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# SCIENTIFIC AMERICAN

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## PARKINSON'S DISEASE:

IRON, FROZEN ADDICTS AND DEADLY NIGHTSHADE HELP TO EXPLAIN THE "SHAKING PALSY"

# SCIENTIFIC AMERICAN

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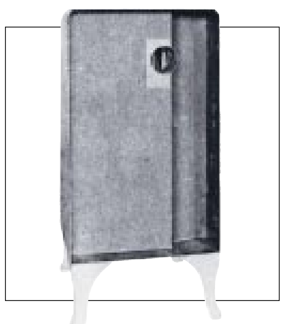



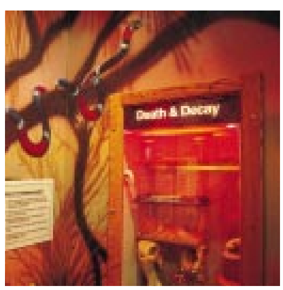


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## REVIEWS AND COMMENTARIES



**About the Cover**
Air turbulence affects the performance of golf balls, planes and other moving objects. Supercomputers can help model airflow, sometimes better than wind tunnels. Image by Slim Films.

## FROM THE EDITORS

# Defending Reason Reasonably

Alarmed by the public's continuing enthusiasm for the paranormal, the illogical and the unreasonable, many scientists and skeptics have gone on the defensive. They warn that this wave of irrationalism threatens to engulf society and, in the process, impede science by robbing it of support and brains suitably equipped for the rigors of future research. Mindful of these consequences, Gary Stix, Sasha Nemecek and Philip Yam of *Scientific American*'s editorial board therefore took a closer look at the ominous phenomenon that has come to be known as antiscience. Their report appears on page 96.

JASON GOLTZ

***ANTISCIENCE UNDER SCRUTINY by Philip Yam, Sasha Nemecek and Gary Stix.***

They quickly discovered that defining antiscience, let alone assessing its danger, is no easy task. Antiscience has become like "political correctness," an all-purpose slur that defines the position of the person using the phrase better than it does the thing being described. Are astrology columns, creationist textbooks, television programs about angels and tracts on feminist physics all antiscience? Are they all antiscientific in the same way? Does calling them antiscience do much to explain or refute them? For that reason, it seemed most sensible and informative to get past the broad heading and instead examine a few of the movements labeled antiscientific in their particulars.

Few of the phenomena called antiscience are unique to our era. Belief in the supernatural predates the written word; conversely, more people may know at least some of the rudiments of science today than ever before. The root causes of modern antiscience probably have less to do with premillennial irrationality than they do with long-standing failures of education (and not merely within the schools).

Even if a discrete antiscience trend does not exist, it is still important to treat the individual problems (if that's what they are) seriously and thoughtfully. Antievolution movements damage the public's understanding of all biology and of the incremental nature of scientific progress. That is why we must be prepared to pursue the maddening fight, over and over again, to make sure that evolution is taught in schools. Ridiculous assertions about UFOs and the supernatural need to be answered. In our zeal to defend science, however, let's not make the mistake of overgeneralizing or falling into conspiracy-minded thinking.

Our greatest misfortune as rationalists is that it usually takes less work to spout nonsense than to debunk it—but that extra effort is the unavoidable price for being on the side of the angels. So to speak.

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

## WELFARE REFORM

I am always sorry to see SCIENTIFIC AMERICAN stray from science into politics, as you did in October 1996 with the article "Single Mothers and Welfare," by Ellen L. Bassuk, Angela Browne and John C. Buckner. You are not very good at it, which perhaps is not surprising, since scientists are not in general any better at such issues than anyone else. There is no reason, though, why people with credentials in psychiatry and psychology should not say something sensible about welfare economics. But when an article is obviously a tendentious piece of political pleading, you should at least attempt to solicit some contrary remarks from actual economists.

*KELLEY L. ROSS*
Los Angeles Valley College

I read "Single Mothers and Welfare" with great interest because I spent seven years as a social worker in a public welfare agency in Alabama. I left the field of social work, however, because of a profound sense of disillusionment with the welfare system. One problem I never see addressed is that welfare bureaucracies actually benefit from having unsuccessful clients. If a caseworker gets her clients to find jobs and become self-supporting, she works herself out of a job. The authors of the study—who reveal their own bias against the recent welfare bill, labeling it "draconian"—fail to address the problems with a system that encourages self-destructive behavior and a bureaucracy that requires more clients so it can exist and grow.

*KATHERINE OWEN WATSON*
Vestavia Hills, Ala.

Bassuk, Browne and Buckner ignore the real inroads states such as Massachusetts, Wisconsin, Indiana and Oklahoma have made in reducing welfare dependency by limiting the time over which they will pay benefits. We have done a terrible disservice to welfare recipients by allowing them to become dependent on a monthly check and expecting nothing in return. I hope those days are over.

*WILLIAM D. STEPANEK*
Mahopac, N.Y.

***Bassuk and Buckner reply:***

The economist David Ellwood once observed that "everyone hates welfare." Even so, extremely poor mothers and children cannot be left scrambling to survive without a safety net. We support welfare reform, but sadly, reform has typically been based on stereotypes and myths, rather than rigorously collected information about the realities of life for poor women and children. We have attempted to fill the gap in empirical knowledge with our epidemiological study. Although issues such as welfare cannot be addressed without discussing values, that does not diminish the scientific rigor of our study or the critical need for relevant research about social issues.

We agree that bureaucracies tend to be self-interested and paradoxically at odds with those they serve. Sometimes, as with welfare, the only solution is to overhaul the system. Unfortunately, states have not evaluated the effects of current reforms. Our home state of Massachusetts, for example, has been touted for reducing its welfare rolls by 10,000, but no one knows what has happened to these people; certainly, not all of them are working.

PAUL FUSCO Magnum

***MOTHERS AND CHILDREN wait in line for lunch vouchers.***

## ALTERNATIVE VIEWS

Gary Stix's profile of Wayne B. Jonas and the Office of Alternative Medicine ["Probing Medicine's Outer Reaches," News and Analysis, October 1996] was colored by the prejudice often advanced against homeopathy in the U.S., which stands in contrast to more accepting attitudes in Europe. Stix chose to describe the OAM in the peculiar American landscape of personal energy, harmonic resonance, assorted nostrums, potions and electromagnetic-field generators. There is no doubt that the range of therapies within alternative medicine strains credulity, but recognizing those therapies that have been assessed by published clinical trials is a simple way to cut through this complexity.

*NORMAN K. GRANT*
Michigan Technological University

Congratulations for your objective appraisal of alternative medicine and the director of the OAM. The terms "alternative" and "complementary" themselves are obscurations meant to suggest that unproved treatments are acceptable in place of standard medical care. Those of us on the front lines of medicine have seen the results of uncritical public acceptance of appealing but unproved claims.

*EDWARD H. DAVIS*
Professor Emeritus,
College of Medicine
State University of New York
at Brooklyn

## MINIATURE MICROBES

In the story by Corey S. Powell and W. Wayt Gibbs discussing the possibility that fossilized bacteria may have been found in a meteorite from Mars ["Bugs in the Data?" News and Analysis, October 1996], Carl R. Woese is quoted as saying, "These structures contain one one-thousandth the volume of the smallest terrestrial bacteria." He expresses doubt that anything so small could possibly be alive. But in another article in the same issue, "Microbes Deep inside the Earth," James K. Fredrickson and Tullis C. Onstott explain that when water or other nutrients are in short supply, bacteria stay alive by shrinking to one one-thousandth of their normal volume and lowering their metabolism. Could the shrinkage of such subterranean bacteria provide a model for the very small size of the alleged Martian bacteria?

*LES J. LEIBOW*
Fair Lawn, N.J.

*Letters selected for publication may be edited for length and clarity.*

# 50, 100 AND 150 YEARS AGO

## JANUARY 1947

Using a radar-transmitter tube and a horn antenna, an unusual cooker, called Radarange, bakes biscuits and gingerbread in 29 seconds, cooks hamburgers with onion in 35 seconds, and grills a frankfurter and roll in ten seconds. The equipment beams the radio-frequency output into the food being cooked. In operation, when cooking is completed, a timer automatically shuts off the machine and the food is ready to eat, according to the Raytheon Manufacturing Company."

"Vibration tests are absolutely essential in aircraft and rockets designed to approach the speed of sound. The principle of resonant vibration is now being utilized for structural tests. Electronic shaker units, essentially like a radio loudspeaker, are positioned near the structure being tested. The moving element of each shaker is coupled to a metal rod that fits onto a rubber suction cup attached to the structure. The shaker need only be energized at the natural vibrating frequency of the structure in order to produce, in a few minutes, vibrating forces so strong that iron beams snap in two and 30-ton bombers actually bounce off their landing wheels."

*Inclined elevator at the Brooklyn Bridge*

"It is really astonishing to find what effects odors can have on purchasers. A case in point: scented hosiery is bought in preference to unscented hosiery, but, oddly enough, a survey has shown that purchasers are not consciously influenced by the odor; they imagine that the scented goods have a better texture or a more appealing color."

"When the city-fathers of a municipality decide to spend some of the taxpayers' money for a new sewage-disposal or water-supply system, one type of piping, made from asbestos fibers and cement, is at or near the top of the list. It is free from various types of corrosion, and its internal smoothness keeps flow capacity at a peak through the years."

## JANUARY 1897

An invention which promises to be of the greatest practical value in the world of telegraphy has received its first public announcement at the hands of Mr. William H. Preece, the telegraphic expert of the London post office. During a lecture on 'Telegraphy Without Wires' recently delivered in London, Mr. Preece introduced a young Italian, a Mr. Marconi, who, he said, had recently come to him with such a system. Telegraphing without wires was, of course, no new idea. In 1893 telegrams were transmitted a distance of three miles across the Bristol Channel by induction. But young Marconi solved the problem on entirely different principles, and post office officials had made a successful test on Salisbury Plain at a distance of three-quarters of a mile."

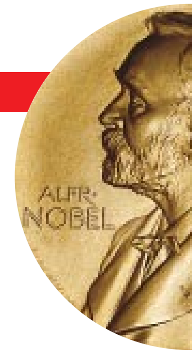
"Crowding close on the heels of famine comes the bubonic plague, and to-day half the population of Bombay have fled from the city. The point which most interests Europeans is whether the awful disease is likely to flourish in northern latitudes if the infection is introduced there; but no evidence is forthcoming as yet. Dr. Waldemar Haffkine, who is investigating the subject in Bombay, fastens the responsibility for carrying the infection upon rats, and ants. Rats have the plague. They die and are eaten by ants, which carry the germs into the crevices of buildings and to watertaps and sinks. Thus the poison is diffused and cannot be eradicated except by fire. Dr. Haffkine has, it is said, proved the efficiency of attenuated plague virus as an antidote for the disease."

"Our engraving shows the working of a new style of elevator which is being put to a practical test by the trustees of the Brooklyn Bridge. It is the invention of Mr. Jesse W. Reno, who, by way of introducing it to public and official notice, erected this same machine at Coney Island last September, where it carried over 75,000 people. The movable flooring has an inclination of 25 degrees, the vertical lift being 7 feet."

## JANUARY 1847

An iron bridge, in size and magnificence, perhaps, never before equaled, is about to be erected, with a viaduct across the Tyne, from Gateshead to Newcastle-upon-Tyne, for the Newcastle and Berwick railway. The contractors are to make, supply, and erect all the cast and wrought iron and wood work for bridges and approaches, according to the designs, and under the instructions of Robert Stephenson, Esq." [*Editors' note: Opened in 1849, the High Level Bridge still carries road and rail traffic across the Tyne.*]




# The 1996 Nobel Prizes in Science

*The Royal Swedish Academy of Sciences has again recognized four sets of researchers for their outstanding contributions. Here is a look at the work behind these achievements in chemistry, physics, medicine and economics*

## CHEMISTRY

### BUCKYBALLS

ROBERT F. CURL
Rice University

HAROLD W. KROTO
University of Sussex

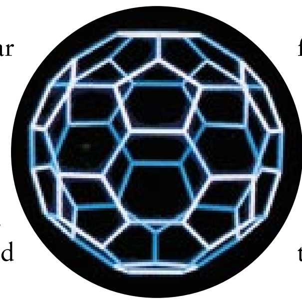
RICHARD E. SMALLEY
Rice University

Robert F. Curl, Harold W. Kroto and Richard E. Smalley won the Nobel Prize for Chemistry for their 1985 discovery of buckminsterfullerene, a third form of carbon, in which the atoms are arranged to form a closed, cagelike sphere. (The other two forms of carbon are graphite and diamond, which are, respectively, sheetlike and tetrahedral.) The archetype of the fullerene family is carbon 60 ($C_{60}$), which has the shape of a soccer ball. The name derives from the molecule's resemblance to the geodesic dome designed by the American architect and inventor Buckminster Fuller. Five years after the discovery, others uncovered a way to make macroscopic quantities of them easily, thus opening an entirely new branch of organic chemistry.

Curl, Kroto and Smalley, along with Rice graduate students James R. Heath and Sean C. O'Brien, found "buckyballs" serendipitously. At Sussex, Kroto had been studying the carbon-rich atmospheres of red giant stars and, through spectroscopy, noted that they contain long chains of carbon and nitrogen molecules.

Kroto sought help from his Rice colleagues to explain how such molecules formed in stellar atmospheres. Smalley had built a device that could create small agglomerations of molecules. In the device, a laser ablates, or cooks off, a bit of a sample material. The ablated matter, in the form of plasma, is cooled with helium gas and ejected into a vacuum chamber. This jet of material expands supersonically. As a result, the molecules cluster into various sizes and cool to near absolute zero, making them stable enough for study in a mass spectrometer.

Smalley and Curl had been using the device to examine metal clusters that might be useful in semiconductors. The feedstock changed to carbon on September 1, 1985, when Kroto arrived for a visit. With the apparatus, they found that carbon preferred to form clusters of 60 (and to a lesser extent, 70) atoms. These clusters were extremely stable: $C_{60}$ did not react when exposed to gases such as hydrogen or ammonia. At first the investigators could not fathom how 60 carbon atoms, if arranged in the typical sheets or pyramids, could fail to have dangling chemical bonds that would react with other molecules. After days of discussion, in the laboratory and in a Mexican restaurant, they concluded that the 60 carbon atoms must be arranged as a truncated icosahedron, consisting of 12 pentagons and 20 hexagons—in other words, a soccer ball.

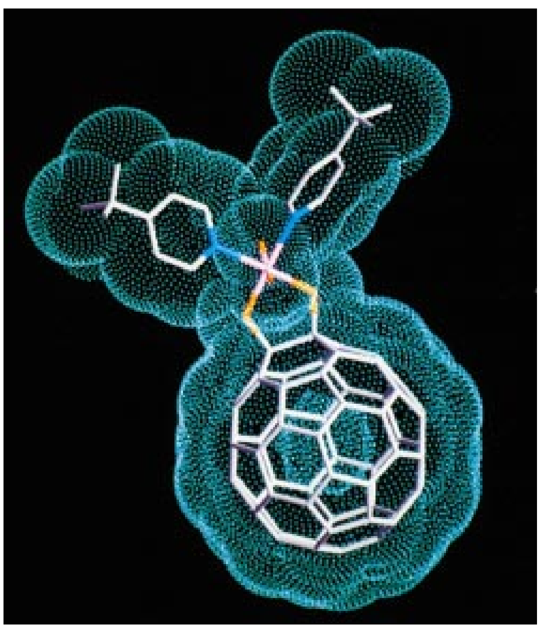


RICHARD E. SMALLEY

**CARBON 60 has the cagelike shape of a soccer ball.**

Further investigation showed that carbon could form a variety of closed, cagelike structures, starting with a minimum of 32 atoms. The formation pattern agrees with Euler's law, which states that any polyhedron with more than 22 even-numbered edges can be constructed from 12 pentagons and some number of hexagons.

Smalley's apparatus had one drawback: it could create only microscopic amounts of fullerenes. In 1990 Donald R. Huffman and Lowell Lamb of the University of Arizona and Wolfgang Krätschmer and Konstantinos Fostiropoulos of the Max Planck Institute for Nuclear Physics in Heidelberg found a simple way to make fullerenes in gram quantities. They



JOEL M. HAWKINS *University of California, Berkeley*

**"BUNNYBALL," more formally described as $C_{60}(OsO_4)$(4-*tert*-butylpyridine)$_2$, is one of numerous chemical variations on the basic buckyball.**


AP/WIDE WORLD PHOTOS

showed that an electric arc between two graphite rods would vaporize some of the carbon, which would then recondense as fullerenes.

With this technique, fullerene research exploded. Workers found they could encase other atoms within a buckyball ($C_{60}$ has a diameter of about one nanometer). Adding rubidium and cesium to $C_{60}$ turned it into a substance that superconducted at 33 kelvins (degrees Celsius above absolute zero). Buckyball structures could also be stretched to form hollow nanotubes.

Fullerenes have been proposed as lubricants, catalysts and drug-delivery vehicles. Carbon nanotubes, if they can be grown to suitable lengths without defects, might serve as ultrathin wires stronger than steel. So far, though, imagination has outstripped the elusive practical applications. Making defect-free samples is still expensive and time-consuming. Many observers nonetheless feel it is only a matter of time before the molecules find technological uses. And in any case, fullerenes have forever changed the theoretical foundations of chemistry and materials science.

From *Scientific American*

THE FULLERENES. Robert F. Curl and Richard E. Smalley, October 1991.

THE ALL-STAR OF BUCKYBALL (PROFILE: RICHARD E. SMALLEY). Philip Yam, September 1993.

## PHYSICS

# A NEW SUPERFLUID

**DAVID M. LEE**
Cornell University

**DOUGLAS D. OSHEROFF**
Stanford University

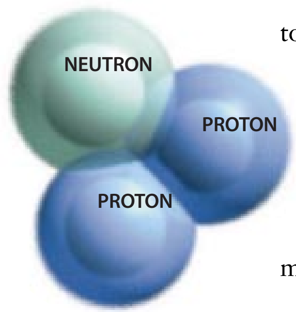
**ROBERT C. RICHARDSON**
Cornell University

Superfluidity is an odd phenomenon unique to the element helium. When helium 4, the most common isotope, is cooled to 4.2 kelvins, the gas condenses into a liquid. Cooled further to 2.7 kelvins, it does not freeze solid, like all other substances. Instead it becomes a superfluid: it flows without viscosity, can move through tiny pores and, when rotated, produces minivortices that obey quantum rules.

The Russian physicist Pjotr Kapitza first observed superfluidity in 1938 while studying helium 4. Now the Nobel Prize in Physics has gone to David M. Lee, Douglas D. Osheroff and Robert C. Richardson for demonstrating superfluidity in a rare isotope, helium 3—a phenomenon once regarded as impossible.

Helium 4 can become superfluid because it consists of an even number of subatomic particles (two protons, two neutrons and two electrons), making it what physicists call a boson. Bosons obey certain rules, known as Bose-Einstein statistics, which permit all the helium atoms in a sample to condense into a common state of minimum energy. The atoms then lose their individuality and essentially act as a single entity. (Technically, all the atoms acquire the same wave function, an equation that describes quantum particles.) On the macroscopic scale, this singular identity manifests itself as superfluidity.

But for years after the discovery of superfluidity in helium 4, physicists did not think the same thing could happen to helium 3. Its odd number of constituents (two protons, one neutron, two electrons) classifies the helium 3 atom as a fermion. It obeys Fermi-Dirac statistics, which specify that fermions cannot share the same energy state.



LAURIE GRACE

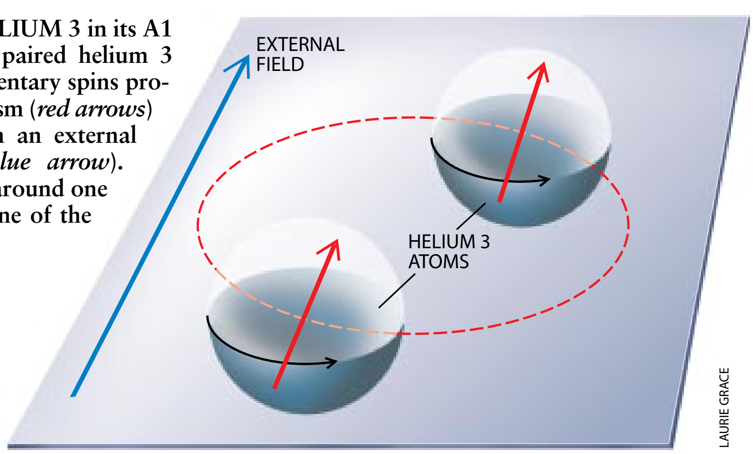
**HELIUM 3 NUCLEUS consists of two protons and one neutron.**

In 1957, however, John Bardeen, Leon Cooper and J. Robert Schrieffer proposed a way for fermions to combine like bosons. The researchers were studying superconductivity, the resistanceless flow of electrons. They argued that two electrons (which, as lone particles, are fermions) can pair up under the influence of surrounding atoms, effectively turning into a single boson. Likewise, two atoms of helium 3 can pair to form one boson, through a more complicated process involving magnetism.

Once physicists realized that helium 3 could conceivably become bosonic in character, they sought to chill the isotope enough to see if superfluidity would set in. Exploiting new cooling techniques developed in the 1960s, Lee, Osheroff and Richardson devised their own refrigerator at Cornell University. They made use of an unusual property of helium 3: one must *add* heat to cool it, because the solid phase is actually less well ordered (that is, warmer) than the liquid phase. The physicists realized that pressure applied to liquid helium could change parts of it into a solid. The solidifying part would thus draw heat from the surrounding liquid, cooling it. This process can chill the liquid to just below two millikelvins (0.002 kelvin) before all the liquid solidifies.

The Cornell workers were actually exploring the magnetic properties of helium 3 when they made their discovery. Osheroff, a graduate student at the time, noticed changes in the way the internal pressure varied over time. These changes corresponded to the transition of helium 3 to superfluidity.

