progenetica,* is found in incredibly acidic peat wetlands in Indonesia. "Tiny backbone living in corrosive swamp" would ordinarily describe a member of the House ethics committee, but in this case it's a kind of carp.

The scientists published their finding in *Proceedings of the Royal Society B: Biological Sciences,* a journal title that takes up almost 10 times the space on this page than would the creature cited as the previous record holder for world's smallest vertebrate. That beastie is the eight-millimeter-long dwarf goby. Henceforth and in comparison to be known as the moby goby.

A quick aside: what you definitely don't use to catch any of these petite pisces is a *Driloleirus americanus,* better known (to probably half a dozen people) as the giant Palouse earthworm. In February a graduate student at the University of Idaho became the first person in almost 20 years to see one. It's a white worm, as Ahab might have noted, that can reach a length of one meter. Which

is puny compared with some Australian earthworms that can be three meters long. Fortunately, they're down under down under.

Back to our untall tale. The print had barely dried on the various newspaper stories touting the teeny titleholder (talk about small victories) when a petition for priority appeared—the University of Washington was quick to point out that their Theodore W. Pietsch had plumbed new depths, or heights, I'm not sure which, in lack of length September. Publishing in the Ichthyological Society of Japan's journal, *Ichthyological Research,* Pietsch revealed that full-grown males of the species *Photocorynus spiniceps,* a kind of anglerfish collected in the Philippines, have come in as small as 6.2 millimeters. These boys are more than (or less than, I'm not sure which) normal males. Female *P. spiniceps* can measure a massive 46 millimeters long—males are so small because they marry way up, engaging in what is known as sexual parasitism.

In his journal article, Pietsch explains sexual parasitism with this 1938 quote from naturalist William Beebe: "To be driven by impelling odor headlong upon a mate so gigantic, in such immense and forbidding darkness, and willfully to eat a hole in her soft side, to feel the gradually increasing transfusion of her blood through one's veins, to lose everything that marked one as other than a worm, to become a brainless, senseless thing that was a fish—this is sheer fiction, beyond all belief unless we have seen the proof of it." And you thought the Sigourney Weaver movie where the hideous monster latches onto its victim was bizarre. *Alien,* not *Working Girl.*

The minuscule male has chosen a life basically as a sex organ: the major occupants of its body cavity are its testes. The female carries on all the usual functions of life for both, and the sole job of the mindless, attached male is to breed. And you thought the Tom Hanks movie where the dim-witted guy gets the girl was unbelievable. *Forrest Gump,* not *Splash.* In that one, the dim-witted guy gets the fish. SA

ILLUSTRATION BY MATT COLLINS; PHOTOGRAPH BY FRANK VERONSKY

ASK THE EXPERTS

Q Why is oil usually found in deserts and arctic areas?

—B. Sterling, Deltaville, Va.

Roger N. Anderson, professor at the Lamont-Doherty Earth Observatory at Columbia University, explains:

Most oil and gas fields have ended up where they are because of plate tectonics—the shifting over time of large plates on the surface of the earth. River deltas and continental margins offshore also hold reserves.

Oil and gas result mostly from dead microorganisms buried quickly in anoxic environments, where oxygen is so scarce that they do not decompose. This lack of oxygen enables them to maintain their hydrogen-carbon bonds, a necessary ingredient for the production of fossil fuels. Newly developing ocean basins, formed by plate tectonics and continental rifting (deformation), provide just the right conditions for rapid burial in anoxic waters. Rivers fill these basins with sediments carrying abundant organic remains. Because the basins have constricted water circulation, they also have lower oxygen levels than the open ocean.

Plate tectonics is also responsible for creating the "pressure cooker" that slowly matures the organics into oil and gas. This process usually takes millions of years, giving the oil and gas deposits time to migrate around the globe on the back of plate movements. Because these hydrocarbons are much more buoyant than water, they eventually force their way to the surface. Alternatively, rifting, collisions between landmasses, and other tectonic forces can free the mature oil and gas from deep within sedimentary basins and then trap these organic fluids in reservoirs before they escape to the earth's surface. We know these reservoirs as oil and gas fields.

The same plate tectonics that creates the locations and conditions for anoxic burial is also responsible for the geologic paths that these sedimentary basins subsequently take. Continental drift, subduction (where one plate thrusts under another) and collision with other continents provide the movement from swamps, river deltas and mild climates—where most organics are deposited—to the poles and deserts, where they have ended up today by coincidence.

Q Why does lactic acid build up in muscles?

Stephen M. Roth, professor in the department of kinesiology at the University of Maryland, offers this answer:

Lactic acid accumulates when circumstances—such as a sprint—require the body to produce energy faster than it can deliver oxygen to working muscles.

The body prefers to generate most of its energy using aerobic methods, meaning with oxygen; during strenuous exercise, we breathe faster to bring in more air. Some circumstances, however—such as when we sprint or lift heavy weights—require that our bodies produce energy faster than they can deliver adequate oxygen. As a result, the tissues generate energy anaerobically, by breaking down glucose into a substance called pyruvate. When the body has plenty of oxygen, pyruvate is shuttled to an aerobic pathway to be further broken down for more energy. But when oxygen is limited, the body temporarily converts pyruvate into a substance called lactate, which lets glucose breakdown—and thus energy production—carry on. The muscle cells can sustain anaerobic energy production for one to three minutes, during which time lactate can accumulate to high levels.

The high lactate levels increase acidity in the muscle cells as well as disrupt other metabolites. The same metabolic pathways that permit the anaerobic breakdown of glucose to energy perform poorly in this acidic environment. The result is a reduction in capacity, which protects us from severe muscle damage during extreme exertion. Once the body slows down, oxygen becomes available, and lactate reverts back to pyruvate, allowing continued aerobic metabolism and energy for recovery. SA

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

MATT COLLINS