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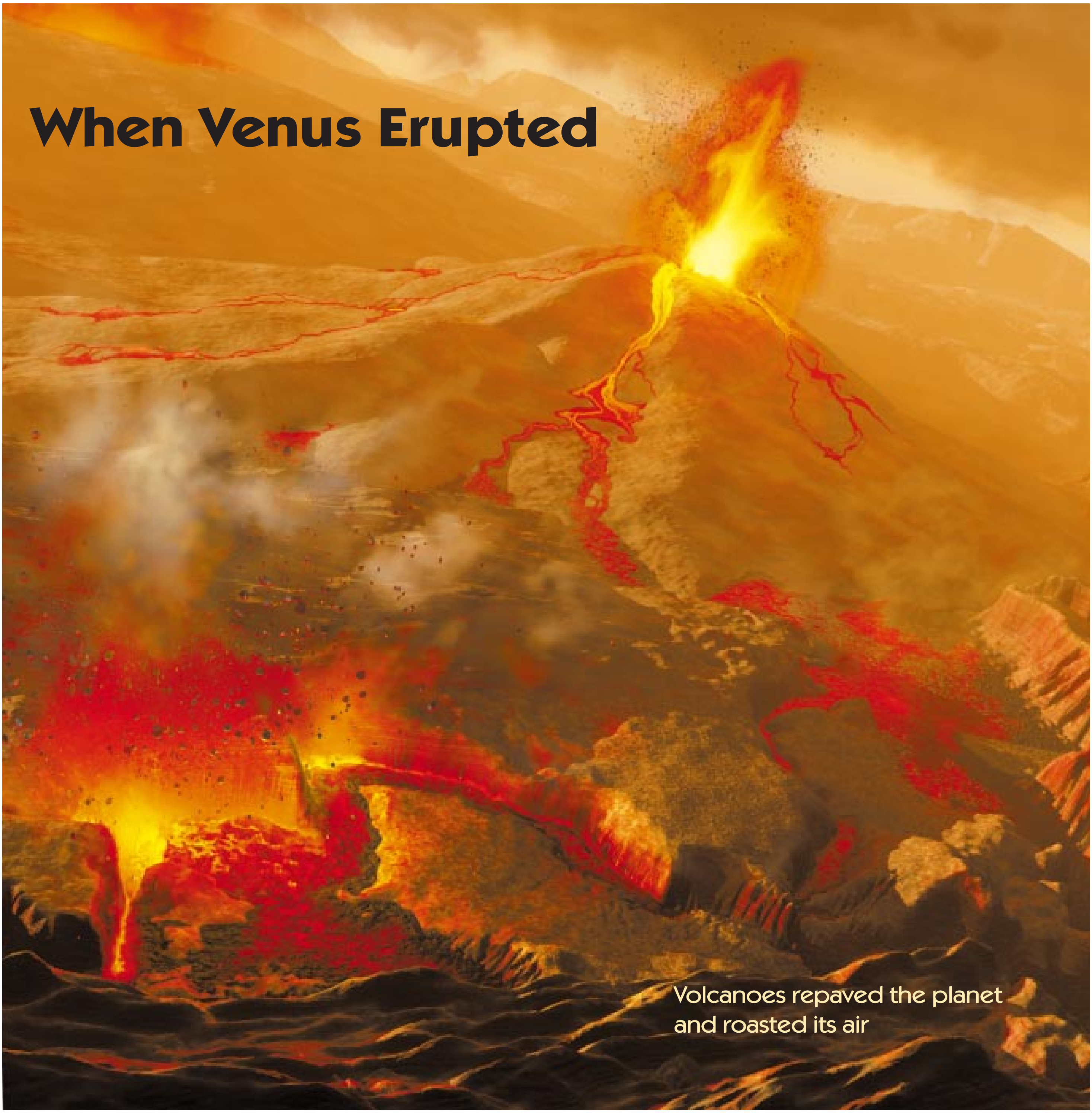
# When Venus Erupted



Volcanoes repaved the planet and roasted its air

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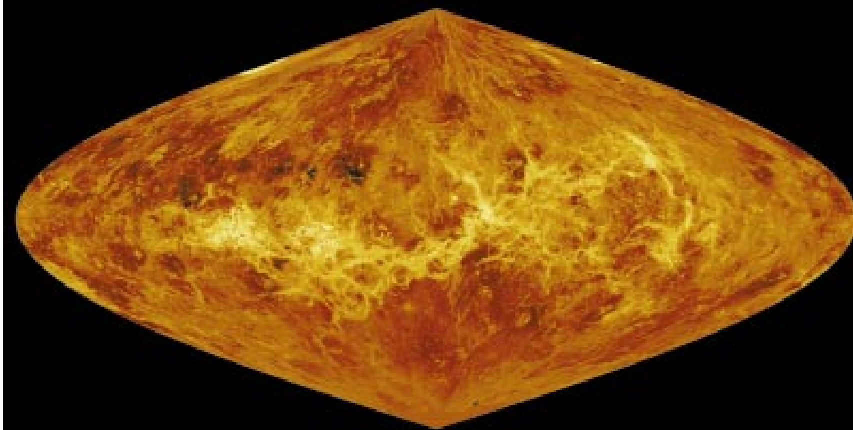
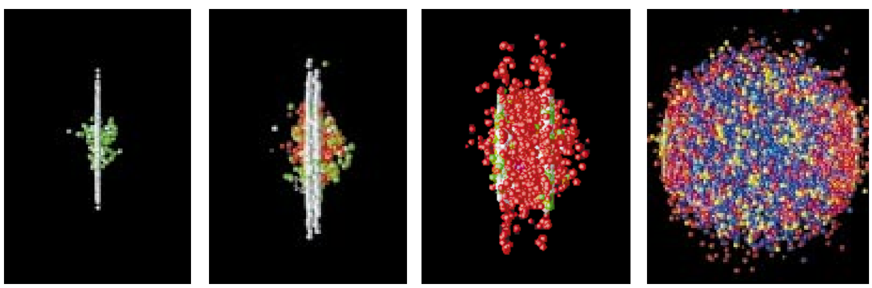
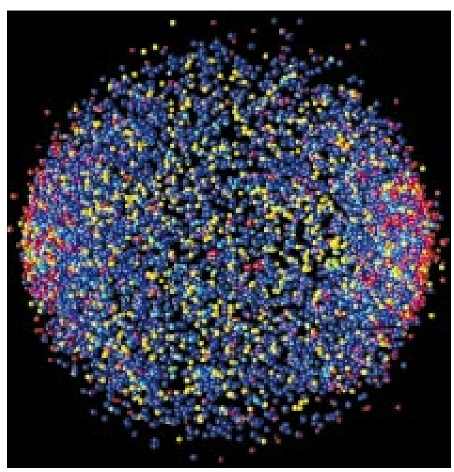


Venus was not always a red-hot cauldron holding a cloudy soup of pressurized carbon dioxide and sulfuric acid. Roughly 800 million years ago volcanoes repaved the planet's surface with lava and released gases that ultimately triggered a powerful greenhouse effect. Researchers have reconstructed how geologic catastrophes doomed Venus's climate.





By smashing together nuclei traveling at close to the speed of light, physicists at Brookhaven National Laboratory hope to create matter as dense and hot as existed in the early universe.



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## FROM THE EDITORS

# The Elite Inventions

The editor and literary agent John Brockman recently challenged the salon of scientists that he hosts on his EDGE Web site by asking, "What is the most important invention in the past two thousand years?" Luckily, my job buys me admission to that on-line gathering and the chance to kibitz with the professionals.

Nobody starts a debate over the most important *anything* in the hope of settling it—the point is to ignite the argument, then sit back and enjoy the conversation. Not content to be merely right (what fun would that be?), Brockman's invitees vied for originality, provocativeness and intellectual panache. Of course, many couldn't resist bending the rules to interpret the question as they wished. Some drifted outside the 2,000-year limit. A few nominated more than one invention. And so on. (Most of these thinkers didn't get where they are by following the rules.)

What were the results? Gutenberg's printing press won the most endorsements and passing nods. But neuroscientist Colin Blakemore and others argued for the birth-control pill. Biologist Richard Dawkins nominated the spectroscope. Physicist Freeman Dyson made a case for hay. John Maddox, the former editor of *Nature,* favored the calculus. Technologist W. Daniel Hillis suggested the clock. Psychologists Howard Gardner and Nicholas Humphrey respectively liked Western classical music and reading glasses. Computers, the atomic bomb, electricity, the telescope, the mirror, airplanes, anesthesia, waterworks, paper, space travel and the Internet all had their champions. And as many of the contributors wrote, ideas are inventions, too: the scientific method, democracy, the number zero, the concept of the unconscious mind, evolution by natural selection . . .

*Which mattered most? The computer? The printing press? The pill? Reading glasses?*

My own choice—oh, let's face it, the correct choice—was Volta's electric battery. But if you want to know my reasoning, or to read the musings of better minds, visit www.edge.org and browse the complete list of entries. You might change your opinion of the most important invention while reading it; I did, several times.

For inventors, the National Medal of Technology is this country's highest honor. Our coverage of the most recently named winners, beginning on page 46 and also on www.sciam.com, shows how deserving they are. Achievements in computer science, genetic engineering for medicine and agriculture, cardiology, and pharmacological development have all been recognized. The computer, you will notice, was suggested as the most important invention of the past two millennia. Given another few years, who's to say that recombinant DNA, artificial hearts and rational drug design wouldn't be, too?

JOHN RENNIE, *Editor in Chief*
editors@sciam.com

"Evolution and the Origins of Disease," by Randolph M. Nesse and George C. Williams [November 1998], prompted mail from several readers who questioned whether evolutionary medicine is truly a science or just intelligent speculation. For instance, Christian Erickson, a medical student at Duke University, wrote that "analysis can provide evidence that coughing reduces pulmonary infection rates but cannot validate the further claim that coughing, by virtue of functional value, conferred a selective advantage in the past. For all we know, coughing may have been a spurious by-product of evolutionary whim." Additional comments about the article follow.

## EVOLUTIONARY MEDICINE

"Evolution and the Origins of Disease," by Randolph M. Nesse and George C. Williams [November 1998], described "bold guppies" that weren't afraid of facing their bass predators and who were eaten as a result of this trait of low anxiety. Is it not possible that the guppies were instead lacking in the trait of "smarts" and just didn't realize the threat confronting them?

*DOUG BERGER*
Department of Psychiatry
Albert Einstein College of Medicine

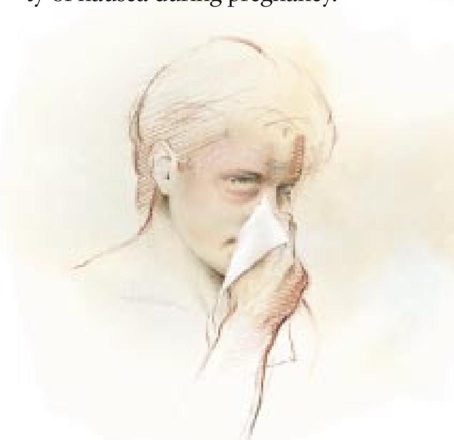
Nesse and Williams provide novel insights into evolutionary biology and make cogent arguments for its recognition as a basic medical science. Their comment regarding investigations into possible teratogenic effects of antinausea drugs deserves clarification, however. The authors assert that no consideration has been given to the possibility that an inherently nonteratogenic antinausea drug could still be associated with birth defects by suppressing morning sickness and thus permitting ingestion of harmful foods. In fact, much of the research on the most widely used morning-sickness medication, Bendectin, was epidemiological and therefore could detect such an association. This research consistently showed no convincing link between Bendectin use and an increase in birth defects. Nevertheless, the product remained a target of litigation until it was voluntarily withdrawn from the U.S. market by its manufacturer in 1983. In this case, scientifically sound research was insufficient to exonerate a useful medication.

*RANDALL K. ABSHER*
Wesley Long Community Hospital
Greensboro, N.C.

***Nesse and Williams reply:***

A major goal of Darwinian medicine is to call attention to the subtle problems involved in deciding whether a trait is an adaptation, a trade-off, a defect or something else. Could a coordinated, complex and obviously useful mechanism like cough be "a spurious by-product of evolutionary whim?" No way. That a future doctor thinks it might be only confirms the desperate need for evolutionary biology in medical curricula.

As for Berger's question about whether bold guppies might just lack "smarts": no, it is a trade-off. On average, bold guppies die young but have more offspring per month, because females (for their own interesting reasons) prefer bold mates. Finally, could nausea in pregnancy be a mere mistake? Yes, and we thank Absher for pointing out that epidemiological research on Bendectin supports this hypothesis, at least in modern environments. Our point about Bendectin was that, despite a long controversy about its potential dangers, litigants seem not to have considered any possible utility of nausea during pregnancy.



***BODY'S DEFENSES*** *include the common symptoms of fever, cough and sneezing.*

CRAIG KIEFER

## FLIGHT OF FANCY

Albert E. Moyer's October 1998 article "Simon Newcomb: Astronomer with an Attitude" must have left many readers asking, "Where are you, Simon Newcomb, now that we need you!" But as I pointed out in *Profiles of the Future* (1962), he once made a complete fool of himself in an essay that concluded: "The demonstration that no possible combination of known substances, known forms of machinery and known forms of force, can be united in a practical machine which men shall fly long distances through the air, seems to the writer as complete as it is possible for the demonstration of any physical fact to be." When news of the Wright brothers reached the astronomer, he was only momentarily taken aback. Flying machines *might* be a marginal possibility, he conceded—but they were certainly of no practical importance, for they could never carry the extra weight of a passenger as well as that of a pilot.

*SIR ARTHUR C. CLARKE*
Sri Lanka

## SEAWORTHY SOFTWARE

In "Rough Sailing for Smart Ships," by Alden M. Hayashi [News and Analysis, November 1998], the partial quote attributed to me and incomplete detail on the performance of Smart Ship technology could create further misunderstanding and misevaluation of a complex and highly successful U.S. Navy program. The underlying cause of the brief September 1997 system failure (the only one in almost two years of operation) was not the result of any system software or design deficiency but rather a decision to allow the ship to manipulate the software to stimulate machinery casualties for training purposes and the "tuning" of propulsion machinery operating parameters. In the usual shipboard installation, this capability is not allowed.

CAE Electronics was on record with the navy in January 1997 expressing serious concern for system integrity and reliability while this unorthodox and risky access to the core software was allowed. The Smart Ship program is a success story by any measure, and the navy deserves

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accolades for its vision and achievements realized with this program.

*HARVEY McKELVEY*
Clifton, Va.

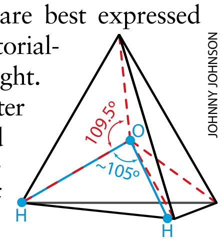
## A FRESH ANGLE

Regarding "Simulating Water and the Molecules of Life," by Mark Gerstein and Michael Levitt [November 1998]: the authors write that "the angle formed between the two sides of the V [of a tetrahedron] is close to 105 degrees—slightly less than the 109.5-degree angle formed between any two sides of a perfect tetrahedron." Any two triangular, planar sides of a perfect tetrahedron meet to form an angle of just over 70 degrees. The V formed by two radii connecting the geometric center of a regular tetrahedron with two of its vertices has an angle of 109.5 degrees. These radii represent the bonds formed between an oxygen nucleus and hydrogen nuclei in a water molecule; these bonds do form an angle of 105 degrees, as mentioned previously.

*JOHN W. JOHNSON*
Santa Barbara, Calif.

***Gerstein and Levitt reply:***

Johnson is correct that the way we described the geometry of a water molecule was somewhat imprecise. The exact details of this geometry and its relation to the tetrahedron are best expressed not in words but pictorially, as shown at the right. The bonds in the water molecule correspond to the radii rather than to the sides of the tetrahedron.



JOHNNY JOHNSON

*Letters to the editors should be sent by e-mail to editors@sciam.com or by post to Scientific American, 415 Madison Ave., New York, NY 10017. Letters may be edited for length and clarity.*

ERRATUM

In the Further Reading for "Evolution and the Origins of Disease" [November 1998], the publisher of *Darwinian Psychiatry*, by M. T. McGuire and A. Troisi, was misidentified. The correct publisher is Oxford University Press. We regret the error.

# 50, 100 AND 150 YEARS AGO

SCIENTIFIC AMERICAN

### MARCH 1949

**EINSTEIN'S INFLUENCE**— "Albert Einstein, whose 70th birthday this month is being noted throughout the civilized world, occupies a position unique among scientists. It is relativity, of course, that has made Einstein's name a household word. Our portrait of Einstein was made in the year of his greatest productivity, 1905. While he worked as a clerk in the Swiss patent office, he made his great contribution to the quantum theory and set forth the special theory of relativity."

**STRESS RESPONSE**— "Experiments on the 'general adaptation syndrome' have led Dr. Hans Selye, of the University of Montreal, to formulate the following current hypothesis: Long-lasting stress provokes an excessive production of adrenal-stimulating hormone in the anterior pituitary; this forces the adrenal cortex to an intensive discharge of the desoxycorticosterone-like hormones, which, among other things, affect the kidney in such a way as to release hypertensive substances. Should further research prove that chronic stress can produce the same disorders in man as in animals, it would appear that the most frequent and fatal diseases of today are due to the 'wear and tear' of modern life."

### MARCH 1899

**ASTRONOMY AND POLITICS**— "The great observatories of the world are near large cities or universities—places selected from local or political motives—where atmospheric conditions make them unfit for the most delicate astronomical research. It was a bold step to deviate from this precedent, but this step was taken, and taken by a woman, Miss Catherine Bruce, of New York, who gave $50,000 to the Harvard College Observatory. The Bruce photographic telescope, of 24 inches aperture, is mounted in Arequipa, Peru, in a climate unsurpassed for astronomical work. By its aid, new stars have been found in the Large Magellanic Cloud, showing an additional connection of this object with the Milky Way."

**LIFE SUPPORT**— "M. Georges Jaubert has been experimenting on the supply of air for the use of a man in a hermetically inclosed space like a diving bell. He proposed that 79 per cent of nitrogen contained in respirable air remains intact after 21 per cent of the oxygen has been consumed, and the same nitrogen mixed with another fresh supply of oxygen becomes respirable air when the carbon dioxide and the water vapor produced by breathing are removed. He found that his hypothesis was correct; he has also discovered a chemical substance which by contact with the atmosphere clears the vitiated air of all the impure gases produced by respiration."

**FRIENDS, ROMANS**— "In new excavations of the Roman Forum, one discovery of unsurpassed interest is the base of the column set up where Caesar's body was burned. Suetonius tells of a column of Numidian marble dedicated *parenti patriae* on this place. An altar also was placed there but was destroyed because the worship of Caesar was illegal. Afterward, Augustus built there the Temple of Julius. Before the podium of the temple is a semicircular recess; there, on a pavement of well cut travertine blocks, are the remains of a base such as one would expect the column to have had. Here is the very spot where once his body rested. Here Antony aroused the deeper emotions of the plebs, and here from the phoenix ashes of a dead republic rose the young empire."

### MARCH 1849

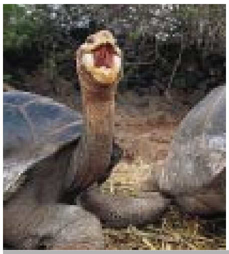
**INVENTION OF THE AIR RAID**— "The Presse, of Vienna, Austria, has the following: 'Venice is to be bombarded by balloons, as the lagunes prevent the approaching of artillery. Five balloons, each twenty-three feet in diameter, are in construction at Treviso. In a favorable wind the balloons will be launched and directed as near to Venice as possible, and on their being brought to vertical positions over the town, they will be fired by electro magnetism by means of a long isolated copper wire with a large galvanic battery placed on the shore. The bomb falls perpendicularly, and explodes on reaching the ground." [*Editors' note: This experimental idea became the first use of aerial bombing, and its effect, though minor, contributed to the collapse of the Venetian revolt.*]

**LUXURY**— "Lyons is the center of the great silk manufacturing region of France. Its population of nearly 200,000 swarms through the lofty irregular houses which crowd and darken the narrow, crooked and filthy streets. There are no large buildings like cotton factories—everything is done in private houses. The living is of the poorest kind, and the whole weaving population is wretchedly depraved. For a few sous a day, weary and hungry, and sick, these wretched beings toil on for the decoration of those who can scarcely believe that there is such a thing as misery in the world."

*Albert Einstein in 1905*

# NEWS AND ANALYSIS

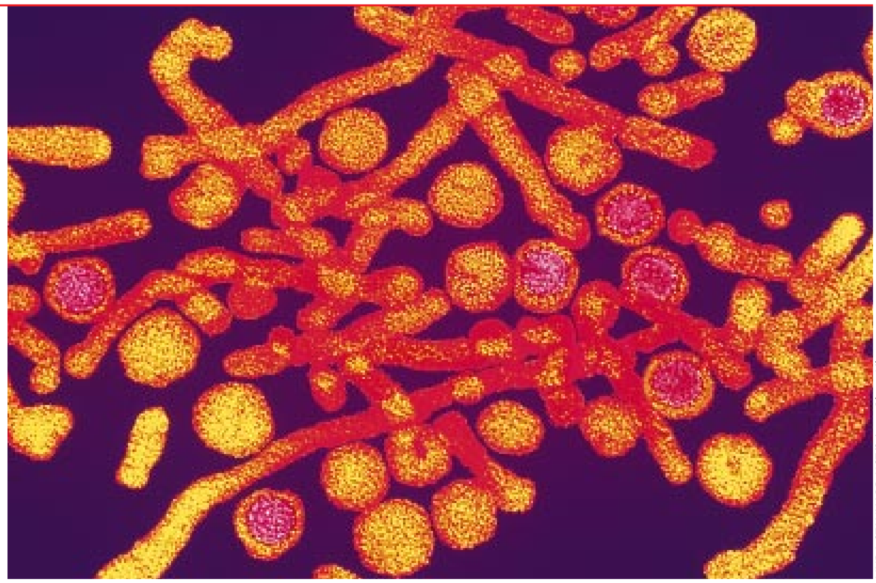




## IN FOCUS

### $R_X$ FOR B AND C

*Promising new drugs bring reinforcements to the battle against hepatitis epidemics*



LINDA STANNARD UCT/Science Photo Library

***HEPATITIS B VIRUS CANNOT BE ELIMINATED** once it infects the liver. But new drugs can force it into hiding, at least for a while.*

Last year the outlook for humanity's struggle with hepatitis seemed grim. In March, U.S. Surgeon General David Satcher went before Congress to warn that hepatitis C posed "a grave threat to our society." By summer, magazine covers and newspaper headlines were decrying the "silent killer" as an insidious epidemic. The one treatment approved in the U.S. for chronic hepatitis B and C—alpha-interferon—cost $700 a month, caused sometimes intolerable side effects and beat back the virus in only 30 to 40 percent of sufferers. Meanwhile researchers were quietly fretting about a new hepatitis virus, called G, which appeared to be nearly as widespread as its cousin C, coursing through the blood of some four million people in the U.S. alone.

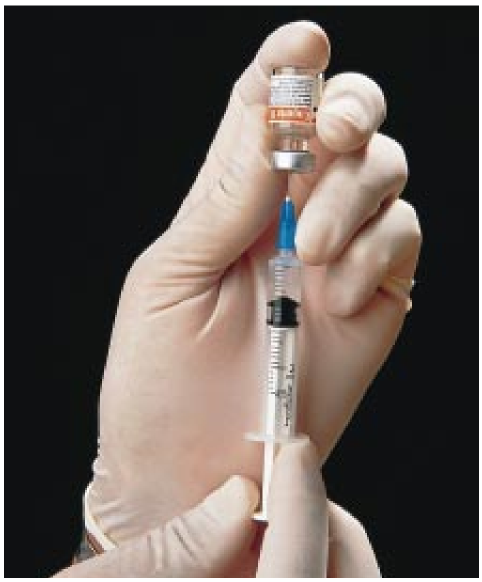
But now there are good reasons to think that science is gaining the upper hand, that millions of those already chronically infected with a hepatitis virus will be able to avoid the typical course of the disease: decades of slow liver damage often culminating in organ failure or cancer. Last December the U.S. Food and Drug Administration cleared two new hepatitis drugs for market. Several other compounds are moving briskly through clinical trials. Childhood immunization is sweeping the feet out from under hepatitis B. Biologists have mapped a key vulnerability in the C virus and have started making drugs to attack it. And closer observations of people carrying the G virus have shown that it seems to do little if any damage to its hosts.

In truth, much of the media frenzy that followed Satcher's call to arms last spring probably exaggerated, or at least misplaced, the severity of the problem. According to the Centers for Disease Control and Prevention, the incidence of acute hepatitis B has fallen about 70 percent in the U.S. since its peak in 1985. The C virus is now spreading at less than one fifth the rate of a decade ago. Although chronic hepatitis C carriers outnumber those with hepatitis B by at least three to one in America, the CDC estimates that B still imposes the greater economic cost. Globally, the B virus is by far the most common cause of liver disease, infecting about 350 million people and killing more than a million a year. Because it spreads readily via sexual contact, unlike the C virus, half the world's population faces better than a 60 percent chance of contracting hepatitis B at some point in their lives.

Those odds should improve now that more than 80 countries have begun inoculating children against the disease. Saudi Arabia's immunization program, for example, cut the hepatitis B infection rate among young children from 7 to 0.5 percent in just eight years. But the vaccine is still so expensive that adding it to the shots donated to poor countries would require doubling or tripling the vaccine budgets of donor organizations.

To the millions already infected, a vaccine is of no use. Fortunately, a handful of new medicines, though no cheaper than interferon, do promise to help some of those whom it fails. The first to go on sale is lamivudine, a drug discovered by BioChem Pharma in Laval, Quebec, and also known as 3TC, which has been used for several years in higher doses to treat HIV infection.

In a recent experiment, 16 percent of the subjects who swallowed one tablet a day for a year knocked the hepatitis B in their blood down to undetectable levels. But in reducing one problem, lamivudine creates another: drug-resistant strains of the virus that flourish in up to a third of the patients within months. "I'm worried that doctors are going to start using lamivudine too freely, and then we're going to have a mess on our hands," says Jay Hoofnagle, head of digestive diseases and nutrition research at the National Institutes of Health. "I recommend it only to my patients who have severe hepatitis."


SATURN STILLS SPL Photo Researchers, Inc.

***DESPITE AN EFFECTIVE VACCINE,** hepatitis B virus claims more than a million lives every year.*

E. Jenny Heathcote, a professor of medicine at the University of Toronto, goes further. "I'm not convinced that any patient with viral hepatitis should be treated with a single agent," she says. "It's like many years ago when we were trying to treat HIV with just AZT. In retrospect we realized that we should have been using cocktails [of several agents], because the virus becomes resistant so quickly to just one drug."

She and other liver specialists hope that two other drugs, lobucavir and adefovir, will make it to market within the next few years. Bristol-Myers Squibb launched large-scale human tests of lobucavir in November. And Gilead Sciences in Foster City, Calif., began enrolling 500 patients this past January for a pivotal trial of adefovir. In smaller tests completed in November, just 12 weeks on adefovir pills depleted levels of the B virus in two thirds of patients by 99.99 percent—"from several billion copies to just a few hundred," Heathcote reports.

Equally important, observes Alison Murray, Gilead's director of clinical research, is that adefovir is effective against the lamivudine-resistant virus strains. That is a pleasant surprise, because all three antivirals work in roughly the same way. "The drug molecules resemble building blocks of DNA and RNA, except that they are missing a crucial side chain," Murray explains. As the drug seeps into all the cells of the liver, viruses pick it up and try to use it to construct copies of themselves. Without the critical link, however, the virus cannot attach other blocks onto the drug, and the viral assembly line shuts down.

If lobucavir and adefovir pass their final tests, medicine may at last turn the tables on hepatitis B. But researchers entertain little hope of finding a final cure. "The hepatitis B virus, like HIV, is made of DNA, so it is very stable once it gets into cells," Hoofnagle says. "The only way to get it out is to kill the infected cells—which would mean killing the liver," Murray adds. "So the best we can hope for is to control the disease and help the immune system suppress the virus."

A third experimental drug may be handy for that purpose. In recent tests in Asia, alpha-thymosin, made by SciClone Pharmaceuticals in San Mateo, Calif., appeared to give a general boost to T cells, immune fighters that attack infected liver cells. Six months of twice-weekly injections reduced the virus to undetectable levels in 40 percent of the Taiwanese subjects who received it, an effect that lasted at least 18 months. If large-scale trials in Asia go well this year, thymosin might provide an additional ingredient for a potent cocktail against hepatitis B.

Because hepatitis C is based on RNA, which is unstable, it should in theory be easier to cure. Spurred by the public anxiety about the disease, "almost every pharmaceutical company on the planet is looking for a new treatment for hepatitis C," Murray says. But the search is hampered by the fact that the C virus refuses to thrive in lab animals and human cell cultures. There is simply no fast way to tell whether a potential drug will work safely.

As a result, most of the advances against hepatitis C have been incremental improvements on interferon. In December the FDA granted Schering Plough permission to give its drug ribavirin, along with interferon, to anyone with hepatitis C. The two together seem to clear the virus from about 40 percent of patients, versus the 20 to 30 percent helped by interferon alone.

Roche Pharmaceuticals is reportedly testing interferon doped with polyethylene glycol. "At a conference recently, they claimed this raised the response rate to more than 60 percent," Hoofnagle remarks. The additional ingredient also allows patients to reduce weekly injections from three to one, he says, which may ease the flulike side effects considerably.

With little hope of a vaccine—because people do not produce lasting immunity to hepatitis C even if they fight off the initial infection—Hoofnagle wagers that the best way forward will be drugs that attack the C virus more directly. Some, such as VX-497 from Vertex Pharmaceuticals in Cambridge, Mass., will try to deny the virus access to the human enzymes it needs to reproduce. Vertex began human tests on VX-497 last September and expects to have results in by summer.

Other drugmakers have been studying the molecular map of the C virus finally produced in 1996 in the hope of finding chemicals that will fit into its crevices, paralyzing it. Schering, for one, is aiming to start early human trials of such agents this year or next. It is a safe bet that its competitors are not far behind. *—W. Wayt Gibbs in San Francisco*

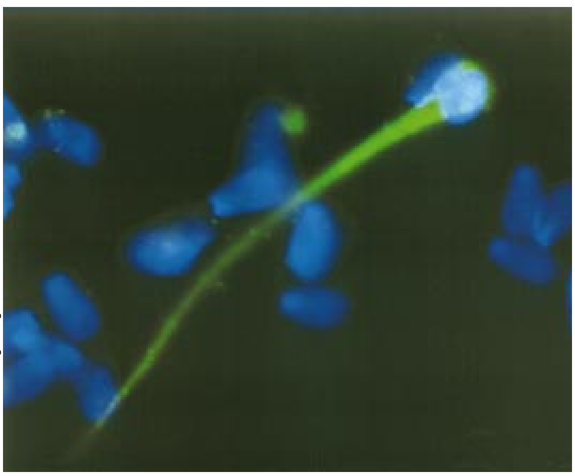
# SCIENCE AND THE CITIZEN

MOLECULAR BIOLOGY

## DEATH TO SPERM MITOCHONDRIA

*A ubiquitin clue to why mitochondrial DNA comes only from Mom*

So you got your crooked schnozz from your mother and your mud-brown eyes from Dad. That's the luck of the draw. But if you're a mammal, you got all your mitochondria from Mom. These little organelles—which provide the energy for your metabolic needs—derive from the maternal side, so they have proved indispensable in tracing human lineages. Sperm, like oocytes, also have mitochondria, but the organelles vanish from the embryo shortly after fertilization. Of course, just how they are made to disappear has always been a mystery.



PETER SUTOVSKY *Oregon Regional Primate Research Center*

***TARGETED FOR DESTRUCTION** is a defective bull sperm. Ubiquitin (green) coats the tail, where mitochondria live.*

Now researchers led by Peter Sutovsky and Gerald Schatten of the Oregon Regional Primate Research Center in Beaverton, Ore., think they have figured out the signal that dooms paternal mitochondria to destruction. Their findings—presented at the American Society for Cell Biology meeting last December—suggest that mitochondria in developing sperm become tagged with a protein that is known to route damaged proteins to the cellular trash bin. After fertilization, the egg may recognize the tag and dispose of the foreign organelles.

"This is big," says Jim Cummins, an authority on mitochondria and fertilization at Murdoch University in Australia. "I think they've finally found the main mechanism for the destruction of mitochondria in mammals." The findings may also be relevant to cloning efforts or to the newer assisted-reproduction techniques, he says, because if abnormal or immature sperm are injected into eggs, there is no telling whether the second set of mitochondria will be properly eliminated. And mixed mitochondria might send conflicting growth signals to an embryo, causing it to develop abnormally or to die.

When a sperm penetrates an egg, it brings its mitochondria—packed in a sheath around its tail—with it (contrary to what some current textbooks erroneously say, Cummins notes). But the egg soon destroys the invading organelles—with good reason, Cummins points out. "Sperm mitochondria are pretty badly degraded by the time they get to the egg." Their DNA—which encodes some 13 proteins required for mitochondrial function—accumulates mutations, deletions and "all sorts of garbage," he says. Because a number of diseases are caused by mutations in mitochondrial DNA, Cummins notes, "it makes sense for the egg to start out with the best mitochondria and to get rid of the damaged ones."

What happens to the sperm mitochondria? Scientists previously thought that they might simply be diluted after fertilization, remarks Justin St. John, a reproductive biologist at the University of Birmingham: sperm may possess 50 to 100 mitochondria, compared with the 100,000 present in the egg. As the zygote divides, their numbers are further diminished, St. John explains.

But Sutovsky's findings suggest a means by which the egg may actively destroy the invading mitochondria. He and his colleagues treated bull sperm with an antibody that binds to ubiquitin—a protein used by all cells in the body to flag other proteins for subsequent recycling. Their mitochondria lit up, indicating that ubiquitin was decorating the sperm organelles—both in developing sperm and in early fertilized eggs. None of the oocyte mitochondria, however, were marked. "There's just something about sperm mitochondria that makes them different from oocyte mitochondria—and it could easily be the ubiquitin tag," Sutovsky asserts.

The Oregon researchers are now trying to identify which proteins in or on the mitochondria are marked by ubiquitin. With a target in hand, Sutovsky and his colleagues could devise experiments that would show that their mechanism is not just plausible but operable. Would preventing the ubiquitination of the target proteins, for example, allow mitochondria to escape degradation?

"It's not a trivial experiment to do," says Mark Hochstrasser, who researches ubiquitin at the University of Chicago. "But if it worked, and they could demonstrate that this is the mechanism for destroying mitochondria, it would solve a fundamental mystery of mammalian biology."—*Karen Hopkin in San Francisco*

*KAREN HOPKIN, a freelance science writer based in Silver Spring, Md., wrote about circadian rhythms in the April 1998 issue.*

CONSERVATION

## ON THE ORIGINS OF SUBSPECIES

*DNA analysis to the rescue in figuring out where to repatriate Galápagos Islands tortoises*

During the 1800s, whalers and seal hunters slaughtered the Galápagos giant tortoises for an easy supply of food. Those invaders and colonists also brought with them goats, rats and other animals that have eaten the tortoises' food, trampled their nests and attacked their hatchlings. The result, according to some researchers, is that three subspecies of the venerable reptile are now extinct, and a fourth has dwindled to a single known survivor. To stem this trend, conservationists have raised hundreds of hatchlings

# IN BRIEF

*Planet Parade*

The January meeting of the American Astronomical Society produced news of planets found by means other than orbital perturbations. Alycia Weinberger of the University of California at Los Angeles reported that the Hubble Space Telescope images show a planet circling star HD 141569. Blotting out the star's light revealed a surrounding dust cloud some 13 times the diameter of Neptune's orbit. Part of the disk appears dark; debris has apparently been swept away by an orbiting planet. Similarly, Brad Smith of the University of Hawaii reports that a sharply defined ring circles star HR 4796A, implying the presence of two planets that maintain the ring's structure. In the third planet find, Sun Hong Rhie and David Bennett of the University of Notre Dame and their colleagues have located the smallest one yet, about the size of Neptune. Orbiting 300 million kilometers from its star, the planet was found through microlensing, which measures how the light from a star is gravitationally bent by a fainter star passing in front of it. A planet around the fainter star alters the light intensity in a distinct way.

NASA


*HD 141569 dust ring*

*Neural Stem Cells Found*

In another discovery that is changing the fundamental understanding of neurons, Jonas Frisen of the Karolinska Institute in Stockholm has located the stem cells of rat brains. Stem cells differentiate into other cells of the body; scientists did not know where neural stem cells lurked, however. Reporting in the January 8 issue of *Cell,* Frisen's team found that the rodent ependymal cells, which line the cavities of the brain's ventricles and the spinal cord, actually slowly divide, creating stem cells that can rapidly form into either neurons or support structures called glial cells. Humans are likely to have neural stem cells in a similar location. The identification of such cells could form the basis for treatment of spinal cord injuries or neural disorders such as Parkinson's.

*More "In Brief" on page 26*

JEFF GREENBERG *Peter Arnold, Inc.*

***GALÁPAGOS GIANT TORTOISES,*** *some confiscated from poachers, are held in captivity pending DNA analysis to determine their home islands.*

until the young tortoises were large enough to be introduced to the wild with minimal danger from predators. In a similar vein, authorities want to set free dozens of adult tortoises of unknown origins—many of them confiscated from poachers—but scientists have been unsure on which island to place each animal. Now DNA analysis could provide the answers.

The tortoises are currently being held at the Charles Darwin Research Station on Santa Cruz Island in the Galápagos archipelago. Conservationists there have been reluctant to release the animals back into the wild without knowing for sure where they came from because the islands have, according to some experts, evolved genetically distinct subspecies. The problem is that many of those subspecies are difficult to distinguish visually, and mixing them could lead to "unnatural" hybrids. "The challenge is to conserve biological diversity as it exists in the wild and not to create forms that would not have any counterparts in the natural world," asserts Oliver A. Ryder of the Center for Reproduction of Endangered Species at the Zoological Society of San Diego. Consequently, warns James P. Gibbs, a conservation biologist at the State University of New York College of Environmental Science and Forestry in Syracuse, "You really don't want to be tossing tortoises just anywhere."

So Gibbs, along with a team headed by geneticist Jeffrey R. Powell of Yale University, has taken blood samples from hundreds of wild tortoises on the different islands. By analyzing the DNA of the samples, the researchers report they so far have found unique markers for all but four of the reputed 11 extant subspecies. (The taxonomy of Galápagos tortoises has been controversial; one debate questions the validity of at least several of the subspecies.) Using these signature sequences, the scientists plan to identify the home islands of many of the tortoises held in captivity.

The animals, however, may not be returning to their native habitats anytime soon because conservationists warn against a hasty repatriation. "For one thing, some of the females could be pregnant by males of other subspecies. And remember that female tortoises can retain fertilized ova that would not develop into full eggs for quite a long time, perhaps several years," notes Peter C. H. Pritchard of the Florida Audubon Society in Winter Park, Fla.

Another potential problem is that the captivity of the tortoises, especially with a mixture of subspecies, may have altered the natural behavior and instincts of the animals, which could prove disruptive if they are returned to the wild. Pritchard cautions that one possible result is that a tortoise might no longer be able to follow an important migratory path on its home island. Such considerations, conservationists warn, make repatriation a tricky issue. "We can provide information on a particular tortoise's origin," Powell notes, "but there are a lot of questions about what to do with that information." —*Alden M. Hayashi*

*In Brief,* continued from page 24

### *No Rest for the Thymus*

Overturning conventional wisdom, a collaboration supported by the National Institute of Allergy and Infectious Diseases has found that the thymus remains active into old age, albeit at a reduced level. The gland, located in the chest, produces the immune system's T cells and was thought to function only through childhood. The researchers drew their conclusions in the December 17, 1998, *Nature* after measuring T cell DNA fragments that correlate with thymic output. Moreover, they found antiviral therapy to treat HIV infection—the virus adversely affects the thymus—restored some function to the gland.

### *Fat-Fighting Fidgeting*

It seemed like the ultimate pig-out: 16 volunteers each day consumed an extra 1,000 calories (equal to two Big Macs) for two months. It was, though, all in the name of science. James Levine and his Mayo Clinic colleagues were investigating why some people put on weight seemingly at the sight of food, whereas others can gorge themselves and stay svelte. The volunteers, who were limited to little exercise, gained an average of 10 pounds, but the range varied from two to 16. The investigators report in *Science* that fidgeting was the key. On average, fidgeting expended one third of the extra calories, but for those who gained the least weight, it burned 69 percent of the calories.

HULTON GETTY *Liaison Agency*

*Start fidgeting*

### *Immortality without Cancer*

Two papers in the January *Nature Genetics* provide good news for researchers seeking to immortalize cells: genetically introducing the enzyme telomerase does not make cells malignant. Telomerase, absent from most normal cells, keeps chromosomal tips (telomeres) from shortening, a process that limits a cell's life span. In contrast, 90 percent of cancer cells contain telomerase, relying on it to divide indefinitely. One report found that human cells modified to express telomerase divided more than 220 times without signs of malignancy (normal cells divide about 75 times). An accompanying paper reported similar finds with transformed cells; moreover, the cells did not cause any tumors after implantation into mice.

*More "In Brief" on page 28*

ANTI GRAVITY

## Feathers, Flight and Faith

The whole town has just pitched in to save Jimmy Stewart's hide at the end of *It's a Wonderful Life,* and I'm watching and thinking, *not good enough.* Yeah, they may have covered the eight large that Uncle Billy lost, but what about fines and penalties?

I'm definitely in a funk. The Yankees aren't scheduled to beat up on the Red Sox again until May 18, and if all this impeachment nonsense hasn't slithered back under the rock it crawled out from by the time you're actually reading this in late February or March, my depression is going to be deep enough to perhaps warrant pharmaceutical intervention. All of which leads, inevitably of course, to Emily Dickinson.

The Belle of Amherst (that's Dickinson, for any readers who have been working on that chemistry or physics doctorate since George Bush was president) had the immortal insight once that "hope is the thing with feathers." Now comes a study that shows that while hope may have feathers, feathers had little hope, almost from their inception. Soon after evolution came up with the fantastic invention of the feather, it also cobbled together those annoying little bird banes, feather mites.

In *Nature,* researchers from the University of Portsmouth in England report the discovery of what certainly appear to be the fossilized eggs of mites sticking to a 120-million-year-old fossil feather. The feather was found in Brazil and eventually wound up at the National Science Museum of Japan. (I would bet that it flew there, showing that nature may not be malicious, but it is certainly ironic.) Between 68 and 75 microns across, these attached tiny spheres—the feather had over 100—are the wrong shape and size to be the pollen grains or spores common to the same deposit in which the feather was found. Instead they closely resemble the eggs of parasitic mites that infest birds today. And they are stuck to the feather, which may not be a smoking gun, but hey, they've been on it for 120 million years. So it would seem that feathers, a supreme evolutionary achievement, were fouled from nearly the start.

My depression grows. Clearly, nature has decreed that any good thing be accompanied by its drawbacks—a conservation law, but of misery. And yet I find a ray of—dare I say it?—hope. This glimmer of possibility exists in a recent *Proceedings of the Royal Society of London* article. Researchers from Switzerland and Madagascar discovered a genus of mayflies that has renounced the potential inherent in its name and evolved stunted, ineffectual wings—it most definitely may *not* fly. That might seem like a bad thing, but wait.

This genus, *Cheirogenesia,* apparently gave up flight because the waterways in its Madagascar home are notoriously lacking in predatory fish. Other mayflies need to propel themselves from the water's surface to escape a fish-bait fate. The unthreatened *Cheirogenesia,* however, adapted and adopted a less flighty lifestyle, content merely to skim the water's surface. Its incredibly hopeful response to such a sanguine situation also had a lower cost of living; it was able to shift from expensive lipids to cheaper carbohydrates as its form of fuel storage. Being stuck at sea level, it could also devote more of its energy supplies to reproduction than can its airborne mayfly relatives.

Like some insect version of the Amish, the *Cheirogenesia* rejected newfangled technology and carved out a nice little niche indeed. Now, if predatory fish move into the neighborhood, these maynotflies are cooked. But right now times are good. My lifted spirits tell me that Ms. Dickinson can keep the feathers. Hope, in fact, is the thing with stubby wings. —*Steve Mirsky*


MICHAEL CRAWFORD

***In Brief,*** *continued from page 26*

***Don't Forget Your Vitamins***

Ming-Yi Chiang, Ronald Evans and their colleagues at the Salk Institute for Biological Studies have found that vitamin A plays a crucial role in learning, at least in mice. As they reported in *Neuron,* the investigators genetically modified mice to lack two vitamin A receptors, some of which appear in cells of the hippocampus, a region involved in learning and memory. The mice developed normally but fared poorly in intelligence tests; apparently, their hippocampus cells could not modify their connections—a neuronal feat characteristic of learning.

***Arctic Warmth***

The discovery of fossilized bones of a crocodilelike creature called a champosaur could help climate modeling. John Tarduno of the University of Rochester and his colleagues described in *Science* that they found several bones of the cold-blooded, 2.4-meter-long (eight-foot-long) animal in the high Canadian Arctic. Its presence suggests that some 90 million years ago, the Arctic averaged 14 degrees Celsius (57 degrees Fahrenheit) and did not go below freezing. Extensive volcanism apparently injected heat-trapping carbon dioxide into the air.

*A champosaur*

SCIENCE MUSEUM OF MINNESOTA

***Environmental Myths***

Last December the National Environmental Education and Training Foundation issued its seventh annual report on Americans' knowledge of environmental issues. Misinformation abounds: 56 percent believe six-pack rings cause most wildlife entanglement (only 10 percent know it is discarded fishing lines); 57 percent hold oil spills and coastal refineries responsible for most oil pollution (16 percent know it's improper disposal of motor oil); 51 percent believe the government tests bottled water; and 83 percent do not know what happens to spent nuclear fuel. Maybe good news: 71 percent of Americans consider environmental protection more important than economics. *—Philip Yam*

**FIELD NOTES**

## CRIMES AGAINST NATURE

*A medical examiner's laboratory—for protected animals*

When dozens of rotting, headless, three-quarter-ton walrus carcasses started showing up in 1990 on Alaska's beaches, wildlife officials found themselves in a sticky situation. Undercover agents figured that poachers had killed the animals and sold their tusks illegally; the suspected poachers claimed that they had merely scavenged heads and ivory from walruses that had washed ashore dead. What was the truth?

The National Fish and Wildlife Forensics Laboratory, founded in 1989, investigates just this kind of crime. Based in Ashland, Ore., it is the only facility in the world devoted full-time to wildlife forensics. Here morphologists toil alongside serologists, pathologists, chemists and firearms experts in an unusual crime lab, examining evidence ranging from tiny green parrot feathers to bags of bear claws.

Such evidence pours in from Fish and Wildlife officers across the nation and from wildlife inspectors around the globe—spoils of the war on the illegal wildlife trade, an industry worth an estimated $1 billion to $2 billion annually. The lab's scientists examine more than 900 cases every year, always mindful that their results might wind up in court. "Our job is to remain neutral, to stay true to the science, whatever it shows," explains laboratory director Kenneth W. Goddard.

Many of the lab's techniques are familiar from human forensics, including autopsy, ballistics, fiber analysis and DNA fingerprinting—methods designed to establish cause of death and to link victim and crime scene to suspect. But wildlife forensics presents special problems, not the least of which is figuring out the species of the deceased. Poachers and traffickers target hundreds of types of animals around the world. Identifying a victim as a member of a protected species is a crucial step in building a prosecutable case.

It doesn't help matters that evidence of wildlife trafficking rarely comes in the form of an intact body. Often all the lab has to work with is a smear of blood on a poacher's truck, an entrée ordered off a restaurant menu, a leather belt, a lampshade, a jar of caviar. "We deal with pieces, parts and products," Goddard muses. "That can make identification tough."

Sometimes these bits and pieces are amenable to high-tech forensic assays. When DNA is readily available from a sample, the lab will examine a certain portion of the mitochondrial DNA. This "hypervariable" region has mutated quickly enough over the course of evolution that its sequence varies significantly from species to species; determining the sequence can help pin down the identification.

DNA is often scarce, though, and the

MARK GAMBA

***POSTMORTEM EXAMINATION* by Richard Stroud will determine if this raven was intentionally poisoned. Such wildlife forensics help to prosecute illegal hunters and poachers.**

MARK GAMBA

*IGNOBLE END FOR* BUFO MARINUS, *as a coin purse, did not violate animal-protection laws, but the fates of others identified by the Ashland lab did.*

lab must rely on the time-honored observational science of morphology. "I think morphology will always have a place beside DNA technology in our lab," says deputy director Edgard O. Espinoza. "The techniques complement each other." In one memorable case, investigators had worked for days without luck trying to extract DNA from a contraband bone to identify the animal. By chance, mammologist Bonnie Yates wandered by. "Look at that cool giraffe vertebra!" she recalls exclaiming. Case solved.

Yates and her co-workers search for subtle details of structure, color and pattern that are indicative of a given species, guided first by visual memory and later by painstaking measurements. The distinctive look of a crocodile hide immediately gives away one $6,400 handbag seized from an upscale department store, for example, and the striking pattern of python skin that lurks beneath the black dye of another bag is easily recognized under infrared light.

The morphologist's task becomes more difficult when the sample is just a bit of an animal processed into a commercial product and there are no clues to its geographic origin. A stool crafted from an elephant foot may be evident even to the untrained eye, but a pair of average-looking hiking boots fashioned from elephant hide, say, are less obvious. "I had one person call and ask if I could do dried noses," Yates chuckles. (She could—the nose turned out to be from a serow, a protected Asian bovid that looks something like a goat.) Goddard estimates that in the end, the lab can determine whether evidence comes from a protected animal for about two thirds to three fourths of the samples it receives.

As for the mysterious deaths of the walruses, the scientists cracked that case, too. Their experiments indicated that the exposed, bleached neck bones of the decapitated animals had been submerged in saltwater for weeks—meaning that the animals were first beheaded and then dumped in the water. The carcasses later floated up on the beach as they decomposed. Another crime solved.

