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Recycling **Nuclear Waste** into Energy

DECEMBER 2005
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Echoes of BLACK HOLES

What is **spacetime?** Experimental models hint that it could be a kind of fluid

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The Brain of a Memory Savant

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What Must Be Done Today to Stop It

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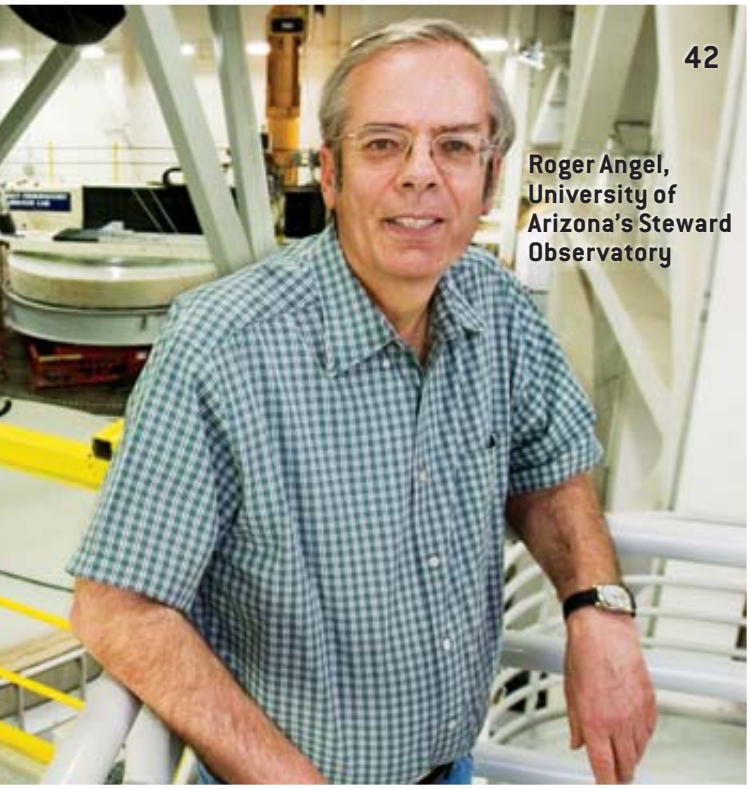

Roger Angel, University of Arizona's Steward Observatory

columns

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Running on Empty

It was a remarkable turnabout. In September, after Hurricanes Katrina and Rita pushed gasoline prices to more than $3 a gallon, President George W. Bush spoke out for energy conservation. The president, who had previously insisted that new oil wells and refineries were the solution to the nation's energy woes, called on Americans to save gas by driving less. Listeners with long memories recalled President Jimmy Carter's television appearances during the oil crisis of the 1970s, when he urged Americans to turn down their thermostats. The only thing missing was the cozy cardigan that Carter had worn when he made his plea.

RISING gas prices prompted conservation.

Environmentalists, though, were less than thrilled by the Bush administration's new strategy, which focused on public-service advertisements encouraging conservation. When it comes to transportation, which consumes 70 percent of U.S. oil and generates a third of the nation's carbon emissions, voluntary measures may be ineffective. Decades of suburban sprawl and neglect of public transit have made it harder for Americans to cut back on driving; from 1990 to 2001, the average length of a shopping trip grew from five to seven miles, and the number of shopping trips per household rose from 341 to 496 a year. Driving to schools, churches, doctors and vacation spots also increased significantly.

A more constructive approach would be to improve the fuel efficiency of cars and trucks. The rise in gas prices has prompted some movement in this direction: after the hurricanes disrupted the oil industry, car buyers shunned gas-guzzling SUVs and snapped up more efficient models. This trend, however, may prove short-lived if gas prices subside as oil companies rebuild their facilities. For this reason, some economists recommend raising the federal gas tax by 50 cents a gallon. The increase could be gradually imposed as prices at the pump decline, so that the impact on consumers is minimized. To offset the disproportionate burden on working-class drivers, revenues from the gas tax could be used to reduce payroll taxes.

Unfortunately, Bush and Congress are adamantly opposed to any new tax, even one that would protect the environment, lessen our dependence on oil from the Middle East and save consumers money in the long run. Instead the Bush administration has proposed revising the corporate average fuel economy (CAFE) standards for light trucks, a category that includes SUVs, pickup trucks and minivans. Whereas passenger cars must average 27.5 miles per gallon, the required average for light trucks is now 21 mpg and scheduled to rise to 22.2 mpg by the 2007 model year. The administration's proposal divides light trucks into six subcategories; although small SUVs have to average 28.4 mpg by 2011, the target for big pickups is only 21.3 mpg. The average for all light trucks would rise to 24 mpg, just 8 percent more than what the current CAFE rules would require by then.

Such feeble measures will do little to ease America's addiction to foreign oil or slow the global warming caused by vehicle exhaust. Lawmakers should press for more stringent CAFE standards that would boost fuel economy for both cars and light trucks by at least 40 percent over the next decade. The goal is technologically feasible—by adopting hybrid engines and strong but lightweight auto bodies, manufacturers can make their vehicles more efficient without compromising passenger safety or inflating sticker prices. What we need are political leaders genuinely committed to energy conservation, not just to speeches and public-service ads.

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2005 Science & Technology WEB AWARDS

In the year since we last presented these awards, both the world and the Web have changed in dramatic ways. The spheres of science and politics have become seemingly inextricable, forcing biologists to go to the mat with policymakers over the issue of teaching intelligent design in school. The influence of "citizen journalist"–penned blogs has become a driving force behind the dissemination of information. And most recently, the devastation caused by Hurricanes Katrina and Rita has sparked discussion of whether global warming is responsible for the increase in storm intensity. The implications of all these developments loomed large as we chose our winners for this year.

Snowball Earth Theory Comes under Fire

Geologists have produced evidence of abundant marine life on the earth from a period when others say a thick layer of ice gripped the entire planet. The find lends considerable support to one side of a scientific controversy that has been widely debated for decades.

Ask the Experts

Why does skin wrinkle with age? What is the best way to slow or prevent this process?
Suzan Obagi, assistant professor in dermatology at the University of Pittsburgh and director of the Cosmetic Surgery and Skin Health Center, explains.

Coming Attractions

SciAm Observations

A blog from the editors of *Scientific American*.

The ScientificAmerican.com Gift Guide

Our editors pick their favorite gifts to give and get this holiday season.

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Letters

EDITORS@SCIAM.COM

NUMEROUS READERS responded to "Mindful of Symbols," by Judy S. DeLoache, in the August issue, which described the difficulties children encounter as they learn to think symbolically. Geoff Baldwin of Portola Valley, Calif., recalled his own childhood experience: "I saw drawings of airplanes and thought I could cut them out to get small model planes. I remember being baffled and frustrated when they did not pop into three dimensions."

Even curiouser is when adults respond to symbols rather than what they represent: an illustration of an orchestra in "Is the Universe Out of Tune?" by Glenn D. Starkman and Dominik J. Schwarz, showed discordance in the "symphony" of the cosmic microwave background emanating from the tuba. Carl Dershem chimed in: "Sure, blame us tuba players! The tuba is the Rodney Dangerfield of instruments—it gets no respect!" But there was nothing abstract about an e-mailed reality check that challenged the statement made in the story's cover headline, "Bad Harmonies in the Microwave Music Defy Theory." Wrote Duane Bonvallet: "Really. I'm betting the universe is right and the theory is wrong. How are you betting?"

SYMBOL-MINDED

In "Mindful of Symbols," by Judy S. DeLoache, the images of children exploring the conceptual relationship between perceptions and reality are whimsical reminders that a child is not a small adult.

After making a good case about the development of concepts, however, DeLoache blows it in her discussion of their educational ramifications. Blocks are not symbolic representations of quantity; they *are* quantity. And manipulating them does not "help children appreciate abstract mathematical principles." Rather it allows the students to demonstrate the base 10 number system.

If the six- and seven-year-olds using pencil and paper learned to "borrow" in subtraction in a third of the time as those using blocks, the chances are they just learned to remove 1 from the number in the 10's place and put a 1 in front of the number in the 1's place. That is a trick. It does not develop or utilize concepts that can be transferred to other situations. Faster? Maybe now, but not in the long run. Better? Absolutely not! Teach concepts first, then teach the shortcuts.

Bernice Fiske
Albuquerque, N.M.

DeLOACHE REPLIES: I received several letters from math teachers, some echoing Fiske's sentiments. At least an equal number expressed their disenchantment with manipulatives, however, thanking me for introducing healthy skepticism to this important topic.

For many math educators, it is an article of faith that manipulatives help children learn fundamental mathematical concepts. Unfortunately, empirical research does not support that widespread belief. What research there is indicates that the current use of manipulatives is at best questionable and at worst counterproductive.

COSMIC SOUR NOTE

Studying subtle variations of microwave-background temperatures and how they differ from prediction opens a fascinating window onto the early universe [see "Is the Universe Out of Tune?" by G. D. Starkman and D. J. Schwarz].

One number, the temperature, is being measured at each point, and now a vector will be added when polarization is also mapped. But it seems much more information may be contained in the details of this radiation observed at each point. Looking for small deviations from the perfect blackbody spectrum may lead to new insights and to further identification of possible radiation contaminants or measurement interferences.

Peter Thieberger
Brookhaven National Laboratory

STARKMAN AND SCHWARZ REPLY: *The Far Infrared Absolute Spectrophotometer onboard the Cosmic Background Explorer satellite studied the radiation at different wavelengths and found no measurable difference from a blackbody spectrum. Admittedly, this finding involved an average over a large patch of the sky. Whereas in principle it would be good to have much more detailed spectra in each direction, in practice it would be enormously expensive and time-consuming, with little likelihood of our learning very much given the technical means now at our disposal. Attention is currently focused on measuring smaller angular scales and polarization.*

TEARS OF THE HEART

In "Beating a Sudden Killer," John A. Elefteriades pointed out that aortic aneurysms can be hereditary or may arise from conditions such as Marfan's syndrome. But he left out some commonly known risk factors. Most thoracic and abdominal aneurysms occur during the sixth or seventh decade of life. Men are affected about twice as often, and a strong correlation exists between smoking and aneurysm formation. Readers might look at the box "Who Should Worry" and feel falsely reassured because they didn't have any of the risk factors that Elefteriades chose to include.

Robert Hoyt, M.D.
Pensacola, Fla.

ELEFTERIADES REPLIES: *Male sex, advanced age and smoking are definitely important risk factors for atherosclerosis, which in turn increases the odds of having an aneurysm in the abdominal aorta or in the descending thoracic aorta. Yet atherosclerosis has not been found to increase risk for an aneurysm in the ascending aorta.*

SOME ROCKET SCIENCE, PLEASE

Referring to our proposed space militarization in "Great Teller's Ghost" [SA Perspectives], the editors say "the policy makes no sense on technical, geopolitical or economic grounds." They make a categorical assertion and then only partially support it. Carl Sagan reminded us that strong claims require strong proof. Based only on a short position statement, your editorial is mostly an opinion, not a well-demonstrated case study.

Have you considered these three facts? The U.S. is not the only one contemplating such a move. Our military and society now depend on satellites, and we can ill afford a "space Pearl Harbor." Finally, monitoring any satellite militarization is extremely difficult.

Although the cost has not been fully evaluated at this early conceptual stage, the technical feasibility is certainly within our capabilities, and on geopolitical grounds, inaction could be even more costly—perhaps devastating. Consequently, I would love to see you enlarge on your previous coverage of research in this field. I think your readership expects hard science, not rumors or opinions.

BATTLE SPACE: **The Pentagon's high-fire act.**

Alan Bertaux
Bethany Beach, Del.

MOORE OR LESS?

In "Kryder's Law" [Insights], Chip Walter writes that Kryder's Law surpasses Moore's Law in growth. Unfortunately—and disappointingly—it does not.

Walter states that a 50-millionfold increase in disk storage density has been achieved since 1956; this represents about 25.6 doublings. According to my calculations, assuming 50 years, or 600 months of increase time, a density doubling occurs every 24 months. This is not nearly as fast as the roughly 18-month doubling time for Moore's Law.

Nicholas M. Myrman
Mercury Computer Systems
Chelmsford, Mass.

WALTER REPLIES: *Moore's and Kryder's "laws" are observations of trends, not immutable principles like Newton's three laws of motion. Two important points should be made: the 50-millionfold increase in hard-disk capacity since 1956 is admittedly not as great as what Moore's Law predicted for computer chips when averaged over the past 49 years. But this increase has not been linear. Over the past four years, hard-drive capacity per square inch has been doubling roughly every 11 months, whereas processor capacity has been doubling somewhat less than every 18 months and even slightly less than every 24 months (Moore's original law).*

Second, information density for hard drives is measured in bits per square inch. But the areal density of semiconductors is measured in transistors per device. Square inches are a fixed space; the size of semiconductor devices is not and has expanded over time, in some cases doubling in size. This has helped Moore's Law keep pace with its own predictions. The contrast between the two elements might therefore be regarded as an apples-and-oranges comparison. But the purpose was to make a general point, not to calculate precise math.

ERRATA In "The Early Evolution of Animals," by David J. Bottjer, the molecular clock rate derived from invertebrates is not slower than that based on vertebrates; it is faster.

In "Kryder's Law," by Chip Walter [Insights], a terabit was said to be equal to about 200 DVD movies. The amount should have been 25 DVDs.

"Is the Universe Out of Tune?" by Glenn D. Starkman and Dominik J. Schwarz, stated on page 53 that the note with a single node in the middle ($n = 1$) is the first harmonic oscillation. The first harmonic is the same as the fundamental tone ($n = 0$). The $n = 1$ note is the second harmonic.

GEORGE RETSECK

150, 100 & 50 Years Ago
FROM *SCIENTIFIC AMERICAN*

Watching the Heavens ▪ Sailing around America ▪ Invading the Amazon

DECEMBER 1955

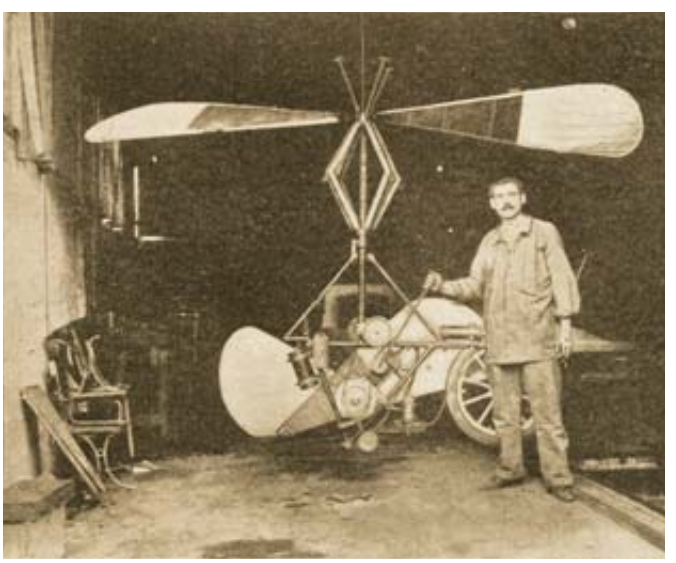
SPACE BIRD—"Some time in the next few years a new object will appear in the heavens. It will be quite inconspicuous. But as men lift their heads and, watching, catch a glimpse of this faint body racing across the sky, they will feel the excitement of witnessing a great historic event. For the tiny object circling the heavens will be metal that man has touched, a satellite that man has made and flung from the earth into space. The satellites that the U.S. will launch for the International Geophysical Year (1957–1958) are still, of course, only scribbles and sketches on pieces of paper."

THERAPY OR POISON?—"In 1940 a Boston ophthalmologist was abruptly confronted with a new disease which defied his skill to diagnose, let alone to treat. In the course of just a few months he examined six cases of babies going blind from some obscure cause. By July 1950, statistics seemed to show that the babies who developed retrolental fibroplasia had been treated for oxygen deficiency, as evidenced by the fact that they were kept under oxygen longer. It had not yet sunk in that the giving of oxygen might itself be the cause of the trouble. Retrolental fibroplasia emerged in epidemic proportions when hospitals began to expose premature babies to very high oxygen atmosphere in efficient new incubators. Often the atmosphere used was 50 percent oxygen."

DECEMBER 1905

FIRST PASSAGE—"The recent reports that Capt. Roald Amundsen, of Norway, has succeeded in finding and traversing the historic Northwest Passage, and has, furthermore, definitely located the north magnetic pole, have aroused great interest in scientific circles. The search for the Northwest Passage began almost as soon as it was established that America was not a part of Asia, but it appears, nevertheless, that Capt. Amundsen is the first to force his way around the northern edge of the continent. Capt. Amundsen left Norway on June 1, 1903, in his 46-ton sloop, the 'Gjoa,' with a crew of eight men. The 'Gjoa' is wintering near Kay Point, Herschel Island. The account of the expedition's successful completion was received from Fort Egbert, Alaska."

EARLY HELICOPTER—"Two well-known French aeronauts—Messrs. Louis Goddard and Felix Faure—conducted experiments with horizontal propellers. A six-bladed propeller driven by foot power from a specially rigged bicycle frame obtained an upward pull of 6.6 pounds. Diminishing the number of blades constantly improved results. With a 1 3/4 horse-power gasoline motor the lift was quickly raised to 51 pounds [*see illustration*]. By adding a propeller and using a reciprocating motion, the machine was made to lift as much as 220 pounds with an expenditure of 10 horse-power."



VERTICAL LIFT: Early helicopter, 1905

DECEMBER 1855

INTERNAL COMBUSTION—"Messrs. Editors: Will you grant me a small space in your valuable journal, to remark that the percussive action of explosive mixtures of gas and atmospheric air, when fired in a properly constructed engine, is not of that injurious character you suppose, much of the *jar* in the working of the machine you saw being the result of a sudden and violent shutting of the valves at the moment of ignition—a fault which will be remedied. You have overlooked also the ability of using as fuel the *liquid* hydro-carbons, such as turpentine, naphtha and oil of tar. There being no boiler, there is much economy, and with the small bulk of fuel, there is great additional room for freight or passengers. —Alfred Drake, Philadelphia" [*Editors' note: Drake's pioneering engine used heated tubes to ignite a fuel-air mixture.*]

A BAD IDEA—"At a recent meeting of the British Association for the Advancement of Science, Senor Susini read a paper on the valley of the Amazon. He states that 'the regions watered by the Amazonas, reclaimed from the savage tribes, ferocious animals, and noxious reptiles which now infest them, and traversed by the plowshare, might be capable of sustaining the population of the entire globe.'"

ECONOMICS

Trials for the Poor

RISE OF RANDOMIZED TRIALS TO STUDY ANTIPOVERTY PROGRAMS **BY JR MINKEL**

Governments and aid organizations spend tens of billions of dollars a year trying to lift the people of developing nations out of poverty through better education, health care and other programs. Evaluating those efforts, however, has proved difficult. Retrospective studies of different populations could not control for differences in wealth and culture. Some economists became frustrated with their inability to answer specific policy questions, such as how to increase school attendance. Increasingly, however, economists are finding success with a method well honed in medicine: the randomized trial.

KUNJAL M. SHAH

SEEING WHAT WORKS: Randomized trials could indicate whether particular efforts can alleviate poverty, such as this education program in the Indian city of Baroda developed by Pratham, a Mumbai-based nongovernmental organization.

Using randomized prospective trials in economic development policy is not new. Since the 1960s, the U.S. has occasionally implemented them to answer important practical questions in health care, welfare and education policy. By randomly splitting people into two groups, one of which receives an experimental intervention, researchers can set up potentially simple, unbiased comparisons between two approaches. But these evaluations typically cost hundreds of thousands to millions of dollars, largely putting them out of reach of academic researchers, says development economist Abhijit Banerjee of the Massachusetts Institute of Technology.

The emergence of cheap, skilled labor in India and other countries during the 1990s changed that, Banerjee says, because these workers could collect the data inexpensively. At the same time, nongovernmental organizations (NGOs) were proliferating and started looking for ways to evaluate their antipoverty programs.

In 2003 Banerjee and his colleagues Esther Duflo and Sendhil Mullainathan found-

ed an M.I.T. institute devoted to the use of randomized trials, called the Poverty Action Lab. Lab members have completed or begun a variety of projects, including studies of public health measures, small-scale loans (called microcredit), the role of women in village councils, AIDS prevention, and barriers to fertilizer use. The studies typically piggyback on the expansion of an NGO or government program. Researchers work with the organization to select appropriate measures of the program's outcome and hire an agency to collect or spot-check the data.

Doling out interventions by lottery may seem unethical, Duflo says, but "in most instances we do not know whether the program will work or whether it is the best use of the money." Many programs start as small pilots, she points out. "We just propose to conduct the pilot so that we can learn something." The sponsoring organization may already perceive an intervention as beneficial, in which case it might select a needy, nonrandom group to receive it first, Banerjee says. In many instances, researchers have to randomly assign different communities to the two study groups, because selecting only some individuals from a classroom or neighborhood would be perceived as unfair. "That's the place where we hit the ethical constraint bang-on all the time—what's the unit of randomization?" Banerjee says.

Beyond ethical quandaries, randomized trials are also much trickier to interpret in a social context than they seem, argues Alok Bhargava of the University of Houston. An intervention that causes one change, such as deworming children to see the effects on school absenteeism, may cause others, such as encouraging parents to send their kids to school, he explains. Others contend that experiments are limited because the social programs themselves are. "Helping us to understand which of these programs are effective is very useful," says Mark Rosenzweig of the Kennedy School of Government at Harvard University, "but one should not think these programs will create economic growth that will alleviate poverty." Growth depends more on institutions, such as the status of property rights, which affect how people respond to interventions, he says.

The designers of these experiments are aware of the limits of studying a small group of people in a single place over a small fraction of a lifetime. But they say they are trying to create solid ground from which to generalize. "If you have a number of these things, you start to build up a picture," says Michael Kremer, a Harvard University affiliate of the M.I.T. lab. "Development goes through a lot of fads. We need to have evidence on what works."

JR Minkel is a frequent contributor.

NEED TO KNOW: TRIAL RUN

The idea of deploying randomized prospective trials for economic development got a big boost early this decade, when results began coming in from a Mexican government program that offered cash incentives to parents who sent their kids to school and took them to the clinic regularly. The government rolled out the program, called Progresa, in the late 1990s. Officials solicited outsiders to study the outcome, which was found to be generally positive. For instance, Progresa boosted secondary school enrollment by 8 percent for boys and 14 percent for girls, and it cut the incidence of illness by 12 percent among children younger than five years. The success of the program "was a sea change," says Shanta Devarajan, the World Bank's chief economist for South Asia.

BIOLOGY

Cold War Clues

ATOMIC TESTS ALLOW CARBON DATING OF BABY BOOMERS

BY CHRISTINE SOARES

Frustration was the mother of invention for Jonas Frisén of the Medical Nobel Institute in Stockholm, when he set out to map the ages of various body parts in living people. As a neuroscientist working toward regenerating brain tissue, he would have found it handy to know whether some or all of the human brain ever regenerates naturally and, if so, how often. "I was pretty annoyed," Frisén says, because the question was unanswerable for humans: the techniques used to tag cells and watch their life cycles in animals employ toxic chemicals that could not ethically be used on people.

Then Frisén learned of a natural tag unique to people born after 1955, when aboveground testing of nuclear weapons increased substantially. The explosions, which stopped after the 1963 Limited Test Ban Treaty, threw enormous amounts of carbon 14 isotope into the atmosphere that quickly diffused around the globe. Plants incorporated the carbon 14 into their cells, animals ate the plants, and people ate both, absorbing the isotope into their own cells and creating a trail Frisén could follow.

FOR THE AGES: Aboveground nuclear tests led to a nearly 900 percent spike in atmospheric carbon 14 that left traces in human tissue useful for dating.

CORBIS

He teamed up with Bruce A. Buchholz of Lawrence Livermore National Laboratory, who had already used atomic-era carbon 14 traces to determine the age of plaques in brain tissue samples from Alzheimer's victims. Frisén's project was much more complex, however, because cells are chock-full of proteins that are continually being produced and degraded. To learn the true age of a cell, Frisén needed something that is formed at the moment of the cell's birth and remains stable throughout its life, which meant he needed to isolate and date its DNA.

By measuring the amount of carbon 14 incorporated into the DNA molecule at its creation, then correlating it with atmospheric carbon 14 levels, Frisén finally had a test that could give him answers. As it turns out, the team reported in the journal *Cell* this past summer, many parts of our bodies are much younger than the whole. Jejunum cells from the gut tissue of subjects in their mid-30s were less than 16 years old. Skeletal muscle from two subjects in their late 30s was just over 15 years old.

But the big surprises were in the brain, where Frisén tested cells from the cerebellum and occipital cortex. Neurons in both tissues dated to a period at or near the subjects' birth, indicating that those parts of the brain are formed at the beginning of life and do not normally turn over.

Frisén thinks it is too soon to know whether his finding means less hope for therapeutic approaches to regenerating damaged brain tissue. "I wouldn't say so. Perhaps a little less hope than if there was ongoing vigorous regeneration," he admits. But he is eager to do follow-up studies on brain tissue from stroke victims, for example, to see if those neurons do regenerate after injury. He also plans to study heart muscle and the insulin-producing beta cells of the pancreas, both tissues whose regenerative capacity is hotly debated and both of great therapeutic interest. Frisén hopes other researchers will employ the technique as well to study their favorite organs.

Bomb-era carbon 14 levels started dropping rapidly after 1965, sloping downward by 50 percent every 11 years. After 1990, according to Buchholz, the signal left in human cells is faint. Scientists can use this technique indefinitely to date stored tissue samples from the period, Frisén notes. And Buchholz is now employing the method for forensic work. Given the "huge segment of the population" born during the relevant era, Buchholz—a baby boomer himself—says, "the technique will certainly be very useful for the rest of my career."

TOOTHY CARBON DATING

Bruce A. Buchholz of Lawrence Livermore National Laboratory and Jonas Frisén of the Medical Nobel Institute in Stockholm dated the ages of cells based on atomic-age carbon 14 in DNA. As a control, they used tooth enamel. It contains no DNA, but enamel is 0.4 percent carbon and forms at known stages of life. By matching atmospheric carbon 14 levels with isotope traces in the enamel, they found they could determine a person's age within 1.6 years. Forensic age estimates typically rely on tooth wear and provide only a five- to 10-year range. Buchholz used carbon 14 dating of teeth to help identify remains from victims of last year's tsunami and has offered aid in identifying Hurricane Katrina victims.

NANOTECH

Cheaper Dots

NEW PROCESS SLASHES THE COST OF QUANTUM DOTS **BY GRAHAM P. COLLINS**

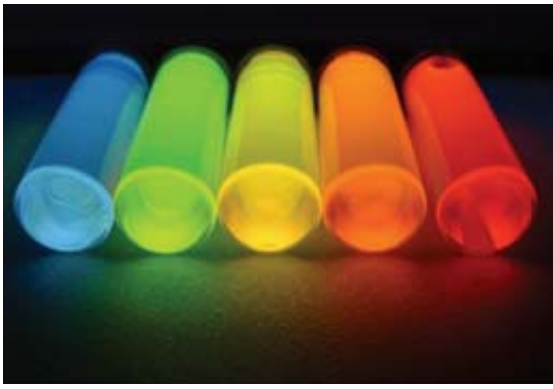
Quantum dots are fluorescent nanoparticles of semiconducting material. The color of light that they emit varies with the size of the dot, shifting toward the blue end of the spectrum as they get smaller. Proposed applications for dots include lasers, color displays and bioimaging. But realizing their commercial potential has been slow, because the dots are expensive; they go for at least $2,000 a gram, largely because of pricey solvents used in their manufacture. Now a team at Rice University has demonstrated that much more economical solvents work just as well, slashing the outlay on materials. They have also determined how properties of the solvent affect dot formation, which may help in developing large-scale systems of production.

Indeed, the desire to scale up existing

synthesis methods led chemist Michael S. Wong and his colleagues at Rice to the price-saving technique. In particular, they were interested in cadmium selenide dots, one of the most studied varieties. The commonly used recipes for cooking up cadmium selenide dots were 10 years old and involved heating precursor chemicals to temperatures of around 250 degrees Celsius in special solvents.

The researchers quickly realized that the cost of the standard recipes was prohibitive, and 90 percent of the material's expense came from the solvent octadecene. They then studied the literature to try to determine what made octadecene so special. For example, it is a long-chain hydrocarbon, which means it is compatible with oleic acid, another component of the recipe. But after an extensive review, they decided this molecular structure might not be so important after all.

What *was* important? Clearly, the solvent had to have a high boiling point and resist decomposing—and be cheaper than octadecene. The chemists were familiar with so-called heat-transfer fluids that met all three of those requirements. Heat-transfer fluids, however, are not used as solvents, being neither as clean nor as pure as typical solvents. But fortunately, that is not an issue for quantum dot manufacture.



QUANTUM DOTS of cadmium selenide fluoresce in different colors according to the dot size.

SUBASHINI ASOKAN AND MICHAEL S. WONG *Rice University*

So the team tried making quantum dots in two fluids, Dowtherm A and Therminol 66. Sure enough, the dots formed, much like in the conventional expensive octadecene. "We were very excited," Wong recalls. Using the cheaper of the two, Dowtherm A, cut the costs by 80 percent. The group is now also making dots of different composition than cadmium selenide using the same fluids.

The dots produced were somewhat smaller than those made using octadecene. After some study, the researchers came up with a mathematical model to account for those differences. The

model predicts the rate of dot growth according to three quantities: the solvent's viscosity, the solubility of cadmium selenide in the solvent and the surface free energy, which relates to the stability of the quantum dot's surface in the presence of the solvent.

The number of dots made is still small—the team created only about 20 milligrams per batch. Batch processing may be suitable for applications that need only grams of dots, Wong says, but "the next step on the horizon is to develop a continuous-flow system for making quantum dots" in kilogram amounts. Because the quantum dot chemistry is very touchy, "we need to learn how to control it well in a reactor, so our mathematical model is a great starting point."

DIABETES

Grow Your Own

GETTING A DIABETIC PANCREAS TO REGROW ITS ISLETS

BY PHILIP E. ROSS

In 2000, when doctors at the University of Alberta in Edmonton announced that they had successfully transplanted pancreatic islets into diabetic patients, people around the world began clamoring for the therapy. Because islets secrete the right amount of insulin at the right time, they can control the concentration of glucose in the blood far more precisely than a patient can do, even with five or six injections a day. But islets must be harvested from suitable organ donors, and there just are not enough to go around.

Now another group, led by Alex Rabinovitch at the same university, is targeting a far better class of donors: the patients themselves. By administering chemical signals, or growth factors, they hope to provoke the patients' pancreas to grow its own beta cells, which are the insulin-making engines of the islets. It would not be the first such use of a growth factor; for instance, erythropoietin stimulates the production of red blood cells. This time, however, the object is not to speed up a process but to restart one that has stopped.

In type 1 diabetes, the beta cells essentially die off, victims of a ferocious autoimmune reaction. But in the late 1970s autopsies revealed that a very few beta cells continue to bud off from the pancreatic ducts, apparently reproducing the original process by which these cells are born. Diabetologists had long regarded duct cells as mere chaff, to be removed from the islet tissue they were trying to transplant. Now, however, mounting evidence suggests that that chaff may be pure gold.

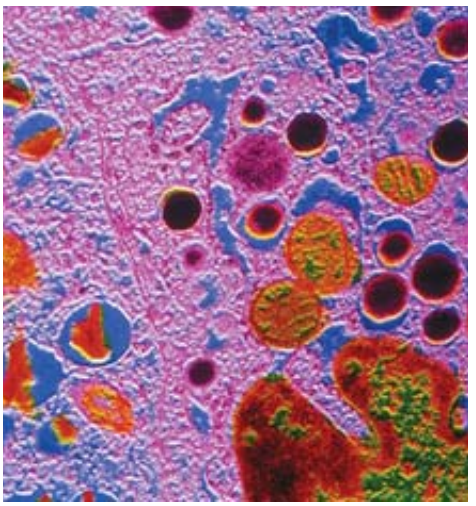
"Our colleagues in surgery have a paper saying that patients with the best insulin response to islet transplantation were those whose islets were most 'contaminated' with duct cells," Rabinovitch says. Why do patients benefit from added duct cells, seeing that they have plenty of their own intact? He does not know for sure but suspects that the duct cells need to be cheek by jowl with the islets to receive chemical feedback. He has been studying many possible growth factors and has struck pay dirt with two of them.

One is gastrin, which is made in the stomach, and the other is epidermal growth factor, or EGF, an all-purpose growth chemical. Their role in beta-cell generation was first suggested in 1993 by Stephen Brand and his colleagues at Harvard Medical School. They found an unusually large number of beta cells in mice with mutations that caused them to churn out more than the usual amount of the two factors. Rabinovitch reproduced the result by administering the factors to a strain of mice bred to model autoimmune diabetes.

In newly diabetic mice, the results were spectacular. After two weeks of treatment, the beta-cell mass had tri-

DANGER FROM RAISING THE DEAD

Gastrin and epidermal growth factor show an ability to resurrect insulin-producing beta cells. Their side effects, however, are not clear yet and are being explored in human trials. Gastrin, at least, has a 10-year track record in ulcer patients who take proton-pump inhibitors. "All these patients have high blood levels of gastrin, not as high as what we'll give, but still two to three times higher than normal," says Alex Rabinovitch of the University of Alberta in Edmonton, who is leading the study. Yet if these growth factors disappoint, he says, plenty of others are under investigation. In unpublished animal studies, some of them appear to do an even better job of revving up beta-cell production.



BETA CELLS (*green* and *orange*) in the islets of the pancreas secrete insulin. Growth factors could restore beta cells lost in type 1 diabetes.

CNRI/PHOTO RESEARCHERS, INC.

pled, the insulin content had increased eightfold, and the blood glucose concentration had fallen to normal levels. It did not go so well in mice with long-standing diabetes: their glucose levels fell substantially, yet they needed some immunosuppressive medication. That drug regimen made possible islet transplantation in the first place, but because it can damage the kidneys, it is suitable only for patients with dangerously uncontrolled diabetes. Even a partial regeneration in patients would at least get around the shortage of donor tissue and would probably require less immunotherapy; native cells would need defense from autoimmunity alone, not from that and organ rejection combined.

Phase II human trials of gastrin and EGF began in August. They should yield results on safety and efficacy by the spring of 2006. The enrolled subjects include those with both type 1 and the more common type 2 diabetes, in which there is no autoimmune reaction and the islets make insulin, but not enough.

A great result, Rabinovitch says, would be if the type 2 patients no longer needed any insulin and if the type 1 patients could get by with less. A little of the body's own insulin goes a long way, because beta cells that produce it react so sensitively to the momentary rise and fall of blood glucose. The better the glucose control, the better the patient's chances will be for avoiding nerve damage and other long-term complications of diabetes.

EVOLUTION

Lean Gene Machine

OCEAN BACTERIUM HAS THE MOST STREAMLINED GENOME **BY STEVEN ASHLEY**

Some 25,000 genes code for the proteins required to build each human being, a figure representing only 1 or 2 percent of our entire genome. The remainder is "junk DNA"—base-pair sequences that do not directly code for proteins. But where organisms must operate extremely efficiently to endure hostile habitats, evolution has greatly optimized the DNA, shaving the genome down to what some regard as the minimum genetic requirement to create and develop life.

A new champion in this special bantamweight class has emerged. An oceanic bacterium, *Pelagibacter ubique* (or SAR11), one of the smallest self-replicating cells known, has only 1,354 genes, investigators report in the August 19 *Science*. "SAR11 has almost no wasted DNA," says Stephen J. Giovannoni, the microbiologist who led the collaboration between research groups at Oregon State University and Diversa Corporation (a prospector for useful natural pharmaceuticals and enzymes). Stripped down to the bare essentials for living, the bacterium's gene sequence has almost none of the clutter that most genomes have amassed over time: no duplicate entries, no viral genes, no introns or noncoding sequences. (Many organisms—namely, parasites and symbionts—have smaller genomes, but they rely on others to perform bodily housekeeping tasks.)

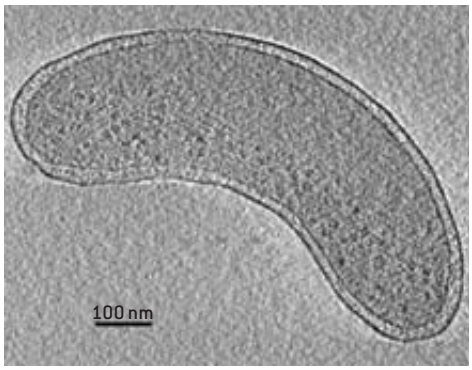
Evolutionary biologists believe that the overhead required to maintain junk DNA is justified because it preserves a reservoir of potentially useful genes for a new or chang-

ing environment. *P. ubique* apparently has traded potential for economy in a big way, making its genome the equivalent of a fuel-stingy Volkswagen Beetle, whereas human DNA is more akin to a gas-guzzling Hummer pulling an RV trailer plus a boat.

Paring down the bacterium's genome appears to be evolution's way of conserving genetic energy for an abundant organism in the face of limited resources. First identified in 1990, SAR11 may be the most numerous bacterium on earth (about 10^{28} cells). It inhabits all oceans and nearly the entire water column. In fact, the tiny bug's combined weight exceeds that of all the fish in all the world's seas.

SAR11 eats dead organic matter that is dissolved in saltwater, what Giovannoni refers to as "a very dilute chicken soup." Because carbon is always available, the minuscule ocean dweller need not develop special biosynthetic pathways and metabolic systems to withstand feast and famine. Indeed, *P. ubique*'s minimal genome is related to its thrifty lifestyle. The shorter the DNA sequence that has to be copied each generation, the less work involved.

The pattern of gene reduction supports the hypothesis that genome streamlining occurs in a very large population for faster or more efficient genome replication, according to Stephen J. Freeland, an evolutionary biologist at the University of Maryland, Baltimore County. "The ability of natural selection to discriminate tiny differences in fitness is affected very much by population size," he explains.



DANIELA NICASTRO AND J. RICHARD MCINTOSH *Boulder Laboratory for 3-D Electron Microscopy of Cells, University of Colorado*

NO JUNK HERE: The bacterium *Pelagibacter ubique* thrives with greatly stripped-down DNA.

BIG COG IN THE CARBON CYCLE

The smallest, simplest free-living cell plays a critical role in the cycling of oceanic carbon, a part that is only now becoming clear. The sheer abundance of *Pelagibacter ubique* means the bacterium is a major consumer of the organic carbon in the oceans, which nearly equals the amount of carbon dioxide in the entire atmosphere. As the bug consumes the dissolved carbon, it produces nutrients required by algae for growth; the algae then convert carbon dioxide into oxygen. Ocean algae are responsible for producing about half the photosynthetic oxygen on the planet.

In smaller groups, random genetic drift may determine the fate of genes. With so many copies of the bacterium in the ocean, however, selection can discriminate subtle fitness effects. Essentially, there were so many of the little critters living in a huge, stable environment that they did not go through stress-induced evolutionary bottlenecks during which nonadaptive DNA sequences often get carried along with highly adaptive genes. During the course of a billion years or more, natural selection thus reduced *P. ubique*'s genome size to save on the metabolic burden of replicating DNA with no adaptive value.

"Although natural selection is about the survival of the fittest, what's fittest changes with the specific circumstance," Freeland concludes. The ubiquitous SAR11 embodies just another example of this phenomenon.

PLANETS

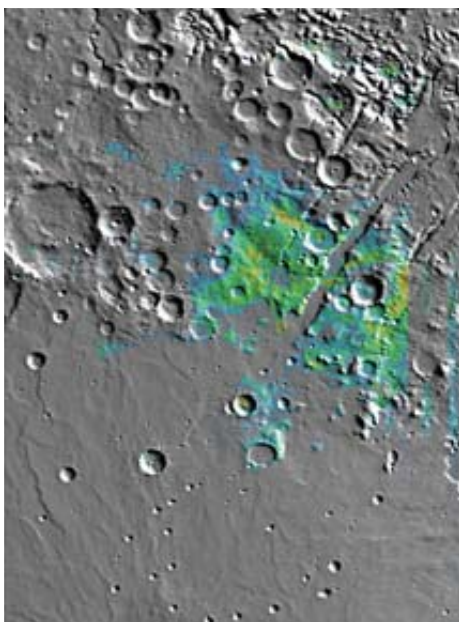
Martian Claymation

AN ANCIENT, WATERY MARS WAS NOT ALWAYS AN ACID BATH **BY GEORGE MUSSER**

In one of the less subtle episodes of the original Star Trek series, hippies hijack the *Enterprise* to get to a planet that looks like paradise but turns out to be a grim, acid-soaked purgatory. Over the past two years, a similar allegory has played itself out in Mars science. Drawn to Mars largely by signs of past Earth-like conditions, researchers have finally found definitive relics of gently lapping seas and balmier skies: in particular, deposits of sulfate salts. To form those sulfates, though, the ancient seas must have been acidic enough to burn off skin.

But a different tale is told by another class of minerals, fully mapped only recently: clays. They suggest that even before the era of the sulfates, Mars was drenched in water safe enough to dunk a hand in. "The clays indicate alteration with a lot of water," says François Poulet of the University of Paris–South, a member of the discovery team. "The sulfate indicates a second step in the climate of Mars."

The Viking missions of the mid-1970s and subsequent ground-based telescopic observations saw hints of clay, but they were ambiguous, and mid-infrared spectrometers on NASA's orbiting Mars Global Surveyor and Mars Odyssey probes came up blank. The OMEGA spectrometer on the European Space Agency's Mars Express orbiter has gone where no spectrometer has gone before, covering near-infrared wavelengths and offering 10 times the resolution of earlier instruments. It first detected clays (technically called phyllosilicates) last year, but the data were spotty, and some scientists wondered whether the clays were merely superficial layers, the result of gradual weathering rather than thorough soaking.



WATER-RELATED CLAY minerals (*color*) show up in the Nili Fossae/Syrtis Major region on Mars.

"CRUSTAL FORMATION, VOLCANISM, AND ALTERATION IN THE SYRTIS MAJOR REGION REVEALED BY OMEGA DATA," BY J. MUSTARD ET AL., LUNAR AND PLANETARY SCIENCE CONFERENCE, 2005, AND J.-P. BIBRING/OMEGA/ESA

At a September meeting of the American Astronomical Society, Poulet described how clays now show up on numerous small and widely dispersed outcrops, as well as in crater debris and rock strata—evidence for a substantial deposit. The terrain appears to be the oldest on the planet, arguing against a gradual process. "They're located in the

CARBONATE CONUNDRUM

The clays reanimate one of the biggest mysteries about Mars: that it seems to have every breed of water-related mineral except the one that scientists thought would be the most abundant—carbonate. If Mars once had a thick carbon dioxide atmosphere and liquid water, the surface should be stacked high with limestone and other rocks that form when carbon dioxide reacts with water. But the only carbonates seen so far are thin coatings on dust grains.

Acidic conditions, generated by volcanic emissions of sulfur dioxide, would have neatly explained the absence of carbonate deposits on Mars, because acid dissolves them away or prevents them from forming altogether. In fact, by forcing carbon dioxide to remain in gaseous form, sulfurous waters would have greatly prolonged the greenhouse effect on early Mars, as Jeffrey M. Moore of the NASA Ames Research Center, Alberto Fairén of the Autonomous University of Madrid and others have recently argued. That, in turn, would explain how Mars had enough time to lay down thick deposits of sulfates and carve intricate valley networks. The clays may force them back to the drawing board.

older, more battered-looking exposures," says geologist Ray Arvidson of Washington University in St. Louis. These areas are devoid of sulfates. Almost all the chemical varieties of clay are represented, notably smectites, which on Earth form in neutral to alkaline water. In addition to the ancient deposits, OMEGA saw thin coatings of dark clay of unknown origin.

To be sure, spectra measured from orbit can be tricky to interpret, and the clays have yet to be confirmed by rovers on the ground. Mineralogist Richard Morris of the NASA Johnson Space Center says, "For something as important as phyllosilicates, I'd like to see two things point to it"—that is, two independent lines of evidence. Tantalizingly, Diana Blaney of the Jet Propulsion Laboratory, a member of the Mars Exploration Rover team, announced at the September meeting that a rock found by the Spirit rover, christened Independence, is claylike. Next March, NASA's Mars Reconnaissance Orbiter is due to arrive, carrying a spectrometer that covers the same wavelengths as OMEGA but at 10 times the resolution—and, crucially, a different viewing angle. Combining the two instruments' data will help isolate the confounding effects of atmospheric dust.

Another question is whether novel chemistry, unknown on Earth but common on Mars, could be fooling geologists. NASA plans to launch a lander in 2007 to conduct experiments on the Martian soil. Phoenix, so named because it is basically a copy of the ill-fated Mars Polar Lander of 1999, carries four small vials of water to wet the soil and measure its pH and composition.

If researchers confirm that clays exist, then one of the greatest mysteries in Martian science will deepen—specifically, the lack of carbonates. "If you have an alkaline solution, you should get carbonates, so where are the carbonates?" Poulet asks. "It's clearly a problem." Maybe it will just take an even more sensitive instrument to find them, or maybe early Mars, for some still unknown reason, was less of an Eden than scientists suspect it was.