**SUPERFLUID HELIUM 3 in its A1 phase consists of paired helium 3 atoms whose elementary spins produce a net magnetism (*red arrows*) that lines up with an external magnetic field (*blue arrow*). The atoms rotate around one another in the plane of the external field.**



LAURIE GRACE

Subsequent measurements revealed that unlike helium 4, helium 3 has three superfluid phases, which arise from differences in the elementary spins of the atoms. In the A phase, which takes place at 2.7 millikelvins, both helium 3 atoms in a boson pair have parallel spins, roughly speaking. In the B phase, occurring at 1.8 millikelvins, the atoms have opposing (parallel and antiparallel) spins. The third, or A1, phase appears when a magnetic field is applied to the A phase; the paired atoms have parallel spins that all point in the same direction.

Later research showed how much superfluid helium 3 differs from helium 4. Both superfluids, when rotated, produce microscopic vortices whose circulation takes on quantized values. But helium 3 shows a much richer variety of vortices with more complex appearances.

Applications of superfluid helium 3 are so far strictly limited to fundamental physics, mostly to serve as a testing ground for other theories. For instance, physicists have used the vortices in superfluid helium 3 to simulate cosmic strings, entities that are hypothesized to have formed when the young universe cooled after the big bang and that may have seeded the formation of galaxies. Studies of helium 3 may also illuminate high-temperature superconductivity, for which there is no definitive explanation.

From *Scientific American*

SUPERFLUID HELIUM 3. N. David Mermin and David M. Lee, December 1976.

THE $^3$HE SUPERFLUIDS. Olli V. Lounasmaa and George Pickett, June 1990.

PHYSIOLOGY OR MEDICINE

## UNVEILING AN ANTIVIRAL DEFENSE

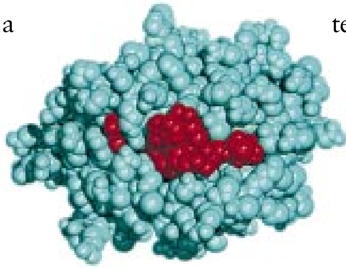
PETER C. DOHERTY
St. Jude Children's Research Hospital, Memphis, Tenn.

ROLF M. ZINKERNAGEL
University of Zurich

Few recent insights in the field of immunology have proved so basic as MHC restriction, a principle pivotal to understanding how the body fights infection. Remarkably, Peter C. Doherty and Rolf M. Zinkernagel hit on this idea while trying to solve a relatively narrow problem in veterinary medicine; that unexpected outcome has now brought them the Nobel Prize for Physiology or Medicine.

For much of the past century, immunology researchers had generally assumed that bacteria and viruses were sufficient in themselves to stir the defenses of the immune system. Antibodies recognized and attacked invaders directly, and so it seemed possible that *T* lymphocytes and other white blood cells did as well. That assumption left many mysteries unsolved, however.

One was how the immune system distinguished between healthy cells and infected cells, inside which viruses appeared to be safely hidden from immunologic scrutiny. A second concerned the variability of immune responses. In the 1960s, for example, Hugh O. McDevitt of Harvard University showed that the intensity of an animal's response correlated with the presence of genes for certain major histocompatibility complex (MHC) proteins. These proteins were known to be important in organ transplantation—unless a donor and a recipient had matching MHC profiles, a graft was rejected—but their natural function was unclear. How MHC proteins and other factors intervened in an immune assault was clearly an issue of far-reaching significance.

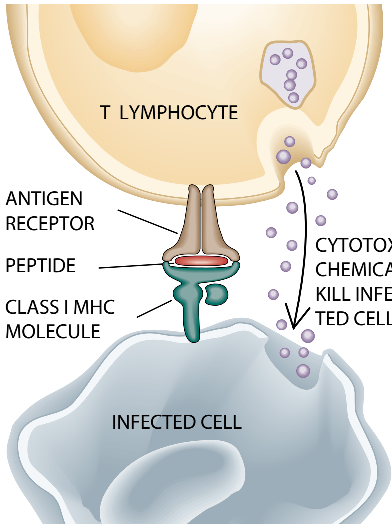


PAUL TRAVERS *Birkbeck College*

**MHC PROTEIN (*blue*) displays an antigen peptide (*red*).**

Thrown together by chance in the early 1970s at the John Curtin School of Medical Research at the Australian National University, Doherty and Zinkernagel became concerned with a far less lofty problem. They hoped to learn why laboratory mice died if infected with the lymphocytic choriomeningitis virus, which does not kill the cells it enters. Their hunch was that *T* cells acting against the virally infected tissues in the brain and spinal cord were igniting a lethal inflammation.

Doherty and Zinkernagel checked this idea by isolating *T* cells from the cerebrospinal fluid of mice with meningitis, then putting them into cultures with cells taken from healthy mice and later exposed to the virus. The *T* cells killed the infected cells, as hypothesized.




DIMITRY SCHIDLOVSKY

**COMPLEX of major histocompatibility (MHC) protein and a viral peptide on a cell's surface allows a *T* lymphocyte to recognize the cell as infected. The antigen receptor on the *T* cell must fit to both the MHC protein and the peptide.**

But mindful of McDevitt's previous finding and other studies, Doherty and Zinkernagel decided to repeat their work using mice of assorted breeds. A startling pattern emerged: *T* cells from one strain of mouse did not kill infected cells from another strain unless they shared at least one MHC protein. The investigators proposed a dual-signal hypothesis: that the *T* cells could not initiate an immune response unless they were exposed both to antigenic peptides (protein fragments) from a virus or bacterium and to suitable histocompatibility proteins.

That discovery laid the foundation for much of the detailed understanding of the immune regulatory system that has accumulated since then. Subsequent work has shown that MHC molecules on the surface of cells hold and present antigenic peptides; the peptides fit into a cleft on the top of the MHC molecules much like a hot dog fits into a bun. Class I MHC molecules present peptides derived from a cell's own proteins; they are therefore important in flagging cells that are sick or otherwise abnormal. Class II MHC molecules, found only on certain cell types, display peptides from scavenged cellular debris. They are especially important in the surveillance for extracellular parasites.

*T* cells have receptor molecules that complementarily fit against the MHC-peptide complex. A *T* cell does not become active unless its receptor matches a specific MHC-peptide combination—which explains the dual-signal result that Doherty and Zinkernagel observed.

In fact, immunologists now know that a *T* cell's activity also depends on other cofactor molecules, whose presence or absence on a cell being scrutinized for infection can further modulate the immune response. Nevertheless, it is recognition of the MHC-peptide complex that lies at the heart of the immunologic mechanism, and it is for their role in that discovery that Doherty and Zinkernagel are now honored.

From *Scientific American*

HOW THE IMMUNE SYSTEM RECOGNIZES INVADERS. Charles A. Janeway, Jr., September 1993.
HOW CELLS PROCESS ANTIGENS. Victor H. Engelhard, August 1994.

ECONOMICS

## MAKING HONESTY PAY

**WILLIAM VICKREY**
Columbia University

**JAMES A. MIRRLEES**
University of Cambridge

Traditional economic analyses of the efficiencies of markets assume perfect knowledge. That is, everyone involved in a transaction supposedly knows all the pertinent facts about the goods being exchanged and the values that the buyers and sellers place on them. In the real world, of course, such a symmetric distribution of information almost never occurs. The Nobel Prize for Economics went to William Vickrey and James A. Mirrlees for helping to make these analyses more realistic and for developing schemes to overcome these inequalities.

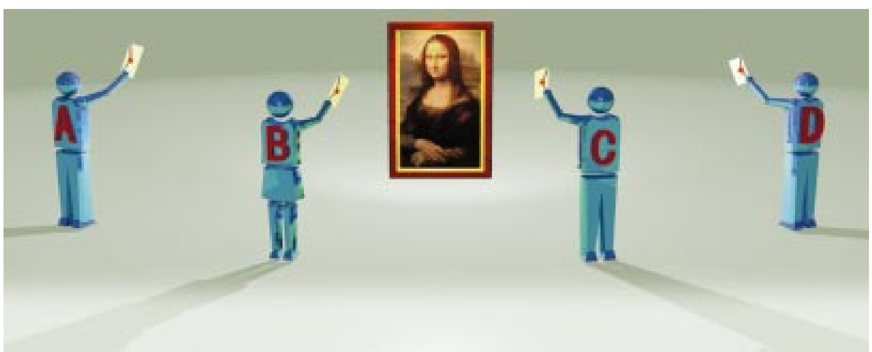
Consider the case of a sealed-bid auction, in which no one knows how much the other bidders are willing to pay for a prize. The collected bids do not reveal much about the true value of the prize, because the bidders may be looking for bargains. The odds are that the winner will end up paying too much (because she valued the prize significantly more than her competitors) or too little (because everyone bid low). Either result harms economic efficiency because the price paid does not reflect real worth.

During the early 1960s, Vickrey solved the auction problem with a technique known as a second-price auction. Potential buyers submit sealed bids; the highest bidder wins but pays only the second-highest bid. Everyone has incentive to bid what she thinks the prize is worth: bidding too low can take her out of the competition; bidding too high runs the risk that the second-highest bid will also be more than she is willing to pay. The crucial insight of Vickrey's solution was his design of a market institution that makes it in people's interest to reveal information that would otherwise remain hidden.

Vickrey had previously looked at similar asymmetries in taxation. As he pointed out during the 1940s, the government does not know how hard people are willing to work to earn an extra dollar, so it cannot predict what income tax rate will decrease overall economic production by discouraging people from working or by forcing them to work longer hours to meet their necessities when they would rather be at leisure. He wrestled with finding an optimal tax structure but, despite progress, could not overcome the sheer mathematical complexity of the problem.

His efforts nonetheless inspired Mirrlees, who in 1971 succeeded in making the mathematics more tractable. His analytical method, which proved applicable to a broad range of situations, demonstrated that, in general, the best way to overcome informational inequities is to create incentives for revealing knowledge, directly or indirectly. In the case of taxes, the government should set rates so that workers find it worthwhile to reveal their productivity preferences, rather than feeling constrained to work more—or less—than they would choose. (For practical and political reasons, no one has ever tried to implement Mirrlees's taxation technique.)

These techniques have been applied to many other areas of economics. During the 1970s, for example, Mirrlees developed a formal theory of management pay scales that specified how much of a bonus executives should get for a good year and—less often used—how far their salaries should be cut for bad performance. Vickrey concentrated on the pricing of public goods, such as roads and mass transit. He was an early proponent of congestion-based road tolls, which set the cost of entering a highway according to the number of cars already traveling it. Such tolls have been proposed in a number of countries and in particular car-bound states such as California; new digital-transaction technology could soon make them more feasible. Until his death from a heart attack three days after the announcement of the prize, Vickrey himself worked in New York City, where subways, buses and sidewalks are the overwhelming choices for transportation.




BRYAN CHRISTIE

**SEALED-BID AUCTION shows how unequal knowledge hurts efficiency. In a conventional auction, buyers underbid or overbid because they do not know others' valuations. A "second price" auction makes revealing valuations profitable.**

*Reporting by John Rennie, Paul Wallich and Philip Yam.*

# NEWS AND ANALYSIS



## IN FOCUS

### FLIGHT OF FANCY

*Will a new kind of submersible truly benefit research?*

CHUCK DAVIS

***OCEAN ENGINEER GRAHAM S. HAWKES** peers out from the cockpit of* **Deep Flight.**

To the oohs and aahs of a handpicked audience and the whir of camera shutters, Graham S. Hawkes gently tugs away a logo-emblazoned veil to reveal a new and truly odd submarine. Adorned with tail fins, stubby wings and a hull hardly bigger than a coffin, *Deep Flight* would look more at home on a movie set than on this corner patio of the Monterey Bay Aquarium in California. That is probably no coincidence—the eight-year project was funded in large part by television and film companies. But Hawkes, a veteran ocean engineer and the craft's creator, sketches a grandiose vision of the science to be enabled by his new designs.

"We live on an aquatic planet with most of the biosphere under the sea. The bulk of it remains unexplored," he expounds. Current tools for oceanic research, he asserts, are too slow, cumbersome and expensive: "To open up access to the deep ocean, we're going to have to learn how to fly underwater." Hence *Deep Flight*'s strange stature. In other submersibles that can transport a human to the ocean's depths, the pilot sits upright and maneuvers using directional thrusters. In this sub, which is designed to dive down to one kilometer, the pilot lies prone as the craft flies through the water. Puttering slowly around the shallows near the aquarium, Hawkes shows how flaps on the vehicle's wings and tail allow it to turn, dive and roll—much like an airplane with its wings on upside down. The sub even floats toward the surface if it stops (and the wings stall), a feature that makes the craft safer but also prevents it from hovering over the bottom.

Later, after a champagne reception, several distinguished scientists join Hawkes to share publicly their enthusiasm for the day's events and to drum up backing for *Deep Flight II*, a successor designed to dive 11 times as far, down to the very deepest part of the ocean floor. The panel reflects the oceanographic community's general support for piloted submersibles despite their stiff competition from robots called ROVs (remotely operated vehicles) that do their undersea work tethered to a ship on the surface. *Deep Flight,* exclaims Bruce H. Robison, a marine biologist at the Monterey Bay Aquarium Research Institute, is pioneering “a revolutionary technology that I firmly believe will lead to revolutionary scientific discoveries.” The sub’s key advantage, he contends, is its mobility: “It can acquire continuous data over kilometers, allowing us to study questions that can’t be answered with small-scale measurements. Where do the salmon go? Why do the tuna swim with the dolphins?”

Sylvia A. Earle, former chief scientist for the National Oceanic and Atmospheric Administration and Hawkes’s business partner, invokes a more visceral argument for sending a person to the bottom. “Three-dimensional imaging and head-coupled camera systems can come pretty close to transporting


MICHAEL TOPOLOVAC

***WINGED SUBMARINE***
*prepares for an underwater flight in Monterey Bay.*

your presence down to a remote vehicle,” she concedes. “But you aren’t twitching with every nerve, because you are warm and dry sitting on the surface. If some problem happens, you don’t have the same edge pushing you to solve it.”

Neither, as some more detached scientists are quick to point out, do you have the same handicaps. Maurice A. Tivey, a geologist at the Woods Hole Oceanographic Institution who has conducted research on the ocean bottom using a variety of underwater vehicles, notes that with an ROV, scientists on the support ship can leave the control room at will (when, for example, nature calls). And if need be, they can fetch a specialist to help them interpret images of objects below. Whereas a submersible is limited by batteries (*Deep Flight* can run for less than four hours, or for about 20 kilometers), ROVs can provide a virtual presence underwater for days on end. During a recent expedition with an ROV, Tivey boasts, “we were on the seafloor for 87 hours straight.”

Still, piloted submersibles have traditionally had an advantage in their heft. Geologists such as Tivey sometimes need to extract samples from formations on the seafloor, and ROVs lack the mass necessary to break things off. Woods Hole biologist Lauren S. Mullineaux further suggests that *Alvin* (a three-person undersea vehicle operated by the institution) can perform delicate experimental manipulations more easily because it can plant itself firmly on the ocean floor. ROVs, which typically use thrusters to hover over the bottom, tend to be less stable.

But *Deep Flight* and its successors will be little bigger or stronger than many ROVs. And because winged subs would tend to float upward when they stopped moving, pilots would find close, stationary work difficult. Moreover, says Robert D. Ballard, president of the Institute for Exploration, in Mystic, Conn., the complications of using ROVs are negligible compared with the main drawback of submersibles: the physical risk at which they put their occupants. Ballard, whose name became synonymous with deep-sea exploration after his investigations of the wreck of the *Titanic,* is perhaps one of the most vocal champions of the kind of ROV technology that he and colleagues at Woods Hole—and, ironically, Graham Hawkes—helped to pioneer. Certainly, he admits, exploring the deep in person is more exciting, more romantic: “When I landed on the *Titanic* with *Alvin,* it was definitely spiritually different” than steering tethered vehicles around the sunken liner with a joystick. Nevertheless, Ballard says, “Robots are better.”

Ballard believes oceanographers remain reluctant to use ROVs instead of submersibles out of an inherent conservatism. Most researchers, he finds, are willing to take risks in formulating their scientific ideas but not in testing them: they do not want to take the chance that unexpected problems with new technology will foul up their experiments. Piloted subs are a known quantity, with a longer track record than ROVs. Yet Ballard maintains that although delicate manipulations may be trickier when looking at a video monitor rather than out a window, time pressure is much less severe. And in many cases, he says, the video camera actually offers a clearer view or a better vantage point than the view ports of a deep-diving submersible.

Although Ballard applauds the construction of *Deep Flight* and is intrigued by the prospect of flying gracefully through the abyss, he doubts the diminutive sub offers much value for scientists: “I would be the first person who would want to ride—but I’m not putting it on my research grant.” Without the advantages of size and stability that scientists such as Tivey and Mullineaux want for their research, it is not clear who, if anyone, will pay for a multimillion-dollar flying submarine. Preliminary sketches of a 10-seat “tour sub” that Hawkes presented at the postlaunch symposium may reveal his thoughts on that question. So perhaps the new underwater craft could be better labeled: Ballard calls it “a recreational vehicle, pure and simple.”

*—David Schneider in New York City and W. Wayt Gibbs in Monterey*

NEUROBIOLOGY

## STEPS TO RECOVERY

*Researchers find ways of coaxing spinal nerves to regrow*

Nerves throughout most of the body regenerate when they are damaged, just like any other tissue. Damage to the central nervous system, however—the brain and spinal cord—is different. Something goes tragically wrong. Nerve bundles start feebly to repair themselves but then degenerate around the site of the injury. For many patients, that means life confined to a wheelchair.

Experiments in two laboratories now seem to bear out earlier indications that the degeneration is not because of an intrinsic inability of spinal nerves to regrow. Rather it seems to be a consequence of a separate effect that may be controllable.

Nurit Kalderon and Zvi Fuks of the Memorial Sloan-Kettering Cancer Center in New York City did most of their experiments on rats that had just one side of their spinal cord cut. The investigators found that treating the injury with high doses of x-rays during the third week after injury allowed nerve cells to grow across the site and prevented the usual degeneration. Subsequent experiments confirmed that nerve impulses could be transmitted across injury sites following x-ray treatment during the critical time window. The treatment even allowed some rats that had suffered a complete cut across their spinal cord to regain partial use of their hind limbs. Kalderon, who described the work in the *Proceedings of the National Academy of Sciences*, believes the effect works because the x-rays kill specialized nervous system cells that slowly migrate to the site of an injury and cause incidental damage.

Michal Schwartz and her colleagues at the Weizmann Institute of Science in Israel used a different system to encourage regeneration in severed rat optic nerves. Schwartz found evidence that she could promote regrowth of nerve cells by injecting the injury with immune system cells—macrophages—that she had previously incubated with nerves that

FIELD NOTES

### Suburban Amber

The moist, black lignite breaks into rough planes studded with weathered grains of red amber. Carefully, I crumble away the matrix to extract the globules, some only five millimeters wide. A few feet away David A. Grimaldi of the American Museum of Natural History takes a pickax to a large chunk of earth, breaking into curses when he discovers in its

MADHUSREE MUKERJEE

depths the fractured remnants of a fist-size piece of amber. The extremely brittle fossilized globs of tree sap are 93 million years old. In them are stuck flowers, leaves and insects that lived in a grove of giant conifers, at a time when the first flowering plants appeared.

We are in New Jersey, an hour and a half from New York City. The taxi driver had looked quite suspicious when we asked to be dropped off at the roadside, at no address at all. (For security reasons, the location is kept secret.) Slouched in the sun on a vast sandy riverbed, we are sorting through soil that a bulldozer has just excavated from 10 feet below. A few hundred yards away, forming a horizon, sit brand-new rows of boxlike prefab housing. Bordering the empty riverbed are cliffs that harbor exquisitely preserved flowers, turned into charcoal by an ancient forest fire; a heap of old tires lies at their base.

The site was discovered about five years ago by Gerard Case, a fossil hunter who has been prospecting the East Coast for 35 years. Grimaldi relates how Case walked into his office one day and put a bagful of amber on his desk, saying the classic line: "I have something here you might be interested in." There are several amber deposits in the region; early in this century clay miners on Staten Island burned the fragrant fossil in barrels to keep warm at night.

The amber from this site embalms the greatest diversity of Cretaceous life ever found. "The community is preserved in beautiful detail," Grimaldi explains, so that ecological connections between its members can be inferred. Why flowering trees suddenly proliferated in that period remains controversial. The 80 taxa of charcoal flowers unearthed here, in combination with hundreds of kinds of insects—some related to modern pollinators—may help solve that mystery.

Today we have hit a rich vein. The lignite, made of compressed forest litter, is loose; the forms and patterns of the original leaves are still evident in places. Alongside the amber occur glittering nodules of pyrite. "Easy to see how people got bit by gold fever in the old days," offers volunteer Jamie Luzzi. I hear a long-drawn-out "Oh, man": Caroline Chaboo, also of the museum, is holding up a large, clear, wine-red fragment and grinning with delight. A big piece very likely has more insects, and its transparency allows them to be seen. A local resident walking his Labradors brings us ice-cream cookie sandwiches. We stop and eat, wiping off our filthy fingers on our jeans.

Soon the lignite will be exhausted. Like other amber sites in suburbia, the riverbed is destined to be developed, probably into an industrial park. The prospect doesn't bother Grimaldi. "Any amber left will far outlive anything built here," he muses. "If it becomes a parking lot, the amber is sealed in. It is protected for generations to come." When we leave, fatigued, the sun is setting over the tract housing, throwing long shadows of its pointed rooftops across the sand. —*Madhusree Mukerjee*

# IN BRIEF

***Women Gain on Pain***

Morphine, codeine, Percodan. These mu-opioids, which mimic the body's own painkilling endorphins, are among the most powerful drugs around. Until now, kappa-opioids, chemical cousins that act on different endorphin receptors in the brain, were considered second rate. But a recent study at the University of California at San Francisco has found that kappa-opioids can work as well and cause fewer side effects, but only in women. Lead researcher Jon D. Levine speculates that testosterone counteracts the kappa-agonists in men or that the brain circuitry for pain relief differs between the sexes.