*—Mia Schmiedeskamp in Ashland, Ore.*

*MIA SCHMIEDESKAMP is a freelance science writer based in Seattle, Wash.*

**PHYSICS**

## REVENGE OF THE WIMPS

*Italian physicists have found the missing dark matter—or maybe not*

Astronomers claim to be terribly embarrassed that they can't find 90 percent of the matter in the universe. But they usually say this with a big smile. Something swirls in the heavens and streams through our bodies without a whisper; it cannot be seen; in short, it is as compelling a mystery as any scientist could hope for. And the fun has not stopped despite the recent announcement by Italian physicists that they had found the first hint of the elusive dark matter.

The concept of dark matter resides in the gap among three ways of weighing the universe: a direct census of stars, dust and gas; measurement of the relative amounts of light elements; and analysis of the dynamics of galaxies and galaxy clusters. The discrepancies indicate that the universe is filled with some kind of extraordinary material.

As it happens, such matter would solve one of the biggest mysteries in fundamental physics: Why do the fundamental forces of nature—gravity, electromagnetism, and the weak and strong nuclear forces—vary so widely in strength? For the forces to differ, the quantum effects that tend to equalize them—namely, a battle between particles of force and particles of matter—must be neutralized. One way to do so is supersymmetry, which arranges a dynastic marriage between the two particle families. The photon (a particle of force) pairs off with a "photino" (a particle of matter), the quark with the "squark" and so on. For each known type of particle, physicists believe there is a more massive "sparticle" that remains to be discovered.

The search for sparticles is a central goal of particle physics today. The easiest one to find should be the lightest one, the "neutralino." To have eluded detection so far, it must be weak both in the usual sense of the word (that is, unlikely to affect anything else) and in the technical sense (able to interact only via the weak nuclear force). The particle should weigh 50 to a few hundred times as much as a proton—hence the moniker WIMP, for "weakly interacting massive particle." (Imperfections in the big bang could even have created "WIMPZILLAS," a billion times heavier still.)

WIMPs are physicists' best candidate for the astronomers' dark matter. By an intriguing coincidence, the number of such particles that would have been created by the big bang approximately equals the amount of extraordinary dark matter deduced by astronomers. The elusive neutrinos may also contribute to this dark matter, now that they are known to have a small mass, but alone they could not suffice; they are too footloose to have seeded galaxy formation.

WIMPs are comparatively static, which is how the Italian group claims to have found them. The team, known as DAMA and led by Rita Bernabei of the University of Rome, relies on scintillators, a type of particle detector that looks for the light given off as particles strike atoms. To pick WIMPs out from other particles, such as those given off by naturally occurring radioactivity, DAMA watches for the seasonal fluctuation predicted by American astrophysicists Andrzej K. Drukier, Katherine Freese and David N. Spergel in 1986.

Whereas the solar system orbits around the center of the Milky Way, WIMPs should have no organized motion. To exert the gravitational influence inferred by astronomers, they must be distributed spherically, and revolution would distort that shape. Consequently, the solar system should encounter a headwind of WIMPs—which should be slightly faster in June, when Earth's orbital motion around the sun adds to its motion around the galactic center, than in December. The flux of other particles should remain constant. DAMA observed just such a variation during its first two periods of operation. This suggests a particle 60 times as massive as the proton and a trillion times less likely to interact with other particles.

The result, though consistent with previous theoretical and experimental limits, has met with widespread skepticism. As Bernard Sadoulet of the University of California at Berkeley, Jonathan R. Ellis of CERN and others have argued, DAMA showed only that the energy of particles was higher in June than in December. They have not yet looked for a decrease from December to June. Moreover, because the energy resolution of the scintillators is coarse, instrumental noise could masquerade as WIMPs. Other physicists, such as Gilles Gerbier of the Saclay Center of the French Atomic Energy Commission, have complained that DAMA has not provided them the raw data needed for corroboration. “I’m certainly not saying they are wrong,” Sadoulet says. “I’m asking them to provide the proper evidence.”

Several competing teams are now checking the result using a different type of detector, one that looks for the electric current that incoming particles let loose in a crystal of germanium. To differentiate particles internally, rather than rely on the controversial seasonal effect, Sadoulet’s group also monitors the crystal for telltale vibrations set up by WIMPs as they hit atomic nuclei. Another system, used by Laura Baudis and her colleagues at the Max Planck Institute for Nuclear Physics in Heidelberg, sorts particles by using multiple detector layers. If confirmed, the detection of WIMPs would open up a whole unseen universe. No one knows quite what to expect of it. *—George Musser*

BY THE NUMBERS

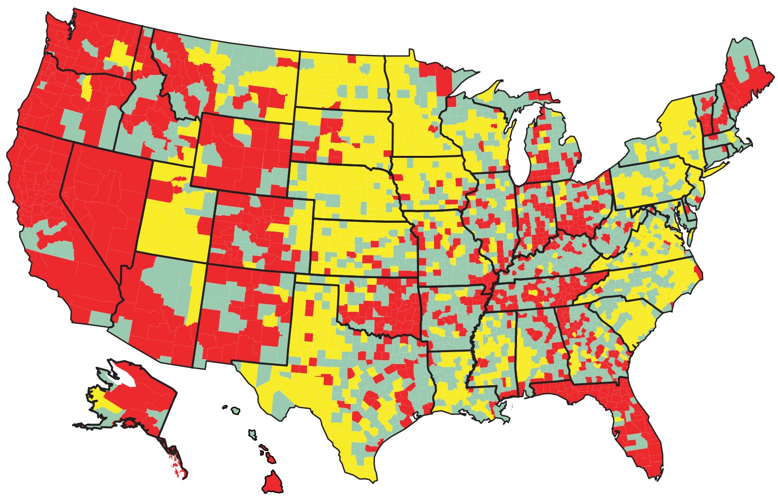
## Divorce, American-Style

The late social scientist Jessie Bernard of Pennsylvania State University once observed that “there are two marriages … in every marital union, his and hers. And his … is better than hers.” The growing awareness of this particular perspective among women most likely contributed to the dramatic rise in divorce rates in the 1960s and 1970s, along with urbanization, the growing role of women in the workforce and more liberal divorce laws. But why is the U.S. the world leader in divorce?

A possible explanation lies in the restlessness of Americans, who are far more apt to migrate than, say, Europeans. Those who move, particularly a long distance, may be more likely to divorce because the inhibitions of traditional family and community ties have been left behind. Divorce has colonial roots, too: Puritan courts granted divorces, and disgruntled husbands and wives often simply abandoned their spouses.

The map shows the estimated proportion of Americans 18 and older who were divorced as of March 1997. The reasons for the marked regional disparities are not definitively known, but they probably reflect several factors, including church membership, which may reinforce marriage ties. Not surprisingly, therefore, Florida and most of the western states, where church membership is low, have a higher proportion of divorced people. Migration may contribute to the high proportion of divorced people in the West and Florida, which have a larger proportion of peripatetic individuals than other areas have. The broad swath of counties stretching from North Dakota and Wisconsin down to the Rio Grande is an area with few divorced people, which might be expected in view of high church membership and the relatively few migrants to this area. The low prevalence of divorce in Virginia, North Carolina and South Carolina may stem in part from fairly high church attendance. The huge triangular area with its apex in Michigan and its base from eastern Texas to southern Georgia shows a mixed pattern in the proportion of divorced people. This area has wide variations in migration.

There is little doubt that divorce rates rose sharply in the 1960s and 1970s, but there have been some difficulties in interpreting divorce statistics since the early 1980s. Larry L. Bumpass of the University of Wisconsin, who has done the most extensive work on this point, concludes that the divorce rate has stabilized in the past two decades. As of March 1997, the U.S. had more than 19 million divorced people, or 9.9 percent of those 18 and over. The median age of divorced people is about 50, and 58 percent are women. Among whites, 9.8 percent are divorced, compared with 11.3 percent of blacks and 7.6 percent of Hispanics. Divorce rates in urban areas are higher than in rural areas. *—Rodger Doyle (rdoyle2@aol.com)*



ESTIMATED PROPORTION OF AMERICANS 18 AND OVER WHO WERE DIVORCED AS OF MARCH 1997

LESS THAN 8 PERCENT | 8 TO 9.9 PERCENT | 10 PERCENT OR MORE

*SOURCE: Estimates based on 1990 U. S. Census data by county and 1997 Bureau of Census data for the U. S. Because the method of estimation is subject to substantial error, data for individual counties may not be accurately coded; however, the broad regional patterns are believed to convey an accurate pattern.*

RODGER DOYLE

## Humans Unite!

*Ben Shneiderman wants to make computers into more effective tools—by banishing talk about machine intelligence*

If software designers ever finally give up fashioning cutesy humanoid icons and voices to advise users on how to navigate ever more unwieldy programs, the person to thank will be Ben Shneiderman, head of the Human-Computer Interaction Laboratory at the University of Maryland. Shneiderman, who since 1981 has argued that effective programs allow people to manipulate onscreen objects directly, is on a personal campaign to purge his field of anthropomorphism, which he regards as an affront to human dignity. The mere mention of the fashionable software "agents" that operate independently and anticipate users' needs makes Shneiderman sigh and roll his eyes theatrically. But it takes him only an instant to summon some quotable zingers to express his disdain. It's hard to avoid the impression that Shneiderman relishes his role as an iconoclast.

According to Shneiderman, agents and their cyber-kin, which have been promoted most notably by Massachusetts Institute of Technology professor Patti Maes, are a new version of the "mimicry game," the long and undistinguished tradition of making devices that look or work like humans. He sees them as descendants of 17th-century dolls that amused courtiers by playing musical instruments and about as likely to improve suffering humanity's lot. Yet Shneiderman's criticisms also have a serious side. He thinks enhancing computers' autonomy raises troubling questions about who will be responsible if machines controlling air traffic or medical equipment, for example, make disastrous errors. (Maes is now taking this fear seriously, he allows.) And he completely rejects the related notion of giving computers "emotions" so that they might attempt to calm a distressed user. "Machines don't have emotions," he declares roundly.

Shneiderman is almost as dismissive of efforts at M.I.T. to create a humanoid robot called Cog based on biological design principles [see "Here's Looking at You," News and Analysis, January]. The plan is a "dangerous" distraction, he announces, adding a little too casually that it might lead to "better animatronic dolls for Disney World or better crash-test dummies."

James A. Landay, a computer scientist at the University of California at Berkeley, says that Shneiderman's opinions on agents and autonomous software in general have forced researchers to pay attention to hard questions about accountability for machine actions. And Terry Winograd, a prominent researcher at Stanford University, agrees that his "energy and enthusiasm" have been "a useful corrective" to exaggerated claims made for agents. But Oren Etzioni of the University of Washington, chair of the Agents '99 conference, counters that Shneiderman fails to consider the rewards agents can offer. "Yes, you lose some control. That's the cost. But the benefit is enormous," Etzioni maintains.

Maes, for her part, says Shneiderman is attacking a straw man. The goal of agents research, she remarks, is not to mimic human intelligence but to help the user suffering from information overload by providing "simple, understandable, predictable programs" that can act on his or her behalf. She believes it is clear that a user who instructs an agent should assume responsibility for its actions.

Shneiderman asserts that his own goal is to "amplify human creativity 1,000-fold." He punctuates his views with grins, chuckles and shrugs that conjure an aura of gentle reasonableness. "Creative explorations" in artificial intelligence are justifiable, he concedes. But he holds that most people do not want to deal with an on-screen "deception"—a program portrayed as a person. Too many artificial-intelligence projects waste tax dollars in pursuit of unclear goals and fail to evaluate their products adequately, he complains. He cites the instance of a Unix natural-language interface whose

MARTIN SIMON

***MAN OVER MACHINE:* *Ben Shneiderman says computers should support human creativity, not simulate intelligence.***

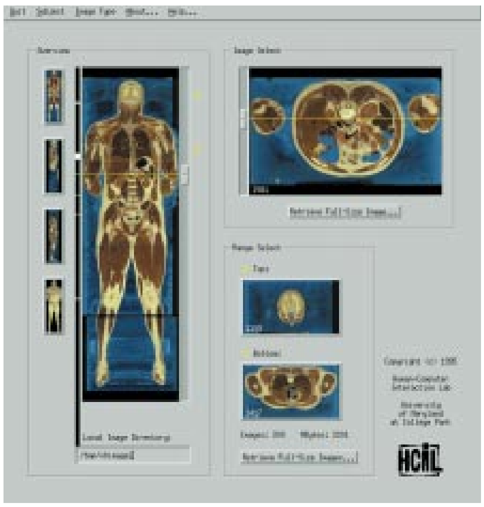
author recounted that he had not had time to test it with naive users. Shneiderman emphasizes that software should be checked for ease and speed of use as well as for the number of errors it provokes.

Shneiderman's perspective is consistent with his own broader philosophical views. He declares that he is a humanist. His bottomless respect for human potential appears to leave him close to vitalism, although he grants that there is no reason humans should not ultimately understand how the mind works. But he insists that most research carried out under the banner of artificial intelligence has actually slowed progress toward developing more accessible technologies. Researchers in artificial intelligence have "such a shallow model of human performance and human emotions—that's the tragedy," he observes. He maintains that delays in devising machines that can respond to natural language have forced workers to push back that goal to more than a decade hence. Deep Blue, the IBM computer that beat chess champion Garry Kasparov, is "merely a tool with no more intelligence than a wooden pencil," Shneiderman wrote in a 1997 article in *Educom Review*.

People, on the other hand, are "richly creative and generative in ways that amaze me and that defy simple modeling," he states. So the last thing they want is "an electronic buddy or chatty bank machine." Names and products that try to indicate humanlike intelligence do not endure, he elaborates. Tillie the Teller and Harvey Wallbanker, early automated teller machines, have joined the U.S. Postal Service's Postal Buddy and Microsoft's Bob computer characters on the trash heap of computer history. Bob's electronic progeny Einstein and Clip-It, now found in Microsoft's Office suite, will go the same way, Shneiderman predicts.

The offspring of two journalists, Shneiderman grew up in a European intellectual circle in New York City that he says taught him to appreciate the arts as well as technology. (His uncle, David Seymour, traveled the world photographing wars as well as actresses for *Look* and *Life,* among other magazines.) As a physics student at City College of New York during the 1960s, he was swept up in post-Sputnik enthusiasm for all things scientific. Resisting pressure to specialize and inspired by Marshall McLuhan's portrait of a global electronic village, he sought ways of "getting out of linear culture" through electronics. He tried to bridge psychology and computing while remaining alert to the arts. He held academic appointments at the State University of New York at Stony Brook and at Indiana University before moving to Maryland.

The purpose of computing is insight, not numbers, Shneiderman likes to reiterate, and likewise the purpose of visualization is insight, not pictures. What people want in their interactions with computers, he argues, is a feeling of mastery. That comes from interfaces that are controllable, consistent and predictable. Direct manipulation of on-screen objects—moving a file to the trash can, say—is the ideal solution. Natural-language dialogue is a loser (except as an aid for the visually impaired) because it slows down users' thinking. "We want to fly through a library, not mimic the dialogue with a reference librarian," he comments.



COURTESY OF BEN SHNEIDERMAN

***VISIBLE HUMAN INTERFACE* features controllable views of data designed by Shneiderman and his associates.**

Shneiderman believes that unlike adaptive systems, which change their behavior in nonobvious ways, successful programs offer rapid, incremental and reversible actions. Such insights led him to invent in the early 1980s what is now known as the hyperlink, in a videodisc exhibit he helped to design for the U.S. Holocaust Memorial Museum. A green screen offered numbered items on a menu: Shneiderman decided to drop the numbers and highlight words to denote choices (his research is behind the pale-blue color of most links). The idea was commercialized by Cognetics as "Hyperties" and used in a high-profile electronic book for computer professionals and a Smithsonian Institution exhibit. Tim Berners-Lee, the originator of the World Wide Web, referenced the idea in 1989 in an early description of his concept. Shneiderman has since worked on the small, high-precision screens used in pocket-size computers and organizers.

Today he supervises a variety of projects. His mantra, printed 12 times consecutively in his textbook *Designing the User Interface,* is "overview first, zoom and filter, then details on demand." He favors shallow search trees, slide controllers and information-rich screens with tightly coordinated panel views of data. "A pixel is a terrible thing to waste" is one of his many maxims.

He and his colleagues Chris North and Catherine Plaisant have applied these principles to develop an interface that makes it easier for researchers to select images from the National Library of Medicine's Visible Human digital library, which contains thousands of high-resolution sections of a cadaver. Another product, commercialized as Spotfire, displays data as color- and size-coded blobs on graphs whose axes can be selected and scaled at will.

Spotfire and similar programs are "a new form of telescope" that allow users to discern patterns in data they might otherwise never discover, Shneiderman maintains. And important customers are convinced he has something to offer. The National Aeronautics and Space Administration has adopted one of his group's ideas as an interface for its master directory of research on global change. IBM has come knocking for advice on electronic commerce and on presenting medical records.

Shneiderman's latest book, *Readings in Information Visualization: Using Vision to Think,* written with Stuart K. Card and Jock Mackinlay, was published in January. His longer-term project goes by the name of genex, a somewhat vague scheme to improve software for creativity. Shneiderman thinks today's programs have a long way to go toward maximizing human potential. Hierarchical browsing, self-describing formats and synchronized scrolling are among the notion s that are featured in his writings on genex. "We have to do more than teach our kids to surf the Web. We have to teach them to make waves," he pronounces. Shneiderman himself seems already to have created quite a storm.

—*Tim Beardsley in Washington, D.C.*

ENVIRONMENT

## OIL IN WATER

*Studies arising from the* Exxon Valdez *oil spill suggest that fish are more sensitive to hydrocarbons than previously thought*

Ten years ago this month the *Exxon Valdez* tanker crashed into Bligh Reef, releasing at least 11 million gallons or so of crude oil into Prince William Sound in Alaska. The spill had enormous implications not only for the environment and people of the surrounding area but for public perceptions of oil pollution and for the federal law governing oil spills as well. The spill also created a massive experiment.

ROBERT GLENN KETCHUM

***PRINCE WILLIAM SOUND,* a decade after the spill, is still providing scientists with insights about pollution's effects.**

Despite many scientific conflicts, ongoing studies have led to some important insights. Researchers now have a better understanding of the impact of cleanup and of how an ecosystem recovers. They also have a clearer picture of how hydrocarbons—the building blocks of oil—affect certain species. Of these latter studies, work on pink salmon has recently produced some surprising results that, if they hold up, could have widespread implications for water-quality standards.

As a commercially critical fish, pink salmon received much attention after the spill. For years, biologists have documented the size and health of salmon populations returning to oiled and unoiled sites in the sound and have conducted laboratory experiments to decipher the precise dangers of hydrocarbons. Such studies are proving to be eye-opening. "Now we believe that oil pollution has much longer effects at much lower concentrations and with different compounds than we had thought," says Ronald A. Heintz, a biologist at the National Marine Fisheries Service's Auke Bay Laboratory in Juneau.

Oil is composed of thousands of compounds, including polynuclear aromatic hydrocarbons, or PAHs. PAHs are not regulated in the aggregate nor for their impact on aquatic life. The Environmental Protection Agency issues water-quality recommendations only for human consumption of specific PAHs—such as naphthalene and chrysene—although states can devise their own regulations.

What Heintz and his team did was to expose pink salmon eggs and embryos to different amounts of total PAHs. In previously published papers, the researchers reported that postspill concentrations of PAHs—from a high of 51.5 parts per billion to a low of 4.4 ppb—can, variously, kill the fish, impair their ability to reproduce and lower their growth rates. "Exposing an embryo to oil is like taking a shotgun to its DNA," Heintz describes. It has lots of different effects, he adds, and "over the whole life cycle, those little effects really add up."

Now Heintz and his colleagues have determined that PAH levels as low as 1 ppb harm both pink salmon and Pacific herring. In their most recent studies, which appear in this month's *Environmental Toxicology and Chemistry,* the scientists found that mortality increased for both species of fish exposed to 1 ppb. And they discovered that the effects of very weathered oil were the same as those of fresh oil—which means that the old oil persisting under gravel in some parts of Prince William Sound could still be harmful.

The fact that 1 ppb is damaging to two species suggests that intertidal organisms everywhere may be affected by the chronic pollution brought about by small spills or leaks. "You'd be hard-pressed to find any coastal area where you wouldn't get total PAH concentrations of that magnitude," asserts Judith E. McDowell of the Woods Hole Oceanographic Institution in Massachusetts.

If more researchers determine that PAHs at 1 ppb are damaging fish and other organisms, new regulations may be needed to ensure water quality—which could affect oil exploration offshore and ballast-water discharges. Even Alaska, which has the strictest criteria in the world at 15 ppb, might have to rethink its standards, observes Jeffrey W. Short, a chemist at the Auke Bay Laboratory. But it could prove virtually impossible to regulate the many nonpoint sources of PAHs, such as stormwater runoff and people's sloppiness with their motor oil. "The consciousness has got to change with the public and the way that we set standards," says Usha Varanasi of the Northwest Fisheries Science Center in Seattle. "It is not always a company."

For now, as Heintz and both his supporters and critics point out, much more work is needed. "You need replication by an outside group," notes Paul D. Boehm, a petroleum expert at the consulting firm Arthur D. Little who has worked in the sound for Exxon. In addition, other species need to be studied to see if the observations extend beyond salmon and herring—although there is some evidence to support the Auke Bay findings. For instance, a 1991 study from Prince William Sound found that growth rates of capelin were affected at PAH concentrations of 4 ppb. And researchers in Puget Sound are finding similar effects in juvenile salmon, Varanasi remarks.

But in general, low-level PAH analyses remain uncharted terrain. Many intertidal regions are polluted, and discerning the specific effects of PAHs against a background of other contaminants is difficult. Heintz notes that his findings came to light because Prince William Sound had been a pristine area. "The *Exxon Valdez* is the stimulus that motivated a new way of looking at it for us," he says. "It has radically changed the way we think about oil pollution." —*Marguerite Holloway*

# GREEN IS GOOD

*With negotiations on climate change policy stalled, some major corporations are setting their own environmental policies*

For the past year, the Kyoto Protocol, the international treaty addressing climate change, has been just a guest star on the world's political stage, capturing momentary attention but then quickly fading into the backdrop. The reason: the protocol will not become a permanent fixture until 55 countries ratify it. To date, only three countries, Antigua and Barbuda, Fiji, and Tuvalu, have done so. Yet as the Kyoto Protocol waits in the wings, some unexpected supporting characters—major corporations—have emerged as advocates for the environment.

The Kyoto Protocol, negotiated in December 1997, set targets for developed countries to reduce their emissions of the greenhouse gases most scientists believe have contributed to increases in average global temperature over the past century. Last November, at a meeting in Buenos Aires, negotiators of the original treaty reunited to specify how and when these reductions will take place. And as the sessions concluded, the U.S. signed the Kyoto Protocol amid much fanfare. But it was largely a ceremonial act, because the U.S. is not bound by the treaty unless the Senate ratifies it. Opposition to the treaty is so strong that the Clinton administration will not be sending it to Capitol Hill for a vote anytime soon.

So with the Kyoto Protocol essentially on hold, what's a good environmentalist to do? Try pairing up with a major oil company or automobile manufacturer. For instance, the World Resources Institute (WRI), an environmental organization based in Washington, D.C., recently entered just such a partnership—the "Safe Climate, Sound Business" initiative—with the oil and gas company BP Amoco (formed by the merger of British Petroleum and Amoco), automaker General Motors and the agriculture and biotechnology firm Monsanto.

Paul Faeth, program director for economics and population at WRI, explains the decision to work with big business: "It would be an enormous mistake to ignore industry," considering the capital and human resources such companies control. Faeth describes how the partners in the initiative first agreed on a set of policy recommendations for businesses and governments to mull over. For example, the group has called for businesses to measure and report greenhouse gas emissions, to work to reduce and sequester emissions, and to include global climate considerations when making investment decisions. The partners also suggested that governments eliminate subsidies for fossil fuels (the U.S. government provides an estimated $9 billion in annual subsidies to the oil industry) and increase support for basic research on climate science.

Now all four organizations are implementing the business recommendations internally, starting with the measurement of their emissions of greenhouse gases. In addition, over the next few years, the companies will start reducing these emissions. BP Amoco has set a goal of lowering its output of greenhouse gases by 10 percent from 1990 figures by 2010. General Motors aims to cut its total energy use by 20 percent from 1995 levels by 2002. And Monsanto is studying how certain agricultural practices might in-


***INVESTMENT IN RENEWABLE ENERGY,* such as wind power (shown here at Altamont Pass, Calif.), by power companies is on the rise.**

crease sequestration of carbon in soil.

Kenneth E. Blower, director of health, safety and environment at BP Amoco, says the company's decision to address climate change on its own and in collaboration with WRI and the Environmental Defense Fund was a business one: "We want to be early into this [issue]—this will be valuable to stockholders in the long term."

Indeed, the company did start talking about global warming early on, at least compared with many in the oil industry who continue to dispute that human activity has had any impact on global climate. In a speech at Stanford University in May 1997, John Browne, the chief executive officer of what was then just British Petroleum, acknowledged that "there is a discernible human influence on the climate and a link between the concentration of carbon dioxide and the increase in temperature." Browne later described the reaction he received from others in the oil industry: they saw it as "'leaving the church,' as one particular commentator suggested," he said.

But if BP Amoco was the first major firm out the climate change door, others are now following. Royal Dutch Shell joined BP Amoco in leaving the Global Climate Coalition, an industry organization that has lobbied heavily against the Kyoto Protocol. The two have signed on with the pro-treaty group, the International Climate Change Partnership, which in the past year has doubled in size to more than 40 companies. (All this is not to say that relations between big business and environmental groups are perfect. For instance, in late January, Greenpeace filed a lawsuit to halt construction by BP Amoco of the first offshore oil project in the Arctic Ocean.)

Lester R. Brown, head of the environmental group Worldwatch Institute, has observed a shift in corporate attitudes. There have been some "fundamental changes," Brown notes, such as increasing investments by the energy industry in wind and solar power. "Corporations are doing some ingenious rethinking," he says. "Something is happening in a way that has not happened before."

Brown also mentions another event that has not happened before: the average global surface temperature in 1998 set a new record, surpassing the previous record year of 1995 by 0.2 degree Celsius (0.4 degree Fahrenheit), the largest jump ever recorded. Many scientists are pointing to this rise in temperature as the most compelling evidence yet that the earth's climate has indeed been altered by human activity—evidence that puts the heat on more businesses to take action to prevent climate change. —*Sasha Nemecek*

CONSTRUCTION

## THIS OLD SPACE STATION

*Adapting earth tools for space use*

Construction is a term the National Aeronautics and Space Administration has bandied about before, although previous space-based building efforts resembled Erector sets more than new housing start-ups. This time it's no hyperbole. During the next six years, space suit–clad hard hats floating in microgravity will lever, bolt and even pound together 100 separate elements into a place that a select few will call home sweet orbital workstation: the International Space Station. NASA has spent the past few years preparing the right tools for the job—although it may take a while before they appear on *This Old House: The Next Generation.*

"It's more in the other direction," according to Phil West, the project manager of space-walk tools for the space station. "How can we use something built on earth in space?" No *Star Wars*–style "hydrospanners" here. Instead they are power tools that resemble a cordless Makita drill on steroids, high-strength ratchet wrenches and even decidedly low-tech crowbars for prying loose black boxes frozen to a module's side. "The challenge is to make them small enough to not take up too much space and large enough to operate while wearing bulky gloves," says Col. Mark Lee, a veteran of the second Hubble Telescope maintenance mission.

To prevent the proliferation of tools, NASA planners asked contractors to design modules and their external accessories with a single "EVA bolt"—one with a very tall, 7⁄16-inch head. Yes, metrics falls by the wayside on this international project. Many major components were first devised when the station was an all-American effort, but even after other nations got on board, NASA decided that the cost of reengineering would be a little too significant. "This country is not tooled to go metric," West explains. What happens if American astronauts need to work on another country's modules? "We'll use Russian tools," he says.

The most important part of any astronaut's tool belt (or "miniworkstation," as NASA calls it) is the battery-powered, 3⁄8-inch-drive pistol grip tool, or PGT, first used on the Hubble maintenance missions. The orbital features of this driver include an ability to count the number of turns and to limit the torque applied; together they prevent overtightening of bolts, which could damage parts. The PGT can also store and download data for later analysis if something goes wrong. "If you snap a bolt head in a car, you've got time to figure out what to do," West remarks. "But we've got to get these guys back in before their oxygen runs out." An array of swiveling socket extensions permit PGT use in hard-to-reach places. In case of battery failure, astronauts can resort to a manual ratchet wrench capable of 100 foot-pounds of torque, fairly high by earthly standards.

West and his team have also packed a kit of what they call "contingency tools," which consists of an adjustable wrench, should the astronauts happen on a metric bolt outside; a so-called cheater bar, for sliding onto the handle of a tool for a little additional leverage; and, yes, that crowbar. Purchased off the shelf, these tools are made from beryllium copper, which can easily manage the –200 to –250 degrees Fahrenheit (–129 to –157 degrees Celsius) work environment—

NASA

***POWER DRILL IN HAND AND BOLTS IN MOUTH,*** ***astronaut Frederick W. Sturckow helped to connect space station modules last December. Tools were specially modified to perform inside the module—and outside.***

temperatures that turn normal tool steel brittle. Also, the astronauts will have tools from the medical industry, namely, vise grips, scissors and a dead-blow hammer. The hammer, useful in bone surgery, has a pocket of shot in its head to absorb the recoil. Astronauts "don't want the hammer bouncing off their heads or out of control," West elaborates.

Losing tools in orbit has a unique set of ramifications, the least of which is that the nearest replacement could lie 240 miles (386 kilometers) below. For the socket set, West and his associates incorporated a pin-and-tether system called an interloc. When an astronaut pushes the pin into a hole on the socket extension, the extension locks onto the pin. When the astronaut fits the extension onto a wrench or onto a storage post on the space suit's miniworkstation, the extension locks onto the wrench or post and releases the pin.

The other tools—and just about anything else the astronauts take outside—have attached loops, so that they can be held with an array of tethers. Most popular is one with seven hooks spaced at intervals along its length. "We call it the fish stringer," Lee says. "Now flights take along four or five of them." If an astronaut needs to be held down, there are the body-restraint tethers, which can become rigid, and foot restraints, which fit into sockets on the sides of the station. Without them, of course, astronauts "will literally spin around a bolt," West explains. "It's entertaining but not very productive."

Still, on the December mission to attach the Zarya and Unity modules, three items did float away. "We can't speculate why," West offers. "It could have been the operator; it could have been hardware failure."

Despite the philosophy of adapting earth tools for orbital use, there in fact could be an earthly market for some of the station's tools. At one recent NASA technology show, West spoke at length to one man who was intrigued by the drop-proof interloc system. The man, it turned out, worked in the window-washing industry. *—Phil Scott*

*PHIL SCOTT, a freelance technology writer based in New York City, once witnessed an out-of-control cheater bar break an oil worker's arm.*

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**SEMICONDUCTORS**

## RUSHING THE DOUBLE-GATE

*Keep future semiconductor transistors switching—by adding a second gate*

Despite relentless miniaturization, the primary structural components of the transistor have remained intact since the late 1960s. That may soon change, however. Some researchers are betting that a new type of transistor, called a self-aligned, double-gate transistor, could be made to solve a headache intrinsic to ultraminiature circuits of the future—an inability to switch off.

Conventional transistors, such as the metal-oxide semiconductor (MOS) type that dominates the computing landscape, work by governing the flow of current: voltage applied to a gate allows current to flow from a source, across a channel and out a drain. When the voltage is stopped, the gate shuts, stemming the current and turning the transistor off.

Diminishing size, though, upsets this standard operating procedure. Today's transistors have gate lengths of 250 nanometers (gate lengths help to determine the distance between source and drain and hence computing speed); the Semiconductor Industry Association in San Jose, Calif., estimates that through advanced chip-etching (lithography) technology, 70-nanometer features will be reached sometime after 2010. But as the distance between source and drain shrinks, competition between gate and drain for control of the electric field across the channel increases. As a result of this so-called short-channel effect, electrons leak uncontrollably across the channel, and the transistor becomes stuck in the "on" position.

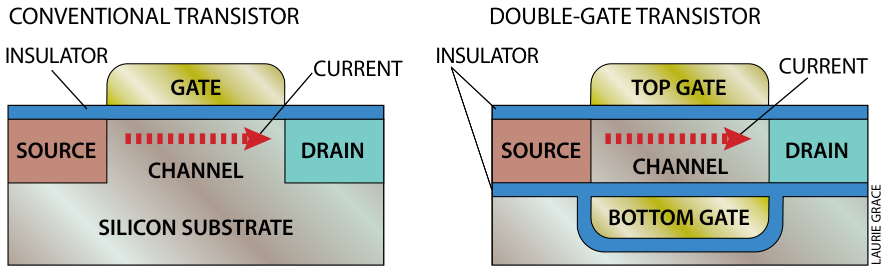
The double-gate transistor, which had been proposed in the 1980s, is a solution in part because of strength in numbers: when it comes to controlling the flow, two gates are better than one. But it also works in another way. In conventional MOS transistors, part of the drain's ability to overcome gate signals at reduced dimensions stems from the bending of electric fields and current into the depths of the silicon wafer, where they avoid the gate's influence. Sandwiching the channel's semiconducting material between two gates curbs this opportunity. Double-gate technology is expected to function down to channel lengths of 20 to 25 nanometers (about where fundamental physics will no longer permit conventional MOS technology to function).

Although it appears that double-gate structures won't be necessary for at least a decade, researchers have not been dallying. Miniaturization aside, they are inherently higher performing structures and will give circuits "an immediate boost," observes Dimitri Antoniadis, an electrical engineer at the Massachusetts Institute of Technology. "For a given width of a transistor, you have twice, or more than twice, the current drive capability." That, Antoniadis says, directly translates to a boost in processing speed. Another benefit of the second gate is that it could modulate the threshold voltage of the transistor and, remarks Philip Wong of the IBM Thomas J. Watson Research Center, "optimize operation for either higher performance or lower-power consumption." That could be particularly significant for portable electronics.

Creating a double-gate structure, however, is not as simple as slapping a second gate onto the bottom of existing transistors. The thickness of the silicon wafer on which transistors are built precludes this possibility. Moreover, the source, drain, channel and gates require precise alignment; otherwise electric fields will overlap, and current flow compromised.

In December 1997 Wong and his IBM colleagues successfully solved the construction challenges: they made the first self-aligned, double-gate transistor, basically by reversing the steps used to make conventional transistors. Instead of starting with a silicon wafer and progressively etching it away to produce transistor components, they began with a set of dummy gates and then "grew," through successive deposition, crystalline silicon in a mold to create the source, drain and channel. The permanent top and bottom gates were then laid down through chemical vapor deposition simultaneously, thus ensuring alignment. The IBM team has since pioneered a method whereby the necessary features are created on two separate wafers, which are then sandwiched together. After bonding, a single etching step cuts the top and bottom gates, guaranteeing alignment. Although both methods have yielded functional transistors, it is still too early to say which process is preferable. Right now the IBM team is at work on a third construction method, which will draw on both approaches to improve the fabrication process. The University of California at Berkeley, M.I.T. and a handful of others are also devising their own construction methods along similar lines; the Berkeley researchers successfully demonstrated their technique last December.

Still, Wong notes, "from a manufacturing point of view, all these methods look very foreign and unconventional." But it seems to be a safe bet that double-gate transistors will be manufacturable one day and become common—at least until 20 nanometers. *—Brandon D. Chase*




***DOUBLE-GATE TRANSISTOR*** *is a conventional transistor with an extra gate for added channel control. Manufacturing hurdles remain, though.*

*BRANDON D. CHASE freelances between Yorktown Heights, N.Y., and Portland, Ore., where he also teaches environmental science.*

## *The Best Things in Cyberspace Are Free*

In a courtroom in Washington, D.C., software giant Microsoft stands accused of attempting to dominate access to the Internet by means of software so proprietary and closely held that the company itself claims to be unable to locate some of the original source code. Meanwhile the software that actually runs the Internet—deciding what destinations packets should go to, transferring e-mail, serving up World Wide Web pages—is free and open to all. Not only can you download the programs for nothing, but you can also read the source code, make changes and even distribute your modified version for others to use.

Microsoft, Netscape Communications and others have tried to make inroads into the market for under-the-hood Internet software, but their success has been nowhere near complete. The free Apache Web server, for example, still accounts for more installations than all other server packages combined, and its market share is growing. Some advocates predict that open-source programs will eventually dominate the entire software market.

Although Microsoft's Windows operating system is still a de facto standard for the desktop, its fastest-growing competitor is open-source OS Linux, a Unix variant that has an estimated 10 million or more adherents. You can download Linux from at least half a dozen different Web sites or purchase a CD-ROM with the code for $50 or less. A number of major companies, including IBM, have released versions of their software that run under Linux. Furthermore, internal Microsoft memos leaked to the Web (at www.opensource.org/halloween.html) indicate that the company considers Linux a significant threat, especially since it has captured the hearts, minds and resources of countless computer science students and recent graduates.

In some ways, it only makes sense that the Internet should run on free software: almost all its basic protocols were developed with U.S. government funding by universities or other contractors. The Web is the brainchild of CERN, the European laboratory for particle physics near Geneva. But even after most of the Net's infrastructure has been privatized, with former graduate students and researchers working for enormous stock options, development of free, open software continues. After more than 20 years of trying to develop a market in reusable software, programmers seem to have found a method that works: give it away.

Many exponents of open-source software contend that it is simply better than its commercial counterpart. Even if a company can afford tens of thousands of testers to find bugs, those testers will generally not be in a position to say, "And here's rewritten software that fixes the bug, along with three crucial new features that everyone has been asking for."

DAVID SUTER

Eric S. Raymond, a longtime free-software author and editor of the *New Hacker's Dictionary,* has argued that open-source development is inherently superior to conventional top-down design. The logic of the intellectual marketplace ensures that only the best code and overall structure—as judged by a programmer's peers—will survive. Corporate software is generally built according to a predetermined plan that leaves little room for deviation or innovation.

What about tech support for free software? Thus far it may be better than for many commercial programs—for example, archives of Usenet articles about Linux contain about 200,000 postings, with 1,000 or more added every day. Linux Web pages: in the neighborhood of three million. Programmers who write the code communicate directly with those who use it. Several companies are also making a profitable business offering Linux help and consulting (a logical next step to the kind of "unbundling" that has led Microsoft to charge $295 for a "10-incident" support package for its products). Red Hat Software (www.redhat.com), for instance, offers anything from a $50 Linux CD-ROM to 24-hour technical consultation for Linux-based corporate networks at $60,000 a year.

As for the care and feeding of open-source programmers, their employers appear to be perfectly happy to pay them to produce programs for other people as well as their own companies. (Many open-software authors work for firms whose revenues depend on Internet access or consulting services rather than software sales.) An example, though perhaps extreme, is Netscape. It now employs over 100 full-time programmers writing code for its open-source Web browser. The free browser helps to increase sales of other software and pumps up the advertising base for Netscape's Web site.

Raymond has suggested that sought-after programmers are part of a new, essentially nonmarket economy: instead of measuring their worth in terms of how much they earn or what resources they control, they compete by the beauty and utility of the programs they give away. Medieval craft guilds and Renaissance artists operated in roughly the same fashion, as did several since exterminated aboriginal cultures.

There has, however, been a distinct paucity of open-source word processors, spreadsheets, database programs, graphical user interfaces and other software that ordinary human beings might use on a daily basis. Although such programs are vital, they are not known for capturing the imagination of most hackers—who are free, in the open-source world, to choose the projects they will pursue. Furthermore, if text-editing software built by hackers for hackers (such as Emacs) is any guide, average consumers and programmers may have almost antithetical ideas of what elegant, useful programs and documentation look like.

If the current stylistic distinctions between open-source and commercial software persist, an open-software revolution could lead to yet another divide between haves and have-nots: those with the skills and connections to make use of free software, and those who must pay high prices for increasingly dated commercial offerings. *—Paul Wallich*


COURTESY OF U.S. DEPARTMENT OF COMMERCE

# The 1998 National Medal of Technology

The nation's highest honor for technological innovation, the medal recognizes breakthrough achievements in the development and commercialization of technology

*On December 8, 1998, President Bill Clinton announced that year's winners of one of the highest civilian commendations that the U.S. can bestow, the National Medal of Technology. These awards, which have been administered by the Department of Commerce's Office of Technology Policy since 1985, recognize individuals, teams and corporations whose technological breakthroughs have resulted in new or significantly improved products, processes or services. An independent committee of experts from the scientific and technological community evaluates the candidates, who are nominated through an open, national competitive solicitation. Photographs of the winners and additional information about them appear on the Scientific American Web site (www.sciam.com/explorations/1998/121498medal/index.html).*

## DENTON A. COOLEY

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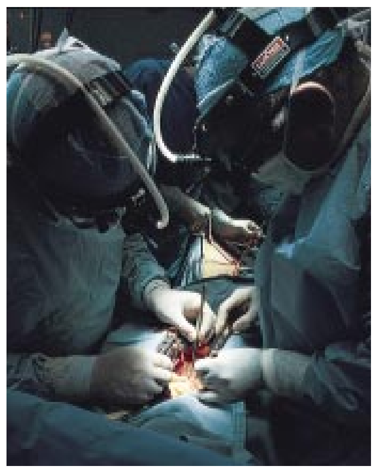
Texas Medical Center
Houston, Tex.



GEORGE CHAN Photo Researchers, Inc.

***OPEN-HEART SURGERY** techniques were pioneered by Denton A. Cooley.*

Fourteen million Americans have coronary heart disease, and 500,000 die from the condition every year, making it the leading killer of men and women in the U.S. That number might have been substantially higher were it not for the advances made by renowned surgeon Denton A. Cooley. The awards committee has honored him "for his inspirational skill, leadership, and technical accomplishments during six decades of practicing cardiovascular surgery."

Cooley has personally conducted more than 200,000 cardiovascular procedures—45,000 of them open-heart surgeries. More important than quantity, however, were his pioneering efforts to change the way such operations are done. In 1962 he began to use glucose solutions rather than blood to prime the heart-lung machine, which circulates oxygenated blood through the patient during surgery. This change enabled surgeons to conserve blood, thereby boosting the number of operations that could be done. Cooley also developed techniques to repair and replace defective heart valves and designed about 200 surgical instruments, grafts and related materials.

Several of Cooley's high-profile operations led the way on procedures now used much more routinely. He performed the first successful human heart transplant in the U.S. in 1968. (Surgeon Christiaan Barnard's success in South Africa had been a year earlier.) Cooley was the first surgeon in the world, in 1969, to keep a patient on an artificial heart, as a temporary measure until an appropriate donor heart could be located. He also founded the Texas Heart Institute at Houston's Texas Medical Center in 1962. Considered one of his most significant contributions, the institute has become world-famous in cardiology. It has produced implantable devices that assist failing hearts and, with its clinical partner, St. Luke's Episcopal Hospital, operated on more than 400,000 patients. Through the institute, more than 1,900 physicians have learned to treat cardiovascular disease.

The 78-year-old Cooley, who has garnered more than 80 honors and awards, almost had another coup this past summer. He was scheduled to perform the first open-heart surgery—a quadruple bypass—broadcast over the Internet. A medical team in Seattle, however, heard the announcement and decided to beat him, by one day. Cooley graciously accepted runner-up status. "I'm not interested in an exclusive," he told Reuters. "Ours is strictly an educational process." The Seattle physicians, though, have far to go to match Cooley's distinguished record.

## ROBERT T. FRALEY
## ROBERT B. HORSCH
## ERNEST G. JAWORSKI
## STEPHEN G. ROGERS

Biotechnologists
Monsanto Company
St. Louis, Mo.

For at least 10,000 years, humans have sought to boost the quality of their crops—by saving the seeds of the best plants, for instance, or by crossbreeding to develop new varieties. Today scientists can manipulate plant qualities at the genetic level. The Monsanto scientists won the national medal "for their pioneering achievements in plant biology and agricultural biotechnology and for global leadership in the development and commercialization of genetically modified crops to enhance agricultural productivity and sustainability."

PHOTOGRAPHS BY MONSANTO

***COTTON PLANTS genetically engineered to make their own insecticide thrive as their ordinary cousins are devastated by insects*** **(above).** ***The same antipest gene was inserted into corn, whose stalks remain healthy*** **(top right)*****; ordinary stalks are devoured by the European corn borer*** **(bottom right).**

Potent chemicals have been the foundation of agriculture's battles with insects, weeds and disease. But in 1980 Monsanto's Ernest G. Jaworski wondered how molecular biology could help. He recruited Stephen G. Rogers, Robert T. Fraley and Robert B. Horsch to explore the genetic engineering of crops. Thanks to their efforts, Monsanto has developed several transgenic crops, including tomato, cotton, soybean and corn.

The most widely used method of introducing new genes into plants is through the bacterium *Agrobacterium tumefaciens*. This pathogen naturally transfers some of its DNA into the chromosomes of infected plants. The commandeered cells produce hormones that lead to tumors and root masses in which the bacteria prefer to live. The bioengineering trick is to remove the disease-causing genes of the pathogen, preserving the bacteria's ability to infect and piggybacking new genes for desirable traits on the bacterial DNA. The researchers accomplished this goal in 1983 [see "Transgenic Crops," by Charles S. Gasser and Robert T. Fraley; SCIENTIFIC AMERICAN, June 1992].

With the bioengineering skills at hand, Monsanto scientists produced plants that resist premature ripening, withstand the widely used herbicide Roundup and make their own insecticidal protein. Monsanto says that such plants reduce the need for spraying. In a 1996 trial 60 percent of farmers who planted the modified cotton did not need to spray to protect against bollworm, and most of the others had to spray only once. Traditional cotton fields, in contrast, generally need four to six sprayings. The environment was thus spared, by Monsanto's estimates, some 250,000 gallons (nearly a million liters) of insecticide.

The U.S. Department of Agriculture has approved 35 transgenic crops for cultivation. Domestically, more than 50 million acres (20 million hectares) of them, under such trade names as Bollgard cotton and NewLeaf potatoes, have been sown. Some investigators, however, are concerned that insecticide-producing plants could someday lead to resistant insects. Others fear that transgenic crops could decrease the diversity of crops planted.

And although the U.S. has largely accepted Monsanto's biotechnology, the rest of the world remains wary. In Europe, radical environmental groups have destroyed crop trials being performed by Monsanto—often with admiring publicity. In December, an uproar swept India when rumors circulated that Monsanto had inserted a "terminator" gene in its transgenic cotton. Such a gene would render the seed sterile, so that farmers would have to buy seeds every planting season. (Traditionally, farmers set aside some of their harvested seeds.) According to Monsanto, it is still years away from incorporating a terminator gene into transgenic plants, although it also argues such a gene could be needed to protect its patents.

Despite the controversy abroad, Monsanto remains committed to transgenic crops. "Biotechnology, combined with other proven agricultural methods and practices," it states in a corporate background paper, "offers exciting and environmentally responsible ways to help meet consumer demands for sustainable and healthy food and fiber production—today and in the future."

## KENNETH L. THOMPSON
## DENNIS M. RITCHIE

Computer scientists
Bell Laboratories, Lucent Technologies
Murray Hill, N.J.

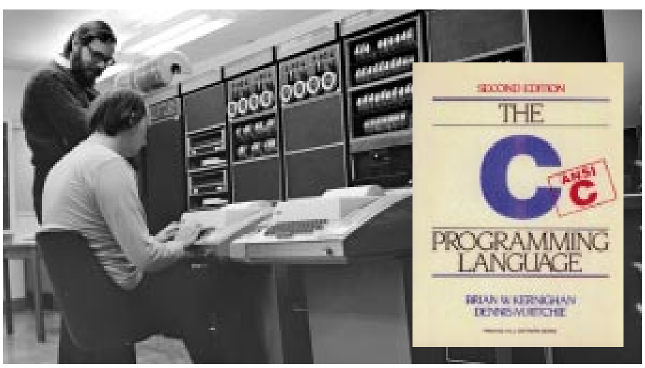
When visiting a Web page or searching through a company database, you are benefiting from the labors of Kenneth L. Thompson and Dennis M. Ritchie. Thanks to their influential and pioneering efforts, they won the medal "for the invention of the Unix operating system and the C programming language, which led to enormous advances in computer hardware, software and networking systems."

Unix is one of the landmark steps in computing. Before it came into being in 1969, operating system software was large and machine-specific. Unix was the first portable operating system, one that could be used on devices ranging from personal computers to mainframes. It is now the operating system of most large Internet servers, businesses and universities. Ritchie, Thompson and their Bell Labs colleagues later devised the C language in the early 1970s as a means to implement Unix. C was the first general-purpose language to combine the efficiency of assembler (the language closest to the machine code of 0's and 1's) with higher-level programming expressions. Like Unix, it could be used with little change across a variety of machines. With its descendant languages C++ and Java, C is the most common language of commercial software.

The development of Unix and C serves as an object lesson in how creativity and necessity lead to innovation. In the mid-1960s Thompson and Ritchie worked on the huge Multics project, a collaboration among Bell Labs, General Electric and the Massachusetts Institute of Technology that attempted to develop an operating system. Soon Bell Labs withdrew from the project and began reorganizing its computing division. Among the last Bell Labs workers on the Multics project, Thompson and Ritchie wished to complete the project's goal. As Ritchie described in a 1984 paper in the *AT&T Bell Laboratories Technical Journal,* "What we wanted to preserve was not just a good environment in which to do programming, but a system around which a fellowship could form."

Time and again, though, management rejected their proposals for a medium-scale machine on which they could develop such a system. (Ritchie writes that in retrospect, "we were asking the Labs to spend too much money on too few people with too vague a plan.") Thompson did find a little-used, eight-kilobyte-memory machine (a DEC PDP-7 computer), on which the workers developed Unix—in part, by adapting Thompson's game called Space Travel, which involved flying a ship through the solar system. Colleague Brian W. Kernighan suggested the name Unix—a pun on Multics.