BY THE NUMBERS

Forgive Us Our Debts

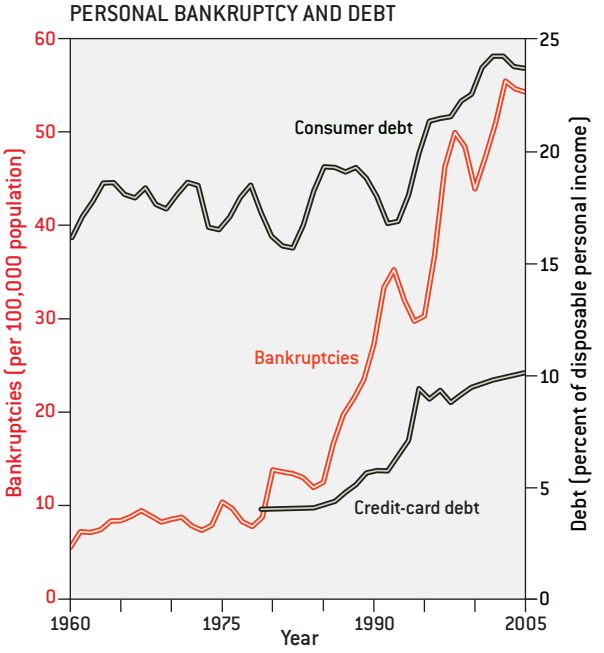
EXPLAINING THE RISING TIDE OF BANKRUPTCY **BY RODGER DOYLE**

Bankruptcy rates in the U.S. have been growing for more than two decades despite generally rising levels of personal income. The most prominent explanation puts the blame squarely on credit cards, which became vastly more popular in the past 30 years. University of Pennsylvania law professor David A. Skeel, who has done the most comprehensive recent analysis of the subject, notes that a 1978 Supreme Court decision allowed credit-card companies to charge the interest rate allowed in their state of incorporation. As a result, many incorporated in the high-rate states of Delaware and South Dakota. Being able to charge high rates throughout the country, they could afford to issue cards to those with limited ability to repay. Many high-risk cardholders, overburdened with debt, filed for bankruptcy.

Skeel also notes that the impersonality of credit-card borrowing may have helped weaken the moral imperative to repay debts: in the 1960s a prospective borrower met face-to-face with a bank lending officer, but today the borrower gets credit by responding to a junk-mail offer. Another aspect of the credit-card problem is the failure of lenders to police their own loans.

Other developments also fueled the rise in bankruptcy, including medical bills. A Harvard University study found that about a quarter of filers cited illness or injury as the specific reason for their troubles. Loss of jobs probably also drove some credit-card holders into bankruptcy. Other possible contributors include the growth of the gambling industry in recent years and the Supreme Court's 1977 decision to allow lawyers to advertise directly to the general public.

Changes in bankruptcy law apparently have had little effect on filings. The Bankruptcy Reform Act of 1978 was designed to make it easier for consumers to pay off debts and start anew. As under previous acts, impecunious debtors could file for complete discharge of debts under Chapter 7, and debtors with substantial assets could arrange for partial repayment under Chapter 13. Most filers opted for the more generous provisions of Chapter 7. During the six years following implementation of the act, filings rose substantially. The act was amended in 1984 to curb opportunistic petitions. As the graph dramatically illustrates, however, filings went in the opposite direction than expected. Evidently, easy credit and other debt-creating forces have been more powerful.



SOURCES: Bureau of Economic Analysis and Administrative Office of the U.S. Courts. Consumer credit excludes mortgage debt.

The latest legal effort is the Bankruptcy Abuse Prevention and Consumer Protection Act of 2005, which went into effect in October. The new act lays down far more stringent standards for debtors, including a means test to qualify for Chapter 7 relief. Despite the new restrictions, bankruptcy experts tend to be skeptical or noncommittal about the effectiveness in reducing filings.

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RODGER DOYLE

FURTHER READING

The Impact of the Bankruptcy Reform Act of 1978 on Consumer Bankruptcy. Ian Domowitz and Thomas L. Eovaldi in *Journal of Law and Economics*, Vol. 36, No. 2, pages 803–835; October 1993.

The Bankruptcy Puzzle. F. H. Buckley and Margaret F. Brinig in *Journal of Legal Studies*, Vol. 27, No. 1, pages 187–207; January 1998.

Why It Pays to File for Bankruptcy: A Critical Look at the Incentives under U.S. Personal Bankruptcy Law and a Proposal for Change. Michelle J. White in *University of Chicago Law Review*, Vol. 65, pages 685–732; Summer 1998.

The Fragile Middle Class: Americans in Debt. Teresa A. Sullivan, Elizabeth Warren and Jay Lawrence Westbrook. Yale University Press, 2000.

Marketwatch: Illness and Injury as Contributors to Bankruptcy. David U. Himmelstein, Elizabeth Warren, Deborah Thorne and Steffie Woolhandler in *Health Affairs* (Web exclusive), February 2, 2005. www.healthaffairs.org

THE 2005 NOBEL PRIZES

Almost 110 years ago Alfred Nobel left a will outlining how to award what would become the most recognized academic prize in the world. This December 10, once again, the Royal Swedish Academy will impart the diplomas and medals that accompany the prizes, intended for scientists whose work has contributed to the benefit of humanity. For more details, visit www.sciam.com/ontheweb and nobelprize.org
—Sarah Todd Davidson

- **PHYSICS: Roy J. Glauber, for his 1963 research on how coherent light (light waves traveling at the same frequency and phase) behaves at the quantum scale; and John L. Hall and Theodor W. Hänsch, for their description in 2000 of ways to measure precisely the frequency of that laser light.**

- **CHEMISTRY: Yves Chauvin, Robert H. Grubbs and Richard R. Schrock, for their development from the 1970s to the 1990s of so-called metathesis reactions, which allow new molecules to be built by replacing the ends of carbon compounds with different atoms.**

- **PHYSIOLOGY OR MEDICINE: Barry J. Marshall and J. Robin Warren, for their discovery in the 1980s that the bacterium *Helicobacter pylori* plays a significant role in stomach ulcers and inflammation.**

- **ECONOMICS: Robert J. Aumann and Thomas C. Schelling, for their nearly half a century of work employing game theory to better understand human conflict and cooperation.**

PUBLIC HEALTH

Killer Resurrected

The 1918 pandemic flu virus is back, at least in the lab. After fishing out the virus's genes from preserved tissue samples, Jeffery Taubenberger of the Armed Forces Institute of Pathology and his colleagues report in the October 6 *Nature* that the virus was not a combination of human and avian flu strains, as was the case for other, milder pandemics. Rather the 1918 virus probably leaped whole into the human population from another host. That means the H5N1 avian flu now raging throughout Asia and spreading to Europe might be able to do the same. In fact, it may be deadlier. In the October 7 *Science*, Terrence Tumpey of the Centers for Disease Control and Prevention described the re-creation of the 1918 virus from the genome sequence. The revivified killer was lethal to mice initially infected with as few as 1,000 virus particles, whereas some H5N1 virus isolates have killed mice infected with just 10 or 15 particles. *—Christine Soares*

NANOTECH

One Small Step

Scientists have created the first molecule that can move in a straight line by itself on a flat surface by mimicking how a person walks. The molecule—9,10-dithioanthracene, or DTA—is made of a coal-tar derivative linked to a pair of sulfurous organic compounds. When heated, the linked compounds moved in alternation so only one was lifted from a copper surface at a time. The planted "foot" kept the molecule from stumbling or veering off course, even when pushed or pulled with a fine probe.

In tests, DTA took some 10,000 steps without the assistance of rails or grooves and without losing its balance once. The investigators at the University of California, Riverside, and their colleagues suggest that the project could lead to molecular computers, with DTA or like molecules operating in nano-abacuses. Peruse the October 14 *Physical Review Letters* for more details.
—Charles Q. Choi

MARINE BIOLOGY

Going the Distance

A female great white shark has completed a transoceanic journey of 20,000 kilometers in nine months, a feat that has astounded scientists. Ramón Bonfil of the World Conservation Society in New York City and his colleagues captured and tagged the animal off the coast of South Africa in November 2003. The creature made its way to western Australia in 99 days and was back in African waters in August 2004. The shark spent about two thirds of her time near the surface, indicating that she may have relied on celestial cues to navigate. More than just a speed record for a marine organism, the shark's journey suggests that distant great white populations may mix. It also means that saving this endangered species may be more difficult, because even if nations protect the great white locally from human fishing, the shark would be vulnerable in international waters. *—Philip Yam*

NICOLE, a great white shark named after actor Nicole Kidman, has set a long-distance speed record among marine animals.

AP PHOTO (*top*); M. MEYER *MCM* (*bottom*)

AIDS

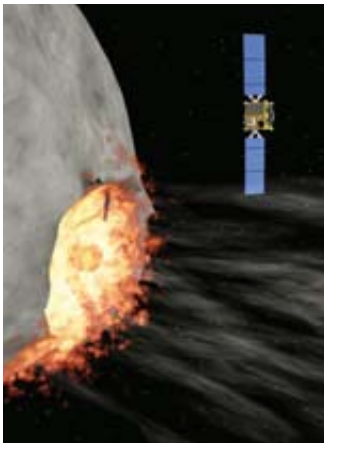
Weakening HIV?

The AIDS virus may have lost strength, at least in terms of how well it multiplies. Using HIV-1 from untreated patients, molecular virologists tested samples from 1986 to 1989 and from 2002 to 2003. After dosing human blood and immune cells with the viruses, they found the older HIV replicated significantly better than more recent samples and also appeared less sensitive to anti-HIV drugs. HIV-1, the most common strain of the virus worldwide, may be adapting to humans as it passes from person to person and becoming less efficient at multiplying to guarantee its continued survival in the host. The virus could fade into a nonlethal form "in 20, 200 or 2,000 years; there is no way to tell without further studies," says Eric Arts of Case Western Reserve University, member of a team that includes researchers from the Institute of Tropical Medicine in Antwerp. The results appear in the October 14 *AIDS*. —*Charles Q. Choi*

NEAR-EARTH OBJECTS

Tilting at Asteroids

Don Quixote may never have reached the unreachable star, but the Man of La Mancha's namesake (with a modern Spanish spelling) could soon fly to an asteroid. The European Space Agency has chosen two asteroids, designated 2002 AT4 and 1989 ML, one of which will be a target for its Don Quijote mission. The undertaking, to practice deflecting asteroids away from Earth, will send out two spacecraft. The first, the roughly 380-kilogram Hidalgo, named after Don Quixote's noble rank, will impact the chosen asteroid at some 48,000 kilometers per hour. The second, dubbed Sancho after the knight's squire, will rendezvous with and circle the asteroid about six months beforehand to observe the asteroid's orbit before and after Hidalgo's impact. The orbiter will also monitor readings from seismometers it will have deployed on the rock. (Neither 500-meter-wide asteroid is close to crossing Earth's orbit.) The agency will decide which asteroid to attack in 2007, and the mission may depart Earth in 2011. —*Charles Quixote Choi*



DODGE THIS: Don Quijote mission would smash a spacecraft into an asteroid while another watched.

ESA/DEIMOS SPACE

PHYSICS

Going through the Brownian Motions

In addition to relativity, Albert Einstein explained Brownian motion, the dance of minute particles when suspended in fluids, by showing that impacts with surrounding molecules could create this random jittering. Theorists have argued that Brownian motion may not be completely random, as Einstein predicted, and now experimentalists have confirmed it. They tracked micron-size plastic and glass spheres in water with lasers at microsecond intervals and nanometer-length scales. Their results validate a corrected form of the standard theory describing Brownian motion, wherein the inertia of the fluid makes the trajectories of the particles more predictable for much longer than previously expected. The findings, published October 11 online by *Physical Review Letters*, are fundamental to understanding the dynamics of a living cell and building structures at the nanoscale, says biophysicist Ernst-Ludwig Florin of the University of Texas at Austin. —*Charles Q. Choi*

BRIEF POINTS

- **Screening for C-reactive protein as a cardiovascular risk factor may not help, because the protein typically occurs with traditional risk factors, such as smoking, high blood pressure and obesity.**

  Archives of Internal Medicine, October 10

- **Losing consciousness on falling asleep results not because parts of the brain are shutting down but because the connections among different areas cease.**

  Science, September 30

- **The Hall effect, the sideways deflection of electrons by a magnetic field, can also occur in phonons—or vibrations in a crystal lattice—even though phonons are not charged. The deflection showed up as a slight temperature variation across a sample.**

  Physical Review Letters, October 4

- **A gene called *SEPS1* underlies inflammation. Ordinarily, the gene helps to clear out a cell's faulty proteins, but individuals who had an impaired *SEPS1* variant suffered from higher levels of inflammation.**

  Nature Genetics online, October 9

Mr. Skeptic Goes to Esalen

Science and spirituality on the California coast

BY MICHAEL SHERMER

The Esalen Institute is a cluster of meeting rooms, lodging facilities and hot tubs all nestled into a stunning craggy outcrop of the Pacific coast in Big Sur, Calif. In his 1985 book, *"Surely You're Joking, Mr. Feynman!"* Nobel laureate physicist Richard Feynman recounts his experience in the natural hot spring baths there, in which a woman is being massaged by a man she just met. "He starts to rub her big toe. 'I think I feel it,' he says. 'I feel a kind of dent—is that the pituitary?' I blurt out, 'You're a helluva long way from the pituitary, man!' They looked at me, horrified … and said, 'It's reflexology!' I quickly closed my eyes and appeared to be meditating."

With that as my introduction to the Mecca of the New Age movement, I accepted an invitation to host a weekend workshop there on science and spirituality. Given my propensity for skepticism when it comes to most of the paranormal piffle proffered by the *prajna* peddlers meditating and soaking their way to nirvana here, I was surprised the hall was full. Perhaps skeptical consciousness is rising!

It was in the extracurricular conversations, however, during healthy homegrown meals and while soaking in the hot tubs, that I gleaned a sense of what people believe and why. Once it became known that Mr. Skeptic was there, for example, I heard one after another "How do you explain *this*?" story, mostly involving angels, aliens and the usual paranormal fare. But this being Esalen—ground zero for all that is weird and wonderful in the human potential movement—there were some singularly unique accounts.

One woman explained the theory behind "energy work," a combination of massage and adjusting the body's seven energy centers called chakras. I signed up for a massage, which was remarkably relaxing, but when another practitioner told me about how she cured a woman's migraine headache by directing a light beam through her head, I decided that practice and theory do not always match. Another woman warned about the epidemic of satanic cults. "But there's no evidence of such cults," I countered. "Of course not," she explained. "They erase all memories and evidence of their nefarious activities."

One gentleman recounted a lengthy tantric sexual encounter with his lover that lasted for many hours, at the culmination of which a lightning bolt shot through her left eye followed by a "blue-light-being child" entering her womb, ensuring conception. Nine months later friends and gurus joined the couple in a hothouse, sweating their way through their own "rebirthing" process before the mother gave birth to a baby boy. The father then told him that he would need to become an athlete in order to get into college; two decades later this young man became a professional baseball player. "How do you explain *that*?" I was asked. I quickly closed my eyes and appeared to be meditating.

A "blue-light-being child" entered her womb.

People have and share such experiences and impart larger significance to them because we have a cortex big enough to conceive of such transcendent notions and an imagination creative enough to concoct fantastic narratives. If we define the spirit (or soul) as the pattern of information of which we are made—our genes, proteins, memories and personalities—then spirituality is the quest to know the place of our essence within the deep time of evolution and the deep space of the cosmos.

There are many ways to be spiritual, and science is one, with its awe-inspiring account about who we are and where we came from. "The cosmos is within us. We are made of star stuff. We are a way for the cosmos to know itself," began the late astronomer Carl Sagan in the opening scene of *Cosmos*, filmed just down the coast from Esalen, in referring to the stellar origins of the chemical elements of life. "We've begun at last to wonder about our origins, star stuff contemplating the stars, organized collections of ten billion billion billion atoms contemplating the evolution of matter, tracing that long path by which it arrived at consciousness.... Our obligation to survive and flourish is owed not just to ourselves but also to that cosmos, ancient and vast, from which we spring."

That is spiritual gold. SA

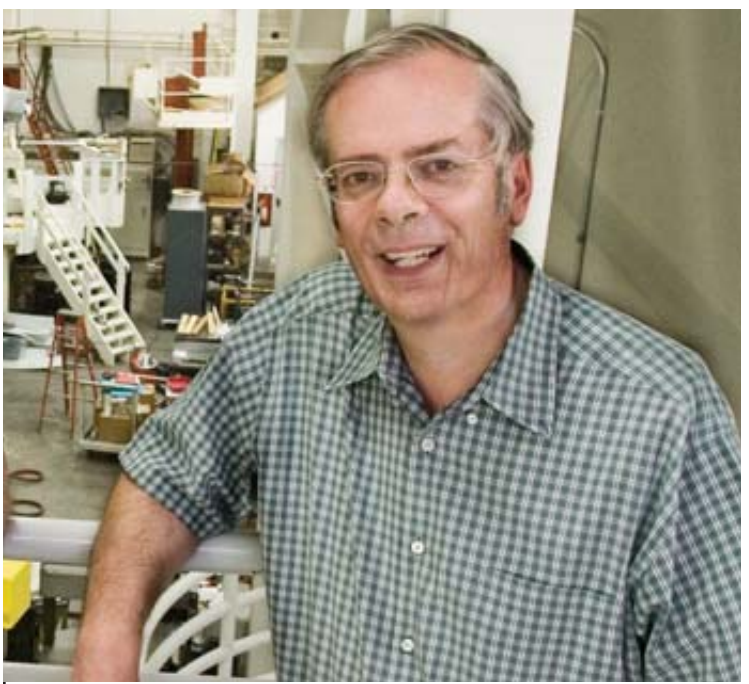
Michael Shermer is publisher of Skeptic *(www.skeptic.com). His latest book is* Science Friction.

BRAD HINES

Breaking the Mold

As the glass cools on his latest giant mirror, Roger Angel keeps pushing telescope design. His next one might even find Earth-like planets around other stars By W. WAYT GIBBS

Not long after he founded the Mirror Laboratory at the University of Arizona's Steward Observatory in 1984, astronomer Roger Angel threw some Pyrex custard cups into a backyard kiln to get a feel for how borosilicate glass melts. He has been playing with fire ever since. On a sweltering July day in Tucson, his seventh giant mirror takes shape in a 200-ton rotating oven underneath the campus football stadium. After a week of heating, the borosilicate blocks in the oven have reached 1,170 degrees Celsius and begun to liquefy, sending molten glass seeping over hexagonal pillars to form a 21-ton honeycomb that is 8.4 meters (28 feet) in diameter, roughly a meter high, but nowhere thicker than three centimeters.



JEFF SMITH *FOTOSMITH*

ROGER ANGEL: MIRROR MASTER

- **Hopes to complete the Giant Magellan Telescope (GMT), which would become the world's largest, with an effective diameter of 21.4 meters.**
- **On polishing the GMT mirrors: "We want to shape each to within a millionth of an inch of the mathematically perfect surface. The tricky part is knowing where, and how hard, to rub next."**

Usually Angel would be in the control room, nervously watching the hot, red carousel spin five times a minute, just fast enough to pull the solid top of the glass honeycomb into the desired gentle curve. To Angel, after all, this process represents the birth both of a new era of astronomy and of the Giant Magellan Telescope (GMT), which, by banding together seven huge mirrors with sophisticated control mechanisms, would outdo the Hubble Space Telescope. And the first time his team made a mirror of this size, the mold leaked two tons of glass, causing months of delay. This first GMT mirror is trickier still, Angel explains, because "it is wickedly curved into an extreme shape that no one has ever made before at this scale."

But Angel had to leave the control center this morning to zip over to a hotel, where he is trying to persuade some of the high rollers of science funding that the GMT is worth its $400-million price. Wendy Freedman, director of the Carnegie Observatories, which is a GMT partner, says she has full confidence in Angel and his mirror-casting abilities. As a cosmologist, Freedman is keen to use the GMT to solve mysteries about dark energy and the "dark ages" before stars and galaxies formed. But those are not the questions that most excite Angel.

"I got into this because we have been searching for another Earth for the past two millennia, and for the first time it seems possible to find planets like ours around other stars," he says in a British accent tempered by almost four decades in the U.S. "You can now sit down and plan seriously what kind of telescopes you would need to image an Earth-like planet and to take its spectra," to look for the chemical signatures of liquid water and alien life.

Angel did those calculations before he came up

with the basic design of the GMT, and he figures that with a bit of luck and some technical wizardry, it may be able to pick evidence of an Earth-like world out of the glare of its star. His characteristically unconventional solution is to arrange the primary collectors like the petals of a daisy, with one symmetric mirror in the center surrounded by six off-axis partners, each distinctly lopsided in shape. The assembly will gather 4.6 times as much starlight as does one of the California Institute of Technology's two 10-meter Keck Telescopes, currently the world's largest.

To snap legible photographs of such planets, GMT will use advanced adaptive optics to make images that are 10 times as sharp as those from Hubble. Each primary mirror will focus its photons onto a separate, 1.1-meter secondary reflector, a thin membrane attached to 672 actuators. Computers will then cancel out much of the atmospheric blurring by making 1,000 subtle adjustments to the shape of each secondary mirror every second. This past summer Angel and his co-workers installed a similar adaptive optics system in the Multiple Mirror Telescope and demonstrated that it boosted the resolving power of the instrument to its theoretical maximum.

NICE SIGHTS: Model of the Giant Magellan Telescope. With mirrors from Roger Angel's lab, the telescope may spot another Earth-like planet.

"When we started describing our plans for the GMT, lots of people told us it would never work," says Peter A. Strittmatter, director of Steward Observatory. Angel faced similar skepticism 20 years ago when he and his colleague Nick Woolf first proposed making large mirrors with honeycomb backs, a strategy that cuts the weight by four fifths and enables the mirror to settle to the temperature of the night air within half an hour.

But the idea worked: as evidence, Freedman points to the twin Magellan Telescopes, precursors of the GMT equipped with two Angel-baked mirrors cast a decade ago and now operating on an Andean mountaintop in Chile. "These are the best natural imaging telescopes in the world, bar none," she avers. Making such mirrors is sufficiently complicated, however, that the Arizona mirror lab is still the only outfit in the world that does it at large sizes.

Although the GMT has high-profile partners backing it—including the Carnegie Institution, the Harvard-Smithsonian Center for Astrophysics and five major universities—it competes with several other mega-telescopes for funding. Two of the competing proposals would scale up the Keck's segmented mirror design. Caltech and others want to build one 30 meters in diameter. The European Southern Observatory is working out plans for a 1.2-billion-euro, 100-meter observatory that it has dubbed the OWL, for Overwhelmingly Large Telescope.

"It may come to a shootout, with only one getting funded," Angel says. To get a foot in the door, GMT proponents opted to spend nearly all their $20 million start-up money on this first off-axis mirror. "All the other groups who are thinking about building really big telescopes are still writing talking points," he observes. "We're the first to do something about it."

With this hurdle nearly cleared, Angel is already turning his attention elsewhere. "By the time things get into the planning stage, Roger has already moved on to the next exciting thing," Freedman notes. "He's just full of ideas that have revolutionized how telescopes are being built." Those ideas now include designs for large telescopes in deep space and at the poles of Earth and the moon.

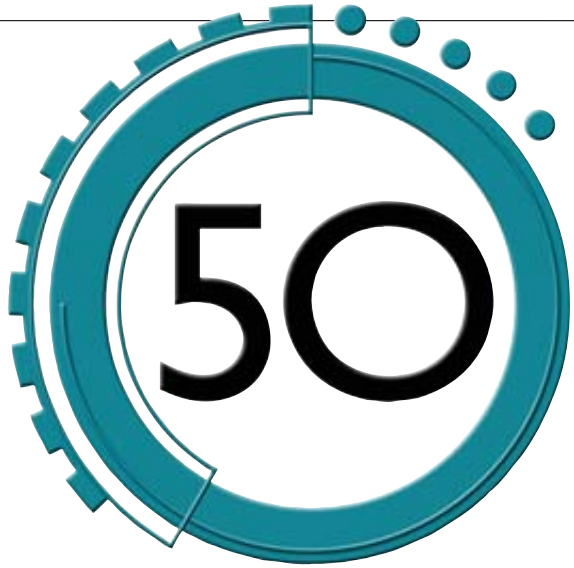
In recent papers, Angel has touted a plateau in central Antarctica at an altitude of 3,300 meters, called Dome C, as a near-ideal observing site. "At Dome C, every quality factor important for ground-based astronomy is better by a factor of two or more than at any other spot on the planet," he enthuses. The polar base completed there last year has on average the least wind, the lowest temperatures, and the driest air of any human outpost. Although the National Science Foundation recently rejected a proposal to construct a two-meter telescope in Antarctica, Angel continues to push the idea. "A 100-meter telescope there could rival the best you could do in space," he argues.

Of course, space has its allure as well. Angel has analyzed the advantages of a 20-meter lunar telescope built in a crater near the moon's south pole by using a spinning pool of reflective liquid as a mirror. "The idea of installing something on the moon makes most astronomers nervous, because it means being the tail on a very large dog," he acknowledges. But by staring for long periods at the same patch of sky above it, such a telescope could peer to the very edges of the visible universe.

Even if the Giant Magellan Telescope finds funding, it is unlikely to see its first light before the middle of the next decade. At age 64, Angel has little hope of living to see any of his more ambitious designs completed. But that doesn't bother him. "It's like building cathedrals," he says. "You can't set the criterion of wanting to see it finished in your lifetime." SA

MARSHA MILLER *University of Texas at Austin*

SCIENTIFIC AMERICAN



Trends

Stem Cells

Search Engines

Flu Preparedness

Solar Cells

Climate Change

Flexible Electronics

HIV Treatments

Open Internet Access

Chinese Environmentalism

Super Wi-Fi

Artificial Life

Mega Jumbo Jets

Brain Scanning

Nanotubes

Green Architecture

Gene Therapy

Silicon Lasers

New technologies appear all the time. Right at this moment scientists are laboring away on the Herculean task of making an artificial cell, a challenge that for the first nine tenths of the 20th century many biologists would have dismissed as an impossibility. Just as important as new invention, though, is the translation of ingenuity into practice. This year's SCIENTIFIC AMERICAN 50 represents a testament to pragmatism. Many of the reports that have wowed the public on advances in nanotechnology or stems cells, to name just two, have taken a big step from graduate-level research toward becoming items for purchase at Wal-Mart or routine therapies at your local hospital.

A Korean researcher gained worldwide attention by achieving a 10-fold improvement in the number of stem cell lines derived from cloned human embryos. Japanese investigators created a solar cell that both generates and stores electricity. For the fourth year, the SCIENTIFIC AMERICAN 50 recognizes people, teams and organizations whose recent accomplishments, whether in research, business or policymaking, demonstrate leadership in shaping both established and emerging technologies.

In naming the winners of 2005, the magazine's editors and their expert advisers identified noteworthy trends related to technology ranging from polymer memory chips to a technique for regenerating damaged heart tissue. As you will see, the awards provide evidence once again that the application of new science, business acumen and policymaking skills not only can help build new machines but also can make a substantial difference in the way we all live.

Woo Suk Hwang

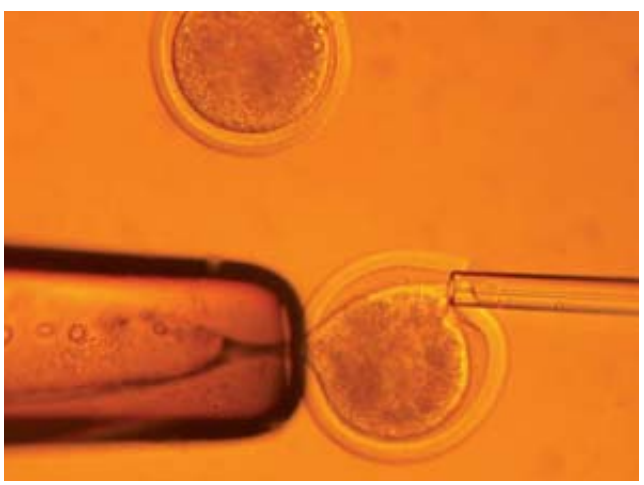
Seoul National University

This Korean researcher racked up a series of important advances in embryonic stem cell technology, including the first lines of cells from patients

While political debate over stem cells continues, the science has made tremendous strides during the past 18 months. In the frenzy of activity, Woo Suk Hwang has stood out for the impact his team from Seoul National University has had on the still nascent field. Hwang has achieved remarkable progress in a short period.

In February 2004 Hwang and his research group reported the first embryonic stem cell line derived from a cloned human embryo. By May 2005 they had used cloning techniques to create 11 stem cell lines, each one the perfect genetic match of a different patient, another first. In August 2005 they introduced the first cloned dog. And in October 2005 they announced a plan for a stem cell bank open to scientists worldwide.

Among those accomplishments, it is the second that truly marks the greatest biomedical advance with the greatest direct repercussions. Hwang and his team harvested stem cells—the self-renewing progenitors of all cells in the body—from cloned early-stage embryos made by slipping the nucleus of a skin cell into a nucleus-free egg. They then went on to demonstrate that the stem cell lines originated from the skin cell donors. This work has revolutionized the field of therapeutic cloning and could bring its promise—to better understand and treat a variety of diseases—a step or two closer to reality.



Placing the nuclei from a skin cell into an empty egg enabled Woo Suk Hwang's Korean research team to establish embryonic stem cell lines.

Hwang's 2004 work illustrated the feasibility of therapeutic cloning, but he was still working out kinks in his protocol. His group began with 242 eggs, but after removing the eggs' nuclei and swapping in those of somatic cells, the investigators produced only 30 blastocysts (week-old embryos), from which they coaxed just one stem cell line into being. In addition, the sources of the replacement nuclei were the egg donors' own cumulus cells, which encircle developing eggs in the ovary. This approach meant that it was possible the egg had spontaneously begun to divide on its own rather than developing by cloning.

What a difference a year makes. Although its blastocyst generation remained largely the same (31 blastocysts, after beginning with 185 eggs), Hwang's team was able to establish 11 stem cell lines, a 10-fold improvement over the previous work. Even more remarkable was that each stem cell line genetically matched one of 11 skin cell donors. These 11 patients—nine have spinal cord injuries, one has a genetic immunodeficiency disorder, and another has type 1 diabetes—consisted of males and females whose ages ranged from two to 56 years. In 10 cases, the nucleus of a skin cell was fused with an egg from a biologically unrelated woman (the remaining woman provided both her own egg and skin cells). Before this work, no one knew whether cell lines could be established using nuclei donated from men or young girls.

Hwang's laboratory reported that the 11 stem cell lines were able to differentiate into the trinity of embryonic cell layers that become all cells in the body. Initial tests also indicated that the cell lines would be compatible with the patients' immune systems. This feature would be critical for clinical uses, such as transplanting stem cells—with their defects corrected—back into patients, but the researchers emphasize that years of further study remain before such treatments might be possible.

Hwang's successes add urgency to many ethical considerations, and the specter of reproductive cloning attempts by fringe scientists lingers (Hwang emphatically denounces such research). But if a time does come when therapeutic cloning becomes the gold standard of care for a variety of diseases, Hwang's innovative and groundbreaking explorations will have paved the way. —*Aimee Cunningham*

LEE JIN-MAN *AP Photo (top)*; UPI PHOTO/WOO SUK HWANG/SEOUL NATIONAL UNIVERSITY *(bottom)*

Google, Inc.

Mountain View, Calif.

The Web's leader in accessing information gets better

Corporate data storage grows by 50 percent yearly. Desktop hard disks routinely hold multiple gigabytes. This ocean of information would not be navigable without superior search tools.

Since it went live in 1998, Google has evolved into the innovator that Microsoft and other established information technology companies now strive to match. Google has extended search capabilities that even help the user organize photographs and word-processing files on a PC desktop. Today Google's users can do more than snag reams of data. They can get the sensation of flying over a graphical landscape, thanks to the company's new mapping tool.

Google has achieved its preeminence by developing novel approaches to navigating the Web, most notably the company's search algorithm that takes into account the number of links to a page from other sites, a signal of its relevance to a particular query. Its success has enhanced the credibility of what can be found on the Web. The company continues to unveil more and more specialized tools for helping us find exactly what we want, quickly and easily.

That flying sensation, for one, results from this year's introduction of Google Earth, which not only maps terrain and finds routes and addresses but allows flightlike movement over three-dimensional landscapes, from the Grand Canyon to the skyscraper chasms of Manhattan. Google's services and software all carry the same significant $0 price tag. (There is a charge for optional enhancements to Google Earth.) Its business genius has exploited revenue derived from subdued and unobtrusive advertising.

Google, Inc., represents a tribute to the vision of Larry Page and Sergey Brin, Stanford University computer science graduate students who launched the search engine in 1998 in a garage in Menlo Park, Calif. They have since graduated to their "Googleplex" headquarters in Mountain View, Calif., and last year had sales of more than $3 billion.

Online, Google continues to offer more and more services. Google Local uncovers location-specific businesses and services. Google Image Search indexes more than two billion pictures on the basis of the pictures' captions and the text adjacent to the pictures.

The company reached out to academic researchers with the unveiling in November 2004 of Google Scholar, which performs searches of scholarly journals. Researchers can sift the contents of peer-reviewed academic journals without having to wade through reams of extraneous material that Web searching too often produces.

The list goes on. Google Video, in its early testing stages, will let a user search videos from selected channels according to their closed captioning or to the descriptive text provided by whoever uploaded the material. Innovation continues to emerge from the company even as the Internet itself grows apace—so that more data will mean more resources, not yet more headaches. —*Lamont Wood*

Sergey Brin (*left*) and Larry Page unveiled Google Earth (*inset*) this year, which allows a computerized flyover of landscapes that reveals the topography of the Grand Canyon or Manhattan's urban canyons.

GOOGLE (*top*); BEN MARGOT *AP Photo* (*bottom*)

Fred Kavli

Founder, Kavli Foundation, Santa Barbara, Calif.

This technology entrepreneur and philanthropist has dedicated millions to help inspire revolutions in astrophysics, nanoscience and brain research

A sensor-manufacturing company generated a fortune for Norwegian-born Fred Kavli. From those earnings, Kavli decided to show his gratitude for the opportunities afforded by the U.S., his adoptive country.

Fred Kavli has always followed the road less traveled. The Norwegian engineer came to the U.S. in 1956, shortly after earning a degree in engineering physics from the Norwegian Institute of Technology. Two years later he launched his own company, Kavlico Corporation, which, on the basis of his designs, patents and leadership, grew into one of the world's largest manufacturers of sensors for the aeronautics and automotive industries.

"I could not, as a foreigner just three years out of college, have started my own business in any other country than the United States," he has said. "For this I will be forever grateful." He made his gratitude tangible in 2000 when he sold his company and established the Kavli Foundation, whose current assets total $99.5 million. Instead of funding research directed at near-term payoffs, as most major funders do, he is supporting nondirected basic research aimed at eventually improving the quality of life for people around the world. The support comes at a crucial time, as federal money for fundamental science is drying up. But it is his willingness to let researchers follow their own dreams that sets him apart [see "He'll Pay for That," by Sally Lehrman; Insights, Scientific American, July 2005].

The foundation has funded basic science research institutes at 10 universities. It got under way in 2001 by contributing $7.5 million to a center for theoretical physics at the University of California, Santa Barbara, and the same amount to an institute for particle astrophysics and cosmology at Stanford University. Funded institutions now also include centers for neuroscience at Columbia and Yale universities and U.C. San Diego; nanoscience at the California Institute of Technology, Cornell University and the Delft University of Technology in the Netherlands; and astrophysics and cosmology at the University of Chicago and the Massachusetts Institute of Technology.

Kavli chooses senior scientists through a network of contacts, negotiates the support of their institutions, and then creates research centers or expands those already in place. In 2004 three of the eight science Nobel Prizes went to researchers affiliated with his institutes.

In addition to the foundation, he started the Kavli Operating Institute in Santa Barbara, which conducts its own research, holds symposia and engages in public education. He recently set out a plan to offer three $1-million awards, biannually, in astrophysics, nanoscience and neuroscience. These prizes, which would be given out in Norway beginning in 2008, would compete with the Nobels in building public awareness and appreciation for science.

In announcing the prizes not far from where he was born 77 years ago, Kavli explained to the audience: "I used to ski across the vast white expanses of a quiet and lonely mountaintop. At times, the heavens would be aflame with the northern lights, shifting and dancing across the sky and down to the white-clad peaks. In the stillness and solitude … I pondered the mysteries of the universe, the planet, nature, and of man. I'm still pondering."

To make a measurable impact on science, Kavli decided to focus on the three areas that continue to intrigue him. "I don't think we'll ever know so much about these subjects that we will run out of questions." —*Michelle Press*

BRAD SWONETZ

Research Leader of the Year
1. Woo Suk Hwang, Seoul National University

Business Leader of the Year
2. Google, Inc.

Policy Leader of the Year
3. Fred Kavli, Kavli Foundation

Other Research, Business and Policy Leaders

Getting Serious about Flu
4. Robert G. Webster, St. Jude Children's Research Hospital (policy)
5. Klaus Stöhr, WHO (policy)
6. Robert B. Belshe, Saint Louis University, and Iomai Corporation (research)
7. NexBio, Inc. (business)

More Power to Solar
8. Edward H. Sargent, University of Toronto (research)
9. Michael Grätzel, Swiss Federal Institute of Technology, and Tsutomu Miyasaka and Takurou N. Murakami, Toin University of Yokohama (research)
10. Hydrogen Solar (business)

Stem Cell Imperative
11. Robert Klein, California Institute for Regenerative Medicine (policy)
12. Stem Cell Sciences (business)
13. R. Michael Roberts, University of Missouri at Columbia (research)

Repairing Broken Hearts
14. Mark T. Keating, Harvard Medical School (research)

Protections for the Earth's Climate
15. Inez Y. Fung, University of California, Berkeley (research)
16. Regional Greenhouse Gas Initiative (policy)
17. Steve Howard, Climate Group (policy)

A Future in Plastics
18. Paul W. M. Blom and Ronald C. G. Naber, University of Groningen, and Philips Research Eindhoven (research)
19. John A. Rogers, University of Illinois, and Michael E. Gershenson, Rutgers University (research)
20. Samuel I. Stupp, Northwestern University (research)

New Offensives against HIV
21. Daniel C. Douek, National Institutes of Health (research)
22. Joachim Hauber, Heinrich Pette Institute (research)
23. Treatment Action Campaign, South Africa (policy)

Creative Paths to Open Access
24. Patrick O. Brown and Michael B. Eisen, Public Library of Science (policy)
25. IBM (business)
26. MyPublicInfo, Inc. (business)
27. Senator Arlen Specter of Pennsylvania and Senator Patrick Leahy of Vermont (policy)

A Force for Change
28. Green Watershed and Friends of Nature, China (policy)

Waiting for Wi-Far
29. Carl Stevenson, IEEE (policy)
30. Advanced Automotive Antennas (A3) (business)

Designing Artificial Life
31. James J. Collins, Boston University (research)
32. George M. Church, Harvard Medical School (research)
33. Albert Libchaber, Rockefeller University (research)

New Aircraft, Big and Small
34. Airbus (business)
35. Embraer SA/Indústria Aeronáutica Neiva (business)

Watching the Brain at Work
36. R. Clay Reid, Harvard Medical School (research)
37. Yukiyasu Kamitani, ATR Computational Neuroscience Laboratories, and Frank Tong, Vanderbilt University (research)
38. Bradley Hyman, Massachusetts General Hospital (research)
39. Nathan N. Urban, Carnegie Mellon University (research)

Practical Nanotubes
40. James E. Jaskie, Motorola Physical Sciences Research Lab (business)
41. DuPont Central Research and Development (business)
42. Bradley J. Nelson, Swiss Federal Institute of Technology (research)
43. Hewlett-Packard Laboratories (business)
44. U.K. Royal Society and the Royal Academy of Engineering (research)

True Green
45. Paul T. Anastas, Green Chemistry Institute (policy)
46. U.S. Green Buildings Council, Fox & Fowle, William McDonough & Partners, and Foster and Partners (business)

Hope for Fixing Gene Defects
47. Yehoash Raphael, University of Michigan Medical School at Ann Arbor, and Zheng-Yi Chen, Massachusetts General Hospital (research)
48. Paras N. Prasad, University of Buffalo (research)

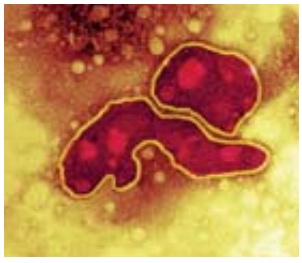
Photons, Electrons and Silicon
49. Ozdal Boyraz and Bahram Jalali, University of California, Los Angeles (research)
50. Haisheng Rong, Intel (business)

Getting Serious about Flu

A combination of public health measures and technology raises hope for the flu fight

As the specter of a global flu pandemic looms ever larger, both veteran flu scientists and newcomers to the field are making important progress against the disease. **Robert G. Webster**, now at St. Jude Children's Research Hospital in Memphis, Tenn., first discovered during the 1960s that the novel flu viruses that seem to sweep through the human population every 30-odd years can arise from combinations of bird and human flu strains. He realized then that preventing new pandemics would require humans to control the avian half of the threat at its source.

After a 1997 human outbreak in Hong Kong of an avian flu virus called H5N1, Webster turned his insight into action, guiding a reform of the territory's live-animal markets to avert new opportunities for birds, animals and people to infect one another with flu viruses that might combine into a pandemic strain. The H5N1 virus has since raged throughout Asia's bird populations and infected more than 100 people, yet Hong Kong has been largely spared. That stark contrast has in the past year prompted several Asian nations as well as global agriculture and public health authorities to begin seriously discussing regional agricultural reforms that would follow the Hong Kong model.



The avian flu virus H5N1 threatens to cause the next pandemic.

Much of the intensified awareness of the avian flu threat to humans is also owed to the efforts of **Klaus Stöhr**, head of flu surveillance and response for the World Health Organization. Stöhr has been working tirelessly behind the scenes to break down barriers to better global preparedness for the crisis, including fostering international scientific collaborations, advising countries on how to bolster their detection of flu cases, and brokering negotiations between vaccine makers and national governments.

Both vaccines and antiviral drugs will be in short supply during a pandemic, but expanded choices are in the pipeline. **Robert B. Belshe** of Saint Louis University and his colleagues demonstrated a dose-sparing approach to flu vaccination this year, showing that administering vaccine just under the skin, instead of into muscle, prompts a greater immune response with less vaccine. This insight could also lead to an array of new techniques for administering regular flu vaccine to groups, such as the elderly, who often have a weak response to the traditional flu shot.

The **Iomai Corporation** in Gaithersburg, Md., is working on intradermal vaccination toward the goal of doing away with flu shots entirely and instead delivering the vaccine through a skin patch. Iomai has already shown that a patch containing an adjuvant—a substance that enhances immune system response—improves the effect of an intradermal vaccine when the patch is placed on or near the vaccination site. A patch that combines vaccine with an adjuvant boost would represent a radically new approach to flu immunization.

Innovative thinking also distinguishes **NexBio, Inc.**, in San Diego, which is gearing up for the first clinical trials of its antiflu drug, Fludase. Most flu antivirals work by disabling specific parts of the virus, so their effectiveness can vary considerably depending on the individual strain's defenses. Fludase instead blocks the doorway in lung cells that flu viruses use to enter them. By targeting the door rather than the intruder, the company hopes to create a drug that is equally effective on all flu viruses and offers them no way to develop resistance. This work illustrates how science, technology and policy are being marshaled to combat future flu pandemics.

—Christine Soares

More Power to Solar

Photovoltaic advances make the ever lagging technology more of a competitor

Brazilians joke that theirs is the country of the future—and always will be. Likewise, solar power has always been the ultimate green technology of the future. But maybe the sun is finally rising. The photovoltaic market, though small, has been growing briskly: by more than 60 percent in 2004. Plastering your roof with solar cells now runs as little as 20 cents per kilowatt-hour over the system's estimated lifetime, which is approaching what most households pay for electricity.

One especially promising technology that emerged in the 1990s was to make solar cells from plastic spiked with nanometer-scale crystals. Even those composite devices, though, were restricted to absorbing visible light. This year a group led by **Edward H. Sargent** at the University of Toronto coaxed them to

NIBSC/Photo Researchers, Inc.

absorb infrared light as well. A concoction of lead sulfide particles a few nanometers in size can absorb wavelengths as long as two microns. Thus able to harvest a wider swath of the solar spectrum, inexpensive plastic cells could rival the performance of pricey silicon ones.

Other avant-garde photovoltaic devices consist of nanoparticles coated with dye and doused in electrolyte, an approach pioneered by **Michael Grätzel** of the Swiss Federal Institute of Technology in Lausanne a decade ago. The dye handles the job of absorbing photons and generating a current of electrons. Because the source of the electrons (the dye) is divorced from the matrix through which they flow in (the electrolyte) and out (the nanoparticles), electrons are less likely to get prematurely recaptured by atoms, a process that impairs current flow in conventional cells. Consequently, the dye-based cells work better under weak lighting conditions.

Tsutomu Miyasaka and **Takurou N. Murakami** of the Toin University of Yokohama have extended the technique to create the world's first photocapacitor: a solar cell that both generates and stores electricity. Alongside the dye-coated particles, the researchers slapped down layers of activated carbon, which traps electrons and holds them until a switch completes the circuit. Under a 500-watt bulb, their latest design takes a couple of minutes to charge up to 0.8 volt. It has a capacitance of about 0.5 farad per square centimeter, which would give a typical solar panel the same energy storage capacity as the so-called ultracapacitors developed to replace or supplement batteries in hybrid cars and uninterruptible power supplies. In 2004 Miyasaka founded a company, Peccell Technologies, to commercialize this and other innovations.

A novel type of solar cell, which has been crafted into array panels, produces hydrogen rather than electricity.

HYDROGEN SOLAR

Another way to store energy is in the form of hydrogen gas. In the late 1960s Japanese researchers Akira Fujishima and Kenichi Honda discovered that a solar cell can act like an artificial tree leaf, splitting water into its constituent elements. The trouble was that the materials involved, such as titanium dioxide, absorb mostly ultraviolet light. Restricted to such a narrow band of spectrum, the process was pitifully inefficient. Tinkering with their chemical properties allowed the cells to absorb visible light but also made them prone to corrosion.