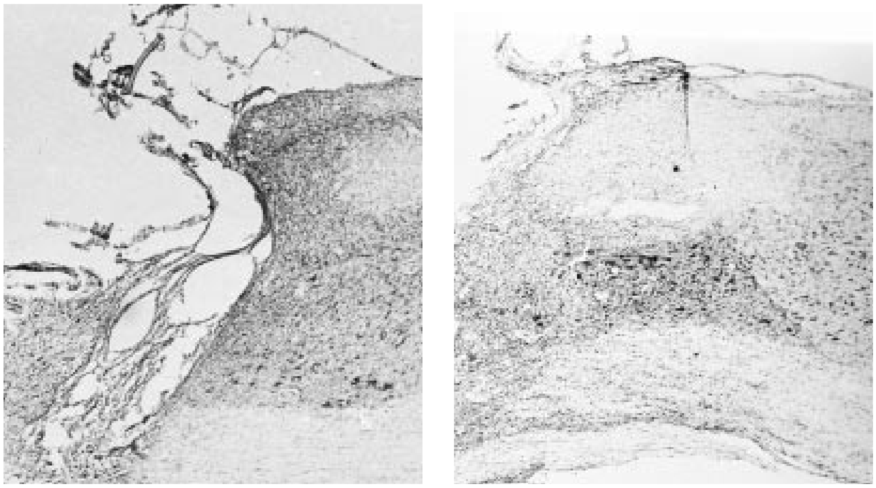
***Not So Smart Cards***

The public-key encryption schemes and digital signatures that secure your bank card can now be crippled through brute force, report Bellcore scientists Dan Boneh, Richard DeMillo and Richard Lipton. They describe an algorithmic attack that gleans critical information from computational errors liable to occur when a smart card—or any other tamperproof device used in networked transactions—undergoes physical stress. Because the method does not rely on solving the difficult problems, such as factoring large numbers, on which most encryption schemes are based, it presents an all-new kind of threat.


BETH PHILLIPS

***Femtosecond Flash***

Tracking an atom during a chemical change is trickier than spying on Clark Kent switching to his Superman suit. Most reactions take place in mere femtoseconds, or hundred millionths of a billionth of a second. But now scientists at Lawrence Berkeley National Laboratory have created a superfast x-ray for the job. By crossing the path of an infrared laser and a tightly focused electron beam, they produced x-ray pulses lasting only 300 femtoseconds. Unlike lasers previously used in this way, the x-rays interact directly with nuclei and core electrons and so better reveal atomic structure.



NURIT KALDERON

*TREATMENT OF HALF-SEVERED RAT SPINAL CORDS with x-rays 18 days after injury prevents degeneration usually observed weeks later. Cord on the left was untreated; that on the right was irradiated.*

can regenerate, such as the sciatic nerve in the leg. Macrophages allowed to sit for 24 hours with sciatic nerve caused optic nerve cells to regrow across the cut. Schwartz, who described the results last fall in the *FASEB Journal,* has conducted similar experiments on spinal cord and achieved the same kind of results.

Schwartz believes, in contrast to Kalderon's theory, the central nervous system of mammals prevents immune cells from carrying out a function that is essential to recovery. Perhaps, she suggests, mammals have evolved a way of suppressing immune system activity in the central nervous system in order to avoid damaging inflammation that could disrupt mental functioning. The suppression might have a net benefit except in serious injuries. Schwartz maintains that she has identified a previously unknown molecule in the central nervous system that causes immune suppression, and an affiliate of the Weizmann Institute has licensed her system for spinal cord regrowth to a start-up firm in New York City, Proneuron Biotechnologies.

Wise Young of the New York University Medical Center, a prominent researcher in the field, says he has no doubt that Kalderon "has a very interesting phenomenon on her hands" with x-ray-induced healing. But he emphasizes that her experiments must be repeated, because untreated rats often exhibit a surprising degree of recovery from incomplete damage, sometimes learning to walk again. Young wonders whether an infection or other extraneous effect might have hurt Kalderon's untreated animals, thus making the x-ray-treated groups appear better off by comparison. Schwartz's results, which employed only a few animals, also have alternative explanations, Young thinks. The central nervous system might, for example, simply lack an important element rather than have some active means to suppress immune function.

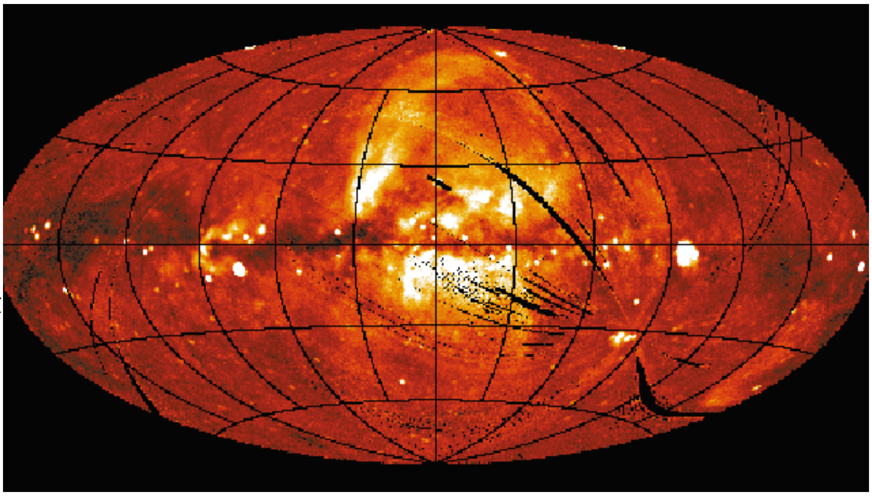
Young asserts that the value of Kalderon's and Schwartz's theories should become clearer when current studies with standardized experimental systems are complete. But some success with a different approach to spinal cord repair had been reported earlier by Henrich Cheng, Yihai Cao and Lars Olson of the Karolinska Institute in Stockholm. The team, which described its results last July in *Science*, removed a section of rats' spinal cords, bridged the gap with nerves transplanted from another part of the body and finally added a protein glue containing a nerve growth factor. The rats regained some use of their hind limbs, a demonstration that Young terms a "milestone."

The Swedish technique is not directly applicable to humans, unless a way is found to achieve regeneration without removing a section of cord that may still perform some function (most injuries leave tissue intact). Experiments are continuing, although Young says progress is still slower than he would like. Fewer than 30 laboratories in the U.S. are engaged in spinal cord injury research. And the $40 million the U.S. spends on the field will need to be doubled, he says, to pursue all promising avenues.

*—Tim Beardsley in Washington, D.C.*

From S. L. Snowden et al. in *Astrophysical Journal*, Vol. 454, No. 2, Part 1; December 1, 1995



*X-RAY VIEW OF THE SKY*
*highlights energetic objects whose rapid variability defies easy explanation.*

ASTRONOMY

## ALL IN THE TIMING

*A quick-seeing satellite catches cosmic cannibals in the act*

Over the years, astronomers have gained new perspectives on the universe by exploring sections of the electromagnetic spectrum invisible to human eyes. More subtly, they have also learned to broaden their perspective on time, looking for events that happen so swiftly that we might never notice them. The National Aeronautics and Space Administration's orbiting *Rossi X-ray Timing Explorer* (*RXTE*) has a clever talent for both kinds of insight. It focuses on the energetic x-rays that originate in violent processes occurring around hyperdense objects such as neutron stars and black holes. And unlike previous x-ray observatories, *RXTE* can observe lightning-fast flickerings that reveal unprecedented details of their underlying phenomena.

When seen through *RXTE*'s eyes, the sky flares with radiation from a class of variable stars known as x-ray binaries. In these misfit duos, one member has evolved either into a neutron star—a dense stellar corpse just 20 kilometers across—or into an even smaller yet more massive black hole. The collapsed star's powerful gravity snatches material from its partner, a more sedate star like the sun. Gas spiraling inward grows fiercely hot, emitting the observed x-rays.

Or so the theory goes—nobody understands the exact details of what happens around a neutron star. But using *RXTE*, such researchers as Tod E. Strohmayer of the NASA Goddard Space Flight Center are starting to find out. In a recent paper in *Astrophysical Journal Letters*, Strohmayer and his colleagues report that the emissions from one x-ray binary fluctuate an astounding 1,100 times per second. "The first thing you say when you see something like that is, this can't be!" he exclaims. M. Coleman Miller of the University of Chicago thinks the x-ray stuttering is a kind of beat pattern from the overlapping periods of the neutron star's rotation and the cyclic orbiting of hot gas about to crash onto the star's surface.

Related *RXTE* studies may finally settle the mystery concerning the origin of a group of astronomical speedsters called millisecond pulsars. About 15 years ago radio astronomers discovered that some pulsars (spinning neutron stars that emit pulses of radiation) have rotation periods of just a few thousandths of a second. Startled theorists proposed that these pulsars might be born in x-ray binaries, where the disk of gas crashing into the neutron star could give it an intense kick of angular momentum.

*RXTE* observations of three star systems that emit brilliant bursts of x-rays bolster the speculation. Those bursts are thought to result from episodic nuclear detonations on the surfaces of the neutron stars in these systems; the resulting hot spots may act as beacons that temporarily allow astronomers to observe directly each neutron star's rotation. Strohmayer reports that the oscillation period during bursts is just $^1/_{600}$

### *Earliest Earthlings*

The oldest known bacterial fossils, found back in 1993, are some 3.5 billion years old, but new evidence reported in *Nature* hints that life on the earth in fact began 300 million years earlier. Burrowing into 3.8-billion-year-old rock in Greenland, scientists led by Gustaf Arrhenius of the Scripps Institution of Oceanography found "light" carbon isotopes sealed in grains of calcium phosphate—samples that could have resulted only from organic activity. The mystery now is how quickly evolution must have proceeded at that time, only 200 million years after the planet was steadily being bombarded with sterilizing meteorites.

### *Preventive Payback*

Cancer deaths have, for the first time in U.S. history, declined. A study in the November 1996 issue of *Cancer* reports that mortality rates fell by some 3.1 percent from 1990 to 1995. The authors credit improved medical care, as well as reductions in smoking and in exposure to other environmental carcinogens.

### *Making a Better Brew*

To curb the effects of carbonyls—chemicals that curdle beer's taste—brewers have in the past added sulfites. Yeast produces these natural preservatives during fermentation, but another compound, *S*-adenosyl methionine, quickly breaks them down. Now genetic engineers at Carlsberg in Denmark have created strains of yeast that lack the genes encoding *S*-adenosyl methionine. Compared with wild strains, these organisms yield 10 times more sulfite and so potentially a fresher brew as well.

PAUL WEBSTER *Tony Stone Images*

### *Genetic Junkyards*

Last year scientists charting the human genome put many key landmarks on the map. Now they have filled in street addresses for 16,354 genes—many of unknown function. Of greater interest, some of the new genetic neighborhoods are heavily populated, whereas others are deserted. One theory posits that barren stretches in the genome may be junkyards for discarded DNA scraps. The map is available at http://www.ncbi.nlm.nih.gov/SCIENCE96/

*Continued on page 30*

*In Brief, continued from page 29*

***The Price of Silence***

Explaining why high blood pressure is more common among blacks than whites is not hard. To some extent, socioeconomic and environmental differences divide the races in terms of risk. Also, some evidence suggests that blacks have a genetic predisposition to the disease. But a new study from the Harvard School of Public Health cites another source: racial discrimination. The researchers found that blacks who challenged unjust acts were less likely to have high blood pressure than those who did not and so presumably internalized their reaction.

**FOLLOW-UP**

***Under the Wire***

A committee from the National Research Council has concluded that electromagnetic fields (EMFs) pose no real health threat, as was first alleged in 1979. The group surveyed more than 500 studies conducted over the past 17 years investigating the link between EMFs and, among other diseases, cancer, reproductive abnormalities and behavioral problems. They found that only exposures 1,000 to 10,000 times stronger than what is common in residential settings could alter cellular function; in no study did EMF exposure affect cellular DNA. (See September 1996, page 80.)

A & L SINIBALDI *Tony Stone Images*

***Young Planets Shine Brightly***

Through current ground-based telescopes, distant planets are a million times more faint than their parent stars. But new work from Alan Stern at the Southwest Research Institute suggests that some planned facilities, such as the Keck Interferometer in Hawaii, will easily spot the infrared radiation of young planets. For 100 to 1,000 years after birth, frequent and large impacts (events postulated by the standard theory of planetary formation) can render a planet molten, making its infrared radiation some 10,000 times greater than it will ultimately be. (See April 1996, page 60.) —*Kristin Leutwyler*

SA

of a second—much shorter than the spin rate of known newborn pulsars and hence a strong sign that these stars are in fact being sped up. But the process is far from cut and dried. Jean H. Swank of Goddard, the project scientist for *RXTE*, notes that neutron stars in some other x-ray binaries appear to slow down at times; this paradoxical phenomenon may be caused by magnetic interactions between the star and the surrounding accretion disk, but slipping and sliding between the layers of nuclear material that make up a neutron star may also play a role.

These findings are only the beginning. Swank hopes *RXTE* could detect x-ray variations caused by oscillations of a neutron star's surface, which would permit astronomers to trace the star's internal structure. Measurements of the swirling gas around especially massive collapsed stars could prove once and for all that black holes are real. And Swank notes that *RXTE* is looking far beyond our galaxy to study the emissions from quasars, objects that resemble scaled-up x-ray binaries: the central object is thought to be a black hole having as much as a billion times the mass of the sun—a beast capable of swallowing entire stars.

Herein lies a beautiful irony. The rays we see from quasars have been traveling earthward for hundreds of millions of years or more—and yet their deepest secrets might be resolved, literally, in the blink of an eye. —*Corey S. Powell*

**GEOLOGY**

## AWAITING THE BIG BANG?

*Scientists grapple with Montserrat's live volcano*

When a volcano becomes restless, people living nearby often turn to scientific specialists to help them judge the danger. Residents of the Caribbean island of Montserrat did just that in July 1995, when the long-dormant Soufriere Hills volcano became clearly active. But after more than a year of monitoring seismic rumbling, gas venting and bulging of the mountain, the experts are still struggling to anticipate what exactly the volcano will do next. Although stunningly advanced in comparison to earthquake prediction, forecasting volcanic eruptions remains uncomfortably inexact.

The ongoing crisis on Montserrat may be a perfect example of the challenges of forecasting volcanic hazards. After the first series of steam-driven eruptions in the summer of 1995, public officials on Montserrat evacuated thousands of people from the southern part of the island. But after three weeks without a catastrophic eruption, residents were allowed to return home—temporarily.

Throughout the following autumn, the volcano remained sporadically alive, with magma eventually breaching the

GARY L. SEGO

***SOUFRIERE HILLS VOLCANO** looms over the island population of Montserrat, threatening calamity.*

surface. Initially this molten rock had ascended comparatively slowly, allowing the volatile gases it contained to escape gradually. So rather than exploding like uncorked champagne, the lava gently built a mound of new rock. But by the spring of 1996 the volcano began to generate dangerous pyroclastic flows—fiery-hot mixtures of volcanic debris that can travel down the slopes of the mountain at the speed of an automobile. (This behavior stands in contrast to the recent eruptions in Iceland, where the rising magma lacks volatiles and thus seeps out without exploding.)

"I think that the greatest hazards are from pyroclastic flows," explains William B. Ambeh of the University of the West Indies in Trinidad, who has been a leader of the fledgling Montserrat Volcano Observatory. But the danger of explosive activity is also of great concern: recently small explosions hurled hot "rock bombs" a kilometer or more into a nearby settlement. This energetic behavior is consistent with the scientists' conclusion that the rising magma is now moving upward more rapidly.

Does this mean that a truly big bang is impending? Ambeh does not expect to see sudden explosions on a scale larger than those that have already occurred. But he readily admits that the geologists working on the problem have a wide range of opinion about what the volcano might or might not do next, even though they are armed with a dizzying array of sophisticated monitoring equipment—seismometers, laser range finders, satellite surveying instruments and gas analyzers. Ambeh and his colleagues on Montserrat have tried to keep track of the myriad uncertainties using "probability trees," a formalized system that Christopher G. Newhall of the U.S. Geological Survey has championed. This methodology prompts the scientists to identify possible events and assign numerical probabilities to each of them. This approach can help volcanologists communicate their forecasts to public officials and can aid scientists in thinking through clearly the difficult problem of charting the likelihood of different eventualities. "In a crisis situation, you can jump to conclusions; you can be spooked; you can be running on an hour of sleep a night," Newhall explains.

Yet probability trees do not necessarily add precision to the forecasts. The past success of such trees in showing the imminent danger from the Mount Pinatubo volcano in the Philippines just weeks

ANTI GRAVITY

## Chewing the Fat

In any list of history's greatest inventions, the usual suspects include the telephone, the automobile, the computer. The thermos bottle always gets a few votes. (Keeps hot things hot, cold things cold—how does it know?) But has humanity ever really come up with anything better than cream cheese? The phone is merely a convenient way to order cheesecakes. The car serves as a vehicle for getting to where the bagels are. The home computer is just a way for millions to work just steps from their chilled cream cheese caches. And the thermos, of course, holds the coffee to go with the cakes and bagels.

Cream cheese's standing thus demonstrated, what then to make of a scientific study in which human subjects fasted for 10 hours, then got rewarded with cream cheese–covered crackers every five minutes for an hour, which they dutifully chewed until the resulting smoothness danced on every taste bud? And which they then spit into a bucket?

Amazingly, the study was not evaluating the psychological effects of torture. Rather the research showed that just tasting fat, without actually taking it in, somehow raises the levels of blood triglycerides, the form in which fat gets stored and transported.

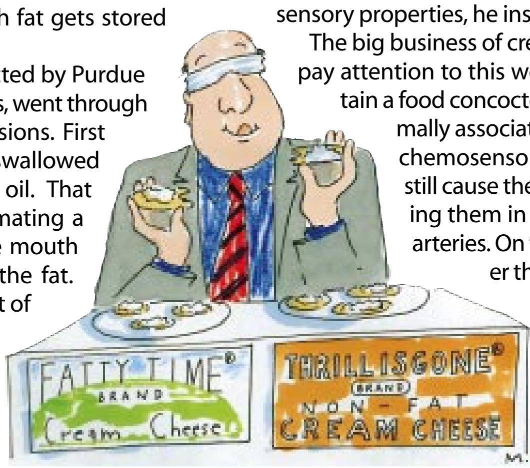
All 15 subjects in the study, conducted by Purdue University nutritionist Richard D. Mattes, went through the ordeal on four randomized occasions. First came the preparation: each subject swallowed 50 one-gram capsules of safflower oil. That gave the gut a fat reservoir approximating a concurrent meal, without having the mouth come in direct contact with any of the fat. "The amount of fat was the equivalent of one serving of Ben & Jerry's butter pecan," Mattes says. Not as good a load as three servings perhaps, but acceptable for scientific purposes.

Then came the actual tastings. On one day subjects got the real deal: full-fat cream cheese. On a second, their crackers held dreaded nonfat cream cheese. In a third run, Mattes cut the cheese, giving his volunteers unadorned crackers. For the fourth pass, subjects received a firm handshake from a grateful researcher. Blood samples revealed that levels of triglycerides almost doubled when subjects masticated the full-fat cheese, but not the nonfat variety or the plain crackers.

"We don't know what is responsible," Mattes acknowledges. "One possibility is that sensory stimulation enhances [fat] absorption from the gut. Another is that your liver makes new triglycerides. And the third possibility is that mechanisms for clearing fat from the blood are somehow turned down." A repeat of the cream cheese experiment, without the safflower oil, is under way to clear up at least the first scenario.

Mattes's finding flies in the face of fat-fanciers' faith. The dogma is that fat is a textural attribute, that you don't taste it, he says. In fact, in a separate trial, participants were unable to differentiate between the full-fat and nonfat cream cheeses. "But that doesn't explain our results. This suggests that there is some kind of chemical detection system in the mouth," Mattes concludes. Such a system has important implications for metabolic studies, which have not paid attention to fat's sensory properties, he insists.