Thompson decided that Unix needed a programming language. After trying FORTRAN, he quickly adapted BCPL, a language used by the Multics project, and thus created B. In 1971 Ritchie extended the technical features of B, creating C. Today the classic book by Kernighan and Ritchie, *The C Programming Language,* first published in 1978, has been translated into more than a dozen languages and remains an indispensable reference for all serious programmers.




COURTESY OF BELL LABORATORIES, LUCENT TECHNOLOGIES; PRENTICE-HALL

***DEVELOPERS OF UNIX AND C** were Kenneth L. Thompson* (standing) *and Dennis M. Ritchie, shown here in the early 1970s. The text describing C has become a classic reference.*

## BIOGEN, INC.

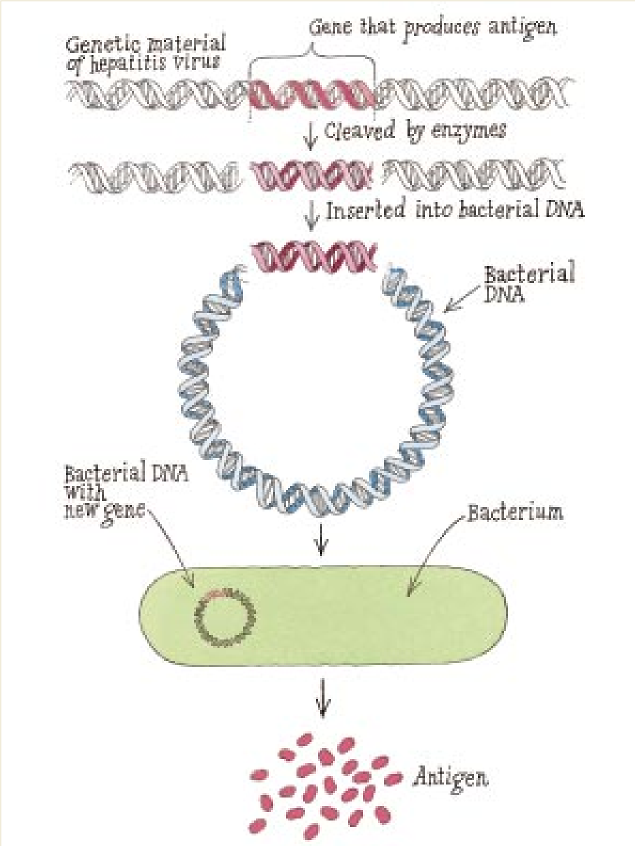
Biopharmaceuticals
Cambridge, Mass.
James Vincent, chairman

In 1977 an international group of scientists—including two who would later win Nobel prizes (Walter Gilbert of Harvard University and Phillip A. Sharp of the Massachusetts Institute of Technology)—began discussing with venture capitalists a new way to develop pharmaceuticals. At the time, academic scientists rarely delved into the commercial realm. But a year later Gilbert, Sharp and their colleagues founded Biogen, dedicated to creating drugs through molecular-biology techniques. Biogen has since become a leading biopharmaceutical company: combined sales of its licensed products exceeded $2 billion in 1996. The medal committee has applauded Biogen "for its leadership in applying breakthroughs in biology to the development of life-saving and life-enhancing pharmaceutical products designed to treat large, previously underserved patient populations throughout the world."

The product cited for special recognition was Biogen's vaccine for hepatitis B (marketed by SmithKline Beecham and Merck, among others). Like its cousin hepatitis C, which is making the most headlines these days [see "$R_x$ for B and C," News and Analysis, on page 17], hepatitis B is a viral infection that can seriously, even fatally, damage the liver. The significance of Biogen's anti–hepatitis B product lies not just in its lifesaving potential but also in its origin: it is the first vaccine ever created through recombinant DNA.

Biogen researchers analyzed the genes of the hepatitis B virus and identified those that code for antigens, the proteins that trigger an immune response in humans. Isolating these genes, Biogen scientists then inserted them into bacteria, which manufactured the antigens in abundance. These antigens could then be injected into people, whose immune systems would "remember" those antigens and in the future destroy any cell presenting them. In this way, the immune system could protect the body from the hepatitis B virus.

In a similar way, Biogen is also responsible for Intron A, or alpha-interferon. Interferons have strong antiviral and anticancer properties. Biogen took DNA that coded for interferon production and then spliced it into the genome of an *Escherichia coli* bacterium. The new gene forced the bacterium to produce




DUSAN PETRICIC

***RECOMBINANT DNA TECHNIQUE** was the basis for the hepatitis B vaccine. The virus's gene for antigens was identified, isolated and merged with the DNA of a bacterium, which then produced the antigen in abundance.*

alpha-interferon. With this technique, researchers could make large quantities of the interferon at a reasonable cost.

Biogen, which also conducts research in developmental biology and gene therapy, has several other drugs in clinical testing. It also licenses its basic know-how so that other firms can create or boost production of proteins from bacterial hosts.

## BRISTOL-MYERS SQUIBB COMPANY

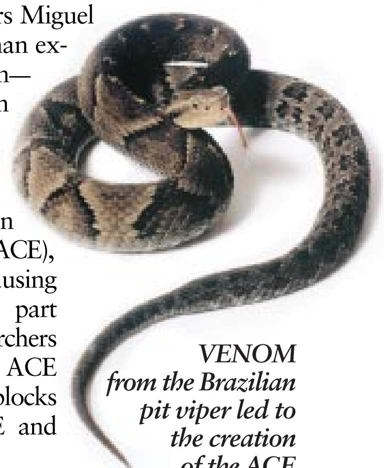
Pharmaceuticals
New York City
Charles A. Heimbold, Jr., chairman

Your medicine cabinet is likely to hold plenty of products from Bristol-Myers Squibb, such as painkillers and hand lotions. But those represent just a small fraction of the products made by this multibillion-dollar worldwide firm, which also makes drugs that fight cancer and infectious diseases, among other maladies. The awards committee bestowed its medal on Bristol-Myers Squibb "for extending and enhancing human life through innovative pharmaceutical research and development, and for redefining the science of clinical study through groundbreaking and hugely complex clinical trials."

Bristol-Myers Squibb is particularly proud of two of its cardiovascular drugs. One is captopril (sold under the brand-name Capoten). This agent for hypertension is the first to have been designed by a process called rational (or structure-based) drug design. Most pharmaceuticals today have been found by chance observation or by painstaking trial-and-error screening of large numbers of candidate drugs [see "Combinatorial Chemistry and New Drugs," by Matthew J. Plunkett and Jonathan A. Ellman; Scientific American, April 1997]. In contrast, rational drug design tries to develop compounds that attack specific parts of molecules that are involved in disease. In principle, such an approach can be a faster, less expensive way to produce drugs that are more potent and have fewer side effects [see "Drugs by Design," by Charles E. Bugg, William M. Carson and John A. Montgomery; Scientific American, December 1993].

The key is to determine the molecular architecture of the target substance, which can be accomplished by shining x-rays through crystals of it. The crystalline structure diffracts the x-rays, producing a characteristic splatter of spots from which researchers, with computer help, can determine the three-dimensional arrangement of the constituent atoms.

In the 1970s Squibb researchers Miguel A. Ondetti and David W. Cushman exploited this kind of information—with the help of the venom from the Brazilian pit viper. The toxin catastrophically lowers the blood pressure of its victims. A component of the venom blocks the action of angiotensin converting enzyme (ACE), which raises blood pressure by causing blood vessels to constrict. In part through crystallography, the researchers constructed a model of the active ACE site and created captopril, which blocks the site, thereby inhibiting ACE and bringing down the blood pressure.

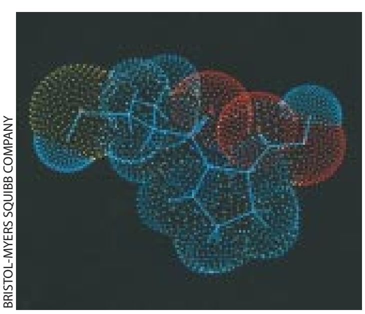


BRISTOL-MYERS SQUIBB COMPANY

***VENOM** from the Brazilian pit viper led to the creation of the ACE inhibitor captopril.*

Pravastatin (Pravachol) is the other noteworthy drug made by Bristol-Myers Squibb. Like its cousins in the statin family, such as simvastatin and lovastatin (from Merck), the drug lowers cholesterol. In a five-year study of 6,595 men published in 1995, pravastatin lowered total cholesterol by 20 percent and low-density lipoprotein cholesterol ("bad" cholesterol) by 26 percent. In addition to the large trial size, a key aspect of this study was that it examined ostensibly healthy men (most previous cholesterol-busting drug studies focused on those with demonstrated heart problems). Perhaps more important, this and subsequent trials showed that pravastatin not only lowered cholesterol but also cut the risk of death from heart disease.

Spearheading Bristol-Myers Squibb's R&D efforts is its Pharmaceutical Research Institute, based in Princeton, N.J. It currently has some 50 agents in development. In all, the company invests about $1.3 billion every year in drug research. SA

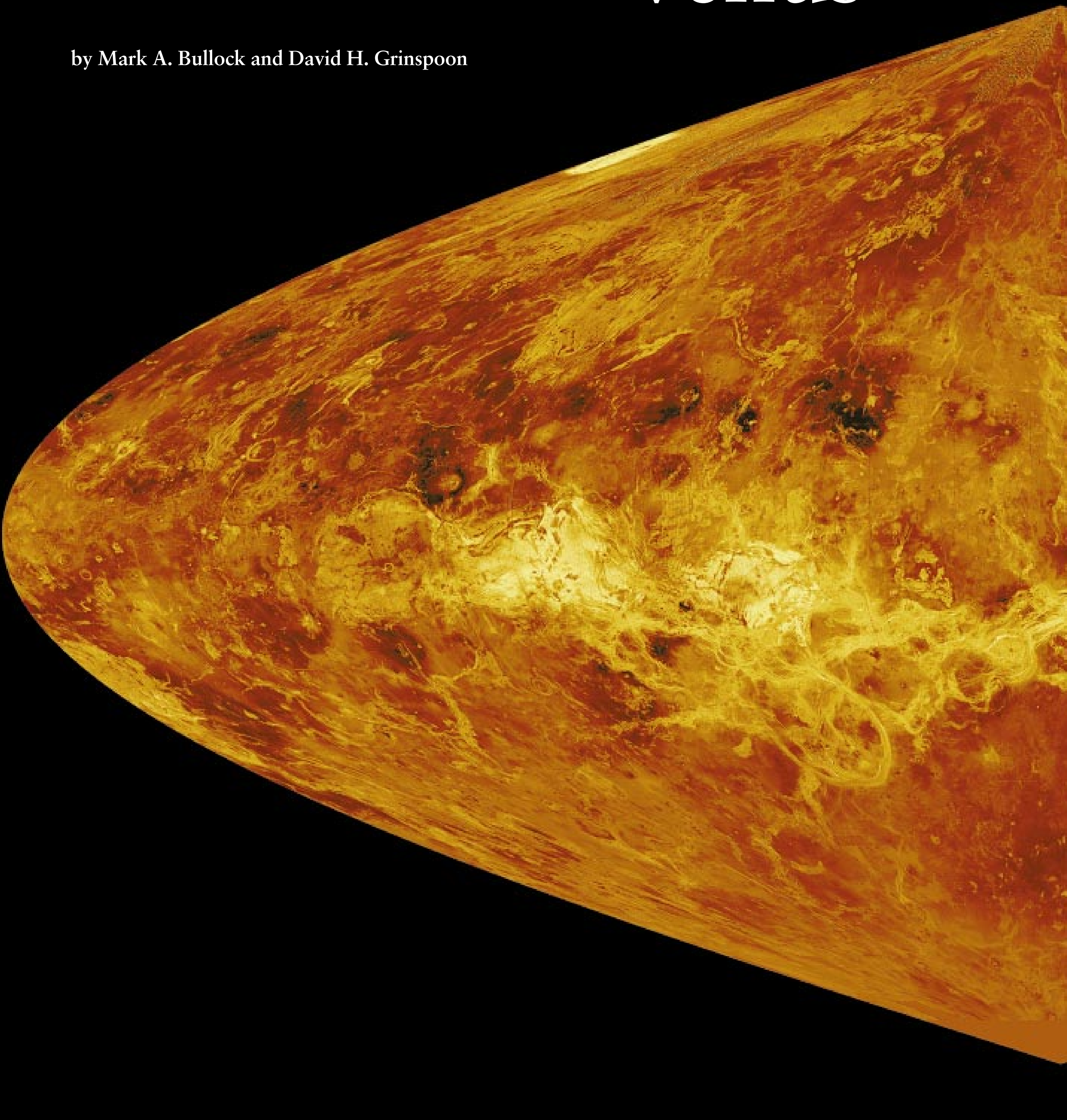


BRISTOL-MYERS SQUIBB COMPANY

***CAPTOPRIL** reveals its molecular structure through x-ray crystallography.*

# Global Climate Change on Venus

by Mark A. Bullock and David H. Grinspoon

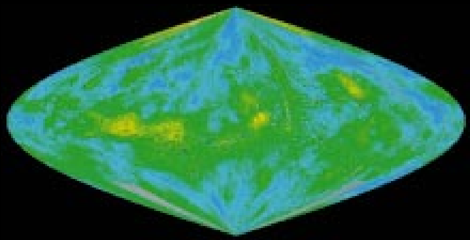


*Venus's climate, like Earth's, has varied over time—the result of newly appreciated connections between geologic activity and atmospheric change*

NASA/JET PROPULSION LABORATORY

**SURFACE OF VENUS** was scanned by a radar system on board the Magellan space probe to a resolution of 120 meters (400 feet)—producing the most complete global view available for any planet, including Earth. A vast equatorial system of highlands and ridges runs from the continentlike feature Aphrodite Terra (*left of center*) through the bright highland Atla Regio (*just right of center*) to Beta Regio (*far right and north*). This image is centered at 180 degrees longitude. It has been drawn using a sinusoidal projection, which, unlike traditional map projections such as the Mercator, does not distort the area at different latitudes. Dark areas correspond to terrain that is smooth at the scale of the radar wavelength (13 centimeters); bright areas are rough. The meridional striations are image artifacts.

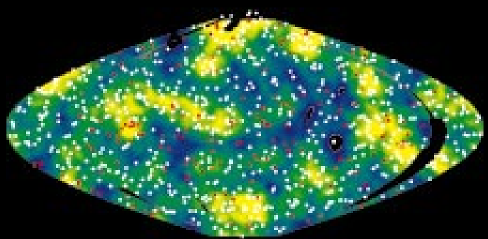
## TOPOGRAPHY



The topography of Venus spans a wide range of elevations, about 13 kilometers from low (*blue*) to high (*yellow*). But three fifths of the surface lies within 500 meters of the average elevation, a planetary radius of 6,051.9 kilometers. In contrast, topography on Earth clusters around two distinct elevations, which correspond to continents and ocean floors.

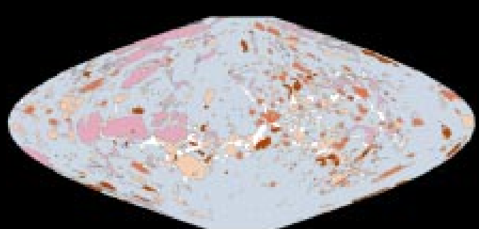
NASA/JET PROPULSION LABORATORY

## IMPACT CRATERS



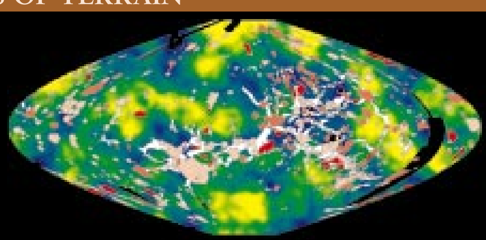
Impact craters are randomly scattered all over Venus. Most are pristine (*white dots*). Those modified by lava (*red dots*) or by faults (*triangles*) are concentrated in places such as Aphrodite Terra. Areas with a low density of craters (*blue background*) are often located in highlands. Higher crater densities (*yellow background*) are usually found in the lowland plains.

## TYPES OF TERRAIN



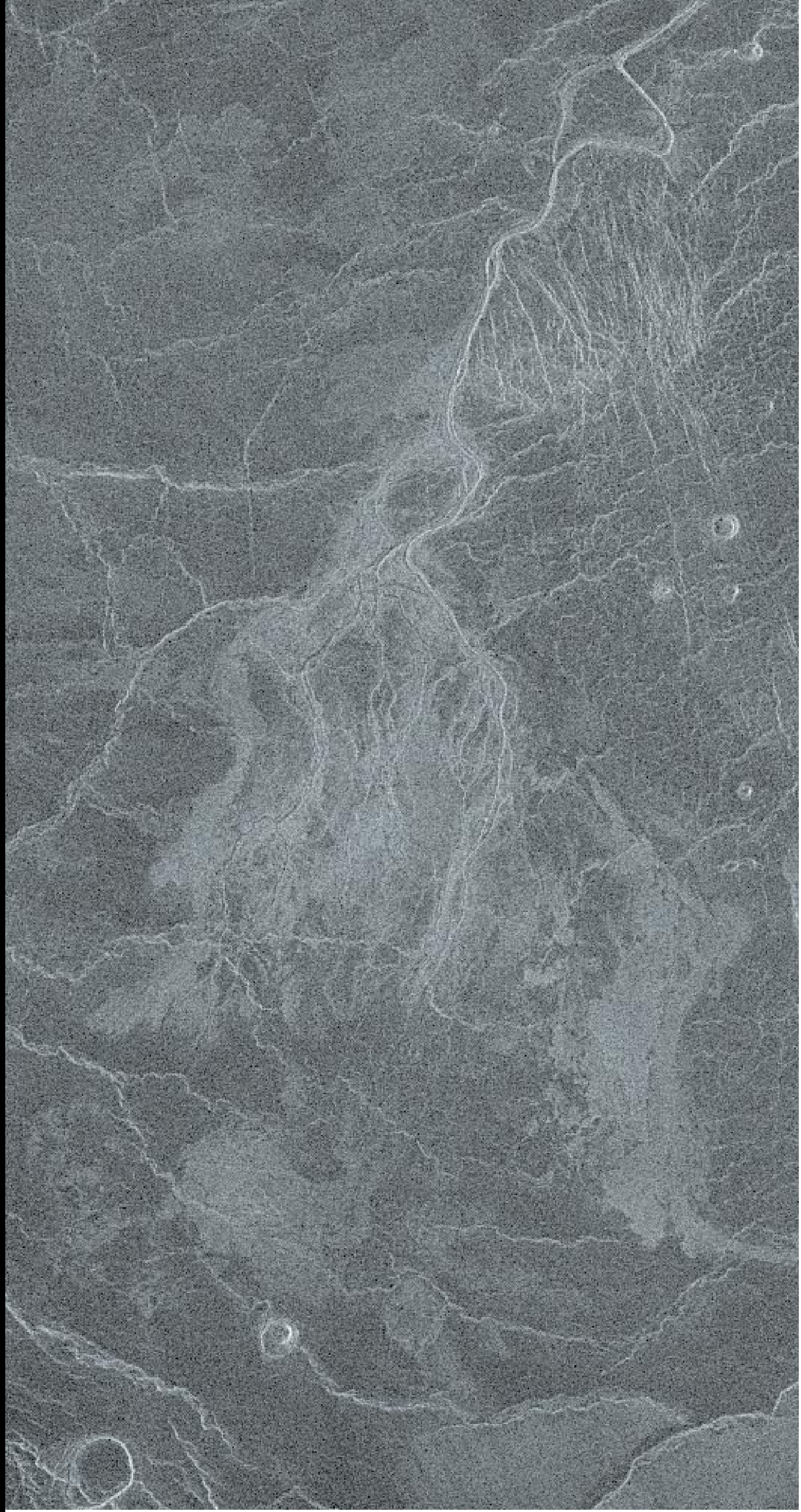
The terrain of Venus consists predominately of volcanic plains (*blue*). Within the plains are deformed areas such as tesserae (*pink*) and rift zones (*white*), as well as volcanic features such as coronae (*peach*), lava floods (*red*) and volcanoes of various sizes (*orange*). Volcanoes are not concentrated in chains as they are on Earth, indicating that plate tectonics does not operate.

## AGES OF TERRAIN



This geologic map shows the different terrains and their relative ages, as inferred from the crater density. Volcanoes and coronae tend to clump along equatorial rift zones, which are younger (*blue*) than the rest of the Venusian surface. The tesserae, ridges and plains are older (*yellow*). In general, however, the surface lacks the extreme variation in age that is found on Earth and Mars.

MARIBETH PRICE *South Dakota School of Mines and Technology (bottom three images)*



NASA/JET PROPULSION LABORATORY

RIVER ON VENUS? This delta exists at the terminus of a narrow channel that runs for 800 kilometers through the northern volcanic plains. Water could not have carved it; Venus is too hot and dry. Instead it was probably the work of lavas rich in carbonate and sulfate salts—which implies that the average temperature used to be several tens of degrees higher than it is today. The region shown here is approximately 40 by 90 kilometers.

NASA/JET PROPULSION LABORATORY

**WRINKLE RIDGES are the most common feature on the volcanic plains of Venus. They are parallel and evenly spaced, suggesting that they formed when the plains as a whole were subjected to stress—perhaps induced by a dramatic, rapid change in surface temperature. This region, which is part of the equatorial plains known as Rusalka Planitia, is approximately 300 kilometers across.**

Emerging together from the presolar cauldron, Earth and Venus were endowed with nearly the same size and composition. Yet they have developed into radically different worlds. The surface temperature of Earth's sister planet is about 460 degrees Celsius—hot enough for rocks to glow visibly to any unfortunate carbon-based visitors. A deadly efficient greenhouse effect prevails, sustained by an atmosphere whose major constituent, carbon dioxide, is a powerful insulator. Liquid water is nonexistent. The air pressure at the surface is almost 100 times that on Earth; in many ways it is more an ocean than an atmosphere. A mélange of gaseous sulfur compounds, along with what little water vapor there is, provides chemical fodder for the globally encircling clouds of sulfuric acid.

This depiction of hell has been brought to us by an armada of 22 robotic spacecraft that have photographed, scanned, analyzed and landed on Venus over the past 37 years. Throughout most of that time, however, Venus's obscuring clouds hindered a full reconnaissance of its surface. Scientists' view of the planet remained static because they knew little of any dynamic processes, such as volcanism or tectonism, that might have occurred there. The Magellan spacecraft changed that perspective. From 1990 to 1994 it mapped the entire surface of the planet at high resolution by peering through the clouds with radar [see "The Surface of Venus," by R. Stephen Saunders; Scientific American, December 1990]. It revealed a planet that has experienced massive volcanic eruptions in the past and is almost surely active today. Coupled with this probing of Venusian geologic history, detailed computer simulations have attempted to reconstruct the past billion years of the planet's climate history. The intense volcanism, researchers are realizing, has driven large-scale climate change. Like Earth but unlike any other planet astronomers know, Venus has a complex, evolving climate.

Earth's other neighbor, Mars, has also undergone dramatic changes in climate [see "Global Climate Change on Mars," by Jeffrey S. Kargel and Robert G. Strom; Scientific American, November 1996]. Its atmosphere today, however, is a relic of its geologic past. The interior of Mars is too cool now for volcanism to be active, and the surface rests in a deep freeze. Although variations in Mars's orbital and rotational motions can induce climate change there, volcanism will never again participate. Earth and Venus, on the other hand, have climates that are driven by the dynamic interplay between geologic and atmospheric processes.

From our human vantage point next door in the solar system, it is sobering to ponder how forces similar to those on Earth have had such a dissimilar outcome on Venus. Studying that planet has broadened research on climate evolution beyond the single example of Earth and given scientists new approaches for answering pressing questions: How unique is Earth's climate? How stable is it? Humankind is engaged in a massive, uncontrolled experiment on the terrestrial climate brought on by the growing effluent from a technological society. Discerning the factors that affect the evolution of climate on other planets is crucial to understanding how natural and anthropogenic forces alter the climate on Earth.

To cite one example, long before the ozone hole became a topic of household discussion, researchers were trying to come to grips with the exotic photochemistry of Venus's upper atmosphere. They found that chlorine reduced the levels of free oxygen above the planet's clouds. The elucidation of this process for Venus eventually shed light on an analogous one for Earth, whereby chlorine from artificial sources destroys ozone in the stratosphere.

## Climate and Geology

The climate of Earth is variable partly because its atmosphere is a product of the ongoing shuffling of gases among the crust, the mantle, the oceans, the polar caps and outer space. The ultimate driver of geologic processes, geothermal energy, is also an impetus for the evolution of the atmosphere. Geothermal energy is a product primarily of the decay of radioactive elements in the interior, and a central problem in studying solid planets is understanding how they lose their heat. Two mechanisms are chiefly responsible: volcanism and plate tectonics.

The interior of Earth cools mainly by means of its plate tectonic conveyor-belt system, whose steady recycling of gases has exerted a stabilizing force on Earth's climate [*see box on page 56*]. Whereas volcanoes pump gases into the atmosphere, the subduction of lithospheric plates returns them to the interior. Most volcanoes are associated with plate tectonic activity, but some of the largest volcanic edifices on Earth (such as the Hawaiian Islands) have developed as "hot spots" independent of plate boundaries. Historically, the formation of immense volcanic provinces—regions of intense eruptions possibly caused by enormous buoyant plumes of magma within the underlying mantle—may have spewed large amounts of gases and led to periods of global warming [see "Large Igneous Provinces," by Millard F. Coffin and Olav Eldholm; SCIENTIFIC AMERICAN, October 1993].

What about Venus? Before the Magellan mission, much of the planet's geologic history remained speculative, relegated to comparisons with Earth and to extrapolations based on presumed similarities in composition and geothermal heat production. Now a global picture of the history of Venus's surface is emerging. Plate tectonics is not in evidence, except possibly on a limited scale. It appears that heat was transferred, at least in the relatively recent past, by the eruption of vast plains of basaltic lava and later by the volcanoes that grew on top of them. Understanding the effects of volcanoes is the starting point for any discussion of climate.

A striking feature of Magellan's global survey is the paucity of impact craters. Although Venus's thick atmosphere can shield the planet's surface from small impactors—it stops most meteoroids smaller than a kilometer in diameter, which would otherwise gouge craters up to 15 kilometers (nine miles) across—there is a shortage of larger craters as well. Observations of the number of asteroids and comets in the inner solar system, as well as crater counts on the moon, give a rough idea of how quickly Venus should have collected impact scars: about 1.2 craters per million years. Magellan saw only, by the latest count, 963 craters spread randomly over its surface. Somehow impacts from the first 3.7 billion years of the planet's history have been eradicated.

A sparsity of craters is also evident on Earth, where old craters are eroded by wind and water. Terrestrial impact sites are found in a wide range of altered states, from the nearly pristine bowl of Meteor Crater in Arizona to the barely discernible outlines of buried Precambrian impacts in the oldest continental crust. Yet the surface of Venus is far too hot for liquid water to exist, and surface winds are mild. In the absence of erosion, the chief processes altering and ultimately erasing impact craters should be volcanic and tectonic activity. That is the paradox. Most of the Venusian craters look fresh: only 6 percent of them have lava lapping their rims, and only 12 percent have been disrupted by folding and cracking of the crust. So where did all the old ones go, if most of those that remain are unaltered? If they have been covered up by lava, why do we not see more craters that are partially covered? And how have they been removed so that their initial random placement has been preserved?

To some researchers, the random distribution of the observed craters and the small number of partially modified ones imply that a geologic event of global proportions abruptly wiped out all the old craters some 800 million years ago. In this scenario, proposed in 1992 by Gerald G. Schaber of the U.S. Geological Survey (USGS) and Robert G. Strom of the University of Arizona, impacts have peppered the newly formed surface ever since.

But the idea of paving over an entire planet is unpalatable to many geologists. It has no real analogue on Earth. Roger J. Phillips of Washington University proposed an alternative model the same year, known as equilibrium resurfacing, which hypothesized that steady geologic processes continually eradicate craters in small patches, preserving an overall global distribution that appears random. A problem with this idea is that some geologic features on Venus are immense, suggesting that geologic activity would not wipe craters out cleanly and randomly everywhere.

These two views grew into a classic scientific debate as the analysis of Magellan data became more sophisticated. The truth is probably somewhere in the middle. Elements of both models have been incorporated into the prevailing interpretation of the past billion years of Venus's geologic history: globally extensive volcanism wiped out most impact craters and created the vast volcanic plains 800 million years ago, and it has been followed by a reduced level of continued volcanic activity up to the present.

### Chocolate-Covered Caramel Crust

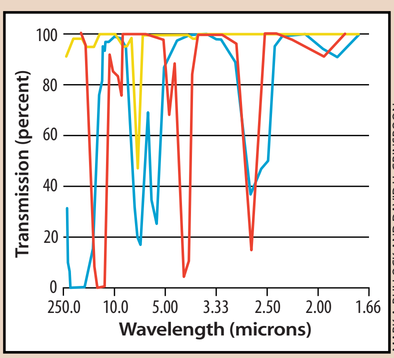
Although there is no doubt that volcanism has been a major force in shaping Venus's surface, the interpretation of some enigmatic geologic features has until recently resisted integration into a coherent picture of the planet's evolution. Some of these features hint that the planet's climate may have changed drastically.

First, several striking lineaments resemble water-carved landforms. Up to 7,000 kilometers long, they are similar to meandering rivers and floodplains on Earth. Many end in outflow channels that look like river deltas. The extreme dryness of the environment makes it highly unlikely that water carved these features. So what did? Perhaps calcium carbonate, calcium sulfate and other salts are the culprit. The surface, which is in equilibrium with a hefty carbon dioxide atmosphere laced with sulfur gases, should be replete with these substances. Indeed, the Soviet Venera landers found that surface rocks are about 7 to 10 percent calcium minerals (almost certainly carbonates) and 1 to 5 percent sulfates.

Lavas laden with these salts melt at temperatures of a few tens to hundreds of degrees higher than Venusian surface temperatures today. Jeffrey S. Kargel of the USGS and his co-workers have hypothesized that vast reservoirs of molten carbonatite (salt-rich) magma, analogous to water

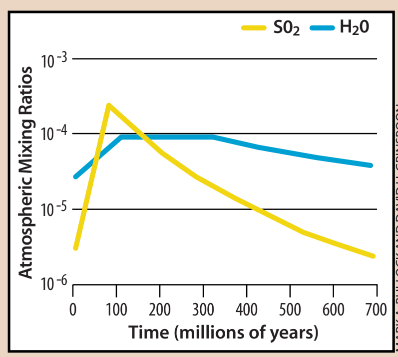
## GREENHOUSE EFFECT

Greenhouse gases let sunlight reach the Venusian surface but block outgoing infrared light. Carbon dioxide (*red*), water (*blue*) and sulfur dioxide (*yellow*) each absorb a particular set of wavelengths. Were it not for these gases, the sunlight and infrared light would balance each other at a surface temperature of about −20 degrees Celsius (−4 degrees Fahrenheit).




## GAS CONCENTRATIONS

Water and sulfur dioxide are removed from the atmosphere after they are belched out by volcanoes. Sulfur dioxide (*yellow*) reacts relatively quickly with carbonates at the surface, whereas water (*blue*) is slowly broken apart by solar ultraviolet radiation.

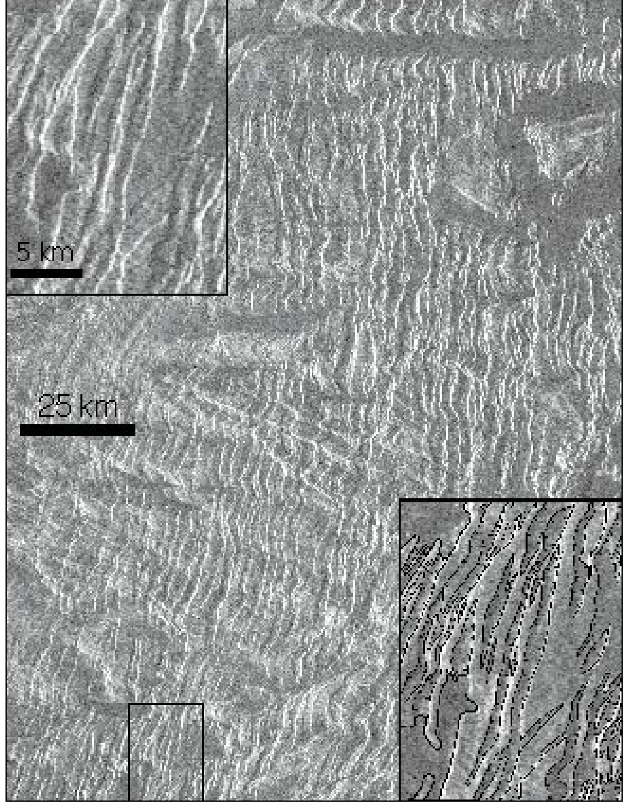


aquifers on Earth, may exist a few hundred meters to several kilometers under the surface. Moderately higher surface temperatures in the past could have spilled salt-rich fluid lavas onto the surface, where they were stable enough to carve the features we see today.

Second, the mysterious tesserae—the oldest terrain on Venus—also hint at higher temperatures in the past. These intensely crinkled landscapes are located on continentlike crustal plateaus that rise several kilometers above the lowland lava plains. Analyses by Phillips and by Vicki L. Hansen of Southern Methodist University indicate that the plateaus were formed by extension of the lithosphere (the rigid exoskeleton of the planet, consisting of the crust and upper mantle). The process was something like stretching apart a chocolate-covered caramel that is gooey on the inside with a thin, brittle shell. Today the outer, brittle part of the lithosphere is too thick to behave this way. At the time of tessera formation, it must have been thinner, which implies that the surface was significantly hotter.

Finally, cracks and folds crisscross the planet. At least some of these patterns, particularly the so-called wrinkle ridges, may be related to temporal variations in climate. We and Sean C. Solomon of the Carnegie Institution of Washington have argued that the plains preserve globally coherent episodes of deformation that may have occurred over short intervals of geologic history. That is, the entire lithosphere seems to have been stretched or compressed all at the same time. It is hard to imagine a mechanism internal to the solid planet that could do that. But what about global climate change? Solomon calculated that stresses induced in the lithosphere by fluctuations in surface temperature of about 100 degrees C (210 degrees Fahrenheit) would have been as high as 1,000 bars—comparable to those that form mountain belts on Earth and sufficient to deform Venus's surface in the observed way.

Around the time that the debate over Venus's recent geologic history was raging, we were working on a detailed model of its atmosphere. Theory reveals that the alien and hostile conditions are maintained by the complementary properties of Venus's atmospheric constituents. Water vapor, even in trace amounts, absorbs infrared radiation at wavelengths that carbon dioxide does not. Sulfur dioxide and other sulfur gases block still other infrared wavelengths [*see illustration below left*]. Together these greenhouse gases conspire to make the atmosphere of Venus partially transparent to incoming solar radiation but nearly completely opaque to outgoing thermal radiation. Consequently, the surface temperature (measured in kelvins) is three times what it would be without an atmosphere. On Earth, by comparison, the greenhouse effect currently




VICKI L. HANSEN *Southern Methodist University* AND ROGER J. PHILLIPS *Washington University*

**RIBBON TERRAIN consists of steep-sided, flat-bottomed, shallow (400-meter) troughs. These features may have resulted from fracturing of a thin, brittle layer of rock above a weaker, ductile substrate. The insets show an enlargement of the region in the box, with the troughs marked on the bottom right.**

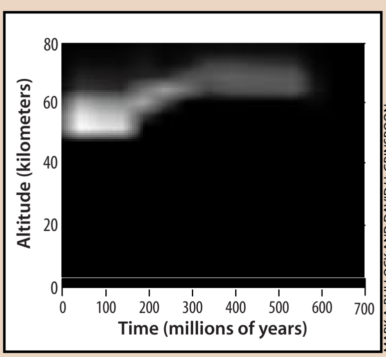
boosts the surface temperature by only about 15 percent.

If volcanoes really did repave the Venusian surface 800 million years ago, they should have also injected a great deal of greenhouse gases into the atmosphere in a relatively short time. A reasonable estimate is that enough lava erupted to cover the planet with a layer one to 10 kilometers thick. In that case, the amount of carbon dioxide in the atmosphere would have hardly changed—there is already so much of it. But the abundances of water vapor and sulfur dioxide would have increased 10- and 100-fold, respectively. Fascinated by the possible implications, we modeled the planet's climate as an interconnected system of processes, including volcanic outgassing, cloud formation, the loss of hydrogen from the top of the atmosphere, and reactions of atmospheric gases with surface minerals.

The interaction of these processes can be subtle. Although carbon dioxide, water vapor and sulfur dioxide all warm the surface, the last two also have a countervailing effect: the production of clouds. Higher concentrations of water vapor and sulfur dioxide would not only enhance the greenhouse

## CLOUD COVER

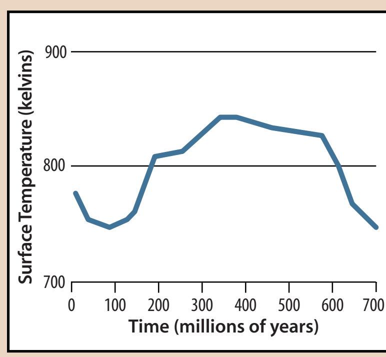
The sulfuric acid clouds vary in thickness after a global series of volcanic eruptions. The clouds first thicken as water and sulfur dioxide pour into the air. Then they dissipate as these gases thin out. About 400 million years after the onset of volcanism, the acidic clouds are replaced by thin, high water clouds.




MARK A. BULLOCK AND DAVID H. GRINSPOON

## TEMPERATURE

The surface temperature depends on the relative importance of clouds and the greenhouse effect. Initially volcanism produces thick clouds that cool the surface. But because water is lost more slowly from the planet's atmosphere than sulfur dioxide is, a greenhouse effect subsequently warms the surface.




MARK A. BULLOCK AND DAVID H. GRINSPOON

## Why Is Venus a Hellhole?

The stunning differences between the climates of Earth and Venus today are intimately linked to the history of water on these two worlds. The oceans and atmosphere of Earth currently have 100,000 times as much water as the atmosphere of Venus. Liquid water is the intermediary in reactions of carbon dioxide with surface rocks. Because of it, carbon dioxide in the air can form minerals. In addition, water mixed into the underlying mantle is probably responsible for the low-viscosity layer, or asthenosphere, on which Earth's lithospheric plates slide. The formation of carbonate minerals and their subsequent descent on tectonic plates prevent carbon dioxide from building up to the levels seen on Venus.

Yet models of planet formation predict that the two worlds should have been endowed with roughly equal amounts of water, delivered by the impact of icy bodies from the outer solar system. In fact, when the Pioneer Venus mission went into orbit in 1978, it measured the ratio of deuterium to ordinary hydrogen within the water of Venus's clouds. The ratio was an astonishing 150 times the terrestrial value [see "The Pioneer Mission to Venus," by Janet G. Luhmann, James B. Pollack and Lawrence Colin; Scientific American, April 1994]. The most likely explanation is that Venus once had far more water and lost it. Both the hydrogen and the deuterium, which are chemically equivalent, were tied up in water molecules. When water vapor drifted into the upper atmosphere, solar ultraviolet radiation decomposed it into oxygen and either hydrogen or deuterium. Because hydrogen, being lighter, escapes to space more easily than deuterium does, the relative amount of deuterium increased.

Why did this process occur on Venus but not on Earth? In 1969 Andrew P. Ingersoll of the California Institute of Technology showed that if the solar energy available to a planet were strong enough, any water at the surface would rapidly evaporate. The added water vapor would further heat the atmosphere and set up what he called the runaway greenhouse effect. The process would transport the bulk of the planet's water into the upper atmosphere, where it would ultimately be decomposed and lost. Later James F. Kasting of Pennsylvania State University and his co-workers developed a more detailed model of this effect [see "How Climate Evolved on the Terrestrial Planets," by James F. Kasting, Owen B. Toon and James B. Pollack; Scientific American, February 1988]. They estimated that the critical solar flux required to initiate a runaway greenhouse was about 40 percent larger than the present flux on Earth. This value corresponds roughly to the solar flux expected at the orbit of Venus shortly after it was formed, when the sun was 30 percent fainter. An Earth ocean's worth of water could have fled Venus in the first 30 million years of its existence.

A shortcoming of this model is that if Venus had a thick carbon dioxide atmosphere early on, as it does now, it would have retained much of its water. The amount of water that is lost depends on how much of it can rise high enough to be decomposed—which is less for a planet with a thick atmosphere. Furthermore, any clouds that developed during the process would have reflected sunlight back into space and shut off the runaway greenhouse.

So Kasting's group also considered the possibility of a solar flux slightly below the critical value. In this scenario, Venus had hot oceans and a humid stratosphere. The seas kept levels of carbon dioxide low by dissolving the gas and promoting carbonate formation. With lubrication provided by water in the asthenosphere, plate tectonics might have operated. In short, Venus possessed climate-stabilizing mechanisms similar to those on Earth today. But they were not foolproof. The atmosphere's lower density could not prevent water from diffusing to high altitudes. Over 600 million years, an ocean's worth of water vanished. Any plate tectonics shut down, leaving volcanism and heat conduction as the interior's ways to cool off. Thereafter carbon dioxide accumulated in the air.

This picture, termed the moist greenhouse, illustrates the intricate interaction of solar, climate and geologic change. Atmospheric and surface processes can reinforce one another and preserve the status quo, or they can conspire in their own destruction. If the theory is right, Venus once had oceans—perhaps even life, although it may be impossible to know for sure. *—M.A.B. and D.H.G.*

effect but also thicken the clouds, which reflect sunlight back into space and thereby cool the planet. Because of these competing effects, it is not obvious what the injection of the two gases did to the climate.

### The Planetary Perspective

Our simulations suggest that the clouds initially won out, so that the surface cooled by about 100 degrees C. But then the clouds were slowly eaten away. Water diffused higher in the atmosphere, where it was dissociated by solar ultraviolet radiation. The hydrogen slowly escaped into space; half of it was lost within 200 million years. The sulfur dioxide, meanwhile, reacted with carbonate rocks. As laboratory experiments by Bruce Fegley, Jr., of Washington University and his co-workers have demonstrated, sulfur dioxide in Venus's atmosphere is taken up by carbonates much more quickly than water is lost to space.

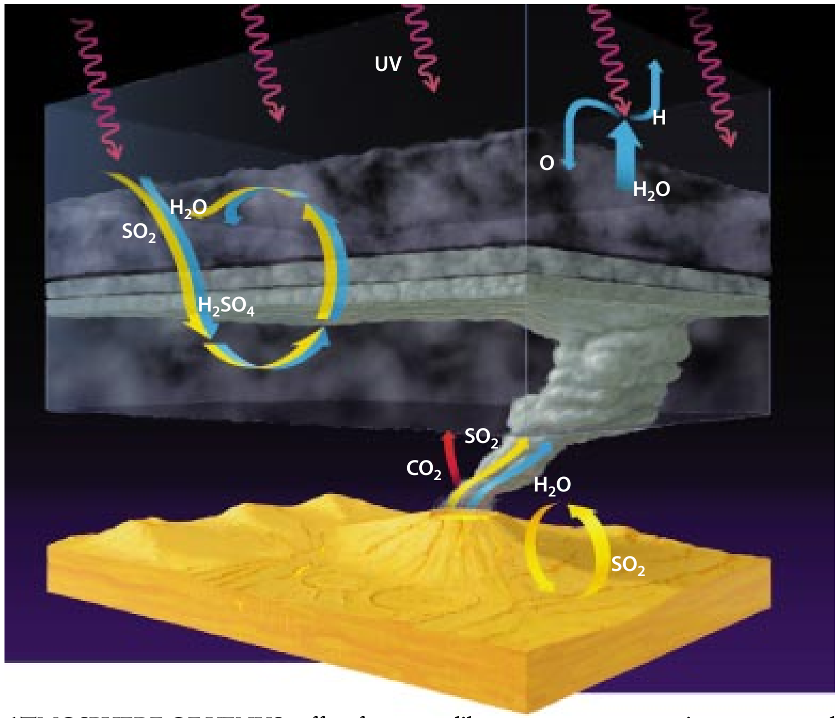
As the clouds thinned, more solar energy reached the surface, heating it. After 200 million or so years, temperatures were high enough to start evaporating the clouds from below. A positive feedback ensued: the more the clouds eroded, the less sunlight was reflected back into space, the hotter the surface became, the more the clouds were evaporated from below, and so on. The magnificent cloud decks rapidly disappeared. For about 400 million years, all that remained of them was a wispy, high stretch of clouds composed mostly of water. Surface temperatures were 100 degrees C higher than at present, because the atmospheric abundance of water vapor was still fairly high and because the thin clouds contributed to the greenhouse effect without reflecting much solar energy. Eventually, about 600 million years after the onset of global volcanism, and in the absence of any further volcanic activity, the clouds would have dissipated completely.

Because sulfur dioxide and water vapor are continuously lost, clouds require ongoing volcanism for their maintenance. We calculated that volcanism must have been active within the past 30 million years to support the thick clouds observed today. The interior processes that generate surface volcanism occur over periods longer than tens of millions of years, so volcanoes are probably still active. This finding accords with observations of varying amounts of sulfur dioxide on Venus. In 1984 Larry W. Esposito of the University of Colorado at

Boulder noted that cloud-top concentrations of sulfur dioxide had declined by more than a factor of 10 in the first five years of the Pioneer Venus mission, from 1978 to 1983. He concluded that the variations in this gas and associated haze particles were a result of volcanism. Surface temperature fluctuations, precipitated by volcanism, are also a natural explanation for many of the enigmatic features found by Magellan.

Fortunately, Earth's climate has not experienced quite the same extremes in the geologically recent past. Although it is also affected by volcanism, the oxygen-rich atmosphere—provided by biota and plentiful water—readily removes sulfur gases. Therefore, water clouds are key to the planet's heat balance. The amount of water vapor available to these clouds is determined by the evaporation of the oceans, which in turn depends on surface temperature. A slightly enhanced greenhouse effect on Earth puts more water into the atmosphere and results in more cloud cover. The higher reflectivity reduces the incoming solar energy and hence the temperature. This negative feedback acts as a thermostat, keeping the surface temperature moderate over short intervals (days to years). An analogous feedback, the carbonate-silicate cycle, also stabilizes the abundance of atmospheric carbon dioxide. Governed by the slow process of plate tectonics, this mechanism operates over timescales of about half a million years.

These remarkable cycles, intertwined with water and life, have saved Earth's climate from the wild excursions its sister planet has endured. Anthropogenic influences, however, operate on intermediate timescales. The abundance of carbon dioxide in Earth's atmosphere has risen by a quarter since 1860. Although nearly all researchers agree that global warming is occurring, debate continues on how




TOM MOORE; SOURCE: MARK A. BULLOCK AND DAVID H. GRINSPOON; BASED ON DIAGRAM BY CARTER EMMART *Hayden Planetarium*

**ATMOSPHERE OF VENUS suffers from ovenlike temperatures, oceanic pressures and sulfuric acid clouds ($H_2SO_4$). The reason is that Venus lacks the cycles that stabilize conditions on Earth. Its atmospheric processes are one-way. Carbon dioxide ($CO_2$), once injected by volcanoes, stays in the atmosphere; water ($H_2O$), once destroyed by ultraviolet light, is lost forever to the depths of space; sulfur dioxide ($SO_2$), once locked up in minerals, piles up on the surface (though a small amount does recycle).**

much of it is caused by the burning of fossil fuels and how much stems from natural variations. Whether there is a critical amount of carbon dioxide that overwhelms Earth's climate regulation cycles is not known. But one thing is certain: the climates of Earth-like planets can undergo abrupt transitions because of interactions among planetary-scale processes [*see box on page 56*]. In the long run, Earth's fate is sealed. As the sun ages, it brightens. In about a billion years, the oceans will begin to evaporate rapidly and the climate will succumb to a runaway greenhouse. Earth and Venus, having started as nearly identical twins and diverged, may one day look alike.

We both recall the utopian view that science and technology promised us as children of the 1960s. Earth's capacity to supply materials and absorb refuse once seemed limitless. For all the immense change that science has wrought in the past few decades, one of the most powerful is the acquired sense of Earth as a generous but finite home. That perspective has been gained from the growing awareness that by-products from a global technological society have the power to alter the planetary climate [see "Global Warming Trends," by Philip D. Jones and Tom M. L. Wigley; SCIENTIFIC AMERICAN, August 1990]. Studying Venus, however alien it may seem, is essential to the quest for the general principles of climate variation—and thus to understanding the frailty or robustness of our home world.

## *The Authors*


MARK A. BULLOCK and DAVID H. GRINSPOON are planetary scientists at the University of Colorado at Boulder. Bullock began his career studying the destruction of organic compounds on Mars and now analyzes the destruction of clement conditions on Venus. At night he takes his young sons, Sean and Brian, outside and shows them the points of light he studies. Grinspoon, in addition to studying the evolution of planetary atmospheres and of life, is a member of the Solar System Exploration Subcommittee, which advises NASA on space policy. He has played electric guitar and percussion in a variety of world-beat and trip-hop bands and lived in Zimbabwe for two months to learn chimurenga music.


## *Further Reading*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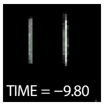
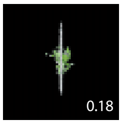
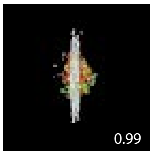
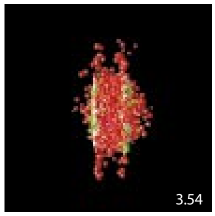
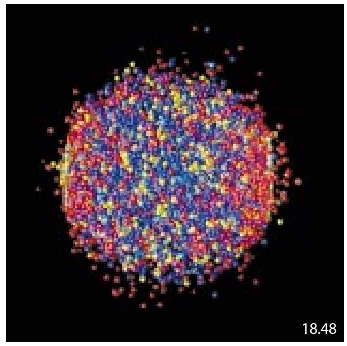
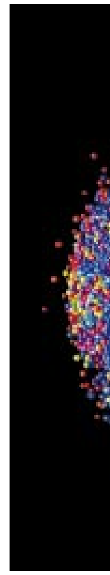












*A new collider will soon create matter as dense and hot as in the early universe*

# A Little Big Bang

by Madhusree Mukerjee, *staff writer*

The subterranean tunnel curves away in both directions, sweeping its two slender beam tubes quickly out of sight. The inside is softly lit in subtle grays—of concrete, of steel, of shiny insulation. A scent of metal shavings lingers in the cool air, and from a distance comes a muffled rattle, of a machine checking for vacuum leaks within the tubes. As we walk along, the tunnel straightens out, and the slim beam tubes merge into a single fat one. Climbing over a set of crisscrossing pipes, we emerge into a cavernous chamber, glowing yellow in sodium floodlights. In the middle of the floor is painted a black circle with the words "Collision Point."