Grätzel recently developed a way around this unhappy trade-off: put two solar cells together. The first contains tungsten trioxide or iron oxide, which soaks up the ultraviolet. The second is one of his dye-sensitized cells, which absorbs the rest of the visible spectrum and provides more electrons to aid the photolysis.

A year ago **Hydrogen Solar**, a British company trying to commercialize the work, made the announcement of a nearly 10-fold improvement in the efficiency of water splitting. It estimates that hydrogen produced this way would still cost about twice as much as hydrogen from natural gas but might become competitive if greenhouse gas emissions were restricted. You wouldn't need to go to a gas station to refill your fuel-cell car; the solar panel on the roof of your house could be your private gas station. —*George Musser*

Stem Cell Imperative

Despite political obstacles, research and commercial endeavors advance

Embryonic stem cells can become any other cell in the body, a capability researchers hope one day to direct toward healing organs ravaged by disease. In the U.S., President George W. Bush restricted federal funding of human embryonic stem cell research in 2001, with just $24.8 million doled out in 2004. But in a dramatic rejection of Bush's policy, the state of California in the past year became the world's largest single backer of stem cell research, a move spearheaded by Palo Alto, Calif.–based housing developer **Robert Klein**.

The California Institute for Regenerative Medicine, created in November 2004, has the power to issue $3 billion in grants over 10 years for embryonic stem cell and other biomedical research. Klein, a Stanford University–educated lawyer, was the chief architect of the campaign for the institute and, at $2.6 million, the campaign's largest financial supporter. Klein, who was unanimously elected as the institute's chairman, is hopeful that stem cells can help cure his youngest son's diabetes [see "A Proposition for Stem Cells," by Sally Lehrman; Insights, Scientific American, September].

The institute's creation has pro-

pelled 10 states in domino fashion to play catch-up and consider establishing their own more modest stem cell funding initiatives, if only to halt brain drains of researchers to California. Yet although Klein has undoubtedly won a victory for U.S. embryonic stem cell research, his success remains controversial. Besides the criticism research on stem cells from human embryos typically attracts, Klein and the institute have drawn fire for alleged secrecy over meetings and potential conflicts of interest of board members who represent corporations, universities and nonprofit groups that stand to gain from research grants.

Internationally, stem cell companies are growing more global, and quite likely the most multinational among them is **Stem Cell Sciences**. Headquartered in Scotland, the company employs roughly 40 people in research and development centers in the U.K., Japan and Australia, and it anticipates establishing a U.S. operation this year.

Stem Cell Sciences's bold plan is focused on commercializing human embryonic stem cells. Its technology can generate an unlimited supply of highly purified stem cells and their differentiated progeny for drug development. That promise has led to licensing agreements with pharmaceutical giants such as Pfizer, GlaxoSmithKline and Aventis. The company's primary goal is to be the first to develop an embryonic stem cell–derived therapy aimed at targets such as diabetes and Parkinson's disease.

One problem with embryonic stem cells is how they can spontaneously differentiate into other cells when scientists do not want them to. **R. Michael Roberts** and his colleagues at the University of Missouri at Columbia have now discovered a way to grow human embryonic stem cells more predictably. They noted that mammal embryos grow in low-oxygen environments in the early stages of their development but that human embryonic stem cells are generally cultured in normal atmospheric oxygen conditions. In atmospheres of only 3 or 5 percent oxygen, the scientists found cells proliferated as well as they did under normal conditions while differentiation was markedly suppressed. The outlook is improving. Good science, new funding and commercial endeavors assure a place for stem cells, no matter what the federal stance.

—Charles Q. Choi

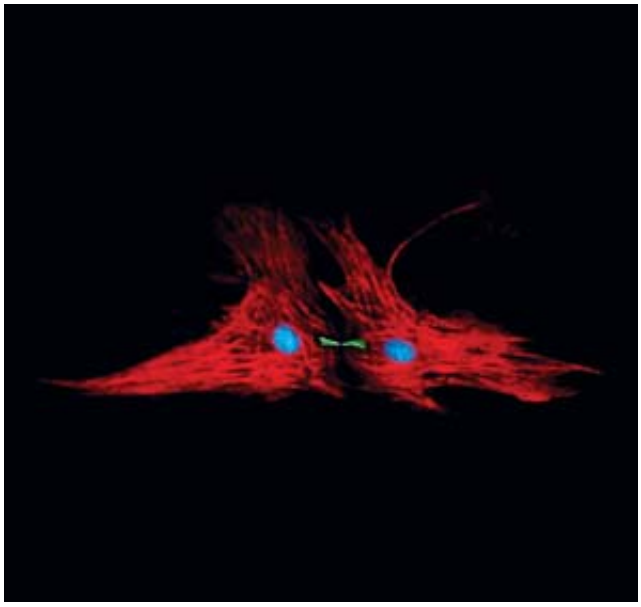
Repairing Broken Hearts

Research in zebra fish could transform cardiology

The human heart possesses stem cells but cannot regenerate after injury, instead replacing damaged muscle with scar tissue. Our powerlessness to mend an ailing heart is the primary cause of death in the developed world.

In May cardiologist **Mark T. Keating** of Harvard Medical School and his colleagues accomplished the long-sought goal of enticing adult mammal heart muscle cells to multiply, the first step on the road to heart-repair therapies. In 2002 Keating discovered that zebra fish could regrow up to a fifth of their hearts within two months without scarring following removal of 20 percent of the muscle from the lower chamber. He then sought to achieve the same results in humans. His laboratory found that activity of the enzyme p38 MAP kinase was lowest in fetal rats when the heart was growing and highest when heart muscle cell growth slowed or halted, suggesting it put the brakes on cell division.

When the researchers partnered a p38-inhibiting drug with growth factor FGF1, this combination spurred adult rat heart muscle cells to proliferate. Keating and his team believe a drug-based approach to repairing hearts could prove more elegant than ones based on stem cells. The scientists are currently testing mixtures of p38 inhibitor and growth factor on animals that have suffered heart attacks to see if they can help the body's most important muscle heal. Such drugs would mark a revolution in cardiology. *—Charles Q. Choi*



Heart cells divide when exposed to a chemical cocktail.

FELIX B. ENGEL *Children's Hospital Boston*

Protections for the Earth's Climate

Industry, local governments and academia look for solutions to global warming

The battle to prevent or at least slow global warming has intensified in the past year as scientists have learned more about the magnitude of the problem. One of the leading climate experts, **Inez Y. Fung**, director of the Atmospheric Sciences Center at the University of California, Berkeley, recently showed that the earth may soon lose its ability to absorb much of the greenhouse gas that is raising temperatures. The oceans and continents currently soak up about half the carbon dioxide produced by the burning of fossil fuels. In the oceans, the gas combines with water to form carbonic acid; on land, plants take in more carbon dioxide and grow faster. But computer modeling done by Fung and her colleagues indicates that these carbon sinks will become less effective as the earth continues to warm. For example, as the tropics become hotter and drier in the summer, plants will curtail their respiration of carbon dioxide to avoid water loss. Atmospheric measurements over the past decade have confirmed this effect. If the oceans and land take in less carbon dioxide, more will remain in the atmosphere and global warming could accelerate catastrophically.

Despite these warning signs, the administration of President George W. Bush has opposed ratification of the Kyoto Protocol, the international treaty mandating reductions in greenhouse gas emissions. (Signed by more than 150 nations, the treaty went into effect this past February.) But nine states in the northeastern U.S. are attempting to sidestep the federal government's opposition by taking action on their own. In 2003 the governors of Connecticut, Delaware, Maine, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island and Vermont created the **Regional Greenhouse Gas Initiative**. Last August the group reached a preliminary agreement to freeze power plant emissions of carbon dioxide by 2009 and then reduce them by 10 percent by 2020. The plan requires approval by the state legislatures, but environmentalists are already hoping that other regions of the U.S. will follow suit. If adopted nationwide, the proposal would lower greenhouse gas emissions by roughly as much as the Kyoto Protocol would have.

Steve Howard, chief executive of the Climate Group, is tackling the global-warming problem from a different angle. Founded in 2004, the Climate Group is a coalition of corporations and state and local governments that have voluntarily committed to reducing their greenhouse gas emissions. Members include oil giant BP, drugmaker Johnson & Johnson, and Starbucks. Businesses in the Climate Group have discovered that improvements in energy efficiency can enhance profits as well as cut fossil-fuel emissions; BP, for instance, slashed its energy bills by $650 million over 10 years. "We have seen important evidence about successful emission reduction scattered here and there in the most surprising places all over the globe," Howard says. "We are working to bring all of it together so that it forms a body of evidence."

—Mark Alpert

Global warming has already shrunk glaciers and sea ice in the Arctic.

JOHN McCONNICO *AP Photo*

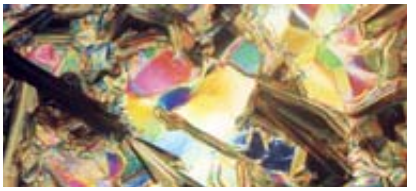
A Future in Plastics

The march toward less expensive, more flexible electronics continues

Organic semiconducting materials will never replace the silicon chips in your computer, but now they are finding their way into applications ranging from flexible displays to low-cost radio-frequency identity tags, for which silicon chips are not suited. The past year has witnessed advances in both the development of specific devices and understanding of the basic physics of the materials.

On the device front, **Paul W. M. Blom** and his student **Ronald C. G. Naber** of the University of Groningen in the Netherlands and their collaborators developed an inexpensive nonvolatile memory chip out of a physically tough polymer. The working element of the device is a field-effect transistor containing a layer of ferroelectric polymer that can be switched between two states by a voltage pulse.

Similar structures have been studied before, but the Groningen device is the first to combine several desirable properties, including a long data-retention time after the power is turned off and a short programming time (it takes only a millisecond to write data to the transistor). In addition, the devices can be manufactured by depositing the various layers of the transistor out of a liquid solution, including the all-important ferroelectric layer. Large-scale industrial production should therefore be feasible using low-cost techniques such as spin-coating or printing. The work was done in collaboration with researchers at **Philips Research Eindhoven** in the Netherlands.



An organic film of phenylene vinylene molecules self-assemble into well-ordered layers that control charge flow.

Of crucial importance for the future of plastic electronics is the cultivation of a good understanding of precisely how electric currents flow in the devices. Most organic semiconductor devices suffer from numerous material defects, which dominate the behavior of moving charges and obscure efforts to understand the intrinsic properties of the material. In August 2004 a research group led by **John A. Rogers** of the University of Illinois and **Michael E. Gershenson** of Rutgers University reported a major advance in unraveling these effects. The group made an extremely pure and defect-free crystal of rubrene by vapor deposition. (Rubrene consists of four benzene rings in a chain with four more attached individually as side groups, like two pairs of wings.) They constructed electrodes separately in the form of a "stamp" that was pressed against the rubrene to create a transistor. This technique avoids damage to the rubrene by the electrode-making process. Measurements of the transistor's properties revealed that the flow of charges in organics is slower than in silicon largely because the charges distort the flexible organic crystal lattice and then drag around the distortions with them.

Samuel I. Stupp and his co-workers at Northwestern University have pursued a different technique to reduce the amount of defects and disorder in organic materials. They worked with a short chainlike molecule called phenylene vinylene, attaching a water-repelling molecule to one end of the chain and a water-attracting molecule to the other end. Then they poured a water-based solution of the molecules onto glass, where the molecules self-assembled into well-ordered layers.

Such tightly packed and orderly films have two advantages over more typically disordered polymers: charges flow through the material far more efficiently, and when used as a light source (phenylene vinylene is widely used to make organic light-emitting diodes), the material has fewer luminescence-quenching defects. The group plans to make light-emitting diodes and solar cells out of the material. It won't be long before these various new findings make their way into the designs of commercial devices. —*Graham P. Collins*

New Offensives against HIV

A research insight, a new drug target and an advocacy group assist in fighting the disease

Treatment Action Campaign wants better access to HIV therapies in South Africa.

In the past decade, HIV infection in the industrial world has largely evolved from a virtual death sentence to more of a chronic disease, which is a testament to the efforts of researchers and patient advocates. But the 40 million HIV-positive people worldwide are a somber reminder of the work ahead. Resistant strains of the virus have appeared; citizens in developing countries lack access to lifesaving drugs; and basic questions about the progression of the virus postinfection remain. Yet 2005 brought hopeful news on all fronts.

Researchers know that HIV infection leads to a massive depletion of CD4 white blood cells, but why this happens is still up for debate. Is the virus killing all the cells directly, or is there an indirect mechanism that explains the widespread death? **Daniel C. Douek**, an immunologist in the Vaccine Research Center at the National Institutes of Health, implicates both direct and indirect mechanisms. His work shows that HIV starts in the gut, home to the largest population of the virus's preferred CD4 targets—those with a receptor called CCR5. HIV attacks and kills these cells directly early in the course of the infection.

The mechanism behind CD4 cell death turns indirect as the disease continues. The lack of immunity in the gut allows other pathogens to thrive. This

JAMES F. HULVAT AND SAMUEL I. STUPP *Northwestern University (top)*; TREATMENT ACTION CAMPAIGN *(bottom)*

condition overstimulates the lymph nodes, and they activate large numbers of CD4 cells. Once activated, the cells progress through a natural process that eventually leads to their death, whether or not they are infected. Continuous rounds of activation and death slowly deplete CD4s. Douek's research not only sheds light on how HIV wreaks havoc, it also suggests that HIV vaccines might do well to initiate an immune response in the gut.

With vaccines still on the horizon and with HIV strains developing resistance to antiretrovirals, identifying new drugs is critical. Current treatments focus on disrupting viral proteins, which have many opportunities to mutate. But HIV also relies on various host cell proteins, so researchers are beginning to investigate as therapeutic targets these human proteins, which are much less likely to mutate.

Joachim Hauber of the Heinrich Pette Institute in Hamburg, Germany, has discovered one such target: deoxyhypusine synthase (DHS), an enzyme that activates a host protein necessary for viral replication. Hauber's group found it could inhibit the virus by blocking DHS with an experimental drug. The drug did not appear to harm host cells or induce resistance after prolonged use and was effective against strains resistant to current antiretroviral therapies. Even though potential treatments are still years away, Hauber's work demonstrates a powerful new offensive strategy.

Today's drugs have made HIV infection a manageable disease for many, but millions in developing countries cannot afford them. A South African advocacy group founded in 1998, **Treatment Action Campaign** (TAC), has worked toward greater access to HIV therapies for the estimated 5.3 million infected in their country. TAC's legal actions have forced the government to provide free antiretrovirals to HIV-positive pregnant women. More recently, TAC has negotiated a discount from Bristol-Myers Squibb on amphotericin B, used to treat a deadly opportunistic infection common to HIV patients. And this past February, TAC launched a campaign urging the government to treat 200,000 people with no-cost antiretrovirals by 2006. TAC chairman Zackie Achmat has said that the government must wake up to AIDS; TAC is ringing the alarm.

The AIDS virus infects a T cell.

NIBSC/Photo Researchers, Inc.

—Aimee Cunningham

Creative Paths to Open Access

Technology supplies new protections against threats of a fortress society

It seems a truism that science and technology function best when new discoveries and ideas can circulate freely and find the widest audience. But governments and businesses face constant pressures toward secrecy. Ideally, society should strike a balance between transparency in government and the privacy that citizens have come to expect, between openness in research and the protections that commercialization requires.

Individuals and companies have launched initiatives recently that enhance open access in many welcome ways. **Patrick O. Brown** and **Michael B. Eisen** have served as effective champions for the burgeoning open-access movement in fundamental research. Eisen and Brown are among the founders of the Public Library of Science and were instrumental in its successful launch of several new journals that are freely available online, including a medical journal inaugurated in October 2004. They worked behind the scenes to persuade Congress and the National Institutes of Health to increase public access to taxpayer-funded research, and they guided the formation of new policies that require that all scientific articles generated by NIH grants be deposited in PubMed Central.

A substantial endowment of intellectual property to the public domain came from **IBM**. The tech giant waived royalties permanently on 500 of its software patents and counterpart patents in other countries, in essence providing a substantial endowment of intellectual property to the fertile community of "open source" programmers. Although the 500 patents represent a small fraction of Big Blue's portfolio, they reinforce numerous other steps that make IBM a noteworthy leader in embracing the open-source movement. IBM buttressed Linux by offering the operating system on a number of its products years ago, and the company has assigned many of its own programmers to develop new software for that free and open platform.

Freeing information of a different kind, **MyPublicInfo, Inc.**, launched in 2004 a novel and valuable service that, for an affordable fee, allows citizens to view the complete contents of public records attached to their identity. Whereas credit reports have been available for a long time, MyPublicInfo gathers a much broader dossier from legal, government and educational records. The company wisely takes pains to authenticate the identity of its customers so that it does not inadvertently abet the very identity thieves that it aims to thwart.

Customers of MyPublicInfo may be

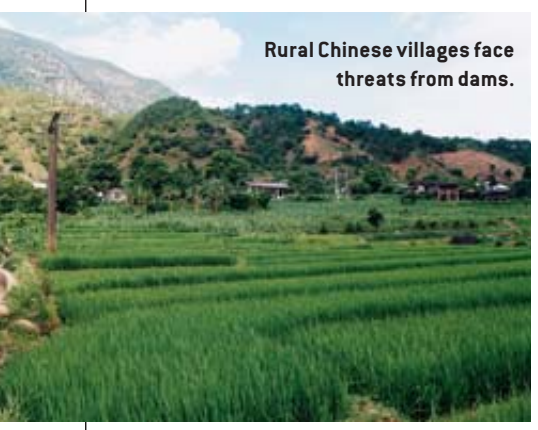
unpleasantly surprised to see how much of their "private" information is available in the public domain—and how much of it is erroneous. In the same vein, **Senator Arlen Specter** of Pennsylvania and **Senator Patrick Leahy** of Vermont introduced legislation earlier this year that would give Americans more control over information that businesses and government agencies collect on them. The Personal Data Privacy and Security Act requires data brokers to let people see what information the brokers have about them and allows citizens to correct many kinds of inaccuracies in the databases. The bill is scheduled for consideration by the Senate this year. —*W. Wayt Gibbs*

A Force for Change

China's homegrown NGOs serve as the nation's environmental conscience

"New Social Power in China" read one 2004 cover of *Economics*, a Beijing-based magazine. The reference cited the work of domestic environmental groups that oppose the building of massive dams in the country. These nongovernmental organizations—along with others that militate on environmental, public health and legal issues—have begun to serve as a vital counterpoint to the government's otherwise unchecked push to propel the nation's blisteringly fast-paced economic development. The NGOs have become a new force for political activism in China's post-Tiananmen era.

They survive by not confronting the government directly but by adopting more subtle paths to social change. "Environmental NGOs … play a critical role in advancing transparency, rule of law and official accountability within the Chinese political system," noted Elizabeth C. Economy of the Council on Foreign Relations at a hearing before the U.S. Congress this past February. "Through this process, they have become a significant force for political reform."



Rural Chinese villages face threats from dams.

Green Watershed, a Chinese NGO dedicated to river management issues, has organized peasants in the province of Yunnan to protect wetlands and to oppose dam construction. There government projects have threatened the ability of farmers and fishers, many of them ethnic minorities, to earn a living. The group has waged a successful campaign to suspend one plan to build 13 dams on the Nu River, which slices through remote gorges in Yunnan. The government had announced the project in 2003, weeks after UNESCO named the surrounding area a World Heritage site. In the summer of 2004 the group made an underground documentary about the poor living conditions of peasants located near the 12-year-old Manwan dam, touted by the government as a paragon of development.

The organizer of the group, Yu Xiaogang, is an environmental scientist and a Communist Party member who illustrates the ambivalent relationship the government has with these groups. A competition organized by several government agencies chose his group as one of the top 10 examples of sustainable development within China for its work on preserving the Lashi watershed. More recently, police have confiscated his passport and prohibited him from leaving China.

The emergence of environmental NGOs in China is a new phenomenon dating only to 1994, when the government gave permission to establish independent organizations that survive typically without government funding. The first group to take advantage was **Friends of Nature**, which has adopted positions on issues such as preserving the golden snub-nosed monkey and the Tibetan antelope.

Seventy-three-year-old Liang Congjie, a former history professor who founded the group, continues to speak out about the environmental price paid to pursue development of the economy. Some of Liang's oft-cited remarks throw cold water on the Chinese economic miracle. "If Chinese wanted to live like Americans, we would need the resources of four worlds to do so," he has said.

Although Friends of Nature often collaborates with the government, the relationship can still be a tenuous one. In 2002 the government gave Friends of Nature an ultimatum: expel Wang Lixiong or shut its doors. Wang is one of the group's founding board members and was a supporter of two Tibetan monks who faced execution. Such tensions may establish a dynamic that delineates the pathway to political as well as environmental reform. —*Gary Stix*

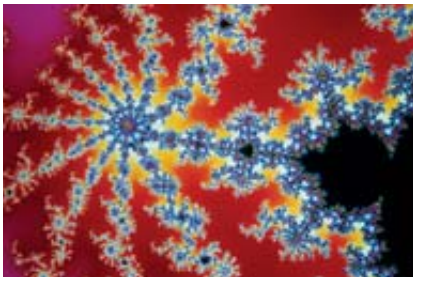
MU LAN *Three Gorges Probe*

Waiting for Wi-Far

New standards and hardware expand the reach of wireless

Wireless networking is expanding beyond the next room—or from downstairs to upstairs. Standards developers have set their sights on unused television bands to create regional-area networks. Makers of fractal-shaped antennas, for their part, hope to integrate suites of wireless services unobtrusively into cars, cell phones and other devices.

The most common networks, based on Wi-Fi technology, radiate only about 100 meters from their source. Compare that with a range of kilometers for the frequencies between 54 and 862 megahertz, home to VHF and UHF television. Lower frequencies that propagate with less loss are better at penetrating foliage and buildings and are better at non-line-of-sight transmission. Hence, frequencies less than 1 GHz are better for longer-range wireless than the 2.4 GHz or higher used in current wireless networks. In 2002 the Federal Communications Commission began soliciting public comments on the feasibility of wireless network transmissions broadcasting over the largely unused frequencies separating these TV channels. Access to these frequencies would mean a huge growth in wireless service.



Fractal patterns inspired the design of A3's antennas.

To pave the way for UHF wireless, the Institute of Electrical and Electronics Engineers (IEEE) has formed a working group to develop standards for wireless interoperability in the UHF channels. Led by chairman **Carl Stevenson**, an early pioneer in wireless standardization, the group is charged with formulating a standard, known as 802.22, specifying how wireless transmitters and receivers must coordinate so as not to interfere with one another or with TV stations. The idea is to use new technology called cognitive (or "smart") radio capable of sensing the spectral environment. Base stations and user terminals would check for an incumbent's presence on a channel, looking for an open channel or adjusting power levels so they do not interfere with the incumbent's signal. Stevenson's group, which works closely with TV broadcasters and other licensed users, hopes to finish in early 2007. The FCC would then have to establish final rules for transmitter powers and frequencies, if it had not already.

As wireless services proliferate, manufacturers have to figure out how to combine them into one device. The obvious approach is multiple antennas. But makers of fractal-shaped antennas contend that a single antenna might do it all. Fractals—branching shapes that look identical at all size scales—scrunch a tremendously long curve into a small space. Fractal antennas would behave like several traditional whip antennas of different lengths all twisted together, allowing them to receive multiple-frequency bands.

In 2002 a Spanish designer of fractal antennas, Fractus, partnered with automotive supplier Ficosa International to bring the technology to vehicles. Fractus supplies antennas for devices, including headsets, gaming systems and European cell phones, and the U.S.-based Fractal Antenna Systems develops antennas for defense and other applications. The joint venture, called **Advanced Automotive Antennas** (or **A3**) and now wholly owned by Ficosa, has supplied fractal antennas for the Fiat Ducato, Peugeot Boxer and Citroën Jumper. In January, A3 signed a licensing agreement with Nippon Antenna, a supplier of Mazda and Nissan. The company produces two antennas that can fit inside the external rearview mirror: a miniature AM/FM radio antenna and a triple-function antenna combining radio, the GSM cellular phone standard and GPS. *—JR Minkel*

Designing Artificial Life

Biologists move a few steps toward building cells from scratch

Think of a biological cell as a tiny programmable device that happens to be alive, and you have the basic idea behind an emerging field called synthetic biology. Instead of trying to unravel the complexities of natural biological systems, "synthetic biologists" ultimately want to build highly predictable, simple living cells from scratch, using off-the-shelf parts. No one has done that just yet, but a growing number of scientists and engineers are now taking the first steps toward manufacturing life-forms to order.

Figuring out how to program an artificial cell is high on the list of priorities. The functions of a natural cell are controlled by complex networks, or circuits, of interacting genes. Much the way that engineers can assemble toggle switches and oscillators in an electron-

FRED ESPENAK *Photo Researchers, Inc.*

ic circuit, the new breed of biologists hopes to build modular "plug and play" genetic circuitry.

One such module was described by **James J. Collins** and his colleagues at Boston University in the June 1, 2004, issue of the *Proceedings of the National Academy of Sciences USA*. Collins's team designed genetic toggles—on/off switches—that could control natural networks, such as those that direct the production of proteins, inside a bacterial cell. The work not only demonstrates that cells can be programmed using modular-design strategies, it also serves as a model for a new class of therapeutics that could regulate the networks. Collins is now busy attempting to reverse-engineer some genetic networks—a technique that may someday help scientists determine the molecular targets of new drugs.

Collins's genetic modules were constructed using standard cloning techniques, basically by cutting and pasting natural DNA into place. Late last year another group of scientists, led by **George M. Church** of Harvard Medical School, described a new method of making synthetic DNA. Assembling DNA, life's programming code, has existed as a laboratory technique for many years. Church and his colleagues used the new method, however, to manufacture all 21 genes needed to make a subunit of a ribosome, the cellular machine that assembles proteins. The ability to construct long sequences of synthetic DNA gives scientists the power to create genes that never existed before.

More recently, Church announced a new DNA-sequencing technology that promises to be faster and about one ninth the cost of conventional methods. It is a crucial step toward developing affordable genome maps that could become part of everyone's medical record.

As scientists begin to manufacture genetic circuits and artificial molecules in greater numbers, they will undoubtedly wish to package them inside a membrane of their own design—in due course producing a truly artificial cell. Last December, **Albert Libchaber** of the Rockefeller University described the creation of a cell-like assembly, which he called a "vesicle bioreactor." The vesicle consists of a fluid extracted from *Escherichia coli* bacteria that is encircled by a laboratory-made lipid bilayer—much like the membrane of a real cell. The vesicles did not have their own DNA, but they were able to metabolize nutrients acquired from the surrounding medium through special proteins in the membrane. Libchaber thinks of the vesicles as enclosed laboratories that not only may have practical applications in chemistry and medicine but also might help us understand how the first natural cells evolved. —*Michael Szpir*

New Aircraft, Big and Small

A 570-metric-ton mammoth and a craft that burns alcohol are now flying

One of the biggest and one of the smallest commercial airplanes took to the skies during the past year. In April, the world's largest passenger airliner, the **Airbus** A380 Navigator, made its maiden flight over the company's Toulouse, France, assembly plant. Soon thereafter the first alcohol-powered aircraft, the EMB 202 Ipanema crop duster, was introduced by Brazil's **Indústria Aeronáutica Neiva**, a subsidiary of **Embraer SA**.

A few months later at the Paris Air Show, the massive A380 superjumbo jet wowed the crowds of onlookers, who were amazed to hear how quiet it was. Designed to carry 555 to 800 passengers, which is at least a third more than the current airline heavyweight, the Boeing 747, the twin-aisle double-decker from Airbus will weigh 570,000 kilograms when fully loaded. The plane's wings span 80 meters, 15 meters more than a 747's, and the jet provides 50 percent more floor space. Yet on a per-seat basis, the A380's four turbo-

The world's largest passenger airplane prepares for its maiden flight in April.

fans burn 12 percent less fuel than a 747's engines do.

This year's debut follows a complex, $15-billion effort by French, German, Spanish and British aerospace firms to develop what promises to be a significant step for the civil airliner. Airbus designers and engineers have enhanced the A380's flight operations and economic performance by incorporating several cutting-edge technologies into structures and systems. The new mega-transporter, for example, achieves significant weight savings by using lightweight but strong carbon-fiber and other advanced resin epoxy composite materials. About 800 kilograms are saved per plane by replacing conventional aluminum fuselage panels with ones constructed of Glare, a glass-fiber reinforced aluminum laminate that is about one quarter lighter and has much better resistance to mechanical fatigue and damage. A new high-pressure hydraulic system for controlling the flight surfaces provides reliability and cost benefits and reduces weight. The giant airliner also boasts a high-tech cockpit with the latest interactive displays and fly-by-wire avionic systems.

After test flights are completed and the A380 is certified, it is slated to enter service in the second half of 2006 with its first operator, Singapore Airlines. If Airbus planners are correct, the European company's flagship will ease congestion at major airports by transporting more people more efficiently than ever on the world's principal air routes.

Ethanol from sugarcane powers the single-seat EMB 202 Ipanema for farm use.

With oil prices at record levels, pollution limits in place at many airports and the threat of emission-control regulations, the global aviation industry has good reason to embrace alternative fuel technology. The single-seat EMB 202 Ipanema agricultural utility aircraft from Neiva/Embraer is the first production-series model to burn ethanol produced from sugarcane. This achievement is a natural progression for Brazil because its automobiles have been running on this type of renewable alcohol fuel for more than two decades, an effort that was launched in response to the 1970s oil crisis.

Not only is ethanol a third or fourth the price of aviation gasoline and a cleaner energy source, it helps to improve the aircraft's overall performance. The new Ipanema piston engine also brings other advantages, including lower maintenance costs and a 20 percent reduction in operating costs. So far Neiva/Embraer has received more than 100 orders for the novel crop duster and has plans to install alcohol-burning engines in some of its other models. Company engineers say that conversion of existing aviation gas engines is not only feasible but cost-effective. —*Steven Ashley*

Watching the Brain at Work

Innovations in imaging let scientists ascertain what's going on in your head

Neuroscientists are exploring previously uncharted territories in the microscopic world of the neuron—observing brain cells while they work, detecting microscopic evidence of Alzheimer's disease in the living brain, and even engaging in some mind reading. The 1990s were touted as the "decade of the brain," but scientists in the 2000s are examining the living brain with far more fantastic precision.

To study the functions of neurons at the microscopic scale, researchers typically use fine-glass electrodes, but that method cannot provide the precise location of the cells while the animal is alive. The researcher can pinpoint a cell's whereabouts only by injecting it with a chemical marker that can be seen by a microscope once the animal is sacrificed.

Now a new technique—called single-neuron functional imaging—allows scientists to watch brain cells at work while they are still in the brain. Earlier in 2005 **R. Clay Reid** and his colleagues at Harvard Medical School made time-lapse images using a laser and a microscope that recorded the simultaneous activity of hundreds of neurons in the visual cortex of laboratory cats and rats. The method, which was described in the February 10 *Nature,* should enable neuroscientists to make architectural maps of brain functions such as vision, movement and learning with single-cell accuracy.

Neuroscientists are not only constructing better maps of the brain, they are taking steps toward reading the human mind. **Yukiyasu Kamitani** of the ATR Computational Neuroscience Laboratories in Japan and **Frank Tong** of Vanderbilt University showed that there is a tight coupling between brain states, as measured by functional magnetic resonance imaging, and subjective mental states. Writing in the May *Nature Neuroscience,* the scientists describe how they

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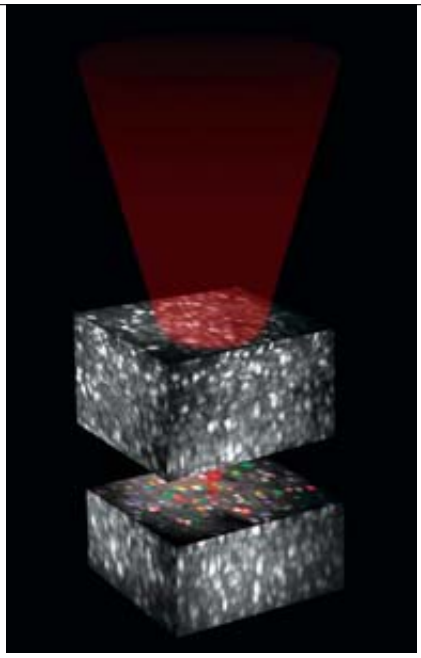
were able to predict which one of eight visual patterns a person was looking at by decoding the activity among small groups of neurons in the visual cortex. They believe this type of mind reading can be extended to investigate the neural basis of awareness, memory and other types of "mental content."

Watching the brain do its job is fine when everything is working well, but when disease strikes, scientists would like to look inside to find out what might be causing the problem. Neurologist **Bradley Hyman** of Massachusetts General Hospital and his colleagues have developed tools that can track microscopic neural changes in a living mouse model of Alzheimer's disease. Using multiphoton microscopy and a fluorescent tracer, the scientists were able to detect the presence of amyloid plaques—a hallmark of the disease—with microscopic accuracy. The scientists are currently exploring a similar method that uses positron-emission tomography to diagnose and study the progress of the disease in humans.

These new techniques allow scientists to catch a glimpse of what is going on in the brain, but another recent development will help them to understand what they are seeing. In the April 22 *Physical Review Letters*, **Nathan N. Urban** of Carnegie Mellon University and his co-workers describe a method that enables them to predict how groups of neurons synchronize their activity. Because synchronized activity is the basis for coding and storing information in the brain, their work has broad implications for sorting out how the brain makes the remarkable thing we call the mind. —*Michael Szpir*



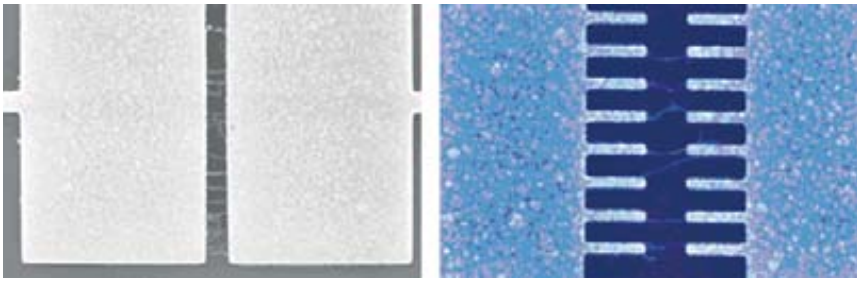
A time-lapse image, taken by R. Clay Reid and his co-workers, shows hundreds of individual neurons firing.

Practical Nanotubes

Molecular-scale fabrication points toward commercial carbon electronics

It is a long way from the slender nanotube—a chicken-wirelike cylinder of carbon a billionth of a meter thick—to a revolution in electronics. The very smallness that makes nanoscale materials so attractive as components of next-generation electronics also makes them extremely challenging to manipulate collectively. Investigators in the field hope, therefore, to realize commercial devices by piggybacking on existing manufacturing techniques. This year has seen several demonstrations of how nanoscale components might be integrated with conventional manufacturing as well as a report outlining a regulatory protocol for nanomaterials.

Motorola Physical Sciences Research Lab in May unveiled a prototype high-definition television screen, eschewing the cathode-ray tube for a glass panel coated with a brushy array of nanotubes. Nanotubes usually will not grow in precise arrays below 1,200 degrees Celsius, but Motorola's **James E. Jaskie** and his colleagues devised a metal catalyst that brought the requisite temperature down to a few hundred degrees, low enough to be achieved in the conventional ovens used to deposit thin silicon films. Other companies had built nanotube screens, but the tubes were suspended randomly in a paste. The paste-based screens have lower resolution, and the addition of a filter adds complexity.



Nanotubes traverse the gap between electrodes in Bradley J. Nelson's laboratory.

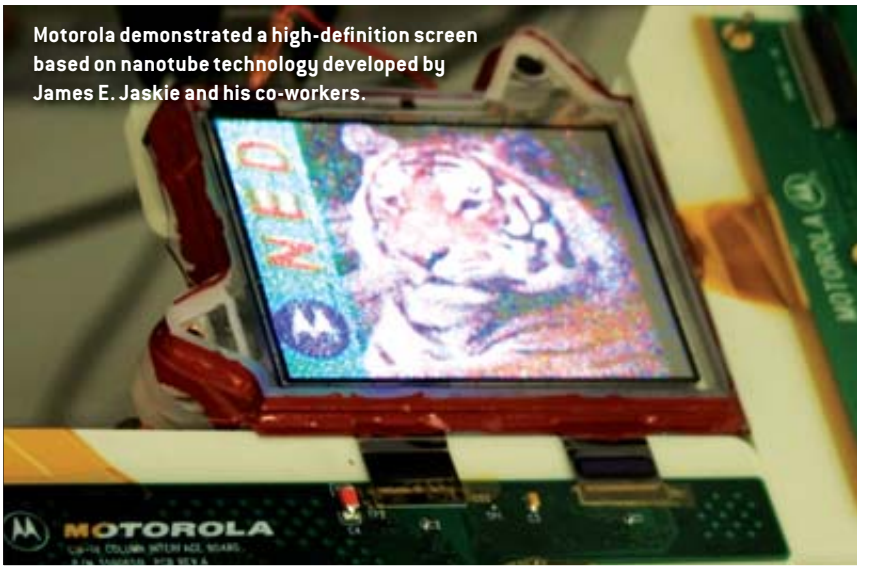
Nanotubes are also front and center in the quest for displays printed from bendable polymer components, so-called flexible electronics. Several groups have mixed nanotubes with a polymer to boost the material's conductivity. In the summer of 2004 a **DuPont Central Research and Development** team reported the first printing of such a

YEANG H. CH'NG (*top*); SWISS FEDERAL INSTITUTE OF TECHNOLOGY (*bottom*)

polymer, in large sheets, using an existing technology. Called thermal printing, it uses a laser to fuse the polymer to a substrate, like an iron-on transfer. This year the researchers reported printing polymer conductors, semiconductors and dielectrics all onto the same surface.

A more advanced question is how to conveniently turn nanotube arrays into more complex devices. **Bradley J. Nelson** of the Swiss Federal Institute of Technology in Zurich aligns hundreds to thousands of multiwalled nanotubes on and between tiny electrodes by applying a standard two-dimensional electrical field to a suspension of tubes. He then burns off the nanotube's top layers, breaks them in the middle, or otherwise tweaks them to create electronically controlled emitters, rotating actuators and telescoping linear actuators. Arrays of such devices might serve as robust chemical sensors or self-focusing light emitters, for example.

Building precise electronic circuits out of nanotubes or other nanowires is a more challenging problem. Today's chipmakers simply etch the pattern they want. **Hewlett-Packard Laboratories** investigators were some of the first to suggest building nanoscale circuits from scores of crisscrossing nanowires, or crossbar arrays, which could be chemically self-assembled at low cost. Electronically activating some of those junctions would create the circuit. The same researchers recently simulated chips made of such nanowire crossbar arrays. They found that given enough redundancy, they could overcome the crossbars' high defect rates and still pack 100 times more devices into a given area than today's chips have.



Motorola demonstrated a high-definition screen based on nanotube technology developed by James E. Jaskie and his co-workers.

A major policy concern in recent years has been whether and how to regulate nanomaterials, which can penetrate cells more easily than larger particles can. Last summer the U.K.'s **Royal Society** and **Royal Academy of Engineering** addressed those fears, concluding after a 12-month study that nanomaterials being produced in large quantities should be classified as new chemical entities under existing U.K. or European Union regulations and recommending that toxicity studies begin at once.

—JR Minkel

True Green

Architects and chemists strive to place an environmental stamp on their work

The color green—read "environmentally friendly"—now prefaces everything from gasoline to mutual funds. But is there anything truly green about these products other than the profits that they make for their purveyors?

In a few instances, industry and the professions have begun to earn their colors. One force steering the chemical industry in this direction is the Green Chemistry Institute (GCI) in Washington, D.C. The GCI has stewardship of

"Living roof" at a Ford plant insulates and filters rainwater.

MOTOROLA (*top*); WILLIAM McDONOUGH & PARTNERS (*bottom*)

A huge glass spire formed in the shape of a chrysalis tops the Swiss Re building in London, finished in 2004. Wind flowing across its walls drives the ventilation system and diminishes air-conditioning needs.

the annual Presidential Green Chemistry Challenge Awards. GCI director **Paul T. Anastas** announced in 1998 the 12 guiding principles of "green chemistry." Number one: "It is better to prevent waste than to treat or clean up waste after it has been created." Green chemistry, according to GCI, is not only easier on the environment, it saves companies millions of dollars they would otherwise spend on cleanup and disposal.

In 2005 Archer Daniels Midland Company, along with Novozymes, won jointly a GCI award for developing a process to replace unhealthful trans-fatty acids in soybean oil (used in vegetable shortening) with healthier unsaturated fats. The Food and Drug Administration requires the labeling of trans-fatty acids on nutritional panels beginning January 1, 2006.

Their process uses an enzyme, a biological catalyst called Lipozyme. It will save hundreds of millions of pounds of sodium methoxide, detergents and bleaching clay, as well as 60 million gallons of water, every year.

In addition to reducing waste, green chemistry seeks to eliminate poisonous reagents in industry. Toxic chemicals are also a concern for architects designing "green buildings," which are friendly to both their occupants and the surrounding environment. Adhesives and paints, the sources of "new car smell," can give off volatile organic compounds that cause headaches and nausea. Other troublemakers include mold spores and dust particles, which can lead to respiratory problems that reduce employee productivity in poorly ventilated office buildings. Innovators in environmentally oriented architecture exist at both the institutional and individual firm level.

In 2000 the **U.S. Green Buildings Council** (USGBC) defined the LEED (Leadership in Energy and Environmental Design) standards. Architects can have their buildings LEED-certified under a system that awards points in categories such as "indoor environmental quality" and "energy and atmosphere." The USGBC launched a pilot LEED program in August for home design. As with green chemistry, green architecture is profitable for its practitioners when all aspects of the process are accounted for, including long-term power bills and disposal of waste generated by construction.

The Condé Nast building at 4 Times Square in Manhattan, the world's most famous LEED-certified building, features an integrated recycling system, solar-cell wall panels and gas-powered fuel cells. Built in 1999, the structure was designed by **Fox & Fowle**, the New York–based architectural firm founded by Robert Fox and Bruce Fowle. The Helena, a 37-story LEED-certified apartment building on Manhattan's Upper West Side designed by Fox & Fowle, was completed in 2005.

The Frito-Lay plant in Henrietta, N.Y., which opened this June, won a LEED Gold award for its innovative use of permeable parking lots (to filter storm water and reduce waste flow), solar cells and nonvolatile furnishings. It was designed by **William McDonough & Partners**, which also drew the plans to cover the Ford plant in Dearborn, Mich., with the world's largest "living roof"—10 acres of roof planted with vegetation that simultaneously insulates buildings, filters rainwater and reduces heat absorption.

Norman Foster founded **Foster and Partners**, a London-based firm that designed the Swiss Re building, a giant chrysalis-shaped glass spire finished in 2004—and London's first green skyscraper. Wind flow across its curved walls creates a pressure differential that drives the ventilation system and reduces the need for air-conditioning. Along with the natural lighting, the air movement halves the power needed to operate the building. A structure's natural environment can be integrated into a building's engineering design by an inspired architect such as Foster. *—Kaspar Mossman*

NIGEL YOUNG *Foster and Partners*

Hope for Fixing Gene Defects

Studies have shown improved hearing in animals and demonstrated a new gene delivery method

Gene therapy tries to replace, repair, augment or manipulate a patient's own genes with the goal of treating illness. The technique not only can save lives but also can treat chronic conditions such as hearing impairment.

Hearing loss affects roughly 28 million Americans because the nearly 50,000 inner ear hair cells that humans are born with die off gradually over time. Unlike those hair cells in fish, amphibians and birds, those of mammals cease proliferating early in life, meaning hearing loss is usually permanent. Two research teams have demonstrated the possibility of regrowing hair cells.

In 2003 **Yehoash Raphael** of the University of Michigan Medical School at Ann Arbor and his colleagues had triggered inner ear hair cell growth in guinea pigs using adenoviruses that inserted a gene called *Atoh1*. Normally *Atoh1* is active only during embryonic development in cells that go on to become hair cells. Expanding on these experiments, they reported the first instance of scientists restoring function to inner ear hair cells in live adult mammals.

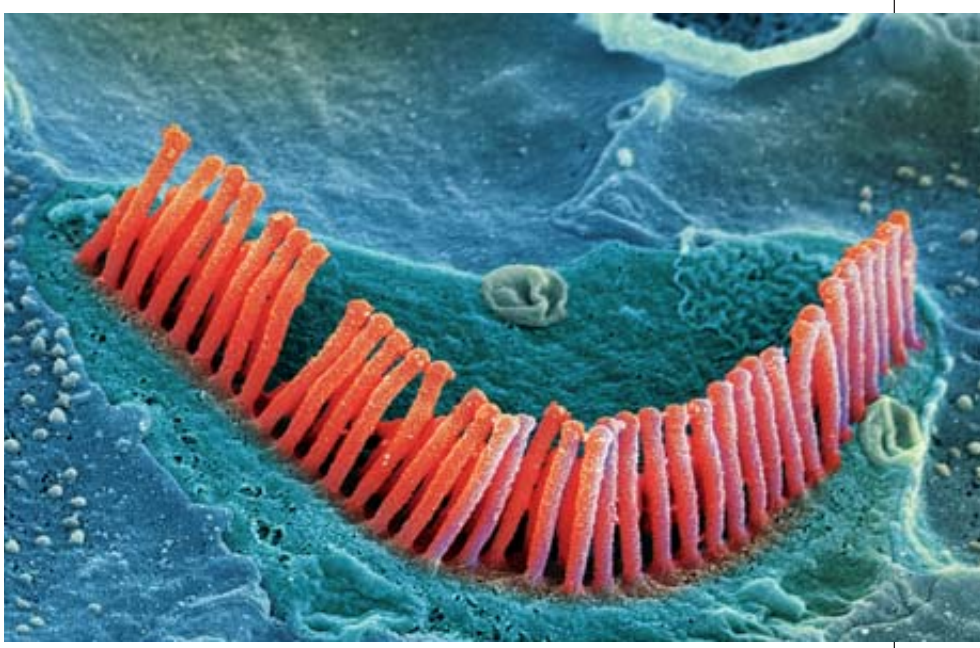
In March they published a study in which they employed their gene therapy on the left ears of 10 guinea pigs deafened by drugs. Eight weeks afterward the nonsensory cells lining the ears transformed into new inner ear hair cells and led to improved hearing. Raphael's group is not the only one working in this area.