The big business of creating fat substitutes also needs to pay attention to this work—if some low-fat victuals contain a food concocted to provide the "mouth feel" normally associated with fat, they might set off that chemosensory mechanism. Hence, they may still cause the body to free up fat stores, circulating them in the blood where they can harden arteries. On the other hand, fat substitutes lower the intake of real fat. On a third hand, anecdotal evidence has it that there is no fat in any foods eaten while standing over the sink, sneaked after midnight or pilfered from the plate of your dinner companion. —*Steve Mirsky*



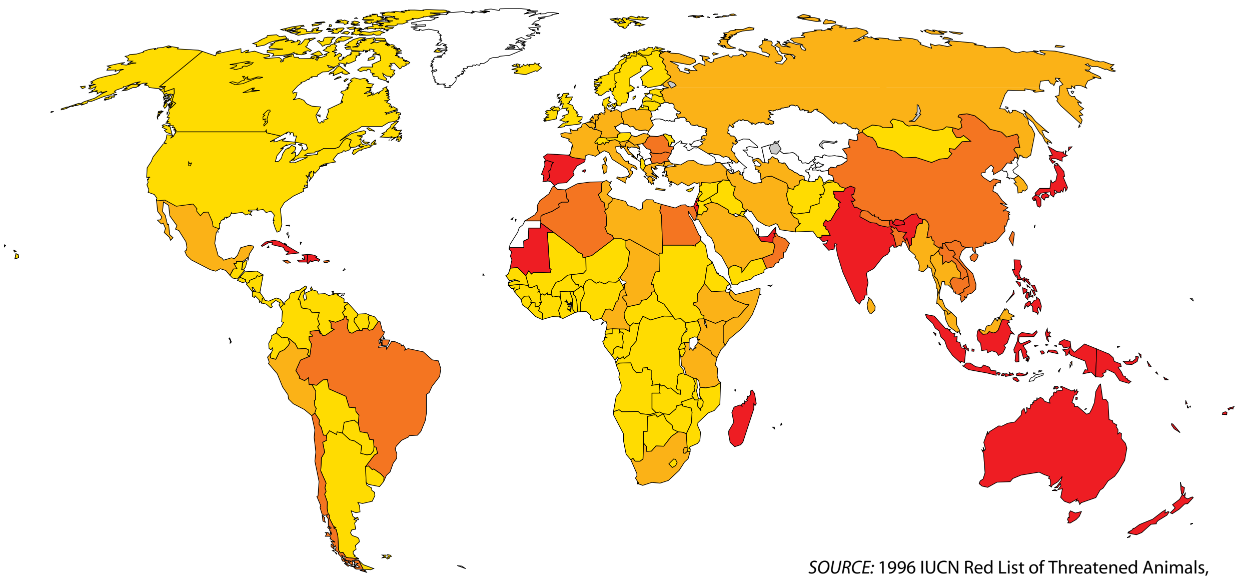

MICHAEL CRAWFORD

before its violent eruption in June 1991 may represent the exceptional case. C. Daniel Miller, a geologist at the USGS's Cascades Volcano Observatory, says it was, in part, just good luck that the Pinatubo volcano went ahead and erupted before people became inured to the warnings. Newhall believes the geologists involved in managing a volcanic crisis can typically offer specific forecasts that are only good to within a factor of 10. Thus, in hazardous situations such as the one now plaguing Montserrat, even the best scientific experts often cannot distinguish with any assurance whether a coming eruption will be large or small, whether it will occur within a few weeks or not for many months. Newhall observes, "I've seen scientists try to cut it closer than that, but they get into trouble." *—David Schneider*

BY THE NUMBERS

## Threatened Mammals



PERCENT OF MAMMAL SPECIES CLASSIFIED AS THREATENED, BY COUNTRY

LESS THAN 10 · 10 TO 14.9 · 15 TO 19.9 · 20 OR MORE · NO DATA

*SOURCE:* 1996 IUCN Red List of Threatened Animals, *by IUCN (Gland, Switzerland, 1996); and* Biodiversity Data Sourcebook, *by World Conservation Monitoring Center (Cambridge, England, 1994)*

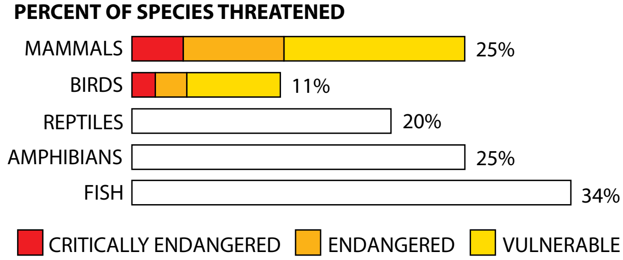
For some time, many naturalists have felt that the world is entering a period of major species extinction, rivaling five other periods in the past half a billion years. A new study by the World Conservation Union (also known as the IUCN), issued in October 1996, provides strong support for this theory. Using more thorough study methods than previously, the IUCN finds a much higher level of threat to several classes of animals than was generally thought. It found that an astonishing 25 percent of mammal species—and comparable proportions of reptile, amphibian and fish species—are threatened. Of five classes of animals, birds are the least at risk [*see bar chart*].

Of the 4,327 known mammal species, 1,096 are at risk, and 169 are in the highest category of "critically endangered"—extremely high risk of extinction in the wild in the immediate future. (The other two are "endangered," meaning very high risk in the near future, and "vulnerable," a high risk in the medium-term future.) Of the 26 orders of mammals, 24 are threatened. Among the most affected are elephants, primates and *Perissodactyla* species (such as rhinoceroses and tapirs).

Although the IUCN data probably understate the number of threatened mammal species in some regions, it is possible to draw conclusions about the pattern on the map, in particular, that habitat disturbance by humans increases the threat to mammals. Also important is a high proportion of endemic species, especially in the case of geographically isolated areas. Such regions have unique evolutionary histories and fixed boundaries to species ranges, and thus, degradation of such habitats is more likely to take a toll on animals. Striking examples are the Philippines and Madagascar, where 32 and 44 percent, respectively, of all mammal species are threatened. In both countries, well over half the species are endemic, and habitat disturbance is high. In contrast are Canada and the U.S. with, respectively, 4 and 8 percent of mammal species threatened. Less than a quarter of the species in the U.S. and only 4 percent in Canada are endemic. Habitat disturbance is moderately above average in the U.S. and very low in Canada.

The countries with the most threatened mammals are Indonesia, with 128 species, and China and India, both with 75. These three account for 43 percent of the world's population and are among the most densely populated. *—Rodger Doyle*

**PERCENT OF SPECIES THREATENED**




*Data for reptiles, amphibians and fish are insufficient to classify accurately the degrees of extinction risk.*

RODGER DOYLE

# PROFILE: MILO MEDIN

## *Do Try This @Home*

Outside, a chilly rain is pelting Silicon Valley on a miserable gray afternoon. Inside, comfortably ensconced in a fake living room at Home—or, technically, @Home—my colleague Wayt Gibbs and I are basking in the glow of a 33-inch, $5,000 Mitsubishi monitor. Officially, I have come to interview Milo Medin, @Home's vice president of networking and Silicon Valley's genius of the moment. Unofficially, we've both come to see whether one of the first Internet services delivered by television cable, rather than by telephone line, is all it's cracked up to be.

@Home was founded on an alluring premise. Cable television systems are broadband: they convey signals occupying a wide piece of the radio-frequency spectrum. They are in effect "fat pipes" that can carry data at up to 10 million bits per second. This capability—with a fair amount of supporting hardware—could make them a much better medium for connecting to the Internet than the narrowband telephone network, which by comparison is a bunch of soda straws, with data poking along at several thousand, or at most tens of thousands, of bits per second.

Although @Home is only two years old, its bold plan has already fired the imagination of a number of technology writers, who have portrayed the company's quest in David and Goliath terms. Besides @Home, David consists of several relative upstarts in the Internet business, such as Netscape Communications Corporation and the three cable television operators that own much of @Home: Tele-Communications, Inc. (TCI), Comcast Corporation and Cox Communications, Inc. Goliath consists of (what else?) Microsoft Corporation and the regional telephone companies, who argue that cable's apparent overwhelming speed advantage will wither if many users flock to cable-Internet systems, gobbling up their fat bandwidth.

Moreover, the telephone people insist, several advanced telecommunications technologies, successors to the integrated-services digital network (ISDN), will narrow the gap in the near future. At present, ISDN service offers typically 56,000 bits per second at a cost of about $25 a month; Internet service adds another $20 or so a month. (A commercial T1 line can transmit data at 1.544 million bits per second but, with corporate Internet access, costs in the neighborhood of $2,500 per month.)

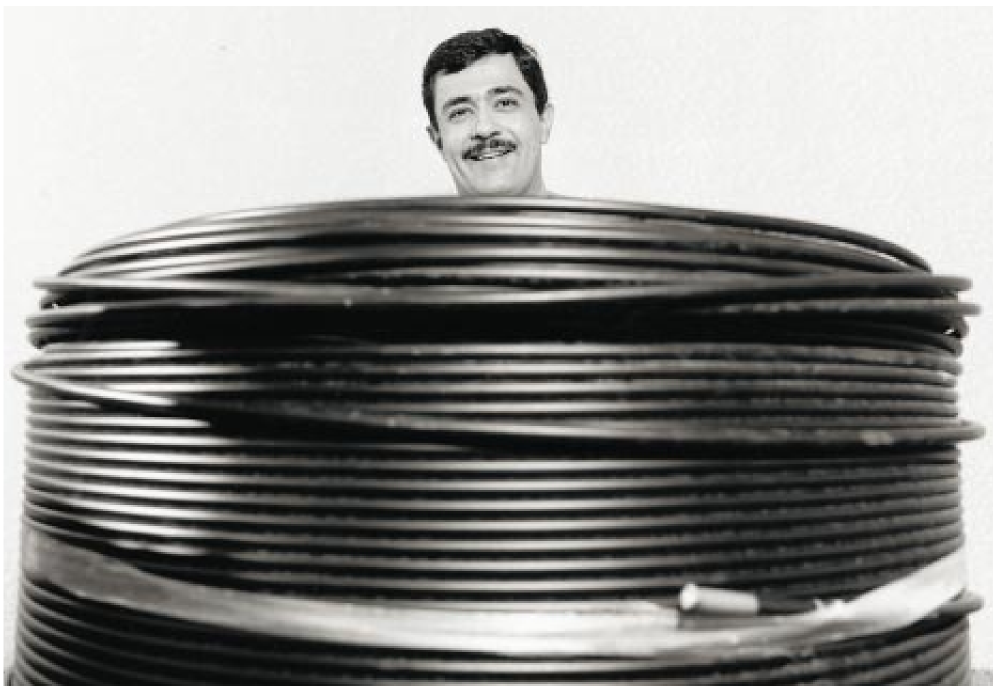
Whether cable-Internet systems can avoid potentially fatal growing pains will largely be determined by the ingenuity of Medin (pronounced meh-DEEN), a 33-year-old communications engineer. Regardless of whether Goliath keels over, Medin may wind up influencing the Internet as much as anyone else in the near future. It would be another in a string of achievements for the man that technology writer George Gilder called a "hard-core Unix Christian libertarian netbender from outer space."

Medin's office is a study in Silicon Valley spartan. On his desk is a Sun Sparcstation 20 and towering heaps of paper. There's a small round table, a tall but empty bookcase and 10 black mugs, all of them containing black coffee in various amounts and vintages. On the table is a partly disassembled cable modem. Exuding technical know-how in a striped oxford shirt, blue jeans, white leather sneakers and a pager, Medin holds forth on @Home's system. Words tumble out at a remarkable rate, as his eyebrows fly up and down, his eyes widen and almost seem to bug out, and his arms and hands jab and wave.

"He can talk about technology for a whole evening and never tire of it," warns Jay A. Rolls, director of multimedia technology for Cox. What sets him apart, Rolls adds, is "an ability to communicate" and "vision. He can look at a technology and see right away where he can take it."

Medin learned early what it was like to face a difficult situation. When he was five years old, his father, a Serbian immigrant who farmed eight hectares of grapes in Fresno, Calif., died of a heart attack. No one else in the family—Milo, his four-year-old sister, Mary Ann, and his mother, Stella—spoke English. His mother could not drive a car and knew nothing about farming or finances. "When I went to kindergarten, I didn't understand a word the teacher was saying," Medin recalls. "My sister, my mom and I went through my kindergarten workbooks together, learning about [English] words." His mother subsequently not only learned how to run the farm but increased its output.

Medin read voraciously, especially about science. An interest in technology blossomed in high school, when his



WILLIAM MERCER MCLEOD

***CABLE GUY MILO MEDIN***
***is delivering the Internet to homes via television cable.***

mother bought him an Apple II computer and a 300-bits-per-second modem. Class valedictorian, he went on to the University of California at Berkeley and loved it. At the height of the nuclear freeze movement of the early 1980s, an activist approached him and exclaimed, “Do you know that Reagan wants to spend a trillion dollars on a defense buildup?” Medin’s incredulous response was, “Is that *all*?” The man’s jaw dropped.

But if Berkeley’s leftists found Medin hard to believe, so, too, did the Federal Bureau of Investigation. While at Berkeley, Medin worked part-time at Lawrence Livermore National Laboratory writing software that was used to design solid-state lasers and to model nuclear weapons effects. The job required a security clearance and therefore a background check by the FBI. Medin’s more liberal friends seemed to sail through the process, but apparently the bureau had trouble accepting the existence, in the Berkeley student body, of a right-wing conservative with strong religious beliefs. “Is this guy a plant? Is he a *nut*?” is how Medin guesses their reaction. While Medin was being investigated, a man approached him and tried to sell him a white powder. If it was a test, Medin passed: he immediately had the man arrested by the campus police. He got his clearance not long after.

After college, Medin went to work at the National Aeronautics and Space Administration Ames Research Center, where he found a hodgepodge of proprietary data networks. His view was that the agency should abandon such networks in favor of an open one that was compatible with any kind of computer. In those days, that meant switching to a brand-new Defense Department creation known as the Transmission Control Protocol/Internetworking Protocol—the foundation of today’s Internet. Medin became a tireless and well-informed evangelist for TCP/IP, and the good times rolled. “Being a nonconformist in the government can be a lot of fun,” he says, “because you’re on a crusade against incompetence.”

A number of achievements and anecdotes burnished the Medin mystique. In 1988 he shut down Scandinavian Internet connectivity (which ran through Ames at the time) because an administrator in Finland refused to rein in a hacker who had invaded Medin’s network. Such stories had made a minor celebrity of Medin when, in 1995, Kleiner Perkins Caufield & Byers, one of the Valley’s top venture capital firms, came calling. Medin ignored them. “I thought it was a law firm,” he explains. K-P partner John Doerr persisted and finally arranged a breakfast meeting with Medin, at which Doerr and others made a pitch for @Home and asked Medin to be its technical chief. Medin politely declined the offer, then went on to tell them why their plan wouldn’t work. “It’s a nice idea, but it’s overly simplistic,” was the gist of what he said. “The expression on their faces was like I ran over their puppy,” he recalls.


@HOME

***@HOME WEB PAGE* *is a gate into information thickets.***

It took Doerr two months, but at last he landed Medin, whose first order of businesss was addressing the flaws in @Home’s technical plan. Although he was a data-networking legend, he only began learning about cable television while he was being recruited for @Home. (He did not even have cable in his own home.) “You mean you have all this fiber?” he remembers thinking. “And you don’t digitize, you AM modulate? Very weird.”

The main problem with @Home’s original scheme was that it did not deal with bottlenecks throughout the Internet that would render pointless @Home’s fat pipes to the home. The only way to ensure high data rates all the way from World Wide Web site to viewer, Medin concluded, was to build a private, high-speed backbone network and, most important, store frequently accessed pages closer to viewers in large caches spread around the country.

With the backbone and caching system largely in place, TCI began offering @Home’s service for $35 a month to its California customers in Sunnyvale and Fremont last September. At press time, Cox, TCI and Comcast were also about to introduce the service to subscribers in Baltimore, Hartford, Orange County, California, and Arlington Heights, Ill.

“We want to show people how broadband is different,” Medin says. While accessing @Home’s own content through its Web browser, screens refresh instantly. The displayed pages are also huge, generated from as many as 50 times more bits as conventional pages. On one side of the screen, reports on traffic, weather, stocks or other subjects are updated at intervals as short as two minutes. In the center of the screen, the main image seems almost frenetically alive, with smart design, flashing graphics and dollops here and there of audio and video. The overall experience compares to conventional Internet in the way water skiing compares to the backstroke.

But how about when the content isn’t @Home’s? During a break in the demonstration, Gibbs, my co-worker, grabs the keyboard and calls up a few sites. Some snap up instantly; others, particularly Apple Computer’s site, are slower (Apple’s site, however, is a notorious underperformer). An informal survey of seven @Home customers by the *San Francisco Examiner* last October found that all were happy with the service.

Of course, speed alone won’t guarantee @Home’s success, not with other cable mavens readying high-speed services of their own. Excalibur, a joint venture of Time-Warner Cable and Time, Inc., is offering its broadband Roadrunner service in Akron and Canton, Ohio, and in Binghamton, N.Y. Like the pesky Finnish hacker, though, the competition will find Medin a formidable adversary. What else would you expect of a man who peppers conversations with allusions to nuclear weapons and whose war cry, dating to his NASA Ames days, is: “If you are willing to bet your job on your beliefs, you can go a long way.” —*Glenn Zorpette*

MEDICAL DIAGNOSTICS

## FETAL CHECKUP

*A simple blood test can replace invasive procedures such as amniocentesis*

Geneticists have devised numerous tests to learn whether a fetus is likely to develop a serious inherited disease during gestation. All these tests, however, need a specimen of fetal cells. Until now, that has meant either amniocentesis or chorionic villus sampling. Both techniques involve putting a needle into the uterus to extract cells from either amniotic fluid or embryonic membrane, and both can be painful for the mother-to-be. More disturbing, once in every 50 to 100 pregnancies, the procedures trigger a miscarriage, and there are suggestions that villus sampling can very occasionally cause limb deformities in the fetus.

Separate teams of researchers in Japan and California have recently demonstrated a novel way to obtain fetal cells without any such risk. The scientists have found an apparently reliable way to isolate immature red blood cells belonging to the fetus from a sample of the mother's blood. They have also shown that they can use the cells successfully to perform various kinds of genetic tests on the fetus.

Researchers have known for over a decade that a few fetal blood cells leak into the mother's circulation. Isolating them routinely has, however, proved to be a challenge, because fetal cells account for only one in several million of the mother's own. Until a little over a year ago, most attempts to pick out fetal cells concentrated on lymphocytes, because unlike the far more numerous red blood cells, they contain genes and so can be used for analysis. This strategy suffered a setback in 1995, when U.S. investigators discovered, to their dismay, that fetal lymphocytes can persist in a mother's blood for as long as 27 years. That greatly limits their use, because a fetal lymphocyte in the blood of a pregnant woman who carried an earlier fetus could be a survivor from the earlier pregnancy.

Efforts have therefore turned to trying to isolate fetal immature red blood cells. Unlike mature red blood cells—which both mother and fetus have in abundance—immature cells have nuclei containing genes, and unlike lymphocytes they cannot survive for long. Akihiko Sekizawa of the National Center of Neurology and Psychiatry in Tokyo and his colleagues first described a successful application of the technique last year. They obtained blood samples from women who were eight to 20 weeks pregnant and concentrated the fetal and maternal immature red blood cells using standard laboratory techniques. They then laboriously picked out fetal cells under the microscope and were able to test them for Duchenne's muscular dystrophy and for the rhesus factor, which can cause dangerous problems if a woman lacks the factor but her fetus has it. The work was published in *Neurology* and in *Obstetrics and Gynecology.*

Yuet Wai Kan and his associates at the University of California at San Francisco have now made the technique easier. They first used an antibody to concentrate fetal and maternal immature red blood cells. The U.S. researchers spread the resulting cells on microscope slides and used a second antibody to stain just those cells that were displaying characteristic fetal proteins. Under a microscope they could then fairly easily pick up 10 or 20 stained cells (out of several thousand unstained maternal cells) on the point of a fine needle. For modern techniques of genetic analysis, 10 or 20 cells are plenty. Kan's work was published in *Nature Genetics.*

Kan and his colleagues have tested cells from fetuses that had been considered at risk for sickle cell anemia, cystic fibrosis or beta-thalassemia and confirmed that the fetuses did not in fact have those conditions. The diagnoses were checked against cells that were obtained conventionally.

Barring any problems that might emerge in bigger tests, there is no obvious reason why Kan's technique should not be used with any genetic test for a disorder caused by a mutation in a single gene. That covers many common genetic diseases. Diane Bianchi of the New England Medical Center says the technique might also be applicable to Down syndrome and other diseases caused by whole-chromosome mutations. Such mutations often occur in harmless form in the placenta, which could complicate diagnoses because placental cells may leak into the mother's circulation. Bianchi is currently participating in a multicenter study to check the value of fetal immature red blood cells for detecting Down syndrome. And Kan points out that although his technique demands some skill and is "quite tedious," it does not require expensive equipment or the costly time of an obstetrician.

—*Tim Beardsley in Washington, D.C.*

WILL AND DEMI MCINTYRE *Photo Researchers, Inc.*

***EXPECTANT MOTHERS UNDERGOING AMNIOCENTESIS** and other uncomfortable invasive methods may soon have an alternative: a simple blood sample that can yield enough fetal cells for genetic diagnosis.*

MICROELECTRONICS

## CHILLING CHIPS

*Microjets of air can cool chips, but... speak up!*

A smoke ring can be a pleasing thing to look at. At the Georgia Institute of Technology, Ari Glezer and Mark G. Allen are building devices that could boost the power of computer chips by blowing similar vortices of fresh air.

Keeping chips cool is a crucial requirement in electronic design. Fans are the traditional solution, but they are cumbersome and inefficient. Glezer and Allen adapted the principle behind a smoke-ring generator to make a device that efficiently cools circuits and can be made small enough to chill individual chips. The concept is straightforward: a box has one flexible wall and a hole, or several holes, in the opposite wall. Vibrating the flexible wall at a suitable frequency causes cooling jets of vortices to emerge from the holes.

Allen has made devices with holes as small as 100 microns in diameter. That makes it possible to think of micromachining such devices into a chip, Glezer notes. They need no external plumbing, and because the microjets are highly directional, they can be pointed where needed. In one test, a device with a hole 1/16 of an inch in diameter allowed the researchers to boost the power of an array of chips by 150 percent, with no increase in temperature. Yet the power consumed by the microjet device itself was only 3 percent of the power gained.

Glezer and Allen's studies originated in work supported by the U.S. Air Force, which is interested in using vastly larger versions for steering thrusters. For cooling chips, an easily made piezoelectric crystal actuator suffices to drive test devices, although other options are possible, Glezer says. Only one problem looms: some actuators emit a whistle while they work. Practical versions might have to be used with sound-absorbing padding. Provided, of course, the padding does not make the chips warmer again. Technology development is seldom simple.

*—Tim Beardsley in Washington, D.C.*

CHEMISTRY

## MORE GALLONS PER MILE

*Chemical signals narrow the search for petroleum*

Prospecting for oil and gas used to be a matter of simply looking for places where oil seeps to the surface, drilling nearby and hoping for the best. These days the search for civilization's lifeblood is more scientific, and oil companies spend many millions of dollars studying the types of rock formations most likely to have trapped worthwhile reserves. Now they have a new tool that could help find places worth exploring—and so eliminate some expensive dry holes.