Just above that point in space, experimenters will create in June matter as hot and dense as in the first microsecond after the big bang. The Relativistic Heavy Ion Collider (RHIC, pronounced "Rick"), just being completed at Brookhaven National Laboratory on Long Island, is designed to accelerate nuclei ranging from hydrogen (a single proton) to gold (197 protons and neutrons). When at rest, a nucleon—that is, a proton or neutron—has a mass or energy of about 1 GeV, or a billion electron volts. RHIC's superconducting magnets will accelerate the nuclei so that, because of relativity, each nucleon within a nucleus will attain any desired mass or energy from 10 to 100 GeV.

Bunches of the projected nuclei will circulate in opposite directions in the two beam tubes until they meet within four detectors placed along the tunnel's 3.8-kilometer (2.4-mile) circumference. If two heavy nuclei hit each other, each pair of colliding nucleons within them will release an energy of 200 GeV, probably raising the temperature to well over $10^{12}$ kelvins—100 million times hotter than the sun's surface. That is, the nuclei will explode.

The debris from the fireball will encode a secret: whether or not, in the tremendous heat of impact, protons and neutrons disintegrated, liberating quarks along with particles called gluons. (A proton consists of three quarks, two of the "up" kind and one of the "down," held together by gluons. A neutron contains two down quarks and one up.) Theorists believe that when the temperature exceeds $10^{12}$ kelvins, a quark-gluon plasma, or a soup of quarks and gluons, will be born. "This stuff is something that hasn't been seen in the universe for several billion years—that we know of," says Frank Wilczek, a theoretician at the Institute for Advanced Study in Princeton, N.J.

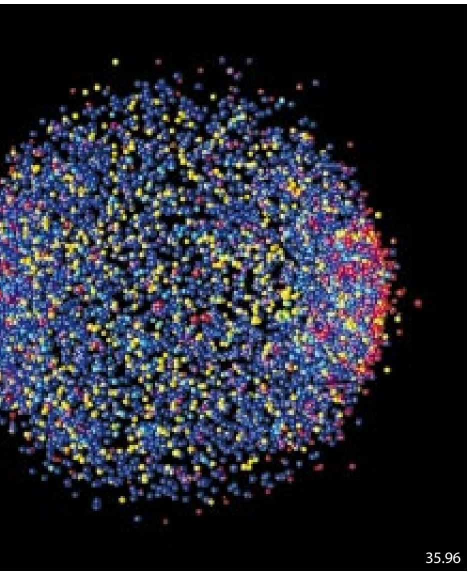
The plasma will last for only $10^{-23}$ second or so—as long as it takes light to cross a nucleus—and occupy a volume that is about 10 fermi on each side (a fermi, a characteristic nuclear size, is $10^{-13}$ centimeter). It will rapidly disintegrate into a slew of other particles, which will travel a trillion times farther before they are caught in the detectors. Whether such a collision will emit 15,000 particles or a mere 1,000 remains to be seen. But in the myriad tracks they leave, physicists will seek evidence of the fleeting plasma.

It's not like looking for a needle in a haystack. It's more like staring at a haystack and trying to figure out if there is a needle inside.

## Crash and Splash

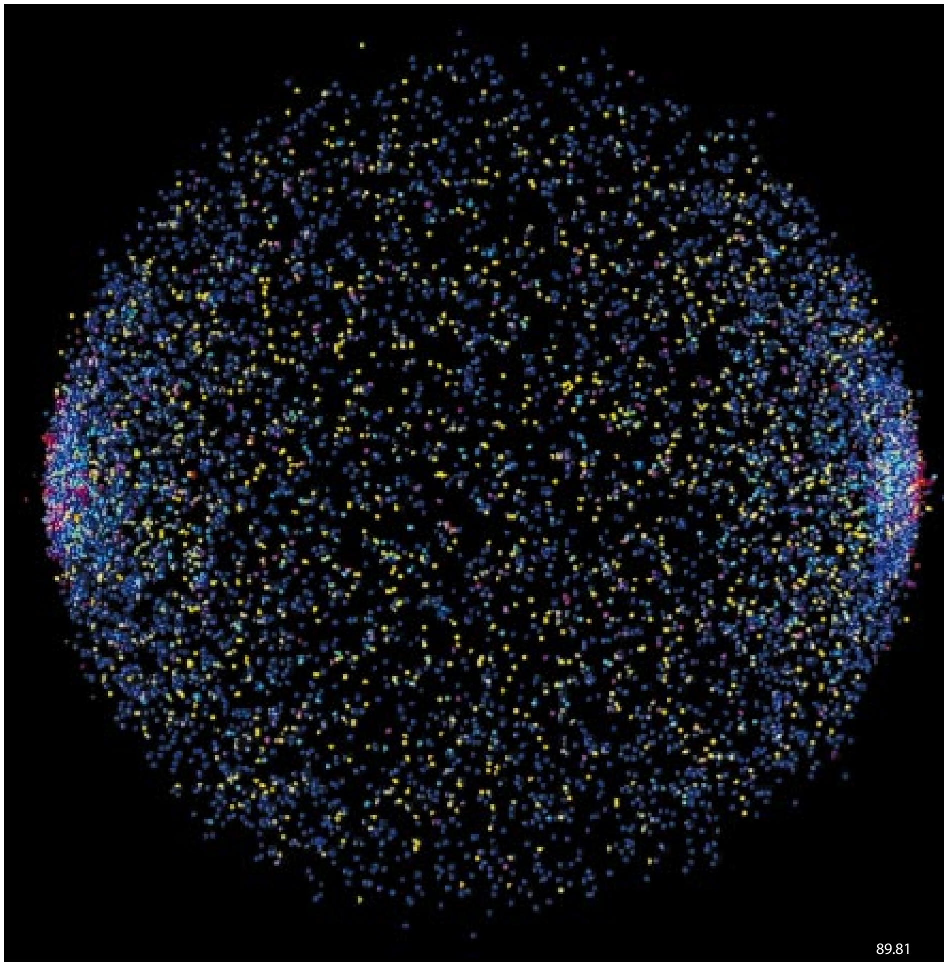
If experimenters face a daunting task, it is partly because theorists can offer only uncertain guidance. "You have only a rough outline for what matter does at those energies," points out Gordon Baym of the University of Illinois. The problem is the strong "color" force, which holds together protons, neutrons and nuclei. It is at least 100 times stronger than electromagnetism. Moreover, it is transmitted by gluons, which, unlike other force conveyors such as photons, have the peculiarity of also attracting one another. The stickiness of gluons, combined with their sheer muscle, makes quantum chromodynamics, or QCD—the theory of the strong color force—often intractable to calculation.

As a result, theorists can only beat the strong force on special occasions, such as when it is feeble. Paradoxically, the strong force wilts when quarks and




NUCLEAR COLLISION, simulated by the "parton cascade" model, shows two gold nuclei initially flattened into pancakes because of relativity. The impact causes some of the quarks (●) and gluons (●) to scatter. But the nuclei pass through one another, leaving behind highly energized quarks and gluons that quickly coalesce into clusters (●). These then break up into pions (●), kaons (●) and other particles, which may interact and decay. The fireball will grow a trillion times larger before it hits the detectors. (The unit of time is that taken by light to cross $10^{-13}$ centimeter.)

DATA: KLAUS KINDER-GEIGER AND RONALD LONGACRE; VISUALIZATION: BALLARD ANDREWS, MICHAEL McGUIGAN AND GORDON SMITH *Brookhaven National Laboratory*




gluons get very close to one another. Think of quarks as being bound to other quarks and antiquarks by strings of gluons. (An antiquark is the alter ego of a quark, having the same mass but opposite charges.) The string acts like a rubber band. When a quark-antiquark pair—called a meson—is pulled apart, the rubber band between them pulls back with constant force. In consequence, it would take infinite energy to separate the pair; free quarks are thus never seen. But when the quark and the antiquark lie very close, the rubber band is slack, and the two can ignore each other's presence. Such a congenial state of affairs should prevail, albeit briefly, in the quark-gluon plasma.

Theorists also believe that seemingly empty space—the unaptly named vacuum—is in actuality teeming with quark-antiquark pairs, which make their presence known only indirectly. The situation is not entirely happy. For whatever reason, the universe has chosen to couple, within the ordinary vacuum, right-handed quarks with left-handed antiquarks, and vice versa. (The handedness of a particle describes the direction of its internal rotation when viewed along its direction of motion.) In doing so, it has violated the aesthetics of physicists or, more accurately, a mathematical nicety called chiral symmetry, which states that left-handed quarks and antiquarks should be independent of right-handed ones. But at high enough temperature or density, the mismatched pairs filling the vacuum should break up, so that it manifests chiral symmetry.

The surest way to gauge how the strong force might behave in realistic situations is to conduct massive computations. Given a supercomputer, theorists can simulate space-time as a grid or lattice of points. On these points they locate quarks and antiquarks, linked by gluon strings, to study how they interact. These calculations, generically called lattice QCD, predict that the quarks and gluons will break free at the same energy density that restores chiral symmetry. In that case, the collisions at RHIC should yield a quark-gluon plasma with flawless chiral symmetry.

Unfortunately, lattice QCD has severe limitations: it cannot deal with dynamic situations, only static ones. That means, among other things, it can cope only with systems at equilibrium. Furthermore, it cannot describe a realm in which the number of quarks is greater than the number of antiquarks. Because protons and neutrons are all quark and no antiquark, such an excess is likely when two nuclei collide. As a result, lattice QCD cannot directly apply to the "crash and splash"—as some physicists call it—of an energetic nuclear impact.


**CURVING BEAM LINES in the Relativistic Heavy Ion Collider (RHIC) will accelerate nuclei by means of electromagnetic fields produced by superconducting magnets. The outer regions of the tube contain cryostats, inside which circulates cold, compressed helium gas. The twinned lines will accelerate bunches of nuclei in opposite directions until they meet at points inside the detectors.**

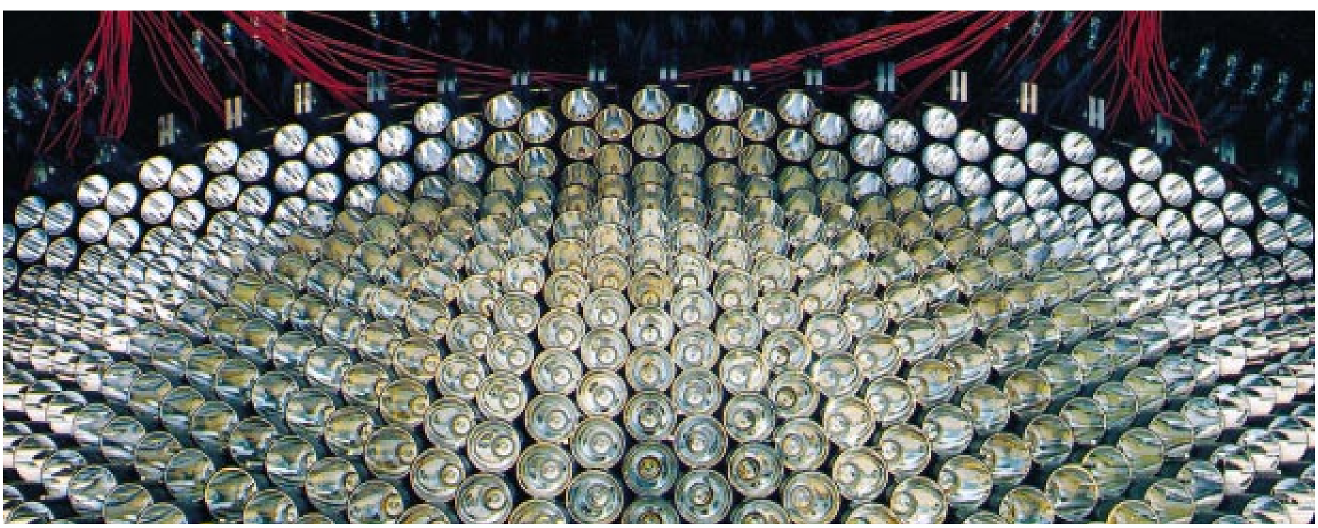
Any realistic theory will have to combine "relativity, which is tough, with field theory, which is tough, with nonequilibrium dynamics, which is tough, with many-body physics, which is tough," points out Horst Stöcker of the Johann Wolfgang Goethe University of Frankfurt. In consequence, theorists rely on a variety of approximations.

One model, for instance, treats the quarks as billiard balls bouncing off one another, with quantum mechanics and the experimentally measured probabilities of creating composite particles added in. (This theory, called the parton cascade, was pioneered by Klaus Kinder-Geiger of Brookhaven. Tragically, Kinder-Geiger perished in last year's Swissair crash.) Another treats the nuclei as globs of fluid and applies the laws of hydrodynamics with parameters calculated by lattice QCD. Combinations and refinements of these basic schemes are also on the market. "There are almost as many models as there are theorists in the field," quips Tim Hallman, an experimenter at Brookhaven. Each model will probably describe some aspect of the collision very well, but no one can get everything right. A case of wine is waiting for whoever submits a correct prediction for *any* quantity that RHIC will measure when it comes on-line.

## Seeking Smoke

Nevertheless, a collision at RHIC is expected to go something like the following. On impact, the two nuclei will first just pass through each other. "It's like when you stub your toe," Baym remarks. "It takes a fraction of a second for the pain to propagate up." But the quarks and gluons in one nucleus will have caught the quarks and gluons in the other by lassos of "glue." As the nuclei separate, these energetic strings will

**PHOTOMULTIPLIER ARRAY constructed by Japanese physicists will help identify electrons by means of their characteristic Cerenkov radiation. The device will fit inside the PHENIX detector, which will mostly measure light particles from the collision.**

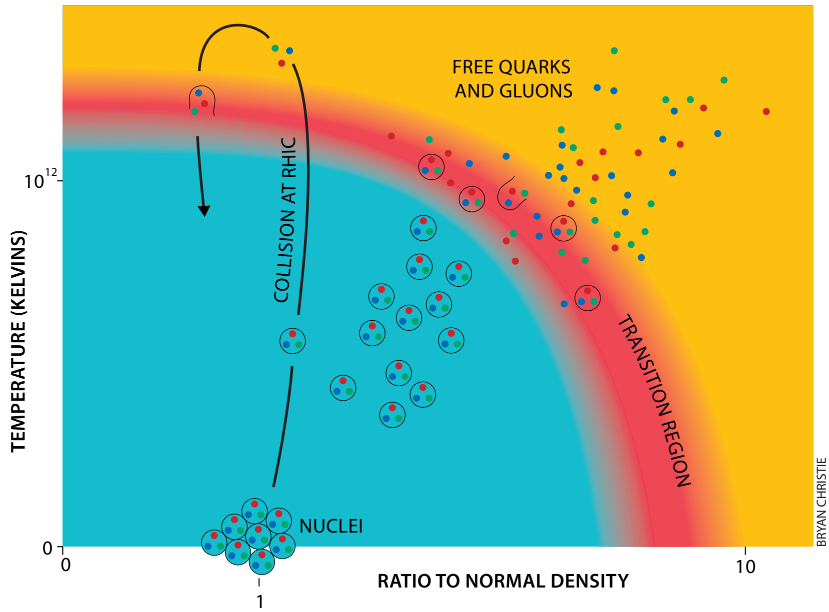


snap, knot or merge—yielding, one hopes, the plasma.

The latter will rapidly cool, radiating electrons, positrons and their heavier cousins, muons and antimuons. By processes that mimic the big bang—but again are extremely hard to calculate—most of the quarks and gluons will condense into composites containing two or three quarks or antiquarks. Some of these "hadrons" will break up into other particles—which may themselves decay. Any evidence of a quark-gluon plasma will lie in these ashes.

The catch is that "there is no smoking gun," as Hallman puts it. "No one specific thing you look for and say, 'Aha!'" Theorists have advanced a long list of things to watch for, each postulated to prove the presence of the vanishing plasma. Unfortunately, an array of convoluted nuclear effects could mimic most of these signals or wash them out.

The first task will be to scoop up the particles flying out at right angles to the beam's direction: these must be coming from the region of the collision. "Their energy tells us whether the conditions are right for the plasma to exist. That's a prerequisite," says Miklos Gyulassy of Columbia University. The analysis might also show if the temperature (deduced from how momentum is distributed among the particles) held steady for a fleeting moment. That could indicate a phase transition, just as the boiling of water might be detected by the temperature of a kettle getting stuck at 100 degrees Celsius. Gyulassy believes, though, that the effect will be too weak to be conclusive: "I wouldn't put too much money on that."




**NUCLEAR PHASE DIAGRAM displays the calculated transition from ordinary nuclei to free quarks and gluons. At very high temperature or density, the protons and neutrons within the nuclei break up, releasing quarks and gluons. Collisions of nuclei at RHIC are expected to reach this regime, albeit briefly.**

Furthermore, delicate studies of pions (mesons containing up and down quarks and antiquarks) and their correlations with one another will reveal the size of the fireball via a quantum-mechanical effect first used to measure the size of stars. This analysis might perhaps even indicate the rate at which the fireball grows. Treating the nuclear substance as a fluid, Gyulassy and others have concluded that the fireball should momentarily slow its expansion, because the speed of sound will become anomalously small as the plasma disintegrates into hadrons. "That would certainly be a smoking gun," he holds. But years of painstaking data collection will be required for the "stall," as he calls it, to be seen.


**PHENIX DETECTOR, shown before assembly, includes conical "wings" designed to capture muons from a nuclear impact. Some of the steel plates in these wings, shipped from St. Petersburg, Russia, are among the largest ever cast.**

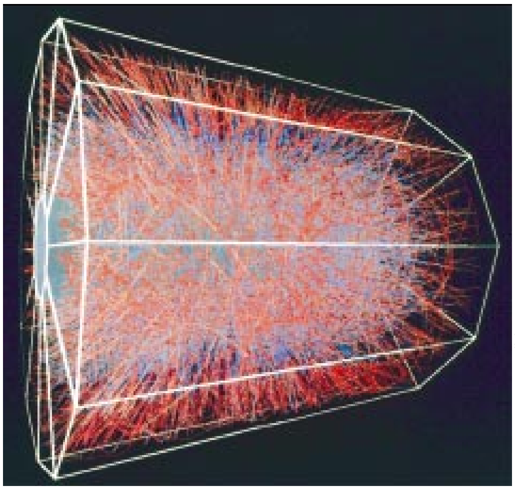
Then there is information carried by electrons, muons and their antiparticles, which are insensitive to the strong interactions. "If you make a pair they come right out," Baym says. "They give you a measure of what is going on in the interior." By combining data on the energies and momenta of these particles, physicists can tell if a pair—a muon and an antimuon, or an electron and a positron—resulted from the decay of a specific meson such as a $\phi$ (phi) or a $\rho$ (rho). Either of these mesons, if made within a chirally restored phase of matter, could have a mass less than its normal value—although that too is contentious.

Another popular "signature" of the quark-gluon plasma is a fall in the rate at which another meson, called $J/\psi$, is created. This meson, a charm quark bound with an anticharm quark, will be produced only rarely in the nuclear collision. Moreover, the argument goes, a $J/\psi$ cannot be born in a quark-gluon plasma, because bombardment by the surrounding particles will break it up. So the meson should be less frequently observed (through its decay products), compared with a calculated rate. Experimenters at CERN, the European laboratory for particle physics near Geneva, using lead nuclei colliding with an effective energy of 17 GeV per nucleon-nucleon impact, have reported signs of such an effect. Stöcker argues, though, that this signature, too, can be mimicked by other means.

Perhaps the most intriguing possibility is the appearance of a strangelet: a quark droplet with many strange quarks. Strange quarks should be plentiful in the quark-gluon plasma and could hypothetically coalesce, along with up and down quarks, into this object. Although finding a strangelet—at least as exotic a state of matter as the quark-gluon plasma itself—would be thrilling, questions remain about whether it would be stable enough to reach the detectors.

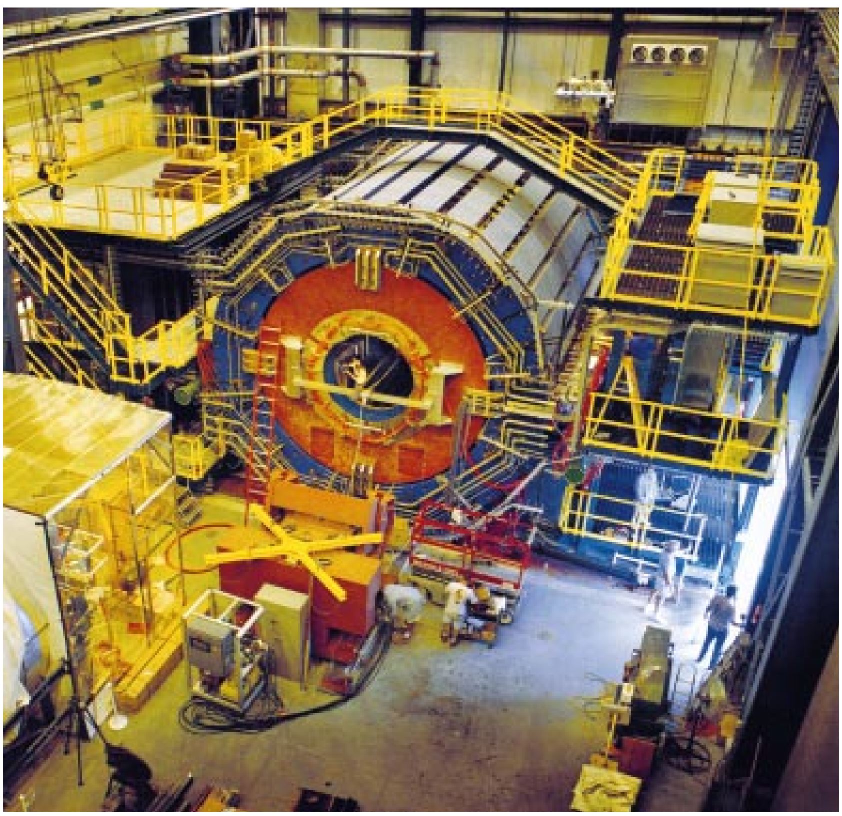
The list goes on and on. Theorists are exhorting experimenters to search for disoriented chiral condensates (resulting from the tiny region of space at the center of the collision being unsure of how to pair its quarks and antiquarks); violation of charge parity (a symmetry normally believed to be obeyed by the strong force); and innumerable other hypothetical phenomena. And if that isn't enough, Stöcker maintains that a quark-gluon plasma is not the simple "free gas" of common conception but a complex, interacting system that in many ways resembles the hadronic phase following it. So the hunt for a smoking gun could be doomed from the start.

The experimenters seem unfazed by the barrage. "I leave the arguments that start to sound like, 'How many angels can dance on the head of a pin?' to the theorists," shrugs Barbara Jacak, an experimenter at the State University of New York at Stony Brook. Soon the detectors will start to do the counting for her, constraining the possibilities by the sheer weight of data.



MATT BLOOMER *STAR Collaboration*

**STAR DETECTOR (*below*) will locate the paths of thousands of particles emerging from a collision at its center and record their energy and momentum. (The internal electronics are not visible in this photograph.) A simulation (*left*) of the traces left in the central "time projection" chamber demonstrates the complexity of the problem.**



BROOKHAVEN NATIONAL LABORATORY

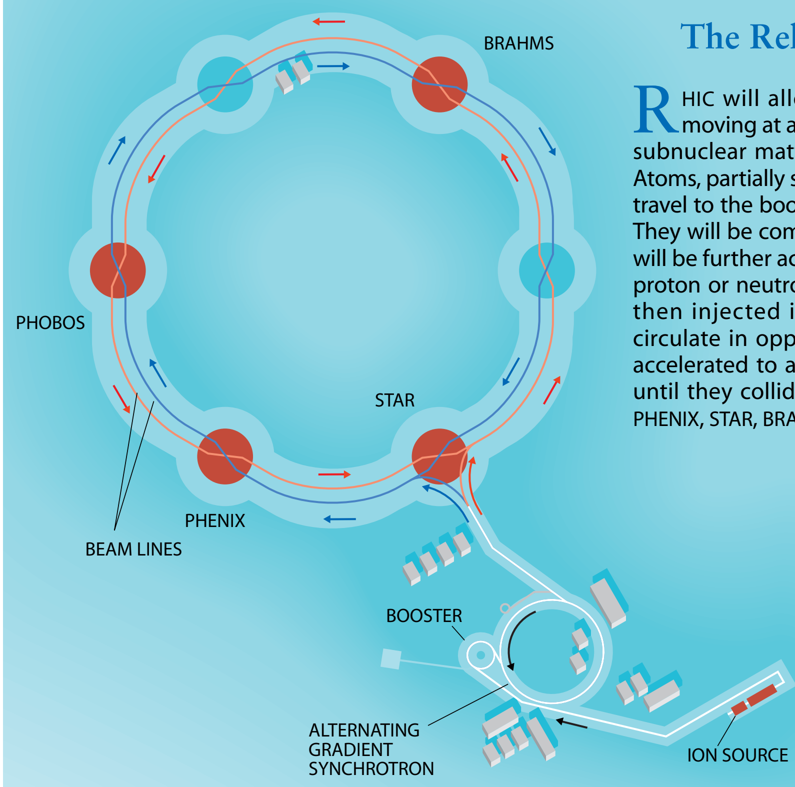
## Counting Angels

The route from the tunnel ducks under several racks of cables on its way to the enormous STAR detector—a set of concentric cylinders, their axis lying along the beam. The primary instrument, a large, silvery contraption streaming with ribbons of wires, will locate in three dimensions the path of every charged particle that enters—and clear its memory fast enough to record the details of 1,000 collisions every second. Surrounding this cylinder are several other arrays, including a calorimeter to measure the energy of each particle.

STAR's specialty is comprehensiveness. Out of 10,000 particles (mostly pions) coming out of each collision, it will measure the momentum, energy and other properties of perhaps 6,000. (The rest of the ejecta will be traveling too close to the beam line.) It will allow scientists to gauge global quantities, such as the temperature and energy density of the fireball. Staring at a bristling simulation of the expected tracks—"a bottlebrush flower," Hallman calls it—I find the abilities of the device close to unbelievable.

An even larger detector is PHENIX, so called because it rose from the ashes of three other devices that never made it off the ground for lack of money and personnel. A dark, brooding hulk that towers 12.2 meters (40 feet) high, PHENIX, if it looks like a bird at all, resembles a vulture. (RHIC scientists prefer a condor.) Its "wings," splayed along the beam lines, are designed to catch muons.

PHENIX's size derives from its mission: to capture and identify light particles. The momentum of an electron, for in-




## The Relativistic Heavy Ion Collider

RHIC will allow experimenters to smash together nuclei moving at almost the speed of light in order to observe how subnuclear matter behaves at high temperature and density. Atoms, partially stripped of their electrons in the "ion source," will travel to the booster, where they will be moderately accelerated. They will be completely stripped on exiting; the resulting nuclei will be further accelerated to 10.8 billion electron volts (GeV) per proton or neutron in the Alternating Gradient Synchrotron and then injected into the collider. Bunches of the nuclei will circulate in opposite directions in the two beam lines, being accelerated to a maximum of 100 GeV per proton or neutron, until they collide in regions where the detectors—at present, PHENIX, STAR, BRAHMS and PHOBOS—are placed.

The Office of Science of the U.S. Department of Energy provided the $365 million for constructing the collider. The detectors, which will cost a total of $200 million, are international efforts. They are funded by the DOE and by Japan, Russia and several other countries. Japan is also contributing to a separate program for RHIC to study the origins of proton spin, as well as funding a theoretical institute and the construction of a supercomputer based at Brookhaven. —*M.M.*

BRYAN CHRISTIE

stance, is revealed by the curvature of its track in an intense magnetic field. And its identity is known by a characteristic ring of photons it emits, called Cerenkov radiation. The accuracy of measuring both depends on the electron's propagating for a long distance. PHENIX should eventually be able to discern, among other things, whether the electrons and muons produced indicate the presence of mesons of deficient mass.

Two smaller detectors are also in the works. BRAHMS will check how many nucleons go through only minimally affected by the impact. PHOBOS, in contrast, will catch particles emitted in all directions, especially those that are of too low an energy to penetrate the larger detectors. The collider's design includes space for two more detectors. "One we have a plan for," says Thomas Ludlam, associate director of the RHIC project. "The other is waiting for a good idea."

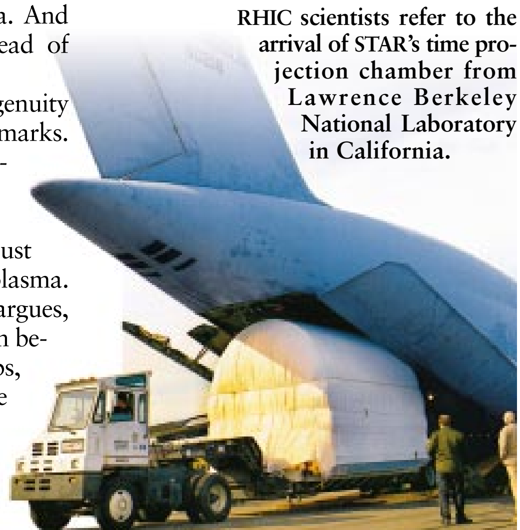
After its initial run in June, RHIC's operators will shut it down for fine-tuning of the detectors and to repair any minor problems that may show up. In November the experiments will begin in earnest. The versatility of RHIC offers hope that it will be able to unravel many aspects of the collision, even if it cannot bypass all the theoretical uncertainties. For example, the operators can ramp up the energy of a gold beam and watch for a change. If the number of particles emitted doubles, say, as the energy crosses some threshold, that will signal some dramatic alteration in the behavior of the quarks and gluons. In the best possible scenario, several of the signals for a quark-gluon plasma will show up at the same time.

In addition, researchers can vary the size of the nuclei in the beam by substituting, for example, sulfur for gold. If the observed threshold is absent in collisions of sulfur, that will further indicate new physics in the gold collisions: sulfur is not hefty enough to yield the plasma. And impacts that are off-center instead of head-on will offer further clues.

"I have a lot of faith in the ingenuity of experimentalists," Wilczek remarks. By painstakingly varying the parameters, scientists should be able to build up a picture of the range of possible fireballs, not just one involving a quark-gluon plasma. That multifaceted view, Stöcker argues, should be the real goal. "A human being has a lot of features—eyes, lips, feet. If you reduce it all to a sphere of mass 100 kilograms, you don't do it justice." Myriad fascinating phenomena could turn up, perhaps even a few as yet unimagined by theorists. Certainly some will bring the hot birth of the universe a little closer to the reach of humans.

Above ground, the day is cloudy and cold, and an unpleasant breeze portends a snowstorm. Ugly stretches of sand and dirt rise in the distance to an arc, revealing the contours of the tunnel snaking beneath. Everything in sight is made of quarks and gluons in their usual place, safely tucked inside protons and neutrons.

**"THE BIRTHING" is how RHIC scientists refer to the arrival of STAR's time projection chamber from Lawrence Berkeley National Laboratory in California.**



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# The Timing of Birth

*A hormone unexpectedly found in the human placenta turns out to influence the timing of delivery. This and related findings could yield much needed ways to prevent premature labor*

by Roger Smith

Over the past 30 years, doctors have become increasingly skilled at saving premature babies—those born before the 38th week of gestation instead of at the more typical 40 weeks. Unfortunately, premature infants who survive are often afflicted by breathing difficulties, cerebral palsy, intellectual handicaps and other problems.

Six to 8 percent of all newborns arrive before term. Of those, perhaps half are delivered early because of spontaneous premature labor. In theory, then, interventions that prevented such labor could spare a great many infants from death or lifelong disability.

Yet prevention has failed entirely. The reason? Until recently, scientists have had little understanding of the biological mechanism that controls birth timing and thus of how to keep that mechanism from operating inappropriately.

In the past few years, researchers in several centers, including my laboratory at the University of Newcastle in Australia, have gained a much clearer sense of the controls on birth timing. With this information in hand, we are beginning to explore exciting new ideas for avoiding premature labor and for delaying delivery until the fetus is mature enough to thrive outside the womb.

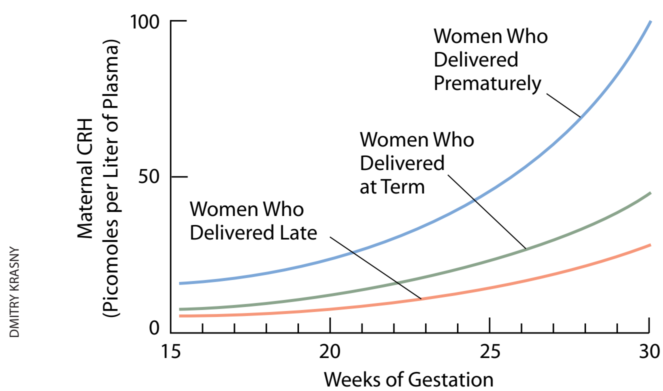
The newly deciphered mechanism actually determines more than the exact moment of birth. It regulates parturition: the uterine, cervical and other changes that make labor possible. Parturition, which usually takes place in the last two weeks of human pregnancy, culminates in delivery.

## Springboard to Progress

The recent progress in deciphering how parturition is controlled has built on many insights into parturition itself. Specifically, scientists have known for some time that throughout most of gestation the uterus is essentially a relaxed bag of disconnected smooth muscle cells. This bag is sealed at the bottom by a tightly closed ring—the cervix—which is kept firm and inflexible by tough collagen fibers. These structural features are maintained by progesterone, a steroid hormone that the placenta secretes into the mother's circulation from early in pregnancy. Yet the placenta also secretes estrogen, a steroid that opposes progesterone and promotes contractility.

At first, maternal estrogen levels are relatively low, but over time they rise. Parturition typically begins when the balance of power shifts so that the estrogen and other forces favoring contraction override those blocking it.

Notably, as maternal estrogen levels soar, cells of the uterine muscle (the myometrium) synthesize a protein called connexin. Connexin molecules then move to the cell membrane and form junctions that electrically link one muscle cell to another. Wired into a network, the muscle cells become able to undergo coordinated contractions. At the same time, estrogen prods the myometrial cells to display large numbers of receptors for oxytocin, a hormone (made in the brain) that can increase the force of uterine contractions and induce labor in a receptive uterus.




**TIMING OF DELIVERY** in humans appears to be determined largely by the rate at which the placenta releases a protein called corticotropin-releasing hormone (CRH) into the maternal and fetal circulations. This "placental clock" was uncovered by measuring CRH levels in the blood of nearly 500 women as their pregnancies progressed. In general, those with the highest levels early on (by 16 to 20 weeks) had the fastest clocks and were most likely to deliver prematurely.

As the uterine muscle prepares for labor, estrogen also promotes the manufacture of chemicals called prostaglandins by placental membranes overlying the cervix. The prostaglandins induce production in the cervix of enzymes that digest its collagen fibers; the enzymes thereby convert the cervix into a malleable structure that will dilate progressively, and finally open, as the infant's head presses against it during labor.

While all these changes are occurring, yet another hormone—cortisol, made by the fetal adrenal gland—ensures that the infant's lungs undergo the final changes required for breathing air. In particular, at high levels cortisol leads to production of substances that remove water from the lungs and enable them to inflate.

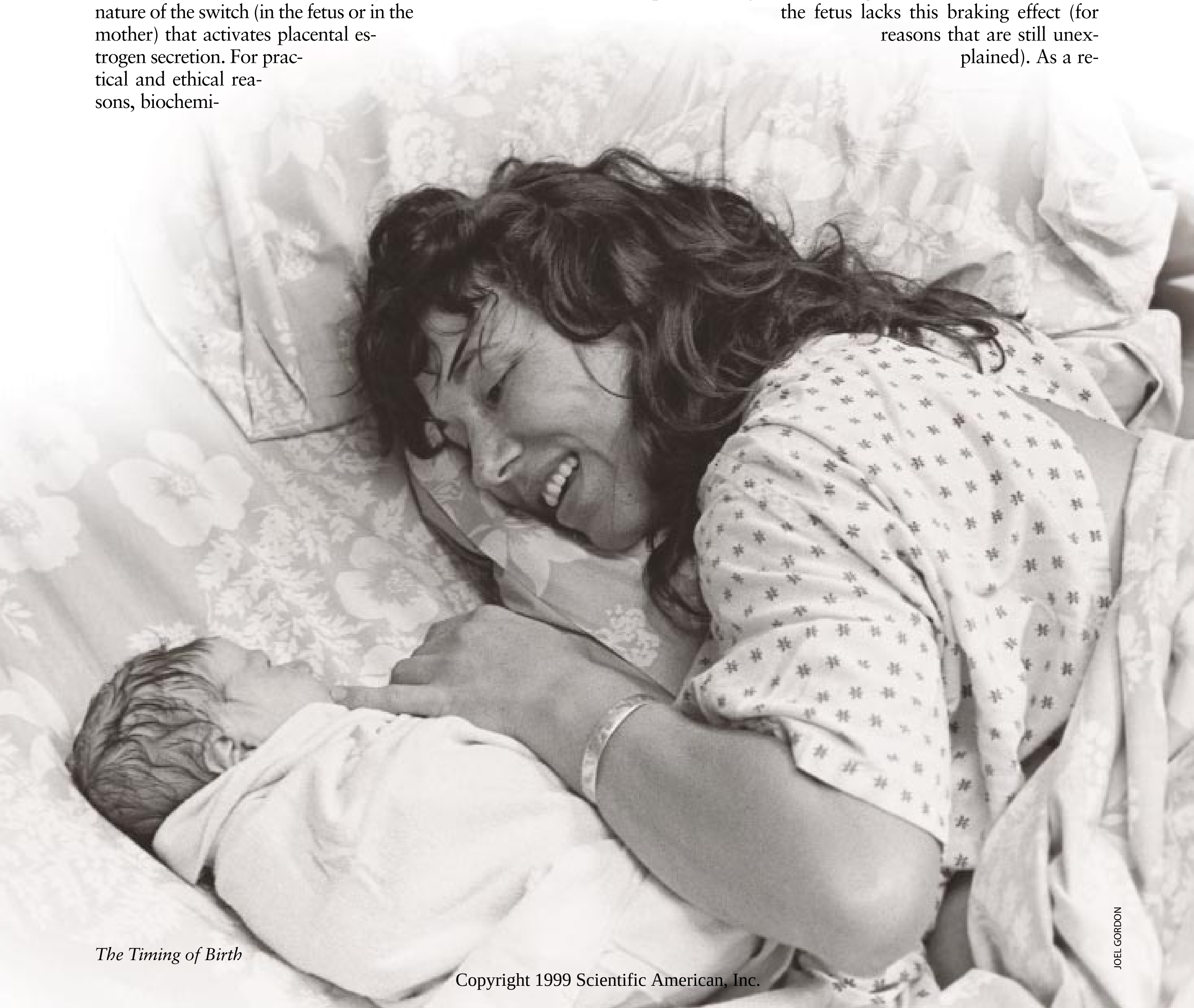
Even as investigators accumulated knowledge of estrogen's role in parturition, they continued to be baffled by the nature of the switch (in the fetus or in the mother) that activates placental estrogen secretion. For practical and ethical reasons, biochemical changes occurring in the developing human fetus, in the placenta and in the pregnant woman are extremely difficult to study closely. Therefore, biologists sought, and found, many clues to the regulation of parturition in experiments performed on other large mammals, especially sheep.

## Sheep System Emerges

By the mid-1980s, such studies—initially pioneered in the 1960s by Graham C. ("Mont") Liggins of the National Women's Hospital in Auckland, New Zealand—had discerned the basic regulatory mechanism in sheep. The same mechanism operates in most mammals.

At some point near the middle of gestation in sheep, the hypothalamus of the developing fetal brain begins to secrete a hormone called corticotropin-releasing hormone (CRH), which induces the pituitary gland, at the base of the brain, to secrete adrenocorticotropin (ACTH) into the fetal circulation. ACTH instructs the fetal adrenal gland to make cortisol. This hormone, in turn, activates enzymes in the placenta that convert progesterone to estrogen. Consequently, secretion of progesterone into the mother's circulation falls, and that of estrogen rises. When cortisol levels in the fetus become quite high, they also facilitate maturation of the lungs.

In the nonpregnant ewe, as in the nonpregnant human, cortisol is part of what is known as a negative-feedback system. The cortisol feeds back to the hypothalamus and pituitary to dampen the release of ACTH and to reduce cortisol manufacture, so that cortisol levels remain stable instead of rising endlessly. Toward the end of gestation, however, cortisol in the fetus lacks this braking effect (for reasons that are still unexplained). As a re-



JOEL GORDON

sult, fetal levels of ACTH and cortisol, and hence maternal estrogen levels, rise throughout the last part of the sheep pregnancy. Ultimately, the mother's estrogen concentrations become high enough, and the progesterone levels low enough, for parturition to commence.

Disappointingly, as this tidy scheme was being pieced together, work in humans revealed that a central feature did not operate in people. As was the case in sheep, fetal cortisol apparently did help the lungs to mature in humans; cortisol-like drugs given to a woman in premature labor did reduce the likelihood that the baby would suffer breathing difficulties. Yet cortisol had no effect on parturition and did not induce pregnant women to go into labor.

Today the collected evidence suggests that CRH drives fetal cortisol production and placental estrogen manufacture, and thus parturition, in humans as well as in sheep. Strikingly, though, most of this CRH in humans comes not from the fetal brain but from the placenta. In addition, CRH induces placental estrogen secretion through a markedly different pathway than is the case in sheep and in most other nonprimate mammals.

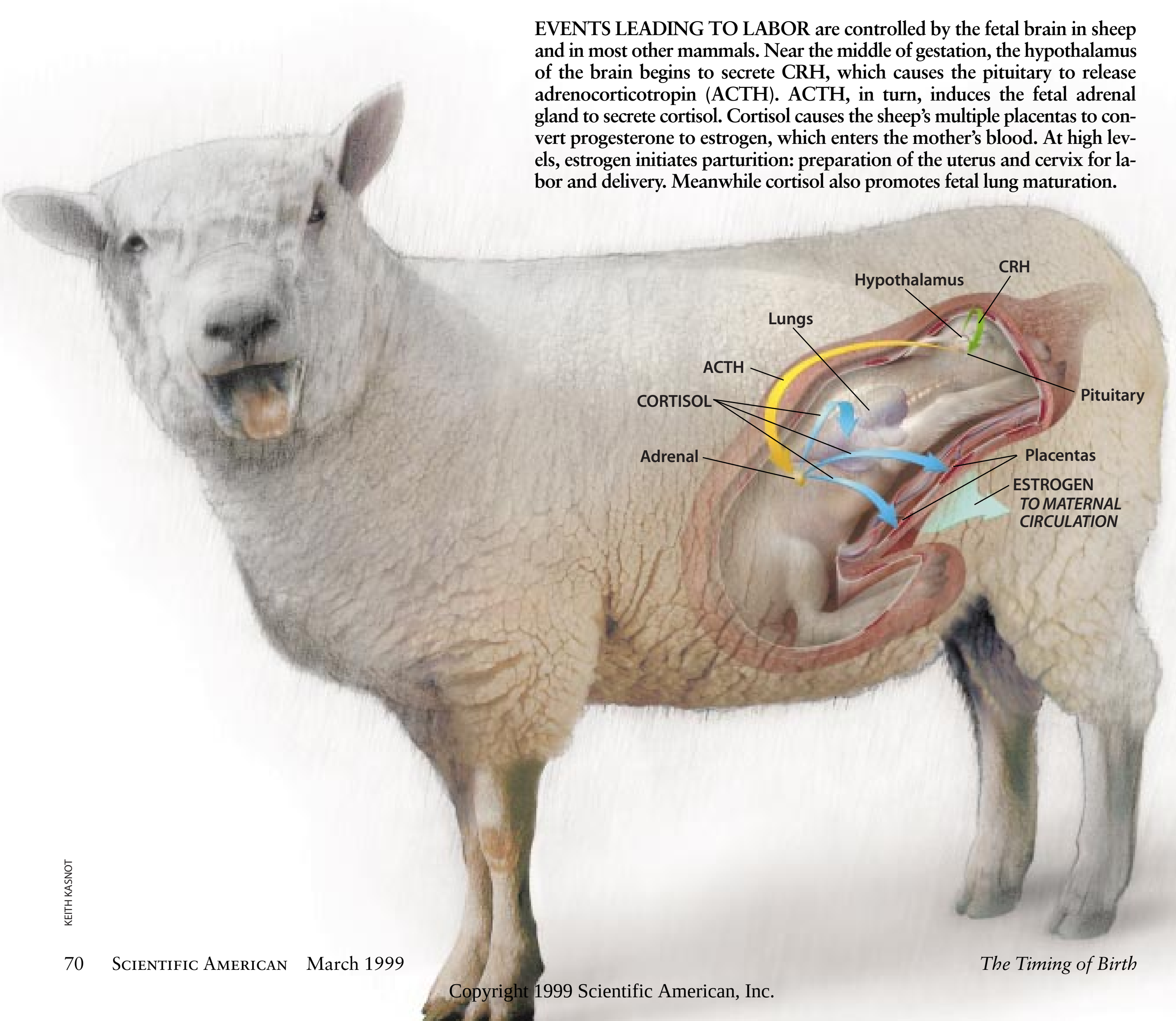
## A Human Placental "Clock"

Hints that placental CRH was important in human parturition first appeared in the 1980s. Early in that decade Tamotsu Shibasaki of Tokyo Women's Medical College and his colleagues made the surprising discovery that the human placenta contained CRH. This revelation was astonishing because the brain was thought to be the sole producer.

In the 1980s as well, various teams demonstrated that CRH from the placenta became detectable and rose sharply in the mother's blood toward the end of pregnancy and then disappeared—signs that it might serve some role in parturition. Equally suggestive, in the second half of the decade, clinicians in England and the U.S. found that women who went into premature labor had higher blood levels of CRH at delivery than did women who were tested at the same week of pregnancy but who did not deliver before term.

At about the same time, a young medical school graduate named Mark McLean joined my group as a Ph.D. student. As his thesis, he undertook a more rigorous test of the possible link between CRH and the onset of parturition. He had blood samples drawn from almost 500 women all through their pregnancies, measured CRH and then looked to see whether the levels correlated with the timing of delivery. The project was time-consuming and took many years, but finally, in the mid-1990s, the day arrived when the analyses were complete.

**EVENTS LEADING TO LABOR** are controlled by the fetal brain in sheep and in most other mammals. Near the middle of gestation, the hypothalamus of the brain begins to secrete CRH, which causes the pituitary to release adrenocorticotropin (ACTH). ACTH, in turn, induces the fetal adrenal gland to secrete cortisol. Cortisol causes the sheep's multiple placentas to convert progesterone to estrogen, which enters the mother's blood. At high levels, estrogen initiates parturition: preparation of the uterus and cervix for labor and delivery. Meanwhile cortisol also promotes fetal lung maturation.




KEITH KASNOT

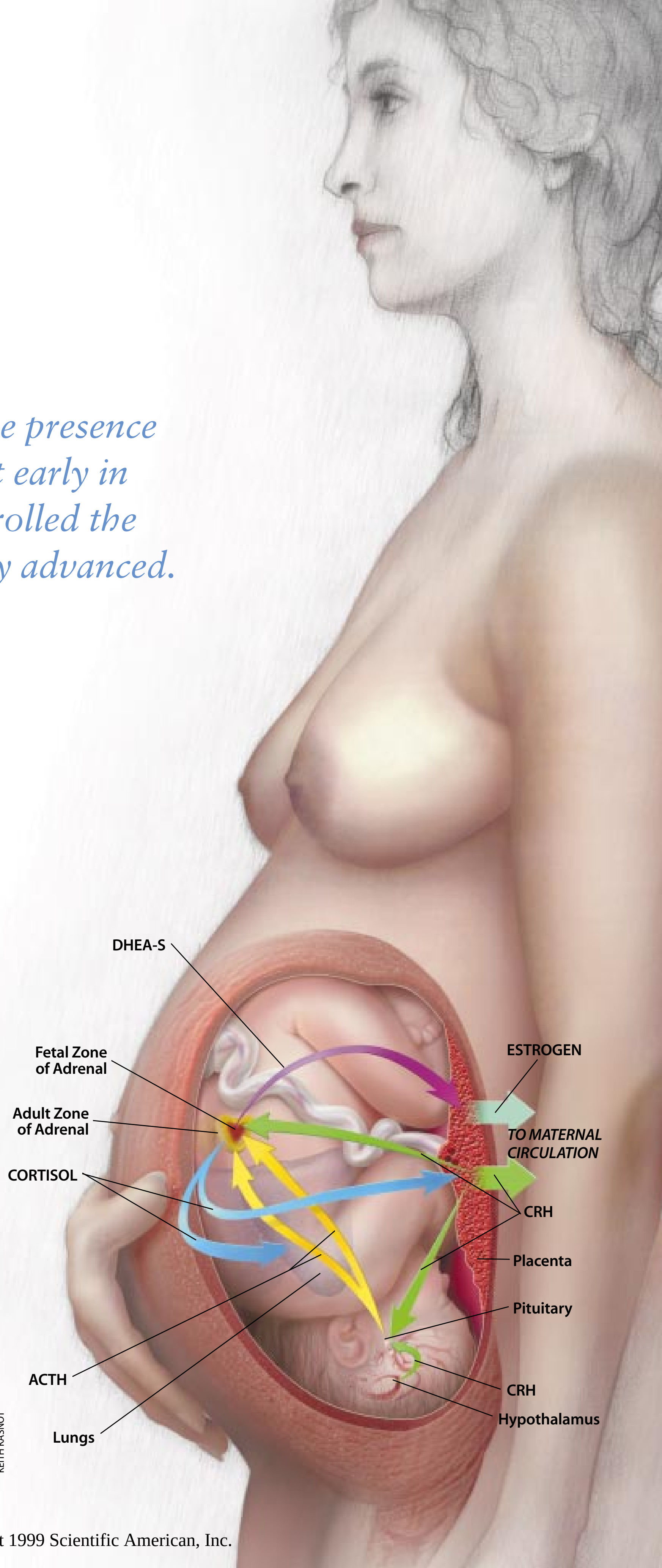
At first glance, the results did not seem surprising. They confirmed that maternal blood concentrations of CRH increase as gestation advances, and they added the discovery that the levels rise exponentially throughout pregnancy. But as we gazed at the results, something much more intriguing became apparent: CRH values at 16 to 20 weeks of pregnancy (the earliest our tools could detect them) roughly predicted when the women would give birth. What is more, mothers with the highest

*McLean had uncovered the presence of a “clock” that was set early in pregnancy and that controlled the speed with which pregnancy advanced.*

levels were most likely to deliver prematurely, and those with the lowest levels were most likely to deliver past their official due dates.