Zheng-Yi Chen of Massachusetts General Hospital and his colleagues also found they could regenerate inner ear hair cells in mice. They started with a broad survey of gene expression patterns during embryonic development of the inner ear in mice and isolated a gene, *Rb1*, that appears to permanently brake hair cell growth. Their study, published in January, reported that deleting *Rb1* led to mice with more apparently functional inner ear hair cells than normal. They also found that cultured mature inner ear hair cells from mice were able to regenerate when they had *Rb1* knocked out.

Raphael and his team caution that they improved hearing but did not restore normal hearing and that it will take many years before *Atoh1* gene therapy will prove ready for humans. Chen and his colleagues remarked that knocking out *Rb1* made hair cells divide continuously, which could potentially lead to tumors. Future research should focus on inactivating *Rb1* only long enough for clinical benefit.

As effective as gene therapy might prove in the future, the viruses that gene therapy often employ to carry genes into the body can sometimes kill a patient or cause cancer. **Paras N. Prasad**, executive director of the University of Buffalo Institute for Lasers, Photonics and Biophotonics, and his team are developing silica particles roughly 30 nanometers wide as nonviral vectors for carrying out gene therapy.

Organic molecules coating the nanoparticle surfaces bind to genetic payloads and protect the delicate DNA from enzymatic digestion. Prasad and his colleagues reported in July that when injected into mouse brains, the nanoparticles affected more than one third of targeted cells, with equal or greater effectiveness than existing viral delivery systems. No mice showed adverse side effects one month after the injections. Research on both new therapies and gene delivery methods point toward ways of overcoming the tremendous obstacles that this form of therapy has confronted. —*Charles Q. Choi*



STEVE GSCHMEISSNER *Photo Researchers, Inc.*

Human inner ear hair cells (*above*) die as people age. Experiments in rodents have demonstrated the possibility of regenerating cells through a gene therapy technique.

Photons, Electrons and Silicon

Silicon lasers enable integration of optics and electronics

Lasers have become indispensable for even the most humdrum tasks, from highlighting Powerpoint presentations to burning music CDs. Lasers are also essential for high-speed communications along optical fiber, which has vastly greater bandwidth and much less crosstalk than electrical transmissions in copper wire. Recently scientists developed lasers made from silicon, an important first step in the development of high-speed chips that will fully integrate light-speed communications with the processing power of silicon electronics.

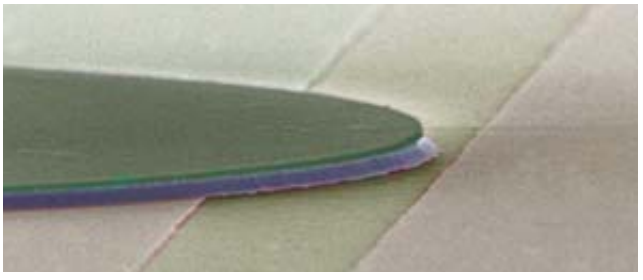
As CPU processing gets faster, the need increases for near-instantaneous clock synchronization within CPUs as well as for fast interchip communications for parallel computation. The integrated-circuit industry is rooted in silicon technology. Anything that can be made out of silicon can be fabricated with submicron dimensions and in huge volume, with great reliability. But silicon's electronic properties prevent it from functioning as a conventional laser. The material has an "indirect bandgap," which means that electrons cannot emit photons by dropping directly from one energy level to another. Solid-state lasers have until recently been made from direct-bandgap materials such as gallium arsenide (GaAs), which can spit out photons in the desired manner. Making an interface between the GaAs devices and silicon systems is difficult, and results are hard to reproduce to industry specifications.

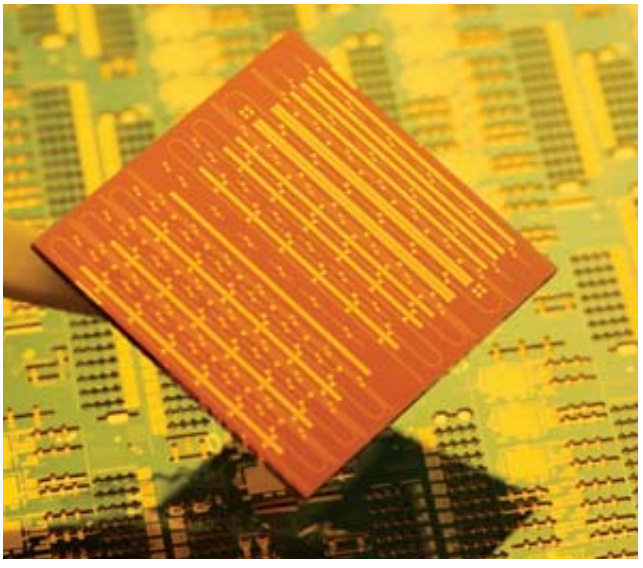
A technique called Raman scattering, though, has overcome this problem. The process begins when electrons first absorb photons. The excited electrons then "scatter" energy by emitting both phonons—a vibration of the silicon's lattice crystal—and photons of lower energy than the ones absorbed. In October 2004 **Ozdal Boyraz** and **Bahram Jalali**, two engineers at the University of California, Los Angeles, announced that they had demonstrated the first silicon Raman laser. It was an infrared device that emits pulses, each lasting 25 trillionths of a second, far shorter than the interval between them. The short pulses were necessary because of a two-photon absorption effect. Silicon atoms can absorb two photons simultaneously, generating an electron and a hole (the absence of an electron). The electron-hole pair remains in the material for a long time, absorbing power and weakening the laser amplification. The long gaps between the pulses in the Raman laser allow the electrons and holes to dissipate.

In February, Intel's **Haisheng Rong** and his colleagues published a paper in *Nature* detailing construction of a continuous-output silicon laser that attacked the two-photon absorption effect in a different way. Their device, a five-centimeter-long, S-shaped silicon waveguide, cleverly sidestepped the issue. Rong used a classic silicon device, the PIN diode. He doped one side of the waveguide with positive charge and the other with negative charge and then applied a voltage sideways across the waveguide to remove electron-hole pairs generated by two-photon absorption before they could absorb laser power.

Rong's innovative device exploited the same five-centimeter length of silicon for use as both an infrared laser and a semiconductor diode. His silicon laser is a significant advance because continuous beams, which can be modulated and chopped, provide the basis for digital communications. Low-cost optoelectronic devices made entirely from an industry-standard silicon process are still a long way off, but these lasers build a foundation from which we can expect to see light-speed information processing technology develop into reality.

—*Kaspar Mossman*





A technique called Raman scattering led to a new type of silicon laser (*top*). Meanwhile a team at Intel crafted a silicon chip capable of producing a continuous-output laser beam (*bottom*).

BAHRAM JALALI *U.C.L.A. (top)*; INTEL *(bottom)*

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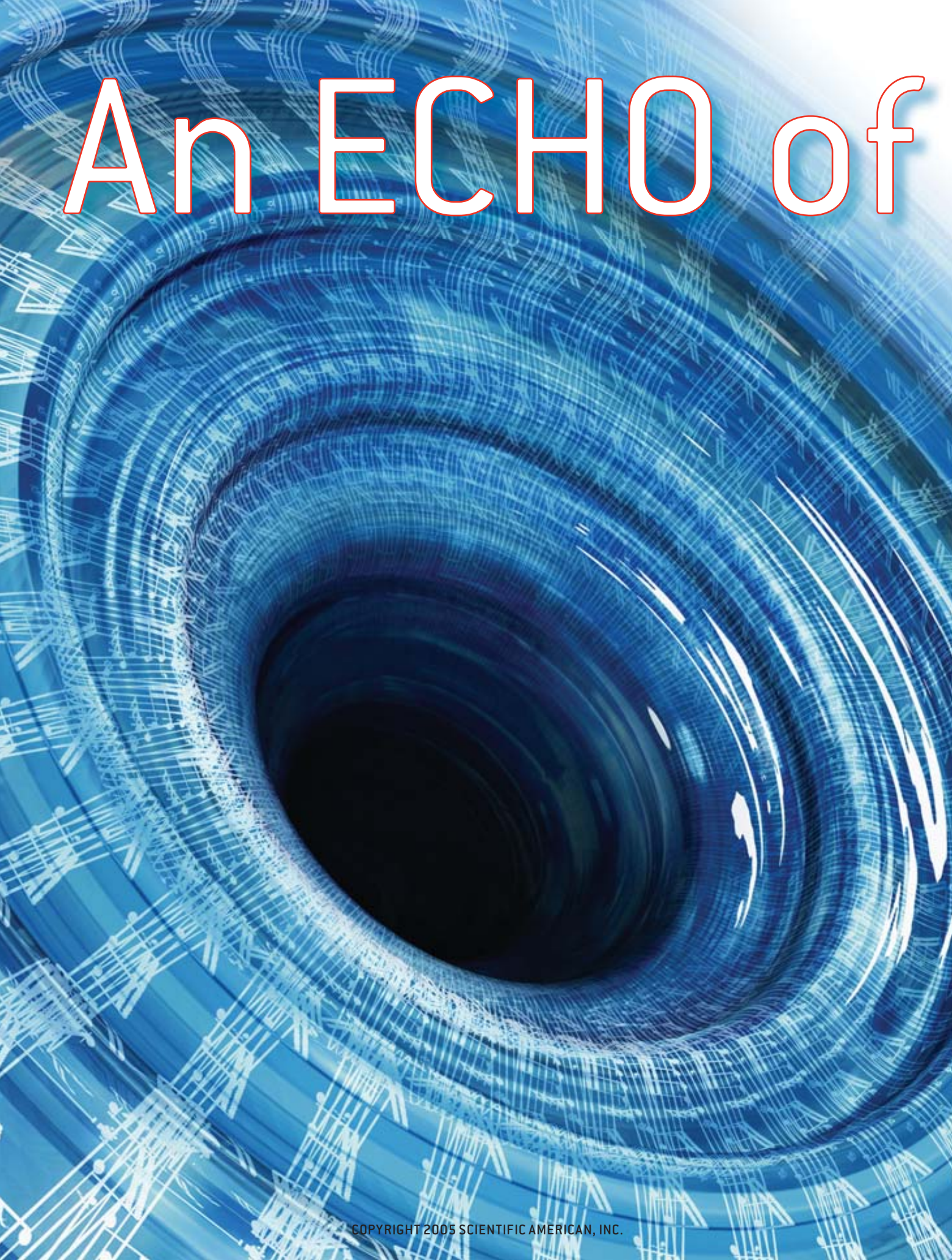


Black Holes

Sound waves in a fluid behave uncannily like light waves in space. Black holes even have acoustic counterparts. Could spacetime literally be a kind of fluid, like the ether of pre-Einsteinian physics?

By Theodore A. Jacobson and Renaud Parentani

When Albert Einstein proposed his special theory of relativity in 1905, he rejected the 19th-century idea that light arises from vibrations of a hypothetical medium, the "ether." Instead, he argued, light waves can travel in vacuo without being supported by any material—unlike sound waves, which are vibrations of the medium in which they propagate. This feature of special relativity is untouched in the two other pillars of modern physics, general relativity and quantum mechanics. Right up to the present day, all experimental data, on scales ranging from subnuclear to galactic, are successfully explained by these three theories.

Nevertheless, physicists face a deep conceptual problem. As currently understood, general relativity and quantum mechanics are incompatible. Gravity, which general relativity attributes to the curvature of the spacetime continuum, stubbornly resists being incorporated into a quantum framework. Theorists have made only incremental progress toward understanding the highly curved structure of spacetime that quantum mechanics leads them to expect at extremely short distances. Frustrated, some have turned to an unexpected source for guidance: condensed-matter physics, the study of common substances such as crystals and fluids.

Like spacetime, condensed matter looks like a continuum when viewed at large scales, but unlike spacetime it has a well-understood microscopic structure governed by quantum mechan-

ics. Moreover, the propagation of sound in an uneven fluid flow is closely analogous to the propagation of light in a curved spacetime. By studying a model of a black hole using sound waves, we and our colleagues are attempting to exploit this analogy to gain insight into the possible microscopic workings of spacetime. The work suggests that spacetime may, like a material fluid, be granular and possess a preferred frame of reference that manifests itself on fine scales—contrary to Einstein's assumptions.

From Black Hole to Hot Coal

BLACK HOLES are a favorite testing ground for quantum gravity because they are among the few places where quantum mechanics and general relativity are both critically important. A major step toward a merger of the two theories came in 1974, when Stephen W. Hawking of the University of Cambridge applied quantum mechanics to the horizon of black holes.

According to general relativity, the horizon is the surface that separates the inside of a black hole (where gravity is so strong that nothing can escape) from the outside. It is not a material limit; unfortunate travelers falling into the hole would not sense anything special on crossing the horizon. But once having done so, they would no longer be able to send light signals to people outside, let alone return there. An outside observer would receive only the signals transmitted by the travelers before they crossed over. As light waves climb out of the gravitational well around a black hole, they get stretched out, shifting down in frequency and lengthening in duration. Consequently, to the observer, the travelers would appear to move in slow motion and to be redder than usual.

This effect, known as gravitational redshift, is not specific to black holes. It also alters the frequency and timing of signals between, say, orbiting satellites and ground stations. GPS navigation systems must take it into account to work accurately. What is specific to black holes, however, is that the redshift becomes infinite as the travelers approach the horizon. From the outside observer's point of view, the descent appears to take an infinite amount of time, even though only a finite time passes for the travelers themselves.

So far this description of black holes has treated light as a classical electromagnetic wave. What Hawking did was to reconsider the implications of the infinite redshift when the quantum nature of light is taken into account. According to quantum theory, even a perfect vacuum is not truly empty; it is filled with fluctuations as a result of the Heisenberg uncertainty principle. The fluctuations take the form of pairs of virtual photons. These photons are called virtual because, in an uncurved spacetime, far from any gravitational influence, they appear and disappear restlessly, remaining unobservable in the absence of any disturbance.

But in the curved spacetime around a black hole, one member of the pair can be trapped inside the horizon, while the other gets stranded outside. The pair can then pass from virtual to real, leading to an outward flux of observable light and a corresponding decrease in the mass of the hole. The overall pattern of radiation is thermal, like that from a hot coal, with a temperature inversely proportional to the mass of the black hole. This phenomenon is called the Hawking effect. Unless the hole swallows matter or energy to make up the loss, the Hawking radiation will drain it of all its mass.

An important point—which will become critical later when considering fluid analogies to black holes—is that the space very near the black hole horizon remains a nearly perfect quantum vacuum. In fact, this condition is essential for Hawking's argument. The virtual photons are a feature of the lowest-energy quantum state, or "ground state." It is only in the process of separating from their partners and climbing away from the horizon that the virtual photons become real.

The Ultimate Microscope

HAWKING'S ANALYSIS has played a central role in the attempt to build a full quantum theory of gravity. The ability to reproduce and elucidate the effect is a crucial test for candidate quantum gravity theories, such as string theory [see "The Illusion of Gravity," by Juan Maldacena; SCIENTIFIC AMERICAN, November]. Yet although most physicists accept Hawking's argument, they have never been able to confirm it experimentally. The predicted emission from stellar and galactic black holes is far too feeble to see. The only hope for observing Hawking radiation is to find miniature holes left over from the early universe or created in particle accelerators, which may well prove impossible [see "Quantum Black Holes," by Bernard Carr and Steven Giddings; SCIENTIFIC AMERICAN, May].

The lack of empirical confirmation of the Hawking effect is particularly vexing in view of the disturbing fact that the theory has potential flaws, stemming from the infinite redshift that it predicts a photon will undergo. Consider what the emission process looks like when viewed reversed in time. As the Hawking photon gets nearer to the hole, it blueshifts to a

Overview/*Acoustic Black Holes*

- The famous physicist Stephen W. Hawking argued in the 1970s that black holes are not truly black; they emit a quantum glow of thermal radiation. But his analysis had a problem. According to relativity theory, waves starting at a black hole horizon will be stretched by an infinite amount as they propagate away. Therefore, Hawking's radiation must emerge from an infinitely small region of space, where the unknown effects of quantum gravity take over.
- Physicists have grappled with this problem by studying black hole analogues in fluid systems. The fluid's molecular structure cuts off the infinite stretching and replaces the microscopic mysteries of spacetime by known physics.
- The analogies lend credence to Hawking's conclusion. They also suggest to some researchers that spacetime has a "molecular" structure, contrary to the assumptions of standard relativity theory.

KENN BROWN (*preceding pages*)

higher frequency and correspondingly shorter wavelength. The further back in time it is followed, the closer it approaches the horizon and the shorter its wavelength becomes. Once the wavelength becomes much smaller than the black hole, the particle joins its partner and becomes the virtual pair discussed earlier.

The blueshifting continues without abatement, down to arbitrarily short distances. Smaller than a distance of about 10^{-35} meter, known as the Planck length, neither relativity nor standard quantum theory can predict what the particle will do. A quantum theory of gravity is needed. A black hole horizon thus acts as a fantastic microscope that brings the observer into contact with unknown physics. For a theorist, this magnification is worrisome. If Hawking's prediction relies on unknown physics, should we not be suspicious of its validity? Might the properties, even the existence, of Hawking radiation depend on the microscopic properties of spacetime—much as, for example, the heat capacity or speed of sound of a substance depends on its microscopic structure and dynamics? Or is the effect, as Hawking originally argued, entirely determined just by the macroscopic properties of the black hole, namely, its mass and spin?

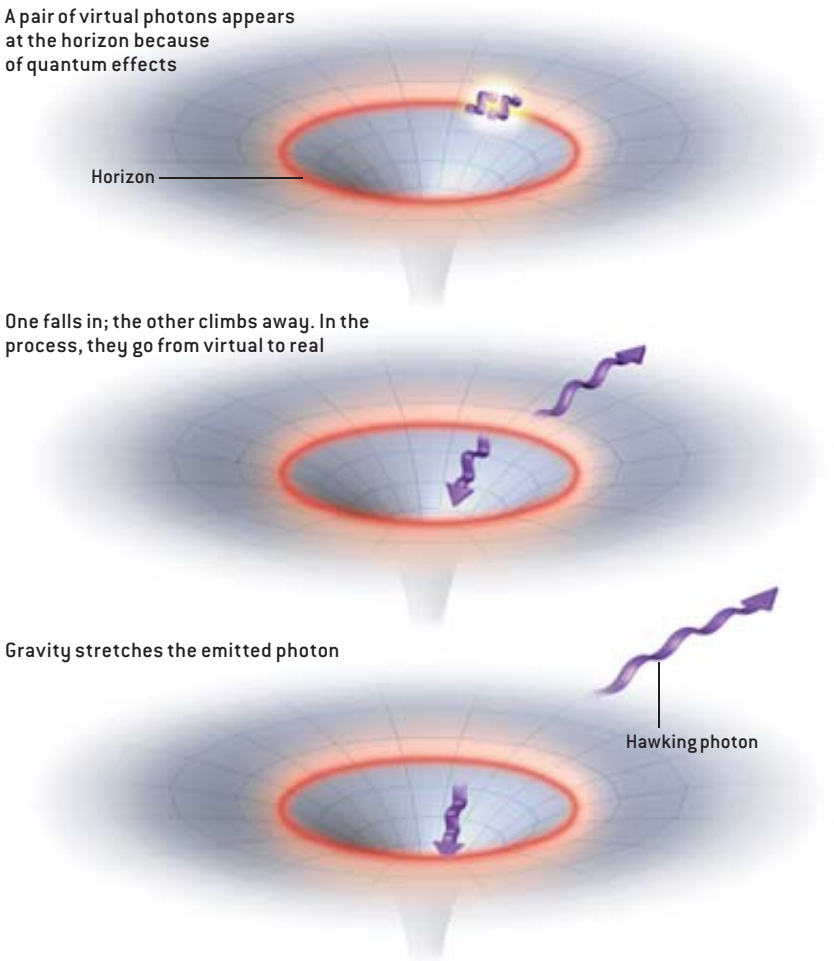
Sound Bites

ONE EFFORT TO ANSWER these embarrassing questions began with the work of William Unruh of the University of British Columbia. In 1981 he showed that there is a close analogy between the propagation of sound in a moving fluid and that of light in a curved spacetime. He suggested that this analogy might be useful in assessing the impact of microscopic physics on the origin of Hawking radiation. Moreover, it might even allow for experimental observation of a Hawking-like phenomenon.

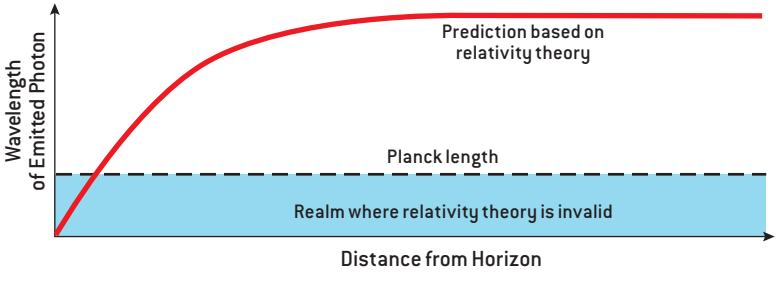
Like light waves, acoustic (sound) waves are characterized by a frequency, wavelength and propagation speed. The very concept of a sound wave is valid only when the wavelength is much longer than the distance between molecules of the fluid; on smaller scales, acoustic waves cease to exist. It is precisely this limitation

WAS HAWKING WRONG?

One of the greatest—and least recognized—mysteries of black holes concerns a flaw in Stephen W. Hawking's famous prediction that black holes emit radiation. A hole is defined by an event horizon, a one-way door: objects on the outside can fall in, but objects on the inside cannot get out. Hawking asked what happens to pairs of virtual particles (which continually appear and disappear everywhere in empty space because of quantum effects) that originate at the horizon itself.



Relativity theory predicts that a photon from the horizon gets stretched by an infinite amount (*red curve, below*). In other words, an observed photon must have originated as a virtual one with a wavelength of almost precisely zero, which is problematic because unknown quantum gravity effects take over at distances shorter than the so-called Planck length of 10^{-35} meter. This conundrum has driven physicists to design experimentally realizable analogues to black holes to see whether they indeed emit radiation and to understand how it originates.



GEORGE RETSECK

RIPPLES IN A STREAM behave much like light waves in spacetime. The flow of the stream around the rock is not uniform, so the ripples are bent and their wavelengths vary. The same happens to light passing through the gravitational field of a planet or star. In some cases, the flow is so fast that ripples cannot propagate upstream—just as light cannot propagate out of a black hole.

that makes the analogy so interesting, because it can allow physicists to study the macroscopic consequences of microscopic structure. To be truly useful, however, this analogy must extend to the quantum level. Ordinarily, random thermal jigging of the molecules prevents sound waves from behaving analogously to light quanta. But when the temperature approaches absolute zero, sound can behave like quantum particles, which physicists call "phonons" to underline the analogy with the particles of light, photons. Experimenters routinely observe phonons in crystals and in substances that remain fluid at sufficiently low temperatures, such as liquid helium.

The behavior of phonons in a fluid at rest or moving uniformly is like that of photons in flat spacetime, where gravity is absent. Such phonons propagate in straight lines with unchanging wavelength, frequency and velocity. Sound in, say, a swimming pool or a smoothly flowing river travels straight from its source to the ear.

In a fluid moving nonuniformly, however, the phonons' velocity is altered and their wavelength can become stretched, just like photons in a curved spacetime. Sound in a river entering a narrow canyon or water swirling down the drain becomes distorted and follows a bent path, like light around a star. In fact, the situation can be described using the geometrical tools of general relativity.

A fluid flow can even act on sound as a black hole acts on light. One way to create such an acoustic black hole is to use a device that hydrodynamicists call a Laval nozzle. The nozzle is designed so that the fluid reaches and exceeds the speed of sound at the narrowest point without producing a shock wave (an abrupt change in fluid properties). The effective acoustic geometry is very similar to the spacetime geometry of a black hole. The supersonic region corresponds to the hole's interior: sound waves propagating against the direction of the flow are swept downstream, like light pulled toward the center of a hole. The subsonic region is the exterior of the hole: Sound waves can propagate upstream but only at the expense of being stretched, like light being redshifted. The boundary between the two regions behaves exactly like a black hole horizon.

Atomism

IF THE FLUID is cold enough, the analogy extends to the quantum level. Unruh argued that the sonic horizon emits thermal phonons analogous to Hawking radiation. Quantum fluctuations near the horizon cause pairs of phonons to appear; one partner gets swept into the supersonic region, never to return, while the other ripples upstream, getting stretched out by the fluid flow. A microphone placed upstream picks up a faint hiss. The sound energy of the hiss is drawn from the kinetic energy of the fluid flow.

The dominant tone of the noise depends on the geometry; the typical wavelength of the observed phonons is comparable to the distance over which the flow velocity changes appreciably. This distance is much larger than the distance between molecules, so Unruh did his original analysis assuming that the fluid is smooth and continuous. Yet the phonons originate near the horizon with wavelengths so short that they should be sensitive to the granularity of the fluid. Does that affect the end result? Does a real fluid emit Hawking-like phonons, or is Unruh's prediction an artifact of the idealization of a continuous fluid? If that question can be answered for acoustic black

LIGHT VS. SOUND

TYPE OF WAVE	CLASSICAL DESCRIPTION	QUANTUM DESCRIPTION	VELOCITY	WHAT CAUSES PATH OF WAVE TO CURVE	WHERE DESCRIPTION BREAKS DOWN
Light	Oscillating electric and magnetic fields	Electromagnetic-wave photon	300,000 kilometers per second	Spacetime curvature, caused by matter and energy	Planck length? (10^{-35} meter)
Sound	Collective movements of molecules	Acoustic-wave phonon	1,500 meters per second (in liquid water)	Variations in fluid speed and direction	Intermolecular distance (10^{-10} meter for water)

BOB FOSBURY

holes, it may by analogy guide physicists in the case of gravitational black holes.

Physicists have proposed a number of black hole analogues besides the transsonic fluid flow. One involves not sound waves but ripples on the surface of a liquid or along the interface between layers of superfluid helium, which is so cold that it has lost all frictional resistance to motion. Recently Unruh and Ralf Schützhold of the Technical University of Dresden in Germany proposed to study electromagnetic waves passing through a tiny, carefully engineered electronic pipe. By sweeping a laser along the pipe to change the local wave speed, physicists might be able to create a horizon. Yet another idea is to model the accelerating expansion of the universe, which generates a Hawking-like radiation. A Bose-Einstein condensate—a gas so cold that the atoms have lost their individual identity—can act on sound like an expanding universe does on light, either by literally flying apart or by being manipulated using a magnetic field to give the same effect.

As yet, experimenters have not created any of these devices in the laboratory. The procedures are complicated, and experimenters have plenty of other low-temperature phenomena to keep them busy. So theorists have been working to see whether they can make headway on the problem mathematically.

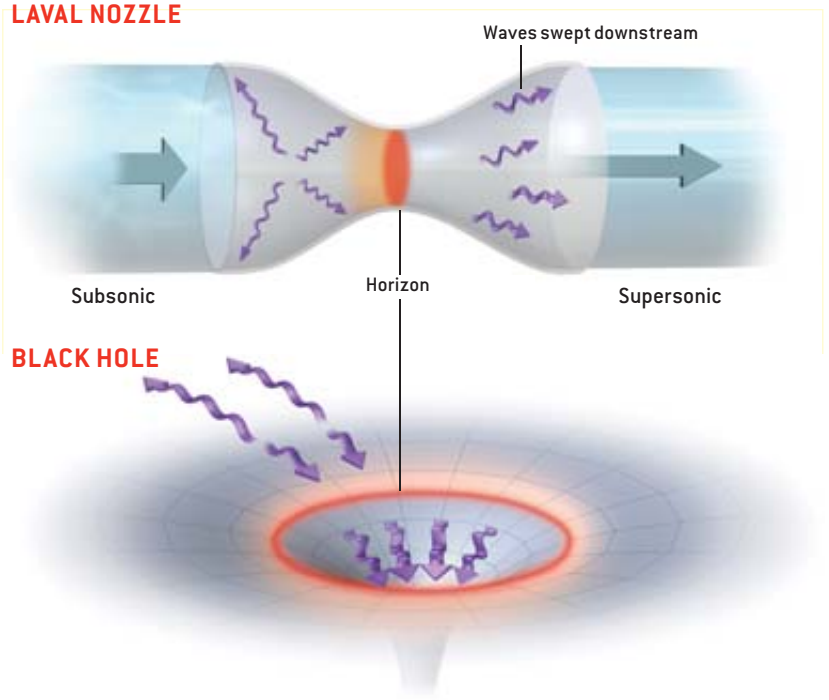
Understanding how the molecular structure of the fluid affects phonons is extremely complicated. Fortunately, 10 years after Unruh proposed his sonic analogy, one of us (Jacobson) came up with a very useful simplification. The essential details of the molecular structure are encapsulated in the way that the frequency of a sound wave depends on its wavelength. This dependence, called the dispersion relation, determines the velocity of propagation. For large wavelengths, the velocity is constant. For short wavelengths, approaching the intermolecular distance, the velocity can vary with wavelength.

Three different behaviors can arise. Type I is no dispersion—the wave behaves the same at short wavelengths as it does at long ones. For type II, the velocity decreases as the wavelength decreases, and for type III, velocity increases. Type I describes photons in relativity. Type II describes phonons in, for example, superfluid helium, and type III describes phonons in dilute Bose-Einstein condensates. This division into three types provides an organizing principle for figuring out how molecular structure affects sound on a macroscopic level. Beginning in 1995, Unruh and then other researchers have examined the Hawking effect in the presence of type II and type III dispersion.

Consider how the Hawking-like phonons look when viewed backward in time. Initially the dispersion type does not matter. The phonons swim downstream toward the horizon, their wavelengths decreasing all the while. Once the wavelength approaches the intermolecular distance, the specific dispersion relation becomes important. For type II, the phonons slow down, then reverse direction and start heading upstream again. For type III, they accelerate, break

BLACK HOLE ANALOGUE

A Laval nozzle—found at the end of rockets—makes a ready analogue to a black hole. The incoming fluid is subsonic; the constriction forces it to accelerate to the speed of sound, so that the outgoing fluid is supersonic. Sound waves in the subsonic region can move upstream, whereas waves in the supersonic region cannot. The constriction thus acts just like the horizon of a black hole: sound can enter but not exit the supersonic region. Quantum fluctuations in the constriction should generate sound analogous to Hawking radiation.



GEORGE RETSECK

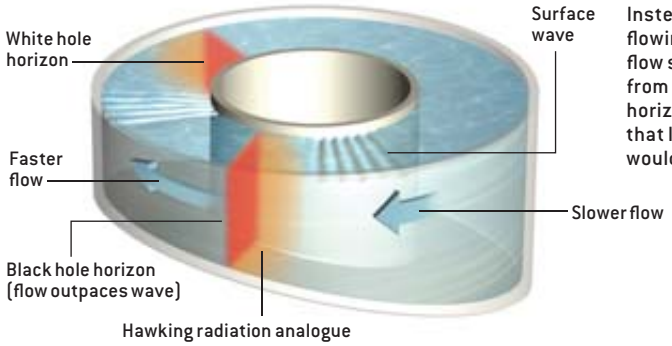
THE AUTHORS

THEODORE A. JACOBSON and *RENAUD PARENTANI* study the puzzles of quantum gravity and its possible observable consequences for black holes and cosmology. Jacobson is a physics professor at the University of Maryland. His recent research focuses on the thermodynamics of black holes, how spacetime might be microscopically discrete and whether that fine structure could be macroscopically detected. Parentani is a physics professor at the University of Paris–Sud at Orsay who does research at the CNRS Laboratory of Theoretical Physics. He investigates the role of quantum fluctuations in black hole physics and cosmology. This article is a translation and update of Parentani's article in the May 2002 issue of *Pour la Science,* the French edition of *Scientific American.*

OTHER BLACK HOLE MODELS

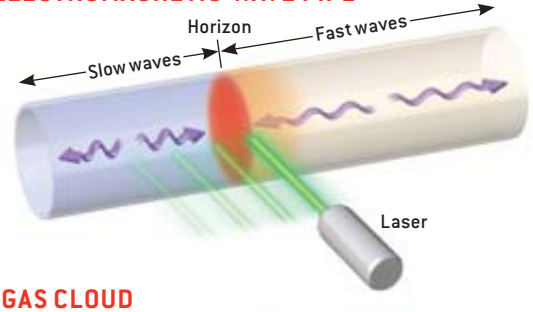
Devices besides the Laval nozzle also reproduce the essential characteristic of a black hole horizon: waves can go one way but not the other. Each offers novel insights into black holes. All should generate the analogue of Hawking radiation.

SURFACE RIPPLES



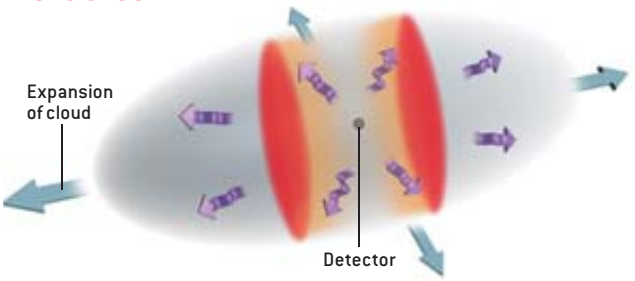
Instead of sound waves, this experiment involves surface waves in liquid flowing around a circular channel. As the channel becomes shallower, the flow speeds up and, at some point, outpaces the waves, preventing them from traveling upstream—thereby creating the analogue of a black hole horizon. Completing the circuit is the horizon of a "white hole": a body that lets material flow out but not in. To observe Hawking-like radiation would require a supercooled fluid such as helium 4.

ELECTROMAGNETIC-WAVE PIPE



This experiment studies microwaves passing through a rod built so that the speed of wave propagation can be tweaked with a laser beam. Sweeping the beam along the rod creates a moving horizon that divides the rod into slow- and fast-wave zones. Waves in the slow zone cannot reach the fast zone, but waves in the fast zone can cross to the slow. The Hawking-like radiation may be stronger and easier to observe than in fluid analogies.

GAS CLOUD



The long axis of an inflating, cigar-shaped gas cloud can simulate a one-dimensional universe expanding at an accelerating rate. Such a universe behaves like an inside-out black hole: waves outside the horizons are swept away too quickly to enter the inner region. A Hawking-like radiation should stream inward. In practice, the gas would be a Bose-Einstein condensate, a supercooled gas with quantum properties that make the Hawking analogy possible.

the long-wavelength speed of sound, then cross the horizon.

Ether Redux

A TRUE ANALOGY to the Hawking effect must meet an important condition: the virtual phonon pairs must begin life in their ground state, as do the virtual photon pairs around the black hole. In a real fluid, this condition would be easily met. As long as the macroscopic fluid flow changes slowly in time and space (compared with the pace of events at the molecular level), the molecular state continuously adjusts to minimize the energy of the system as a whole. It does not matter which molecules the fluid is made of.

With this condition met, it turns out that the fluid emits Hawking-like radiation no matter which of the three types of dispersion relations applies. The microscopic details of the fluid do not have any effect. They get washed out as the phonons travel away from the horizon. In addition, the arbitrarily short wavelengths invoked by original Hawking analysis do not arise when either type II or III dispersion is included. Instead the wavelengths bottom out at the intermolecular distance. The infinite redshift is an avatar of the unphysical assumption of infinitely small atoms.

Applied to real black holes, the fluid analogy lends confidence that Hawking's result is correct despite the simplifications he made. Moreover, it suggests to some researchers that the infinite redshift at a gravitational black hole horizon may be similarly avoided by dispersion of short wavelength light. But there is a catch. Relativity theory flatly asserts that light does not undergo dispersion in a vacuum. The wavelength of a photon appears different to different observers; it is arbitrarily long when viewed from a reference frame that is moving sufficiently close to the speed of light. Hence, the laws of physics cannot mandate a fixed short-wavelength cutoff, at which the dispersion relation changes from type I to type II or III. Each ob-

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server would perceive a different cutoff.

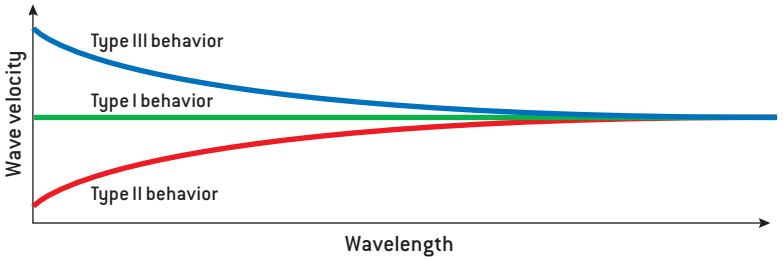
Physicists thus face a dilemma. Either they retain Einstein's injunction against a preferred frame and they swallow the infinite redshifting, or they assume that photons do not undergo an infinite redshift and they have to introduce a preferred reference frame. Would this frame necessarily violate relativity? No one yet knows. Perhaps the preferred frame is a local effect that arises only near black hole horizons—in which case relativity continues to apply in general. On the other hand, perhaps the preferred frame exists everywhere, not just near black holes—in which case relativity is merely an approximation to a deeper theory of nature. Experimenters have yet to see such a frame, but the null result may simply be for want of sufficient precision.

Physicists have long suspected that reconciling general relativity with quantum mechanics would involve a short-distance cutoff, probably related to the Planck scale. The acoustic analogy bolsters this suspicion. Spacetime must be somehow granular to tame the dubious infinite redshift.

If so, the analogy between sound and light propagation would be even better than Unruh originally thought. The unification of general relativity and quantum mechanics may lead us to abandon the idealization of continuous space and time and to discover the "atoms" of spacetime. Einstein may have had similar thoughts when he wrote to his close friend Michele Besso in 1954, the year before his death: "I consider it quite possible that physics cannot be based on the field concept, that is, on continuous structures." But this would knock out the very foundation from under physics, and at present scientists have no clear candidate for a substitute. Indeed, Einstein went on to say in his next sentence, "Then *nothing* remains of my entire castle in the air, including the theory of gravitation, but also nothing of the rest of modern physics." Fifty years later the castle remains intact, although its future is unclear. Black holes and their acoustic analogues have perhaps begun to light the path and sound out the way. SA

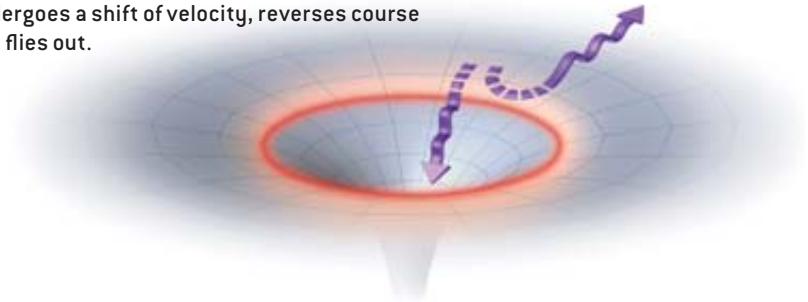
HAWKING WAS RIGHT, BUT ...

The fluid analogies suggest how to fix Hawking's analysis. In an idealized fluid, the speed of sound is the same no matter the wavelength (so-called type I behavior). In a real fluid, the speed of sound either decreases (type II) or increases (type III) as the wavelength approaches the distance between molecules.

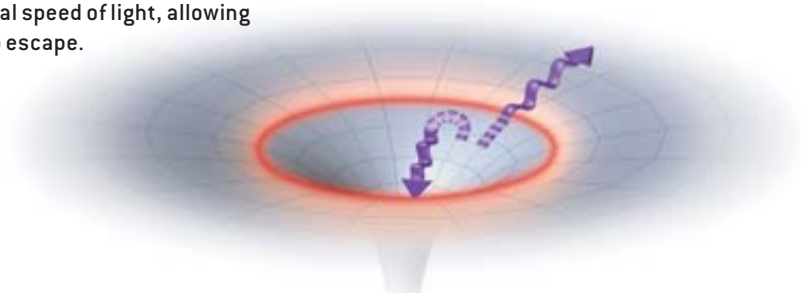


Hawking's analysis is based on standard relativity theory, in which light travels at a constant speed—type I behavior. If its speed varied with wavelength, as in the fluid analogues, the paths of the Hawking photons would change.

For type II, the photons originate outside the horizon and fall inward. One undergoes a shift of velocity, reverses course and flies out.



For type III, the photons originate inside the horizon. One accelerates past the usual speed of light, allowing it to escape.



Because the photons do not originate exactly at the horizon, they do not become infinitely redshifted. This fix to Hawking's analysis has a price: relativity theory must be modified. Contrary to Einstein's assumptions, spacetime must act like a fluid consisting of some unknown kind of "molecules."

MORE TO EXPLORE

Trans-Planckian Redshifts and the Substance of the Space-Time River. Ted Jacobson in *Progress of Theoretical Physics Supplement*, No. 136, pages 1–17; 1999. Available (free registration) at **http://ptp.ipap.jp/cgi-bin/getarticle?magazine=PTPS&volume=136&number=&page=1-17**

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Black-Hole Physics in an Electromagnetic Waveguide. Steven K. Blau in *Physics Today*, Vol. 58, No. 8, pages 19–20; August 2005.

For papers presented at the workshop on "Analog Models of General Relativity," see **www.physics.wustl.edu/~visser/Analog/**

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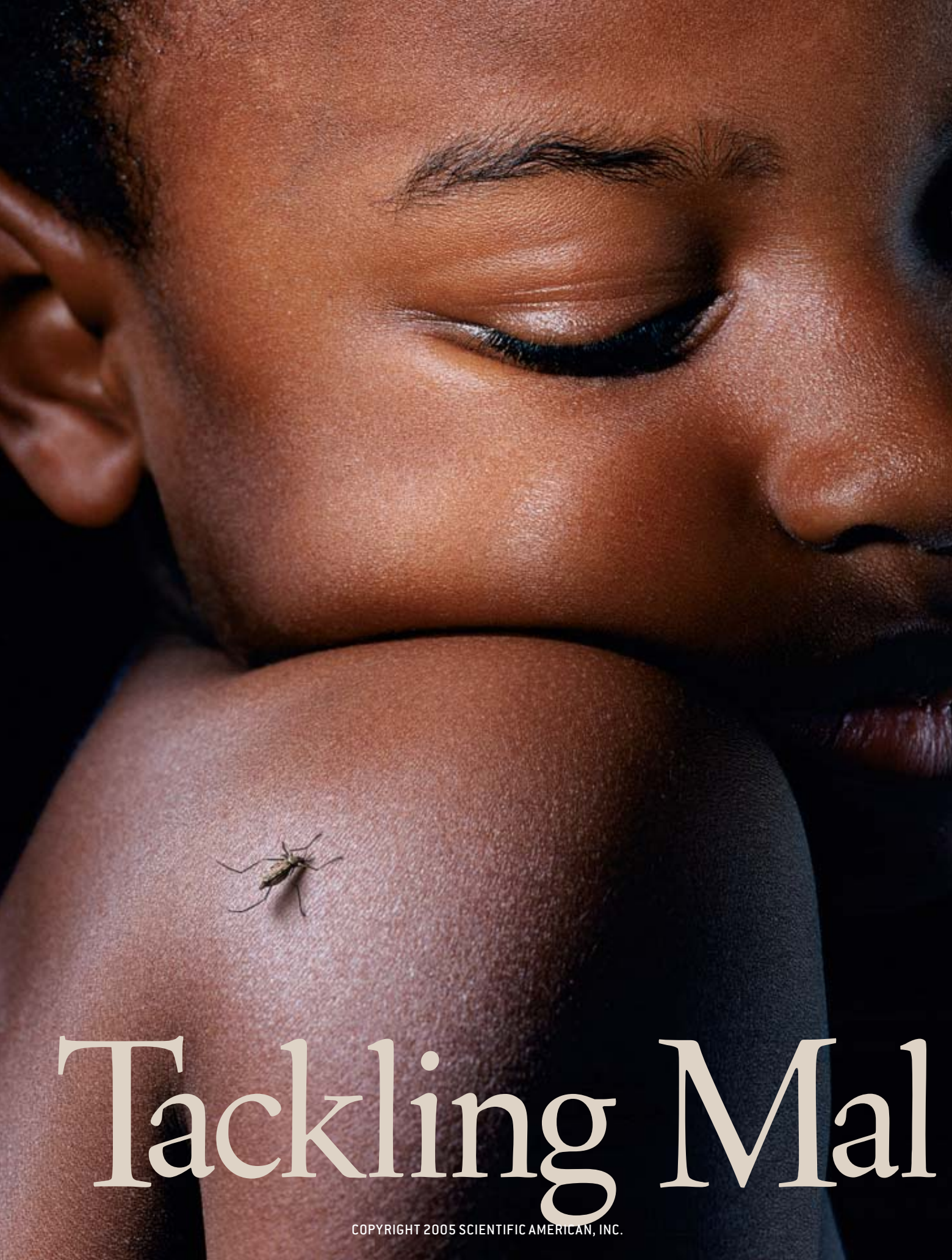


Tackling Mal

aria

PHOTOGRAPH BY RANDY HARRIS; PHOTOILLUSTRATION BY JEN CHRISTIANSEN

Interventions available today could lead to decisive gains in prevention and treatment—if only the world would apply them

By Claire Panosian Dunavan

Long ago in the Gambia, West Africa, a two-year-old boy named Ebrahim almost died of malaria. Decades later Dr. Ebrahim Samba is still reminded of the fact when he looks in a mirror. That is because his mother—who had already buried several children by the time he got sick—scored his face in a last-ditch effort to save his life. The boy not only survived but eventually became one of the most well-known leaders in Africa: Regional Director of the World Health Organization.