Researchers have identified in oil a pair of molecules that seems to reveal how far the oil has migrated from its site of origin. Oil moves laterally through the ground an inch or so every year as the force of buoyancy pushes it up from the depths where it was formed through inclined layers of porous rock. Sometimes it is trapped at accessible depths hundreds of miles from where it started. Explorers already use chemical analysis to try to infer what kind of source rocks are likely to have yielded a given sample. By adding information about how far the sample has moved, they should rule out some suspects.

The new markers of migration distance were described last fall in *Nature* by Steven R. Larter of the University of Newcastle in England, together with a team of co-authors from Norsk Hydro and Saga Petroleum (both in Norway), Shell and Imperial Oil Resources. The chemicals they studied are two variant forms of a carbon- and nitrogen-containing compound called benzocarbazole, which is present in all oils in trace amounts. Although the two forms are chemically very similar, benzo[a]carbazole is slightly more readily absorbed by clay and other minerals than benzo[c]carbazole, an effect the researchers demonstrated experimentally by allowing oil to ooze through wet clay. That means the farther oil moves, the less of the [a] form there is left compared with the [c] form. Conveniently, the ratio does not depend on how long the oil has been on the move.

The benzocarbazole ratios in three well-studied oil fields in Europe and North America seem to confirm the experimentally observed behavior, according to Larter's *Nature* paper. Larter says other fields confirm the effect as well. To use the compounds as markers of migration distance, prospectors have to consider the estimated ratio of the compounds when the oil started its subterranean migration. That adjustment can usually be made as observations accumulate. "It is an important tool," declares Gary H. Isaksen of Exxon Production Research, who notes that more studies will be needed before all the lim-

CURT WILCOTT *Liaison International*

***OIL EXPLORATION*** 
***should become more efficient with a new tracing method.***

itations of the technique are clear. One possible difficulty is that vertical migration may skew results.

Isaksen notes the technique could be especially valuable for guiding offshore exploration, where drilling is monumentally expensive. Offshore West Africa, the Caspian Sea, and Sakhalin Island off Russia all have rich deposits that benzocarbazoles might help explore. Isaksen says several companies, including his own, have started to look at the compounds. And as long as oil companies can keep finding black gold, there seems to be little doubt there will be customers.

—*Tim Beardsley in Washington, D.C.*

COMMUNICATIONS

## BANDWIDTH, UNLIMITED

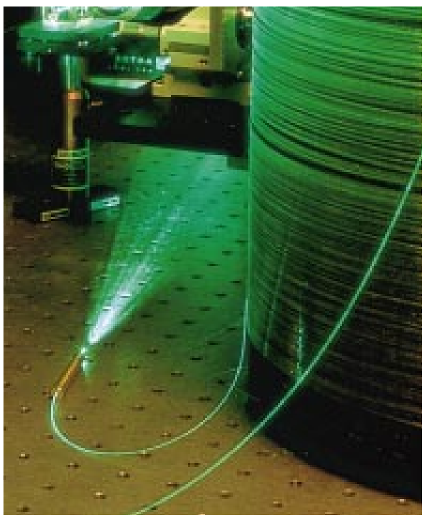
*Optical devices moving to market could boost telephone company profits—or wipe them out*

These should be the best of times for telephone companies: demand for their services is surging thanks to long-distance price wars and burgeoning Internet use. But many firms were caught off guard by the run on bandwidth. The trunks of their fiber-optic networks are perilously full, and some central offices are running out of switches during peak periods. In response, many phone companies are embracing a relatively new technology that can increase the data capacity of their optical networks by 100-fold—perhaps, within a decade, by 1,000-fold.

Last spring research groups at AT&T, Fujitsu and Nippon Telegraph and Telephone (NTT) announced that they had successfully sent data at more than one trillion bits per second over many kilometers of a single optical fiber. Seven months later NEC Corporation doubled the record, demonstrating speeds 1,000 times those used on commercial long-distance networks. "These so-called hero experiments are carefully orchestrated," points out Rajiv Ramaswami, manager of optical network systems for the IBM Thomas J. Watson Research Center. "If you add a kilometer of fiber or change the temperature of the room by 10 degrees, they probably wouldn't work. But they demonstrate what is possible." To demonstrate what is practical, major telephone companies have formed four alliances, each of which is building its own experimental network.

All four are pursuing the same clever idea to get around the speed limit physics imposes on standard optical networks, which encode data in pulses of laser light and dispatch them through wires made of glass. Very fast data rates require very short pulses, which tend to smear into one another as they travel through kilometers of fiber. Electronic devices staggered along the path can clean up the signal, but they are expensive and can work on at most 50 billion bits per second.

To go faster, researchers have borrowed a trick from radio: they transmit many signals simultaneously over a single fiber by encoding them in different wavelengths, or channels. Commercial devices that use this technique, known as wavelength division multiplexing (WDM), can already boost the capacity of existing fiber 20-fold. NEC's hero experiment demonstrated 132 channels, each conveying a full load to 20 billion bits per second—all told, enough speed to carry roughly 40 million telephone calls at once.



LUCENT ARCHIVES

***ONE GLASS FIBER* could transmit 40 million calls at once.**

"I doubt that more than 32 [channels] will be commercially practical for some time," Ramaswami says. But WDM has another strong advantage. By eliminating the need for electronic-signal cleaners, it opens the door to networks that switch light signals directly, without converting them to electronic form [see "All-Optical Networks," by Vincent W. S. Chan; SCIENTIFIC AMERICAN, September 1995]. "Such networks don't care what bit rate or [encoding technique] you send through them," Ramaswami notes. That makes them much cheaper to upgrade. Over time, estimates Joseph Berthold, who leads Bellcore's work on a test-bed project called MONET, "WDM could save [telephone companies] 35 percent of their capital costs, or about $100 million, in high-demand regions."

The telephone industry has remained skeptical of all-optical networks, because optical switches are still expensive and unstable, and they offer no easy way to spot and fix traffic jams. But that is changing swiftly. IBM has built prototype optical switches using photolithography, the process that made microchips so inexpensive. NTT has developed a device that could allow engineers building a 32-channel system to use just one stable, high-power laser and 32 filters instead of 32 tunable lasers. And Rodney C. Alferness of Lucent Technologies predicts that by February, MONET will be running—and monitoring—a small, all-optical local telephone exchange linked to AT&T's long-distance system.

As the test beds begin to prove WDM networks feasible, telephone company executives will have to judge whether they are wise. If a single glass fiber can carry all the voice, fax, video and data traffic for a large corporation yet costs little more than today's high-speed Internet connections, how much will they be able to charge for telephone service? Peter Cochrane of BT Laboratories in Ipswich, England, predicts that "photonics will transform the telecoms industry by effectively making bandwidth free and distance irrelevant." Joel Birnbaum, director of Hewlett-Packard Laboratories, expects that this will relegate telephone companies to the role of digital utilities. "You will buy computing like you now buy water or power," he says.

Others, such as industry analyst Francis McInerney, believe the double-time march of technology has already doomed them to fall behind. AT&T and its ilk, he claims, "are already dead. When individuals have [megabits per second of bandwidth], telephone service should cost about three cents a month." Having discovered how to offer high-bandwidth service, telephone companies may now need to invent useful things to do with it, just to stay in business.

—*W. Wayt Gibbs in San Francisco*

# CYBER VIEW

## *No More 9 to 5*

Fear of computers is creeping back into political debate. Sure, lawmakers still thump about the Internet to show how much they love progress. But underneath the enthusiasm is a fresh emergence of an old fear. In France, politicians are discussing shortening the workweek to share a pool of jobs, which, they say, is being steadily shrunk by the progress of automation. In Belgium, the economics minister proposed that computers be taxed and the proceeds used to subsidize threatened blue-collar jobs. And in the U.S., author and rabble-rouser Jeremy Rifkin is echoing the French call for a shorter workweek.

Like all bad ideas, these are not just wrong but also counterproductive. Computers don't destroy jobs; they create them. But they do so by changing the nature of work beyond all recognition. In that transformation, the notion of the workweek becomes about as accurate a measure of work and opportunity as the erg is a measure of financial success.

Computers alter the nature of employment because they augment workers, not substitute for them. They help to flatten office hierarchies by turning secretaries from typists into assistant managers. Communications technology has lessened—or at least made less obvious—the demands of juggling career and family by enabling some office work to be done at home. Computers also help to increase the total amount of work available. Because it emphasizes brain over brawn, the computer has drawn more women into the paid labor force. With women, more of the developed world's population is now employed than ever before. History's most automated country, the U.S., has the highest employment. In 1950 about 56 percent of adults were employed (some 59 million people). By 1992 the figure had reached 62 percent (118 million).

This transformation of work renders obsolete the idea that hours, weeks and months can serve as true accountings of labor. Among the first to notice was Frederick P. Brooks, author of the 1975 book, *The Mythical Man-Month*. Brooks was in charge of creating IBM's OS/360 operating system. Despite his best efforts, the system was massively late. Worse, it grew later as Brooks put more programmers on the project.

The problem, Brooks explained in his book, is that man-months of information work just don't add up the way that man-months of physical labor do. Adding more programmers to the OS/360 project ate up more time in the meetings needed to bring newcomers up to speed than it added in code-crunching productivity. But if information work is too complex and interdependent to figure in man-months of effort, as Brooks tried to do, there is no reason to believe that it will subtract or divide, as Rifkin would have it. Time for a new arithmetic.

DAVID SUTER

One of the first to begin formulating the new math was Erik Brynjolfsson of the Massachusetts Institute of Technology. With graduate student Marshall van Alstyne, Brynjolfsson built a simple model in which the basic raw material is ideas, and the potential value of ideas is enhanced by the speed and ease with which technology enables them to be traded. The problems this model illustrates turn out to be different from those discussed by Rifkin and most politicians.

The most important is that, while tradable and transportable ideas make everybody better off, not everybody is equally better off. The more tradable ideas become, according to Brynjolfsson's model, the more the information-rich accelerate away from the information-poor (the assumption is that information-haves will generally prefer to hobnob with other information-haves). This model is fairly simple, so it has no overlay of money and doesn't take into account the possibility that the relatively ignorant could just purchase expertise. Nor does it admit the possibility that knowledge can lose relevance.

But what is interesting about the model is how resistant it is to any of the traditional political tools used to try to distribute work and rewards. Reducing work hours rapidly leaves everyone worse off. Value in the new economy comes from weighing evidence to make decisions and deductions, and that work is ultimately done in a single brain. So someone laboring 60 hours a week can make many more decisions and connections than two people working 30 hours.

Somewhat ironically, increasing access to technology improves overall wealth but also exacerbates inequality, because access benefits the information-rich the most. More and broader education is the single most effective way of reducing disparity, but it doesn't work on the kind of timescale that wins elections.

Brynjolfsson's results do show some of the questions that politicians must try to answer. Is there an emerging information elite? Certainly the compensation of bosses is surging ahead of that of workers. But the evidence that computers have redistributed income throughout the population is inconclusive. Equally unproved is the assumption that salaried income—rather than, say, equity or intangible benefits—is the right measure of success in the information economy.

A second question concerns the natural measure of work: it's no longer weeks, hours or months. An intriguing aspect of the new economy is the growing bands of consultants who flit from one project to the next—staying only so long as their skills are needed. Their rewards are typically defined by results as well as by time. Perhaps, in this world, there is a trade-off between job security and equality of opportunity: the more temporary the jobs, the more opportunities exist to get one. But to begin to understand such trade-offs requires a definition of "project" that will enable different information jobs to be compared.

Indeed, participating in the creation of that definition is one of the greatest opportunities to emerge from the transformation of work. We have more work for more people than ever before—and more ways of working. That looks a lot like liberation for the worker, rather than oppression.

*—John Browning in London*

# Cosmic Rays at the Energy Frontier

*These particles carry more energy than any others in the universe. Their origin is unknown but may be relatively nearby*

by James W. Cronin, Thomas K. Gaisser and Simon P. Swordy

Roughly once a second, a subatomic particle enters the earth's atmosphere carrying as much energy as a well-thrown rock. Somewhere in the universe, that fact implies, there are forces that can impart to a single proton 100 million times the energy achievable by the most powerful earthbound accelerators. Where and how?

Those questions have occupied physicists since cosmic rays were first discovered in 1912 (although the entities in question are now known to be particles, the name "ray" persists). The interstellar medium contains atomic nuclei of every element in the periodic table, all moving under the influence of electrical and magnetic fields. Without the screening effect of the earth's atmosphere, cosmic rays would pose a significant health threat; indeed, people living in mountainous regions or making frequent airplane trips pick up a measurable extra radiation dose.

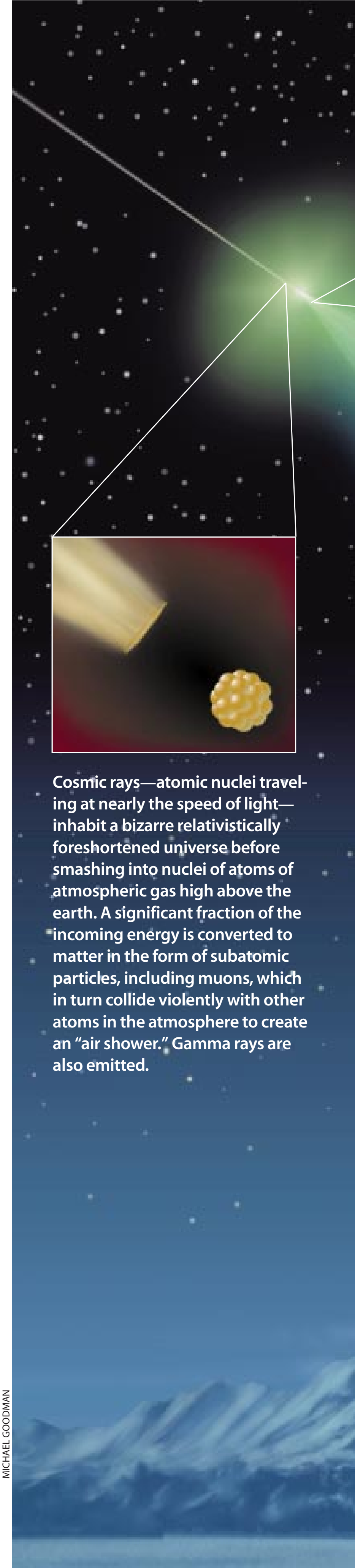
Perhaps the most remarkable feature of this radiation is that investigators have not yet found a natural end to the cosmic-ray spectrum. Most well-known sources of charged particles—such as the sun, with its solar wind—have a characteristic energy limit; they simply do not produce particles with energies above this limit. In contrast, cosmic rays appear, albeit in decreasing numbers, at energies as high as astrophysicists can measure. The data run out at levels around 300 billion times the rest-mass energy of a proton because there is at present no detector large enough to sample the very low number of incoming particles predicted.

Nevertheless, evidence of ultrahigh-energy cosmic rays has been seen at intervals of several years as particles hitting the atmosphere create myriad secondary particles (which are easier to detect). On October 15, 1991, for example, a cosmic-ray observatory in the Utah desert registered a shower of secondary particles from a 50-joule ($3 \times 10^{20}$ electron volts) cosmic ray. Although the cosmic-ray flux decreases with higher energy, this decline levels off somewhat above about $10^{16}$ eV, suggesting that the mechanisms responsible for ultrahigh-energy cosmic rays are different from those for rays of more moderate energy.

In 1960 Bernard Peters of the Tata Institute in Bombay suggested that lower-energy cosmic rays are produced predominantly inside our own galaxy, whereas those of higher energy come from more distant sources. One reason to think so is that a cosmic-ray proton carrying more than $10^{19}$ eV, for example, would not be deflected significantly by any of the magnetic fields typically generated by a galaxy, so it would travel more or less straight. If such particles came from inside our galaxy, we might expect to see different numbers coming from various directions because the galaxy is not arranged symmetrically around us. Instead the distribution is essentially isotropic, as is that of the lower-energy rays, whose directions are scattered.

### Supernova Pumps

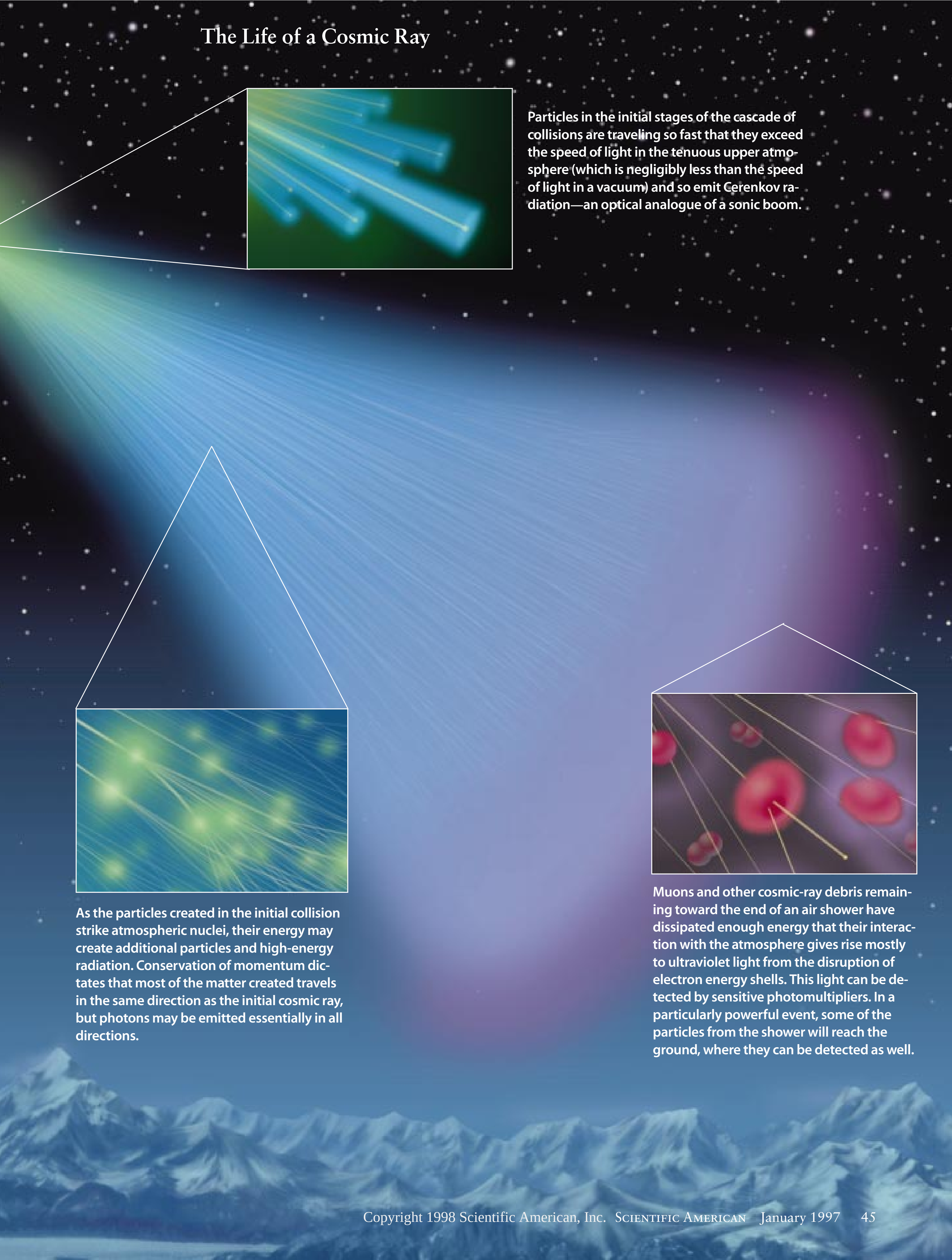
Such tenuous inferences reveal how little is known for certain about the origin of cosmic rays. Astrophysicists have plausible models for how they might be produced but no definitive answers. This state of affairs may be the result of the almost unimaginable difference between conditions on the earth and in the regions where cosmic rays are born. The space between the stars contains only about one atom per cubic centimeter, a far lower density than the best artificial vacuums we can create. Furthermore, these volumes are filled with vast electrical and magnetic fields, intimately connected to a diffuse population of



Cosmic rays—atomic nuclei traveling at nearly the speed of light—inhabit a bizarre relativistically foreshortened universe before smashing into nuclei of atoms of atmospheric gas high above the earth. A significant fraction of the incoming energy is converted to matter in the form of subatomic particles, including muons, which in turn collide violently with other atoms in the atmosphere to create an "air shower." Gamma rays are also emitted.

MICHAEL GOODMAN



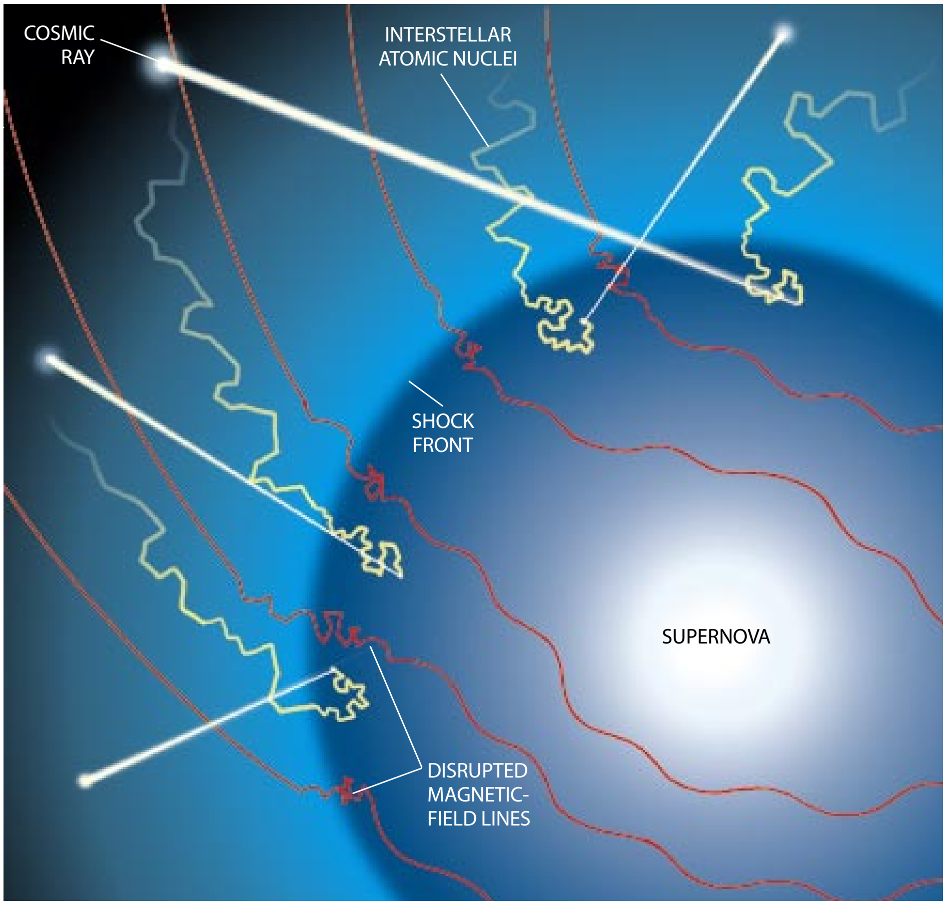
## The Life of a Cosmic Ray

Particles in the initial stages of the cascade of collisions are traveling so fast that they exceed the speed of light in the tenuous upper atmosphere (which is negligibly less than the speed of light in a vacuum) and so emit Cerenkov radiation—an optical analogue of a sonic boom.