In other words, McLean had uncovered the presence of a “clock” that was set early in pregnancy and that controlled the speed with which a pregnancy advanced. The clock could be read (albeit rather crudely) by looking at the amount of CRH in a mother’s blood. It now seems likely that the rate of CRH production is itself controlling the duration of pregnancy, although at the time we had to consider that placental CRH manufacture might be a mere by-product, or marker, of some other process that was truly orchestrating parturition.

The results were more exciting than we could have anticipated. Beyond adding basic insight into human parturition, they raised the possibility that by assessing CRH levels relatively early in



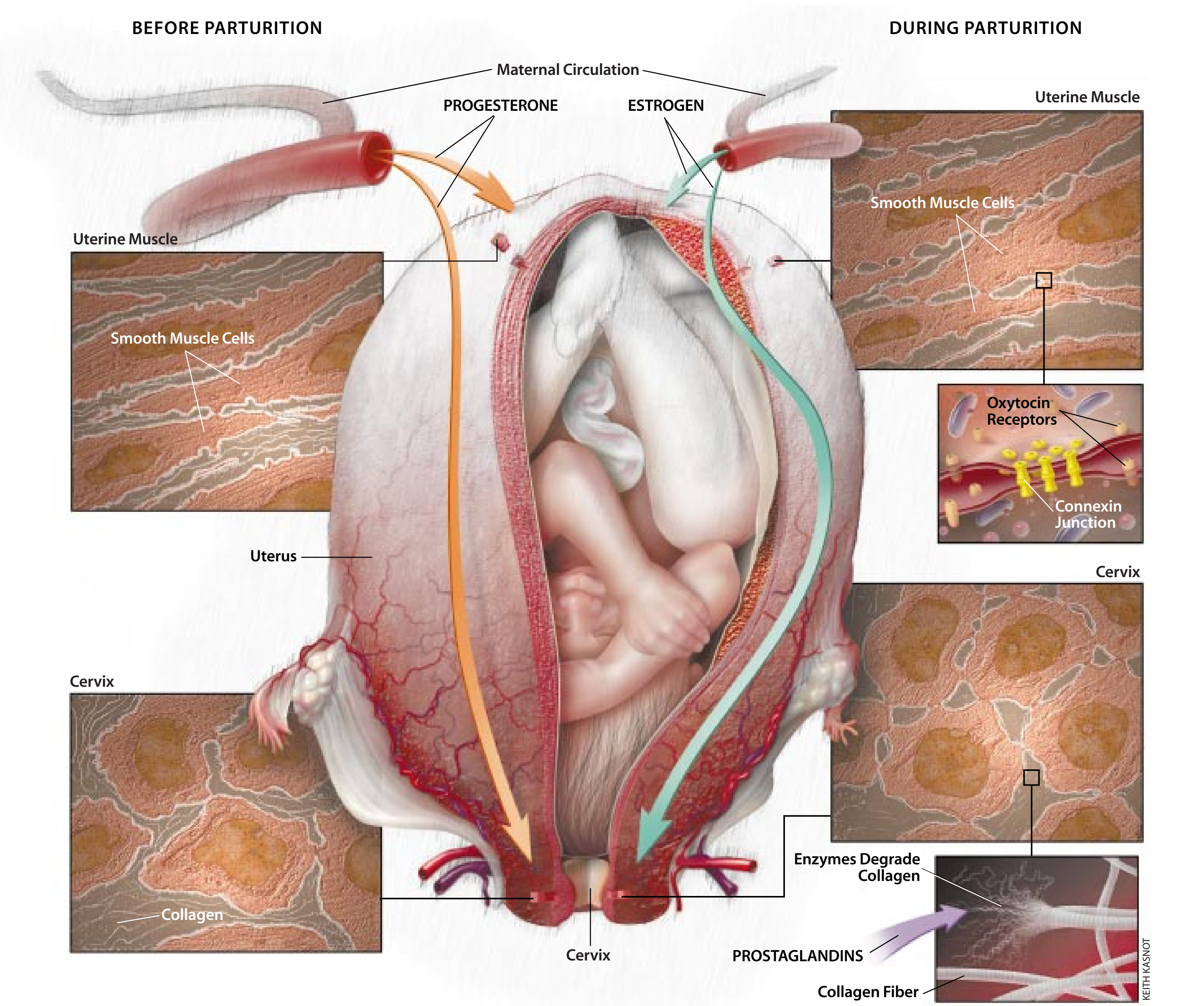

**CONTROLS ON PARTURITION in humans differ from those in sheep. Notably, much CRH comes from the placenta, not solely from the fetal brain. CRH acting on the fetal pituitary leads to cortisol manufacture by the fetal adrenal gland, just as occurs in sheep, but this cortisol does not induce the placenta to make the estrogen required for parturition. Instead it mainly promotes maturation of the fetal lungs and helps to maintain CRH manufacture by the placenta. Estrogen is made after CRH from the placenta and ACTH from the fetal pituitary stimulate the fetal adrenal gland to secrete dehydroepiandrosterone sulfate (DHEA-S), which the placenta converts to estrogen.**

KEITH KASNOT

pregnancy, physicians might be able to identify women at risk for premature spontaneous labor. Such identification would warn these expectant mothers that they need to be monitored closely and to give birth at facilities with neonatal intensive care units. Moreover, the ability to find women at risk would enable scientists to conduct systematic trials of new preventive therapies, comparing treatment against nontreatment in equivalent populations of women known to be in danger of going into early labor.

CRH analyses are not yet done routinely, in part because the best methods for measurement and the most useful time to perform the tests are still under evaluation. Such assays may well be used in the future, though. I should note that CRH levels vary considerably from woman to woman and that normal or low levels do not guarantee protection against early labor. In some cases, infections of the baby or other events can result in premature delivery even when CRH levels are not initially elevated.

Why do many researchers now think that placental CRH plays a crucial role in regulating human birth timing and is not merely a marker of some more




**ESTROGEN HAS MANY EFFECTS** on the uterus and cervix of pregnant mammals. For most of pregnancy, maternal progesterone ensures that uterine muscle cells are relaxed and that tough collagen fibers keep the cervix firm (*details at left*). Eventually, though, sharply elevated estrogen levels cause uterine muscle cells to display receptors for oxytocin, a hormone that "tells" the cells to contract during labor (*top details at right*). Estrogen also prods the cells to make connexins, which electrically wire the cells together, enabling them to contract in synchrony during labor. Meanwhile chemicals called prostaglandins lead to production in the cervix of enzymes able to digest collagen (*bottom details at right*); these enzymes make the cervix malleable.

powerful regulatory process? They have been swayed by studies that over the past 10 years have revealed a molecular cascade by which that hormone could well lead to the estrogen increase required for parturition.

## How CRH Regulates Parturition

When it became clear that parturition was regulated by a somewhat different process in people than in sheep, many teams began to study closer relatives of humans, namely, nonhuman primates. Experiments on monkeys and apes are more complicated to perform than studies on sheep, but those animals are the only ones whose placenta, like that of humans, produces CRH during pregnancy.

In the late 1980s my group and, independently, that of Robin S. Goland of Columbia University turned to baboons. Each of us found that in contrast to the ever rising levels of CRH in human mothers-to-be, levels in baboons go up rapidly early in pregnancy and then drop back to moderately elevated levels, which remain constant for the rest of gestation. This result led us exactly nowhere until one day in 1996, when I was sitting in a lecture hall at the International Congress of Endocrinology, watching a presentation on the development of the fetal adrenal gland by two leading experts on baboon pregnancy: Eugene D. Albrecht of the University of Maryland and Gerald J. Pepe of Eastern Virginia Medical School.

By then, reproductive scientists already knew that the adrenal gland of the primate fetus is different from that of the sheep fetus and of the sheep and primate adult. Instead of being divided into a central medulla and an outer cortex that can secrete cortisol, the primate fetal adrenal has no medulla and a two-part cortex, most of which consists of an internal area called the fetal adrenal zone. The smaller, outer part of the cortex still produces cortisol, but the fetal adrenal zone makes a steroid hormone with a tongue-twister name: dehydroepiandrosterone sulfate, or DHEA-S for short.

Also in contrast to the findings in sheep, the primate placenta lacks the cortisol-responsive enzymes needed to make estrogen from progesterone. Instead the placenta constructs the estrogen needed for parturition out of DHEA-S. (This activity explains why progesterone levels do not fall at the end of human pregnancies as they do in sheep; the human placenta cannot cannibalize progesterone to make estrogen, so the progesterone continues to survive and make its way into the maternal circulation.)

Albrecht and Pepe's data indicated that the relative size of the baboon's fetal adrenal zone—the size compared with that of the fetus—grew in a very interesting way. Whereas the relative size in humans and rhesus monkeys peaked near the end of gestation, that of the baboon was largest in midgestation. Later the zone grew more slowly, and it disappeared after delivery.

As I watched their slides, I noticed that the pattern paralleled the rise and fall of placental CRH in the pregnant baboon. Most likely, CRH from the placenta was directly or indirectly controlling the secretion of DHEA-S from the baboon's fetal adrenal zone. Could it be doing the same thing in humans and thereby causing the late rise in estrogen secretion by the placenta?

I could not wait to begin testing that idea. On my return to Newcastle, my colleagues and I quickly showed that human fetal adrenal tissue contains receptors for CRH, an indication that it is responsive to signals from that hormone. Then, with Robert B. Jaffe and Sam Mesiano of the University of California at San Francisco, we established that human fetal adrenal zone cells do indeed respond to CRH by making DHEA-S, not cortisol. (They also make DHEA-S in response to ACTH from the pituitary.)

## Other Roles for CRH

For parturition and labor to occur only when the fetus is ready for life outside the womb, the master controller of parturition would have to ensure not only that estrogen levels were high before delivery but also that enough cortisol was made for lung maturation. Placental CRH apparently meets that requirement, too. As Joseph A. Majzoub of Harvard Medical School has proposed, placental CRH in the fetal circulation could very well stimulate the release of ACTH from the fetal pituitary and thereby stimulate the adrenal gland to produce the cortisol needed for lung maturation. In other words, placental CRH is well situated to coordinate fetal development with parturition and thus to assure that the baby is ready for delivery when labor begins.

Other work indicates that CRH, in addition to prompting estrogen production by the placenta and cortisol manufacture by the fetal adrenal gland, acts directly on the uterus and cervix. In so doing, it may augment the changes induced by estrogen or may sometimes compensate for inadequate production of estrogen.

For example, a British team has some evidence that maternally circulating CRH, like estrogen, enhances the concentration of prostaglandins in the cervix and thus facilitates its softening. And researchers in England and Italy have demonstrated in strips of human uterine muscle that incubation with CRH can potentiate the contractions induced by other substances, including the hormone oxytocin.

Further, Edward W. Hillhouse and Dimitri Grammatopoulos of the University of Warwick in England report that several different forms of the CRH receptor can appear on uterine muscle cells and that the mix of receptors changes during parturition. Early in pregnancy, receptors that are bound by CRH react by causing intracellular reactions that normally promote the relaxation of muscle cells. Later the receptors on the laboring uterus promote contraction.

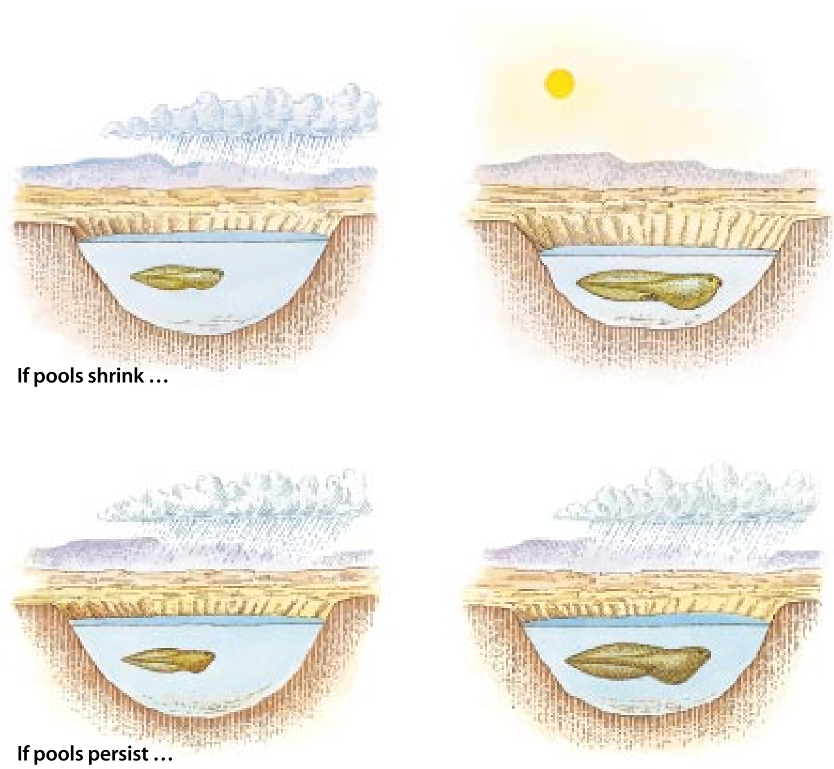
What, though, causes the placenta to make CRH, and what controls how much is made? These fascinating questions remain unanswered. Majzoub and Bruce G. Robinson of the University of Sydney Medical School in Australia have, however, demonstrated that once the placenta begins to release CRH, cortisol can support its continued secretion. Among the factors that could conceivably cause one person to manufacture more CRH than another from the start are differences in the mother's nutrition early in pregnancy and subtle variations in the genetic makeup of the CRH-producing cells in the placenta.

*The way seems open for the creation of tests able to identify pregnant women at high risk of premature labor.*

## An Evolutionary Clue from Toads

When did CRH first become a key regulator of birth timing? No one has an answer yet, but a recent discovery in amphibians hints that CRH has had that role for a good chunk of evolutionary time. The Western spadefoot toad, a desert dweller, lays its eggs in pools formed by rain. If the pools shrink from lack of precipitation, the tadpoles from those eggs quickly metamorphose into small toads (*top row*). If the pools persist, the tadpoles develop more slowly and grow large before metamorphosing (*bottom row*).

Robert J. Denver of the University of Michigan has found that the environmental effects are mediated by CRH, which is produced at a higher rate in the rain-deprived group. This finding suggests that reliance on CRH to control development might have evolved well before mammals appeared. —*R.S.*




It appears that in humans, placental production of CRH, which is made from about the 12th week of gestation, begins slowly. At first it stimulates the growing fetal adrenal zone to secrete small amounts of DHEA-S, which the placenta converts to estrogen. Meanwhile CRH from the placenta, and probably from the fetal brain, signals another part of the adrenal gland to secrete some cortisol into the fetal circulation. This cortisol, as Majzoub and Robinson have suggested, further stimulates placental release of CRH, thus forming a "feed-forward" system in which CRH production never shuts down. Instead the circuit operates relentlessly. When critical thresholds of CRH, estrogen, prostaglandins and probably other factors are all passed, the uterus and cervix undergo many changes, and labor begins.

### More Complexity

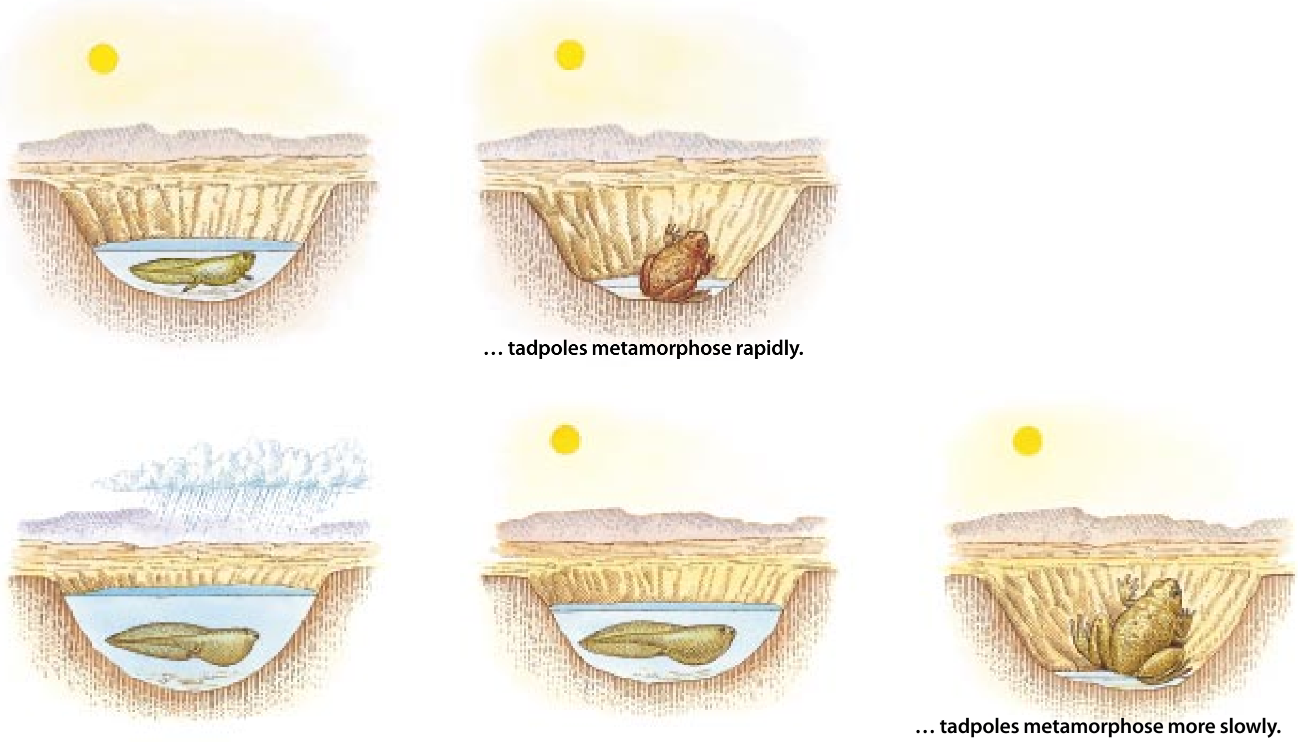
Still, this scenario is incomplete. Factors other than the self-perpetuated, feed-forward circuit can influence parturition and delivery. The size of the fetus may have an effect. A mature baby will stretch the uterine muscle, and stretching can intensify the muscle's responsiveness to contractile stimulation.

The nutritional state of the fetus may also play a part, according to I. Caroline McMillen of the University of Adelaide in Australia. She has suggested that in sheep, nutrient deprivation can precipitate delivery. Such deprivation may occur when a fetus grows large and the placenta ages. Supporting evidence for this concept has also been noted in humans. Pregnant Jewish women observing the fast of Yom Kippur, and thus reducing the nutrient supply to their fetuses, show a peak in delivery rates that is not observed on Yom Kippur in nonfasting Bedouin women living in the same region. Perhaps the stress of inadequate nutrition activates the fetal stress system, which involves production of CRH by the hypothalamus in the fetal brain. CRH release by the hypothalamus would be expected to boost ACTH and cortisol levels and thus to amplify the activity of the entire parturition-inducing circuit.

The finding that estrogen and CRH both can magnify contractility of uterine muscle suggests even more complexity. We have presented one sequence of events that seems to regulate parturition, but aspects of the control mechanism might be redundant. The direct action of CRH on the uterine muscle might, for instance, play a minor part most of the time but take on a more critical role if estrogen manufacture is impaired. Such redundancy may serve as more than a safety net. As Stuart A. Kauffman of the Santa Fe Institute has pointed out, redundancy in complex systems allows such systems to evolve. If change in one redundant pathway improves the operation of the system, the change will be retained; if the alteration is detrimental, an ostensibly extraneous pathway could prevent the change from becoming deadly.

To address how the system regulating human parturition evolved, my colleagues and I at Newcastle are collaborating with E. Jean Wickings and others at the International Center for Medical Research of Franceville in Gabon. In these experiments, we are trying to determine roughly when primates acquired more intricate controls on parturition than those that operate in other mammals. We are also attempting to gain a handle on why that change occurred.

One thing is clear, however. Reliance on CRH as a major director of development has a long evolutionary history, possibly dating to a time before mammals joined amphibians and other animals on the earth. Robert J. Denver of the University of Michigan has evidence, for example, that CRH influences the speed at which tadpoles of the desert-dwelling Western spadefoot toad (*Scaphiopus hammondii*) develop and




ROBERTO OSTI; SOURCE: LEIF SAUL

metamorphose into toads [*see box beginning on opposite page*].

As fascinating as the evolutionary questions are, the overriding reason for investigating parturition is to find ways to prevent preterm labor. Improved understanding of the regulatory system in humans has suggested a range of therapeutic options.

### Prospects for Intervention

As a case in point, we and others are exploring the value of CRH inhibitors as preventives of premature labor. In collaboration with George P. Chrousos's team at the National Institutes of Health, my colleagues and I at Newcastle have recently shown that a CRH antagonist called antalarmin can delay delivery in sheep. If such antagonists prove safe and effective in nonhuman primates, trials in people will surely follow. Human trials of oxytocin antagonists are under way, and preliminary data in women imply that prostaglandin blockers might be helpful as well.

Work on identifying women at risk is also proceeding. Aside from exploring the value of measuring CRH levels in maternal blood, scientists are seeking other markers of trouble. In my laboratory we are assessing whether untoward rises in collagen-degrading enzymes in the cervix can identify expectant mothers who are about to enter labor too early.

In an interesting sidelight, my team has shown that the level of maternal CRH may be a useful indicator of whether artificial induction of labor will be successful. Expectant mothers with high levels of CRH are more likely to respond to induction procedures than are those whose levels are low.

The way now seems open for the creation of tests able to identify pregnant women at high risk of premature labor and for the development of agents able to modify the production of CRH or to otherwise slow the placental clock that controls the timing of delivery. Such application-oriented efforts will be informed by many results from more basic research. In concert, both kinds of endeavors hold promise for achieving a precious goal: giving more babies the chance to realize their full potential, free of the physical and educational handicaps too often associated with preterm birth. SA

## *The Author*

ROGER SMITH is professor of endocrinology at the University of Newcastle and John Hunter Hospital in Australia. He earned his medical degree from the University of Sydney Medical School in 1975. After receiving a doctorate in neuroendocrinology at St. Bartholomew's Hospital in London, he returned to Australia in 1981 to join what was then a new medical school at Newcastle. In 1989 he established the Mothers and Babies Research Center, which emphasizes investigations into the endocrinology of parturition.

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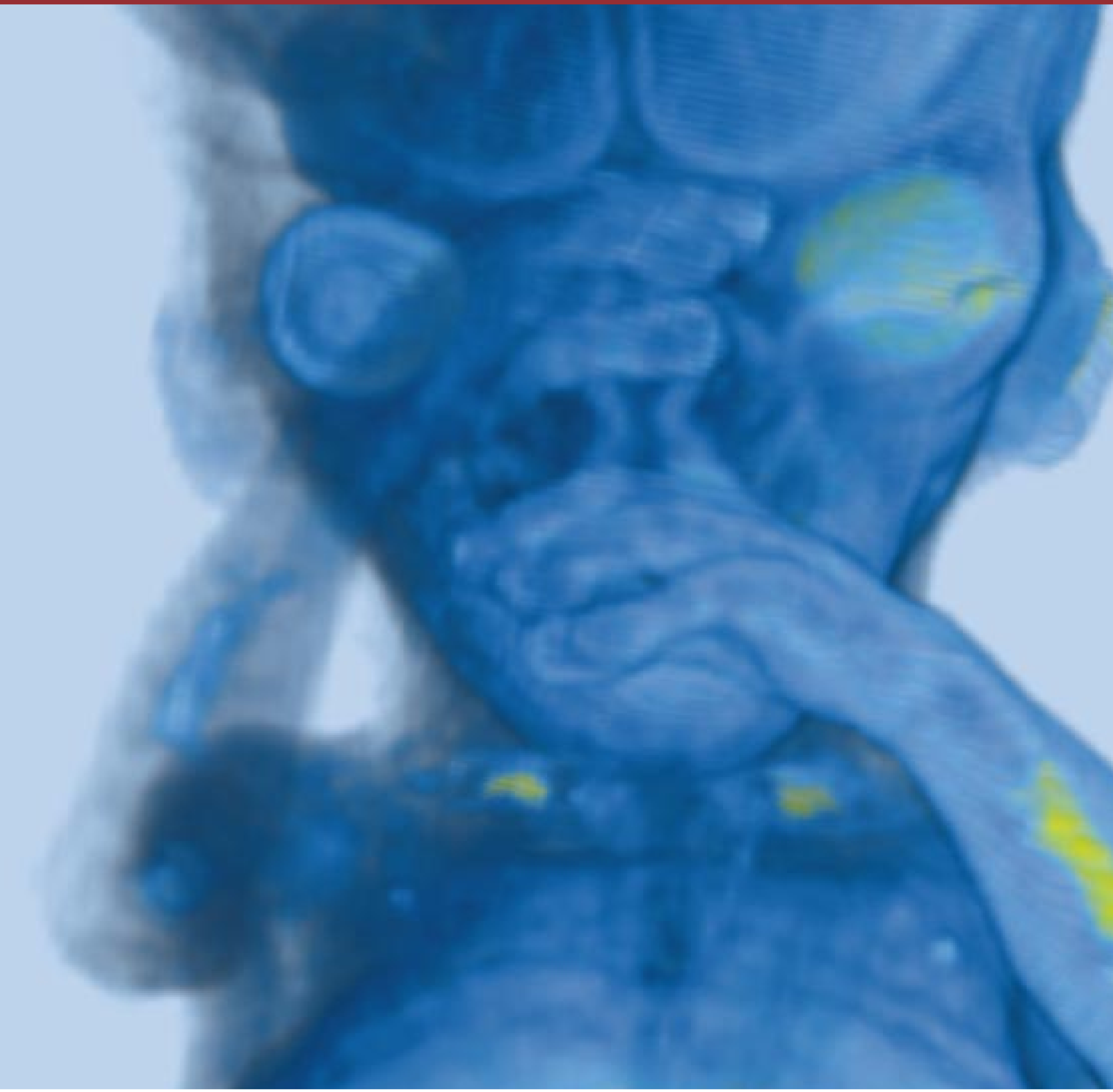
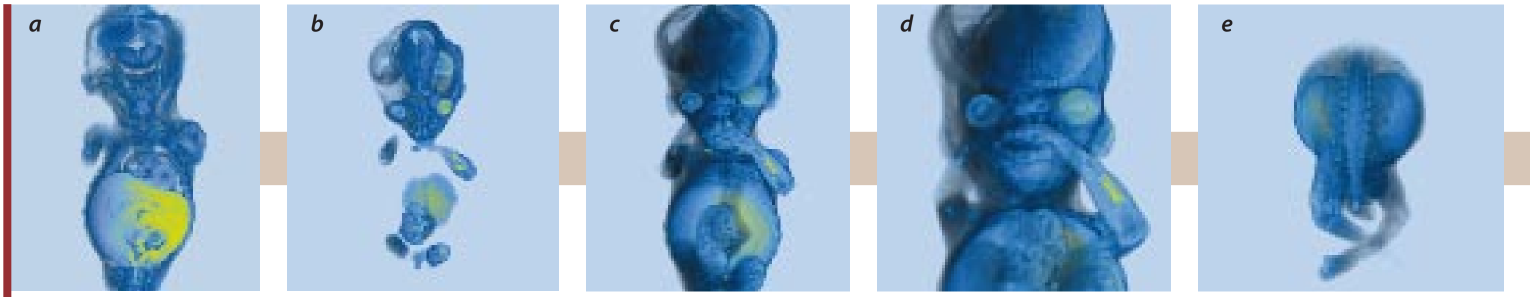
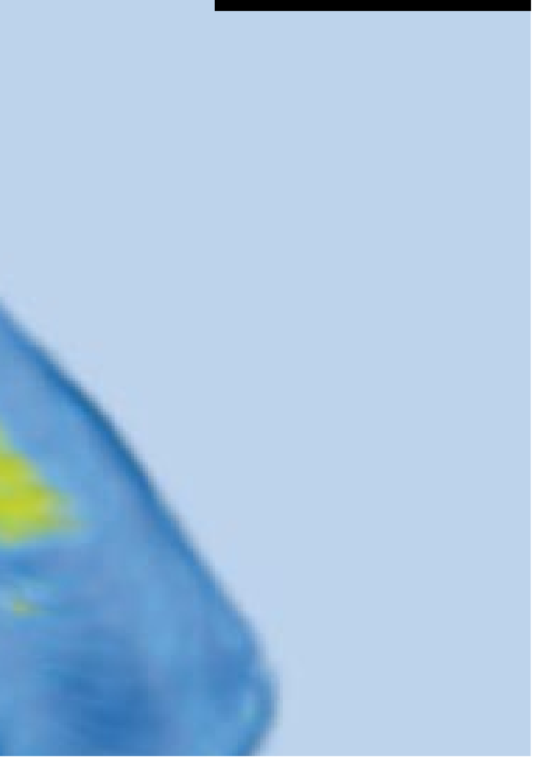





Early fetus (64 days)

# Visualizing Human Embryos



*Light micrograph*

*A technique called magnetic resonance microscopy is revealing the secrets of early human development*

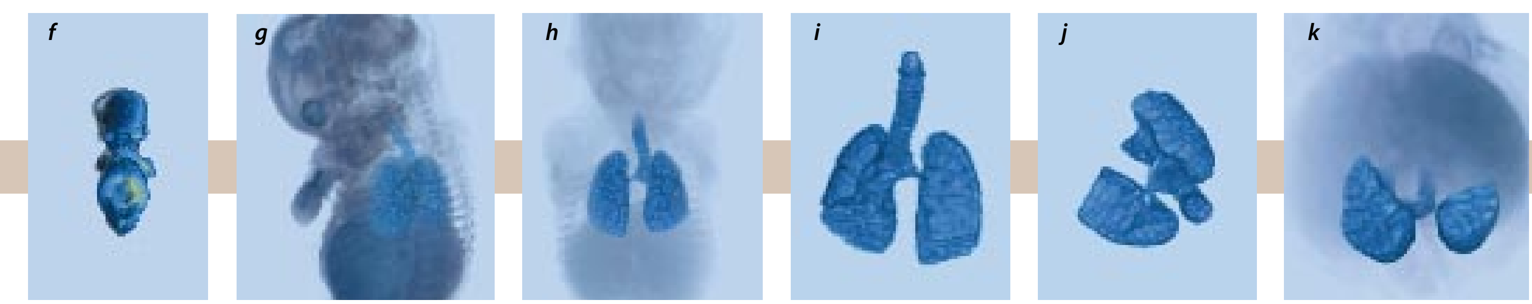
by Bradley R. Smith

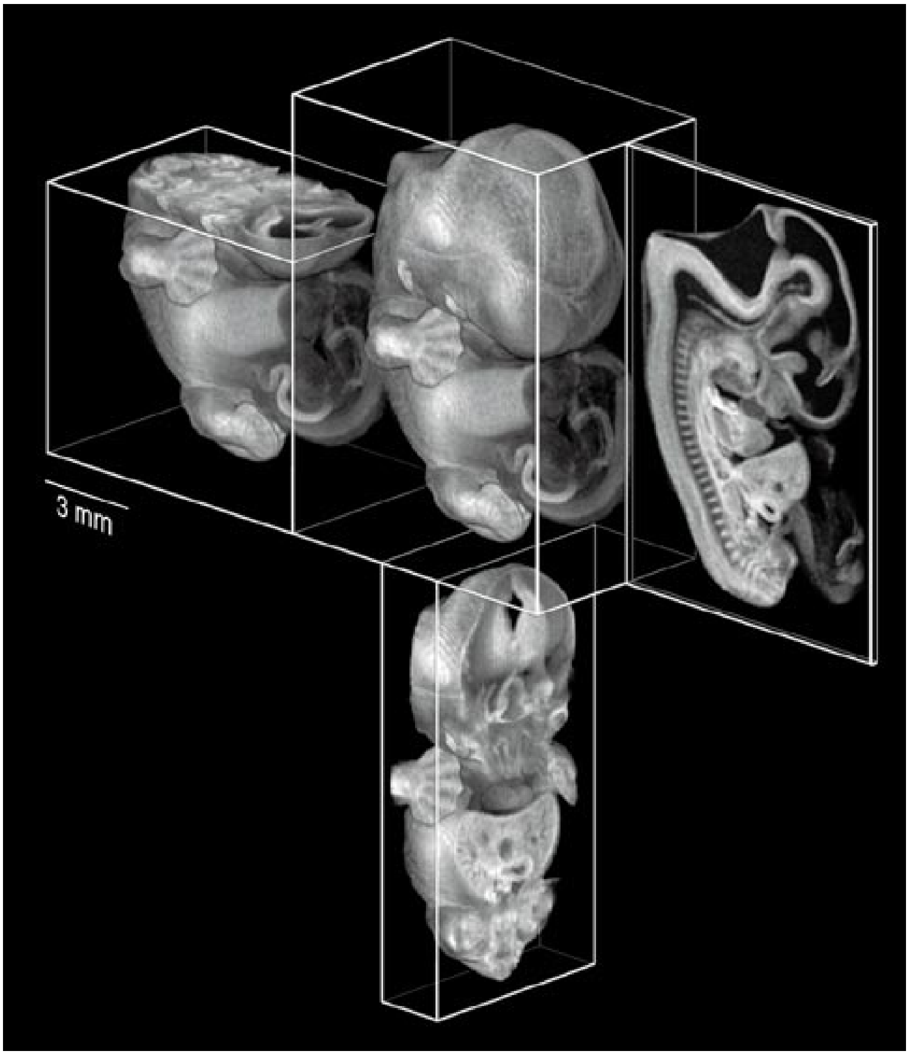
A striking new biological landscape awaits me each morning when I arrive at the Center for In Vivo Microscopy at Duke University Medical Center. It features interior views of preserved human embryos as revealed by a technology known as magnetic resonance microscopy (MRM). These three-dimensional images are both exquisite and enlightening. Such "virtual" embryos allow me to take computer-simulated voyages through all the systems of the human body at its earliest stages. Using the images, I can also generate animations of embryonic development that have been impossible until now.

Such detailed information is increasingly in demand as biologists attempt to understand the steps in both normal and abnormal development as well as the factors that dictate each process. Most existing knowledge comes from studying two-dimensional slices of embryos from normal animals and animals that have been altered genetically. But to diagnose and treat human congenital malformations and diseases better, scientists must correlate the information from such animal models

PRESERVED EARLY HUMAN FETUS (64 days postconception) has been imaged by magnetic resonance microscopy (MRM) and by traditional light microscopy (*small inset above*). At this stage, the embryo is about 30 millimeters long. Computer visualization techniques can render selected parts of the embryo translucent while leaving others opaque. By adjusting the opacity of the specimen in this manner, researchers can see internal structures at varying depths and in their natural context without damaging the specimen (*a–c*). Scientists can also zoom in on, rotate or back away from the embryo (*d–f*) or use a visualization procedure called segmentation to focus on specific organs, such as the developing lungs (*g–k*).

ALL PHOTOGRAPHS BY BRADLEY R. SMITH

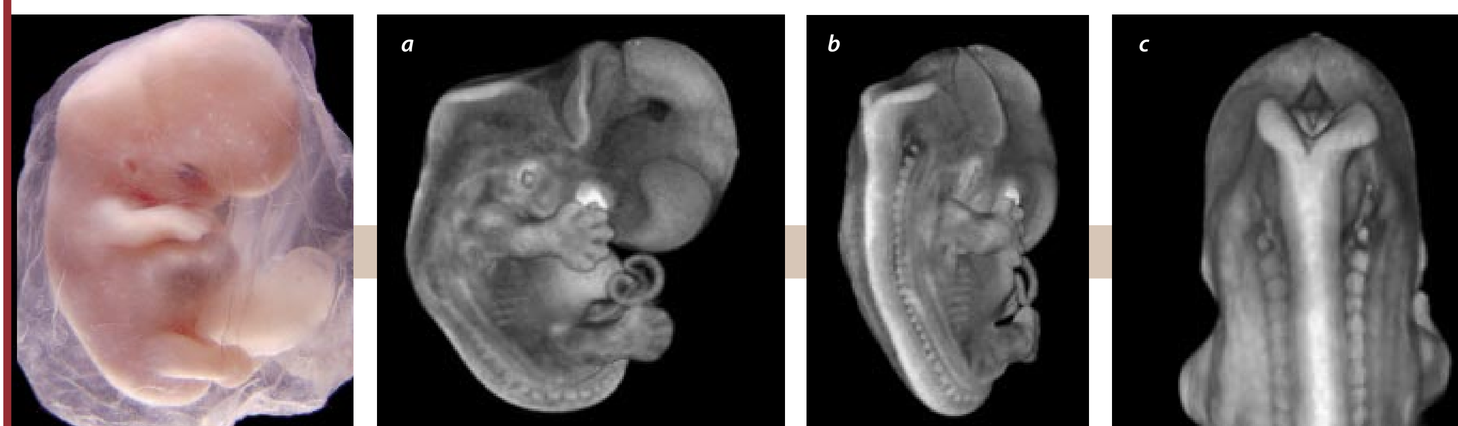





Carnegie stage 18 (44 days)

CROSS SECTIONS OF 3-D IMAGE reveal even finer details of the interior of a human embryo—in this case one preserved 44 days after conception, at a time known as Carnegie stage 18 (*shown above using light microscopy*). The embryo, which is roughly the size of a navy bean, still has webbed fingers and toes but is already developing a brain with two hemispheres, the precursors of vertebrae (*dashlike structures in right slice*) and internal organs. MRM allows researchers to view a given specimen cut in many different planes. It provides a wealth of internal information without destroying the specimen.

NEURAL TUBE of a 47-day human embryo (*shown in its amniotic sac in light micrograph at far left below*) can be examined using MRM. By manipulating the digital images, researchers can create computer animations called fly-throughs of the neural tube, which will form the brain and spinal cord. In this fly-through, the embryo is rotated (*a–c*) and the viewer enters the neural tube (*d*) to take a virtual voyage through the cranial vesicles, which will become the ventricles of the brain. The sequence proceeds over the hindbrain, through the roof of the fourth ventricle and into the midbrain (*e–h*) before backing out of the ventricle (*i, j*) to show the cerebral hemispheres.




Carnegie stage 19 (47 days)

with the corresponding stages of early development in people.

Accordingly, in 1996 I was awarded a contract from the National Institute of Child Health and Human Development (NICHD) to compile an on-line database of virtual human embryos based on the priceless Carnegie Collection of Human Embryos. The Carnegie Collection, which is housed at the National Museum of Health and Medicine of the Armed Forces Institute of Pathology in Washington, D.C., consists of preserved human embryos from each stage of embryonic development. It encompasses embryos from one day after conception to eight weeks as well as early-stage fetuses (an embryo becomes a fetus at eight weeks). The smallest specimen is approximately 0.2 millimeter long; the largest is roughly 30 millimeters in length, the size of an almond. The core of the Carnegie Collection consists of embryos that were the products of miscarriages and abortions; they were obtained between 1887 and 1917 by embryologist Franklin Paine Mall. The collection now also contains embryos discovered during routine autopsies of pregnant women.

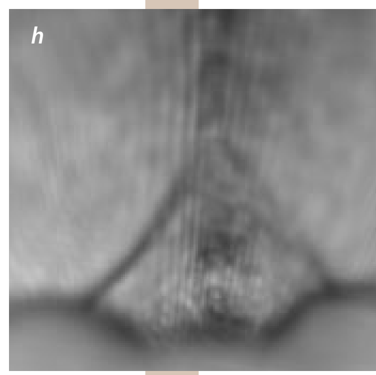
The developers of the collection divide embryonic development into 23 stages according to specific milestones, such as when the limb buds first appear. The NICHD has charged me to create MRM images of embryos from Carnegie stage 10 (22 days postconception)—when the first pharyngeal arch, which becomes part of the jaw, arises—through the first week of fetal development. (Dale S. Huff of Children's Hospital of Philadelphia surveyed the Carnegie Collection embryos to select the best ones for imaging.) The fruits of my efforts are being made available to developmental biologists and physicians—as well as the general public—through a World Wide Web site entitled the Multidimensional Human Embryo [see Further Reading on page 81]. Information on Carnegie stages 14, 15, 17, 19, 22 and 23 can be viewed now; data on the other stages will be posted by June 2000.

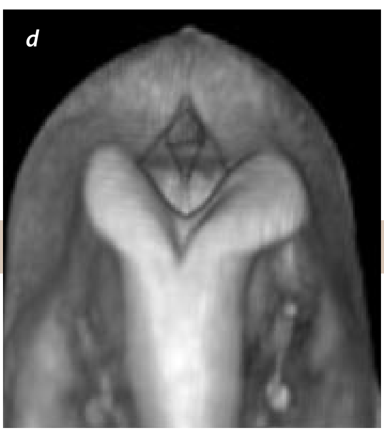
To create such unprecedented views of human embryos, I carefully position each embryo inside a vial that I then place into a superconducting magnet. The MRM technique is similar to the magnetic resonance imaging (MRI) performed by many hospitals. Like MRI, MRM uses radio-frequency energy to excite and detect protons in the water within tissues. MRM reveals much finer detail than would be useful or practical for medical diagnostics, however. Although MRI can produce images with a voxel (volume element) resolution of one cubic millimeter, MRM can record voxels that are a million times smaller. It achieves this higher resolution by using more powerful magnets, stronger gradients to perturb the magnetic field and smaller imaging coils to accommodate its tiny specimens.

The MRM techniques, which were developed at Duke University by G. Allan Johnson and his colleagues, do not damage the embryos in any way. In contrast, to view embryos with conventional microscopes, researchers traditionally have had to slice the specimens physically into hundreds of very thin cross sections. MRM generates nondistorted, three-dimensional virtual embryos in a fraction of the time required to create reconstructions from optical microscopy. A three-dimensional data set can be produced from an embryo specimen in less than two hours, much faster than the hundreds of hours required to create reconstructions from optical microscopy.

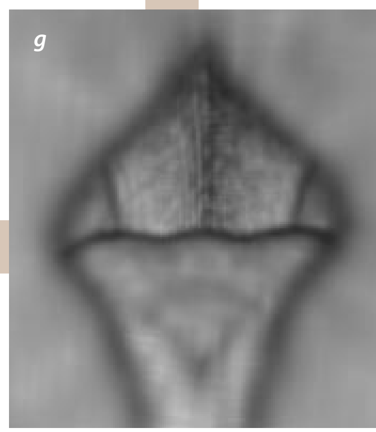
Although MRM creates detailed three-dimensional data sets, researchers rely on computer software to display the results. To create an image such as those depicted in this article, my colleagues and I use volume-rendering software to stack the individual MRM image slices—128 in all, each containing 256 × 256 pixels—to form a cubic array of 8.4 mil-

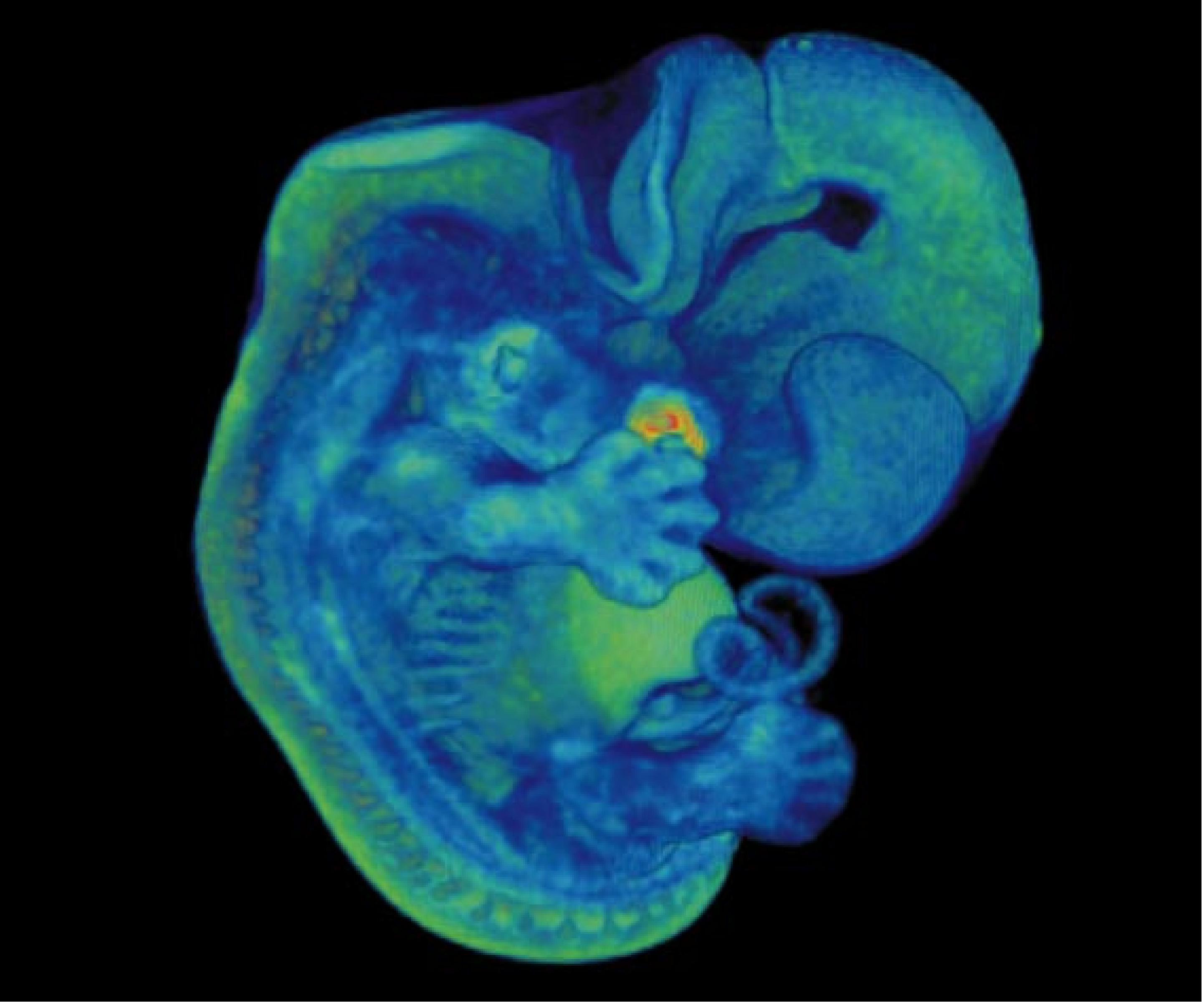




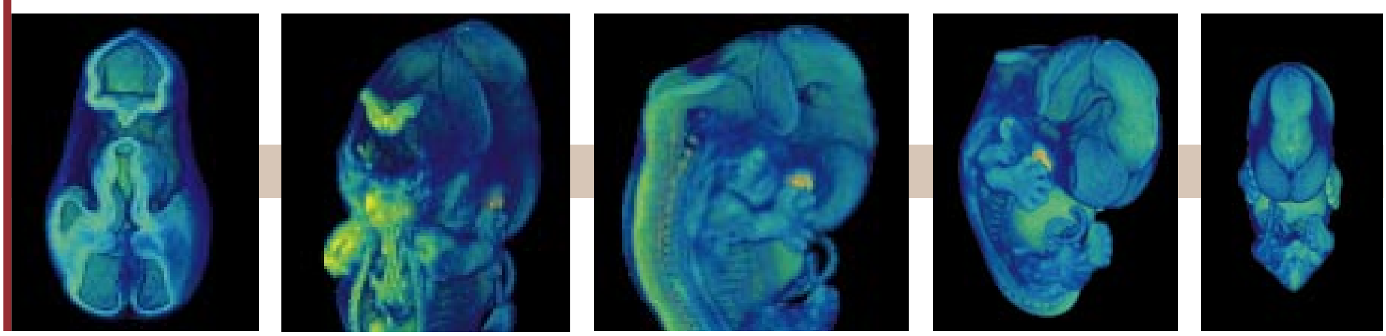




**Carnegie stage 19 (47 days)**

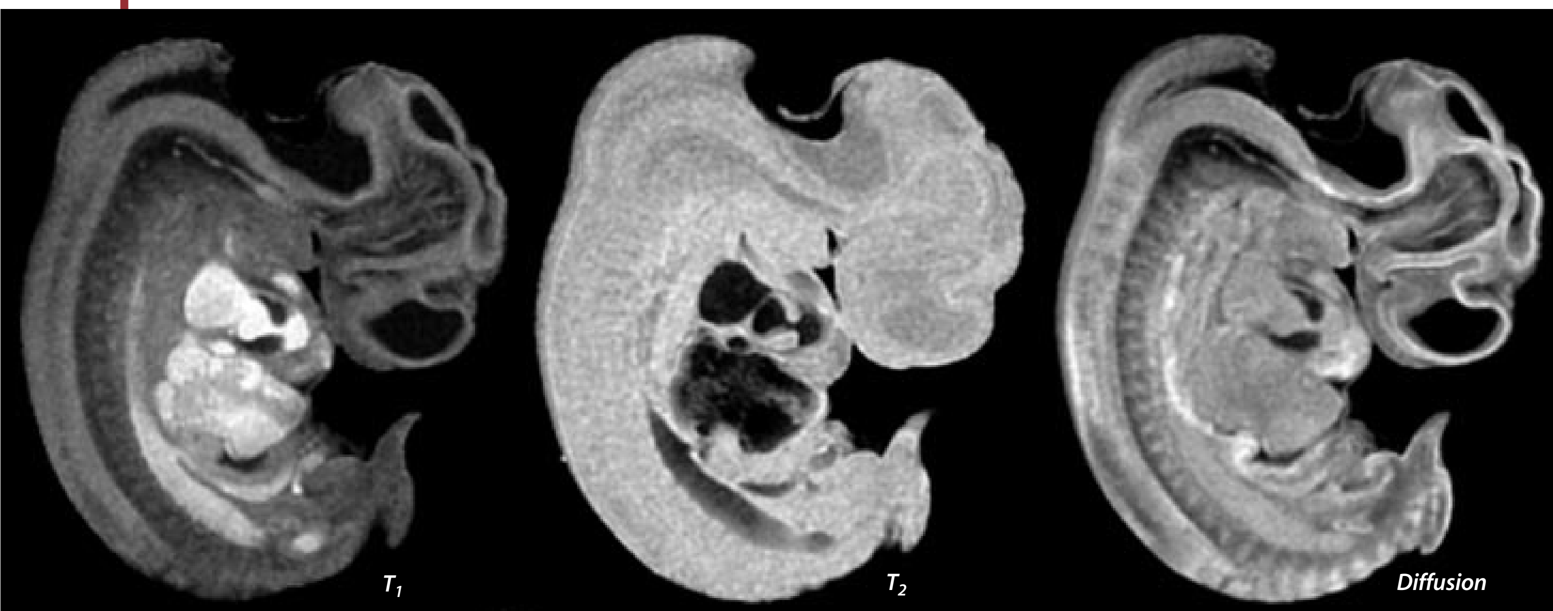
PSEUDOCOLORING allows researchers to assign colors to the MRM images to highlight various structures, such as the developing organs in the 47-day preserved human embryo shown here. In the colorized images above and below, the optic cup (developing retina) of the eye glows yellow-orange; amber ovals mark the spinal ganglia, where the spinal nerves emerge from the spinal cord; the liver shines through the abdomen in bright green; and the developing ear is seen clearly in bright green above the shoulder. The images also reveal the formation of cartilaginous ribs underneath the arm and a subtle reduction in the degree of webbing between the fingers.



lion voxels. Each voxel represents a tiny portion of the embryo. The software allows us to rotate this matrix of voxels, cut away layers of voxels, or even colorize or adjust the grayscale of voxels based on criteria such as their signal intensity. We then use computer algorithms to pass virtual rays of light through each matrix from back to front. The rays are modified by the voxels they encounter, and they form an image in the plane of the computer monitor. Our tools enable us to slice images digitally in any orientation; we can also render the surfaces of specimens transparent to reveal internal structures. In addition, we can isolate individual organ systems for inspection and measurement.