Needless to say, scarification is not what rescued Ebrahim Samba. The question is, What did? Was it the particular strain of parasite in his blood that day, his individual genetic or immunological makeup, his nutritional state? After centuries of fighting malaria—and conquering it in much of the world—it is amazing what we still do not know about the ancient scourge, including what determines life and death in severely ill children in its clutches. Despite such lingering questions, however, today we stand on the threshold of hope. Investigators are studying malaria survivors and tracking many other leads in efforts to develop vaccines. Most important, proven weapons—principally, insecticide-treated bed nets, other antimosquito strategies, and new combination drugs featuring an ancient Chinese herb—are moving to the front lines.

In the coming years the world will need all the malaria weapons it can muster. After all, malaria not only kills, it holds back human and economic development. Tackling it is now an international imperative.

A Villain in Africa

FOUR PRINCIPAL SPECIES of the genus *Plasmodium,* the parasite that causes malaria, can infect humans, and at least one of them still plagues every continent save Antarctica to a lesser or greater degree. Today, however, sub-Saharan Africa is not only the largest remaining sanctuary of *P. falciparum*—the most lethal species infecting humans—but the home of *Anopheles gambiae,* the most aggressive of the more than 60 mosquito species that transmit malaria to people. Every year 500 million falciparum infections befall Africans, leaving one million to two million dead—mainly children. Moreover, within heavily hit areas, malaria and its complications may account for 30 to 50 percent of inpatient admissions and up to 50 percent of outpatient visits.

The clinical picture of falciparum malaria, whether in children or adults, is not pretty. In the worst-case scenario, the disease's trademark fever and chills are followed by dizzying anemia, seizures and coma, heart and lung failure—and death. Those who survive can suffer mental or physical handicaps or chronic debilitation. Then there are people like Ebrahim Samba, who come through their acute illness with no residual effects. In 2002, at a major malaria conference in Tanzania where I met the surgeon-turned–public health leader, this paradox was still puzzling researchers more than half a century after Samba's personal clash with the disease.

BITE OF INFECTED MOSQUITO begins the deadly cycle of malaria—a disease that kills one million to two million people annually, mainly young children in sub-Saharan Africa.

That is not to say we have learned nothing in the interim regarding inborn and acquired defenses against malaria. We now know, for example, that inherited hemoglobin disorders such as sickle cell anemia can limit bloodstream infection. Furthermore, experts believe that antibodies and immune cells that build up over time eventually protect many Africans from malaria's overt wrath. Ebrahim Samba is a real-life example of this transformed state following repeated infection; after his early brush with death, he had no further malaria crises and to this day uses no preventive measures to stave off new attacks. (As a tropical medicine doctor, all I can say is: Don't try this on safari, folks, unless you, too, grew up immunized by hundreds of malarial mosquitoes every year.)

Samba's story also has another lesson in it. It affirms the hope that certain vaccines might one day mimic the protection that arises naturally in people like him, thereby lessening malaria-related deaths and complications in endemic regions. A different malaria vaccine might work by blocking infection altogether (for a short time, at least) in visitors such as travelers, aid workers or military peacekeepers, whose need for protection is less prolonged.

On the other hand, the promise of vaccines should not be overstated. Because malaria parasites are far more complex than disease-causing viruses and bacteria for which vaccines now exist, malaria vaccines may never carry the same clout as, say, measles or polio shots, which protect more than 90 percent of recipients who complete all recommended doses. And in the absence of a vaccine, Africa's malaria woes could continue to grow like a multiheaded Hydra. Leading the list of current problems are drug-resistant strains of *P. falciparum* (which first developed in South America and Asia and then spread to the African continent), followed by insecticide resistance among mosquitoes, crumbling public health infrastructures, and profound poverty that hobbles efforts to prevent infections in the first place. Finally, the exploding HIV/AIDS pandemic in Africa competes for precious health dollars and discourages the use of blood transfusions for severe malarial anemia.

> Malaria not only kills, it holds back human and economic development.

Where does this leave us? With challenges, to be sure. But challenges should not lead to despair that Africa will always be shackled to malaria. Economic history, for one, teaches us it simply isn't so.

Lessons of History

WHEN I LECTURE about malaria to medical students and other doctors, I like to show a map of its former geography. Most audiences are amazed to learn that malaria was not always confined to the tropics—until the 20th century, it also plagued such unlikely locales as Scandinavia and the American Midwest. The events surrounding malaria's exit from temperate zones and, more recently, from large swaths of Asia and South America reveal as much about its perennial ties to poverty as about its biology.

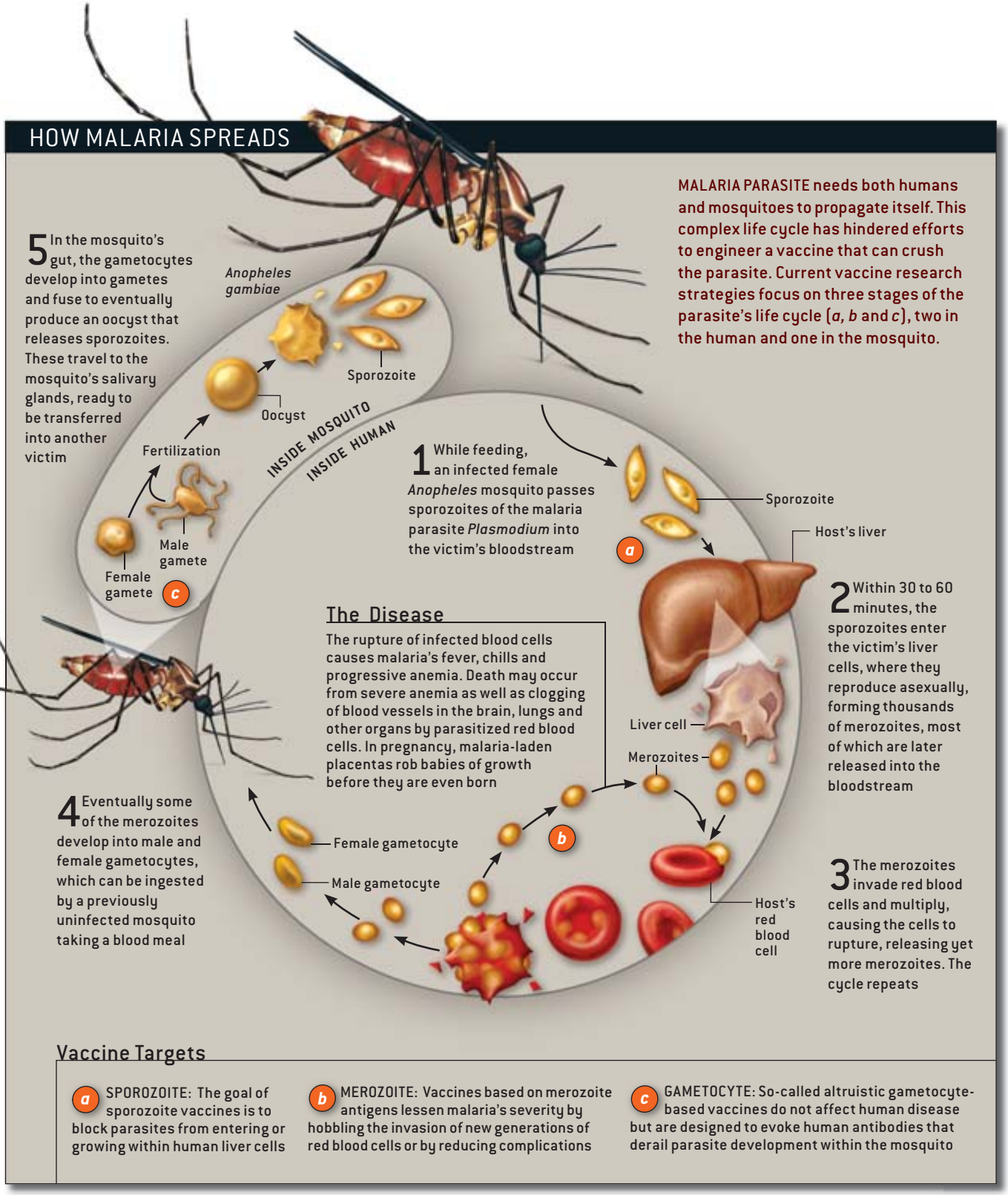
Take, for example, malaria's flight from its last U.S. stronghold—the poor, rural South. The showdown began in the wake of the Great Depression when the U.S. Army, the Rockefeller Foundation and the Tennessee Valley Authority (TVA) started draining and oiling thousands of mosquito breeding sites and distributing quinine (a plant-based antimalarial first discovered in South America) to purge humans of parasites that might otherwise sustain transmission. But the efforts did not stop there. The TVA engineers who brought hydroelectric power to the South also regulated dam flow to maroon mosquito larvae and installed acres of screen in windows and doors. As malaria receded, the local economies grew.

Then came the golden days of DDT (dichlorodiphenyltrichloroethane). After military forces used the wettable powder to aerially bomb mosquitoes in the malaria-ridden Pacific theater during World War II, public health authorities took the lead. Five years later selective spraying within houses became the centerpiece of global malaria eradication. By 1970 DDT spraying, elimination of mosquito breeding sites and the expanded use of antimalarial drugs freed more than 500 million people, or roughly one third of those previously living under malaria's cloud.

Sub-Saharan Africa, however, was always a special case: with the exception of a handful of pilot programs, no sustained eradication efforts were ever mounted there. Instead the availability of chloroquine—a cheap, man-made relative of quinine introduced after World War II—enabled countries with scant resources to replace large, technical spraying operations with solitary health workers. Dispensing tablets to almost anyone with a fever, the village foot soldiers saved millions of lives in the 1960s and 1970s. Then chloroquine slowly began

Overview/*Where We Stand Today*

- Researchers are laboring to create vaccines that would prevent malaria or lessen its severity.
- But existing interventions could fight the disease now. They include insecticide-treated bed nets, indoor spraying and new combination drugs based on an ancient Chinese herb.
- The question comes down to one of will and resources: In view of all the competing scourges—in particular, HIV/AIDS—is the world ready to take on malaria in its principal remaining stronghold, sub-Saharan Africa?



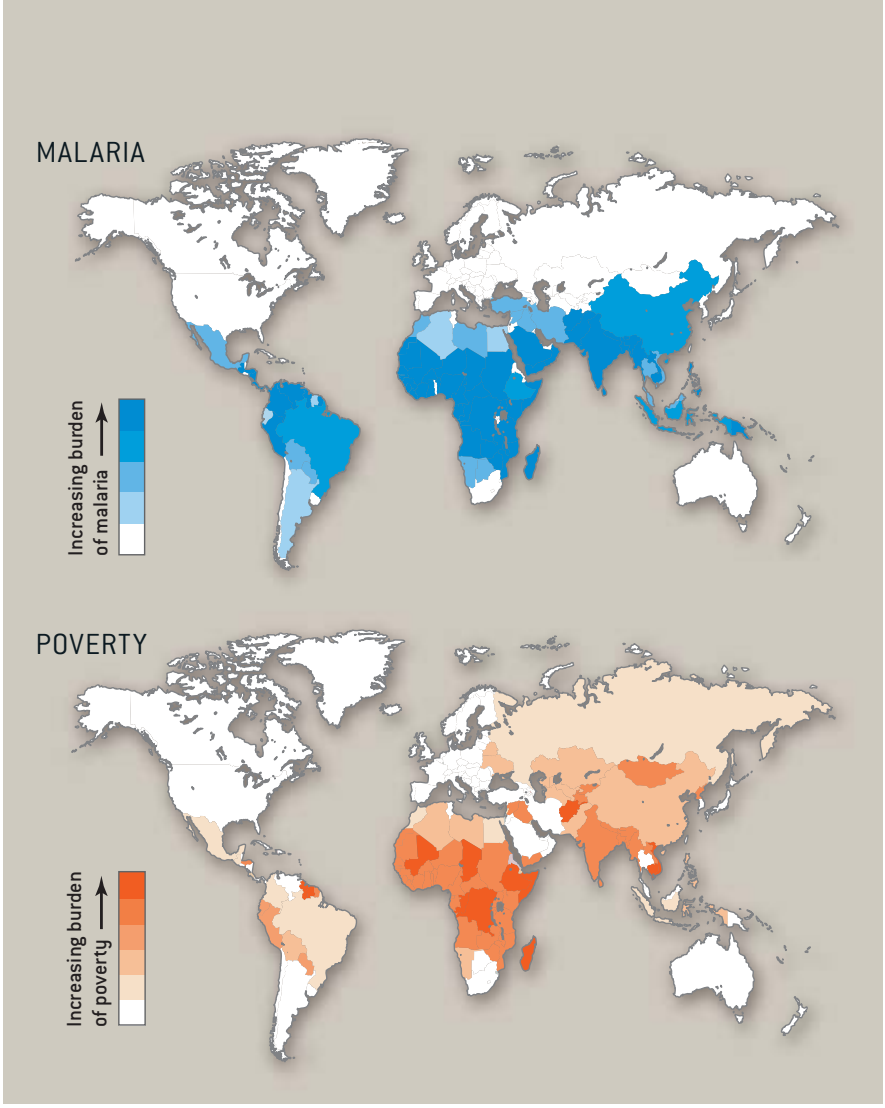
JEN CHRISTIANSEN

to fail against falciparum malaria. With little remaining infrastructure and expertise to counter Africa's daunting mosquito vectors, a rebound in deaths was virtually ordained.

Along the way, economists learned their lesson once again. Today in many African households, malaria not only limits income and robs funds for basic necessities such as food and youngsters' school fees, it fuels fertility because victims' families assume they will always lose children to the disease. On the regional level, it bleeds countries of foreign investment, tourism and trade. Continentwide, it costs up to $12 billion a year, or 4 percent of Africa's gross domestic product. In short, in many places malaria remains entrenched because of poverty and, at the same time, creates and perpetuates poverty.

Battling the Mosquito

YEARS AGO I THOUGHT everyone knew how malaria infected humans: nighttime bites of parasite-laden *Anopheles* mosquitoes. Today I know better.



MALARIA AND POVERTY cover common ground. Costs levied by the disease go far beyond expenditures on prevention and treatment to include lost income, investment and tourism revenue. Annual economic growth in countries with endemic malaria averaged 0.4 percent of per capita GDP between 1965 and 1990, compared with 2.3 percent in the rest of the world.

Some highly intelligent residents of malaria-plagued communities still believe that an evil spirit or certain foods cause the illness, a fact that underscores yet another pressing need: better malaria education. Nevertheless, long before Ronald Ross and Giovanni Batista Grassi learned in the late 19th century that mosquitoes transmit malaria, savvy humans were devising ways to elude mosquito bites. Writing almost five centuries before the common era, Herodotus described in *The Histories* how Egyptians living in marshy lowlands protected themselves with fishing nets: "Every man has a net which he uses in the daytime for fishing, but at night he finds another use for it: he drapes it over the bed.... Mosquitoes can bite through any cover or linen blanket ... but they do not even try to bite through the net at all." Based on this passage, some bed-net advocates view nets steeped in fish oil as the world's earliest repellent-impregnated cloth.

It was not until World War II, however, when American forces in the South Pacific dipped nets and hammocks in 5 percent DDT, that insecticides and textiles were formally partnered. After public opinion swung against DDT, treating bed nets with a biodegradable class of insecticides—the pyrethroids—was the logical next step. It proved a breakthrough. The first major use of pyrethroid-treated nets paired with antimalarial drugs, reported in 1991, halved mortality in children younger than five in the Gambia, and later trials, without the drugs, in Ghana, Kenya and Burkina Faso confirmed a similar lifesaving trend, plus substantial health gains in pregnant women. Moreover, with wide enough use, whole families and communities benefited from the nets—even people who did not sleep under them.

But insecticide-treated bed nets also have drawbacks. They work only if malaria mosquitoes bite indoors during sleeping hours—a behavior that is not universal. Nets make sleepers hot, discouraging use. Until recently, when PermaNet and Olyset—two long-lasting pyrethroid-impregnated nets—became available, nets had to be redipped every six to 12 months to remain effective. Finally, at $2 to $6 each, nets with or without insecticide are simply unaffordable for many people. A recent study in Kenya found that only 21 percent of households had even one bed net, of which 6 percent were insecticide-treated. A summary of 34 surveys conducted between 1999 and 2004 reached an even more depressing conclusion: a mere 3 percent of African youngsters were protected by insecticidal nets, although reports on the ground now suggest that use is quickly rising.

Insecticide resistance could also undermine nets as a long-term solution: mosquitoes genetically capable of inactivating pyrethroids have now surfaced in several locales, including Kenya and southern Africa, and some anophelines are taking longer to succumb to pyrethroids, a worrisome adaptive behavior known as knockdown resistance. Because precious few new insecticides intended for public health use are in sight (largely because of paltry economic incentives to develop them), one solution is rotating other agricultural insecticides on nets. Decoding the olfactory clues that attract mosquitoes to humans in the

THE AUTHOR

CLAIRE PANOSIAN DUNAVAN, a tropical medicine specialist at the David Geffen School of Medicine at the University of California, Los Angeles, is co-editor of a recently published Institute of Medicine report, *Saving Lives, Buying Time: Economics of Malaria Drugs in an Age of Resistance*. A graduate of Stanford University, Northwestern University Medical School and the London School of Hygiene and Tropical Medicine, she is an avid teacher and clinician whose second career as a medical journalist spans nearly two decades.

JEN CHRISTIANSEN; SOURCE: ROLL BACK MALARIA

first place is another avenue of research that could yield dividends in new repellents. (Ironically, a change in body odor when *P. falciparum* parasites are present in the blood may also attract mosquito bites; according to a recent report, Kenyan schoolchildren harboring gametocytes—the malaria stage taken up by mosquitoes—drew twice as many bites as their uninfected counterparts.)

How about harnessing the winged creatures themselves to kill malaria parasites? In theory, genetic engineering could quell parasite multiplication before the protozoa ever left the insects' salivary glands. If such insects succeeded in displacing their natural kin in the wild, they could halt the spread of malaria parasites to people. Recently native genes hindering malaria multiplication within *Anopheles* mosquitoes have been identified, and genetically reengineered strains of several important species are now on the drawing board. Once they are reared in the laboratory, however, releasing these Trojan insects into the real world poses a whole new set of challenges, including ethical ones.

Bottom line: for the time being, old-fashioned, indoor residual spraying with DDT remains a valuable public health tool in many settings in Africa and elsewhere [*see box below*]. Applied to surfaces, DDT is retained for six months or more. It reduces human-mosquito contact by two key mechanisms—repelling some mosquitoes before they ever enter a dwelling and killing others that perch on treated walls after feeding. A stunning example of its effectiveness surfaced in KwaZulu-Natal in 1999 and 2000. Pyrethroid-resistant *A. funestus* plus failing drugs had led to the largest number of falciparum cases there since the South African province launched its

DDT: A Symbol Gone Awry

In the 1950s a worldwide campaign to eradicate malaria had as its centerpiece the spraying of houses with DDT (dichlorodiphenyltrichloroethane). In less than two decades, the pesticide enabled many countries to control the disease. In India, for example, deaths from malaria plummeted from 800,000 annually to almost zero for a time.

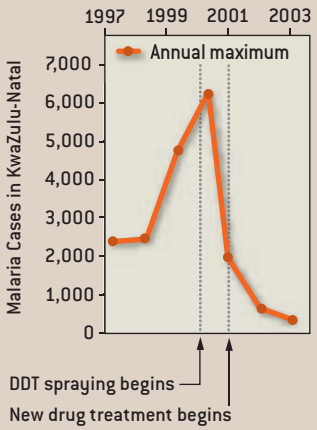
Then, in 1972, the U.S. government banned DDT for spraying crops—although public health and a few other minor uses were excepted. Rachel Carson's eloquent book *Silent Spring,* published a decade earlier, is often said to have sparked the ban. Carson meticulously charted the way DDT travels up the food chain in increasing concentrations, killing insects and some animals outright and causing genetic damage in others. DDT became a symbol of the dangers of playing God with nature, and the developed countries, having got rid of malaria within their borders, abandoned the chemical. Most of Europe followed the U.S. in banning the pesticide for agricultural applications in the 1970s.

For sub-Saharan Africa, where malaria still rages, these decisions have meant the loss of a valuable weapon. Most countries there go without DDT not because they have banned it themselves—in fact, it is allowed for public health uses in most areas of the world where malaria is endemic—but because wealthy donor nations and organizations are resistant to funding projects that would spray DDT even in responsible ways.

Many malaria researchers think DDT should be given another look. In addition to being toxic to mosquitoes, they note, it drives the insects off sprayed walls and out of doors before they bite, and it deters their entry in the first place. It is a toxin, irritant and repellent all rolled into one. Moreover, it lasts twice as long as alternatives, and it costs a quarter as much as the next cheapest insecticide.

The chemical's deadly trajectory through the food chain had its roots in massive agricultural spraying (mainly of cotton fields)—not in its much more moderate use inside dwellings to repel mosquitoes. Dusting a 100-hectare cotton field required some 1,100 kilograms of DDT over four weeks. Spraying the interior surfaces of a house, in contrast, would require roughly half a kilogram, applied once or twice a year.

DDT alone will not save the world from malaria; for instance, spraying houses works only against mosquitoes that bite indoors. Effective drugs for patients already infected are essential, as are other measures to control mosquitoes. But most malaria health professionals support the targeted use of DDT as an important part of the tool kit. *—The Editors*



MALARIA CASES DECLINED dramatically in KwaZulu-Natal when the South African government sprayed dwellings with DDT and later also treated patients with an artemisinin-based combination treatment (*graph*). One of the few African countries wealthy enough to fund its own program, it did not have to rely on aid from donors reluctant to use the chemical. The eaves of a typical African house, such as those in the photograph, provide many points of entry for mosquitoes.

JEN CHRISTIANSEN; SOURCE: IOM REPORT (*graph*); KAREN DUTHIE *AfricanPictures.net* (*photograph*)

malaria-control program years ago. Reintroduction of residual spraying of DDT along with new, effective drugs yielded a 91 percent drop in cases within two years.

Treating the Sick

ANTIMOSQUITO MEASURES alone cannot win the war against malaria—better drugs and health services are also needed for the millions of youngsters and adults who, every year, still walk the malaria tightrope far from medical care. Some are entrusted to village herbalists and itinerant quacks. Others take pills of unknown manufacture, quality or efficacy (including counterfeits) bought by family members or neighbors from unregulated sources. In Africa, 70 percent of antimalarials come from the informal private sector—in other words, small, roadside vendors as opposed to licensed clinics or pharmacies.

An ancient disease that is both preventable and curable still claims at least one million lives every year.

Despite plummeting efficacy, chloroquine, at pennies per course, remains the top-selling antimalarial pharmaceutical downed by Africans. The next most affordable drug in Africa is sulfadoxine-pyrimethamine, an antibiotic that interferes with folic acid synthesis by the parasite. Unfortunately, *P. falciparum* strains in Africa and elsewhere are also sidestepping this compound as they acquire sequential mutations that will ultimately render the drug useless.

Given the looming specter of drug resistance, can lessons from other infectious diseases guide future strategies to beef up malaria drug therapy? In recent decades resistant strains of the agents responsible for tuberculosis, leprosy and HIV/AIDS triggered a switch to two- and three-drug regimens, which then helped to forestall further emergence of "superbugs." Now most experts believe that multidrug treatments can also combat drug resistance in falciparum malaria, especially if they include a form of *Artemisia annua,* a medicinal herb once used as a generic fever remedy in ancient China. *Artemisia*-derived drugs (collectively termed "artemisinins") beat back malaria parasites more quickly than any other treatment does and also block transmission from humans to mosquitoes. Because of these unequaled advantages, combining them with other effective antimalarial drugs in an effort to prevent or delay artemisinin resistance makes sense, not just for Africa's but for the entire world's sake. After all, there is no guarantee malaria will not return someday to its former haunts. We know it can victimize global travelers. In recent years *P. falciparum*–infected mosquitoes have even stowed away on international flights, infecting innocent bystanders within a few miles of airports, far from malaria's natural milieu.

Yet there is a hitch to the new combination remedies: their costs—currently 10 to 20 times higher than Africa's more familiar but increasingly impotent malaria drugs—are hugely daunting to most malaria victims and to heavily affected countries. Even if the new cocktails were more modest in price, the global supply of artemisinins is well below needed levels and requires donor dollars to jumpstart the 18-month production cycle to grow, harvest and process the plants. Novartis, the first producer formally sanctioned by the WHO to manufacture a co-formulated artemisinin combination treatment (artemether plus lumefantrine), may not have enough funding and raw material to ship even a portion of the 120 million treatments it once hoped to deliver in 2006.

The good news? Cheaper, synthetic drugs that retain the distinctive chemistry of plant-based artemisinins (a peroxide bond embedded in a chemical ring) are on the horizon, possibly within five to 10 years. One prototype originating from research done in the late 1990s entered human trials in 2004. Another promising tactic that could bypass botanical extraction or chemical synthesis altogether is splicing *A. annua*'s genes and yeast genes into *Escherichia coli,* then coaxing pharmaceuticals out of the bacterial brew. The approach was pioneered by researchers at the University of California, Berkeley.

Preventing, as opposed to treating, malaria in highly vulnerable hosts—primarily African children and pregnant women—is also gaining adherents. In the 1960s low-dose antimalarial prophylaxis given to pregnant Nigerians was found, for the first time, to increase their newborns' birthweight. Currently this approach has been superseded by a full course of sulfadoxine-pyrimethamine taken several times during pregnancy, infancy and, increasingly, childhood immunization visits. Right now the recipe works well in reducing infections and anemia, but once resistance truly blankets Africa, the question is, What preventive treatment will replace sulfadoxine-pyrimethamine? Although single-dose artemisinins might seem the logical answer at first blush, these agents are not suitable for prevention, because their levels in blood diminish so quickly. And repeated dosing of artemisinins in asymptomatic women and children—an untested practice so far—could also yield unsuspected side effects. In an ideal world, prevention equals vaccine.

Where We Stand on Vaccines

THERE IS NO DOUBT that creating malaria vaccines that deliver long-lasting protection has proved more difficult than scientists first imagined, although progress has occurred over several decades. At the root of the dilemma is malaria's intricate life cycle, which encompasses several stages in mosquitoes and humans; a vaccine effective in killing one stage may not inhibit the growth of another. A second challenge is malaria's complex genetic makeup: of the 5,300 proteins encoded by *P. falciparum*'s genome, fewer than 10 percent trigger protective responses in naturally ex-

EBRAHIM SAMBA, who recently retired as the WHO's Regional Director for Africa, still bears delicate hatch marks incised on his cheeks at the age of two, when he was close to death from severe malaria.

posed individuals—the question is, Which ones? On top of that, several arms of the human immune system—antibodies, lymphocytes and the spleen, for starters—must work together to achieve an ideal response to malaria vaccination. Even in healthy people, much less populations already beset with malaria and other diseases, such responses do not always develop.

So far most experimental *P. falciparum* vaccines have targeted only one of malaria's three biological stages—sporozoite, merozoite or gametocyte [*see box on page 79*], although multistage vaccines, which could well prove more effective in the end, are also planned. Some of the earliest insights on attacking sporozoites (the parasite stage usually inoculated into humans through the mosquito's proboscis) came in the 1970s, when investigators at the University of Maryland found that x-ray-weakened falciparum sporozoites protected human volunteers, albeit only briefly. Presumably, the vaccine worked by inducing the immune system to neutralize naturally entering parasites before they escaped an hour later to their next way station, the liver.

The demonstration that antibodies artificially elicited against sporozoites could help fend off malaria prompted further work. Three decades later, in 2004, efforts bore fruit when a sporozoite vaccine more than halved serious episodes of malaria in 2,000 rural Mozambican children between the ages of one and four, the years when African children are most susceptible to dying from the disease. The formula used in this clinical trial (the most promising to date) included multiple copies of a *P. falciparum* sporozoite protein fragment fused to a hepatitis B viral protein added for extra potency. Even so, subjects required three separate immunizations, and the period of protection was short (only six months). Realistically, the earliest that an improved version of the vaccine known as RTS,S (or any of its roughly three dozen vaccine brethren currently in clinical development) might come to market is in 10 years, at a final price tag that leaves even Big Pharma gasping for air. Because of the anticipated costs, public-private partnerships such as the Seattle-based Malaria Vaccine Initiative are now helping to fund ongoing trials.

There is just one more thing to keep in mind about malaria vaccines. Even when they do become available—with any luck, sooner rather than later—effective treatments and antimosquito strategies will still be needed. Why? First of all, because rates of protection will never reach anywhere near 100 percent in those who actually receive the vaccines. Other malaria-prone individuals, especially the rural African poor, may not have access to the shots at all. Therefore, at least for the foreseeable future, all preventive and salvage measures must remain in the arsenal.

Investing in Malaria

ONCE AGAIN THE WORLD is coming to terms with the truth about malaria: the ancient enemy still claims at least one million lives every year while, at the same time, imposing tremendous physical, mental and economic hardships. Given our current tools and even more promising weapons on the horizon, the time has come to fight back.

The past decade has already witnessed significant milestones. In 1998 the WHO and the World Bank established the Roll Back Malaria partnership. In 2000 the G8 named malaria as one of three pandemics they hoped to curb, if not vanquish. The United Nations subsequently created the Global Fund to Fight AIDS, Tuberculosis and Malaria and pledged to halt and reverse the rising tide of malaria within 15 years. In 2005 the World Bank declared a renewed assault on malaria, and President George W. Bush announced a $1.2-billion package to fight malaria in Africa over five years, using insecticide-treated nets, indoor spraying of insecticides and combination drug treatments. More recently, the World Bank has begun looking for ways to subsidize artemisinin combination treatments. As this issue of *Scientific American* went to press, the Bill and Melinda Gates Foundation announced three grants totaling $258.3 million to support advanced development of a malaria vaccine, new drugs and improved mosquito-control methods.

Despite these positive steps, the dollars at hand are simply not equal to the task. Simultaneously with the announcement from the Gates Foundation, a major new analysis of global malaria research and development funding noted that only $323 million was spent in 2004. This amount falls far short of the projected $3.2 billion a year needed to cut malaria deaths in half by 2010. Perhaps it is time to mobilize not only experts and field-workers but ordinary folk. At roughly $5, the price of a lunch in the U.S. could go a long way toward purchasing an insecticide-treated bed net or a three-day course of artemisinin combination treatment for an African child.

In considering their potential return on investment, readers might also recall a small boy with scars on his cheeks who made it through malaria's minefield, then devoted his adult life to battling disease. Decades from now, how many other children thus spared might accomplish equally wondrous feats? SA

MORE TO EXPLORE

What the World Needs Now Is DDT. Tina Rosenberg in *New York Times Magazine,* pages 38–43; April 11, 2004.

Medicines for Malaria Venture: **www.mmv.org/**

World Health Organization, Roll Back Malaria Department: **www.who.int/malaria**

Smarter Use of

Fast-neutron reactors could extract much more energy from recycled nuclear fuel, minimize the risks of weapons proliferation and markedly reduce the time nuclear waste must be isolated

By William H. Hannum, Gerald E. Marsh and George S. Stanford

Despite long-standing public concern about the safety of nuclear energy, more and more people are realizing that it may be the most environmentally friendly way to generate large amounts of electricity. Several nations, including Brazil, China, Egypt, Finland, India, Japan, Pakistan, Russia, South Korea and Vietnam, are building or planning nuclear plants. But this global trend has not as yet extended to the U.S., where work on the last such facility began some 30 years ago.

If developed sensibly, nuclear power could be truly sustainable and essentially inexhaustible and could operate without contributing to climate change. In particular, a relatively new form of nuclear technology could overcome the principal drawbacks of current methods—namely, worries about reactor accidents, the potential for diversion of nuclear fuel into highly destructive weapons, the management of dangerous, long-lived radioactive waste, and the depletion of global reserves of economically available uranium. This nuclear fuel

JANA BRENNING

NUCLEAR WASTE

cycle would combine two innovations: pyrometallurgical processing (a high-temperature method of recycling reactor waste into fuel) and advanced fast-neutron reactors capable of burning that fuel. With this approach, the radioactivity from the generated waste could drop to safe levels in a few hundred years, thereby eliminating the need to segregate waste for tens of thousands of years.

For neutrons to cause nuclear fission efficiently, they must be traveling either slowly or very quickly. Most existing nuclear power plants contain what are called thermal reactors, which are driven by neutrons of relatively low speed (or energy) ricocheting within their cores. Although thermal reactors generate heat and thus electricity quite efficiently, they cannot minimize the output of radioactive waste.

All reactors produce energy by splitting the nuclei of heavy-metal (high-atomic-weight) atoms, mainly uranium or elements derived from uranium. In nature, uranium occurs as a mixture of two isotopes, the easily fissionable uranium 235 (which is said to be "fissile") and the much more stable uranium 238.

The uranium fire in an atomic reactor is both ignited and sustained by neutrons. When the nucleus of a fissile atom is hit by a neutron, especially a slow-moving one, it will most likely cleave (fission), releasing substantial amounts of energy and several other neutrons. Some of these emitted neutrons then strike other nearby fissile atoms, causing them to break apart, thus propagating a nuclear chain reaction. The resulting heat is conveyed out of the reactor, where it turns water into steam that is used to run a turbine that drives an electric generator.

Uranium 238 is not fissile; it is called "fissionable" because it sometimes splits when hit by a fast neutron. It is also said to be "fertile," because when a uranium 238 atom absorbs a neutron without splitting, it transmutes into plutonium 239, which, like uranium 235, is fissile and can sustain a chain reaction. After about three years of service, when technicians typically remove used fuel from one of today's reactors because of radiation-related degradation and the depletion of the uranium 235, plutonium is contributing more than half the power the plant generates.

In a thermal reactor, the neutrons, which are born fast, are slowed (or moderated) by interactions with nearby low-atomic-weight atoms, such as the hydrogen in the water that flows through reactor cores. All but two of the 440 or so commercial nuclear reactors operating are thermal, and most of them—in-

cluding the 103 U.S. power reactors—employ water both to slow neutrons and to carry fission-created heat to the associated electric generators. Most of these thermal systems are what engineers call light-water reactors.

In any nuclear power plant, heavy-metal atoms are consumed as the fuel "burns." Even though the plants begin with fuel that has had its uranium 235 content enriched, most of that easily fissioned uranium is gone after about three years. When technicians remove the depleted fuel, only about one twentieth of the potentially fissionable atoms in it (uranium 235, plutonium and uranium 238) have been used up, so the so-called spent fuel still contains about 95 percent of its original energy. In addition, only about one tenth of the mined uranium ore is converted into fuel in the enrichment process (during which the concentration of uranium 235 is increased considerably), so less than a hundredth of the ore's total energy content is used to generate power in today's plants.

This fact means that the used fuel from current thermal reactors still has the potential to stoke many a nuclear fire. Because the world's uranium supply is finite and the continued growth in the numbers of thermal reactors could exhaust the available low-cost uranium reserves in a few decades, it makes little sense to discard this spent fuel or the "tailings" left over from the enrichment process.

The spent fuel consists of three classes of materials. The fission products, which make up about 5 percent of the used fuel, are the true wastes—the ashes, if you will, of the fission fire. They comprise a mélange of lighter elements created when the heavy atoms split. The mix is highly radioactive for its first several years. After a decade or so, the activity is dominated by two isotopes, cesium 137 and strontium 90. Both are soluble in water, so they must be contained very securely. In around three centuries, those isotopes' radioactivity declines by a factor of 1,000, by which point they have become virtually harmless.

Uranium makes up the bulk of the spent nuclear fuel (around 94 percent); this is unfissioned uranium that has lost most of its uranium 235 and resembles natural uranium (which is just 0.71 percent fissile uranium 235). This component is only mildly radioactive and, if separated from the fission products and the rest of the material in the spent fuel, could readily be stored safely for future use in lightly protected facilities.

The balance of the material—the truly troubling part—is the transuranic component, elements heavier than uranium. This part of the fuel is mainly a blend of plutonium isotopes, with a significant presence of americium. Although the transuranic elements make up only about 1 percent of the spent fuel, they constitute the main source of today's nuclear waste problem. The half-lives (the period in which radioactivity halves) of these atoms range up to tens of thousands of years, a feature that led U.S. government regulators to require that the planned high-level nuclear waste repository at Yucca Mountain in Nevada isolate spent fuel for over 10,000 years.

Overview/*Nuclear Recycling*

- To minimize global warming, humanity may need to generate much of its future energy using nuclear power technology, which itself releases essentially no carbon dioxide.
- Should many more of today's thermal (or slow-neutron) nuclear power plants be built, however, the world's reserves of low-cost uranium ore will be tapped out within several decades. In addition, large quantities of highly radioactive waste produced just in the U.S. will have to be stored for at least 10,000 years—much more than can be accommodated by the Yucca Mountain repository in Nevada. Worse, most of the energy that could be extracted from the original uranium ore would be socked away in that waste.
- The utilization of a new, much more efficient nuclear fuel cycle—one based on fast-neutron reactors and the recycling of spent fuel by pyrometallurgical processing—would allow vastly more of the energy in the earth's readily available uranium ore to be used to produce electricity. Such a cycle would greatly reduce the creation of long-lived reactor waste and could support nuclear power generation indefinitely.

An Outdated Strategy

EARLY NUCLEAR engineers expected that the plutonium in the spent fuel of thermal reactors would be removed and then used in fast-neutron reactors, called fast breeders because they were designed to produce more plutonium than they consume. Nuclear power pioneers also envisioned an energy economy that would involve open commerce in plutonium. Plutonium can be used to make bombs, however. As nuclear technology spread beyond the major superpowers, this potential application led to worries over uncontrolled proliferation of atomic weapons to other states or even to terrorist groups.

The Nuclear Non-Proliferation Treaty partially addressed that problem in 1968. States that desired the benefits of nuclear power technology could sign the treaty and promise not to acquire nuclear weapons, whereupon the weapons-holding nations agreed to assist the others with peaceful applications. Although a cadre of international inspectors has since monitored member adherence to the treaty, the effectiveness of that international agreement has been spotty because it lacks effective authority and enforcement means.

Nuclear-weapons designers require plutonium with a very high plutonium 239 isotopic content, whereas plutonium from commercial power plants usually contains substantial quantities of the other isotopes of plutonium, making it difficult to use in a bomb. Nevertheless, use of plutonium from spent fuel in weapons is not inconceivable. Hence, President Jimmy Carter banned civilian reprocessing of nuclear fuel in the U.S. in 1977. He reasoned that if plutonium were not recovered from spent fuel it

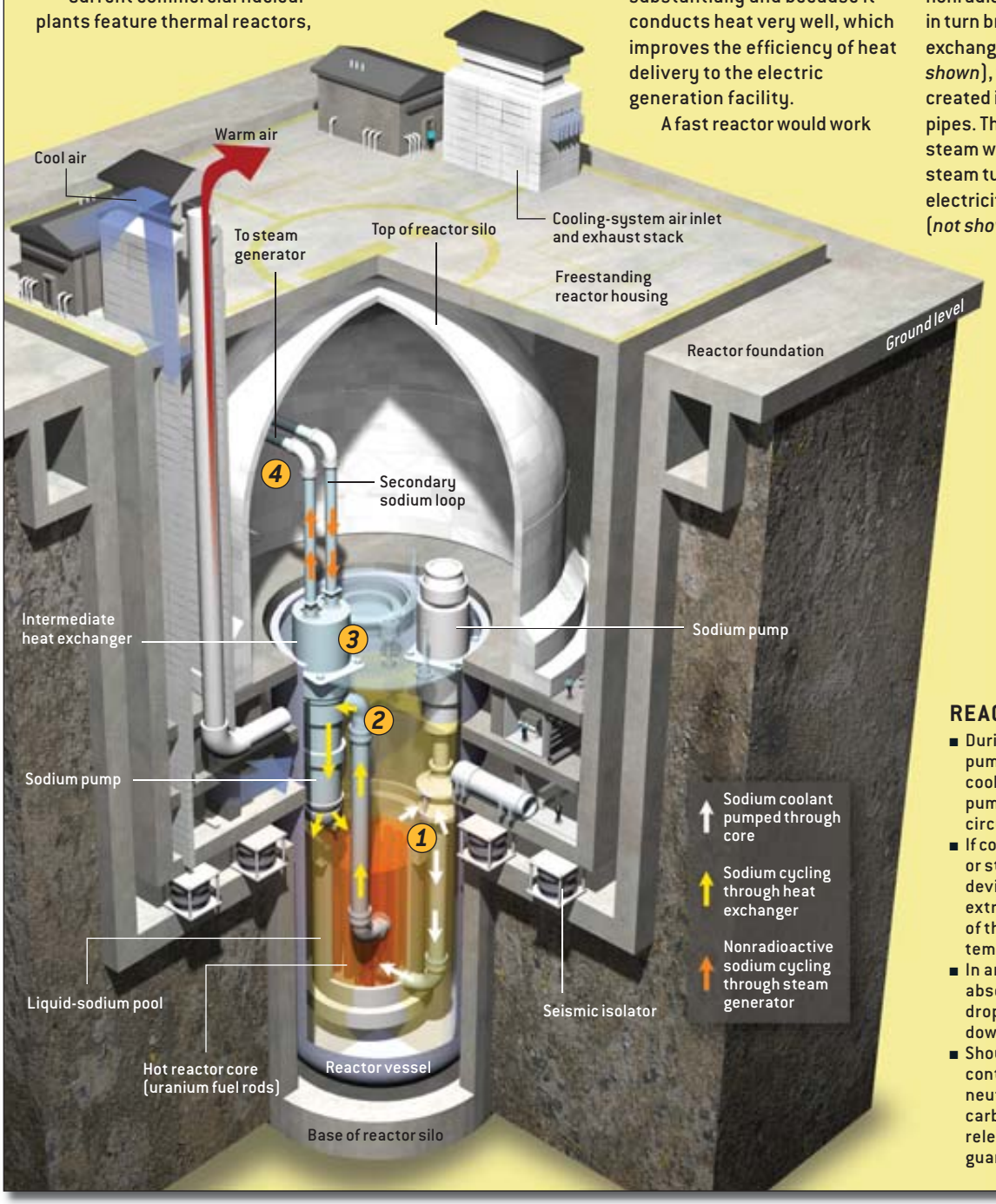
NEW TYPE OF NUCLEAR REACTOR

A safer, more sustainable nuclear power cycle could be based on the advanced liquid-metal reactor (ALMR) design developed in the 1980s by researchers at Argonne National Laboratory. Like all atomic power plants, an ALMR-based system would use nuclear chain reactions in the core to produce the heat needed to generate electricity.

Current commercial nuclear plants feature thermal reactors, which rely on relatively slow moving neutrons to propagate chain reactions in uranium and plutonium fuel. An ALMR-based system, in contrast, would use fast-moving (energetic) neutrons. This process permits all the uranium and heavier atoms to be consumed, thereby allowing vastly more of the fuel's energy to be captured. In the near term, the new reactor would burn fuel made by recycling spent fuel from thermal reactors.

In most thermal-reactor designs, water floods the core to slow (moderate) neutrons and keep it cool. The ALMR, however, employs a pool of circulating liquid sodium as the coolant (*1*). Engineers chose sodium because it does not slow down fast neutrons substantially and because it conducts heat very well, which improves the efficiency of heat delivery to the electric generation facility.

A fast reactor would work like this: Nuclear fire burning in the core would heat the radioactive liquid sodium running through it. Some of the heated sodium would be pumped into an intermediate heat exchanger (*2*), where it would transfer its thermal energy to nonradioactive liquid sodium flowing through the adjacent but separate pipes (*3*) of a secondary sodium loop. The nonradioactive sodium (*4*) would in turn bring heat to a final heat exchanger/steam generator (*not shown*), where steam would be created in adjacent water-filled pipes. The hot, high-pressure steam would then be used to turn steam turbines that would drive electricity-producing generators (*not shown*).



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REACTOR SAFEGUARDS

- During operation, powerful pumps would force sodium coolant through the core. If the pumps failed, gravity would circulate the coolant.
- If coolant pumps malfunctioned or stopped, special safety devices would also permit extra neutrons to leak out of the core, lowering its temperature.
- In an emergency, six neutron-absorbing control rods would drop into the core to shut it down immediately.
- Should chain reactions continue, thousands of neutron-absorbing boron carbide balls would be released into the core, guaranteeing shutdown.

could not be used to make bombs. Carter also wanted America to set an example for the rest of the world. France, Japan, Russia and the U.K. have not, however, followed suit, so plutonium reprocessing for use in power plants continues in a number of nations.

An Alternative Approach

WHEN THE BAN was issued, "reprocessing" was synonymous with the PUREX (for *p*lutonium *u*ranium *ex*traction) method, a technique developed to meet the need for chemically pure plutonium for atomic weapons. Advanced fast-neutron reactor technology, however, permits an alternative recycling strategy that does not involve pure plutonium at any stage. Fast reactors can thus minimize the risk that spent fuel from energy production would be used for weapons production, while providing a unique ability to squeeze the maximum energy out of nuclear fuel [*see box below*]. Several such reactors have been built and used for power generation—in France, Japan, Russia, the U.K. and the U.S.—two of which are still operating [see "Next-Generation Nuclear Power," by James A. Lake, Ralph G. Bennett and John F. Kotek; SCIENTIFIC AMERICAN, January 2002].