As the particles created in the initial collision strike atmospheric nuclei, their energy may create additional particles and high-energy radiation. Conservation of momentum dictates that most of the matter created travels in the same direction as the initial cosmic ray, but photons may be emitted essentially in all directions.

Muons and other cosmic-ray debris remaining toward the end of an air shower have dissipated enough energy that their interaction with the atmosphere gives rise mostly to ultraviolet light from the disruption of electron energy shells. This light can be detected by sensitive photomultipliers. In a particularly powerful event, some of the particles from the shower will reach the ground, where they can be detected as well.

**COSMIC-RAY ACCELERATOR is believed to arise from a supernova explosion. Astrophysicists hypothesize that atomic nuclei crossing the supernova shock front will pick up energy from the turbulent magnetic fields embedded in the shock. A particle may be deflected in such a way that it crosses the boundary of the shock hundreds or even thousands of times, picking up more energy on each passage, until it escapes as a cosmic ray. Most of the particles travel on paths that result in relatively small accelerations, accounting for the general shape of the cosmic-ray energy spectrum (*far right*), which falls off at higher energies. The "knee," or bend, in the curve suggests that most of the particles are accelerated by a mechanism incapable of imparting more than about $10^{15}$ electron volts. The relative excess of ultrahigh-energy particles indicates an additional source of acceleration whose nature is as yet unknown.**




GEORGE KELVIN

charged particles even less numerous than the neutral atoms.

This environment is far from the peaceful place one might expect: the low densities allow electrical and magnetic forces to operate over large distances and timescales in a manner that would be quickly damped out in material of terrestrial densities. Galactic space is therefore filled with an energetic and turbulent plasma of partially ionized gas in a state of violent activity. The motion is often hard to observe on human timescales because astronomical distances are so large; nevertheless, those same distances allow even moderate forces to achieve impressive results. A particle might zip through a terrestrial accelerator in a few microseconds, but it could spend years or even millennia in the accelerator's cosmic counterpart. (The timescales are further complicated by the strange, relativity-distorted framework that ultrahigh-energy cosmic rays inhabit. If we could observe such a particle for 10,000 years, that period would correspond to only a single second as far as the particle is concerned.)

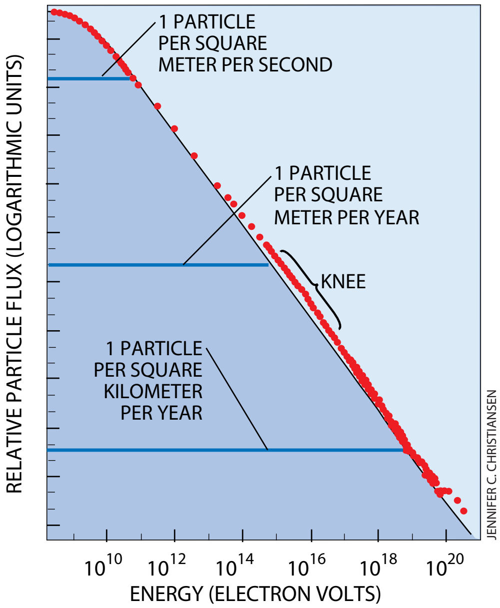
Astronomers have long speculated that the bulk of galactic cosmic rays—those with energies below about $10^{16}$ eV—originate with supernovae. A compelling reason for this theory is that the power required to maintain the observed supply of cosmic-ray nuclei in our Milky Way galaxy is only slightly less than the average kinetic energy delivered to the galactic medium by the three supernova explosions that occur every century. There are few, if any, other sources of this amount of power in our galaxy.

When a massive star collapses, the outer parts of the star explode at speeds of up to 10,000 kilometers per second and more. A similar amount of energy is released when a white dwarf star un-

B. BOLA *U.S. Army*

**AIR-SHOWER DETECTOR watches for traces of cosmic rays entering the upper atmosphere. Photodetectors can track flashes of light caused by particles interacting with air molecules and determine the energy and probable identity of the incoming rays. The Fly's Eye detector (*close-up at far right*) is located in Utah.**




dergoes complete disintegration in a thermonuclear detonation. In both types of supernovae the ejected matter expands at supersonic velocities, driving a strong shock into the surrounding medium. Such shocks are expected to accelerate nuclei from the material they pass through, turning them into cosmic rays. Because cosmic rays are charged, they follow complicated paths through interstellar magnetic fields. As a result, their directions as observed from the earth yield no information about the location of their original source.

By looking at the synchrotron radiation sometimes associated with supernova remnants, researchers have found more direct evidence that supernovae can act as accelerators. Synchrotron radiation is characteristic of high-energy electrons moving in an intense magnetic field of the kind that might act as a cosmic-ray accelerator, and the presence of synchrotron x-rays in some supernova remnants suggests particularly high energies. (In earthbound devices, synchrotron emission limits a particle's energy because the emission rate increases as a particle goes faster; at some point, the radiation bleeds energy out of an accelerating particle as fast as it can be pumped in.) Recently the Japanese x-ray satellite *Asca* made images of the shell of Supernova 1006, which exploded 990 years ago. Unlike the radiation from the interior of the remnant, the x-radiation from the shell has the features characteristic of synchrotron radiation. Astrophysicists have deduced that electrons are being accelerated there at up to $10^{14}$ eV (100 TeV).

The EGRET detector on the *Compton Gamma Ray Observatory* has also been used to study point sources of gamma rays identified with supernova remnants. The observed intensities and spectra (up to a billion electron volts) are consistent with an origin from the decay of particles called neutral pions, which could be produced by cosmic rays from the exploding star's remnants colliding with nearby interstellar gas. Interestingly, however, searches made by the ground-based Whipple Observatory for gamma rays of much higher energies from some of the same remnants have not seen signals at the levels that would be expected if the supernovae were accelerating particles to $10^{14}$ eV or more.


A complementary method for testing the association of high-energy cosmic rays with supernovae involves the elemental composition of cosmic-ray nuclei. The size of the orbit of a charged particle in a magnetic field is proportional to its total momentum per unit charge, so heavier nuclei have greater total energy for a given orbit size. Any process that limits the particle acceleration on the basis of orbit size (such as an accelerating region of limited extent) will thus lead to an excess of heavier nuclei at high energies.

Eventually we would like to be able to go further and look for elemental signatures of acceleration in specific types of supernovae. For example, the supernova of a white dwarf detonation would accelerate whatever nuclei populate the local interstellar medium. A supernova that followed the collapse of a massive star, in contrast, would accelerate the surrounding stellar wind, which is characteristic of the outer layers of the progenitor star at earlier stages of its evolution. In some cases, the wind could include an increased fraction of helium, carbon or even heavier nuclei.

The identity of high-energy cosmic rays is all but lost when they interact with atoms in the earth's atmosphere and form a shower of secondary particles. Hence, to be absolutely sure of the nuclear composition, measurements must be made before the cosmic rays reach dense atmosphere. Unfortunately, to collect 100 cosmic rays of energies near $10^{14}$ eV, a 10-square-meter detector would have to be in orbit for three years. Typical exposures at present are more like the equivalent of one square meter for three days.

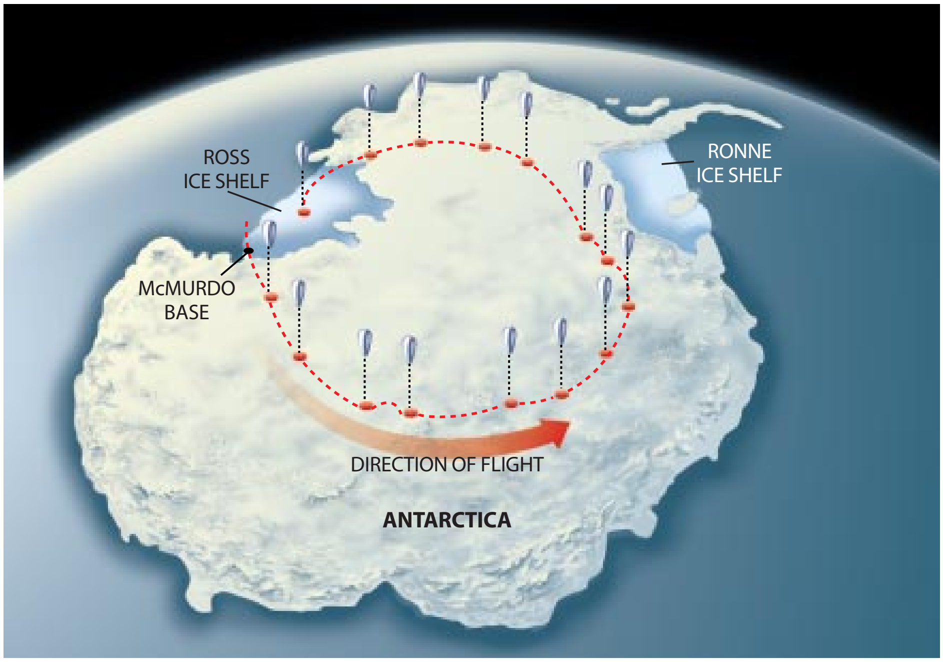
Researchers are attacking this problem with some ingenious experiments. For example, the National Aeronautics and Space Administration has developed techniques to loft large payloads (about three tons) with high-altitude balloons for many days. These experiments cost a tiny fraction of what an equivalent satellite detector would. The most successful flights of this type have taken place in Antarctica, where the upper atmosphere winds blow in an almost constant circle around the South Pole.

A payload launched at McMurdo Sound on the coast of Antarctica will travel at a nearly constant radius from the Pole and return eventually to near the launch site. Some balloons have circled the continent for 10 days. One of us (Swordy) is collaborating with Dietrich Müller and Peter Meyer of the University of Chicago on a 10-square-meter detector that could measure heavy cosmic rays of up to $10^{15}$ eV on such a flight. There are efforts to extend the exposure times to roughly 100 days with similar flights nearer the equator.

## Across Intergalactic Space

Studying even higher-energy cosmic rays—those produced by sources as yet unknown—requires large ground-based detectors, which overcome the problem of low flux by watching enor-

**HIGH-ALTITUDE BALLOON launched near McMurdo Base in Antarctica carries cosmic-ray detectors above most of the atmosphere. Winds 40 kilometers above the ice cap blow in a circle around the Pole, returning the balloon to the vicinity of its starting point after about 10 days. Balloon detectors are not as sensitive as those placed on board satellites, but they can be made much larger and lofted much more cheaply.**




GEORGE KELVIN

mous effective areas for months or years. The information, however, must be extracted from cascades of secondary particles—electrons, muons and gamma rays—initiated high in the atmosphere by an incoming cosmic-ray nucleus. Such indirect methods can only suggest general features of the composition of a cosmic ray on a statistical basis, rather than identifying the atomic number of each incoming nucleus.

At ground level, the millions of secondary particles unleashed by one cosmic ray are spread over a radius of hundreds of meters. Because it is impractical to blanket such a large area with detectors, the detectors typically sample these air showers at a few hundred or so discrete locations.

Technical improvements have enabled such devices to collect increasingly sophisticated data sets, thus refining the conclusions we can draw from each shower. For example, the CASA-MIA-DICE experiment in Utah, in which two of us (Cronin and Swordy) are involved, measures the distributions of electrons and muons at ground level. It also detects Cerenkov light (a type of optical shock wave produced by particles moving faster than the speed of light in their surrounding medium) generated by the shower particles at various levels in the atmosphere. These data enable us to reconstruct the shape of the shower more reliably and thus take a better guess at the energy and identity of the cosmic ray that initiated it.

The third one of us (Gaisser) is working with an array that measures showers reaching the surface at the South Pole. This experiment works in conjunction with AMANDA, which detects energetic muons produced in the same showers by observing Cerenkov radiation produced deep in the ice cap. The primary goal of AMANDA is to catch traces of neutrinos produced in cosmic accelerators, which may generate upward-streaming showers after passing through the earth.

In addition to gathering better data, researchers are also improving detailed computer simulations that model how air showers develop. These simulations help us to understand both the capabilities and the limitations of ground-based measurements. The extension to higher energies of direct cosmic-ray detection experiments, which allows both ground-based and airborne detectors to observe the same kinds of cosmic rays, will also help calibrate our ground-based data.

### Rare Giants

Cosmic rays with energies above $10^{20}$ eV strike the earth's atmosphere at a rate of only about one per square kilometer a year. As a result, studying them requires an air-shower detector of truly gigantic proportions. In addition to the 1991 event in Utah, particles with energies above $10^{20}$ eV have been seen by groups elsewhere in the U.S., in Akeno, Japan, in Haverah Park, U.K., and in Yakutsk, Siberia.

Particles of such high energy pose a conundrum. On the one hand, they are likely to come from outside our galaxy because no known acceleration mechanism could produce them and because they approach from all directions even though a galactic magnetic field is insufficient to bend their path. On the other hand, their source cannot be more than about 30 million light-years away, because the particles would otherwise lose energy by interaction with the universal microwave background—radiation left over from the birth of the cosmos in the big bang. In the relativistic universe that the highest-energy cosmic rays inhabit, even a single radio-frequency photon packs enough punch to rob a particle of much of its energy.

If the sources of such high-energy particles were distributed uniformly throughout the cosmos, interaction with the microwave background would cause a sharp cutoff in the number of particles with energy above $5 \times 10^{19}$ eV, but that is not the case. There are as yet too few events above this nominal threshold for us to know for certain what is going on, but even the few we have seen provide us with a unique opportunity for theorizing. Because these rays are essentially undeflected by the weak intergalactic magnetic fields, measuring the direction of travel of a large enough sample should yield unambiguous clues to the locations of their sources.

It is interesting to speculate what the sources might be. Three recent hypotheses suggest the range of possibilities: galactic black-hole accretion disks, gamma-ray bursts and topological defects in the fabric of the universe.

Astrophysicists have predicted that black holes of a billion solar masses or more, accreting matter in the nuclei of active galaxies, are needed to drive relativistic jets of matter far into intergalactic space at speeds approaching that of light; such jets have been mapped with radio telescopes. Peter L. Biermann of the Max Planck Institute for Radioastronomy in Bonn and his collaborators

STEVEN PETERZEN *National Scientific Balloon Facility*

suggest that the hot spots seen in these radio lobes are shock fronts that accelerate cosmic rays to ultrahigh energy. There are some indications that the directions of the highest-energy cosmic rays to some extent follow the distribution of radio galaxies in the sky.

The speculation about gamma-ray bursts takes off from the theory that the bursts are created by relativistic explosions, perhaps resulting from the coalescence of neutron stars. Mario Vietri of the Astronomical Observatory of Rome and Eli Waxman of Princeton University independently noted a rough match between the energy available in such cataclysms and that needed to supply the observed flux of the highest-energy cosmic rays. They argue that the ultrahigh-speed shocks driven by these explosions act as cosmic accelerators.

Perhaps most intriguing is the notion that ultrahigh-energy particles owe their existence to the decay of monopoles, strings, domain walls and other topological defects that might have formed in the early universe. These hypothetical objects are believed to harbor remnants of an earlier, more symmetrical phase of the fundamental fields in nature, when gravity, electromagnetism and the weak and strong nuclear forces were merged. They can be thought of, in a sense, as infinitesimal pockets preserving bits of the universe as it existed in the fractional instants after the big bang.

As these pockets collapse, and the symmetry of the forces within them breaks, the energy stored in them is released in the form of supermassive particles that immediately decay into jets of particles with energies up to 100,000 times greater than those of the known ultrahigh-energy cosmic rays. In this scenario the ultrahigh-energy cosmic rays we observe are the comparatively sluggish products of cosmological particle cascades.

Whatever the source of these cosmic rays, the challenge is to collect enough of them to search for detailed correlations with extragalactic objects. The AGASA array in Japan currently has an effective area of 200 square kilometers, and the new Fly's Eye HiRes experiment in Utah will cover about 1,000 square kilometers. Each detector, however, can capture only a few ultrahigh-energy events a year.

For the past few years, Cronin and Alan A. Watson of the University of Leeds have been spearheading an initiative to gather an even larger sample of ultrahigh-energy cosmic rays. This development is named the Auger Project, after Pierre Auger, the French scientist who first investigated the phenomenon of correlated showers of particles from cosmic rays. The plan is to provide detectors with areas of 9,000 square kilometers that are capable of measuring hundreds of high-energy events a year. A detector field would consist of many stations on a 1.5-kilometer grid; a single event might trigger dozens of stations.

An Auger Project design workshop held at the Fermi National Accelerator Laboratory in 1995 has shown how modern off-the-shelf technology such as solar cells, cellular telephones and Global Positioning System receivers can make such a system far easier to construct. A detector the size of Rhode Island could be built for about $50 million. To cover the entire sky, two such detectors are planned, one each for the Northern and Southern hemispheres.

As researchers confront the problem of building and operating such gigantic detector networks, the fundamental question remains: Can nature produce even more energetic particles than those we have seen? Could there be still higher-energy cosmic rays, or are we already beginning to detect the highest-energy particles our universe can create? SA

## *The Authors*

JAMES W. CRONIN, THOMAS K. GAISSER and SIMON P. SWORDY work on both the theoretical questions of how cosmic rays are created and the practical problems inherent in detecting and analyzing them. Cronin, a professor of physics at the University of Chicago since 1971, earned his master's degree from the university in 1953 and his doctorate in 1955. In 1980 he shared the Nobel Prize with Val L. Fitch for work on symmetry violations in the decay of mesons. Gaisser, a professor of physics at the University of Delaware, has concentrated on the interpretation of atmospheric cosmic-ray cascades; he earned his doctorate from Brown University in 1967. In 1995 Gaisser spent two months in Antarctica setting up cosmic-ray detectors. Swordy, an associate professor at Chicago, has been active in cosmic-ray measurement since 1976. He earned his Ph.D. from the University of Bristol in 1979.

## *Further Reading*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# Understanding Parkinson's Disease

*The smoking gun is still missing, but growing evidence suggests highly reactive substances called free radicals are central players in this common neurological disorder*

by Moussa B. H. Youdim and Peter Riederer

AP/WIDE WORLD PHOTOS

**MUHAMMAD ALI, who suffers from parkinsonism, lit the Olympic flame at the 1996 Summer Games in Atlanta. The unsteadiness of this once indomitable athlete served as a stark reminder of the pressing need for more effective therapies.**

One of the more emotional moments of the 1996 summer Olympics in Atlanta occurred at the opening ceremonies, even before the games started. Muhammad Ali—the former world heavyweight boxing champion and a 1960 Olympic gold medal winner—took the torch that was relayed to him and, with trembling hands, determinedly lit the Olympic flame. His obvious effort reminded the world of the toll Parkinson's disease and related disorders can take on the human nervous system. Ali, who in his championship days had prided himself on his ability to "float like a butterfly, sting like a bee," now had to fight to control his body and steady his feet.

Ali's condition also highlighted the urgent need for better treatments. We cannot claim that a cure is around the corner, but we can offer a glimpse into the considerable progress investigators have made in understanding Parkinson's disease, which afflicts more than half a million people in the U.S. alone. Although still incomplete, this research has recently begun suggesting ideas not only for easing symptoms but, more important, for stopping the underlying disease process.

Parkinson's disease progressively destroys a part of the brain critical to coordinated motion. It has been recognized since at least 1817, when James Parkinson, a British physician, described its characteristic symptoms in "An Essay on the Shaking Palsy." Early on, affected individuals are likely to display a rhythmic tremor in a hand or foot, particularly when the limb is at rest. (Such trembling has helped convince many observers that Pope John Paul II has the disorder.) As time goes by, patients may become slower and stiffer. They may also have difficulty initiating movements (especially rising from a sitting position), may lose their balance and coordination and may freeze unpredictably, as their already tightened muscles halt altogether.

Nonmotor symptoms can appear as well. These may include excessive sweating or other disturbances of the involuntary nervous system and such psychological problems as depression or, in late stages, dementia. Most of the problems, motor or otherwise, are subtle at first and worsen over time, often becoming disabling after five to 15 years. Patients typically show their first symptoms after age 60.

The motor disturbances have long been known to stem primarily from destruction of certain nerve cells that reside in the brain stem and communicate with a region underlying the cortex. More specifically, the affected neurons are the darkly pigmented ones that lie in the brain stem's substantia nigra ("black substance") and extend projections into a higher domain called the striatum (for its stripes).