The Multidimensional Human Embryo will allow researchers around the world to use the precious resource of the Carnegie Collection and to obtain more information from its embryos than was possible ever before. My colleagues and I predict that the on-line resource will prove helpful in training clinicians to detect birth defects using MRI and ultrasound. It will also bring valuable image data directly into the laboratories of researchers who lack expertise in embryology and into the classrooms of students learning basic embryonic anatomy. And in the process of generating these remarkable images, we will be preserving for posterity a very rare and irreplaceable collection of human embryos. SA

Carnegie stage 17 (41 days)




41-DAY EMBRYO—shown at top under the light microscope with its yolk sac—has well-differentiated tissues that show up in various ways in these views obtained using three different MRM techniques: $T_1$-, $T_2$- and diffusion-weighting. The three techniques allow researchers to view the water within specimens in three ways by contrasting how the water interacts with other molecules—a characteristic that differs from tissue to tissue. $T_1$- and $T_2$-weighting reflect two ways of detecting relaxation time: how protons in water readjust after being perturbed by the radio-frequency energy used to excite them. In the $T_1$ image, the major blood vessels, the chambers of the heart and the liver appear prominently. The $T_2$ image reflects nonvascular tissues but does not provide contrast between them. Diffusion imaging takes advantage of the fact that water diffuses more readily in one direction than another in many tissues; it is particularly informative for studying neural structures such as the cerebral cortex (*thin white outlines at top right of right image*).

### *The Author*

BRADLEY R. SMITH is an assistant research professor in the department of radiology at Duke University Medical Center, where he uses magnetic resonance microscopy to study the development of the cardiovascular system. Besides developing the digital atlas of human embryology described in this article, he has compiled a similar atlas of mouse embryos. Smith received his Ph.D. in anatomy from Duke University and an M.A. from the department of art as applied to medicine at Johns Hopkins University. In addition to his research, Smith owns and operates BioImage, a medical illustration business.

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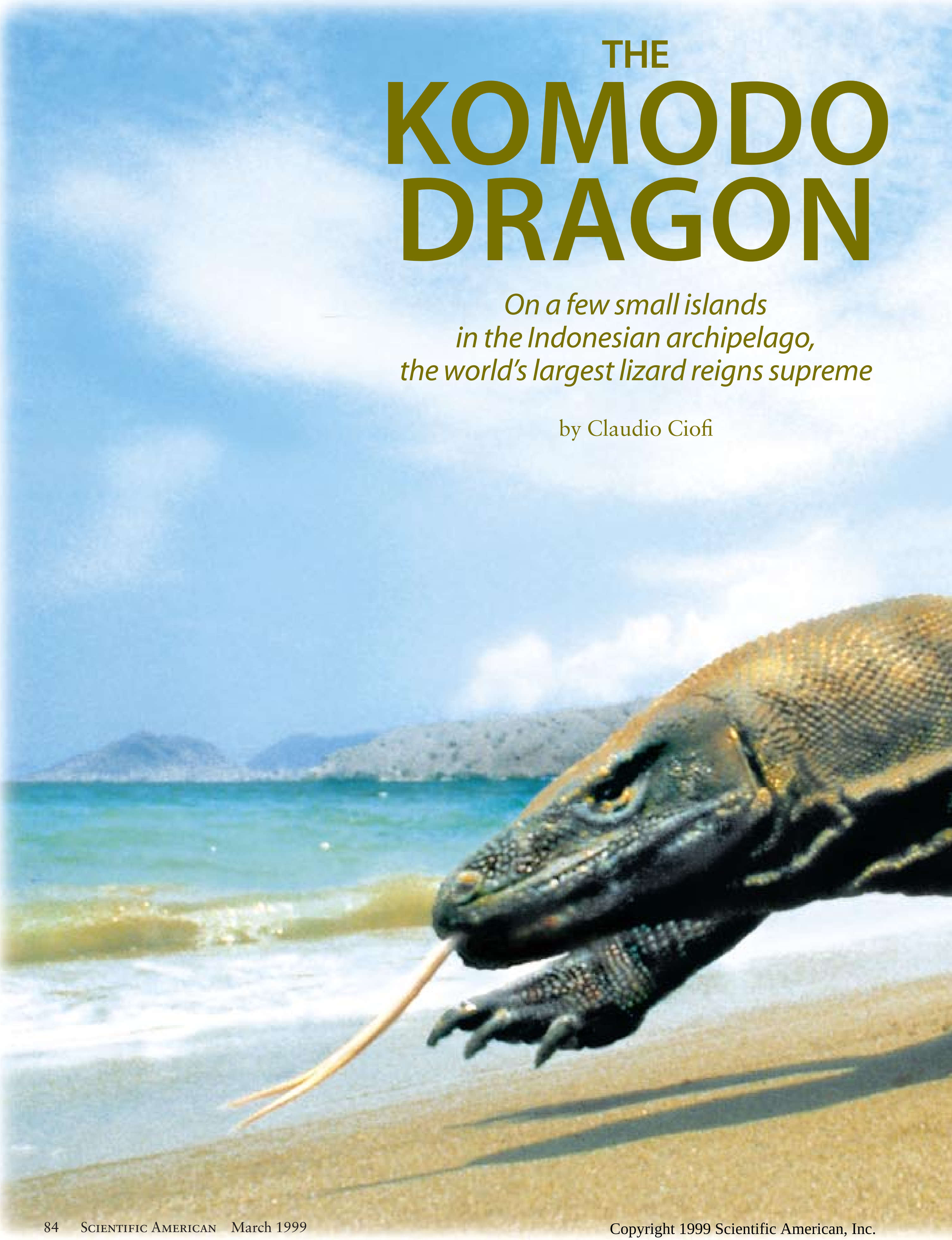


# THE KOMODO DRAGON

*On a few small islands in the Indonesian archipelago, the world's largest lizard reigns supreme*

by Claudio Ciofi

A deer nimbly picks its way down a path meandering through tall savanna grasses. It is an adult male of its species, *Cervus timorensis,* weighing some 90 kilograms (about 200 pounds). Also known as a Rusa deer, the animal knows this route well; many deer use it frequently as they move about in search of food. This Rusa's home is the Indonesian island of Komodo, a small link in a chain of islands separating the Flores Sea from the Indian Ocean. Most wildlife find survival a struggle, but for the deer on Komodo, and on a few of the nearby islands, nature is indeed quite red in tooth and claw. This deer is about to encounter a dragon.

The Komodo dragon, as befits any creature evoking a mythological beast, has many names. It is also the Komodo monitor, being a member of the monitor lizard family, Varanidae, which today has but one genus, *Varanus*. Residents of the island of Komodo may call it the *ora*. Among some on Komodo and the islands of Rinca and Flores, it is *buaja darat* (land crocodile), a name that is descriptive but inaccurate; monitors are not crocodilians. Others call it *biawak raksasa* (giant monitor), which is quite correct; it ranks as the largest of the monitor lizards, a necessary logical consequence of its standing as the biggest lizard of any kind now living on the earth. (A monitor of New Guinea, *Varanus salvadorii,* also known as the Papua monitor, may be longer than the lengthiest Komodo dragons. The former's lithe body and lengthy tail, however, leave it short of the thickset, powerful dragon in any reasonable assessment of size.) Within the scientific community, the dragon is *Varanus komodoensis*. And most everyone also calls it simply the Komodo.

### The Komodo's Way of Life

The deer has wandered within a few meters of a robust male Komodo, about 2.5 meters (eight feet) long and weighing 45 kilograms. The first question usually asked about Komodos is, How big do they get? The largest verified specimen reached a length of 3.13 meters and was purported to weigh 166 kilograms, which may have included a substantial amount of undigested food. More typical weights for the largest wild dragons are about 70 kilograms; captives are often overfed. Although the Komodo can run briefly at speeds up to 20 kilometers per hour, its hunting strategy is based on stealth and power. It has spent hours in this spot, waiting for a deer, boar, goat or anything sizable and nutritious.

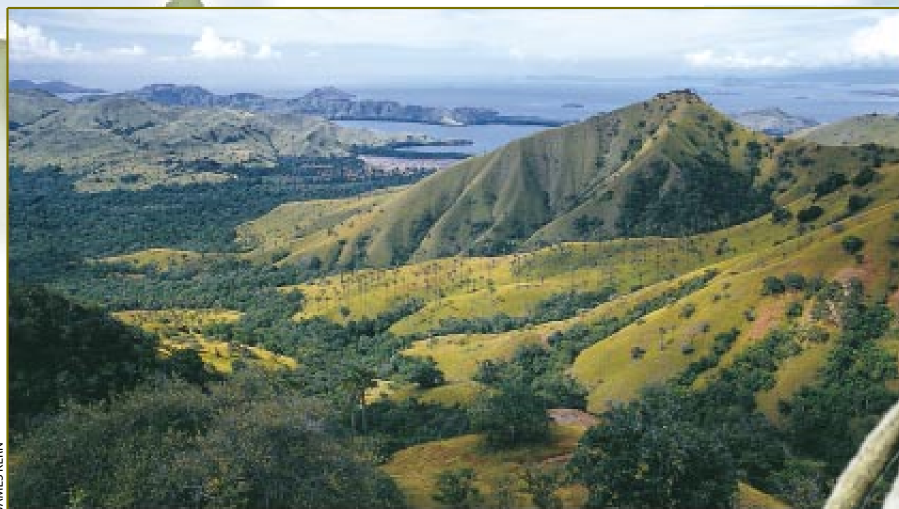
Monitors can see objects as far away as 300 meters, so vision

**KOMODO DRAGON** flicks his foot-long, yellow forked tongue to taste the air.

JOSE AZEL *Aurora*


LAURIE GRACE

**KOMODO ISLAND** has an area of about 340 square kilometers (130 square miles) and is clearly hilly. The highest points are about 735 meters above sea level. Komodo dragons tend to stay below 500 meters but are found at all elevations. The creatures live only on a few Indonesian islands. As shown on the map, Australia is 900 kilometers southeast, with Java some 500 kilometers to the west and New Guinea 1,500 kilometers to the northeast.



JAMES KERN

does play a role in hunting, especially as their eyes are better at picking up movement than at discerning stationary objects. Their retinas possess only cones, so they may be able to distinguish color but have poor vision in dim light. Today the tall grass obscures the deer.

Should the deer make enough noise the Komodo may hear it, despite a mention in the scientific paper first reporting its existence that dragons appeared to be deaf. Later research revealed this belief to be false, although the animal does hear only in a restricted range, probably between about 400 and 2,000 hertz. (Humans hear frequencies between 20 and 20,000 hertz.) This limitation stems from varanids having but a single bone, the stapes, for transferring vibrations from the tympanic membrane to the cochlea, the structure responsible for sound perception in the inner ear. Mammals have two other bones working with the stapes to amplify sound and transmit vibrations accurately. In addition, the varanid cochlea, though the most advanced among lizards, contains far fewer receptor cells than the mammalian version. The result is an animal that is insentient to such sounds as a low-pitched voice or a high-pitched scream.

Vision and hearing are useful, but the Komodo's sense of smell is its primary food detector. Its long, yellow forked tongue samples the air, after which the two tongue tips retreat to the roof of the mouth, where they make contact with the Jacobson's organs. These chemical analyzers "smell" the deer by recognizing airborne molecules. The concentration present on the left tongue tip is higher than that sampled from the right, telling the Komodo that the deer is approaching from the left. This system, along with an undulatory walk in which the head swings from side to side, helps the dragon sense the existence and direction of odoriferous carrion from as far away as four kilometers, when the wind is right.

The Komodo makes its presence known when it is about one meter from its intended victim. The quick movement of its feet sounds like a "muffled machine gun," according to Walter Auffenberg, who has contributed more to our knowledge of Komodos than any other researcher. Auffenberg, a herpetologist at the University of Florida, lived in the field for almost a year starting in 1969 and returned for briefer study periods in 1971 and again in 1972. He summed up the bold, bloody and resolute nature of the Komodo assault by saying, "When these animals decide to attack, there's nothing that can stop them." That is, there is nothing that can stop them from their attempt—most predator attacks worldwide are unsuccessful. The difficulties in observing large predators in dense vegetation turn some quantitative records into best estimates, but it is informative that one Komodo followed by Auffenberg for 81 days had only two verified kills, with no evidence for the number of unsuccessful attempts.

For the sake of instructive exposition, the Komodo that has ambushed the deer reaches its target. It attacks the feet first, knocking the deer off balance. When dealing with smaller prey, it may lunge straight for the neck. The basic strategy is simple: try to smash the quarry to the ground and tear it to pieces. Strong muscles driving powerful claws accomplish some of this, but the Komodo's teeth are its most dangerous weapon. They are large, curved and serrated and tear flesh with the efficiency of a plow parting soil.

Its tooth serrations harbor bits of meat from the Komodo's last meal, either fresh prey or carrion. This protein-rich residue supports large numbers of bacteria, which are currently being investigated by Putra Sastrawan, once Auffenberg's student, and his colleagues at the Udayana University in Bali and by Don Gillespie of the El Paso Zoo in Texas. They have found some 50 different bacterial strains, at least seven of which are highly septic, in the saliva.

If the deer somehow maneuvers away and escapes death at this point, chances are that its victory, and it, will nonetheless be short-lived. The infections it incurs from the Komodo bite will probably kill it within one week; its attacker, or more likely other Komodos, will then consume it. The Komodo bite is not deadly to another Komodo, however. Dragons wounded in battle with their comrades appear to be unaffected by these otherwise deadly bacteria. Gillespie is searching for antibodies in Komodo blood that may be responsible for saving them from the fate of the infected deer.

Should the deer fail to escape immediately, the Komodo will continue to rip it apart. Once convinced that its prey is incapacitated, the dragon may break off its offensive for a brief rest. Its victim is now badly injured and in shock. The Komodo

**JUVENILE KOMODOS** spend much of their time in trees, a behavior that keeps them from being eaten by larger, less agile members of their species.

suddenly launches the coup de grâce, a belly attack. The deer quickly bleeds to death, and the Komodo begins to feed.

The muscles of the Komodo's jaws and throat allow it to swallow huge chunks of meat with astonishing rapidity: Auffenberg once observed a female who weighed no more than 50 kilograms consume a 31-kilogram boar in 17 minutes. Several movable joints, such as the intramandibular hinge that opens the lower jaw unusually wide, help in the bolting. The stomach expands easily, enabling an adult to consume up to 80 percent of its own body weight in a single meal, which most likely explains some exaggerated claims for immense weights in captured individuals.

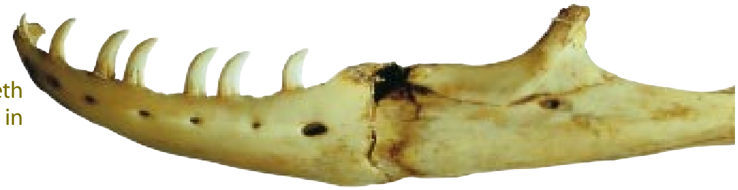
Large mammalian carnivores, such as lions, tend to leave 25 to 30 percent of their kill unconsumed, declining the intestines, hide, skeleton and hooves. Komodos eat much more efficiently, forsaking only about 12 percent of the prey. They eat bones, hooves and swaths of hide. They also eat intestines, but only after swinging them vigorously to scatter their contents. This behavior removes feces from the meal. Because large Komodos cannibalize young ones, the latter often roll in fecal material, thereby assuming a scent that their bigger brethren are programmed to avoid consuming.

More Komodos, attracted by the aromas, arrive and join in the feeding. Although males tend to grow larger and bulkier than females, no obvious morphological differences mark the sexes. One subtle clue does exist: a slight difference in the arrangement of scales just in front of the cloaca, the cavity housing the genitalia in both sexes. Sexing Komodos remains a challenge to researchers; the dragons themselves appear to have little trouble figuring out who is who. With a group assembled around the carrion, the opportunity for courtship arrives.

Most mating occurs between May and August. Dominant males can become embroiled in ritual combat in their quest for females. Using their tails for support, they wrestle in upright postures, grabbing each other with their forelegs as they attempt to throw the opponent to the ground. Blood is usually drawn, and the loser either runs or remains prone and motionless.

The victorious wrestler initiates courtship by flicking his tongue on a female's snout and then over her body. The temple and the fold between the torso and the rear leg are favorite spots. Stimula-

CLAUDIO CIOFI


CLAUDIO CIOFI

**KOMODO FEASTS** on a deer (*below*). Curved, serrated teeth (*right; set in jawbone*) easily tear through flesh. Meat caught in the serrations supports the growth of septic bacteria.


CLAUDIO CIOFI

tion is both tactile and chemical, through skin gland secretions. Before copulation can occur, the male must evert a pair of hemipenes located within his cloaca, at the base of the tail. The male then crawls on the back of his partner and inserts one of the two hemipenes, depending on his position relative to the female's tail, into her cloaca.

The female Komodo will lay her eggs in September. The delay in laying may serve to help the clutch avoid the brutally hot months of the dry season. In addition, unfertilized eggs may have a second chance with a subsequent mating. The female lays in depressions dug on hill slopes or within the pilfered nests of Megapode birds. These chicken-size land dwellers make heaps of earth mixed with twigs that may reach a meter in height and three meters across. While the eggs are incubating, females may lie on the nests, protecting their future offspring. No evidence exists, however, for parental care of newly hatched Komodos.

The hatchlings weigh less than 100 grams and average only 40 centimeters in length. Their early years are precarious, and they often fall victim to predators, including their fellow Komodos. They feed on a diverse diet of insects, small lizards, snakes and birds. Should they live five years, they can weigh 25 kilograms and stretch two meters long. By this time, they have moved on to bigger prey, such as rodents, monkeys, goats, wild boars and the most popular Komodo food, deer. Slow growth continues throughout their lives, which may last more than 30 years. The largest Komodos, three meters and 70 kilograms of bone, teeth and sinew, rule their tiny island kingdoms.

## The Komodo's Past

Komodos, as members of the class Reptilia, do have a relationship with dinosaurs, but they are not descended from them, as is sometimes believed. Rather Komodos and dinosaurs share a common ancestor. Both monitor lizards and dinosaurs belong to the subclass Diapsida, or "two-arched reptiles," characterized by the presence of two openings in the temporal region of the skull. The earliest fossils from this group date back to the late Carboniferous period, some 300 million years ago.

Two distinct lineages arose from those early representatives. One is Archosauria, which included dinosaurs. The ancestor of monitor lizards, in contrast, stemmed from primitive Lepidosauria at the end of the Paleozoic era, about 250 million years ago. Whereas some dinosaurs evolved upright stances, the monitor lineage retained a sprawling posture and developed powerful forelimbs for locomotion. During the Cretaceous, and starting 100 million years ago, species related to present-day varanids appeared in central Asia. Some of these were large marine lizards that vanished with the dinosaurs, about 65 million years ago. Others were terrestrial forms, up to three meters in length, that preyed on smaller animals and probably raided dinosaur nests. About 50 million years ago, during the Eocene, these species dispersed throughout Europe and south Asia and even into North America.

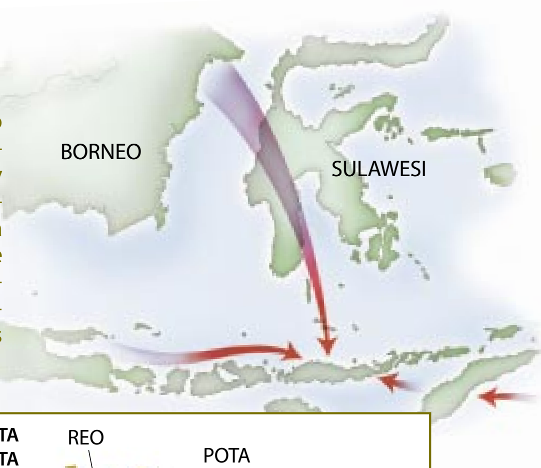
Wolfgang Böhme of the museum of natural history in Bonn has contributed much to our understanding of the rise and evolution of the *Varanus* genus, based on morphological data. Dennis King of the Western Australian Museum and Peter Baverstock and his colleagues at Southern Cross University are continuing research into the evolutionary history of the genus through comparisons of DNA sequences and chromosomal structure of varanid species and related families. They have concluded that the genus originated between 40 and 25 million years ago in Asia.

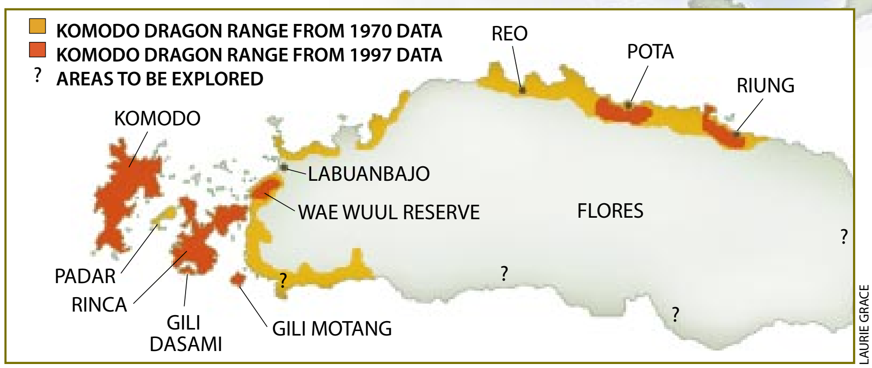
Varanids reached Australia by about 15 million years ago, thanks to a collision between the Australian landmass and southeast Asia. Numerous small varanid species, known as pygmy monitors, quickly colonized Australia, filling multiple ecological niches. More than two million years later a second lineage differentiated and spread throughout Australia and the Indonesian archipelago, which was at the time far closer to Australia than it is today, because much of the continental shelf was above water. *V. komodoensis* is a member of that lineage, having differentiated from it about four million years ago.

The Indo-Australian varanids could take advantage of their unique faunal environment. Islands simply have fewer resources than large landmasses do. Because reptilian predators can subsist on much lower total energy requirements than mammals can, a reptile will have the advantage in the race for top predator status under these conditions.

In such a setting, reptiles can also evolve to huge size, an advantage for hunting. A varanid called *Megalania prisca,* extinct for around 25,000 years, may have reached a length of six meters and a weight of 600 kilograms; the late extinction date means that humans may have encountered this monster. Komodos adopted a more moderate giantism. Reasons for the Komodo's current restricted home range—the smallest of any large predator—are the subject of debate and study. Various researchers subscribe to alternative routes that the dragons' ancestors may have taken to their present locale of Komodo, Flores, Rinca, Gili Motang and Gili Dasami.

**POSSIBLE ROUTES** (*right*) by which Komodo ancestors traveled to their current island habitat are still the subject of debate. Whether they came from Asia directly or through Java or Australia first is not clear. Certainly the lower sea levels of the past made more routes possible than are obvious today. The more recent research in the region has updated the decades-old knowledge that we had of the Komodo's current territory (*below*).




LAURIE GRACE

Komodo has a different paleogeography from its neighbors. According to worldwide sea-level changes over the past 80,000 years and bathymetric data of the study area, Flores and Rinca were joined until 10,000 years ago. Gili Motang was connected several times to their combined landmass. Komodo was long isolated but appears to have joined its eastern neighbors about 20,000 years ago, during the last glacial maximum. That association may have lasted 4,000 years. (This scenario is based on my calculations of the effect of sea-level variations of about 130 meters during the last Pleistocene glaciation, combined with available bathymetric data for the area.)

Tantalizing fossil evidence supports the notion that today's Komodo populations are relics of a larger distribution that once reached Timor, to the east of Flores. Fossils of two identical forms of a now extinct pygmy elephant, *Stegodon,* about 1.5 meters at the shoulder, on both Timor and Flores suggest that those two islands might have been sufficiently close in the Pleistocene to allow migration.

The limited resources of an island could have driven the evolution of the pygmy elephants, because smaller individuals, with lower food requirements, would have been selected for. In contrast, today's Komodo dragon may have evolved from a less bulky ancestor; the availability of the relatively small elephants as prey may have been a driving force in the selection of largeness that resulted in the

TUI DE ROY

**FRESHWATER** is so scarce during the dry season that most Komodos do without any from April to December. When water is available, the dragons often drink what has collected in hog wallows.

modern three-meter Komodo. (A large reptile still needs far less food than a mammal of similar size.) Auffenberg suggests that the Komodo could once "have been a highly specialized pygmy stegodont predator," although prey species similar to modern deer and boars may also have been present before the arrival of modern humans within the past 40,000 years.

Further attempts to reconstruct the Komodo's evolutionary history require more comprehensive fossil finds and accurate dating of the islands that harbor extant populations. The work of King and Baverstock, as well as the integration of paleogeographic data and genome analysis, should shed more light on the origin of the species.

### The World Discovers a Dragon

The West was unaware of the Komodo until 1910, when Lieutenant van Steyn van Hensbroek of the Dutch colonial administration heard local stories about a "land crocodile." Members of a Dutch pearling fleet also told him yarns about creatures six or even seven meters long. Van Hensbroek eventually found and killed a Komodo measuring a more realistic 2.1 meters and sent a photograph and the skin to Peter A. Ouwens, director of the Zoological Museum and Botanical Gardens at Bogor, Java.

Ouwens recruited a collector, who killed two Komodos, supposedly measuring 3.1 and 2.35 meters, and captured two young, each just under one meter. On examination of these specimens, Ouwens realized that the Komodo was in fact a monitor lizard. In the 1912 paper in which Ouwens introduced the Komodo to the rest of the world, he wrote simply that van Hensbroek "had received information ... [that] on the island of Komodo occurred a *Varanus* species of an unusual size." Ouwens ended the paper by suggesting the creature be given the name *V. komodoensis*.

Understanding the Komodo to be rare and magnificent, local rulers and the Dutch colonial government instituted protection plans as early as 1915. After World War I, a Berlin Zoological Museum expedition roused worldwide interest in the animal. In 1926 W. Douglas Burden of the American Museum of Natural History undertook a well-equipped outing to Komodo, capturing 27 dragons and describing anatomical features based on examinations of some 70 individuals.

### The Komodo's Future

More than 15 expeditions followed Burden's, but it was Auffenberg who performed the most comprehensive field study, looking at everything from behavior and diet to demographics and the botanical features of their territory. Auffenberg determined that the Komodo is, in fact, rare. Recent estimates suggest that fewer than 3,500 dragons live within the boundaries of Komodo Island National Park, which consists of the islands of Komodo (1,700 individuals), Rinca (1,300), Gili Motang (100) and Padar (none since the late 1970s), and some 30 other islets. A census on Gili Dasami has never been done. About another 2,000 Komodos may live in regions of the island of Flores. The Komodo is now officially considered a "vul-

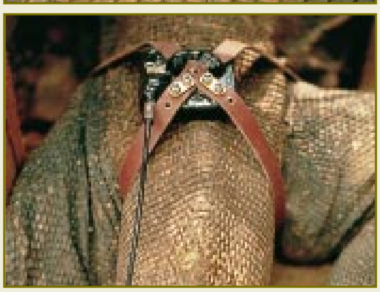
## From Grad Student to Dragon Wrangler

I became interested in Komodos as a graduate student at the University of Kent at Canterbury in England. My doctoral thesis, in conservation biology, required me to perform field research on a rare or endangered species. I wished to work with reptiles, and I wanted to combine fieldwork with state-of-the-art molecular biological techniques, which are useful in determining genetic relationships and divergences between populations. Such studies require collecting blood from a study specimen. Based on these parameters, the creatures that would have most benefited from study were limited to two species.

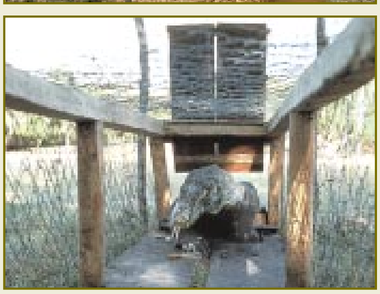
The first was a tortoise, *Testudo hermanni,* that is distributed throughout southern Europe. I instead chose the Komodo both for the challenge and because it is still one of the world's least studied large predators. I would discover many of the reasons for this continuing ignorance. All the materials needed for fieldwork must be shipped in or created from scratch; building Komodo dragon traps is arduous and time-consuming; while rare, attacks by Komodos on humans are not unheard of; and then there is the smell.

I wanted mobile traps and immobilized Komodos. I therefore built devices along the lines of humane mousetraps, only my mice might reach lengths of three meters. I made the devices with local timber and iron-mesh fencing material. Each trap measured three meters by a half meter by a half meter and had

RON LILLEY



CLAUDIO CIOFI



CLAUDIO CIOFI

**DRAGON WRANGLING:** taking blood; dragon equipped with a hip harness carrying telemetric instruments; the view from the other end of a homemade dragon trap.

a closable door. Goat served as both bait and as rations for me and a local ranger assistant. Komodos would force themselves into the trap as far as they could to get to the meat at the other end. Once they touched the bait, which was connected to a trigger mechanism, the entrance to the trap closed.

At this point, we would hang the entire trap on a balance, thus determining the weight of the captured individual. Then we would open the door at the tail end and pull the Komodo out. Komodos smell quite intense to begin with, what with their oral bacterial factories and their frequent association with carrion. The rotting goat meat adds to the aroma, and punctuating the olfactory experience is the habit of the threatened Komodo to immediately vomit and defecate, in preparation for fight or flight. Once the rear legs were free, we would tie them together. We would then continue to pull the Komodo from the trap until the front legs appeared, and we tied those. Finally, we would tape the mouth shut, allowing us to do a quick physical examination and take blood. We went through this routine on animals smaller than about 2.5 meters in length. When we happened to trap any of the largest individuals, we contented ourselves with drawing blood while the Komodo remained ensnared. Using these techniques, I was able to get blood samples from 117 Komodos over five months in 1994 and 1997, and I am currently analyzing them. Also in 1997 I attached transmitters to eight Komodos to obtain information about movement and home-range size. —*C.C.*

nerable" species, according to the World Conservation Union; it is also protected under the Convention on International Trade in Endangered Species of Wild Fauna and Flora.

The Komodo dragon has faced major challenges during the past 20 years that threaten its survival in part of the national park and on Flores. The disappearance of dragons on Padar probably stems from poaching of their primary prey, deer. Policing this rugged and sometimes inaccessible habitat is difficult; two days after I finished a census of the island in 1997, 10 deer were poached. Nevertheless, a trend toward less poaching overall on Padar has moved officials to discuss a reintroduction program.

Padar covers an area of only about 20 square kilometers and supports no more than 600 deer, in turn limiting the number of Komodos. Consequently, genetic diversity, as insurance against inbreeding, would be highly desirable among a new, small Komodo population.

To assist this plan, I started a genetic study of the remaining Komodo populations in 1994 to determine the degree of genetic similarity within and between the existing groups. I am currently analyzing DNA from blood samples of 117 dragons drawn in 1994 and 1997 [*see box on opposite page*]. The findings should eventually allow the authorities to choose the most appropriate source populations for restocking Padar, based on genetic diversity. Sex ratio and age structure will also be factors in the choice of individuals.

Komodos on Flores face the twin threats of prey depletion and habitat encroachment by humans. New settlers slash and burn the monsoon forest, and Komodo dragons are among the first species to disappear. In 1997 I set up a biotelemetric study to look at movement and home-range size of adult dragons in areas with differing degrees of human presence, both inside and outside the national park. A data collection covering a number of consecutive years can show conclusively whether human interference drives Komodos simply to migrate to different areas or to extinction.

I also initiated a long-term survey to obtain information on the distribution and level of threat to Komodo populations throughout Flores. The survey relies on traps set in localities chosen on the basis of habitat and on sighting reports by local people. Over the past 20 years, habitat loss has caused the species to vanish from an area stretching for 150 kilometers along Flores's northwest coast. Populations on the north and west coasts are also threatened by deforestation and indirectly through deer hunting.


**KRAKEN**, born at the National Zoo in Washington, D.C., on September 13, 1992, was the first Komodo hatched in captivity outside of Indonesia. She still lives there and is now 87 centimeters from her snout to the base of her tail and weighs 22 kilograms. Another 54 dragons eventually were hatched at the zoo, from eggs produced by Kraken's mother, a gift from Indonesia in 1988. Those dragons are now in zoos across the U.S. and in Japan, Germany, the Netherlands and Singapore.

The fortunes of the Komodo dragon are inexorably linked with those of numerous other species of fauna and flora, and measures to protect this giant lizard must take into account the entirety of its natural habitat. For example, although central Flores is inhospitable to dragons, the southern and eastern regions of the island may harbor scattered populations, still unknown to researchers, that could act as "umbrellas" to protect the ecosystem as a whole. The charismatic dragon already draws some 18,000 visitors a year to the area, and patches of forest containing Komodos could be the cornerstone of an economically viable protection plan for the entire habitat, based on ecotourism.

In addition, I hope to save the extant populations of Komodos by altering the current usage patterns of natural resources, in a transition to sustainable land use. Local officials have already expressed interest in such a plan. For example, slash-and-burn agriculture could be superseded by the cultivation of plant species that do not require clearing of the canopy to be economically useful. A technique as simple as instruction in the manufacture and laying of brick could save hardwood now harvested for house construction.

The fate of the world's few thousand Komodos, living out their lives in a tiny corner of the earth, is probably now in human hands. Policy decisions, as in so many wildlife conservation issues, will be as much aesthetic as scientific or economic. We can choose to create a homogeneous world of stultifying sameness. Or we can choose to maintain a remnant of the mystery that provoked medieval cartographers to mark the unexplored territories of their maps with the exhilarating warning, "Here there be dragons." SA

*The Author*

CLAUDIO CIOFI received his undergraduate education at the University of Florence. In 1998 he completed his Ph.D. at the Durrell Institute of Conservation and Ecology at the University of Kent at Canterbury in England. He is now based at the Zoological Society of London. Ciofi has worked in collaboration with the University of Gadjah Mada in Java and with Udayana University in Bali. His Komodo project, originating as a population genetic study, has broadened to include behavioral ecology and demography and the consequent protection of habitat and involvement of indigenous people. His research has been supported by the Zoological Society of London, the Wildlife Conservation Society, the Smithsonian Institution, Earthwatch Institute and British Airways.

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A lecture by Walter Auffenberg is available (in RealAudio) at www.si.edu/natzoo/hilights/lectures.htm on the World Wide Web.

# THE CRASH

by Stefan Thomke, Michael Holzner and Touraj Gholami

**SIMULATED FRONTAL COLLISION of a BMW 5-series hitting a barrier at 64 kilometers per hour (40 miles per hour) shows an end result (*above*) similar to that of an actual prototype frontal crash of the same vehicle at the same speed (*right*). The tests were carried out at BMW's Research and Engineering Center in Munich, Germany.**

If you live in a developed country, chances are good that you ride in an automobile every day without thinking much about the risks. Indeed, several factors have made car travel safer since the mid-1980s: the inclusion of air bags and other design improvements in vehicles, the use of seat belts and even the increasing maturity of the driving population have combined to lower the fatality rate on U.S. highways by 29 percent since 1987.

Nevertheless, driving remains a relatively risky means of transportation. In the U.S. alone in 1997 there were 6,764,000 accidents reported to the police, according to the National Highway Traffic Safety Administration (NHTSA). These accidents killed 41,967 people and injured nearly 3,400,000. It is a sad fact that motor vehicle accidents are the leading cause of death for young people between the ages of six and 27. In addition to this incalculable loss of life, there are enormous economic costs. In 1994 the NHTSA estimated that the annual cost of motor vehicle crashes exceeded a staggering $150 billion.

Cars that are better designed to protect their human occupants in a crash are a major reason the rate of fatalities is lower today than it was in the mid-1980s. Unfortunately, though, competitive pressures in the automobile industry are forcing most companies to spend less money and time developing new automobiles. In short, at a time when customers and governments are

# IN THE MACHINE

***Increasingly, automakers are relying on computer simulations of accidents to develop safer cars more quickly and efficiently***


BMW SIMULATION DEPARTMENT

demanding safer cars, the budgets to design such cars are shrinking.

In computer technology, many automakers are finding a way out of this dilemma. Increasingly, these companies are replacing their traditional crash tests—in which they verify new engineering concepts by running heavily instrumented prototype cars into concrete barriers—with "virtual" crashes, in which high-performance computers simulate a collision. Over the past 10 years, tremendous increases in computer speed and improved software have advanced crash simulation to the point where the results are trusted with a high degree of confidence. The resulting surge in the use of computers is revolutionizing the way vehicles are designed.

The savings in time and money have been impressive. For a traditional crash test, the first step is building the prototype vehicle, which generally takes four to six months and costs hundreds of thousands of dollars. Then it must be outfitted with several crash-test dummies, which have embedded electronic sensors to record acceleration and can cost $65,000 apiece. A variety of instruments, including high-speed cameras, record the crash. Unfortunately, glass and other debris often partially obstruct the view, and crash dummies sometimes accelerate through interior regions that are not covered by the cameras. Thus, the postcrash films usually give engineers precious little that they can use to improve a design.

A simulated test, on the other hand, can be conceived, programmed on a computer and carried out in days or weeks, and the main expense is paying the salaries of the simulation engineers. True, the computers are typically either top-of-the-line workstations costing tens

**CHRONOLOGY OF A CRASH shows a simulated collision with a deformable barrier at 64 kilometers per hour. The interval between successive images is 10 milliseconds.**

of thousands of dollars or supercomputers that cost millions. But unlike the crash-test prototype vehicles, the computers are used over and over again and sometimes can have other applications within the company apart from verifying crashworthiness.

Perhaps most important, computer simulations let design engineers work in ways that would be impossible otherwise. For example, in a relatively short period, they can carry out a barrage of tests aimed at improving a structural piece—such as one of the "pillars" that connects the roof of a car to the chassis below the windows—that strongly affects the crashworthiness of the entire vehicle. They can "replay" a simulation as slowly as they like and zoom in on any structural element or even on a small piece of a structural element to see how it reacts.

Such capabilities not only generate a wealth of useful detail, they also enable engineers to make the most of the expensive prototype collision tests. With a good set of simulated crashes, the development team can reduce the chances that an actual prototype crash test will go poorly and require another round of costly redesign and retesting.

## When Cars Collide

Although their economy and other advantages are earning them a larger share of the design and development process, computer simulations will complement, rather than replace, traditional crash tests for the foreseeable future. Steady increases in computer processing power have let programmers achieve a remarkable level of fidelity and detail, but simulations do have inherent limitations. A fundamental one is that each individual simulation can answer only a specific question, such as: What effect would a pillar 7 percent thinner have on a side impact at 50 kilometers per hour (30 miles per hour)?

Indeed, the kinds of questions that can be answered by simulation are limited by the range of phenomena that can be modeled. For example, it is very difficult today to simulate and predict the outcome of rollover accidents because of their duration and complexity. A rollover can take a full three seconds, as opposed to 100 to 150 milliseconds for a more typical smashup. To simulate that much time requires prodigious computer power. The behavior of a car in a rollover can also be difficult to predict, because it depends on road friction and other factors. It is also essentially impossible to use computers to discover whether any parts of the car will present a fire hazard in an accident—for example, whether a fuel tank is prone to explode.

Another reason prototype crash tests are not likely to become obsolete anytime soon is that government traffic safety agencies in most developed countries still require data from them. In the U.S. the NHTSA works with other organizations to develop safety regulations that carmakers must meet in order to sell vehicles. In Europe the specific regulations are somewhat different, but the legislative process is similar; the United Nations's Economic Commission for Europe issues regulations to its members, which the European Union may then adopt, and vice versa.

These laws require automakers to record data from prototype crashes in the three main accident categories: frontal, rear and side impact. The regulations are detailed—specifying, for example, a frontal collision with a concrete barrier at up to 48 kilometers per hour. Typically these tests are first applied to early prototypes during automotive development and later used by government agencies to sample the safety of production vehicles. Automakers often augment the standard prototype collisions with their own (more stringent) tests or with those of the Insurance Institute for Highway Safety in the U.S., which permit them to attain levels of crashworthiness well beyond the government mandates.

The government requirements were developed based on accident statistics. In the U.S. in 1997, according to the transportation safety administration, 45.2 percent of all crashes involving passenger cars were frontal, 33.9 percent were side impact, and 19.6 percent were rear impact. Yet frontal crashes were disproportionately deadly: 61.9 percent of fatal accidents involved frontal crashes, 25.2 percent were side impact, and only 5.5 percent were rear impact. These figures were fairly typical; thus, in their efforts to improve crashworthiness, government safety agencies have traditionally focused on head-to-head collisions. The result has been seat-belt laws and the increasing use of air bags. In recent years, though, automakers have been paying more attention to improving the ability of vehicles to protect passengers in side-impact crashes, generally through the use of head air bags [*see bottom illustration on next page*] and through redesign of the pillars and other key structural pieces in the side of a car.

To understand how designers use crash data to make cars safer requires some knowledge of the physics of collisions. An automobile accident is basically just a transformation of energy: from the kinetic energy of the moving vehicles to the energy used in deforming their bodies during the crash. The single most influential characteristic is the vehicle's speed at impact, because the absorbed crash energy goes up with the square of velocity (a crash at 90 kilometers per hour is four times more energetic than a crash at 45).

Weight is another key factor. Although weight is a disadvantage in a single-vehicle crash, it can be a plus in a multivehicle accident. When heavy and light vehicles collide, passengers in the heavy ones generally fare better—unless the light vehicles are built with stiffer materials, relative to the heavy cars, in key impact areas. In fact, this issue points to an unfortunate situation: government-mandated prototype crash tests require crashworthiness to be evaluated in isolation, despite the fact that 63 percent of all fatal crashes involve two or more vehicles. If automakers

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had to minimize the damage to all the vehicles in a crash—for example, by balancing weight and stiffness—sport-utility and other relatively heavy passenger vehicles would be built with materials that were somewhat more pliant. Indeed, a few automakers are just now starting to incorporate this principle into their designs.

Basically, all injuries that occur in an accident can be traced to one of two causes: the body's collision with objects—the steering wheel, for one—resulting in external injuries such as bruises or punctures; or the body's sudden acceleration during the crash, which causes injuries inside the body such as bone fractures and organ ruptures accompanied by internal bleeding. In a prototype crash test, sensors in the dummies record peak acceleration; a lower acceleration indicates better crashworthiness and thus a lower probability of death or severe injury.

This acceleration comes from momentum, which the vehicle and whatever it hits transfer to each other in a collision. For safety purposes, one of the most significant factors is the rate at which the momentum is transferred to the vehicle. This factor in turn depends on many variables; in the vehicle, material strength and stiffness, structural supports, the position of the engine and the rigidity of the steering wheel column—to name a few of many design parameters—can all influence the degree to which a collision causes injury.

## Piece by Piece

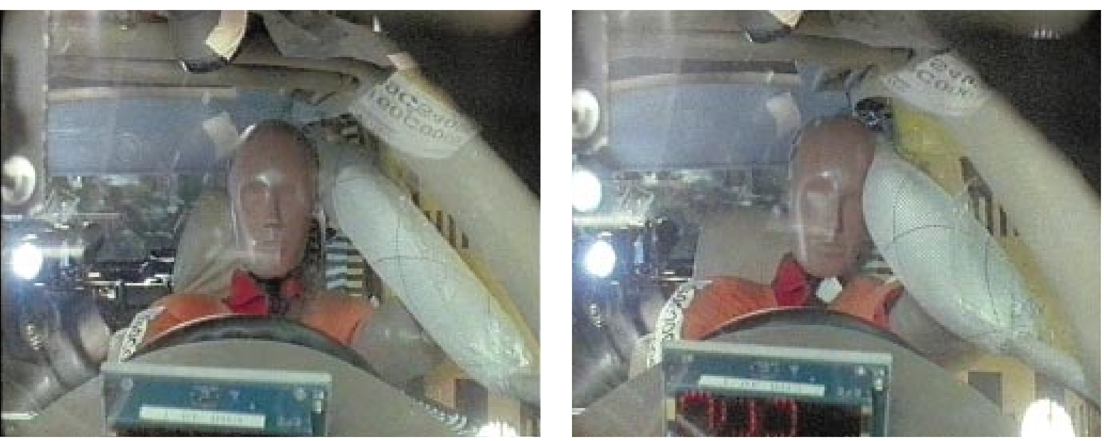
The computer programs that model all these parameters are based on an algorithmic technique known as finite element analysis. With this method, programmers represent each piece of the structure as a group of finite elements, each of which is a polygon that has associated with it a mathematical description of its physical and material properties, such as stiffness and tensile strength. For a crash test, the complete model generally consists of several components: the body of the vehicle, its seats, the engine and the passengers. Each of these pieces is further broken down. The vehicle, for example, consists of door panels, windows, pillars, struts and other parts; programmers represent each of these as a group of finite elements.

The more finite elements in the model, the more closely it simulates reality. Currently engineers use high-end workstations or supercomputers, which are powerful enough to simulate a vehicle model with 200,000 to 300,000 finite elements. The seats, engine and passengers can add another 100,000 to 200,000 polygons. Limitations in computer power have forced programmers to model the passengers as rigid, jointed figures, much like crash dummies; this is still the standard practice in the industry. But higher computing speeds are finally enabling some university researchers to simulate occupants with more realistic features, such as soft tissue and bones. The work is important because as computers continue to become more powerful, it will only be a matter of time before simulation engineers will be able to compute the acceleration of specific organs in the body during a crash. This capability would be another significant advantage for computer-based simulations, because although crash-test dummies have embedded accelerometers, these sensors merely measure the increase in speed of parts of the dummy. They cannot predict how a specific organ suspended in the body, a largely fluid medium, will move.

To generate the many thousands of finite elements in a model, engineers use data from the computer-aided design programs that are created early in the development process. Then they associate with each element the physical properties (mass, density, stiffness and so on) and contact conditions relative to the elements that surround it.

As they connect the elements to create a model, including the passenger modules, engineers fine-tune it, making sure that the mass distribution and the resulting center of gravity represent reality as closely as possible. The finished model is a complex piece of software that computes how kinetic energy is transformed into deformations, acceleration forces and other parameters during a collision.

Before a simulation, engineers create the crash conditions by setting the velocities, just before impact, for the vehicle and whatever it hits. On impact, the kinetic energy is converted into deformation energy according to the laws of Newtonian physics. Cal-



BMW PROTOTYPE TESTING

**PROTOTYPE CRASH TEST was recorded by high-speed still cameras. These images, of a side-impact crash, represent the best possible visual results because they are unobscured by debris. During the collision, the head air bag deployed, keeping the dummy's head from hitting the side of the car.**

**CRASH CHRONOLOGY continues as the vehicle's front end is smashed in by about 70 centimeters. More crumpling could thrust the engine into the passenger compartment.**

culating the conversion from kinetic to deformation involves representing the movement within and between the many finite elements, using simple relations. In effect, the programs sum the forces over all the elements, which results in a system of equations that is solved using various mathematical and numerical methods. The stress within the elements is determined using standard principles of material behavior. The simulation is time-dependent, meaning that the system of equations is solved over and over again, each time updating the position and stress levels of every element. Each new iteration takes as its initial conditions the final results of the previous iteration. The conversion goes on, iteration after iteration, until there is no more kinetic energy left to convert—or, in other words, until all moving pieces have come to rest.