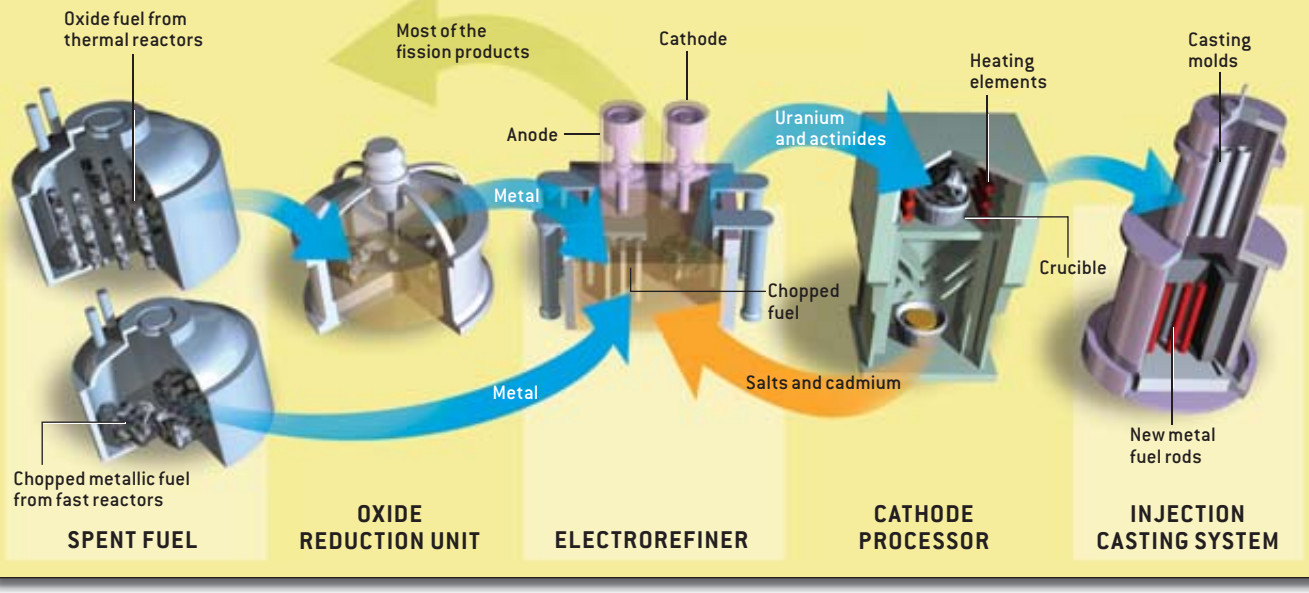
Fast reactors can extract more energy from nuclear fuel than thermal reactors do because their rapidly moving (higher-energy) neutrons cause atomic fissions more efficiently than the slow thermal neutrons do. This effectiveness stems from two phenomena. At slower speeds, many more neutrons are absorbed in nonfission reactions and are lost. Second, the higher energy of a fast neutron makes it much more likely that a fertile heavy-metal atom like uranium 238 will fission when struck. Because of this fact, not only are uranium 235 and plutonium 239 likely to fission in a fast reactor, but an appreciable fraction of the heavier transuranic atoms will do so as well.

Water cannot be employed in a fast reactor to carry the heat from the core—it would slow the fast neutrons. Hence, engineers typically use a liquid metal such as sodium as a coolant and heat transporter. Liquid metal has one big advantage over water. Water-cooled systems run at very high pressure, so that a small leak can quickly develop into a large release of steam and perhaps a serious pipe break, with rapid loss of reactor coolant. Liquid-metal systems, however, operate at atmospheric pressure, so they present vastly less potential for a major release. Nevertheless, sodium catches fire if exposed to water, so it must be managed carefully. Considerable industrial experience with handling the substance has been amassed over the years, and management methods are well developed. But sodium fires have occurred, and undoubtedly there will be more. One sodium fire began in 1995 at the Monju

NEW WAY TO REUSE NUCLEAR FUEL

The key to pyrometallurgical recycling of nuclear fuel is the electrorefining procedure. This process removes the true waste, the fission products, from the uranium, plutonium and the other actinides (heavy radioactive elements) in the spent fuel. The actinides are kept mixed with the plutonium so it cannot be used directly in weapons.

Spent fuel from today's thermal reactors (uranium and plutonium oxide) would first undergo oxide reduction to convert it to metal, whereas spent metallic uranium and plutonium fuel from fast reactors would go straight to the electrorefiner. Electrorefining resembles electroplating: spent fuel attached to an anode would be suspended in a chemical bath; then electric current would plate out uranium and other actinides on the cathode. The extracted elements would next be sent to the cathode processor to remove residual salts and cadmium from refining. Finally, the remaining uranium and actinides would be cast into fresh fuel rods, and the salts and cadmium would be recycled.



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fast reactor in Japan. It made a mess in the reactor building but never posed a threat to the integrity of the reactor, and no one was injured or irradiated. Engineers do not consider sodium's flammability to be a major problem.

Researchers at Argonne National Laboratory began developing fast-reactor technology in the 1950s. In the 1980s this research was directed toward a fast reactor (dubbed the advanced liquid-metal reactor, or ALMR), with metallic fuel cooled by a liquid metal, that was to be integrated with a high-temperature pyrometallurgical processing unit for recycling and replenishing the fuel. Nuclear engineers have also investigated several other fast-reactor concepts, some burning metallic uranium or plutonium fuels, others using oxide fuels. Coolants of liquid lead or a lead-bismuth solution have been used. Metallic fuel, as used in the ALMR, is preferable to oxide for several reasons: it has some safety advantages, it will permit faster breeding of new fuel, and it can more easily be paired with pyrometallurgical recycling.

Pyroprocessing

THE PYROMETALLURGICAL process ("pyro" for short) extracts from used fuel a mix of transuranic elements instead of pure plutonium, as in the PUREX route. It is based on electroplating—using electricity to collect, on a conducting metal electrode, metal extracted as ions from a chemical bath. Its name derives from the high temperatures to which the metals must be subjected during the procedure. Two similar approaches have been developed, one in the U.S., the other in Russia. The major difference is that the Russians process ceramic (oxide) fuel, whereas the fuel in an ALMR is metallic.

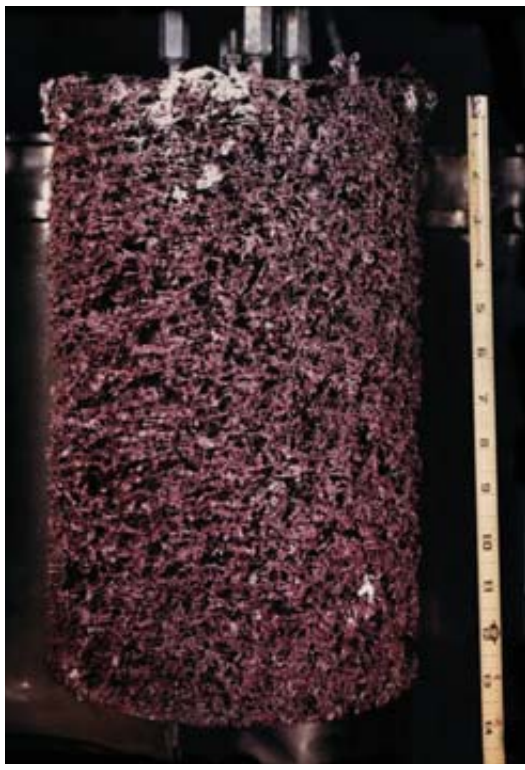
In the American pyroprocess [*see box on opposite page*], technicians dissolve spent metallic fuel in a chemical bath. Then a strong electric current selectively collects the plutonium and the other transuranic elements on an electrode, along with some of the fission products and much of the uranium. Most of the fission products and some of the uranium remain in the bath. When a full batch is amassed, operators remove the electrode. Next they scrape the accumulated materials off the electrode, melt them down, cast them into an ingot and pass the ingot to a refabrication line for conversion into fast-reactor fuel. When the bath becomes saturated with fission products, technicians clean the solvent and process the extracted fission products for permanent disposal.

Thus, unlike the current PUREX method, the pyroprocess collects virtually all the transuranic elements (including the plutonium), with considerable carryover of uranium and fission products. Only a very small portion of the transuranic component ends up in the final waste stream, which reduces the needed isolation time drastically. The combination of fission products and transuranics is unsuited for weapons or even for thermal-reactor fuel. This mixture is, however, not only tolerable but advantageous for fueling fast reactors.

Although pyrometallurgical recycling technology is not quite ready for immediate commercial use, researchers have demonstrated its basic principles. It has been successfully demonstrated on a pilot level in operating power plants, both in the U.S. and in Russia. It has not yet functioned, however, on a full production scale.

Comparing Cycles

THE OPERATING CAPABILITIES of thermal and fast reactors are similar in some ways, but in others the differences are huge [*see box on next page*]. A 1,000-megawatt-electric thermal-reactor plant, for example, generates more than 100 tons of spent fuel a year. The annual waste output from a fast reactor with the same electrical capacity, in contrast, is a little more than a single ton of fission products, plus trace amounts of transuranics.



EXTRACTED URANIUM and actinide elements from spent thermal-reactor fuel are plated out on the cathode of an electrorefiner during the pyroprocessing procedure. After further processing, the metallic fuel can be burned in fast-neutron reactors.

Waste management using the ALMR cycle would be greatly simplified. Because the fast-reactor waste would contain no significant quantity of long-lived transuranics, its radiation would decay to the level of the ore from which it came in several hundred years, rather than tens of thousands.

If fast reactors were used exclusively,

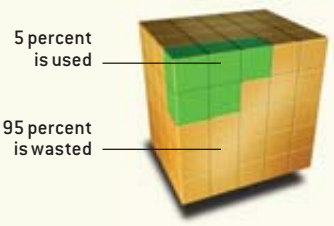
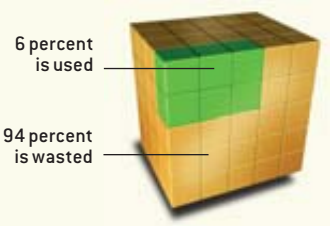
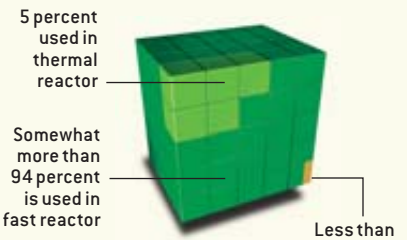
THE AUTHORS

WILLIAM H. HANNUM, GERALD E. MARSH and *GEORGE S. STANFORD* are physicists who worked on fast-reactor development before retiring from the U.S. Department of Energy's Argonne National Laboratory. Hannum served as head of nuclear physics development and reactor safety research at the DOE. He was also deputy director general of the Nuclear Energy Agency of the Organization for Economic Co-operation and Development in Paris. Marsh, a fellow of the American Physical Society, worked as a consultant to the U.S. Department of Defense on strategic nuclear technology and policy in the Reagan, Bush and Clinton administrations and is co-author of *The Phantom Defense: America's Pursuit of the Star Wars Illusion* (Praeger Press). Stanford, whose research focused on experimental nuclear physics, reactor physics and fast-reactor safety, is co-author of *Nuclear Shadowboxing: Contemporary Threats from Cold War Weaponry* (Fidlar Doubleday).

ARGONNE NATIONAL LABORATORY

COMPARING THREE NUCLEAR FUEL CYCLES

Three major approaches to burning nuclear fuel and handling its wastes can be employed; some of their features are noted below.

ONCE-THROUGH ROUTE	PLUTONIUM RECYCLING	FULL RECYCLING
Fuel is burned in thermal reactors and is not reprocessed; occurs in the U.S.	Fuel is burned in thermal reactors, after which plutonium is extracted using what is called PUREX processing; occurs in other developed nations	Recycled fuel prepared by pyrometallurgical processing would be burned in advanced fast-neutron reactors; prototype technology
FUEL UTILIZATION		
 Initial fuel supply		
Uses about 5 percent of energy in thermal-reactor fuel and less than 1 percent of energy in uranium ore (the original source of fuel) Cannot burn depleted uranium (that part removed when the ore is enriched) or uranium in spent fuel	Uses about 6 percent of energy in original reactor fuel and less than 1 percent of energy in uranium ore Cannot burn depleted uranium or uranium in spent fuel	Can recover more than 99 percent of energy in spent thermal-reactor fuel After spent thermal-reactor fuel runs out, can burn depleted uranium to recover more than 99 percent of the rest of the energy in uranium ore
REQUIRED FACILITIES AND OPERATIONS		
Red: requires rigorous physical safeguards	Orange: needs only moderate physical safeguards	Blue: potential risks for future generations
Uranium mines Fuel enrichment to concentrate fissile uranium Fuel fabrication Power plants Interim waste storage (until waste can be permanently disposed of) Permanent storage able to securely segregate waste for 10,000 years (Needs no plutonium handling or waste processing operations)	Uranium mines Fuel enrichment Plutonium blending (mixing) Off-site fuel fabrication Off-site PUREX reprocessing Power plants Interim waste storage Off-site waste processing Permanent storage able to securely segregate waste for 10,000 years	On-site fuel fabrication On-site pyrometallurgical processing (prompt recycling of spent fuel) Power plants On-site waste processing Storage able to segregate waste for less than 500 years (No mining needed for centuries; no uranium enrichment needed, ever)
PLUTONIUM FATE		
Increasing inventories of plutonium in used fuel Excess weapons-grade plutonium degraded only slowly by mixing into fresh fuel	Increasing inventories of plutonium in used fuel and available for economic trade Excess weapons-grade plutonium degraded only slowly by mixing into fresh fuel	Inventories eventually shrink to only what is in use in reactors and in recycling Existing excess weapons-grade plutonium can be degraded rapidly Plutonium in the fuel is too impure for diversion to weapons
TYPES OF WASTE		
Energy-rich used fuel isolated in containers and underground storage facility Waste is radioactive enough to be defined as "self-protected" for a few hundred years against most groups wanting to obtain plutonium 239 for building nuclear weapons	Energy-rich, highly stable glassy waste Waste is radioactive enough to be defined as "self-protected" for a few hundred years against most groups wanting to obtain plutonium 239 for building nuclear weapons	Tailored waste forms that would only have to remain intact for 500 years, after which material would no longer be hazardous Lacking plutonium, waste would not be useful for making weapons

DON FOLEY

transportation of highly radioactive materials would occur only under two circumstances—when the fission product waste was shipped to Yucca Mountain or an alternative site for disposal and when start-up fuel was shipped to a new reactor. Commerce in plutonium would be effectively eliminated.

Some people are advocating that the U.S. embark on an extensive program of PUREX processing of reactor fuel, making mixed oxides of uranium and plutonium for cycling back into thermal reactors. Although the mixed oxide (MOX) method is currently being used for spoiling excess weapons plutonium so that it cannot be employed in bombs—a good idea—we think that it would be a mistake to deploy the much larger PUREX infrastructure that would be required to process civilian fuel. The resource gains would be modest, whereas the long-term waste problem would remain, and the entire effort would delay for only a short time the need for efficient fast reactors.

The fast-reactor system with pyroprocessing is remarkably versatile. It could be a net consumer or net producer of plutonium, or it could be run in a break-even mode. Operated as a net producer, the system could provide start-up materials for other fast-reactor power plants. As a net consumer, it could use up excess plutonium and weapons materials. If a break-even mode were chosen, the only additional fuel a nuclear plant would need would be a periodic infusion of depleted uranium (uranium from which most of the fissile uranium 235 has been removed) to replace the heavy-metal atoms that have undergone fission.

Business studies have indicated that this technology could be economically competitive with existing nuclear power technologies [see the Dubberly paper in "More to Explore," on this page]. Certainly pyrometallurgical recycling will be dramatically less expensive than PUREX reprocessing, but in truth, the economic viability of the system cannot be known until it is demonstrated.

The overall economics of any energy source depend not only on direct costs but also on what economists call "externalities," the hard-to-quantify costs of outside effects resulting from using the technology. When we burn coal or oil to make electricity, for example, our society accepts the detrimental health effects and the environmental costs they entail. Thus, external costs in effect subsidize fossil-fuel power generation, either directly or via indirect effects on the society as a whole. Even though they are difficult to reckon, economic comparisons that do not take externalities into account are unrealistic and misleading.

Coupling Reactor Types

IF ADVANCED FAST REACTORS come into use, they will at first burn spent thermal-reactor fuel that has been recycled using pyroprocessing. That waste, which is now "temporarily" stored on site, would be transported to plants that could process it into three output streams. The first, highly radioactive, stream would contain most of the fission products, along with unavoidable traces of transuranic elements. It would be transformed into a physically stable form—perhaps a glasslike substance—and then shipped to Yucca Mountain or some other permanent disposal site.

The second stream would capture virtually all the transuranics, together with some uranium and fission products. It would be converted to a metallic fast-reactor fuel and then transferred to ALMR-type reactors.

The third stream, amounting to about 92 percent of the spent thermal-reactor fuel, would contain the bulk of the uranium, now in a depleted state. It could be stashed away for future use as fast-reactor fuel.

Such a scenario cannot be realized overnight, of course. If we were to begin today, the first of the fast reactors might come online in about 15 years. Notably, that schedule is reasonably compatible with the planned timetable for shipment of spent thermal-reactor fuel to Yucca Mountain. It could instead be sent for recycling into fast-reactor fuel.

As today's thermal reactors reach the end of their lifetimes, they could be replaced by fast reactors. Should that occur, there would be no need to mine any more uranium ore for centuries and no further requirement, ever, for uranium enrichment. For the very long term, recycling the fuel of fast reactors would be so efficient that currently available uranium supplies could last indefinitely.

Both India and China have recently announced that they plan to extend their energy resources by deploying fast reactors. We understand that their first fast reactors will use oxide or carbide fuel rather than metal—a less than optimum path, chosen presumably because the PUREX reprocessing technology is mature, whereas pyroprocessing has not yet been commercially demonstrated.

It is not too soon for the U.S. to complete the basic development of the fast-reactor/pyroprocessing system for metallic fuel. For the foreseeable future, the hard truth is this: only nuclear power can satisfy humanity's long-term energy needs while preserving the environment. For large-scale, sustainable nuclear energy production to continue, the supply of nuclear fuel must last a long time. That means that the nuclear power cycle must have the characteristics of the ALMR and pyroprocessing. The time seems right to take this new course toward sensible energy development. SA

MORE TO EXPLORE

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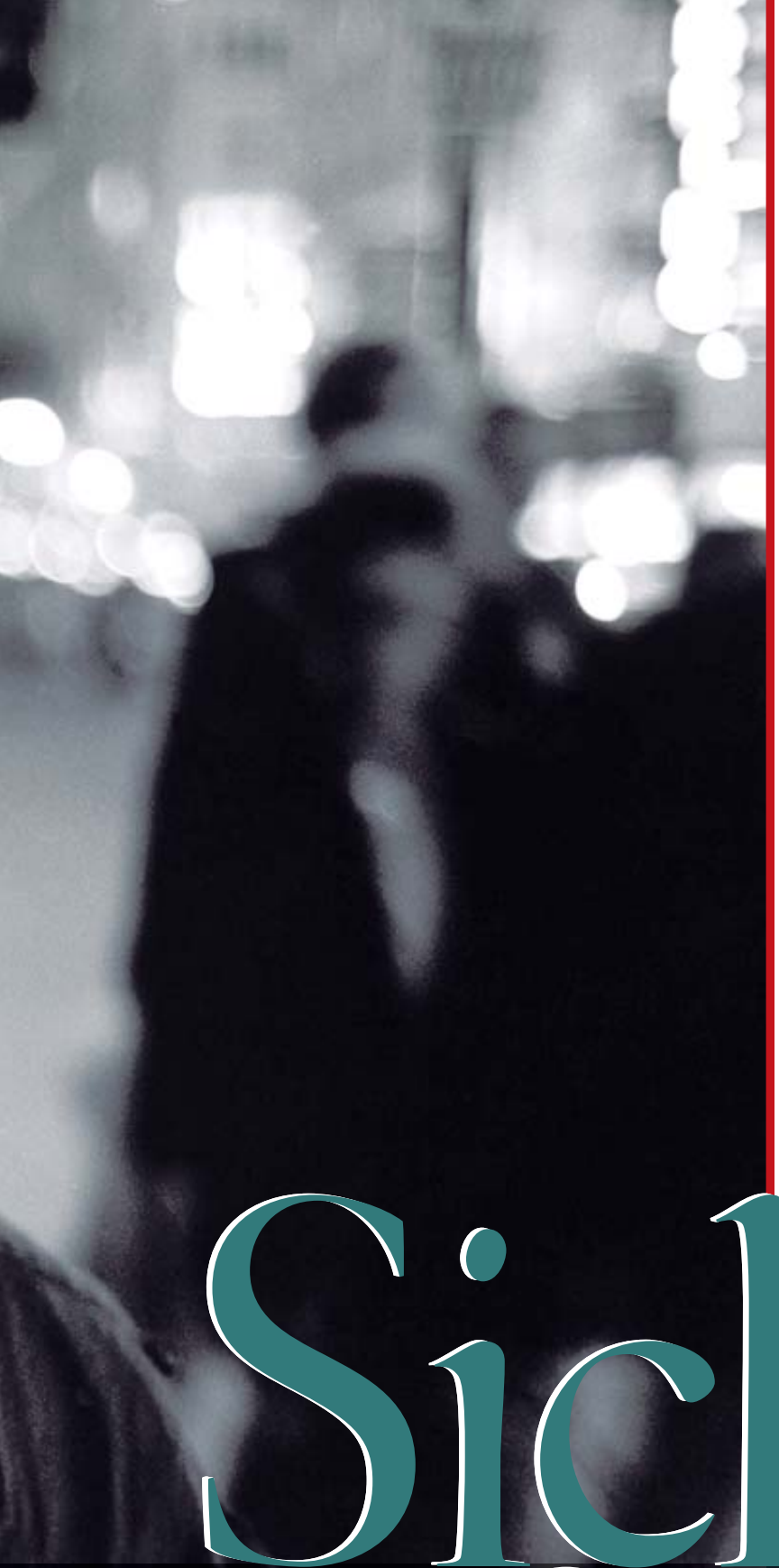
HOMELESS WOMAN in San Francisco.



New studies suggest that the stress of being poor has a staggeringly harmful influence on health

By Robert Sapolsky

Sick of POVERTY

Rudolph Virchow, the 19th-century German neuroscientist, physician and political activist, came of age with two dramatic events—a typhoid outbreak in 1847 and the failed revolutions of 1848. Out of those experiences came two insights for him: first, that the spread of disease has much to do with appalling living conditions, and second, that those in power have enormous means to subjugate the powerless. As Virchow summarized in his famous epigram, "Physicians are the natural attorneys of the poor."

Physicians (and biomedical scientists) are advocates of the underprivileged because poverty and poor health tend to go hand in hand. Poverty means bad or insufficient food, unhealthy living conditions and endless other factors that lead to illness. Yet it is not merely that poor people tend to be unhealthy while everyone else is well. When you examine socioeconomic status (SES), a composite measure that includes income, occupation, education and housing conditions, it becomes clear that, starting with the wealthiest stratum of society, every step downward in SES correlates with poorer health.

This "SES gradient" has been documented throughout Westernized societies for problems that include respiratory and cardiovascular diseases, ulcers, rheumatoid disorders, psychiatric diseases and a number of cancers. It is not a subtle statistical phenomenon. When you compare the highest versus the lowest rungs of the SES ladder, the risk of some diseases varies 10-fold. Some countries exhibit a five- to 10-year difference in life expectancy across the SES spectrum. Of the Western nations, the U.S. has the steepest gradient; for example, one study showed that the poorest white males in America die about a decade earlier than the richest.

It is not a subtle statistical phenomenon.

When you compare the highest versus lowest rungs of the socioeconomic ladder, the risk of some diseases varies 10-fold.

So what causes this correlation between SES and health? Lower SES may give rise to poorer health, but conversely, poorer health could also give rise to lower SES. After all, chronic illness can compromise one's education and work productivity, in addition to generating enormous expenses.

Nevertheless, the bulk of the facts suggests that the arrow goes from economic status to health—that SES at some point in life predicts health measures later on. Among the many demonstrations of this point is a remarkable study of elderly American nuns. All had taken their vows as young adults and had spent many years thereafter sharing diet, health care and housing, thereby controlling for those lifestyle factors. Yet in their old age, patterns of disease, incidence of dementia and longevity were still significantly predicted by their SES status from when they became nuns, at least half a century before.

Inadequate Explanations

SO, TO USE A MARVELOUS PHRASE common to this field, how does SES get "under the skin" and influence health? The answers that seem most obvious, it turns out, do not hold much water. One such explanation, for instance, posits that for the poor, health care may be less easily accessible and of lower quality. This possibility is plausible when one considers that for many of the poor in America, the family physician

Overview/*Status and Health*

- Researchers have long known that people with low socioeconomic status (SES) have dramatically higher disease risks and shorter life spans than do people in the wealthier strata of society. The conventional explanations—that the poor have less access to health care and a greater incidence of harmful lifestyles such as smoking and obesity—cannot account for the huge discrepancy in health outcomes.
- New studies indicate that the psychosocial stresses associated with poverty may increase the risks of many illnesses. The chronic stress induced by living in a poor, violent neighborhood, for example, could increase one's susceptibility to cardiovascular disease, depression and diabetes.
- Other studies have shown a correlation between income inequality and poor health in the U.S. Some researchers believe that the poor feel poorer, and hence suffer greater stress, in communities with wide gaps between the highest and lowest incomes.

PAUL FUSCO *Magnum Photos (preceding pages)*

does not exist, and medical care consists solely of trips to the emergency room.

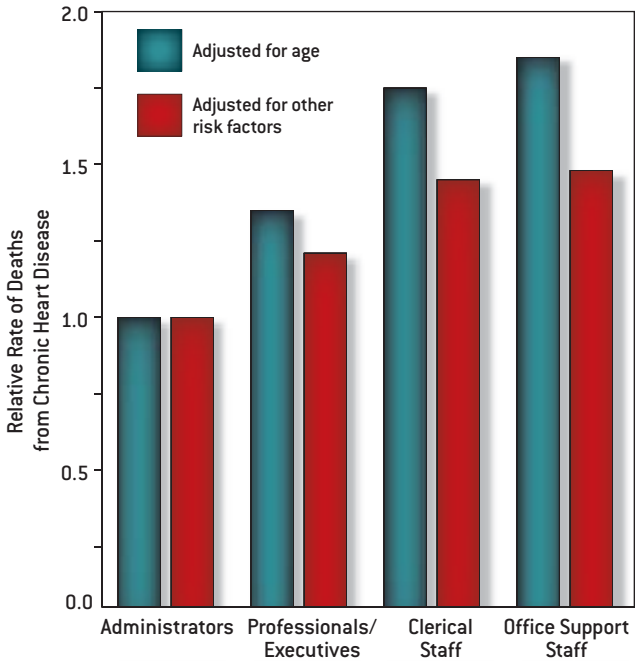
But that explanation soon falls by the wayside, for reasons made clearest in the famed Whitehall studies by Michael G. Marmot of University College London over the past three decades. Marmot and his colleagues have documented an array of dramatic SES gradients in a conveniently stratified population, namely, the members of the British civil service (ranging from blue-collar workers to high-powered executives). Office messengers and porters, for example, have far higher mortality rates from chronic heart disease than administrators and professionals do [*see top illustration at right*]. Lack of access to medical attention cannot explain the phenomenon, because the U.K., unlike the U.S., has universal health care. Similar SES gradients also occur in other countries with socialized medicine, including the health care Edens of Scandinavia, and the differences remain significant even after researchers factor in how much the subjects actually use the medical services.

Another telling finding is that SES gradients exist for diseases for which health care access is irrelevant. No amount of medical checkups, blood tests and scans will change the likelihood of someone getting type 1 (juvenile-onset) diabetes or rheumatoid arthritis, yet both conditions are more common among the poor.

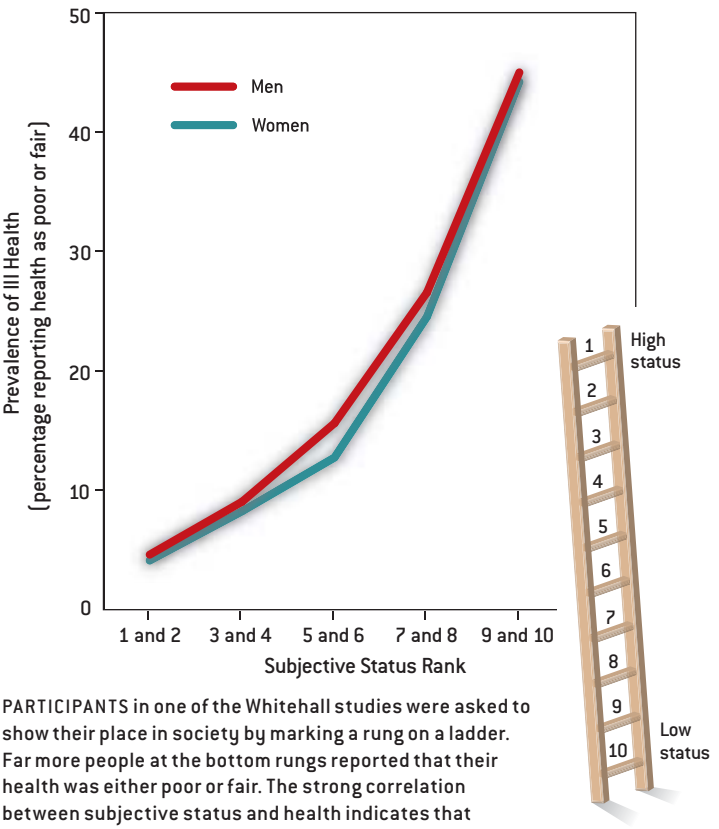
The next "obvious" explanation centers on unhealthy lifestyles. As you descend the SES ladder in Westernized societies, people are more likely to smoke, to drink excessively, to be obese, and to live in a violent or polluted or densely populated neighborhood. Poor people are also less likely to have access to clean water, healthy food and health clubs, not to mention adequate heat in the winter and air-conditioning in the summer. Thus, it seems self-evident that lower SES gets under the skin by increasing risks and decreasing protective factors. As mordantly stated by Robert G. Evans of the University of British Columbia, "Drinking sewage is probably unwise, even for Bill Gates."

What is surprising, though, is how little of the SES gradient these risk and protective factors explain. In the Whitehall studies, controlling for factors such as smoking and level of exercise accounted for only about a third of the gradient. This same point is made by studies comparing health and wealth among, rather than within, nations. It is reasonable to assume that the wealthier a country, the more financial resources its citizens have to buy protection and avoid risk. If so, health should improve incrementally as one moves up the wealth gradient among nations, as well as among the citizens within individual nations. But it does not. Instead, among the wealthiest quarter of countries on earth, there is no relation between a country's wealth and the health of its people.

Thus, health care access, health care utilization, and exposure to risk and protective factors explain the SES/health gradient far less well than one might have guessed. One must therefore consider whether most of the gradient arises from a different set of considerations: the psychosocial consequences of SES.



WHITEHALL STUDIES show that low-ranked British civil servants (office messengers and other support staff) are almost twice as likely to die from heart disease as administrators of the same age. Differences in risk factors—for example, higher smoking rates among the support staff—account for less than half the gap in mortality rates.



PARTICIPANTS in one of the Whitehall studies were asked to show their place in society by marking a rung on a ladder. Far more people at the bottom rungs reported that their health was either poor or fair. The strong correlation between subjective status and health indicates that "feeling poor" may somehow increase disease risks.

EMILY COOPER; SOURCES: MICHAEL G. MARMOT *University College London* (*top graph*); "SUBJECTIVE SOCIAL STATUS: ITS DETERMINANTS AND ITS ASSOCIATION WITH MEASURES OF ILL-HEALTH IN THE WHITEHALL II STUDY," BY A. SINGH-MANOUX, N. E. ADLER AND M. G. MARMOT, IN *SOCIAL SCIENCE AND MEDICINE*; VOL. 56; 2003 (*bottom graph*)

CHRONIC STRESS may explain how poverty "gets under the skin" and exerts a harmful influence on health. The risk of stress-sensitive diseases increases if individuals lack social support, have no outlets for their frustration and feel that their circumstances are worsening—exactly the conditions in many poor communities in the U.S.

Psychosocial Stress

IDEALLY, THE BODY is in homeostatic balance, a state in which the vital measures of human function—heart rate, blood pressure, blood sugar levels and so on—are in their optimal ranges. A stressor is anything that threatens to disrupt homeostasis. For most organisms, a stressor is an acute physical challenge—for example, the need for an injured gazelle to sprint for its life or for a hungry predator to chase down a meal. The body is superbly adapted to dealing with short-term physical challenges to homeostasis. Stores of energy, including the sugar glucose, are released, and cardiovascular tone increases to facilitate the delivery of fuel to exercising muscle throughout the body. Digestion, growth, tissue repair, reproduction and other physiological processes not needed to survive the crisis are suppressed. The immune system steps up to thwart opportunistic pathogens. Memory and the senses transiently sharpen.

But cognitively and socially sophisticated species, such as we primates, routinely inhabit a different realm of stress. For us, most stressors concern interactions with our own species, and few physically disrupt homeostasis. Instead these psychosocial stressors involve the anticipation (accurate or otherwise) of an impending challenge. And the striking characteristic of such psychological and social stress is its chronicity. For most mammals, a stressor lasts only a few minutes. In contrast, we humans can worry chronically over a 30-year mortgage.

Unfortunately, our body's response, though adaptive for an acute physical stressor, is pathogenic for prolonged psychosocial stress. Chronic increase in cardiovascular tone brings stress-induced hypertension. The constant mobilization of energy increases the risk or severity of diseases such as type 2 (adult-onset) diabetes. The prolonged inhibition of digestion, growth, tissue repair and reproduction increases the risks of various gastrointestinal disorders, impaired growth in children, failure to ovulate in females and erectile dysfunction in males. A too-extended immune stress response ultimately suppresses immunity and impairs disease defenses. And chronic activation of the stress response impairs cognition, as well as the health, functioning and even survival of some types of neurons.

An extensive biomedical literature has established that individuals are more likely to activate a stress response and are more at risk for a stress-sensitive disease if they (a) feel as if they have minimal *control* over stressors, (b) feel as if they have no *predictive information* about the duration and intensity of the stressor, (c) have few *outlets* for the frustration caused by the stressor, (d) interpret the stressor as evidence of circumstances *worsening,* and (e) lack *social support* for the duress caused by the stressors.

Psychosocial stressors are not evenly distributed across society. Just as the poor have a disproportionate share of physical stressors (hunger, manual labor, chronic sleep deprivation with a second job, the bad mattress that can't be replaced), they have a disproportionate share of psychosocial ones. Numbing assembly-line work and an occupational lifetime spent taking orders erode workers' sense of control. Unreliable cars that may not start in the morning and paychecks that may not last the month inflict unpredictability. Poverty rarely allows stress-relieving options such as health club memberships, costly but relaxing hobbies, or sabbaticals for rethinking one's priorities. And despite the heartwarming stereotype of the "poor but loving community," the working poor typically have less social support than the middle and upper classes, thanks to the extra jobs, the long commutes on public transit, and other burdens.

Marmot has shown that regardless of SES, the less au-

JACOB HOLDT

THE AUTHOR

ROBERT SAPOLSKY is professor of biological sciences, neurology and neurological sciences at Stanford University and a research associate at the National Museums of Kenya. In his laboratory work, he focuses on how stress can damage the brain and on gene therapy for the nervous system. In addition, he studies populations of wild baboons in East Africa, trying to determine the relation between the social rank of a baboon and its health. His latest book is *Monkeyluv and Other Essays on Our Lives as Animals* (Scribner, 2005).

tonomy one has at work, the worse one's cardiovascular health. Furthermore, low control in the workplace accounts for about half the SES gradient in cardiovascular disease in his Whitehall population.

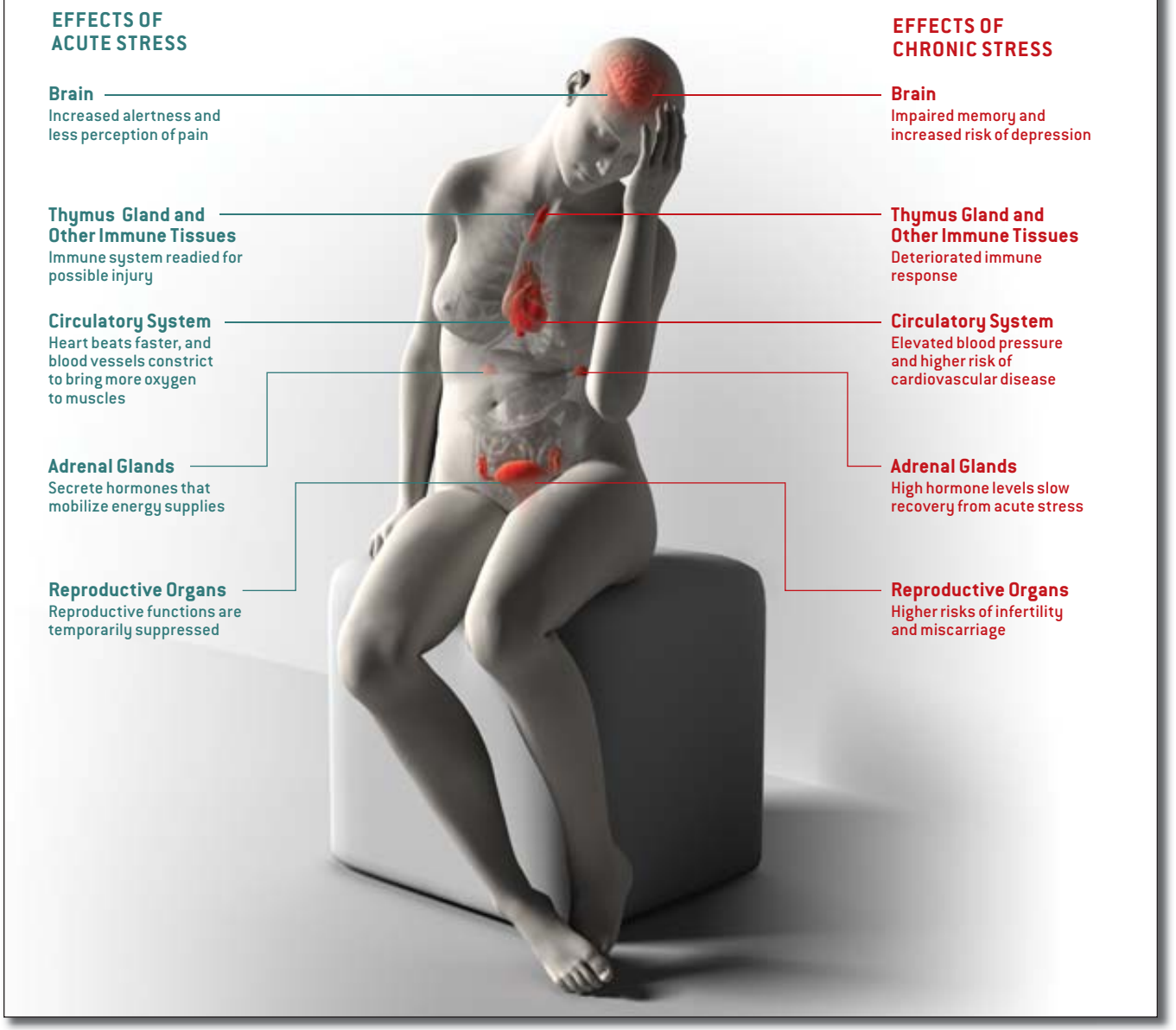
Feeling Poor

THREE LINES OF RESEARCH provide more support for the influence of psychological stress on SES-related health gradients. Over the past decade Nancy E. Adler of the University of California, San Francisco, has explored the difference between objective and subjective SES and the relation of each to health [*see bottom illustration on page 95*]. Test subjects were shown a simple diagram of a ladder with 10 rungs and then asked, "In society, where on this ladder would you rank yourself in terms of how well you're doing?" The very openness of the question allowed the person to define the comparison group that felt most emotionally salient.

As Adler has shown, a person's subjective assessment of his or her SES takes into account the usual objective measures (education, income, occupation and residence) as well as measures of life satisfaction and of anxiety about the future. Adler's provocative finding is that subjective SES is at least as good as objective SES at predicting patterns of cardiovascular function, measures of metabolism, incidences of obesity and

THE GOOD AND BAD EFFECTS OF STRESS

The human body is superb at responding to the acute stress of a physical challenge, such as chasing down prey or escaping a predator. The circulatory, nervous and immune systems are mobilized while the digestive and reproductive processes are suppressed. If the stress becomes chronic, though, the continual repetition of these responses can cause major damage.



BRYAN CHRISTIE DESIGN

levels of stress hormones—suggesting that the subjective feelings may help explain the objective results.

This same point emerges from comparisons of the SES/health gradient among nations. A relatively poor person in the U.S. may objectively have more financial resources to purchase health care and protective factors than a relatively wealthy person in a less developed country yet, on average, will still have a shorter life expectancy. For example, as Stephen Bezruchka of the University of Washington emphasizes, people in Greece on average earn half the income of Americans yet have a longer life expectancy. Once the minimal resources are available to sustain a basic level of health through adequate food and housing, absolute levels of income are of remarkably little importance to health. Although Adler's work suggests that the objective state of *being* poor adversely affects health, at the core of that result is the subjective state of *feeling* poor.

INCOME INEQUALITY appears to exacerbate the stress of poverty. As the divide between the rich and poor grows wider, social support typically becomes less available and the frustrations of the poor intensify.

Being Made to Feel Poor

ANOTHER BODY OF RESEARCH arguing that psychosocial factors mediate most of the SES/health gradient comes from Richard Wilkinson of the University of Nottingham in England. Over the past 15 years he and his colleagues have reported that the extent of income inequality in a community is even more predictive than SES for an array of health measures. In other words, absolute levels of income aside, greater disparities in income between the poorest and the wealthiest in a community predict worse average health. (David H. Abbott of the Wisconsin National Primate Research Center and I, along with our colleagues, found a roughly equivalent phenomenon in animals: among many nonhuman primate species, less egalitarian social structures correlate with higher resting levels of a key stress hormone—an index for worse health—among socially subordinate animals.)

> The surest way to feel poor is to be endlessly made aware of the haves when you are a have-not.

Wilkinson's subtle and critical finding has generated considerable controversy. One dispute concerns its generality. His original work suggested that income inequality was relevant to health in many European and North American countries and communities. It has become clear, however, that this relation holds only in the developed country with the greatest of income inequalities, namely, the U.S.

Whether considered at the level of cities or states, income inequality predicts mortality rates across nearly all ages in the U.S. [*see illustration on opposite page*]. Why, though, is this relation not observed in, say, Canada or Denmark? One possibility is that these countries have too little income variability to tease out the correlation.

Some critics have questioned whether the linkage between income inequality and worse health is merely a mathematical quirk. The relation between SES and health follows an asymptotic curve: dropping from the uppermost rung of society's ladder to the next-to-top step reduces life expectancy and other measures much less drastically than plunging from the next-to-bottom rung to the lowest level. Because a community with high levels of income inequality will have a relatively high number of individuals at the very bottom, where health prospects are so dismal, the community's average life expectancy will inevitably be lower than that of an egalitarian community, for reasons that have nothing to do with psychosocial factors. Wilkinson has shown, however, that decreased income inequality predicts better health for both the poor and the wealthy. This result strongly indicates that the association between illness and inequality is more than just a mathematical artifact.

Wilkinson and others in the field have long argued that the more unequal income in a community is, the more psychosocial stress there will be for the poor. Higher income inequality intensifies a community's hierarchy and makes social support less available: truly symmetrical, reciprocal, affiliative support exists only among equals. Moreover, having your nose rubbed in your poverty is likely to lessen your sense of control in life, to aggravate the frustrations of poverty and to intensify the sense of life worsening.

If Adler's work demonstrates the adverse health effects of feeling poor, Wilkinson's income inequality work suggests that the surest way to feel poor is to be *made* to feel poor—to be endlessly made aware of the haves when you are a have-not. And in our global village, we are constantly made aware of the moguls and celebrities whose resources dwarf ours.

John W. Lynch and George A. Kaplan of the University of Michigan at Ann Arbor have recently proposed another way that people are made to feel poor. Their "neomaterialist" in-

NORBERT MILLAUER AFP/Getty Images

terpretation of the income inequality phenomenon—which is subtle, reasonable and, ultimately, deeply depressing—runs as follows: Spending money on public goods (better public transit, universal health care and so on) is a way to improve the quality of life for the average person. But by definition, the bigger the income inequality in a society, the greater the financial distance between the average and the wealthy. The bigger this distance, the less the wealthy have to gain from expenditures on the public good. Instead they would benefit more from keeping their tax money to spend on their private good—a better chauffeur, a gated community, bottled water, private schools, private health insurance. So the more unequal the income is in a community, the more incentive the wealthy will have to oppose public expenditures benefiting the health of the community. And within the U.S., the more income inequality there is, the more power will be disproportionately in the hands of the wealthy to oppose such public expenditures. According to health economist Evans, this scenario ultimately leads to "private affluence and public squalor."