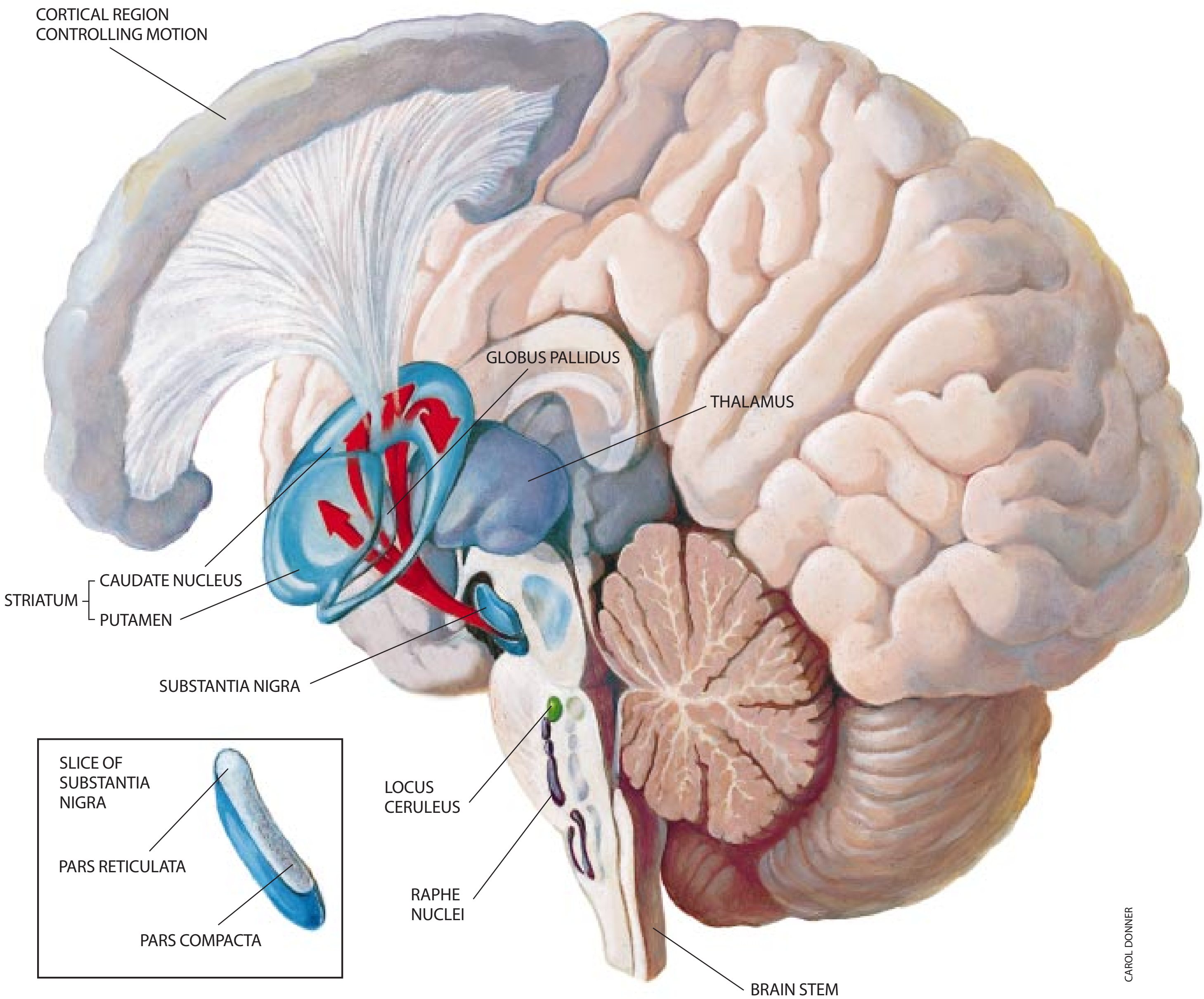
As Arvid Carlsson of Gothenburg University reported in 1959, the injured neurons normally help to control motion by releasing a chemical messenger—the neurotransmitter dopamine—into the striatum. Striatal cells, in turn, relay dopamine's message through higher motion-controlling centers of the brain to the cortex, which then uses the information as a guide for determining how the muscles should finally behave. But as the dopamine-producing neurons die, the resulting decline in dopamine signaling disrupts the smooth functioning of the overall motor network and compromises the person's activity. Nonmotor symptoms apparently result mainly from the elimination of other kinds of neurons elsewhere in the brain. What remains unknown, however, is how the various neurons that are lost usually become injured.

Because damage to the substantia nigra accounts for most symptoms, investigators have concentrated on that area. Some 4 percent of our original complement of dopamine-producing neurons disappears during each decade of adulthood, as part of normal aging. But Parkinson's disease is not a normal feature of aging. A pathological process amplifies the usual cell death, giving rise to symptoms after approximately 70 percent of the neurons have been destroyed. Whether this process is commonly triggered by something in the environment, by a genetic flaw or by some combination of the two is still unclear, although a defect on chromosome 4 has recently been implicated as a cause in some cases.

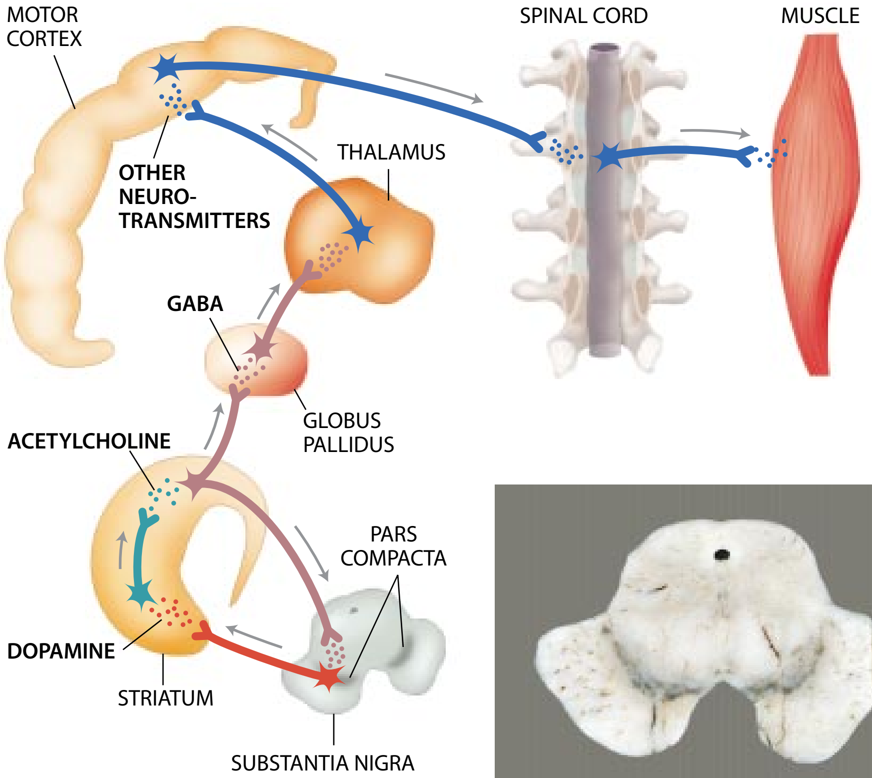
### Drawbacks of Existing Therapies

Research into the root causes of Parkinson's disease has been fueled in part by frustration over the shortcomings of the drugs available for treatment. Better understanding of the nature of the disease process will undoubtedly yield more effective agents.

The first therapeutics were found by chance. In 1867 scientists noticed that extracts of the deadly nightshade plant eased some symptoms, and so doctors began to prescribe the extracts. The finding was not explained until about a century later. By the mid-1900s pharmacologists had learned that the medication worked by inhibiting the activity in the striatum of acetylcholine, one of the chemical molecules that carries messages between neurons. This discovery im-

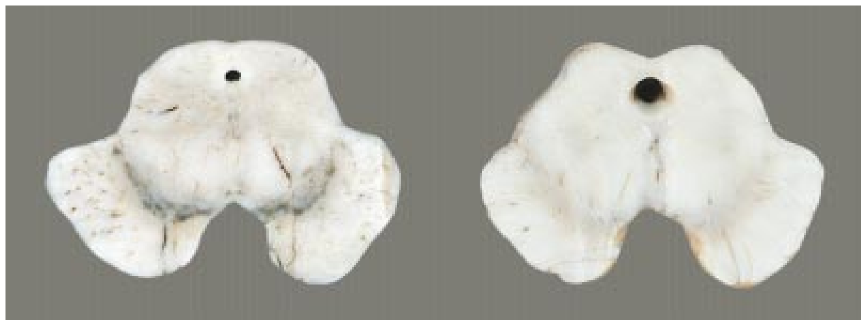



**BRAIN REGIONS affected physically or functionally by Parkinson's disease are highlighted. The pars compacta region of the substantia nigra (*dark area in detail*) loses neurons that normally issue motion-controlling signals (*arrows*) to the striatum in the form of the naturally occurring chemical dopamine. Striatal neurons relay the messages to higher motor centers (*gray*). Death of the nigral neurons lowers dopamine levels and thereby disrupts the circuit and, in turn, a patient's motor control. Dopamine-producing neurons outside the substantia nigra are not harmed much, but areas that lose other kinds of neurons, such as the raphe nuclei and locus ceruleus, contribute to depression and to additional nonmotor manifestations of the disorder.**




LAURIE GRACE

**NEURONAL CIRCUIT disrupted in Parkinson's disease is shown schematically. When dopamine-producing neurons die, loss of dopamine release in the striatum causes the acetylcholine producers there to overstimulate their target neurons, thereby triggering a chain reaction of abnormal signaling leading to impaired mobility. The pars compacta region of the substantia nigra in the normal brain appears dark (*left photograph*) because dopamine-producing neurons are highly pigmented; as neurons die from Parkinson's disease, the color fades (*right photograph*).**



DANIEL P. PERL *Mount Sinai School of Medicine*

plied that dopamine released into the striatum was normally needed, at least in part, to counteract the effects of acetylcholine. Further, in the absence of such moderation, acetylcholine overexcited striatal neurons that projected to higher motor regions of the brain.

Although the acetylcholine inhibitors helped somewhat, they did not eliminate most symptoms of Parkinson's disease; moreover, their potential side effects included such disabling problems as blurred vision and memory impairment. Hence, physicians were delighted when, in the 1960s, the more effective drug levodopa, or L-dopa, proved valuable. This agent, which is still a mainstay of therapy, became available thanks largely to the research efforts of Walter Birkmayer of the Geriatric Hospital Lainz-Vienna, Oleh Hornykiewicz of the University of Vienna, Theodore L. Sourkes and Andre Barbeau of McGill University and George Cotzias of the Rockefeller University.

These and other workers developed L-dopa specifically to compensate for the decline of dopamine in the brain of Parkinson's patients. They knew that dopamine-producing neurons manufacture the neurotransmitter by converting the amino acid tyrosine to L-dopa and then converting L-dopa into dopamine. Dopamine itself cannot be used as a drug, because it does not cross the blood-brain barrier—the network of specialized blood vessels that strictly controls which substances will be allowed into the central nervous system. But L-dopa crosses the barrier readily. It is then converted to dopamine by dopamine-making neurons that survive in the substantia nigra and by nonneuronal cells, called astrocytes and microglia, in the striatum.

When L-dopa was introduced, it was hailed for its ability to control symptoms. But over time physicians realized it was far from a cure-all. After about four years, most patients experience a wearing-off phenomenon: they gradually lose sensitivity to the compound, which works for shorter and shorter increments. Also, side effects increasingly plague many people—among them, psychological disturbances and a disabling "on-off" phenomenon, in which episodes of immobility, or freezing, alternate unpredictably with episodes of normal or involuntary movements. Longer-acting preparations that more closely mimic dopamine release from neurons are now available, and they minimize some of these effects.

As scientists came to understand that L-dopa was not going to be a panacea, they began searching for additional therapies. By 1974 that quest had led Donald B. Calne and his co-workers at the National Institutes of Health to begin treating patients with drugs that mimic the actions of dopamine (termed dopamine agonists). These agents can avoid some of the fluctuations in motor control that accompany extended use of L-dopa, but they are more expensive and can produce unwanted effects of their own, including confusion, dizziness on standing and involuntary motion.

In 1975 our own work resulted in the introduction of selegiline (also called deprenyl) for treatment of Parkinson's disease. This substance, invented by a Hungarian scientist, had failed as a therapy for depression and was almost forgotten. But it can block the breakdown of dopamine, thus preserving its availability in the striatum. Dopamine can be degraded by the neurons that make it as well as by astrocytes and microglia that reside near the site of its release. Selegiline inhibits monoamine oxidase B, the enzyme that breaks down dopamine in the astrocytes and microglia.

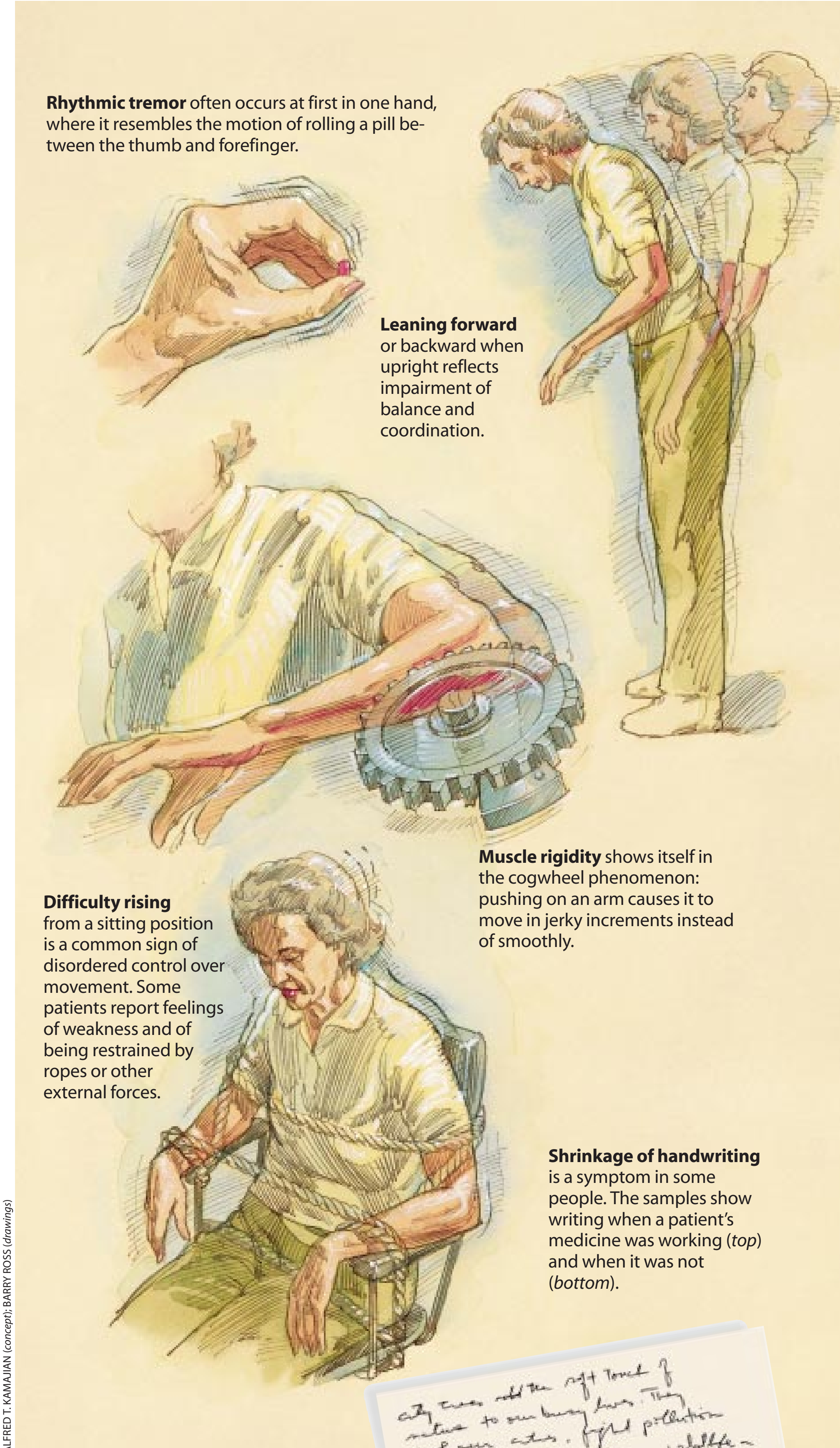
Selegiline has some very appealing properties, although it, too, falls short of ideal. For example, it augments the effects of L-dopa and allows the dose of that drug to be reduced. It also sidesteps the dangers of related drugs that can block dopamine degradation. Such agents proved disastrous as therapies for depression, because they caused potentially lethal disturbances in patients who ate certain foods, such as cheese. In fact, we began exploring selegiline as a treatment for Parkinson's disease partly because studies in animals had implied it would avoid this so-called cheese effect.

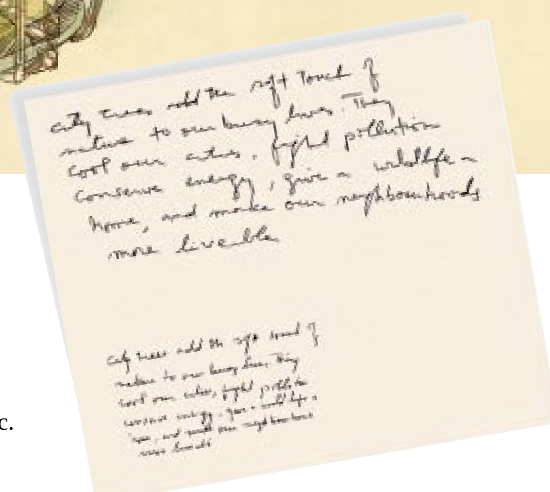
Tantalizingly, some of our early findings suggested that selegiline could protect people afflicted with Parkinson's disease from losing their remaining dopamine-producing neurons. A massive study carried out several years ago in the U.S. (known as DATATOP) was unable to confirm or deny this effect, but animal research continues to be highly supportive. Whether or not selegiline itself turns out to be protective, exploration of that possibility has already produced at least two important benefits. It has led to the development of new kinds of enzyme inhibitors as potential treatments not only for Parkinson's disease but also for Alzheimer's disease and depression. And the work has altered the aims of many who study Parkinson's disease, causing them to seek new therapies aimed at treating the underlying causes instead of at merely increasing the level or activity of dopamine in the striatum (approaches that relieve symptoms but do not prevent neurons from degenerating).

### Key Role for Free Radicals

Of course, the best way to preserve neurons is to halt one or more key steps in the sequence of events that culminates in their destruction—if those events can be discerned. In the case of Parkinson's disease, the collected evidence strongly implies (though does not yet prove) that the neurons that die are, to a great extent, doomed by the excessive accumulation of highly reactive molecules known as oxygen free radicals. Free radicals are destructive because they lack an electron. This state makes them prone to snatching electrons from other molecules, a process known as oxidation. Oxidation is what rusts metal and spoils butter. In the body the radicals are akin to biological bullets, in that they can injure whatever they hit—be it fatty cell membranes, genetic material or critical proteins. Equally disturbing, by taking electrons from other molecules, one free radical often creates many others, thus amplifying the destruction.

The notion that oxidation could help account for Parkinson's disease was first put forward in the early 1970s by Gerald Cohen and the late Richard E. Heikkila of the Mount Sinai School of





ALFRED T. KAMAJIAN (*concept*); BARRY ROSS (*drawings*)

**COMMON SYMPTOMS of Parkinson's disease include tremor, muscle rigidity and bradykinesia—slowing of movement and loss of spontaneous motion. Disorders of balance and changes in handwriting may also be seen.**

**DAMAGE TO BRAIN TISSUE can be strikingly evident in samples from people who died with Parkinson's disease. Dopamine-producing cells (*brown ovals*), visible in the substantia nigra of a healthy brain (*left*), are virtually absent in a specimen from an afflicted individual (*center*). And cells that survive often harbor a distinctive sign that the disease was at work (*right*): abnormal structures known as Lewy bodies (*pink spheres*).**

DANIEL P. PERL *Mount Sinai School of Medicine*

Medicine. Studies by others had shown that a synthetic toxin sometimes used in scientific experiments could cause parkinsonian symptoms in animals and that it worked by inducing the death of dopamine-producing neurons in the substantia nigra. Cohen and Heikkila discovered that the drug poisoned the neurons by inducing formation of at least two types of free radicals.

Some of the most direct proof that free radicals are involved in Parkinson's disease comes from examination of the brains of patients who died from the disorder. We and others have looked for "fingerprints" of free radical activity in the substantia nigra, measuring the levels of specific chemical changes the radicals are known to effect in cellular components. Many of these markers are highly altered in the brains of Parkinson's patients. For instance, we found a significant increase in the levels of compounds that form when fatty components of cell membranes are oxidized.

Circumstantial evidence is abundant as well. The part of the substantia nigra that deteriorates in Parkinson's patients contains above-normal levels of substances that promote free radical formation. (A notable example, which we have studied intensively, is iron.) At the same time, the brain tissue contains unusually low levels of antioxidants, molecules involved in neutralizing free radicals or preventing their formation.

Researchers have also seen a decline in the activity of an enzyme known as complex I in the mitochondria of the affected neurons. Mitochondria are the power plants of cells, and complex I is part of the machinery by which mitochondria generate the energy required by cells. Cells use the energy for many purposes, including ejecting calcium and other ions that can facilitate oxidative reactions. When complex I is faulty, energy production drops, free radical levels rise, and the levels of some antioxidants fall—all of which can combine to increase oxidation and exacerbate any other cellular malfunctions caused by an energy shortage.

## Early Clues from Addicts

What sequence of events might account for oxidative damage and related changes in the brains of people who suffer from Parkinson's disease? Several ideas have been proposed. One of the earliest grew out of research following up on what has been called "The Case of the Frozen Addicts."