During the simulation, programmers can determine the velocities and deformations at the vertices of the finite element polygons. They can then use these values to determine the stress to which each finite element is subjected. For the passenger components of the model (the "software dummies"), they measure accelerations, movements and forces rather than levels of stress.

The three major simulation programs used by auto firms today are PAMCRASH, LS-DYNA3D and RADIOSS. All three are based on programs that were developed in the late 1960s for military purposes in the U.S. They all work on the finite element principles outlined above and differ from one another subtly in the assortment of materials they can easily simulate, the way they handle the simulated surfaces that come into "contact" with one another in the collision and the software support they provide during model-building (preprocessing) and crash-analysis (postprocessing) phases.

The programs grew out of alliances between automotive firms and software vendors. PAMCRASH, for example, was the result of a European effort involving Volkswagen, Ford, Opel and the French software company Engineering Systems International (ESI). PAMCRASH is also widely used by Japanese car companies. The main program among U.S. automakers is LS-DYNA3D, which was based on code written at Lawrence Livermore National Laboratory for modeling nuclear blasts. RADIOSS was developed at Mecallog, a French firm founded by some former employees of ESI.

## Exploring Simulation's Potential

The power of simulation was well illustrated by a recent project at BMW, in which a team of designers, a simulation engineer and a test engineer attempted to develop technical concepts that could improve the side-impact safety for all BMW vehicles. The team set out in 1995 to explore the potential of simulation (they used the PAMCRASH program), deciding to limit prototype testing to only two crashes at the end to verify their final design concepts.

An existing production model, a 1995 5-series vehicle, served as the project's starting point. After each simulation, the team met, analyzed the results and designed another experiment. As expected, the team enjoyed quick feedback, enabling the members to try out an idea and accept or reject it within days. The surprise was that as the trials began to accrue, the whole was more than the sum of the iterations; the group was increasing its fundamental understanding of the underlying mechanics.

One notably fruitful example of this improvement involved the so-called B pillar, one of the six structural members that connects the roof of a car to the chassis below the windows. (There are three such pillars on each side of any car; from front to back, they are labeled A, B and C.) By analyzing the records of prototype side-impact crashes from earlier development projects, engineers on the team had found that in crash after crash, a small section of the B pillar folded. The section was next to the bottom of the pillar [*see illustration on opposite page*]. The folding bothered them because when a pillar buckles, its value as a barrier is compromised and the probability of passenger injuries goes up.

The engineers assumed that adding metal would strengthen the bottom of the pillar, making the car more resistant to penetration from the side. None of them felt that it was necessary to test this assumption. One development team member, however, insisted on a

DANIELS & DANIELS

**IMPACT ENERGY of a 64-kilometer-per-hour head-on crash during a collision with a rigid barrier is roughly equivalent to the automobile dropping vertically from 16 meters—about the height of a six-story building.**

BMW SIMULATION DEPARTMENT

BMW SIMULATION DEPARTMENT

**LOWER B-PILLAR AREA (*green*) of a sedan needed to be weakened, not strengthened, to protect passengers better in a crash.**

verification, pointing out that it would be neither difficult nor expensive on the computer. When the program was run, the group was shocked to discover that strengthening the folded area actually *decreased* crashworthiness significantly.

Initially, none of the team members could explain the phenomenon. After more iterations and careful analysis, though, they found the cause. Reinforcement of the lower part of the B pillar, they discovered, would cause the pillar to be prone to folding higher up, above the reinforced area. Thus, the passenger compartment would be more penetrable higher up—closer to the midsection, chest and head area of passengers. So the solution to the folding B-pillar problem turned out to be completely counterintuitive: weaken the lower B pillar rather than reinforce it.

Equipped with that knowledge, the group undertook a reevaluation of all the reinforced areas in the bodies of all BMW vehicles then in production or under development. The project improved to varying degrees the crashworthiness of all those automobiles.

The team finished its work in 1996, after it had carried out 91 virtual accidents and two prototype crashes in about a year. For the developmental vehicles that were redesigned, side-impact crashworthiness advanced an average of 30 percent over the initial design. This improvement was measured in several ways, such as by calculating and comparing the acceleration, in both virtual and actual crashes, of simulated or dummy body parts, such as the pelvis and chest. It is worth noting that the two prototype crashes at the end of the project strongly confirmed the simulation results and also the economics of testing: at a total of about $300,000, the two prototypes cost more to build, prepare and test than did the entire series of the 91 virtual crashes.

Similar projects at BMW focused on frontal crashes and were successful enough to win a commendation from the Insurance Institute of Highway Safety. In 1997 the institute bestowed its highest crashworthiness rating on the BMW 5-series, one of the cars whose development benefited significantly from simulations.

## Virtual Crashes in the Next Millennium

During the next five to 10 years, software and design engineers will be producing crash simulation models with several million finite elements. The week it now takes to execute another iteration in a series of tests will be down to half a day. These and other advances will bring about some important benefits. For one, software dummies will become considerably more detailed, mimicking human physiology and providing data that no crash-test dummy ever could. Automotive corporations will probably also be able at last to simulate rollover accidents. And such computing power will let engineers model more realistic accident scenarios, such as multiple-vehicle crashes, including ones that occur at various angles of incidence.

Moreover, automotive engineers will be able to use computers to model the performance of so-called smart safety systems, such as air bags that detect a passenger's position, weight and height and use the information to adjust the force and speed at which they deploy. Only with fast and inexpensive simulation will automakers be able to carry out the massive experimentation necessary to optimize these complex safety devices.

Automotive safety experts have really just begun exploiting the power of computer software and hardware. Over the next decade, some major advances will continue to expand the role of computer modeling in the development process. And as simulation technology transforms crashworthiness, the success of this revolution will be measured in the number of lives saved. SA

### *The Authors*

STEFAN THOMKE, MICHAEL HOLZNER and TOURAJ GHOLAMI met three years ago at BMW's Research and Engineering Center in Munich, Germany. Thomke, an assistant professor of technology and operations management at Harvard Business School, was at the center doing field research for an academic project. At Harvard, his work has been mainly on the management of research and development in the automotive, electronics and pharmaceutical industries. Holzner is the head of crash simulation at the BMW center. He holds a doctorate in mechanical engineering from the Technical University of Munich. Gholami is group leader in the crash simulation department. His master's degree is in engineering from the University of Berlin.

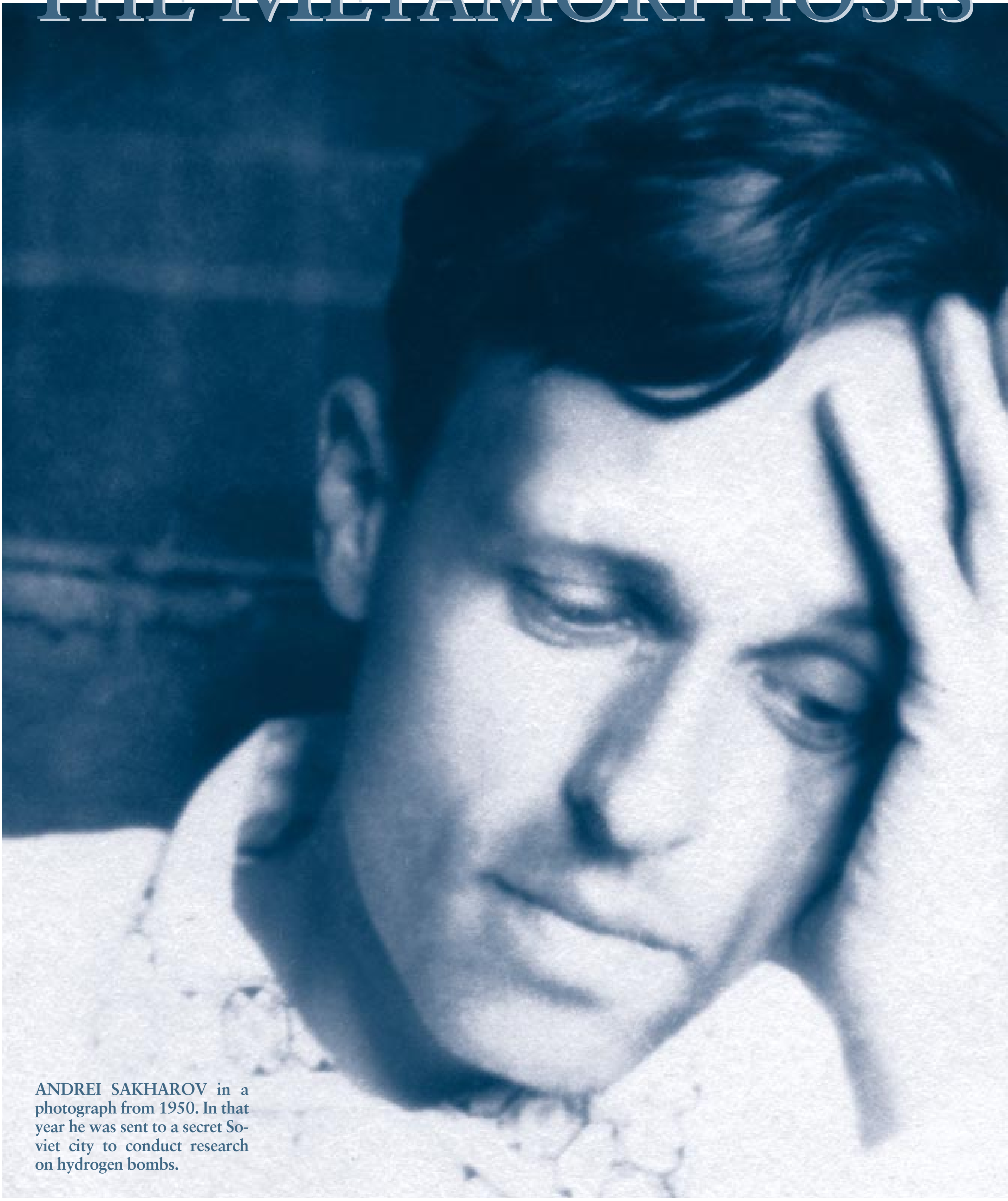
### *Further Reading*

Simulation, Learning and R&D Performance: Evidence from Automotive Development. Stefan Thomke in *Research Policy,* Vol. 27, No. 1, pages 55–74; May 1998.

Modes of Experimentation: An Innovation Process—and Competitive—Variable. Stefan Thomke, Eric Von Hippel and Roland Franke in *Research Policy,* Vol. 27, No. 3, pages 315–332; July 1998.

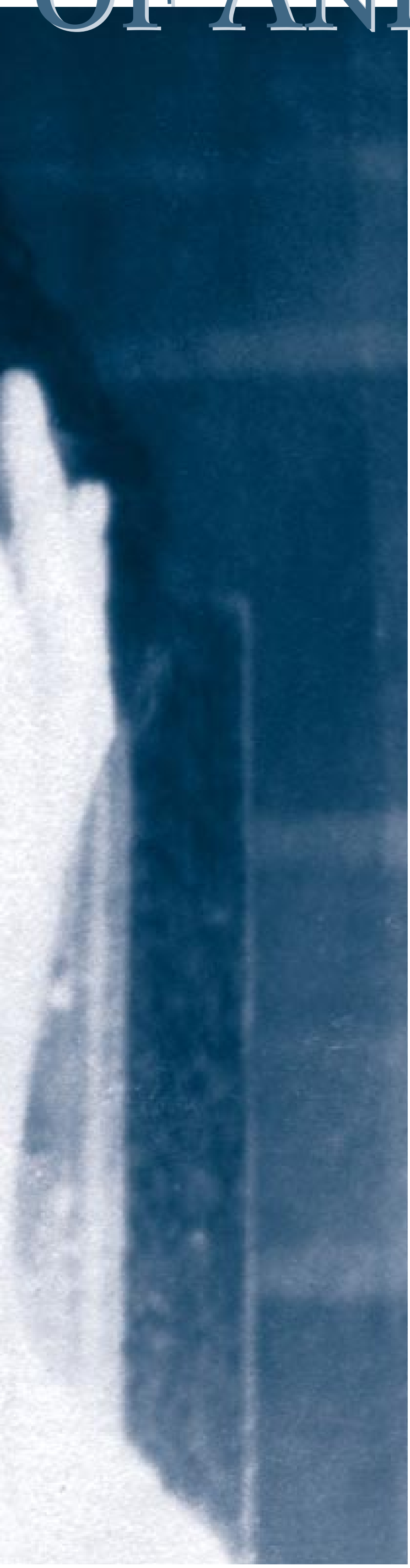
The World Wide Web sites for the National Highway Traffic Safety Association (NHTSA) at www.nhtsa.dot.gov and the Insurance Institute for Highway Safety at www.hwysafety.org include searchable databases with information on traffic safety and the crashworthiness of vehicles.

# THE METAMORPHOSIS



ANDREI SAKHAROV in a photograph from 1950. In that year he was sent to a secret Soviet city to conduct research on hydrogen bombs.

# of Andrei Sakharov



COURTESY OF ELENA BONNER

*The inventor of the Soviet hydrogen bomb became an advocate of peace and human rights. What led him to his fateful decision?*

by Gennady Gorelik

"The cloud turned gray, quickly separated from the ground and swirled upward, shimmering with gleams of orange.... The shock wave blasted my ears and struck a sharp blow to my entire body; then there was a prolonged, ominous rumble that slowly died away after thirty seconds or so.... The cloud, which now filled half the sky, turned a sinister blue-black color."

It was August 12, 1953, and Andrei Dmitrievich Sakharov had just become father of the Soviet hydrogen bomb. Along with a few officials, he donned a dustproof jumpsuit and drove into the blast range. The car stopped beside an eagle that was trying to get off the ground; its wings had been badly burned. "I have been told that thousands of birds are destroyed during every test," Sakharov was later to write in his memoirs. "They take wing at the flash, but then fall to earth, burned and blinded."

The innocent victims of nuclear testing were to become a deepening concern, and ultimately an obsession, for this extraordinary man. While he continued to design ever more efficient bombs, he also agonized over how many human lives the fallout from each blast would cost. Sakharov's many fruitless attempts to stop unnecessary tests at last led to his realizing how little control he had over the weapons he had created.

Numerous tales have been invented to account for Sakharov's transformation to an advocate for human rights. After his death in 1989, the Russian state archives released many secret documents relating to his life and work, which are now to be found in the Sakharov Archives in Moscow. These papers, as well as Sakharov's own writings, show that his metamorphosis derived directly from his involvement in the weapons project. For years, Sakharov genuinely believed that nuclear—and thermonuclear—weapons were vital to maintaining military parity with and preventing aggression by the U.S. His transformation came not from a newfound morality but from his rather old-fashioned one, coupled with his accumulating experience with weapons and in the politics of weaponry.

### A Sugary Layered Roll

Sakharov was born in 1921 to a family of Moscow intelligentsia. His father was a teacher of physics and a writer of popular science books, as well as a humane and forthright man. After graduating from high school, Andrei enrolled in Moscow University in 1938. When war broke out with Germany, his weak heart prevented him from being drafted. Graduating with honors in 1942, he refused to go on to higher studies: he wanted to contribute to the war effort. Accordingly, he became an engineer in a military ammunition plant in Ulyanovsk, where he invented a magnetic device to test the cores of the bullets that were being manufactured.

At the factory he met Klavdia Vikhireva, whom he married at the age of 22.

"HE LEARNED THAT THIS MILITARY FACILITY HAD BEEN BUILT BY PRISON LABOR IN THE OLD MONASTERY TOWN OF SAROV, SITUATED ABOUT 500 KILOMETERS FROM MOSCOW."

COURTESY OF GERMAN GONCHAROV

**The Old Sarov Monastery**

In those years he also dreamed up and solved some small problems in physics, which found their way through his father to Igor Tamm, the leading theoretical physicist at the P. N. Lebedev Physical Institute in Moscow. In early 1945 Sakharov was officially invited to Moscow to conduct graduate studies under Tamm's supervision.

One morning in August he saw in a newspaper that an atomic bomb had exploded over Hiroshima. He realized that "my fate and the fate of many others, perhaps of the entire world, had changed overnight."

Sakharov was clearly very able as a scientist and soon came up with a theory of sound propagation in a bubbly liquid, of importance in detecting submarines with sonar. He also calculated how fusion, the merging of two nuclei into one, might be catalyzed by a light, electronlike particle known as a muon. (Atoms that contain muons in place of electrons are much smaller and therefore would require less compression to be fused.)

Exhilarated by pure physics, he twice declined invitations from senior officials to join the Soviet atomic weapons project. An atomic bomb involves the fission of a heavy nucleus such as uranium 235 into two roughly equal parts, accompanied by the release of energy. But one day in 1948 Tamm announced that he and some selected associates, including Sakharov, had been assigned to investigate the possibility of a hydrogen bomb. This kind of bomb is based on the fusion of light nuclei, most commonly the two forms of hydrogen called deuterium and tritium, emitting greater amounts of energy than a fission bomb does.

Yakov Zel'dovich, a brilliant physicist who headed theoretical research for the nuclear weapons program, handed Tamm a tentative design for the hydrogen bomb. Fusion requires two positively charged nuclei to be brought close enough, despite their mutual repulsion, to touch; such conditions can arise only from the tremendous energy generated by a preceding fission reaction. The idea was to use fission to ignite fusion—otherwise known as a thermonuclear reaction—at one end of a tube of deuterium and somehow make the fusion propagate through the tube. This plan for a "superbomb," devised by American scientists, was given to Soviet intelligence authorities, most likely by physicist and spy Klaus Fuchs in 1945.

Sakharov turned out to be exceedingly adept at the combination of theoretical physics and engineering that was required in making a hydrogen bomb. Despite his junior status, he soon proposed a radically different design, called the *sloika,* or "layered roll": a spherical configuration with an atom bomb in the center, surrounded by shells of deuterium alternating with heavy elements such as natural uranium. The electrons released by the initial atomic explosion generated tremendous pressure within the uranium shell, forcing the fusion of deuterium. The Soviets called the process "sakharization"—literally, "sugaring" (the Russian *sakhar* translates to "sugar"). The fusion in turn released neutrons that enabled the fission of uranium.

The concept, enhanced by an idea from Vitaly Ginzburg—that lithium deuteride replace deuterium as a fuel—allowed the Soviet program to catch up with the American one. It was not until 1950 that American scientists realized that their superbomb design was a dud. But Stanislaw Ulam and Edward Teller of Los Alamos National Laboratory in New Mexico soon invented another design, and the thermonuclear arms race had taken off.

Although Sakharov was fascinated with the physics of fusion, his zeal in pursuing the bomb derived also from patriotism. He believed in concepts such as "strategic parity" and "nuclear deterrence," which suggested that nuclear war was impossible. His emotional investment in the project was immense: "The monstrous destructive force, the scale of our enterprise and the price paid for it by our poor, hungry, war-torn country . . . all these things inflamed our sense of drama and inspired us to make a maximum effort so that the sacrifices—which we accepted as inevitable—would not be in vain. We were possessed by a true war psychology."

Yet when Sakharov received an invitation to join the Communist Party, he refused because of its past crimes. He had


VNIIEF MUSEUM AND ARCHIVE

Research Facilities at Arzamas-16

"THE WHOLE CITY WAS SURROUNDED BY ROWS OF BARBED WIRE AND ERASED FROM ALL MAPS. IT WAS KNOWN TO INSIDERS BY VARIOUS CODE NAMES, AT THE TIME ARZAMAS-16."

no choice, however, when in March 1950 he and Tamm were assigned exclusively to bomb work at a secret city where weapons designers lived and worked. Sakharov learned that this military facility had been built by prison labor in the old monastery town of Sarov, situated about 500 kilometers from Moscow. The entire city was surrounded by rows of barbed wire and erased from all maps. It was known to insiders by various code names, at the time Arzamas-16.

### In a Secret City

Zel'dovich was already at Arzamas-16. The physicists spent much of the day ironing out details of bomb design. Nevertheless, Sakharov found time to conceive an idea for confining a plasma, gas so hot that electrons have been stripped from the atoms, leaving bare nuclei. The plasma would destroy any material walls but could be confined and even induced to fuse by means of magnetic fields. This principle, the basis of the tokamak reactor, is still the most promising design for producing energy from sustained fusion. ("Tokamak" is derived from the Russian phrase for a doughnut-shaped chamber with a magnetic coil.)

In November 1952 the U.S. had detonated a thermonuclear device. And by August 1953 Soviet scientists were ready to test the *sloika*. At the last minute, however, Viktor Gavrilov, a physicist trained as a meteorologist, pointed out that the radioactive fallout from the explosion would spread far beyond the test site and affect neighboring populations. Somehow no one had thought of this problem. Using an American manual on the effects of test explosions, the physicists quickly worked out the fallout pattern and realized that thousands of people would have to be moved. The recommendation was followed (although, as one official informed an anxious Sakharov, such maneuvers typically cause 20 or 30 deaths).

The *sloika* was successfully tested, yielding an energy about 20 times that of the Hiroshima bomb. In a few months Sakharov was elected a member of the Soviet Academy of Sciences—at 32 its youngest physicist ever. He also received the Stalin Prize and was decorated with the title Hero of Socialist Labor. The Soviet leadership had great hopes for Sakharov: not only was he brilliant, he was also non-Jewish (unlike Zel'dovich and Ginzburg) and politically clean (unlike Tamm).

The *sloika* was, however, limited in scope—its yield could not be increased indefinitely—and soon Sakharov and Zel'dovich came up with a new design. The idea was to use the radiation (photons) generated by an initial atomic explosion to compress a tube, thereby igniting fusion within it. The design, similar to the Ulam-Teller one, had potentially unlimited yield because the length of the tube could be increased as required.

Life at Arzamas-16 was unusual in more than one way. The researchers discussed politics quite freely. Moreover, they had access to Western journals, including the *Bulletin of the Atomic Scientists,* which concerned itself mainly with the social dimensions of nuclear energy and demonstrated how scientists on the other side of the Iron Curtain sought to influence public affairs. One inspiring figure was Leo Szilard, who had discovered the "chain reaction" that makes atomic bombs possible but who turned into a vocal critic of nuclear weapons. Sakharov was also aware of the political writings of Albert Einstein, Niels Bohr and Albert Schweitzer, who doubtless influenced him as well.

A memo written by the administrative director of Arzamas-16 in 1955 noted that although Sakharov was an able scientist, he had substantial defects in the realm of politics. He had, for instance, declined an offer to be elected to the Council of People's Deputies, a legislative body at Arzamas. The "defects" were to get worse.

In November 1955 the Soviets tested the unlimited hydrogen bomb. This time the shock wave from the blast collapsed a distant trench, killing a soldier, and crumbled a building, killing a toddler. These events weighed heavily on Sakharov. When asked to propose a toast at the celebratory banquet that night, he announced, "May all our devices explode as successfully as today's, but always over test sites and never over cities." Marshal Mitrofan Nedelin replied with an obscene joke, whose point was that scientists should just make the bombs and let military men decide where they should explode. It was designed to put Sakharov in his place.

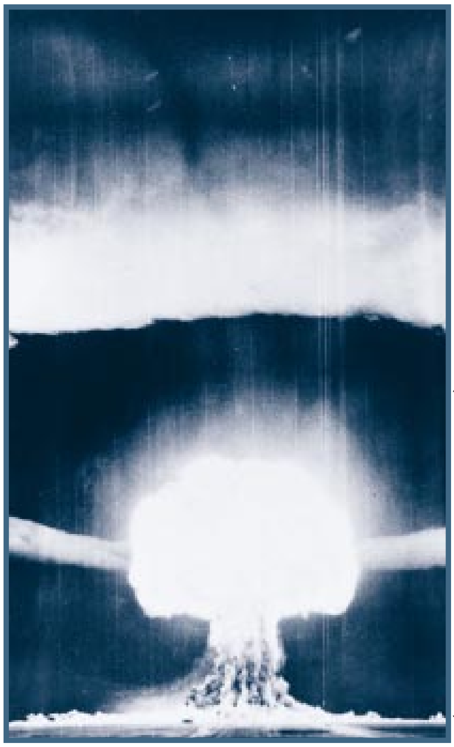
As variations of the basic thermonuclear devices continued to be tested, Sakharov became increasingly concerned about the unidentifiable victims of each blast. He taught himself enough genetics to calculate how many persons worldwide would be affected by cancers and other mutations as a result of nuclear testing.

In 1957 the U.S. press reported the development of a "clean bomb," a fusion bomb that used almost no fissionable material and seemingly produced no radioactive fallout. Sakharov found, however, on the basis of available biological data that a one-megaton (equivalent to a million tons of TNT) clean bomb would result in 6,600 deaths worldwide over a period of 8,000 years because of the proliferation of radioactive carbon 14 (produced when neutrons from the explosion interacted with atmospheric nitrogen). He published his results in 1958 in the Soviet journal *Atomic Energy,* concluding that the atmospheric testing of any hydrogen bomb—"clean" or not—is harmful to humans.

### The Chips Fly

Soviet premier Nikita S. Khrushchev himself endorsed the publication of this article. It suited his purposes: in March of 1958 he had suddenly announced a unilateral cessation of nuclear tests. Sakharov was not, however, playing political games. His figures revealed, as he saw it, that "to the suffering and death already existing in the world there would be added hundreds of thousands of additional victims, including people living in neutral countries as well as in future generations." He was also troubled that "this crime is committed with complete impunity, since it is impossible to prove that a particular death was caused by radiation."

In the same year Teller published a book, *Our Nuclear Future,* laying out the majority view of both American and Soviet hydrogen-bomb experts—who did not share Sakharov's concern. Teller estimated the radiation dose from testing as roughly 100th of that from other sources (such as cosmic rays and medical x-ray examinations). He also noted that radiation from testing reduced life expectancy by about two days, whereas a pack of cigarettes a day or a sedentary job reduced it by 1,000 times more. "It has been claimed," he concluded, "that it is wrong to endanger any human life. Is it not more realistic and in fact more in keeping with the ideals of humanitarianism to strive toward a better life for all mankind?" To Sakharov, that statement sounded a lot like the Soviet slogan "when you chop wood, chips fly." He felt personally responsible for any deaths from the fallout of testing.



VNIIEF MUSEUM AND ARCHIVE; COURTESY OF AIP EMILIO SEGRÈ VISUAL ARCHIVES

***SLOIKA,* a hydrogen bomb based on a design by Sakharov, was tested in August 1953 at Semipalatinsk in Siberia. The picture shows the mushroom cloud and shock wave.**

Meanwhile the U.S. and Britain continued testing, and after six months, a furious Khrushchev ordered that testing be resumed. Deeply concerned—because of the deaths he was convinced would ensue—Sakharov persuaded Igor Kurchatov, the scientific head of the atomic project, to visit Khrushchev and explain how computers, limited experiments and other kinds of modeling could make testing unnecessary. Khrushchev did not agree, nor did he welcome the advice. Sakharov repeated his efforts in 1961, when after a de facto moratorium the premier again announced new tests. Khrushchev angrily told him to leave politics to those who understood it.

In 1962 Sakharov learned that tests of two very similar designs of hydrogen bombs were going to be carried out. He tried his best to stop the duplicate test. He pulled all the strings he could, pleaded with Khrushchev, enraged his colleagues and bosses—all to no avail. When the second bomb was exploded, he put his face down on his desk and wept.

To his surprise, however, he was soon able to solve the larger problem. In 1963 his suggestion of a ban on the most harmful—atmospheric—testing was well received by the authorities and resulted in the signing of the Limited Test Ban Treaty in Moscow that same year. Sakharov was justifiably proud of his contribution. After atmospheric testing was stopped, its harmful effects ceased to worry him.

His concerns, however, had induced him to take two major steps: from science to the sphere of morals and finally to politics. The bomb program did not really need him anymore, but Sakharov was starting to feel that his presence would be essential to his retaining influence over the politics of weapons.

In these years Sakharov also found time to return to his first love, pure science. A problem that continues to plague scientists is the excess of matter over antimatter in the universe [see "The Asymmetry between Matter and Antimatter," by Helen R. Quinn and Michael S. Witherell; Scientific American, October 1998]. He laid out the conditions that could allow such an imbalance to arise, his most important contribution in theoretical physics. Vladimir Kartsev, a young physicist who asked Sakharov to write a preface for his popular science book, recalls that he looked very happy, full of creative energy and ideas about physics.

In 1966 Sakharov signed a collective letter to Soviet leaders against an ominous tendency to rehabilitate Stalin. Most tellingly, in December of that year he accepted an anonymous invitation to participate in a silent demonstration in support of human rights. But when he wrote to the Soviet government in support of dissidents, his salary was slashed, and he lost one of his administrative positions. The events, however, put him in increasing and ultimately fateful contact with activists in Moscow.

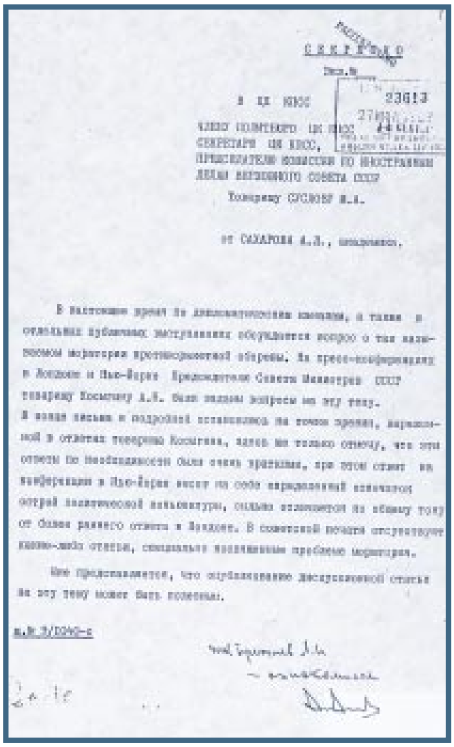
Sakharov's worldview was becoming increasingly radical, and it demanded an outlet. In July 1967 he sent via secret mail a letter to the government. He argued that a moratorium proposed by the U.S. on antiballistic-missile systems was to the benefit of the Soviet Union, because an arms race in this new technology would make a nuclear war much more probable. This nine-page memo, with two technical appendices, is now to be found in the Sakharov Archives. Among other things, the letter sought permission for publishing an accompanying 10-page manuscript in a Soviet newspaper to help "American scientists to curb their hawks." The article's style shows that Sakharov still considered himself a technical expert devoted to the "essential interests of Soviet policy."

Nevertheless, permission was refused. The rejection was yet another confirmation to the physicist that those who mattered were oblivious to the danger to which they were subjecting the world.

### The Die Is Cast

Early in 1968 Sakharov started working on a massive essay, entitled "Reflections on Progress, Peaceful Coexistence and Intellectual Freedom." He made no effort to hide this manuscript—the secretary at Arzamas-16 retyped it, automatically handing a copy to the KGB. (This carbon copy is now in the president's archives in Moscow.) The article described the grave danger of thermonuclear war and went on to discuss other issues, such as pollution of the environment, overpopulation and the cold war. It argued that intellectual freedom—and more generally, human rights—is the only true basis for international security and called for the convergence of socialism and capitalism toward a system that combined the best aspects of both.

By the end of April Sakharov had released to the samizdat, or underground press, this radical essay. In June he sent it to Leonid I. Brezhnev (who had already seen it, courtesy of the KGB), and in July its contents were described by the British Broadcasting Corporation and published in the *New York Times*. Sakharov recalled listening to the BBC broadcast with profound satisfaction: "The die was cast."



**LETTER FROM SAKHAROV** to his government (only the first page is reproduced here) requested authorization to publish a newspaper article that would describe the dangers of antiballistic-missile systems. When permission was refused, Sakharov wrote a radical essay that made its way to the West.

COURTESY OF SAKHAROV ARCHIVES, MOSCOW

Sakharov was ordered to stay in Moscow and restricted from visiting Arzamas-16. He had spent 18 years of his life in the secret city. He was not, however, fired from the bomb project until the next year: deciding the fate of a Hero of Socialist Labor three times over, who, moreover, knows the nation's most sensitive secrets, can be tricky. Shortly after, his wife died of cancer, leaving him with three children, the youngest aged only 11. Grief-stricken, Sakharov donated all his savings to a cancer hospital and the Soviet Red Cross.

For Sakharov, a lifetime had ended, and another was about to begin. He had 20 years of life left. He was to meet Elena Bonner, the friend and love of his life, to be awarded the Nobel Prize in Peace in 1975, to pass seven years in exile at Gorki and, unbelievably, to spend his last seven months as an elected member of the Soviet parliament.

Perhaps the best person to explain Sakharov is Sakharov. "If I feel myself free," he once mused, "it is specifically because I am guided to action by my concrete moral evaluation, and I don't think I am bound by anything else." He always did exactly what he believed in, led by a clear, unwavering inner morality. In the 1970s one of his colleagues, Vladimir Ritus, asked him why he had taken the steps he did, thereby putting himself in such grave danger. Sakharov's reply was, "If not me, who?" It was not that he considered himself chosen in any way. He simply knew that fate, and his work on the hydrogen bomb, had uniquely placed him to make choices. And he felt compelled to make them. SA

### *The Author*

GENNADY GORELIK has just written a biography of Andrei Sakharov with the aid of grants from the Guggenheim foundation and the MacArthur foundation. It is to be published by W. H. Freeman and Company. He received his Ph.D. in 1979 from the Institute for the History of Science and Technology of the Russian Academy of Sciences. Currently he is a research fellow at the Center for Philosophy and History of Science at Boston University. He also wrote for *Scientific American* in August 1997, on an anti-Stalin manifesto co-authored by physicist Lev Landau.

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NEW LIGHT ON EARLY SOVIET BOMB SECRETS. Special issue of *Physics Today*, Vol. 49, No. 11; November 1996.

ANDREI SAKHAROV: SOVIET PHYSICS, NUCLEAR WEAPONS, AND HUMAN RIGHTS. On-line exhibit from the American Institute of Physics is available at www.aip.org/history/sakharov on the World Wide Web.

by Shawn Carlson

# A Homemade High-Precision Thermometer

Last month I described how to build a triple-point cell, a device that reproduces the unique temperature, defined to be exactly 0.01 degree Celsius, at which water can exist with its solid, liquid and vapor phases all in equilibrium. The cell can be used for calibrating state-of-the-art thermometers, but few amateur scientists can afford such expensive instruments, which cost thousands of dollars.

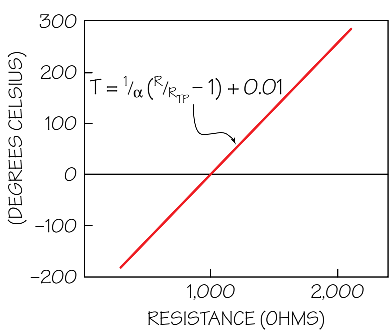
Fortunately, George Schmermund, the creative genius from Vista, Calif., who developed our triple-point cell, has also designed a thermometer capable of measuring temperature to within a few thousandths of a degree C. What is more, you can build this remarkable instrument for less than $100.

Schmermund's thermometer uses something called a resistance temperature detector (RTD), which relies on the fact that the resistance of platinum changes with temperature in a precisely known way. For each degree C of temperature change, these sensors typically change their resistance by 0.00385 ohm per ohm of resistance. For example, if your RTD has a resistance of 100 ohms, each degree C change in temperature will alter the resistance by 0.385 ohm. So if you know the probe's resistance at a particular temperature, such as the triple point of water, you can then convert any measured resistance into a corresponding temperature.

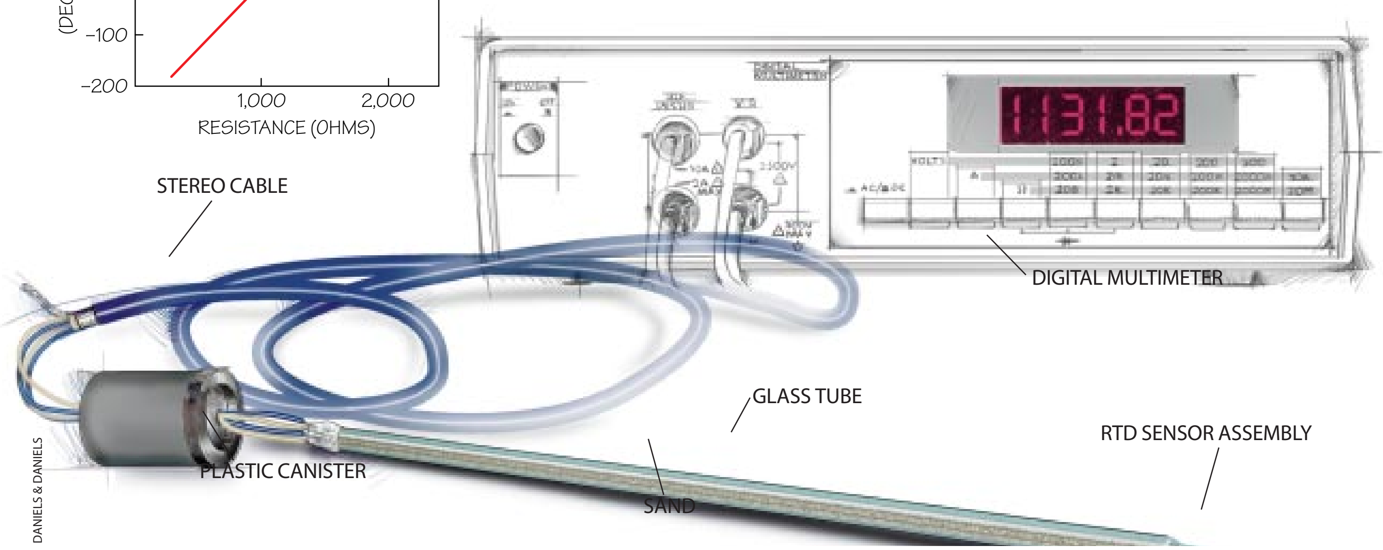
In the past, RTDs were always made of wire. Because the wire had to be thick enough to withstand the manufacturing processes and because a larger-diameter wire has less resistance than a smaller one made of the same material, the operating resistance was limited to about 100 ohms. Recently, though, a new breed of RTDs has been constructed by laying an ultrathin platinum coating on a ceramic substrate. The resistance of some of these devices tops 2,000 ohms. You'll find a smorgasbord of these marvels in the catalogue of Omega Engineering in Stamford, Conn. (www.omega.com; 800-826-6342). For this project you'll need a model like the F3141, a small, unencapsulated 1,000-ohm unit that sells for $19.

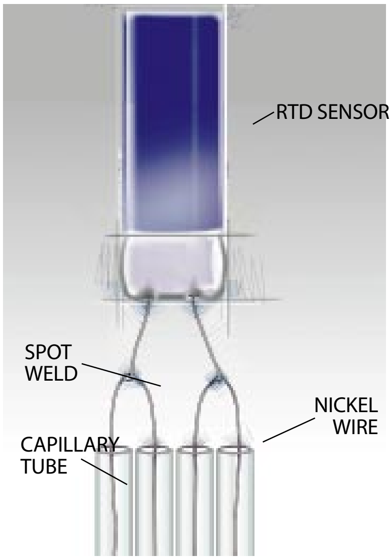
These new RTDs can bring exquisite sensitivity into the home-based laboratory. Using a high-quality handheld digital multimeter that can measure 1,000 ohms of resistance to within 0.02 ohm, amateurs can now resolve temperatures to within 0.005 degree C, or 0.009 degree Fahrenheit. That performance bests liquid-filled thermometers by 20 times and trumps any thermocouple by a factor of 10.

And you can do much better. In practice, the sensitivity of an RTD-based thermometer is limited by how accurately you can determine its resistance, which is measured by observing the voltage drop associated with a known current. With a typical digital multimeter, the lead wires are part of the circuit, and so their resistance affects the results. This error can be eliminated by measuring the voltage drop directly across the resistor with an independent set of wires. Such instru-




*EXACT TEMPERATURE MEASUREMENTS to within millidegrees can be made with a thermometer that relies on a resistance temperature detector (RTD)—a sensor that exploits how the electrical resistance of platinum changes as the material becomes hotter or colder. The relation is linear and is given by the equation shown* (left), *where α is typically 0.00385 and $R_{TP}$ is the resistance of the sensor at 0.01 degree Celsius: the triple-point temperature of water. A digital multimeter measures the RTD's resistance.*



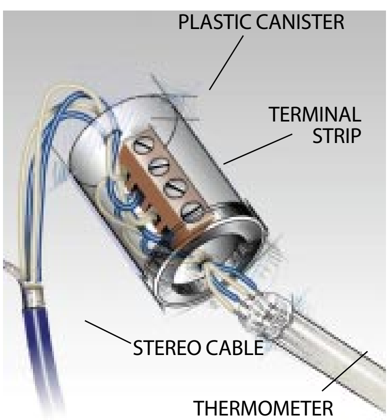



DANIELS & DANIELS

***RTD SENSOR ASSEMBLY** comprises an RTD sensor connected to two bent nickel wires that are threaded through four capillary tubes.*

ments, called four-wire ohm meters, have separate inputs for a current source and a volt meter.

Hewlett-Packard's snazzy HP 34401A multimeter (priced at $995) uses the four-wire technique to measure 1,000 ohms to within 0.001 ohm. And top-of-the-line instruments costing $30,000 apiece enable professionals to resolve temperature differences as slight as 10 millionths of a degree C. In such a four-wire configuration, an RTD-based thermometer is called a standard platinum resistance thermometer (SPRT).




DANIELS & DANIELS

***PLASTIC CANISTER** protects a terminal strip that connects the thermometer to a cable leading to a digital multimeter.*

To build Schmermund's thermometer, contact a local glassblower to purchase a Pyrex tube 30 centimeters (12 inches) long and eight millimeters (0.3 inch) in diameter. At one end of the tube, have the glassblower form a receptacle that is five centimeters (two inches) long for the RTD sensor.

Next, attach lead wires to the sensor. If you solder the leads or use wires insulated with plastic, you'll be restricted to temperatures below the melting point of those substances. That's not a problem for many applications. To allow the maximum possible range of temperatures, however, Schmermund spot-welds the RTD to bare 10-mil nickel wires that he then insulates in thin Pyrex sleeves. He gets these sleeves in 46-centimeter lengths from a local glassblower, but capillary tubes, which are available from any scientific supply house, work equally well when strung on the wire like beads on a necklace.

For a thermometer that will be used with a four-wire ohm meter, Schmermund bundles four of his long tubes and delicately tapes them together at one end. He then bends two one-meter lengths of nickel wire in half and threads each half through a different tube from the untaped end. Finally, he spot-welds the RTD to the bends in the two wires. (Note: If you will not be making four-wire measurements, simply connect one wire to each of the RTD leads.)

To secure the insides of the device and to thwart convection currents from forming, Schmermund packs the instrument with tiny glass beads that are only about 25 microns in diameter. These are expensive and must be purchased from a scientific supply house. Fortunately, fine silica sand (grit 30 or greater) also does the job. You can purchase a 23-kilogram (50-pound) sack from a hardware store for just a few dollars.

Because any moisture that becomes trapped inside the thermometer will distort your readings, all water must be driven from both the filler and the glassware before assembly. Bake everything, including the entire sensor assembly, at 250 degrees F for approximately two hours.

You must complete the next steps while everything is hot, so be sure to exercise the proper care by wearing gloves, an eye shield and protective clothing. Secure the large tube in a vise. A clean rag wrapped around each jaw will allow you to hold the glass tube firmly without breaking it. Insert the RTD assembly into the tube and use a small glass funnel to pour in enough of the desiccated sand to cover the sensor completely. Lift the assembly just a bit to make sure the RTD is suspended about two millimeters above the bottom of the well, without it touching the glass wall. Remove the tape and slowly fill the tube with hot sand to within about half a centimeter from the top, stopping frequently to tap the glass with a pencil to consolidate the material.

Hermetically seal the thermometer by topping off the sand with glue from a hot-glue gun. If you're using uninsulated wires, heat them with a hair dryer for a few seconds before the adhesive sets so that the wires will seat themselves into the glue.

To minimize signal interference, connect the probe to your ohm meter through a stereo microphone cable, which consists of two twisted pairs of wire shielded inside a metal sheath that you must ground. Use a four-wire terminal strip to connect each twisted pair across the device. Solder the wires and protect the strip inside a plastic canister from a roll of 35-millimeter film.

This homemade instrument, which is functional up to about 400 degrees C, can open up fascinating avenues of research. Although the device is a bit cumbersome for fieldwork, you can use it for accurately calibrating other thermometers. In the laboratory, it will also help you probe the nature of phase transitions and measure the strength of chemical bonds (for ideas, see the March 1996 Amateur Scientist). With a little imagination, this thermometer can become a powerful weapon in your arsenal of research techniques.

*As a service to the amateur community, the Society for Amateur Scientists is offering the Schmermund four-wire thermometer (not including an ohm meter) as a kit, complete with spot-welded nickel wire leads, prefabricated Pyrex tubes and insulating glass beads. The cost is $250. To order, send a check to SAS at 4735 Clairemont Square, Suite 179, San Diego, CA 92117, or call the society at 619-239-8807. For more information about this and other projects, check out the SAS Web page at web2.thesphere.com/SAS/WebX.cgi.*

by Ian Stewart

# The Synchronicity of Firefly Flashing

One of nature's most spectacular displays occurs soon after sunset in Southeast Asia, where swarms of fireflies flash in synchrony. As biologist Hugh M. Smith wrote in the 1930s [see "Synchronous Fireflies," by John and Elisabeth Buck; SCIENTIFIC AMERICAN, May 1976]:

> Imagine a tree thirty-five to forty feet high . . . apparently with a firefly on every leaf and all the fireflies flashing in perfect unison at the rate of about three times in two seconds, the tree being in complete darkness between flashes. . . . Imagine a tenth of a mile of river front with an unbroken line of [mangrove] trees with fireflies on every leaf flashing in synchronism, the insects on the trees at the ends of the line acting in perfect unison with those between. Then, if one's imagination is sufficiently vivid, he may form some conception of this amazing spectacle.

Why do the flashes synchronize? One theory cites biological evolution as the reason. The flashes are created solely by male fireflies, and they attract females. Synchronized flashes should attract them from farther away, particularly in geographic areas of dense vegetation such as Southeast Asia. But what about the mathematical reason?

Fireflies employ a special light-emitting chemical to create a flash. They have a good supply of the substance, but they release it in small bursts according to a repeating cycle of "readiness." In effect, it is as if the fly starts counting steadily from zero as soon as it has flashed, and only when it reaches 100 does it flash again. Its state of readiness—the number its count has reached, so to speak—is the "phase" of the cycle.

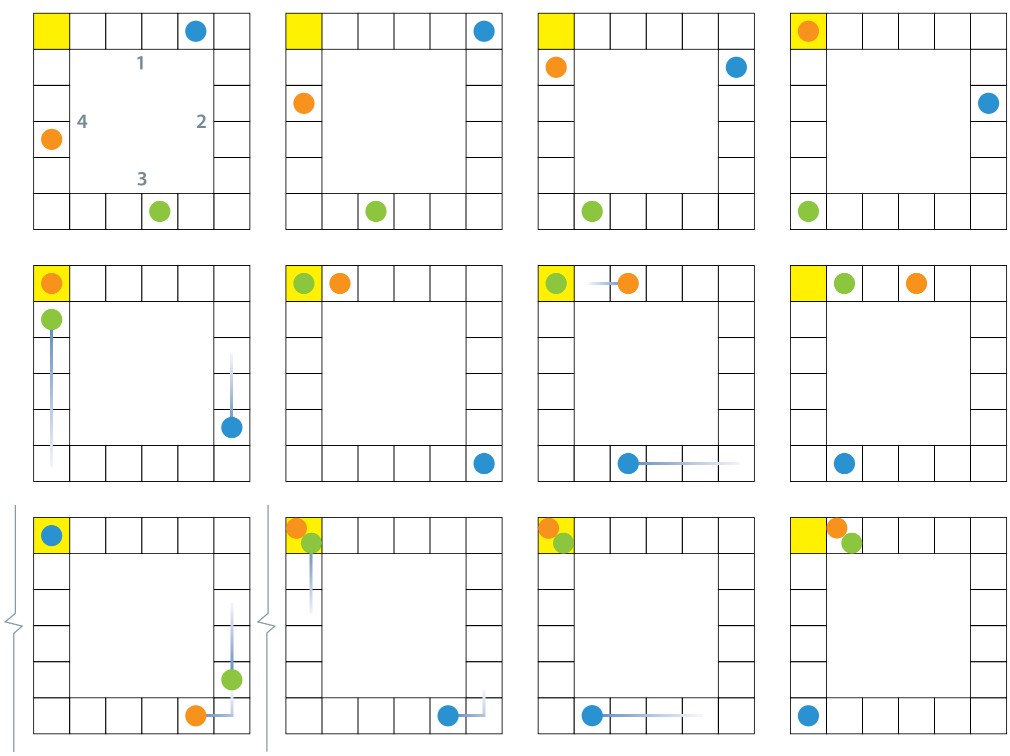
Mathematically, such a cycle is an oscillator—a unit whose natural dynamic causes it to repeat the same behavior continually. Oscillators are a source of periodic rhythms, which are common—and important—in biology. Human hearts and lungs follow such regular cycles, whose timing is adapted to the body's needs.

Why do systems oscillate? Because it is the simplest thing you can do if you don't want, or are not allowed, to remain still. Think of a caged tiger that paces back and forth. An example in physics is the vibration of a violin string. The string cannot remain still, because it has been plucked away from its natural resting point. But it isn't free to do whatever it wants, because its ends are pinned down. So the string vibrates with a periodic oscillation between those two restraints.

With fireflies, the oscillations are created by a mechanism known as integrate-and-fire. In such a system, some quantity builds up (that is, the phase increases) until it reaches a threshold. Crossing this value triggers a sudden action—fire (or, in the case of fireflies, flash)—after which the quantity resets to zero and starts to accumulate again.