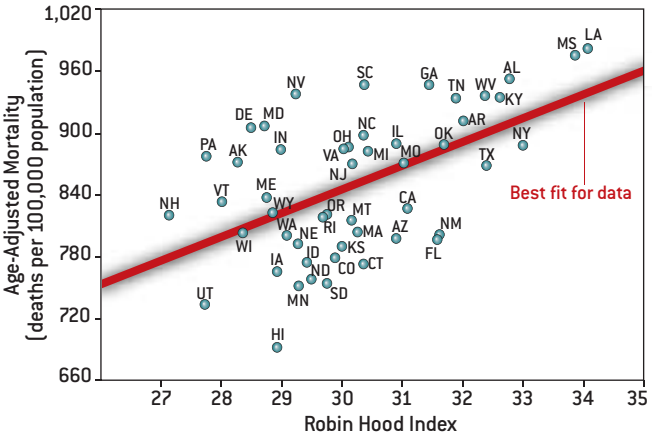
This "secession of the wealthy" can worsen the SES/health gradient in two ways: by aggravating the conditions in low-income communities (which account for at least part of the increased health risks for the poor) and by adding to the psychosocial stressors. If social and psychological stressors are entwined with feeling poor, and even more so with feeling poor while being confronted with the wealthy, they will be even more stressful when the wealthy are striving to decrease the goods and services available to the poor.

Social Capital

A THIRD BRANCH OF SUPPORT for psychosocial explanations for the relation between income inequality and health comes from the work of Ichiro Kawachi of Harvard University, based on the concept of "social capital." Although it is still being refined as a measure, social capital refers to the broad levels of trust and efficacy in a community. Do people generally trust one another and help one another out? Do people feel an incentive to take care of commonly held resources (for example, to clean up graffiti in public parks)? And do people feel that their organizations—such as unions or tenant associations—actually have an impact? Most studies of social capital employ two simple measures, namely, how many organizations people belong to and how people answer a question such as, "Do you think most people would try to take advantage of you if they got a chance?"

What Kawachi and others have shown is that at the levels of states, provinces, cities and neighborhoods, low social capital predicts bad health, bad self-reported health and high mortality rates. Using a complex statistical technique called path analysis, Kawachi has demonstrated that (once one controls for the effects of absolute income) the strongest route from income inequality to poor health is through the social capital measures—to wit, high degrees of income inequality come with low levels of trust and support, which increases stress and harms health.

RATING THE STATES



ROBIN HOOD INDEX is a measure of income inequality; it is the percentage of total community income that must be taken from the rich (those with above-average incomes) and given to the poor (those below the average) to achieve an equal distribution. U.S. states (*blue dots*) with a high Robin Hood index also tend to have high mortality rates.

None of this is surprising. As a culture, America has neglected its social safety nets while making it easier for the most successful to sit atop the pyramids of inequality. Moreover, we have chosen to forgo the social capital that comes from small, stable communities in exchange for unprecedented opportunities for mobility and anonymity. As a result, all measures of social epidemiology are worsening in the U.S. Of Westernized nations, America has the greatest income inequality (40 percent of the wealth is controlled by 1 percent of the population) and the greatest discrepancy between expenditures on health care (number one in the world) and life expectancy (as of 2003, number 29).

The importance of psychosocial factors in explaining the SES/health gradient generates a critical conclusion: when it comes to health, there is far more to poverty than simply not having enough money. (As Evans once stated, "Most graduate students have had the experience of having very little money, but not of poverty. They are very different things.") The psychosocial school has occasionally been accused of promulgating an antiprogressive message: don't bother with universal health care, affordable medicines and other salutary measures because there will still be a robust SES/health gradient after all the reforms. But the lesson of this research is not to abandon such societal change. It is that so much more is needed. SA

MORE TO EXPLORE

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GETTING A LEG UP ON LAND

Recent fossil discoveries cast light on the evolution of four-limbed animals from fish

BY JENNIFER A. CLACK

UP FOR AIR: *Acanthostega,* an early tetrapod, surfaces in a swamp in what is now eastern Greenland, some 360 million years ago. Although this animal had four legs, they would not have been able to support its body on land. Thus, rather than limbs evolving as an adaptation to life on land, it seems that they may have initially functioned to help the animal lift its head out of oxygen-poor water to breathe. Only later did they find use ashore.

IN THE ALMOST four billion years since life on earth oozed into existence, evolution has generated some marvelous metamorphoses. One of the most spectacular is surely that which produced terrestrial creatures bearing limbs, fingers and toes from water-bound fish with fins. Today this group, the tetrapods, encompasses everything from birds and their dinosaur ancestors to lizards, snakes, turtles, frogs and mammals, including us. Some of these animals have modified or lost their limbs, but their common ancestor had them—two in front and two in back, where fins once flicked instead.

The replacement of fins with limbs was a crucial step in this transformation, but it was by no means the only one. As tetrapods ventured onto shore, they encountered challenges that no vertebrate had ever faced before—it was not just a matter of developing legs and walking away. Land is a radically different medium from water, and to conquer it, tetrapods had to evolve novel ways to breathe, hear, and contend with gravity—the list goes on. Once this extreme makeover reached completion, however, the land was theirs to exploit.

Until about 15 years ago, paleontologists understood very little about the sequence of events that made up the transition from fish to tetrapod. We knew that tetrapods had evolved from fish with fleshy fins akin to today's lungfish and coelacanth, a relation first proposed by American paleontologist Edward D. Cope in the late 19th century. But the details of this seminal shift remained hidden from view. Furthermore, estimates of when this event transpired varied wildly, ranging from 400 million to 350 million years ago, during the Devonian period. The problem was that the pertinent fossil record was sparse, consisting of essentially a single fish of this type, *Eusthenopteron,* and a single Devonian tetrapod, *Ichthyostega,* which was too advanced to elucidate tetrapod roots.

With such scant clues to work from, scientists could only speculate about the nature of the transition. Perhaps the best known of the scenarios produced by this guesswork was that championed by famed vertebrate paleontologist Alfred Sherwood Romer of Harvard University, who proposed in the 1950s that fish like *Eusthenopteron,* stranded under arid conditions, used their muscular appendages to drag themselves to a new body of water. Over time, so the idea went, those fish able to cover more ground—and thus reach ever more distant water sources—were selected for, eventually leading to the origin of true limbs. In other words, fish came out of the water before they evolved legs.

Since then, however, many more fossils documenting this transformation have come to light. These discoveries have expanded almost exponentially our understanding of this critical chapter in the history of life on earth—and turned old notions about early tetrapod evolution, diversity, biogeography and paleoecology on their heads.

Finding a Foothold

AMONG THE FIRST fossil finds to pave the way for our modern conception of tetrapod origins were those of a creature called *Acanthostega,* which lived about 360 million years ago in what is now eastern Greenland. It was first identified in 1952 by Erik Jarvik of the Swedish Museum of Natural History in Stockholm on the basis of two partial skull roofs. But not until 1987 did my colleagues and I finally find specimens revealing the postcranial skeleton of *Acanthostega*.

Although in many ways this animal proved to be exactly the kind of anatomical intermediary between fish and full-blown tetrapods that experts might have imagined, it told a different story from the one predicted. Here was a creature that had legs and feet but that was otherwise ill equipped for a terrestrial existence. *Acanthostega*'s limbs lacked proper ankles to support the animal's weight on land, looking more like paddles for swimming. And although it had lungs, its ribs were too short to prevent the collapse of the chest cavity once out of water. In fact, many of *Acanthostega*'s features were undeniably fishlike. The bones of the forearm displayed proportions reminiscent of the pectoral fin of *Eusthenopteron*. And the rear of the skeleton showed a deep, oar-shaped tail sporting long, bony rays that would have provided the scaffolding for a fin. Moreover, the beast still had gills in addition to lungs.

The piscine resemblance suggested that the limbs of *Acanthostega* were not only adapted for use in water but that this was the ancestral tetrapod condition. In other words, this animal, though clearly a tetrapod, was primarily an aquatic creature whose immediate forerunners were essentially fish that had never left the water. The discovery forced scholars to rethink the sequence in which key changes to the skeleton took place. Rather than portraying a creature like *Eusthenopteron* crawling onto land and then gaining legs and feet, as Romer postulated, the new fossils indicated that tetrapods evolved these features while they were still aquatic and only later coopted them for walking. This, in turn, meant that researchers needed to reconsider the ecological circumstances under which limbs developed, because *Acanthostega* indicated that terrestrial demands may not have been the driving force in early tetrapod evolution.

Acanthostega took pride of place as the missing link between terrestrial vertebrates and their aquatic forebears. There was, however, one characteristic of *Acanthostega* that called to mind neither tetrapod nor fish. Each of its limbs terminated in a foot bearing eight well-formed digits, rather than the familiar five. This was quite curious, because before this discovery anatomists believed that in the transition from fish to tetrapod, the five-digit foot derived directly from the bones constituting the fin of *Eusthenopteron* or a similar creature. Ordinarily, scientists might have dismissed this as an aberrant specimen. But a mysterious partial skeleton of *Tulerpeton,* a previously known early tetrapod from Russia, had a six-digit foot. And specimens of *Ichthyostega* also found on our expedition to eastern Greenland revealed that it, too, had a foot with more than five digits.

Findings from developmental biology have helped unravel some of this mystery.

> Many of the critical innovations arose while these beasts were still largely aquatic. And the first changes appear to have been related not to locomotion but to an increased reliance on breathing air.

We now know that several genes, including the *Hox* series and *Sonic Hedgehog,* control elements of fin and limb development. The same sets of these genes occur in both fish and tetrapods, but they do different jobs in each. *Hoxd 11* and *Hoxd 13,* for instance, appear to play a more pronounced role in tetrapods, where their domains in the limb bud are enlarged and skewed relative to those in the fish fin bud. It is in these regions that the digits form. How the five-digit foot evolved from the eight-digit one of *Acanthostega* remains to be determined, but we do have a plausible explanation for why the five-digit foot became the default tetrapod pattern: it may have helped make ankle joints that are both stable enough to bear weight and flexible enough to allow the walking gait that tetrapods eventually invented.

Acanthostega also drew attention to a formerly underappreciated part of early tetrapod anatomy: the inside of the lower jaw. Fish generally have two rows of teeth along their lower jaw, with a large number of small teeth on the outer row complementing a pair of large fangs and some small teeth on the inner row. *Acanthostega* showed that early tetrapods possessed a different dental plan: a small number of larger teeth on the outer row and a reduction in the size of the teeth populating the inner row—changes that probably accompanied a shift from feed-

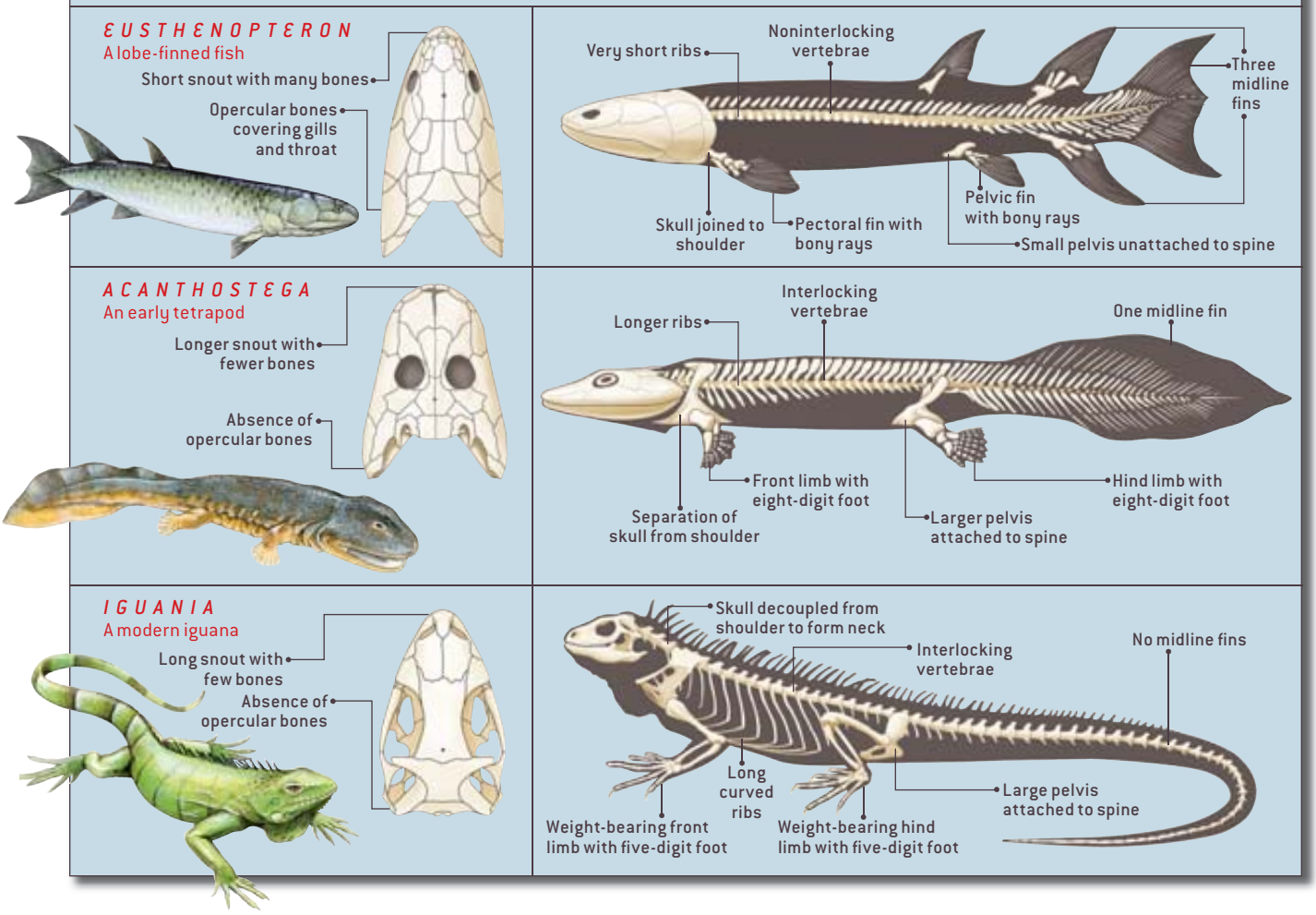
Overview/*The Origin of Tetrapods*

- The emergence of land-going vertebrates was a cornerstone event in the evolution of life on earth.
- For decades, a paltry fossil record obfuscated efforts to trace the steps that eventually produced these terrestrial tetrapods from their fish ancestors.
- Fossils recovered over the past 15 years have filled many of the gaps in the story and revolutionized what is known about tetrapod evolution, diversity, biogeography and paleoecology.
- These recent finds indicate that tetrapods evolved many of their characteristic features while they were still aquatic. They also reveal that early members of the group were more specialized and more geographically and ecologically widespread than previously thought.

RAÚL MARTÍN (*preceding pages*)

TURNING TETRAPOD

The evolution of terrestrial tetrapods from aquatic lobe-finned fish involved a radical transformation of the skeleton. Among other changes, the pectoral and pelvic fins became limbs with feet and toes, the vertebrae became interlocking, and the tail fin disappeared, as did a series of bones that joined the head to the shoulder girdle (*skeletons*). Meanwhile the snout elongated and the bones that covered the gills and throat were lost (*skulls*).



ANDREW RECHER

ing exclusively in the water to feeding on land or with the head above the water.

This insight enabled experts to recognize additional tetrapods among remains that had long sat unidentified in museum drawers. One of the most spectacular of these finds was that of a Late Devonian genus from Latvia called *Ventastega*. In the 1990s, following the discovery of *Acanthostega*, researchers realized that a lower jaw collected in 1933 was that of a tetrapod. Further excavation at the original *Ventastega* site soon yielded more material of exceptional quality, including an almost complete skull.

Meanwhile a number of near-tetrapod fish have also been unveiled, bridging the morphological gap between *Eusthenopteron* and *Acanthostega*. Two of these genera paleontologists have known about for several decades but have only recently scrutinized: 380-million- to 375-million-year-old *Panderichthys* from Europe's Baltic region, a large fish with a pointy snout and eyes that sat atop its head, and 375-million- to 370-million-year-old *Elpistostege* from Canada, which was very similar in size and shape to *Panderichthys*. Both are much closer to tetrapods than is *Eusthenopteron*. And just last year an expedition to Ellesmere Island in the Canadian Arctic led by paleontologist Neil Shubin of the University of Chicago produced some outstandingly well preserved remains of a fish that is even more tetrapodlike than either *Panderichthys* or *Elpistostege*. Shubin and his team have yet to describe and name this species formally, but it is shaping up to be a fascinating animal.

A Breath of Fresh Air

THANKS TO THESE recent finds and analyses, we now have the remains of nine genera documenting around 20 million years of early tetrapod evolution and an even clearer idea of how the rest of the vertebrate body became adapted for life on land. One of the most interesting revelations to emerge from this work is that, as in the case of limb development, many of the critical innovations arose while these beasts were still largely aquatic. And the first changes appear to have been related not to locomotion but to an increased reliance on breathing air.

Oddly enough, this ventilation shift

PRIMEVAL PROMENADE: *Ichthyostega* is the earliest known tetrapod to show adaptations for nonswimming locomotion, although it seems likely to have moved more like a seal than a typical land vertebrate. This animal also had some aquatic features, including a large tail and flipperlike hind limbs, as well as an ear that appears to have been specialized for underwater use. How *Ichthyostega* divided its time between the terrestrial and aquatic realms is uncertain. But it may have dug nests for its eggs on land and hunted and fed in the water.

may have kicked off the gradual morphing of the shoulder girdle and pectoral fins. Indeed, evolutionary biologists have struggled to explain what transitional forms like *Acanthostega* did with their proto-limbs, if not locomote. The hypothesis favored on current evidence is that as the backwardly directed fins gradually turned into sideways-facing limbs with large areas for muscle attachments, they gained in strength. And although it would be millions of years before the forelimbs developed to the point of being able to support the body on land, they may well have functioned in the interim to allow the animal to raise its head out of the water to breathe. The toes could have facilitated this activity by helping to spread the load on the limbs.

Last year Shubin's team announced the discovery of a 365-million-year-old tetrapod upper arm bone, or humerus, that has bolstered this idea. The bone, dug from a fossil-rich site in north central Pennsylvania known as Red Hill, appears to have joined the rest of the body via a hingelike joint, as opposed to the ball-and-socket variety that we and other terrestrial vertebrates have. This arrangement would not have permitted a walking gait, but it would have enabled just the kind of push-up that a tetrapod needing a gulp of air might employ. It also might have helped the animal hold its position in the water while waiting to ambush prey.

Breathing above water also required a number of changes to the skull and jaw. In the skull, the snout elongated and the bones that form it grew fewer in number and more intimately sutured together, strengthening the snout in a way that enabled the animal to lift it clear of water and into an unsupportive medium. The bones at the back of the head, for their part, became the most firmly integrated of any in the skull, providing sturdy anchors for muscles from the vertebral column that raise the head relative to the body. And the fusing of bones making up the lower jaw fortified this region, facilitating the presumed "buccal pump" mode of tetrapod ventilation. In this type of breathing, employed by modern amphibians and air-breathing fish, the mouth cavity expands and contracts like bellows to gulp air and force it into the lungs. Buccal pumping may have demanded more jaw power under the influence of gravity than in the water, where organisms are more or less weightless.

Might the strengthening of the jaws have instead come about as an adaptation for feeding on land? Possibly. The earliest tetrapods were all carnivorous, so it is unlikely that, as adults, they fed much on land during the first phases of their evolution, because the only prey they would have found there were insects and other small arthropods. The babies, on the other hand, needed just this type of prey, and they may have been the ones that initially ventured farthest out of the water to get them.

Meanwhile, farther back in the skeleton, a series of bones that joins the head to the shoulder girdle in fish disappeared. As a result, tetrapods, unlike fish, have a muscular neck that links the head to the rest of the skeleton and allows for movement of the head separate from the body. The gill system also underwent substantial renovation, losing some bones but increasing the size of the spiracle—an opening on the top of the head that led to an air-filled sac in the throat region, making the entire respiratory apparatus better suited to breathing air.

But why, after millions of years of successfully breathing underwater, did some fish begin turning to the air for their oxygen? Clues have come from the overall shape of the skull, which in all early tetrapods and near-tetrapods discovered so far is quite flat when viewed head-on. This observation, combined with paleoenvironmental data gleaned from the deposits in which the fossils have been found, suggests that these creatures were shallow-water specialists, going to low-water places to hunt for smaller fish and possibly to mate and lay their eggs. Perhaps not coincidentally, vascular plants were flourishing during the Devonian, transforming both the terrestrial and aquatic realms. For the first time, deciduous plants shed their leaves into the water with the changing seasons,

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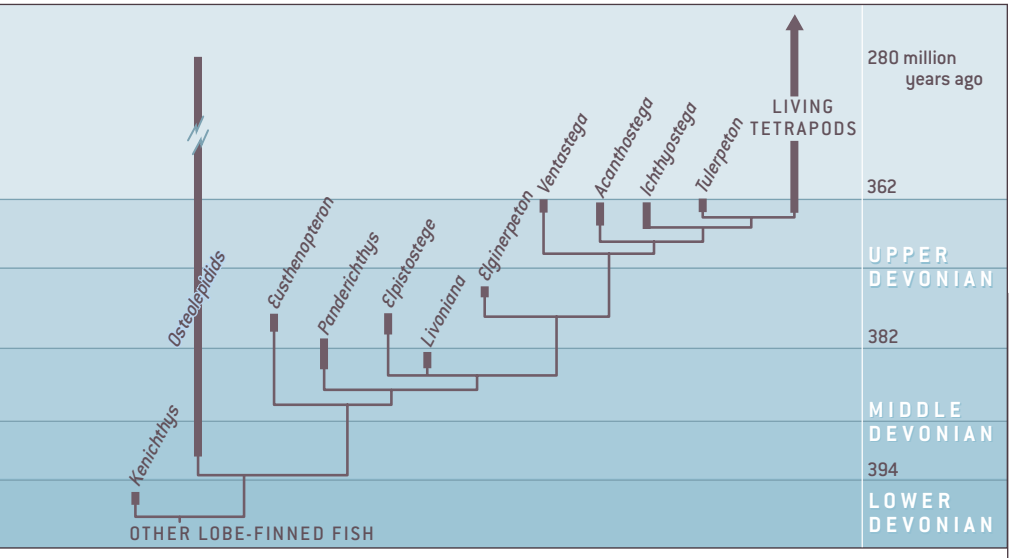
creating environments that were attractive to small prey but difficult for big fish to swim in. Moreover, because warm water holds less oxygen than colder water does, these areas would have been oxygen-poor. If so, the changes to the skeleton described here may have given early tetrapods access to waters that sharks and other large fish could not reach by putting them literally head and shoulders above the competition. It was just happenstance that these same features would later come in handy ashore.

These breathing-related innovations sent tetrapods well on their way to becoming land-worthy. Getting a grip on terra firma required further modifications to the skeleton, however. An overhaul of the ear region was one such development. Many of the details of this transformation are still largely unknown. But it is clear that even in the tetrapodlike fish that still had fins, *Panderichthys* among them, the part of the skull behind the eyes had already become shorter, following a shrinking of the capsules that house the inner ears. If, as paleoenvironmental evidence suggests, *Panderichthys* dwelled in shallow tidal flats or estuaries, the reduction in the inner ear may reflect the growing influence of gravity on the vestibular system, which coordinates balance and orientation. At the same time an increase in the size of the air chamber in its throat may have aided hearing. In some modern fish this air sac "catches" sound waves, preventing them from simply passing straight through the animal's body. From there they are transmitted by the surrounding bones to the inner ear. The enlarged air chamber evident in *Panderichthys* would have been able to intercept more sound waves, thereby enhancing the animal's hearing ability.

Modifications to the ear region were also closely tied to those in the gill system. To wit: a bone known as the hyomandibula—which in fish orchestrates feeding and breathing movements—shrank in size and got lodged in a hole in the braincase, where it became the stapes. In modern tetrapods the stapes magnifies sound waves and transmits them from the eardrum across the air space in the throat to the inner ear. (In mammals, which have a unique hearing system, the stapes is one of the three ossicles making up the middle ear.) The first stage of conversion must have occurred rapidly, given that it was in place by the time of *Acanthostega*. Quite possibly it proceeded in tandem with the shift from fins to limbs with digits. But the stapes would not take on its familiar role as a component of the terrestrially adapted tympanic ear for millions of years. In the meantime, it apparently functioned in these still aquatic tetrapods as a structural component of the skull.

Taken together, these skeletal changes have necessitated a sea change in the way we regard early tetrapods. Gone are the clumsy chimeras of popular imagination, fit for neither water nor land. What were once considered evolutionary works in progress—an incompletely developed limb or ear, for example—we now know were adaptations in their own right. They were not always successful, but they were adaptations nonetheless. At each stage of this transition were innovators pushing into new niches. Some, in fact, were highly specialized to do this.

LUCY READING-IKKANDA



TETRAPOD RELATIONS: Tetrapods arose from lobe-finned fish like *Eusthenopteron* some 380 million to 375 million years ago, in the late Middle Devonian period.

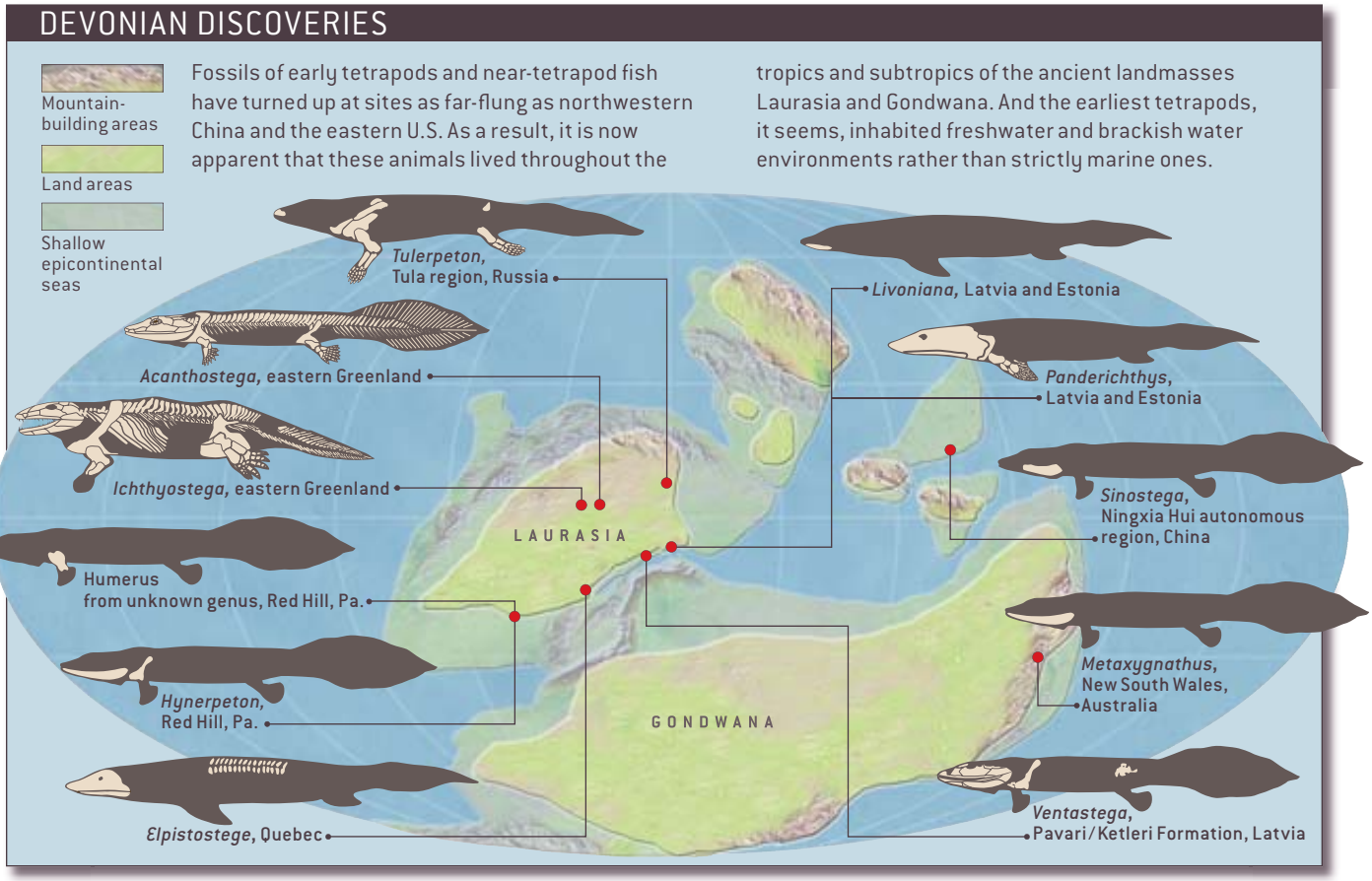
THE AUTHOR

JENNIFER A. CLACK, a Reader in vertebrate paleontology and doctor of science at the University of Cambridge, has been studying tetrapod origins for 25 years. A fellow of the Linnean Society, Clack's outside interests include choral singing (particularly of early sacred music) and gardening. She is also a motorcyclist and rides a Yamaha Diversion 900.

Breaking the Mold

BY AND LARGE, the limbed tetrapods and near-tetrapods unearthed thus far have been sizeable beasts, around a meter long. They preyed on a wide variety of invertebrates and fish and were probably not fussy about which ones. We are beginning to find exceptions to this generalist rule, however. One is *Livoniana,* discovered in a museum in Latvia by Per Erik Ahlberg of Sweden's Uppsala University in 2000. This animal is represented by some lower jaw fragments that exhibit a bizarre morphology: instead of the usual two rows of teeth lining each side of the jaw, it had seven rows. Exactly what *Livoniana* might have been consuming with this corn-on-the-cob dentition we do not know. But it most likely had a diet apart from that of its brethren.

Renewed work on the first known Devonian tetrapod, *Ichthyostega*, is showing that it, too, diverged from the norm—contrary to earlier preconceptions. The ear region and associated parts of the braincase of *Ichthyostega* have long baffled researchers because they display a construction unlike that of any other tetrapod or fish from any period.



But with the aid of new fossils, fresh preparation of previously collected material and, crucially, CT scanning of key specimens, my colleagues and I have begun to make sense of this mysterious construction. The best interpretation seems to be that *Ichthyostega* possessed a highly specialized ear, but one that was geared for use underwater. Instead of having an eardrum, as many modern terrestrial animals do, at each side of the back of the head lay a chamber with strengthened top and side walls that was probably filled with air. Into the membranous floor of this chamber stretched a spoon-shaped and very delicate stapes, which presumably vibrated in response to sound impinging directly on the air in the chamber, transmitting these vibrations to the inner ear through a hole in the wall of the braincase. This arrangement would imply that *Ichthyostega* spent a good deal of time in water. Likewise, the animal's tail fin and flipperlike hind limbs suggest an aquatic lifestyle.

Yet other parts of the *Ichthyostega* skeleton bespeak an ability to get around on land. It had incredibly powerful shoulders and forearms. And the ribs of the chest region were very broad and overlapping, forming a corset that would have prevented the chest cavity and lungs from collapsing when on the ground. Even so, *Ichthyostega* probably did not locomote like a standard-issue land vertebrate. For one thing, its ribcage would have restricted the lateral undulation of the trunk that typically occurs in tetrapod movement. And in contrast to fish, *Acanthostega* or other early tetrapods, *Ichthyostega* had spines on its vertebrae that changed direction along the spinal column, hinting that the muscles they supported were specialized for different jobs and that it moved in a unique fashion. This multidirectional arrangement of the vertebral spines parallels that in mammals today, but it was unheard of in Devonian tetrapods until we studied *Ichthyostega*. All told, this latest evidence suggests that, rather than bending in the horizontal plane, as the body of a fish does, the body of *Ichthyostega* bent mainly in a vertical plane. The paddlelike hind limbs do not seem to have contributed much forward thrust during locomotion—the robust forelimbs and large shoulders provided that. Thus, on land *Ichthyostega* may have moved rather like a seal, first raising its back, then advancing both forelimbs simultaneously, and finally hauling the rest of its body forward.

In September, Ahlberg, Henning Blom of Uppsala University and I published a paper detailing these findings in the journal *Nature*. If we are correct, *Ichthyostega* is the earliest vertebrate on record that shows some adaptations for nonswimming locomotion. It is impossible to say with certainty what *Ichthyostega* was doing ashore. It may have been eating stranded fish there but reproducing in water, in which case it could have used its specialized ear to listen for potential mates. (This scenario implies that *Ichthyostega* was making noises as well as listening to them.) Alternatively, *Ichthyostega* may have been eating in the water and listening for prey there, whereas it was using its forelimbs to dig nests for its eggs on land. Ultimately, however,

ANDREW RECHER (*tetrapods*); LUCY READING-IKKANDA (*map*)

its particular body plan was doomed, because no fossil dating later than 360 million years ago can be reliably attributed to the *Ichthyostega* lineage. No doubt there were many such superseded designs over the course of early tetrapod evolution. Further work will be needed to confirm these ideas, but the latest data demonstrate that Devonian tetrapods were more diverse than previously suspected. We are learning to expect more such surprises as these animals and their relatives become better known.

Have Legs, Will Travel

THE FOSSILS UNCOVERED over the past two decades have done more than allowed scientists to trace many of the changes to the tetrapod skeleton. They have also provided fresh insights into when and where these creatures evolved. We are now reasonably certain that tetrapods had emerged by 380 million to 375 million years ago, in the late Middle Devonian, a far tighter date range than the one researchers had previously postulated. We have also determined that the early representatives of this group were nothing if not cosmopolitan.

Devonian tetrapods were scattered across the globe, ranging from locations that are now China and Australia, where creatures known as *Sinostega* and *Metaxygnathus*, respectively, have turned up, to the eastern U.S., where the Red Hill humerus and a beast called *Hynerpeton* were found. Placing the fossil localities onto a paleogeographic map of the time, we see that these animals dwelled throughout the tropics and subtropics of a supercontinent comprising Laurasia to the north and Gondwana to the south. Their near-ubiquitous distribution in the warmer climes is a testament to how successful these creatures were.

Within these locales, Devonian tetrapods inhabited a startlingly wide range of environments. Deposits in eastern Greenland that were the first to yield such creatures indicate that the area was once a broad river basin dominated by periodic floods alternating with drier conditions. The river was unequivocally freshwater in origin and thus formed the basis for received wisdom about the environments in which tetrapods evolved. But the discoveries of such creatures as *Ventastega* and *Tulerpeton* in deposits representing settings of varying salinity have called that notion into question. The Red Hill site in Pennsylvania has proved particularly rich in providing a context for the tetrapods, yielding many fish species as well as invertebrates and plants. Like the eastern Greenland deposits, it represents a river basin. Yet paleoenvironmental studies suggest that the region had a temperate climate, rather than the monsoonal conditions associated with the Greenland finds. That is to say, early tetrapods may have been even more widespread than we thought.

Although we now have a good explanation for why the front limbs evolved the way they did, we lack one for the origin of the hind limbs because none of the fossils recovered so far contains any clues about them.

Unfinished Business

WE STILL HAVE MUCH to learn about changes in anatomy that accompanied the rise of tetrapods. Although we now have a reasonable hypothesis for why the shoulder girdle and front limbs evolved the way they did, we lack an adequate explanation for the origin of the robust hind-limb complex—the hallmark of a tetrapod—because none of the fossils recovered so far contains any clues about it. Only specimens of *Ichthyostega* and *Acanthostega* preserve this part of the anatomy, and in both these animals the hind limbs are too well formed to reveal how they took shape. Almost certainly no single scenario can account for all the stages of the transition. We also want to acquire a higher-resolution picture of the order in which the changes to the skeleton occurred, say, when the hind limb evolved relative to the forelimb and the ear.

The discovery and description of additional fossils will resolve some of these mysteries, as will insights from evolutionary developmental biology. To that end, studies of the genetic-control mechanisms governing the formation of the gill region in fish and the neck area in mammals and birds are just beginning to provide hints about which processes characterize both tetrapods and fish and which are unique to tetrapods. For example, we know that tetrapods have lost all the bones that protect the gills in fish but that the genes that govern their formation are still present in mice, where they function differently. We have also ascertained that in the neck region, the biochemical pathways that preside over the development of limbs have broken down. Although biologists can easily induce extra limbs to grow on the flank of a tetrapod, this cannot be done in the neck. Something special happened when tetrapods first evolved a neck that prevented limbs from sprouting there.

Other questions may be more difficult to answer. It would be wonderful to know which one of the many environmental contexts in which tetrapod fossils have turned up nurtured the very first members of this group (the available evidence indicates only that these animals did not debut in strictly marine settings). We would also like to comprehend fully the evolutionary pressures at work during each phase of the transition. Lacking a perfect fossil record or recourse to a time machine, we may never piece together the entire puzzle of tetrapod evolution. But with continued work, we can expect to close many of the remaining gaps in the story of how fish gained ground. SA

MORE TO EXPLORE

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Inside the Mind of a Savant

Kim Peek possesses one of the most extraordinary memories ever recorded. Until we can explain his abilities, we cannot pretend to understand human cognition

By Darold A. Treffert and Daniel D. Christensen

When J. Langdon Down first described savant syndrome in 1887, coining its name and noting its association with astounding powers of memory, he cited a patient who could recite Edward Gibbon's *The Decline and Fall of the Roman Empire* verbatim. Since then, in almost all cases, savant memory has been linked to a specific domain, such as music, art or mathematics. But phenomenal memory is itself the skill in a 54-year-old man named Kim Peek. His friends call him "Kim-puter."

KIM PEEK stands in front of an image of his brain.

He can, indeed, pull a fact from his mental library as fast as a search engine can mine the Internet. He read Tom Clancy's *The Hunt for Red October* in one hour and 25 minutes. Four months later, when asked, he gave the name of the Russian radio operator in the book, referring to the page describing the character and quoting several passages verbatim. Kim began memorizing books at the age of 18 months, as they were read to him. He has learned 9,000 books by heart so far. He reads a page in eight to 10 seconds and places the memorized book upside down on the shelf to signify that it is now on his mental "hard drive."

Kim's memory extends to at least 15 interests—among them, world and American history, sports, movies, geography, space programs, actors and actresses, the Bible, church history, literature, Shakespeare and classical music. He knows all the area codes and zip codes in the U.S., together with the television stations serving those locales. He learns the maps in the front of phone books and can provide Yahoo-like travel directions within any major U.S. city or between any pair of them. He can identify hundreds of classical compositions, tell when and where each was composed and first performed, give the name of the composer and many biographical details, and even discuss the formal and tonal components of the music. Most intriguing of all, he appears to be developing a new skill in middle life. Whereas before he could merely talk about music, for the past two years he has been learning to play it.

It is an amazing feat in light of his severe developmental problems—characteristics shared, in varying extents, by all savants. He walks with a sidelong gait, cannot button his clothes, cannot manage the chores of daily life and has great difficulties with abstraction. Against these disabilities, his talents—which would be extraordinary in any person—shine all the brighter. An explanation of how Kim does what he does would provide better insight into why certain skills, including the ordinarily obscure skill of calendar calculating (always associated with massive memory), occur with such regularity among savants. Recently, when an interviewer offered that he had been born on March 31, 1956, Kim noted, in less than a second, that it was a Saturday on Easter weekend.

Imaging studies of Kim's brain thus far show considerable structural abnormality [*see box on page 112*]. These findings cannot yet be linked directly to any of his skills; that quest is just beginning. Newer imaging techniques that plot the brain's functions—rather than just its structure—should provide more insight, though. In the meantime, we believe it is worthwhile to document the remarkable things that Kim can do. People like him are not easily found, and it is useful to record their characteristics for future research. Savantism offers a unique window into the mind. If we cannot explain it, we cannot claim full understanding of how the brain functions.

Overview/*Peek's Peaks*

- Great powers of memory run through every known manifestation of savant skill. In the case of Kim Peek, memory is itself the skill.
- Kim's brain exhibits many abnormalities, including an absent corpus callosum. The role of that particular abnormality in Kim's case remains to be explained, but it evokes a question raised by the skills of all savants: Does brain damage stimulate compensatory development in some other area of the brain, or does it simply allow otherwise latent abilities to emerge?
- Kim's rote learning later developed into a form of associative thinking, with clear evidence of creativity. His success then helped him engage the wider world. The authors conclude that savant skills should never be dismissed but should be cultivated for the patient's intellectual and social development.

An Unusual Brain

KIM WAS BORN on November 11, 1951 (a Sunday, he will tell you). He had an enlarged head, on the back of which was an encephalocele, or baseball-size "blister," which spontaneously resolved. But there were also other brain abnormalities, including a malformed cerebellum. One of us (Christensen) did the initial MRI brain scans on Kim in 1988 and has followed his progress ever since.

The cerebellar findings may account for Kim's problems with coordination and mobility. But more striking still is the absence of a corpus callosum, the sizable stalk of nerve tissue that normally connects the left and right halves of the brain. We do not know what to make of this defect, because although it is rare, it is not always accompanied by functional disorders. Some people have been found to lack the structure without suffering any detectable problems at all. Yet in people whose corpus callosum has been severed in adulthood, generally in an effort to prevent epileptic seizures from spreading from one hemisphere to the other, a characteristic "split-brain" syndrome arises in which the estranged hemispheres begin to work almost independently of each other.

It would seem that those born without a corpus callosum somehow develop back channels of communication between the hemispheres. Perhaps the resulting structures allow the two hemispheres to function, in certain respects, as one giant hemisphere, putting functions normally rather separate under the same roof, as it were. If so, then Kim may owe some of his talents to this particular abnormality. In any case, the fact that some people lacking a corpus callosum suffer no disabilities, whereas others have savant abilities, makes its purpose less clear than formerly thought. Neurologists joke that its only two certain functions are to propagate seizures and hold the brain together.

Theory guides us in one respect. Kim's brain shows abnormalities in the left hemisphere, a pattern found in many savants. What is more, left hemisphere damage has been invoked as an explanation of why males are much more likely

ETHAN HILL (*preceding pages*)

KIM READS a page in eight to 10 seconds, learning it by heart as he goes. His mental library of 9,000 books includes encyclopedic coverage of everything from Shakespeare to musical composers to the maps of all major cities in the U.S.

than females to display not only savantism but also dyslexia, stuttering, delayed speech, and autism. The proposed mechanism has two parts: male fetuses have a higher level of circulating testosterone, which can be toxic to developing brain tissue; and the left hemisphere develops more slowly than the right and therefore remains vulnerable for a longer period. Also supporting the role of left hemisphere damage are the many reported cases of "acquired savant syndrome," in which older children and adults suddenly develop savant skills after damage to the left hemisphere.

What does all this evidence imply? One possibility is that when the left hemisphere cannot function properly, the right hemisphere compensates by developing new skills, perhaps by recruiting brain tissue normally earmarked for other purposes. Another possibility is that injury to the left hemisphere merely unveils skills that had been latent in the right hemisphere all along, a phenomenon some have called a release from the "tyranny" of the dominant left hemisphere.

Kim underwent psychological testing in 1988. His overall IQ score was 87, but the verbal and performance subtests varied greatly, with some scores falling in the superior range of intelligence and others in the mentally retarded range. The psychological report concluded, therefore, that "Kim's IQ classification is not a valid description of his intellectual ability." The "general intelligence" versus "multiple intelligences" debate rages on in psychology. We believe that Kim's case argues for the latter point of view.

Kim's overall diagnosis was "developmental disorder not otherwise specified," with no diagnosis of autistic disorder. Indeed, although autism is more commonly linked with savantism than is any other single disorder, only about half of all savants are autistic. In contrast with autistic people, Kim is outgoing and quite personable. One thing that does seem necessary for the full development of savant skills is a strong interest in the subject matter in question.

Memory and Music

IN KIM'S CASE, all the interests began in rote memorization but later progressed to something more. Although Kim generally has a limited capacity for abstract or conceptual thinking—he cannot, for example, explain many commonplace proverbs—he does comprehend much of the material he has committed to memory. This degree of comprehension is unusual among savants. Down himself coined the interesting phrase "verbal adhesion" to describe the savant's ability to remember huge quantities of words without comprehension. Sarah Parker, a graduate student in psychology at the University of Pennsylvania, in a description of a savant named Gordon stated it more colorfully when she noted that "owning a kiln of bricks does not make one a mason." Kim not only owns a large kiln of bricks, he has also become a strikingly creative and versatile word mason within his chosen areas of expertise.

Sometimes his answers to questions or directions are quite concrete and literal. Once when asked by his father in a restaurant to "lower his voice," Kim merely slid lower into his chair, thus lowering his voice box. In other cases, his answers can seem quite ingenious. In one of his talks he answered a question about Abraham Lincoln's Gettysburg Address by responding, "Will's house, 227 North West Front Street. But he stayed there only one night—he gave the speech the next day." Kim intended no joke, but when his questioner laughed, he saw the point; since then, he has purposely recycled the story with humorous intent and effect.

Yet Kim does have an undeniable power to make clever connections. He once attended a Shakespeare festival sponsored by a philanthropist known by the initials O.C., whose laryngitis threatened to keep him from acknowledging a tes-

THE AUTHORS

DAROLD A. TREFFERT and *DANIEL D. CHRISTENSEN* have long been fascinated by savantism. Treffert, a psychiatrist in Wisconsin, has done research on autism and savant syndrome since 1962, the year he first met a savant. He was consultant to the movie *Rain Man* and is author of *Extraordinary People: Understanding Savant Syndrome*. Christensen is clinical professor of psychiatry, clinical professor of neurology and adjunct professor of pharmacology at the University of Utah Medical School. His work focuses on Alzheimer's disease, but following Kim Peek for more than two decades has given him an ongoing interest in savant syndrome.

ETHAN HILL

timonial. Kim—a fan of Shakespeare, and like him, an incorrigible punster—quipped, "O.C., can you say?"