But what accounts for the synchronicity? Laboratory and field observations have shown that when certain fireflies notice a flash they get excited, and their own phase receives a sudden boost, moving them nearer to threshold.

Such oscillators are said to be "coupled," meaning that one affects the state of the others. The classic example is the observation, made by the great Dutch physicist Christian Huygens, that pendulum clocks on the same shelf affect one another through the vibrations of the shelf. Often this interaction causes them




DMITRY KRASNY

*GAME OF FLASH* *approximates firefly behavior. In this sequence of opening stages, which go from left to right and top to bottom, three fireflies* (colored dots) *move clockwise, approaching the "flash" square* (yellow). *When a firefly reaches that square, the insect emits a flash of light, which then makes all other fireflies skip closer* (blue lines) *to flashing themselves. Several stages of the game have been omitted* (gray lines).

to synchronize, and the task for the inquisitive is to work out why. (Note: Coupled oscillators do not always synchronize, an example being an animal's legs when it walks. Each leg is an oscillator, and the animal's body couples them, but they do not normally all move at once.)

Physiologist Charles S. Peskin took the first step toward such an understanding. In 1975 his study of the synchronization of the muscle fibers of the heart introduced a detailed model of an integrate-and-fire oscillator. The work contained a specific equation for how the phase builds, and the same equation can be applied to fireflies—physiological studies show that it is a reasonable, though not exact, representation of the flash cycle. An important feature of Peskin's model is that the oscillators are "pulse coupled": an oscillator affects the others only when it fires. Then it sends a signal to its neighbors, which gives their phases a boost. If this increase tips another oscillator over the threshold, it, too, fires, and so on.

It turns out that the chemicals in certain fireflies are affected in just this manner by visual signals from other fireflies. When such a firefly sees another's flash, it gets excited, which moves it closer to threshold. Peskin proved that if two identical integrate-and-fire, pulse-coupled oscillators obey his equation, they will eventually almost always synchronize. (If their initial phases are set to very special values, their flashes will not synchronize but will alternate periodically. This state, however, is highly unstable—it can be upset by the smallest disturbance.)

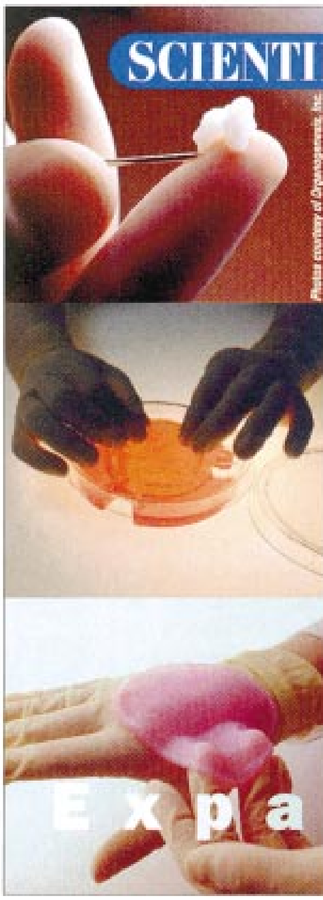
Peskin also conjectured that the same would be true of any network of coupled integrate-and-fire oscillators. In a 1990 paper Renato E. Mirollo and Steven H. Strogatz proved that Peskin was right, assuming a more general equation than his. As subject to a few technical hypotheses stated in the article, Mirollo and Strogatz showed that in a system with any number of identical integrate-and-fire, pulse-coupled oscillators and all-to-all coupling, the oscillators almost always eventually synchronize. (Again, there is a rare set of initial conditions in which the behavior alternates periodically, but these states, too, are unstable.)

Their proof is based on a phenomenon called absorption, which occurs when two oscillators with different phases lock together and thereafter remain in phase with each other. Because the coupling is







fully symmetric (that is, each individual affects all others in exactly the same manner), once a group of oscillators has locked, it stays that way. Mathematically, it can be proved that a sequence of these absorptions must eventually lock all the oscillators together.

You can explore the firefly system with a more simplified model—the solo game of Flash, played with counters that are moved around the edge of a square, such as an 8-by-8 chessboard, a 10-by-10 Monopoly board or a homemade 6-by-6 square [*see illustration on page 104*]. Flash uses only the border, of which one corner (yellow) is designated as the threshold, or "flash," square. The four edges are assigned numbers 1, 2, 3 and 4 in order, going clockwise from the flash square. A few counters representing fireflies are placed at random. The position of a firefly indicates its phase: the closer (in a clockwise direction) the counter is to the flash square, the nearer it is to threshold. The fireflies reach threshold, flash and reset their supply of chemical according to the following rules:

STEP 1. Move each firefly one square clockwise. Although you may have to reposition the flies one at a time, think of them as moving simultaneously. (This step represents an incremental increase in the phase.)

STEP 2. If any firefly has landed on the flash square, move every other firefly clockwise by a number of squares equal to the number of the side of the board on which it sits. For instance, a fly on side 3 would move three squares clockwise. But do not allow any firefly to pass over the flash square; stop it instead on that square. (This step represents pulse coupling. The other flies notice the one that flashes, which makes them move closer to threshold. Fireflies with a bigger phase move more squares, which is how the real insects behave.)

STEP 3. If any firefly lands on the flash square as a result of step 2, go back to the beginning of that step and again move all the other counters accordingly.

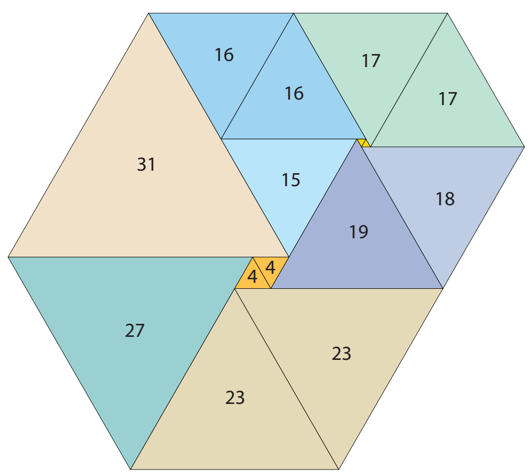
STEP 4. Return to step 1.

Note that if two or more fireflies land on the same square, they have synchronized and should be moved thereafter as a single unit. In the example sequence shown, two of the fireflies do just that. If you keep playing, you will find that eventually all three fireflies will be in unison.

I suspect that for some sizes of boards it may be possible to find initial placements that lead to periodic, asynchronous behavior corresponding to the unstable states in the Mirollo-Strogatz theory. The Flash game is a finite-state model, simpler than the one analyzed by Mirollo and Strogatz, though similar to it, and it may not behave in exactly the same manner. Explore, and let me know what you find. SA

## FEEDBACK

Tetsuro Kawahara, an engineer and geometric-puzzle lover in Amagasaki, Japan, has discovered a better solution to a tiling puzzle that was discussed in the July 1997 and August 1998 Feedbacks. The problem asks for the largest convex area that can be tiled with equilateral triangles whose sides are integers that have no common divisor. For 15 triangles, Kawahara found a beautiful vortex pattern (*right*) that has an area of 4,782 units, which is slightly higher than the 4,751 for the solution that was previously reported. (Note that a unit of area equals that of an equilateral triangle with a side of 1.) Kawahara also points out that the area for the tiling pattern that was given for 11 triangles should have been 495, instead of 496. —*I.S.*

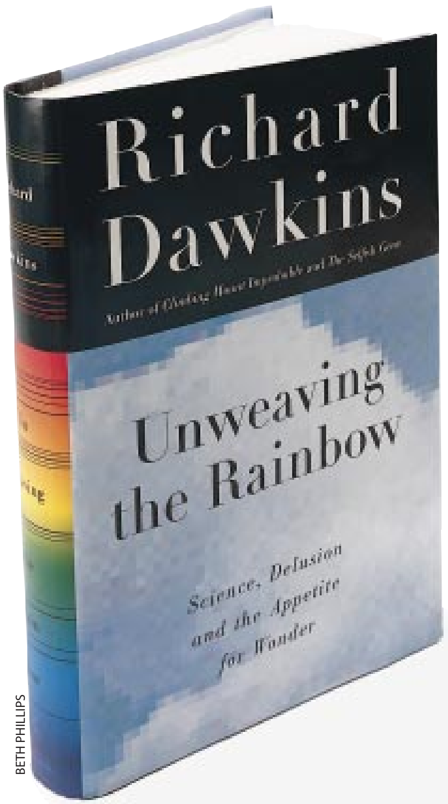



TETSURO KAWAHARA; DMITRY KRASNY

## ONE MAN'S RAINBOW

*Review by Melvin Konner*

**Unweaving the Rainbow: Science, Delusion and the Appetite for Wonder**
BY RICHARD DAWKINS
Houghton Mifflin Company, Boston & New York, 1998 ($26)




BETH PHILLIPS

When a bad writer writes a good book, we are happy to hail the new growth of talent or character. But when a good writer issues a not-so-good book, one almost feels that to express disappointment is somehow small. Richard Dawkins is a British national treasure and (because English is the international language) also the world's. He is a wizard of lively English prose and a grand master of what he has called "the explainer's art." More than any other writer, he has taught scientists and their public to appreciate metaphor. Even the titles of his books are a kind of poetry: *The Blind Watchmaker, River out of Eden, Climbing Mount Improbable.* Some of the most dunderheaded opponents of his first book, *The Selfish Gene,* seem to have read the title alone and not quite realized that it *was* a metaphor; back to English 101.

But for this book Dawkins borrows his metaphor, and it gives him his mission: "My title is from Keats, who believed that Newton had destroyed all the poetry of the rainbow by reducing it to the prismatic colors. Keats could hardly have been more wrong, and my aim is to guide all who are tempted by a similar view towards the opposite conclusion." Dawkins proceeds to challenge Keats—not to mention Blake, Wordsworth, Yeats and many lesser literary lights—to a contest that he cannot win. Keats's lament is in a poem called "Lamia":

> There was an awful rainbow once
>   in heaven;
> We know her texture; she is given
> In the dull catalogue of
>   common things,
> Philosophy will clip an Angel's wings,
> Conquer all mysteries by rule
>   and line,
> Empty the haunted air, and gnomed
>   mine
> Unweave a rainbow . . .

Dawkins goes on to unweave the rainbow quite nicely, in a way that is satisfying to my curiosity (and, I would guess, that of others) but that in no sense addresses the fears Keats raised; in fact, it confirms them. Consider: "I said that light from the sun enters a raindrop through the upper quadrant of the surface facing the sun, and leaves through the lower quadrant. But of course there is nothing to stop sunlight entering the lower quadrant. Under the right conditions, it can then be reflected *twice* round the inside of the sphere, leaving the lower quadrant of the drop in such a way as to enter the observer's eye, also refracted, to produce a second rainbow, 8 degrees higher than the first and less than half as bright." Of such stuff as this Dawkins says, "I think that if Wordsworth had realized all this, he might have improved upon 'My heart leaps up when I behold/A rainbow in the sky . . .' "

A long excerpt of tedious verse by a justly forgotten 18th-century poet, one Mark Akenside, has the bad luck to be on a facing page from the above instance of Keats's genius. Akenside's lines deliver a more or less Newtonian view of the rainbow, and they are very dull indeed. To demand such a view is rather like reading the Psalms and observing that hills don't skip like rams, or interpreting Mercutio's deathless reverie on Queen Mab and her retinue as a throwback to a dark age of imps and demons.

In fact, Keats cannot have been wrong, because it was not his aim to be right in any way Dawkins appears to understand. He was right in the only way he wanted to be, having found words to express the fear that Newton's prismatics inspired in him—in what he would comfortably (though, to be sure, less sublimely) have called his heart and soul. What might have made this book work would have been to start with empathy toward Keats, to attempt to resonate to his fear instead of just explaining it away.

The book's a rousing read. Those who have read Dawkins's earlier works will find some ideas repeated, even in a similar exposition, but there is still much to learn from and enjoy. There are many literary quotations, and the discussion of those sometimes rises above the pedestrian. But Dawkins is most comfortable as a polemicist, with a hair-trigger, all-guns-blazing defense of science against its detractors—whether they are great poets or newspaper columnists, princes of the church or John and Jane Q. Public—and polemics are rarely beautiful.

Readers of this magazine know beauty in science. It emerges from the unification of falling bodies with planetary orbits, of electricity with magnetism, of space with time. It crystallizes in quantum theory, the periodic table of the elements, plate tectonics, and the idea of evolution by natural selection. It emanates from the structure of DNA and from the fact that the ratio of a circle to its diameter invariably produces one endlessly just-out-of-reach universal number. And yes, it is also in Newton's optics. But the beauty in science is not to be found in pages and pages of exposition of every conceivable scientific insight into rainbows, cheek by jowl with petulant criticism of the unscientific thoughts of great poets. Such exposition really does unweave the rainbow, and it suggests that Keats's fear was not unjustified.

In failing to understand such fears, Dawkins is in good company. The famously arrogant genius Richard Feynman is quoted as saying, "I see a deeper beauty that isn't so readily available to others.... The color of the flower is red. Does the fact that the plant has color mean that it evolved to attract insects? This adds a further question. Can insects see color? Do they have an aesthetic sense? And so on. I don't see how studying a flower ever detracts from its beauty. It only adds." There is an obtuseness here, a determined missing of a crucial point; it is well captured by the great art critic John Ruskin, whom Dawkins cites with contempt: "We cannot fathom the mystery of a single flower, nor is it intended that we should; but that the pursuit of science should constantly be stayed by the love of beauty, and the accuracy of knowledge by tenderness of emotion."

*"My title is from Keats, who believed that Newton had destroyed all the poetry of the rainbow by reducing it to the prismatic colors. Keats could hardly have been more wrong."*
—Richard Dawkins

I have a painter friend who looks at a red flower and feels her eyes and mind fairly burst with the thrust of color. She shivers, thrills, becomes warm and at last enters an almost trancelike state in which she makes an inspired transformation of the flower, using her own very different kind of genius to apply pigments in colloidal suspension onto stretched white cloth. Then I or you come along, look at her painting and, if we are lucky, experience something like what she felt and thought before us, even though we ourselves may have completely missed the flower.

If it is possible to think clearly about the coevolution of flowers and insects (a fascinating subject I lecture on in my courses) and at the same time to have the experience the painter had, this must occur in a different sort of brain from mine. That is where Feynman's claim that science never detracts, only adds, is wrong. In the long run, it does add, in a myriad of ways. In the very long run, plate tectonics even makes hills skip, sort of, like rams. But in the moment, you cannot both think through Darwin's argument about why flowers are brightly colored and at the same time have your mind bursting or entranced with *red.*

Dawkins rambles amiably through some other topics of interest to him: forensic use of DNA, probabilistic explanations of coincidences that lead to superstition, and, of course, evolution. Along the way he properly strikes at and bags wizards, astrologers, conjurers and other banes of the gullible, as well as some larger quarry, like journalists, politicians and theologians. The link here seems to be that hoodwinkers feed on public credulity by using bad poetry. So the great but scientifically unsound poetry of Keats and Blake leads, through a kind of guilt by association, to the outright abuse of poetry by charlatans.

**Poetry and Science**

Dawkins reserves some serious animus for scientist-colleagues who also, according to his view, use poetry to mislead. James Lovelock's Gaia hypothesis, Pierre Teilhard de Chardin's evolutionary mysticism and Frans de Waal's "good natured" bonobos come in for valid criticism. But one target is favored: "My remaining examples of bad poetry in evolutionary science come largely from ... Stephen Jay Gould. I am anxious that such critical concentration upon one individual shall not be taken as personally rancorous." Ah, butter wouldn't melt in Dr. Dawkins's mouth. Forget that both of them have been writing contemptuously of each other's ideas for decades, giving off more heat than light.

Gould does need to be reminded: Darwinian ideas are still struggling gamely for their own survival. The world does not need protecting from them, or even from overstatements of them, so much as it needs their small piece of the truth. Don't use your great gifts to restrain honest inquiry in the service of a liberal philosophy that is really outside science. That vision of the world, which I happen to share, will—like any legitimate philosophy—be better served by the truth.

To Dawkins, one wants to say, Lighten up. People believed in God, ghosts, imps and fairy tales before you arrived and will do so after you're gone. Science is a still, small voice in the dark, as difficult to master as Schubert's lieder for the tenor. Cultivate your mastery, teach it to those few of the young who have inclination and aptitude, and be glad that it almost always leads to a more secure income than lieder do. As for people who believe things for which there is no evidence, they too adapt, survive and reproduce. If a spider's web is beautiful, why not a cathedral? If a butterfly's wing, why not faith?

I teach a freshman colloquium on human nature in which we read *The Selfish Gene*—and also Freud, Shakespeare, Toni Morrison, Antonio Damasio and other observers of the passing human scene. Neither Gould nor Dawkins would like the syllabus. Gould would fear that my students won't keep Darwin in his place but become Panglossian adaptationists and cryptoeugenicists. Dawkins would fear that my students won't realize how very, *very* important Darwin's theory is. I won't say, A plague on both their houses, since I admire both too much. But each could use a dollop of restraint, and as for humility, it ought to be poured over both of them like catsup.

Consider this instance of its absence: "I remember once trying gently to amuse a six-year-old child at Christmas time by reckoning up with her how long it would take Father Christmas to go down all the chimneys in the world.... The obvious possibility that her parents had been telling falsehoods never seemed to cross her mind." A grown man using statistics as a wedge between a six-year-old and Santa Claus is scarcely the right person to assuage people's fears of science. The book begins with the despair of a foreign publisher of *The Selfish Gene,* who spent three sleepless nights pondering "what he saw as its cold, bleak message." Dawkins, however, does little in this book to confront such despair. What is missing here is a tragic sense of life, without which no one can transcend despair. We must work our way through it, but Dawkins only tries to brush it away.

"It is a central theme of this book," he writes, "that science, at its best, should leave room for poetry." But his science does not, because he does not seem to understand how poetry works or what it is for. A quarter-century after the fact, I can still hear the almost surreal beauty in the voice of a young Englishwoman, singing these lines of Blake's in her house in an African town where she and her husband were doing conservation work:

And did the Countenance Divine
Shine forth upon our clouded hills?
And was Jerusalem builded here
Among these dark Satanic mills?

Surely an offense against reason, the Second Coming of Jesus in early industrial England, and nothing I find remotely plausible. Yet I love the poem and I feel its greatness by suspending, for a few minutes, my scientific judgment. Dawkins makes little attempt to understand why Keats, Blake, Yeats and other poetic geniuses were afraid of science. At the end of a century in which science gave us mustard gas, Zyklon B, Hiroshima, germ warfare, cyberterrorism, a hole in the ozone layer and a rate of species extinction unprecedented since a stray chunk of cosmic rock went plop at the edge of the Yucatán, we could perhaps show a little more sympathy for people's fears. What Blake did not foresee was that science would also help clean up the soot shed by those same mills—in no small part, I would guess, because generations of English schoolchildren sang Blake's words set as an exquisite hymn. Still, it is not clear that we will continue to keep up with ourselves, and the next great blip in the history of life may yet be caused by human inventiveness.

There would no doubt be a certain aesthetic appeal in wiping the planet's slate clean and starting a new adaptive radiation. But despite the possible elegance of such an event, we want to avoid it. And if we do, it will be in part because of the reaction of poetry to science, with poets reminding scientists of their humanity, their spiritual responsibility and the risks associated with their enterprise. No attempt, however well meaning, to bring poetry under science's wing will ever affect its ultimate, essential independence. Let science tend its garden; poetry, as always the poor, neglected sibling, playing the mandolin and warbling softly but determinedly under a scraggly willow tree, will, I suspect, continue—however improbably—to take care of itself.

*MELVIN KONNER, Samuel Candler Dobbs Professor of Anthropology at Emory University, is the author of* The Tangled Wing: Biological Constraints on the Human Spirit, *soon to be published in a revised edition by Henry Holt and Company.*

## THE EDITORS RECOMMEND

WHEN THINGS START TO THINK. Neil Gershenfeld. Henry Holt and Company, New York, 1999 ($25).

An Associated Press report from Issaquah, Wash., in 1997 told of a man who pulled a gun and shot his personal computer several times. The police took him off for mental evaluation. According to Gershenfeld, "they should have instead checked the computer for irrational and antisocial behavior." Which is to say that Gershenfeld, director of the physics and media group and co-director of the Things That Think (TTT) consortium at the Massachusetts Institute of Technology's Media Lab, is yet another computer wizard who thinks that computers and other high-technology devices are too hard to use. "There is a disconnect," he says, "between the breathless pronouncements of cybergurus and the experience of ordinary people left perpetually upgrading hardware to meet the demands of new software, or wondering where their files have gone, or trying to understand why they can't connect to the network. The [digital] revolution so far has been for the computers, not the people."

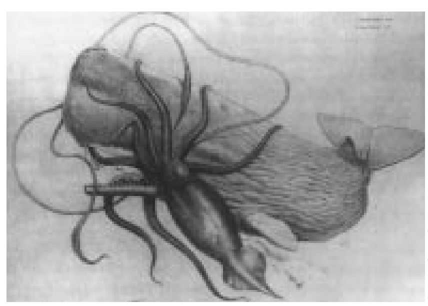
That said, Gershenfeld goes on to describe a number of ways in which devices might be designed to anticipate the user's needs and operate almost invisibly from the user's viewpoint. Taking health care as an example, he envisions what Things That Think might do. "In a TTT world, the medicine cabinet could monitor the medicine consumption, the toilet could perform routine chemical analyses, both could be connected to the doctor to report aberrations, and to the pharmacy to order refills, delivered by FedEx (along with the milk ordered by the refrigerator and the washing machine's request for more soap)."

NIGHT COMES TO THE CRETACEOUS: DINOSAUR EXTINCTION AND THE TRANSFORMATION OF MODERN GEOLOGY. James Lawrence Powell. W. H. Freeman and Company, New York, 1998 ($22.95).

In 1964 Glenn Jepsen, a paleontologist at Princeton University, published an article listing 31 causes, ranging from plausible to implausible, that had been proposed for the extinction of the dinosaurs. Among them, fairly well down on the list, was "meteorites." Since then, the case for meteorites—specifically an asteroid impact on the earth 65 million years ago—has largely won the day. Powell, a geologist who directs the Los Angeles County Museum of Natural History, traces the impact of the impact theory from its introduction in 1980 by physicist Luis Alvarez and his son, Walter, a geologist. Powell lays out persuasively the evidence that has accumulated to give force to the Alvarez theory. He also maintains that the impact theory has transformed geology. Uniformitarianism—the doctrine that all past geologic changes can be understood by studying only processes that can be seen going on today—must now confront, he says, the "strong evidence that major events in earth history are controlled by forces from outside the earth."

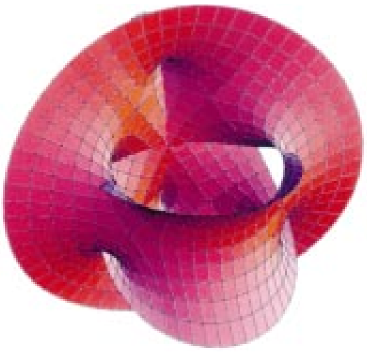
THE SEARCH FOR THE GIANT SQUID. Richard Ellis. Lyons Press, New York, 1998 ($35).

"A single 60-foot-long giant squid represents the stuff of nightmares, with its writhing arms and saucer-sized eyes," Ellis writes. *Architeuthis* also represents the stuff of mystery. Virtually all that is known about it rests on dead or dying specimens that have washed ashore or been hauled in at sea—places remote from the creature's deep-ocean habitat. Ellis's table of authenticated sightings and strandings has 166 entries, beginning in 1545 and extending to 1996. His bibliography indicates the scope of the search he had to make to assemble material about his mysterious subject; it



GLEN LOATES

runs to 38 pages with some 600 entries. He provides a huge amount of information, dealing not only with the scientific aspects of the giant squid but also with its scary appearances in film and fiction.



MATHEMATICA

THE LANGUAGE OF MATHEMATICS: MAKING THE INVISIBLE VISIBLE. Keith Devlin. W. H. Freeman and Company, New York, 1998 ($24.95).

"In the year 1900," Devlin says, "all the world's mathematical knowledge would have fitted into about eighty books. Today it would take maybe a hundred thousand volumes to contain all known mathematics." Whereupon he skillfully gives both a history of the subject and a guide through the terrain. Mathematics, he says, can be defined as the science of patterns; what it does is make the invisible visible. For example, it is through mathematics that one can understand what keeps a jumbo jet in the air (by means of an equation discovered in the 18th century by Daniel Bernoulli). Similarly, Newton's equations of motion and mechanics make it possible to "see" the invisible forces that keep the earth revolving around the sun and cause an apple to fall from a tree to the ground. As Galileo put it, "The great book of nature can be read only by those who know the language in which it was written. And this language is mathematics." Keith Devlin is an apt teacher of the language.

WHAT REMAINS TO BE DISCOVERED. John Maddox. Free Press, New York, 1998 ($25).

Maddox, editor of *Nature* from 1966 to 1973 and 1980 to 1996, suggests that a book of the same title could have been written in 1700, 1800 and 1900, each looking back on the scientific achievements of the previous century and seeing how many questions remained unanswered. And now? "Despite assertions to the contrary, the lode of discovery is far from worked out." Indeed, he says, "there is no field of science that is free from glaring ignorance, even contradiction." Cautioning that what remains to be discovered is not necessarily the same as what will be discovered, because progress in science is so often like "unscrewing successive doll-cases," he focuses on several subjects that seem ripe for major discoveries: the structure of space, a full description of the human genome, the origin of life on Earth, the detailed course of human evolution and an understanding of how the brain works. And no matter how many questions are answered, people a century from now "will be occupied with questions we do not yet have the wit to ask."

GOUT: THE PATRICIAN MALADY. Roy Porter and G. S. Rousseau. Yale University Press, New Haven, 1998 ($35).

Gout has a long tradition as the disease of high living—"just deserts for topers and gluttons," as Porter and Rousseau put it. Indeed, some sufferers saw it as a mark of their high social standing and wealth. But suffer they did; the 19th-century English essayist Sydney Smith said an attack of gout felt "like walking on my eyeballs." (The disease is marked by painful inflammation of the joints of the extremities, particularly the big toe.) The authors' focus is on the cultural history of the disease. They present an abundance of quotations from sufferers (many of them famous men), physicians trying to treat the disease, and quacks offering cures, many of which strike the modern reader as bizarre. But the medical story of how the disease came to be understood and how effective treatments were found is here, too. One should not conclude, however, that gout is a bygone affliction. The "underlying trends are not encouraging, in view of the protein- and fat-rich diets now typical of Western populations." Moreover, the occurrence of gout is rising worldwide "as a consequence of the Westernization of diet and habits."

ENCYCLOPEDIA OF THE SOLAR SYSTEM. Edited by Paul R. Weissman, Lucy-Ann McFadden and Torrence V. Johnson. Academic Press, San Diego, 1999 ($99.95).

An arresting jacket painting by Brad Greenwood shows the solar system as it would be seen from the sun. The 56 contributors to this one-volume encyclopedia—all specialists in solar system science—describe the system from the galaxy inward to the sun and then outward through the planets. They discuss also comets, asteroids, missions of exploration to the planets, and the search for planets outside the solar system. The audience the editors have aimed at includes teachers, students, advanced amateurs, astronomers who do not specialize in the solar system, and professionals in other scientific and technical fields. Such a person could usefully read the volume straight through or plunge at once into any of the topics. Indeed, a reader who knows little about the solar system could do the same; she would end up knowing a lot.

THE RESTLESS SEA: EXPLORING THE WORLD BENEATH THE WAVES. Robert Kunzig. W. W. Norton & Company, New York, 1999 ($25.95).

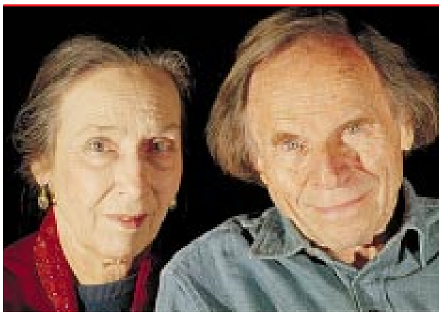
Because of water, Kunzig points out, we live in a divided world. "Thirty percent of it we can see; 70 percent of it we cannot, because it is covered by water, and so we tend to ignore it." With grace and humor and a net cast widely for facts, he presents a compendium of what is known about the ocean and how the men and women we now call oceanographers have assembled that knowledge over the centuries. What is water? How did a billion trillion tons of it get into the ocean? Kunzig deals with these questions and many others: the shape of the ocean bottom; the lively geologic processes there; the life there ("we might find 10 million species of animal or more on the deep-sea floor were we ever to explore it thoroughly, which, given its size and our limitations, we have only just begun to do"); the twilight of the cod and other species because of overfishing; the complex patterns of ocean currents. Kunzig says in his prologue that his purpose is to offer "a glimpse" of what lies beneath the ocean waves. He has, in fact, offered a rich portrait insofar as the picture can be painted today.

GALAPAGOS: ISLANDS BORN OF FIRE. Tui De Roy. Warwick Publishing, Toronto, 1998 ($39.95).

In words and pictures, Tui De Roy, a magazine writer and one of the world's leading wildlife photographers, introduces readers to the islands that were her home for 35 years. Brought to the Galapagos at age two by her Belgian parents, De Roy grew up amongst the giant tortoises, the iguanas, the sea lions and birds that are unique to the islands. These were the creatures that Charles Darwin spent five weeks observing and collecting in 1835 and that formed the basis of his theory of evolution. The book is elegantly structured: each chapter emphasizes one distinct aspect of the Galapagos in the hope that by "displaying visually the essence of its splendid wildness," the volume can serve as an inspiration to ensure the survival of the islands' threatened animals. SA

TUI DE ROY

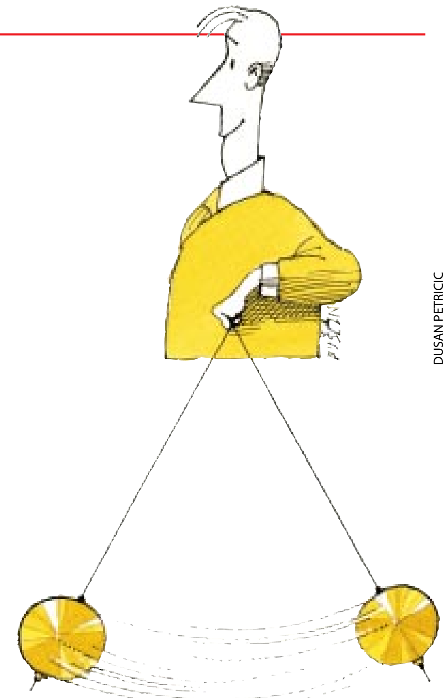
COMMENTARY



# WONDERS

*by Philip and Phylis Morrison*

## Walk, Run—and Skip



DUSAN PETRICIC

A century and more ago Silicon Valley was a place of shady orchards and sunny farms. Fast horses offered a pastime to wealthy landowners such as Palo Alto magnate Leland Stanford, who once wagered a skeptical friend that horses on the gallop often had no hoof touching the ground. The disputants organized a direct test, placing its execution in the hands of Eadweard Muybridge, an ingenious San Francisco photographer. He aligned a dozen or two still cameras to view a stretch of Stanford's racecourse, each camera fitted so that the line of shutters would be tripped one after another by threads extended across the fast horse's path. The image sequence was compelling: Stanford won the bet, and Muybridge, whose whole career was redirected by this success, became a celebrated world pioneer of the nascent cinema. His later 1887 volumes of photographs, still frequently reproduced, provide wonderful motion sequences of every condition of humanity and many creatures of the zoo.

That early inquiry has grown, mostly since World War II, into a science, animal locomotion (the very title of Muybridge's book). The human animal is of course a major subject, with wide applications, from physical training to sports, dance, orthopedics ... (Your authors, too, bedecked with glowing red diodes, have capered on foot before the computer-feeding cameras of a local "gait lab," to generate sequences of stick-figure moving images.)

The state of the art nowadays is suggested by physiologist Alberto E. Minetti at a well-known lab in Milan, Italy. His motion analyzer, he says, consists of "four infrared cameras capable of detecting ... the three-dimensional positions of 18 reflective markers positioned on the subject's joints of interest." The images are computed by the custom software every inch or two as the motorized treadmill glides underfoot.

Two ubiquitous patterns of human locomotion are the walk and the run, both apparently innate. The time and place of the repeated grounding of each foot define the basics of any gait. Timing makes the difference: the two-beat alternation does not differ between walk and run, but a walker always has one foot on the ground, sometimes two. When either foot is raised, its replacement has already made contact. But runners fly free more than 15 percent of the time; in running, contact by the replacing foot is regularly delayed each time it is due. The runner usually does not notice the resulting free-flying intervals; their total duration is less than a tenth of a second at usual speeds.

Two rough models sketch the very extensive analyses. Walking resembles the motions of a pendulum. Consider the walker at the moment when one leg is slanted behind, the other slanted ahead, making an inverted V. Soon the lagging leg rises to pass the other. When they pass more or less straight beneath the torso, both feet are in ground contact, and the walker's center of gravity is raised a little, given that the legs, nearly straight and close to vertical, hold the body's center of gravity higher off the floor than the slanted inverted V did. The inverted V forms again, only now with the legs exchanged. The total mechanical energy alternates in form, changing from the kinetic energy of swinging legs and rising body to gravitational potential energy near maximum body height, and back again. A pendulum handles energy similarly, exchanging kinetic energy near the midpoint of its arc for gravitational energy around the point of least height, then up again. The energy so stored is largely recovered and serves to reduce the energy cost of walking by about half of what would be needed were the swinging legs not also stores of gravitational energy.

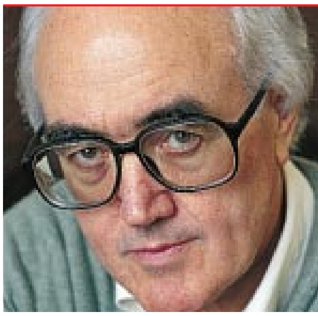
*On the moon the astronauts preferred forms of skipping to the other gaits they tried.*

The walker rolls up and over the high midpoint of a step on near-straight legs, then smoothly down again under gravity. But the runner moves in longer, freer steps, with muscle-driven legs rapidly bending and unbending. The weight of a runner's leg is not enough to bring the extended limb down soon enough. The runner has in effect jumped a little, until at last the limb comes down. Both the kinetic energy—horizontal and vertical—and the potential energy of the center of gravity reach maximum at the same time during the periods of "flight." This substantial energy peak is stored briefly and then released during contact time to feed the alternation.

Yet muscles are not to be recharged by mechanical energy, and gravity is simply too slow to keep pace. Energy is stored in the tight-strung tendons and ligaments that form the linkages that bind muscles and bone; they stretch and relax, smoothing the energy peaks and saving much overall effort. The runner bounces elastically like a ball, enabled by the re-

*Continued on page 113*

COMMENTARY



# CONNECTIONS

*by James Burke*

## Lend Me Your Ear

I was cocking an ear to the weather forecast on the radio last night and remembered one of history's unsung heroes. So let's hear it for William Ferrel, a shy, self-taught schoolteacher from Pennsylvania who, in 1858, first explained the way the earth's rotation affects how the weather moves and came up with the math to fit. I say "unsung" because most people think it was all done by a French guy named Coriolis. *Non.*

Ferrel, like everybody in 19th-century weather work (and indeed in almost anything to do with science), was inspired by the work of Alexander von Humboldt. It's difficult to say what Humboldt *didn't* do. Just a taste of what he *did:* economics, geology, mining, electricity, climatology, geography, oceanography, cosmology, math, exploration (everywhere), vulcanology, botany, chemistry, surveying . . . enough. Humboldt was the maven's maven. He was also one of the first true ecologists. One of the other f.t.e.'s was the guy he visited in 1804, after a strenuous trip around South America: Thomas Jefferson. Who was at this time deeply into Lewis and Clark expeditions, coastal surveys, agricultural improvements and such, so he and Humboldt got on like a house on fire.

They also shared a background deeply influenced by philosophy. Humboldt by Kant, Jefferson by the faculty at the College of William and Mary, second oldest university in the U.S., where he'd studied the subject before going on to other things, like being prez. William and Mary may not entirely appreciate this remark, but I read somewhere that a lot of their foundation money came from one Lionel Wafer, surgeon, writer and buccaneer. Who flaunted body tattoos and a lip plate (courtesy of the Indians of Darién, Panama). And lots of loot ill gotten over five years of piracy. Well, all good things. When he got caught and went to the pokey in Jamestown for two years, the aforesaid loot was confiscated, to be "applied to the building of a college."

Interestingly enough, pirate loot wasn't always gold bullion and jewels and such. Sometimes the Spanish galleons that got knocked off were carrying really valuable cargoes, like crushed, unimpregnated scale insects of the cochineal variety. Brushed off Mexican cacti early in the season, stove-dried and ground, these little thingies were by the 1620s in the hands of a Dutch noodler named Cornelius Drebbel, who was about to change life for the military. Drebbel made microscopes, submarines, magic lanterns—and scarlet. This last involved an accident he had, some time after moving to London, with cochineal insects. Which he let fall into a mix of sulfuric and hydrochloric acid in a tin mug. And noticed the amazingly scarlet result. Told his son-in-law, Abraham Kuffler, who promptly produced a brand-new dye named Kuffler Scarlet. In 1645 Cromwell dyed the uniforms of his New Model Army with it, and from then on the term for anything British marching and carrying a weapon was "redcoat."

*Of 1,000 sailors who set out, only 145 returned. Scurvy killed the rest.*

If in the mouth of a Scot, this was generally a term of opprobrium, given the way the British behaved after the failure of the 1745 Highland uprising led by Bonnie Prince Charlie. As a result of which, life in Scotland became so unpleasant that the Scots fled to America in droves. Many years later, when the dust had settled, one or two fugitives went inconspicuously back home. As did Flora MacDonald (who had helped Charlie escape after the great Scot's defeat at Culloden). Back in Scotland, in

DUSAN PETRICIC

1779, Flora fell ill and was treated by Alexander Monro *secundus,* third of four generations of great doctors at the new Edinburgh University medical faculty. *Secundus* was third, because his father, also name of Alexander, was known as *primus,* because *his* father was named John. Lost? So am I. Anyway, in between dodging the bricks coming through his windows from an irate populace (who didn't like the way his students were raiding graveyards to snitch the corpses of their loved ones for dissection lessons), A. M. *primus* taught a navy type, James Lind, who was the guy who came up with another term of opprobrium used to refer to the Brits (this time by Americans).

In May 1747, on the good ship *Salisbury,* Lind carried out probably the first proper controlled trial in the history of clinical nutrition. For 14 days, he kept six pairs of scurvy patients on the same diet but gave each pair different medicine: cider, elixir vitriol, vinegar, seawater, a "medicinal paste" and oranges with lemons. The citrus fruit did the trick. In 1753 Lind published "A Treatise of the Scurvy," as a result of which, years later, the Royal Navy started issuing lime-juice rations to sailors. Who then never got scurvy but had to put up with being called "limeys."

Lind had been inspired to his researches by the shock of news of a naval expedition gone horribly wrong. In 1740 Commodore George Anson had sailed from England with six ships and more than 1,000 men. His mission: to head for the Pacific and clobber the Spanish wherever he found them. He did so, in spades, attacking Spanish ports and ships, laying waste right and left in the usual manner. He came home four years later with so much treasure it took 30 wagons to haul it from the docks to the Tower of London for safekeeping. Every man walked off Anson's mission rich for life. There was a lot more booty for each man to share because of the original six ships and 1,000 crew, only one ship with 145 men made it back. Scurvy had killed the rest.

Ironically, it was another medical emergency that had been the reason for Anson's voyage in the first place. Back in 1731 the brig *Rebecca* was in the Caribbean, selling smuggled goods to a passing Spanish galleon with more money than sense, when a bunch of newly invented coast guards turned up from nearby Havana and (in the words of a British letter of protest to the Havana government) left her in such a state "that she should perish in her passage." Miraculously, however, the *Rebecca* made it back to England, and seven years later (nothing happens fast in history) the captain, Robert Jenkins, was asked to appear before a parliamentary committee to tell his tale. He did so, flourishing a box in which he had kept his ear ever since the Cuban coast guard skipper, one Juan de Leon Fandino, a well-known crazy, had cut it off during the skirmish. Why you would keep your ear in a box is beyond me, but if Jenkins hadn't, it might never have become a historic appendage. The parliamentary row that followed Jenkins's grisly evidence, and then the public furor whipped up about it, led to a conflict between Britain and Spain now known as the "War of Jenkins's Ear."

French statesman Mirabeau later cited this conflict as a good example of what happens when you let war be declared by a bunch of politicos. After this ringing indictment of democracy, Mirabeau died. France was so grateful for everything he had done (sorry, no time for details) that they renamed the Paris church he was buried in the "Panthéon." Which is where Léon Foucault hung his giant pendulum in 1851. It swung in inertial space and inspired that American weatherman I began with to declare "that if a body is moving in any direction, there is a force, arising from the earth's rotation, which always deflects it to the right in the Northern Hemisphere, and to the left in the Southern." SA

*Wonders,* *continued from page 111*

silience of the tendons. Those cords are subtly woven elastic cables of the protein collagen, a structural polymer much less lossy than any Super Ball.

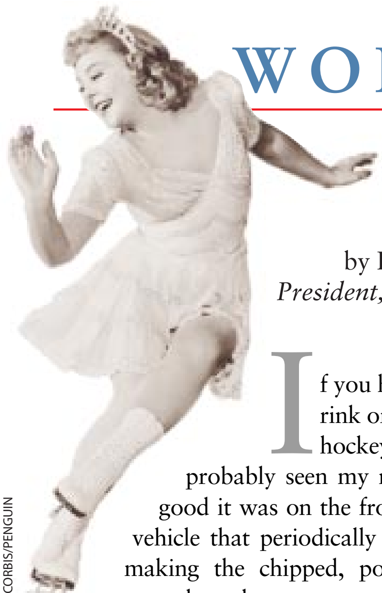
A third gait of human locomotion has been studied systematically as recently as 1998. We all knew the trick, although mostly we have dismissed our old skill. It is *skipping*, the joyful gait of the young. (Adults often skip at tight corners and going downstairs. The Italian lab found that almost all its adult male subjects got used to treadmill skipping after a few minutes of practice.) Skipping follows a basic pattern, usually L-L, R-R, different from the unvarying L-R, L-R of walking and running. Unlike the walker but like the runner, the skipper spends some time in flight. Unlike the runner but like the walker, the skipper normally has intervals of support by both feet at once.

In some respects, the skip is rather extreme; it costs more energy than other gaits, works typically at a high step rate and requires stronger leg forces than the run demands. Skipping suggests the gallop of horses. There is a rising case that force may be as important as energy in locomotion; peak muscle tension may be as much a limit as is the work muscles do. On the moon the astronauts preferred forms of skipping to the other gaits they tried. In low gravity the energy cost of locomotion is low, so anyone can afford to skip, and high force demand is also eased. Maybe a youthful skipping crew—smaller, faster, cheaper?—would be preadapted for field trips on Mars?

It is plain that the last word is far from final, even about human gaits. But both splendid results and admirable popular accounts now ornament this diverse science, which is at home with motion by living things ranging from bacteria to brachiosaurs, on and under land and water, and through the air. Not all these topics require the high technology of modern gait studies; many still invite amateur observers and home and field experimenters.

To read more, one cannot do better than R. McNeill Alexander's *Exploring Biomechanics: Animals in Motion* (Scientific American Library, 1992, distributed by W. H. Freeman and Company), and his CD-ROM *Animals on the Move* (Expert Software, 1998) adds visual resources for the wired (www.expertsoftware.com). SA

# ICE-RESURFACING MACHINES



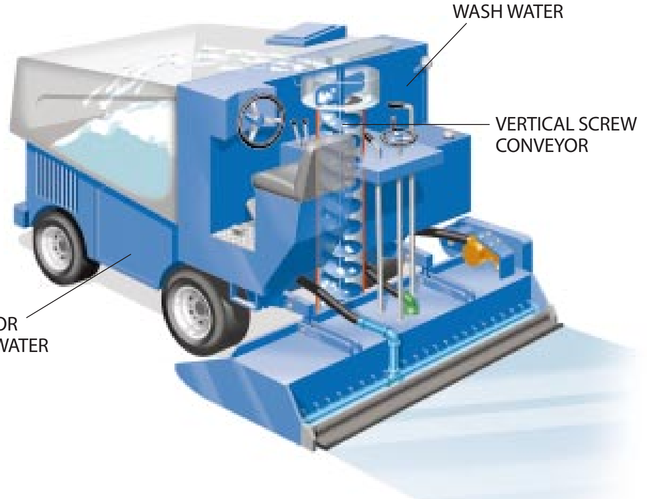
CORBIS/PENGUIN

by Richard F. Zamboni
*President, Frank J. Zamboni & Co.*

If you have ever been to a skating rink or watched figure skating or hockey on television, you have probably seen my name before. Chances are good it was on the front of the unusual-looking vehicle that periodically traveled around the rink, making the chipped, pockmarked ice surface as smooth as glass.

The first such ice-resurfacing machine was built in the 1940s by my father, Frank J. Zamboni, who with his brother and cousin owned and operated the Paramount Iceland skating rink in Paramount, Calif. That ungainly but effective invention, the result of seven years of trial-and-error development, went into regular use at the Paramount rink in 1949. A year later figure-skating legend and actress Sonja Henie (*above, left*) saw the machine in use and immediately ordered two of them for her touring skating show. Those two, the third and fourth machines built, were seen in arenas all over the U.S. and Europe, effectively announcing the arrival of mechanized ice resurfacing.

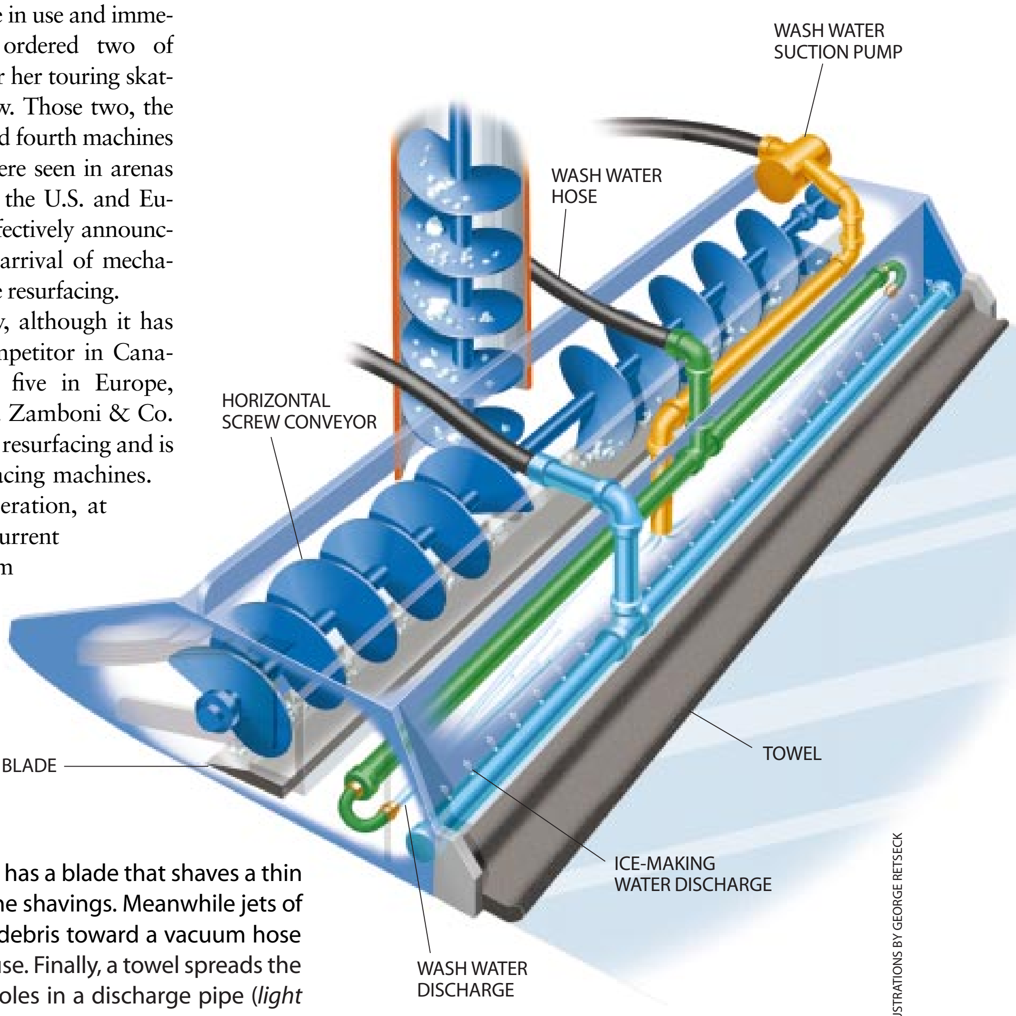
Today, although it has one competitor in Canada and five in Europe, Frank J. Zamboni & Co. has become literally synonymous with ice resurfacing and is the largest producer by far of ice-resurfacing machines. Some 6,000 of our machines are in operation, at least two thirds of the world's total. The current line consists of seven models ranging from small, tractor-pulled units starting at about $7,000 to a state-of-the-art, battery-powered model that costs around $80,000.




ZAMBONI MACHINE has a large bin in front to collect ice shavings scraped by a blade in the conditioner, behind the rear tires. Tanks underneath the bin and in front of the driver store water for conditioning and cleaning the ice.

COURTESY OF RICHARD F. ZAMBONI

EARLY ZAMBONIS, such as this one from 1950, were built around existing jeeps or jeep chassis.




CONDITIONER at the rear of the machine has a blade that shaves a thin layer of ice as screw conveyors remove the shavings. Meanwhile jets of water clean the ice by flushing dirt and debris toward a vacuum hose (*orange*). This dirty water is filtered for reuse. Finally, a towel spreads the ice-making water, which sprays out of holes in a discharge pipe (*light blue*) at 82 degrees Celsius (180 degrees Fahrenheit).

ILLUSTRATIONS BY GEORGE RETSECK