Such creative use of material that had originally been memorized by rote can be seen as the verbal equivalent of a musician's improvisation. Like the musician, Kim thinks quickly, so quickly that it can be difficult to keep up with his intricate associations. Often he seems two or three steps ahead of his audiences in his responses.

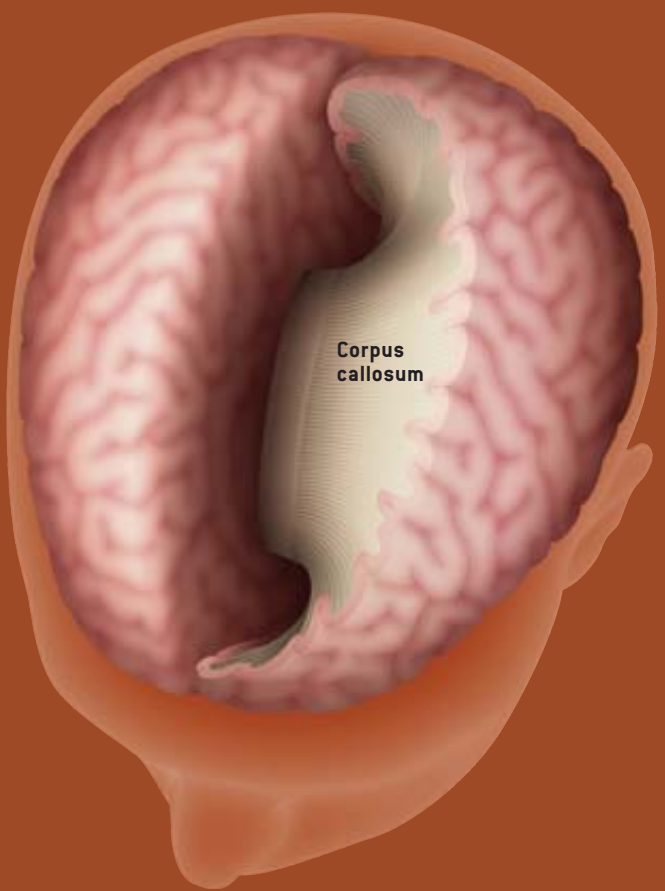
A rather startling new dimension to Kim's savant skills has recently surfaced. In 2002 he met April Greenan, director of the McKay Music Library and professor of music at the University of Utah. With her help, he soon began to play the piano and to enhance his discussion of compositions by playing passages from them, demonstrating on the keyboard many of the pieces he recalled from his massive mental library. Kim also has remarkable long-term memory of pitch, remembering the original pitch level of each composition.

He possesses complete knowledge of the instruments in the traditional symphony orchestra and readily identifies the timbre of any instrumental passage. For example, he presented the opening of Bedrich Smetana's orchestral tone poem *The Moldau*, by reducing the flute and clarinet parts to an arpeggiated figure in his left hand and explaining that the oboes and bassoons enter with the primary theme, which he then reduced to pitches played singly and then in thirds by his right hand (the left-hand figure continuing as it does in the score). His comprehension of musical styles is demonstrated in his ability to identify composers of pieces he had not previously heard by assessing the piece's musical style and deducing who that composer might be.

A MISSING CONNECTION?

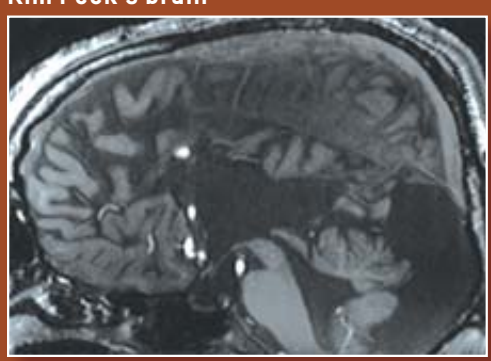
Kim Peek's brain (*bottom right*) differs from typical brains (*diagram* and *top right*) in several ways. (The scans below are front-to-back cross sections constructed with magnetic resonance imaging.)

Kim's brain and head are very large, each in the 99th percentile. Most striking is the complete absence of the corpus callosum, which normally connects the left and right hemispheres. Missing, too, are the anterior and posterior commissures, which also usually link the hemispheres. The cerebellum, responsible for certain motor functions, is smaller than usual and malformed, with fluid occupying much of the surrounding space; this may explain some of Kim's difficulties with coordination. What role these abnormalities play in his mental abilities is the subject of investigation.



Normal brain

Kim Peek's brain



SARA CHEN (*illustration*); PRATIK MUKHERJEE AND DONNA R. ROBERTS *University of California, San Francisco (MRI scans)*

Though Kim is still physically awkward, his manual dexterity is increasing. When seated at the piano, he may play the piece he wishes to discuss, sing the passage of interest or describe the music verbally, shifting seamlessly from one mode to another. Kim pays attention to rhythm as well, lightly tapping the beat on his chest with his right hand or, when playing, tapping his right foot.

Greenan, a Mozart scholar, makes these observations: "Kim's knowledge of music is considerable. His ability to recall every detail of a composition he has heard—in many cases only once and more than 40 years ago—is astonishing. The connections he draws between and weaves through compositions, composer's lives, historical events, movie soundtracks and thousands of facts stored in his database reveal enormous intellectual capacity." She even compares him to Mozart, who also had an enlarged head, a fascination with numbers and uneven social skills. She wonders whether Kim might even learn to compose.

Life after *Rain Man*

IT IS NOT SURPRISING that Kim's prodigious memory caught the attention of writer Barry Morrow at a chance meeting in 1984 and inspired him to write the screenplay for *Rain Man,* whose main character, Raymond Babbitt, is a savant played by Dustin Hoffman. The movie is purely fictional and does not tell Kim's life story, even in outline. But in one remarkably prescient scene, Raymond instantly computes square roots in his head, and his brother, Charlie, remarks, "He ought to work for NASA or something." For Kim, such a collaboration might well happen.

NASA has proposed to make a high-resolution 3-D anatomical model of Kim's brain architecture. Richard Boyle, director of the NASA BioVIS Technology Center, describes the project as part of a larger effort to overlay and fuse image data from as wide a range of brains as possible—and that is why Kim's unusual brain is of particular value. The data, both static and functional, should enable investigators to locate and identify changes in the brain that accompany thought and behavior. NASA hopes that this detailed model will enable physicians to improve their ability to interpret output from far less capable ultrasound imaging systems, which are the only kind that can now be carried into space and used to monitor astronauts.

The filming of *Rain Man* and the movie's subsequent success proved to be a turning point in Kim's life. Before then, he had been reclusive, retreating to his room when company came; afterward, the confidence he gained from his contacts with the filmmakers, together with the celebrity provided by the movie's success, inspired him and his father, Fran Peek, to share Kim's talents with many audiences. They became enthusiastic emissaries for people with disabilities, and over the years they have shared their story with more than 2.6 million people.

We believe that Kim's transformation has general applicability. Much of what scientists know about health comes out of the study of pathologies, and certainly much of what will be learned about normal memory will come from the study of unique or unusual memory. In the meantime, we draw some practical conclusions for the care of other persons with special needs who have some savant skill. We recommend that family and other caregivers "train the talent," rather than dismissing such skills as frivolous, as a means for the savant to connect with other people and mitigate the effects of the disability. It is not an easy path, because disability and limitations still require a great deal of dedication, patience and hard work—as Kim's father, by his example, so convincingly demonstrates.

Further exploration of savant syndrome will provide both scientific insights and stories of immense human interest. Kim Peek provides ample evidence of both. SA

PLAYING THE PIANO is Kim's most recently acquired skill, one at which he is becoming increasingly adept despite having poor coordination. Music professor April Greenan (*seated*) and Kim's father, Fran (*standing*), have encouraged Kim's efforts.

ETHAN HILL

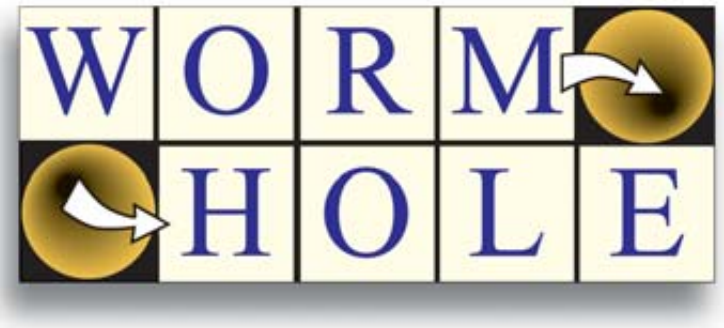
MORE TO EXPLORE

The Real Rain Man. Fran Peek. Harkness Publishing Consultants, 1996.

Extraordinary People: Understanding Savant Syndrome. Reprint edition. Darold A. Treffert. iUniverse, Inc., 2000.

Islands of Genius. Darold A. Treffert and Gregory L. Wallace in *Scientific American,* Vol. 286, No. 6, pages 76–85; June 2002.

www.savantsyndrome.com, a Web site maintained by the Wisconsin Medical Society.



Do wormholes exist, allowing travel across vast expanses in the blink of an eye? They do within the "fabric" of this crossword's grid. Five wormhole-themed entries require you to begin filling in your answer in one spot and then travel through a wormhole to complete the answer in a symmetrically placed location across the grid.

The puzzle also contains 12 clues related to articles that appeared in *Scientific American* in 2005—one for each month. Visuals from the referenced articles frame the grid. (Find answers in next month's issue and at www.sciam.com/ontheweb)

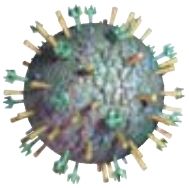
By Patrick Merrell

ACROSS

1 Mold source
6 Instantly, with "in"
12 0's is 16: Abbr.
16 Fiber or oil source
20 Harry's veep Barkley
21 Relieve, as a burn
22 ESA/NASA's sun-orbiting satellite
23 Computer-generated dream girl in *Weird Science*
24 Gullible
25 Robert who wrote *The Bourne Identity*
26 Strigiformes nighttime call
27 Hot spot
28 [Wormhole demonstration]—continued at 122-Across
30 Brewmaster Coors
32 Part of CD-ROM
33 Ned who composed *Air Music*
34 Rigel, notably
36 Percentage of antimalarials sold in Africa that come from roadside vendors (**December**)
38 Rotational line
41 Fabric that a wormhole traverses—continued at 108-Across
43 Chem. lab amts.
44 Family hand-me-downs
46 Record observations
47 "Are you ____ out?"
49 Meditation syllables
52 Coat using electrolysis
55 Heart monitor's reading
56 Film genre
57 Combustible material
58 32,000 ounces
59 It keeps going in circles
61 What a few too many pounds might not necessarily be (**June**)
63 Unsaturated hydrocarbon suffixes
65 Like a cathode: Abbr.
66 Quick, as a pace
70 Nonlustrous finish
71 Hangover location?
73 Where an Einstein-Rosen bridge might lead—continued at 79-Across
76 Tee-hee's big brother
77 Pupa and larva
79 Continued from 73-Across
80 Olympic equivalent of a dueling sword
81 Like a blue whale
82 HBr and HCl
83 Cousteau's assent
85 Sammy famous for his slugs
88 Describing the fermentation process
92 Highest-dwelling equid (**March**)
94 Computer base
95 Put together issues of *Scientific American*
96 Theory's underpinning
97 Combine, as resources
100 Much-discussed troposphere activity
102 Plaintive
103 London art gallery
104 Microsoft's stock market
106 Like Jupiter's red spot
107 Kind of master
108 Continued from 41-Across
111 Greek city or prefecture
112 Neuromorphic chips could help replace these membranes (**May**)
116 *Mayflower* notable
117 Of Gandhi's nation
119 Where George Clooney portrayed a doctor
120 For the first time in history, there are now more old ones of these than young (**September**)
122 Continued from 28-Across
126 File drawer label
127 Ring
128 Phrases such as Apollo 13's *Ex Luna, Scientia*
131 Like inexplicable phenomena
132 ____ Alto
133 U-shaped instrument
134 Hypothesize
135 Nation in Revelation
136 Radar sweep
137 It shouldn't be left in an atlas
138 Brainy matter?
139 Random number generators in Vegas

DOWN

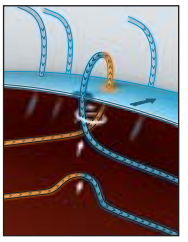
1 Compos mentis
2 Blueprint
3 Expiration notice?
4 Type of polarity the earth exhibits every 250,000 years, on average (**April**)
5 First month, to astronomer Antonio de Ulloa
6 Anesthesized
7 Bobsled team category
8 Ore deposit
9 Challenge for Heyerdahl's *Ra:* Abbr.
10 Moo ____ pork
11 Martian "blueberries" (**July**)
12 Off Darwin's *Beagle*
13 *Homo erectus* possession
14 Conks hard
15 Where a nontheoretical wormhole might go—continued at 89-Down
16 Indonesian home to a possibly recent dwarf human species (**February**)
17 Pep (up)
18 Take ____ (sit down)
19 Types of chromosomes in males, usually
29 15° longitudinal divs.
31 Title for British crystallographer Kathleen Lonsdale
34 Type of ray
35 ASAP, in triage
37 *Nova* taper
38 Quartz variety
39 Gaseous element helpful in identifying ancient natural nuclear reactors (**November**)
40 Where a lecture on wormholes might travel—continued at 49-Down
42 News org.'s foreign reporter
45 Newton follower in encyclopedias
47 It's charged
48 Disease research org.
49 Continued from 40-Down
50 Conductor Zubin
51 More crafty
53 Temperate and Torrid
54 Hot time for the Curies
56 Microwaves, slangily
57 Solar eruptions
60 KGB's predecessor
62 Make ____ (e.g., plot the stars)
64 Exhibited the effects of gravity
66 ____-a-brac
67 George's sitar teacher
68 ____ *Three Lives*
69 Some 35 mm cameras
72 Go off course
74 What a phony puts on
75 First of 13 popes
76 German poet Heinrich
77 Some lava formations
78 Patty Hearst's alias
84 Detroit org.
86 Man-made coolant
87 Most life-threatening aneurysm site (**August**)
89 Continued from 15-Down
90 High-frequency emitter
91 Supporter of Arctic expeditions?
92 *The Birth of a Nation* group
93 Type of reflex during ingestion
97 The deadly 1918–19 flu outbreak, e.g. (**January**)
98 Bone: Prefix
99 Norse god
101 Windpipe-related
103 X
104 Former Steelers' coach Chuck
105 Companion of Sancho Panza
107 Common mineral prized for geochronology (**October**)
108 Oblong pill
109 Gender-neutral
110 Denver setting in Aug.
112 Lopsided contests
113 1940s digital computer
114 Edison rival
115 "Toodle-oo"
118 Parcels up for bid
121 They were employed on Roman galleys
122 Pasteur's state
123 Hence
124 Public disorder
125 Brain tests, for short
129 Meter prefix
130 Rx's "three times"



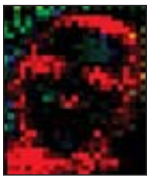
January
97-Down

February
16-Down

March
92-Across



April
4-Down



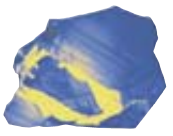
May
112-Across

June
61-Across

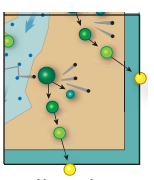
July
11-Down

August
87-Across

September
120-Across



October
107-Down



November
39-Down

December
36-Across

GEORGE RETSECK (*Jan.*); KAZUHIKO SANO (*Feb.*); PATRICIA J. WYNNE (*March*); JEN CHRISTIANSEN (*April*); KAREEM ZAGHLOUL (*May*); BASED ON A PHOTOGRAPH BY HUGH KRETSCHMER (*June*); NASA/JPL/CORNELL (*July*); TAMI TOLPA (*Aug.*); JUDITH S. LARSEN (*Sept.*); SIMON A. WILDE Curtin University of Technology (*Oct.*); JEN CHRISTIANSEN (*Nov. and Dec.*)

THE AUTHOR

PATRICK MERRELL is a professional puzzlemaker and graphic artist. He has published more than 50 crosswords in the *New York Times*, including many in the Sunday edition, and is author of the recently released books *Punchline Puzzles* and *AHA! 125 Original & Amusing Word Puzzles*. Merrell (www.patrick.merrell.org) has also published over a dozen maze books for children.

DIGITAL X-RAYS

Better Exposure

Hospitals are flush with digital MRI and CT scanners, yet the granddaddies—x-ray machines—are still largely analog. Digital x-ray units are finally making inroads, however, and like digital cameras they are poised to replace century-old film technology.

Several imaging methods have arisen [*see illustrations*]. All work with a conventional x-ray generator, but rather than exposing film that must be developed with chemicals in a darkroom, the receivers create a digital image that is displayed on a screen. So-called direct and indirect approaches create an instant readout. The stimulable method traps x-rays in a portable cassette that is inserted into a separate reader.

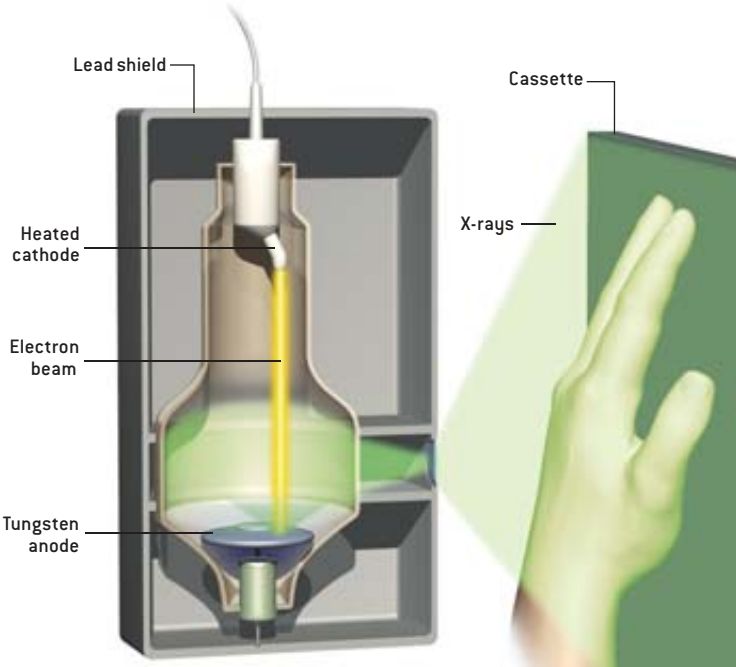
Digital detector systems currently cost several hundred thousand dollars, far more than film systems. But eliminating film and processing saves money and technician time. No darkroom is needed, and thousands of patient images can be stored on a computer instead of in voluminous file cabinets. Staff members can instantly retrieve and send images to off-campus doctors. "A big hospital clinic could reach the break-even point in cost savings in four or five years," says Perry Sprawls, emeritus professor of radiology at Emory University.

Images can also be manipulated to improve contrast, helping radiologists and surgeons see a lung cancer nodule more clearly behind ribs, for example. With film, multiple x-rays would be needed. "Digital image quality is better," says Stephen Metz, chief engineer of global diagnostic x-rays at GE Healthcare in Waukesha, Wis. "Alternatively, you can get the same quality as film with as little as half the x-ray dose." As digital catches on, he adds, prices should come down.

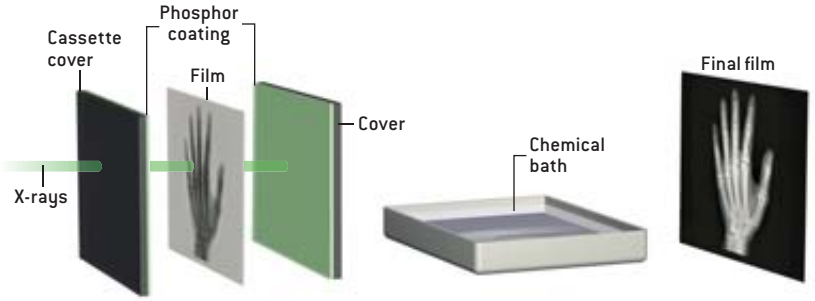
Digital detectors have become practical only in the past five years, as manufacturers have perfected ways to accurately and uniformly deposit x-ray sensitive materials across large-area substrates and optimized electronics to read the faint electronic signals the materials produce. The innovations, in turn, are creating applications that may further spur adoption, Metz says. By taking many low-dose exposures, for instance, radiologists can produce the equivalent of a limited-angle CT scan, which can show emerging cancers without the complex CT procedure. —*Mark Fischetti*

GENERATOR

The x-ray machine operates the same way for all sensing techniques. A heated cathode filament ejects electrons that are accelerated toward a rotating anode plate by a high voltage. The collision emits x-ray photons.



ANALOG



CONVENTIONAL IMAGING

A cassette contains fluorescent coatings that absorb x-rays and glow, exposing film. The film is removed and developed in chemicals, much like a photograph is. New film is inserted for each image.

GEORGE RETSECK

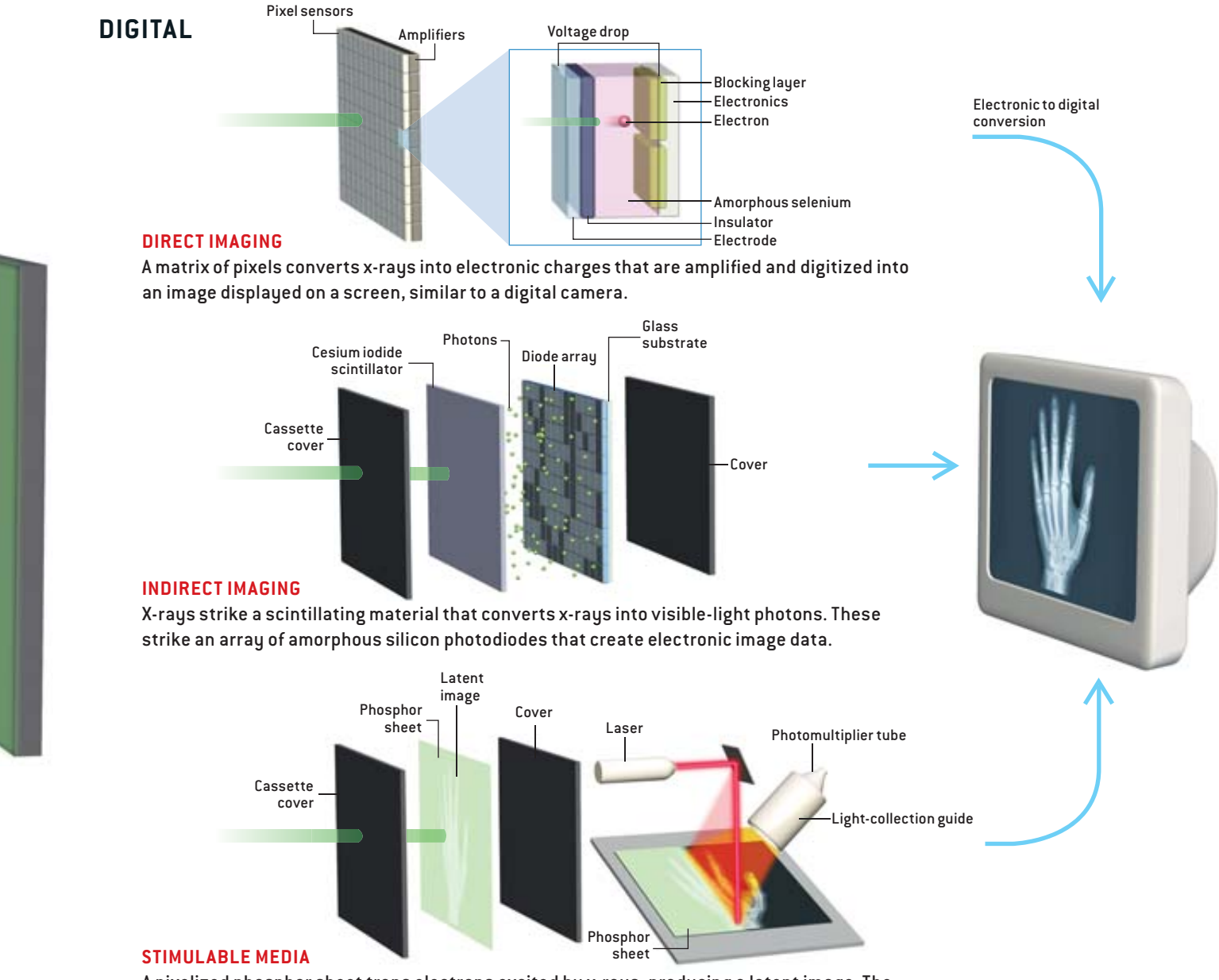
DID YOU KNOW...

▯ TEETH: Dentists have been adopting digital x-ray technology. A small flat sensor, similar in size to the film pad used for years, is placed in the patient's mouth. A thin wire carries pixel data to a computer. The sensor is sterilized between clients. The systems are expensive yet eliminate film costs, end patients' waiting time for developing, and mean that x-ray doses can be lower.

▯ ARTERIES: Surgeons often use fluoroscopy—a type of real-time x-ray movie that shows organs in motion—to guide the insertion of catheters into blood vessels to treat blockages or aneurysms. Patients must lie underneath a large, heavy, barrel-shaped image intensifier tube, however, which can make surgical access difficult, and the image resolution fades at the periphery. Digital machines entering the market are much smaller and lighter, giving surgeons room to work, and images stay crisp to the edges.

▯ LUGGAGE: Early scanners for peering into carry-on bags at airport checkpoints were adapted from hospital fluoroscopes, with a freeze-frame that allows inspectors to scrutinize objects inside. Digital systems are gradually taking over. Machines that analyze checked bags are derived from computed tomography; high-energy x-rays generate a series of slice images that render three-dimensional views. Objects are compared against a database of explosives and contraband, and alarms sound if suspicious matches arise.

DIGITAL



DIRECT IMAGING

A matrix of pixels converts x-rays into electronic charges that are amplified and digitized into an image displayed on a screen, similar to a digital camera.

INDIRECT IMAGING

X-rays strike a scintillating material that converts x-rays into visible-light photons. These strike an array of amorphous silicon photodiodes that create electronic image data.

STIMULABLE MEDIA

A pixelized phosphor sheet traps electrons excited by x-rays, producing a latent image. The cassette is placed into a reader, where a red laser illuminates each pixel, causing a glow that is converted to a digital image. The sheet is erased with bright light.

Topic suggested by reader Karl Stephan.
Send ideas to workingknowledge@sciam.com

Easy Rider

AUTOMATIC TRANSMISSION MAKES CYCLING A BREEZE **BY KASPAR MOSSMAN**

There are two kinds of cyclists in Manhattan: the quick and the dead. This narrow island between the Hudson and East rivers is possibly the least bicycle-friendly place on the planet. Delivery people, couriers and casual cyclists face the challenge of crossing six-lane avenues choked with heavy trucks and honking taxis. And even if you make it to the oasis of Central Park, you must contend with packs of riders on high-end racing bikes who seem to be engaged in a perpetual Tour de France.

As a mild-mannered graduate student from California who was spending the summer in New York City, I sensed that I needed some high-tech edge to compete in this torrent of two-wheeled traffic. I soon learned that Shimano, the Japanese manufacturer of bicycle components, produces the ultimate accessory for recreational cyclists: a digitally controlled automatic transmission that takes all the guesswork out of gearshifting. I called up Shimano's U.S. headquarters in Irvine, Calif., and convinced the company to let me evaluate this voguish velocipede for *Scientific American*.

Just to be clear, I don't have an aversion to hard pedaling. On the West Coast I use my bike to commute to school and cart my groceries. I don't own a car and have no use for a moped or scooter. Bicycling is how I get my exercise. But even as a bike-lane veteran, I'm often stymied by the gearing on a standard bicycle. Take my commuter ride, for example, a hybrid road/mountain model made by Specialized Bicycle Components. It has three chain rings—small, medium and large—bolted to the pedals; working with the bike chain, each of these toothed rings can drive one of seven sprockets on the hub of the rear wheel. In theory, that gives me 21 gears to choose from. The problem is that some of those 21 configurations are redundant. For example, pairing the biggest front chain ring with one of the larger rear sprockets delivers the same gear ratio as combining the smallest chain ring with one of the smaller sprockets.

FREEWHEELING: No shift levers are on the handlebars of this Bianchi Milano bicycle. Instead an automatic transmission system senses acceleration and does all the gearshifting.

Furthermore, the chain is stretched diagonally in some gear combinations, which can wear down the chain links or tear the teeth off the sprockets. In reality, I get only about seven gears out of my bike—and a bit of a headache from trying to figure out the proper pairings. Often I find myself in the wrong gear, which is bad for the bike and terrible on the knees. Legs have an optimum rate for going around in circles; ideally, you should be cranking the pedals at about 90 revolutions per minute.

The solution for cars is an automatic transmission, which shifts the vehicle's gears so that the engine can hum along in its own preferred range (2,000 to 3,000 rpm) no matter what the car's speed. Not surprisingly, automatic transmissions for bicycles have been in development for more than 30 years. The largest market for the most up-to-date models is Europe. Jasen Thorpe, consumer marketing manager for Shimano's American division, notes that in the U.S., "We have our Lance Armstrongs and Greg LeMonds,"

JOHNNY JOHNSON

but the Europeans are more likely to rely on bicycles for their everyday needs.

In the U.S., Shimano is after the leisure market. Racing cyclists want complete control over acceleration, but the typical weekend rider will often take convenience over performance. The bicycle that Shimano sent me was a Bianchi Milano, an Italian model with a somewhat retro look. It was equipped with a seven-speed Nexus internal hub, a transmission system that looked like an oversize beer can enclosing the bike's rear axle. No shift levers were on the handlebars; instead the gears were selected by Shimano's Digitally Integrated Intelligence (Di2) system, which was controlled by a computer chip in a gray, molded-plastic enclosure mounted on the bike frame.

"Take this bike to the coffee shop," Thorpe suggested. Appropriately, the Bianchi Milano sported a decal of a cappuccino cup with the words "Café Racer." I cruised down the bike path paralleling Manhattan's waterfront, admiring the variety of refuse floating between the piers. I was impressed with how smooth and reliable the automatic transmission was. One of my concerns had been that I would have to cross a busy street starting from a dead stop and that the bike would leave me stranded in high gear and heaving wild-eyed on the pedals as a yellow cab careered toward me. But no—every time I came to a stop, the transmission would start from the lowest gear. As I accelerated, it geared up as naturally as I would have done myself. There were no alarming clunks as the gears shifted, either.

The Nexus transmission uses planetary gearing similar to a car's automatic transmission. The bike chain drives a sun gear on the rear axle, which transmits power to planetary gears situated around it. The planetary gears, in turn, mesh their teeth with a ring gear, which drives the rear wheel. In a car, the components of the automatic transmission are much heavier and driven by hydraulics,

PLASTIC ENCLOSURE (*top*) contains the computer chip that selects the gears, which are inside a hub on the bike's rear axle (*bottom*).

JOHNNY JOHNSON

but the systems are otherwise the same.

The Di2 controller continuously monitors wheel rotation using 14 magnetic sensors inside the rear hub. When the device detects acceleration, it sends a signal to a small electric servomotor that rotates a sleeve on the axle to shift the planetary gears. Because all the gears are enclosed within the hub, road grit can't get inside to abrade the metal parts. The electronic transmission actually needs less servicing than the manual version, which can break down if the cable to the shift levers slips or frays.

When I first got the bike, I was concerned to see that it had no batteries—not even a switch to turn on the electronics. A call to Shimano cleared up the mystery: the Di2 is *always* on because it is powered by a generator inside the hub of the bicycle's front wheel. Producing electricity from the wheel's rotation, the same generator can also power a lamp. And the lamp will automatically turn on as soon as the photoelectric eye on the Di2 enclosure (another mystery at first) decides that it is getting dark.

Another worry still nagged at me, though. What happens if something goes wrong with your digitally controlled bicycle? Where would you get it repaired? This was no idle question. I could coax only six gears out of the bike: cruising along in sixth gear, the transmission would strain and click as if it were trying to shift higher but couldn't. With an ordinary bike, I could just pull out a multitool and adjust whatever needed attention. But the hub covering the Nexus transmission prevented any attempts at tinkering. So I took the bike to a repair shop.

Allen Schulmann, owner of Sid's Bike Shop in Manhattan, was as impressed as I was by the Di2. "That's really cool," he marveled after taking it for a jaunt. He wasn't too fazed by the prospect of fixing it. *Scientific American*, though, didn't give me a budget for repairs, so I didn't ask for an estimate.

Even as a grad student, I might be able to afford a Di2-equipped Bianchi, which costs about $800. Unfortunately, it would probably get stolen or stripped if I left it anywhere on campus. But if you live in an area with good bike trails or commute lanes and you don't care how your bicycle shifts gears—as long as it gives you the right one at the right time—then this system is for you. If you're a cyclist in Manhattan, though, shifting gears is the least of your worries. SA

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Tricky, Turbulent, Tribal

FRIEND OR FOE IS A MUTABLE DESIGNATION **BY HENRY GEE**

US AND THEM: UNDERSTANDING YOUR TRIBAL MIND
by David Berreby
Little, Brown, 2005 ($26.95)

OUR INNER APE: A LEADING PRIMATOLOGIST EXPLAINS WHY WE ARE WHO WE ARE
by Frans de Waal
Riverhead Books (Penguin Group), 2005 ($24.95)

No man is an island. In fact, people are less happy and healthy alone than when they are in a group—of kin, of countrymen or indeed of anybody with whom they can identify, however fleetingly. But tribes are tricky, at once so solid and yet so evanescent—*je suis Marxiste,* runs the apocryphal French graffito, *tendance Groucho*. We switch allegiance from one Thousand-Year Reich to another at the drop of the hat. At the dictates of some distant demagogue, your good neighbor can become a deadly foe.

On July 7, 2005, suicide bombers blew themselves up on three London subway trains and a bus, killing themselves and more than 50 other people in the cause of radical Islam. The abiding horror is that the bombers were not foreign insurgents—*Them*—but were British, born and raised; in Margaret Thatcher's defining phrase, *One of Us*. The crisis of tribal identity that the horror unleashed will, eventually, change the characteristics of what we mean by "Britishness," qualifying the laissez-faire multicultural consensus that has held for the past half a century.

Such is the mutability of tribes, entities forever changing with reference to one another, and the protean subject of David Berreby's brave book. Berreby's quest is to understand what he sees as a fundamental human urge to classify and identify with "human kinds." We project this urge onto what we see. Are races and human kinds real? The fact that they change all the time, and we can switch from one to another so easily, suggests not. Instead, Berreby says, our ideas of the "human-kind code" are based "on facts about how we relate to [other] people at the moment we categorize them—what we want, or expect, or fear from them."

Having an inbuilt facility to distinguish between Us and Them was a valuable resource, related to that essential ability to create artificial groupings from what, to a robot, would be entirely distinct objects. We take this talent for granted, but what would life be like if we lacked it: if we were like Funes, the cripple created by Jorge Luis Borges in his story *Funes the Memorious*—a man with mental recall so powerful that he could not stand back and objectify what he saw? Funes saw each dog, each leaf, each cloud as sui generis: his inability to form categories left him utterly unable to make sense of the world.

This vital trick serves us well. But when applied to people, it can cause problems, especially when different kinds of people are all mixed up together, as they are in London, one of the most polyglot cities on the planet. The current crisis swirling around Islam and Britishness, what some see as a symptom of the imminent failure of the multicultural consensus, could have been predicted by the fate of the "contact" hypothesis, in which prejudice is meant to be weakened by familiarity. That foreign-looking man in the hooded jacket will be less threatening if you know he's just Bernie from next door. Most scholars now think, Berreby says, that the contact hypothesis is a muddle: "Actual contact sometimes makes people *more* prejudiced. On many American college campuses … the emphasis on di-

CHOOSING UP tribes begins early.

GIDEON MENDEL *Corbis*

versity has led students to join one of these diverse human kinds and shun much contact with the others." Bernie could be your friend for life—or your worst enemy.

Do we remain forever prey to our irrepressible urges to classify, to create outcasts, *Untermenschen,* untouchables? Because "human kinds" are epiphenomena, results of unspoken contracts between fickle human minds and changeful reality, we can rise above them. "Human kinds exist because of human minds," Berreby concludes. "But how you choose to live with them is up to you." We can actively choose the kinds we want, for evil or for good. Since the bombings, London mayor Ken Livingstone has had posters put up all over the city promoting our unity. "Seven Million Londoners," it reads, "Only One London." Livingstone, like Margaret Thatcher at the opposite end of the political spectrum, is a consummate politician who knows how to play on our instincts.

In times of universal crisis and brouhaha, what we really need is a sense of perspective. *Our Inner Ape,* written by a scientist with a lifetime's experience around apes, is perhaps the most humane treatment of the human condition you can read, for all that it is mostly about chimpanzees. So-called common (but extremely rare) chimpanzees (*Pan troglodytes*) live in male-dominated societies characterized by shifting allegiances and extreme violence. So far, so Berreby. Their close cousins, the even less frequent pygmy chimps, or bonobos (*P. paniscus*), live in matriarchal societies where the stress is on reconciliation, all anxieties smoothed over by liberal applications of sex, in all possible combinations. If chimps are from Mars, bonobos are from Venus. Really? It's tempting to see these creatures as cartoon characters, caricatures of ourselves, done up as clowns or, more seriously, as metaphors for the human condition. De Waal plays this up to engage our interest but is at pains not to overdo it. Chimps and bonobos are not Looney Tunes humans; neither are they human ancestors, but creatures with a long evolutionary history of their own, which has provoked its own adaptive responses, its own repertoire of behaviors. Chimps are many things, but they are not One of Us.

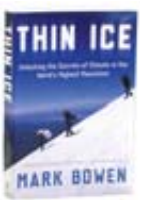
The essential difference between humans and chimpanzees is that we form nuclear families, whereas chimps, so human in many ways, have no such institution. Although we stray from the path more often than we care to admit, human society is all about the age-old business of boy meets girl and sets up home under a roof, so much so that it explains such things as the size of our testicles, the manifest oddities of the female reproductive system, and why we prefer to have sex in private. At root, we define ourselves with reference to our families and closest kin and work outward from there. But we can learn a great deal more of our own humanity by comparing ourselves with something closely related but still Other. And this, in the final analysis, is the lesson of both books. Tribal allegiance means nothing unless there are other tribes out there against which we can get our measure. SA

Henry Gee, who lives in London, is a senior editor of Nature *and former Regents' Professor at the University of California, Los Angeles. He is author of* The Science of Middle-earth *(Cold Spring Press, 2004) and* Jacob's Ladder: The History of the Human Genome *(W. W. Norton, 2004).*

THE EDITORS **RECOMMEND**

THIN ICE: UNLOCKING THE SECRETS OF CLIMATE IN THE WORLD'S HIGHEST MOUNTAINS

by Mark Bowen. Henry Holt, 2005 ($30)



The idea of drilling ice in the tropics as a means of studying changes in climate over thousands of years seems implausible. That work is usu-

REVIEWS

ally done in polar ice. But Lonnie Thompson, professor of geological sciences at Ohio State University, has taken ice cores from glaciers on many high mountains in the tropics and found that they add fruitfully to the history of climate change. His reasoning was that climate arises from flows of energy from the sun and that most of that energy enters the atmosphere through the tropics.

Bowen, a science writer and mountain climber with a doctorate in physics, accompanied Thompson on several expeditions. In a smoothly flowing narrative, he describes drilling ice at high altitudes and explains the science that points to a steady rise in global temperature as a result of human activities. That science prompted the Intergovernmental Panel on Climate Change to declare in 2001 that there "is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities."

"A change of nine or ten degrees would almost certainly cause widespread catastrophe," Bowen writes in summarizing the panel's predictions. "Available freshwater would plummet, taking crop yields along with it.... Increased flooding would pose a deadly risk to tens of millions of residents of low-lying areas." But, Bowen says, doing anything effective to curb the trend will be difficult: "The economic interests who fear any sensible discussion of global warming have succeeded in politicizing this branch of science more perhaps than any other."

A BRIEFER HISTORY OF TIME

by Stephen Hawking, with Leonard Mlodinow. Bantam Dell, 2005 ($25)

Hawking's *A Brief History of Time,* published in 1988, was a surprise best-seller but a tough read for most people who tackled it. Hawking received many requests for a version that would make his discussion of deep questions about the universe more accessible. This book does that. Hawking and Mlodinow, a physicist turned science writer, proceed by small and careful steps from the early history of astronomy to today's efforts to construct a grand unified theory of the universe.

The Trials of Life

BECAUSE ETERNAL VIGILANCE IS THE PRICE OF LIBERTY, WE HAVE TO TALK ABOUT INTELLIGENT DESIGN AGAIN. SORRY **BY STEVE MIRSKY**

Let's review. First there was the oxymoronic, and just plain moronic, creation science, which says that biblical creation, not evolution, accounts for all life on earth. Creation science begat the more subtle intelligent design (ID), which holds that life is too complex to have evolved naturally—an intelligent designer (identity a secret, but it rhymes with Todd) must have done it, producing wonders of nature like the flagellum, that whippy tail some bacteria have, and both Angelina Jolie *and* Jennifer Aniston.

On September 13, the *New York Times* ran an article that discussed how the documentary *March of the Penguins* was a big hit among some groups because of the lessons it imparted. A reviewer in *World Magazine* thought that the fact that any fragile penguin egg survived the Antarctic climate made a "strong case for intelligent design." Conservative commentator Michael Medved thought the movie "passionately affirms traditional norms like monogamy, sacrifice and child rearing."

Coincidentally, I had seen the movie just a few days before. On a blisteringly hot day in south Florida, I intelligently designed my afternoon to be in an air-conditioned theater watching penguins. So perhaps I can be of some help.

Penguins are not people, despite their natty appearance and upright ambulation. Their traditional norms include waddling around naked and regurgitating the kids' lunch. But it would be as absurd to castigate them for those activities as it is to congratulate them for their monogamy. Besides, the movie clearly notes that the penguins are *seasonally* monogamous—like other movie stars usually reviled by moralists, the penguins take a different mate each year. And there are problems with them as evidence of intelligent design. While caring for the egg, the penguins balance it on their feet against their warm bodies; if the egg slips to the ground for even a few seconds, it

freezes and cracks open. A truly intelligent design might have included internal development, or thicker eggshells, or Miami. Finally, penguin parents take turns walking 70 miles to the sea for takeout meals. The *birds* have to *walk*.

From tribulations to trials. On September 26, I sat in a federal courtroom in Harrisburg, Pa., where a lawyer said for almost certainly the first time ever, "Can we have the bacterial flagellum, please?" This groundbreaking moment in legal history came on day one of the trial that will determine if the Dover, Pa., school board violated the First Amendment by introducing religion in a public school when it required the inclusion of an antievolution, pro-ID advisory in ninth-grade biology classes.

Dubbed "Scopes II" by some, the case is really "Scopes III." The 1987 U.S. Supreme Court case *Edwards v. Aguillard,* which barred creation science from public school science classrooms, was often dubbed "Scopes II." And you can't have two Scopes II's, at least not until the forces of irrationality begin futzing with the math curriculum, too.

Members of the Dover school board who want ID taught are free to consult the opening paragraph for an explanation of ID. The curriculum chair, ID proponent William Buckingham, could have used some crib notes when he was asked in a deposition last January, "Do you have an understanding in very simple terms of what 'intelligent design' stands for? What does it teach?" Buckingham responded, "Other than what I expressed, that's—scientists, a lot of scientists—don't ask me the names. I can't tell you where it came from. A lot of scientists believe that back through time, something, molecules, amoeba, whatever, evolved into the complexities of life we have now."

Is our children learning?

Anyway, the trial was only about half over when this issue of *Scientific American* went to press, so we'll have to revisit it at a later date. Hey, nobody said eternal vigilance was going to be easy. SA

ILLUSTRATION BY MATT COLLINS; PHOTOGRAPH BY FRANK VERONSKY

ASK THE EXPERTS

How and why do fireflies light up?

—G. Rice, Washington, D.C.

Marc A. Branham, assistant professor in the department of entomology and nematology at the University of Florida, explains:

A chemical reaction inside fireflies enables them to light up, a process called bioluminescence. A glow is emitted when oxygen in cells combines with calcium, the energy storage molecule adenosine triphosphate (ATP), and luciferin pigments in the presence of the enzyme luciferase. Unlike a lamp, which creates a good deal of heat, a firefly generates "cold light." If its light-producing organ got as hot as a lightbulb, the insect would not survive the experience.

The light organ controls the start and stop of light emission by adding oxygen to the other chemicals needed to produce light. When oxygen is available, the light organ emits light; when it is not, the region goes dark. Insects, which do not have lungs, transport oxygen from outside the body to the interior cells through a complex series of successively smaller tubes known as tracheoles. The muscles that control oxygen flow out of the tracheoles work relatively slowly, so how fireflies flash so fast has been a mystery.

Recently, however, researchers found that nitric oxide plays a critical role. Typically mitochondria inside cells hold on to any available oxygen, which the organelles use to generate energy for the cell. To induce the mitochondria to release some oxygen, a firefly's brain signals the production of nitric oxide, which takes the place of oxygen in the mitochondria. Oxygen that moves into the light organ is then free to be used in the chemical reaction that emits light. But because the nitric oxide breaks down quickly, oxygen is soon bound up again in the mitochondria, and light production ends.

Fireflies shine for a variety of reasons. They produce defensive steroids in their bodies, making them unpalatable to predators, and their light bursts are used as a warning display of that distastefulness. As adults, many fireflies blink in patterns unique to their species, enabling discrimination among members of the opposite sex. Several studies have shown that females choose mates depending on specific male flash-pattern characteristics. Faster flash rates, as well as greater intensity, have been shown to be more attractive to females in two different firefly species. SA

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

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