In 1982 J. William Langston, a neurologist at Stanford University, was astonished to encounter several heroin addicts who had suddenly become almost completely immobile after taking the drug. It was as if they had developed severe Parkinson's disease overnight. While he was exploring how the heroin might have produced this effect, a toxicologist pointed him to an earlier, obscure report on a similar case in Bethesda, Md. In that instance, a medical student who was also a drug abuser had become paralyzed by a homemade batch of meperidine (Demerol) that was found, by Irwin J. Kopin and Sanford P. Markey of the NIH, to contain an impurity called MPTP. This preparation had destroyed dopamine-making cells of his substantia nigra. Langston, who learned that the drug taken by his patients also contained MPTP, deduced that the impurity accounted for the parkinsonism of the addicts.

His hunch proved correct and raised the possibility that a more common substance related to MPTP was the triggering cause in classical cases of Parkinson's disease. Since then, exploration of how MPTP damages dopamine-rich neurons has expanded understanding of the disease process in general and has uncovered at least one pathway by which a toxin could cause the disease.

Scientists now know that MPTP would be harmless if it were not altered by the body. It becomes dangerous after passing into the brain and being taken up by astrocytes and microglia. These cells feed the drug into their mitochondria, where it is converted (by monoamine oxidase B) to a more reactive molecule and then released to do mischief in dopamine-making neurons of the substantia nigra. Part of this understanding comes from study in monkeys of selegiline, the monoamine oxidase B inhibitor. By preventing MPTP from being altered, the drug protects the animals from parkinsonism.

In the absence of a protective agent, altered MPTP will enter nigral neurons, pass into their mitochondria and inhibit the complex I enzyme. This action will result, as noted earlier, in an energy deficit, an increase in free radical production and a decrease in antioxidant activity—and, in turn, in oxidative damage of the neurons.

In theory, then, an MPTP-like chemical made naturally by some people or taken up from the environment could cause Parkinson's disease through a similar process. Many workers have sought such chemicals with little success. Most recently, for instance, brain chemicals known as beta carbolines have attracted much attention as candidate neuro-

**CASCADE OF CELLULAR REACTIONS (*thick arrows*) that might explain the neuronal damage seen in Parkinson's disease begins when some unknown signal (*top*) causes immune cells of the brain (microglia) to become overactive. Other as yet unidentified triggers (*blue question marks*), such as ones that overstimulate glutamate release (*far right*), could well initiate many of the same reactions (*blue arrows*). It is conceivable that Parkinson's disease sometimes results from one sequence depicted here but at other times from a combination of processes.**

toxins, but their levels in the brains of Parkinson's patients appear to be too low to account for the disease. Given that years of study have not yet linked any known toxin to the standard form of Parkinson's disease, other theories may more accurately describe the events that result in excessive oxidation in patients with this disorder.

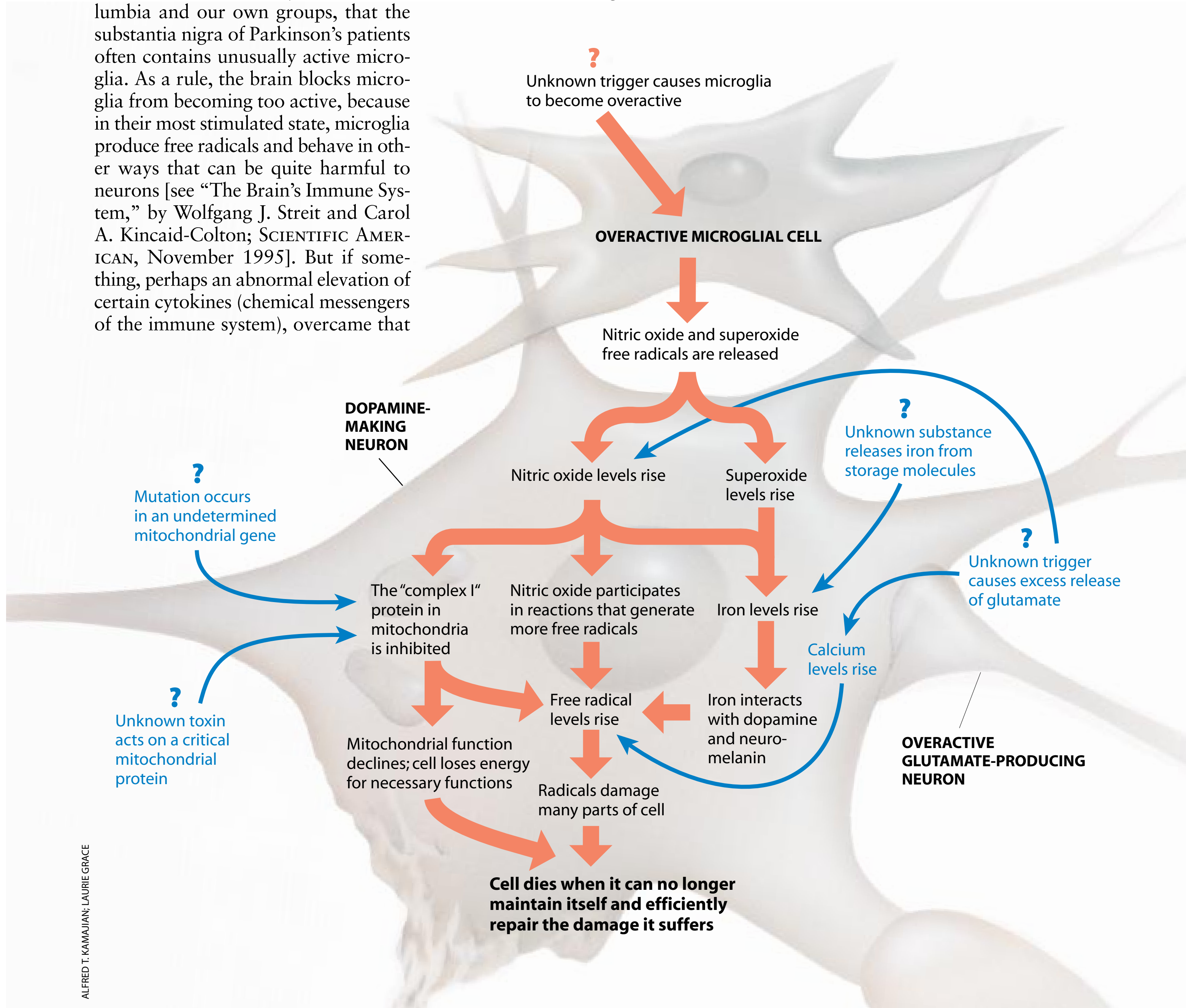
### Are Immune Cells Overactive?

Another hypothesis that makes a great deal of sense places microglia—the brain's immune cells—high up in the destructive pathway. This concept derives in part from the discovery, by Patrick L. McGeer of the University of British Columbia and our own groups, that the substantia nigra of Parkinson's patients often contains unusually active microglia. As a rule, the brain blocks microglia from becoming too active, because in their most stimulated state, microglia produce free radicals and behave in other ways that can be quite harmful to neurons [see "The Brain's Immune System," by Wolfgang J. Streit and Carol A. Kincaid-Colton; Scientific American, November 1995]. But if something, perhaps an abnormal elevation of certain cytokines (chemical messengers of the immune system), overcame that restraint in the substantia nigra, neurons there could well be hurt.

Studies of dopamine-making neurons conducted by a number of laboratories have recently converged with research on microglia to suggest various ways that activated microglia in the substantia nigra could lead to oxidative damage in neurons of the region. Most of these ways involve production of the free radical nitric oxide.

For example, overactive microglia are known to produce nitric oxide, which can escape from the cells, enter nearby neurons and participate in reactions that generate other radicals; these various radicals can then disrupt internal structures [see "Biological Roles of Nitric Oxide," by Solomon H. Snyder and David S. Bredt; Scientific American, May 1992]. Further, nitric oxide itself is able to inhibit the complex I enzyme in mitochondria; it can thus give rise to the same oxidative injury that an MPTP-like toxin could produce.

If these actions of nitric oxide were not devastating enough, we have found that both nitric oxide and another free radical (superoxide) emitted by overactive microglia can free iron from storehouses in the brain—thereby triggering additional oxidative cascades. We have also demonstrated that iron, regardless of its source, can react with dopamine and its derivatives in at least two ways that can further increase free radical




ALFRED T. KAMAJIAN; LAURIE GRACE

levels in dopamine-synthesizing cells.

In one set of reactions, iron helps dopamine to oxidize itself. Oxidation of dopamine converts the molecule into a new substance that nigral cells use to construct their dark pigment, neuromelanin. When iron levels are low, neuromelanin serves as an antioxidant. But it becomes an oxidant itself and contributes to the formation of free radicals when it is bound by transition metals, especially iron. In support of the possibility that the interaction of iron and neuromelanin contributes to Parkinson's disease, we and our colleagues have shown that the pigment is highly decorated with iron in brains of patients who died from the disease; in contrast, the pigment lacks iron in brains of similar individuals who died from other causes.

In the other set of dopamine-related reactions, iron disrupts the normal sequence by which the neurotransmitter is broken down to inert chemicals. Neurons and microglia usually convert dopamine to an inactive substance and hydrogen peroxide, the latter of which becomes water. When iron is abundant, though, the hydrogen peroxide is instead broken down into molecular oxygen and a free radical. Dopamine's ability to promote free radical synthesis may help explain why dopamine-making neurons are particularly susceptible to dying from oxidation. This ability has also contributed to suspicion that L-dopa, which increases dopamine levels and eases symptoms, may, ironically, damage nigral neurons. Scientists are hotly debating this topic, although we suspect the concern is overblown.

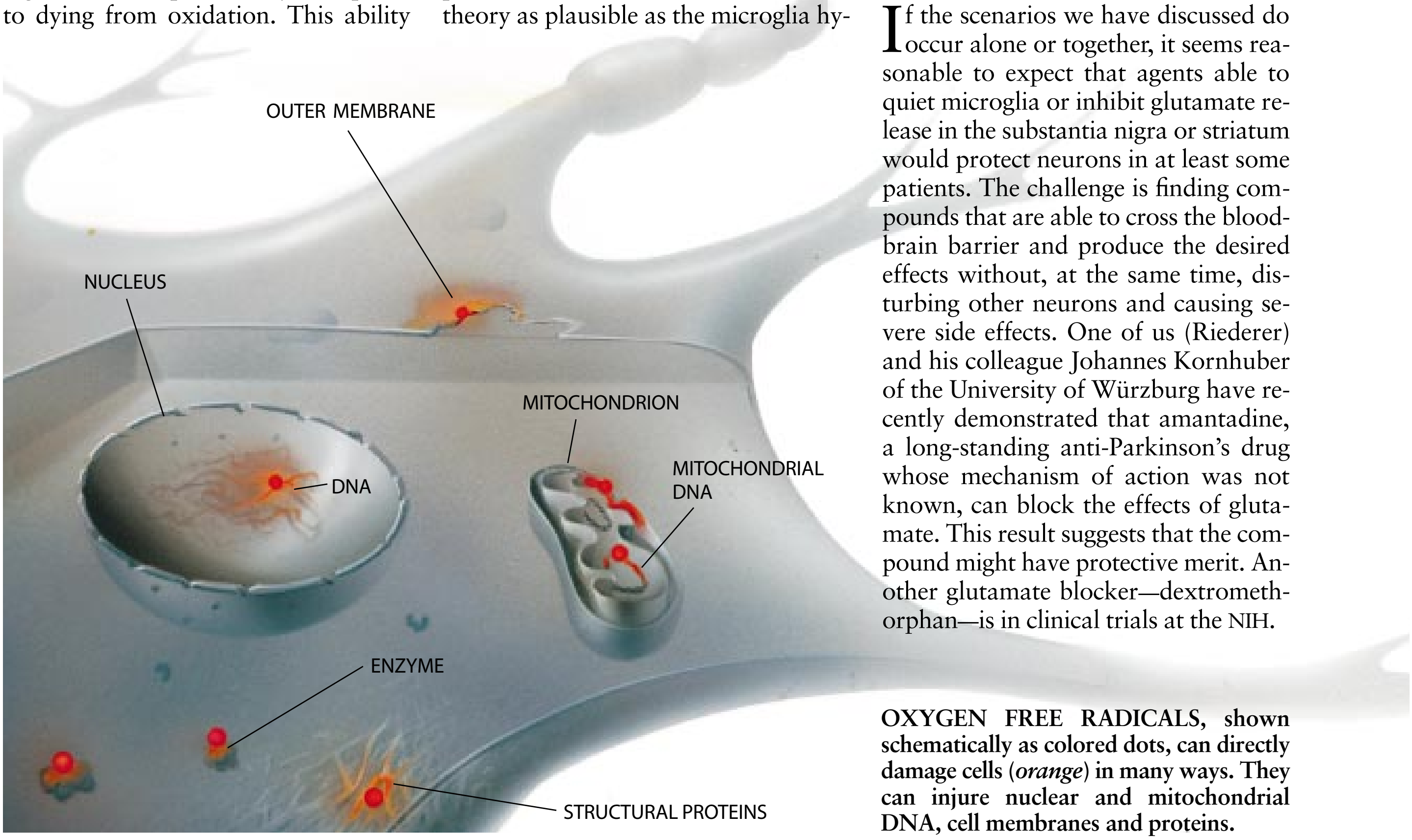
In brief, then, overactive microglia could engender the oxidative death of dopamine-producing neurons in the substantia nigra by producing nitric oxide, thereby triggering several destructive sequences of reactions. And iron released by the nitric oxide or other free radicals in the region could exacerbate the destruction. As we have noted, brain cells do possess molecules capable of neutralizing free radicals. They also contain enzymes that can repair oxidative damage. But the protective systems are less extensive than those elsewhere in the body and, in any case, are apparently ill equipped to keep up with an abnormally large onslaught of oxidants. Consequently, if the processes we have described were set off in the substantia nigra, one would expect to see ever more neurons fade from the region over time, until finally the symptoms of Parkinson's disease appeared and worsened.

Actually, any trigger able to induce an increase in nitric oxide production or iron release or a decrease in complex I activity in the substantia nigra would promote Parkinson's disease. Indeed, a theory as plausible as the microglia hypothesis holds that excessive release of the neurotransmitter glutamate by neurons feeding into the striatum and substantia nigra could stimulate nitric oxide production and iron release. Excessive glutamate activity could thus set off the same destructive cascade hypothetically induced by hyperactive microglia. Overactive glutamate release has been implicated in other brain disorders, such as stroke. No one yet knows whether glutamate-producing neurons are overactive in Parkinson's disease, but circumstantial evidence implies they are.

Other questions remain as well. Researchers are still in the dark as to whether Parkinson's disease can arise by different pathways in different individuals. Just as the engine of a car can fail through any number of routes, a variety of processes could presumably lead to oxidative or other damage to neurons of the substantia nigra. We also have few clues to the initial causes of Parkinson's disease—such as triggers that might, say, elevate cytokine levels or cause glutamate-emitting cells to be hyperactive. In spite of the holes, ongoing research has suggested intriguing ideas for new therapies aimed at blocking oxidation or protecting neurons in other ways.

### Therapeutic Options

If the scenarios we have discussed do occur alone or together, it seems reasonable to expect that agents able to quiet microglia or inhibit glutamate release in the substantia nigra or striatum would protect neurons in at least some patients. The challenge is finding compounds that are able to cross the blood-brain barrier and produce the desired effects without, at the same time, disturbing other neurons and causing severe side effects. One of us (Riederer) and his colleague Johannes Kornhuber of the University of Würzburg have recently demonstrated that amantadine, a long-standing anti-Parkinson's drug whose mechanism of action was not known, can block the effects of glutamate. This result suggests that the compound might have protective merit. Another glutamate blocker—dextromethorphan—is in clinical trials at the NIH.




**OXYGEN FREE RADICALS, shown schematically as colored dots, can directly damage cells (*orange*) in many ways. They can injure nuclear and mitochondrial DNA, cell membranes and proteins.**

Drugs could also be protective if they halted other events set in motion by the initial triggers of destruction. Iron chelators (which segregate iron and thus block many oxidative reactions), inhibitors of nitric oxide formation and antioxidants are all being considered. Such agents have been shown to protect dopamine-producing neurons of the substantia nigra from oxidative death in animals. On the other hand, the same human DATATOP trial that cast doubt on selegiline's protective effects found that vitamin E, an antioxidant, was ineffective. But vitamin E may have failed because very little of it crosses the blood-brain barrier or because the doses tested were too low. Antioxidants that can reach the brain deserve study; at least one such compound is in clinical trials at the NIH.

PHOTOGRAPH BY RUSS LEE in *The Case of the Frozen Addicts*, © Pantheon Books, 1995

**SO-CALLED FROZEN ADDICTS posed together in 1991, after having received treatment. Nine years earlier all suddenly became immobile, as if they had instantly acquired Parkinson's disease, after taking an impure version of a narcotic. Studies of how an impurity in the drug led to the freezing has generated many insights into the biochemical reactions that could contribute to a more classical presentation of the disease.**

Regardless of the cause of the neuronal destruction, drugs that were able to promote regeneration of lost neurons would probably be helpful as well. Studies of animals suggest that such substances could, indeed, be effective in the human brain. Researchers at several American facilities are now testing putting a molecule called glial-derived neurotrophic factor (GDNF) directly into the brain of patients. Efforts are also under way to find smaller molecules that can be delivered more conveniently (via pill or injection) yet would still activate neuronal growth factors and neuronal growth in the brain. One agent, Rasagiline, has shown promise in animal trials and is now being tested in humans. Some studies imply that the nicotine in tobacco might have a protective effect, and nicotinelike drugs are being studied in the laboratory as potential therapies. Patients, however, would be foolish to take up smoking to try to slow disease progression. Data on the value of smoking to retard the death of dopamine neurons are equivocal, and the risks of smoking undoubtedly far outweigh any hypothetical benefit.

As work on protecting neurons advances, so does research into compensating for their decline. One approach being perfected is the implantation of dopamine-producing cells. Some patients have been helped. But the results are variable, and cells available for transplantation are in short supply. Further, the same processes that destroyed the original brain cells may well destroy the implants. Other approaches include surgically destroying parts of the brain that function abnormally when dopamine is lost. This surgery was once unsafe but is now being done more successfully.

The true aim of therapy for Parkinson's disease must ultimately be to identify the disease process long before symptoms arise, so that therapy can be given in time to forestall the brain destruction that underlies patients' discomfort and disability. No one can say when early detection and neural protection will become a reality, but we would not be surprised to see great strides made on both fronts within a few years. In any case, researchers cannot rest easy until those dual objectives are met. SA

*To obtain high-quality reprints of this article, please see page 105.*

## *The Authors*

MOUSSA B. H. YOUDIM and PETER RIEDERER have collaborated since 1974. Youdim, a pioneer in the development of monoamine oxidase inhibitors for the treatment of Parkinson's disease and depression, is professor of pharmacology at Technion-Israel Institute of Technology in Haifa, Israel. He is also director of the Eve Topf and U.S. National Parkinson's Disease Foundation's Centers of Excellence for Neurodegenerative Diseases, both at Technion, and a Fogarty Scholar in Residence at the U.S. National Institutes of Health, where he spends three months every year. Riederer heads the Laboratory of Clinical Neurochemistry and is professor of clinical neurochemistry at the University of Würzburg in Germany. The authors shared the Claudius Galenus Gold Medal for the development of the anti-Parkinson's drug selegiline.

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# Tackling Turbulence with Supercomputers

*Computers only recently became powerful enough to illuminate simple examples of this great classical problem. In some cases, they will let engineers control it*

by Parviz Moin and John Kim

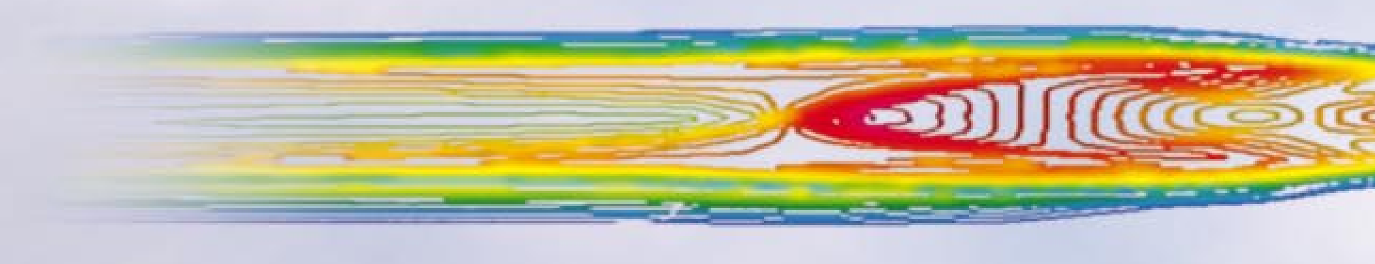
We all pass through life surrounded—and even sustained—by the flow of fluids. Blood moves through the vessels in our bodies, and air (a fluid, properly speaking) flows into our lungs. Our vehicles move through our planet's blanket of air or across its lakes and seas, powered by still other fluids, such as fuel and oxidizer, that mix in the combustion chambers of engines. Indeed, many of the environmental or energy-related issues we face today cannot possibly be confronted without detailed knowledge of the mechanics of fluids.

Practically all the fluid flows that interest scientists and engineers are turbulent ones; turbulence is the rule, not the exception, in fluid dynamics. A solid grasp of turbulence, for example, can allow engineers to reduce the aerodynamic drag on an automobile or a commercial airliner, increase the maneuverability of a jet fighter or improve the fuel efficiency of an engine. An understanding of turbulence is also necessary to comprehend the flow of blood in the heart, especially in the left ventricle, where the movement is particularly swift.

But what exactly is turbulence? A few everyday examples may be illuminating. Open a kitchen tap only a bit, and the water that flows from the faucet will be smooth and glassy. This flow is known as laminar. Open the tap a little further, and the flow becomes more roiled and sinuous—turbulent, in other words. The same phenomenon can be seen in the smoke streaming upward into still air from a burning cigarette. Immediately above the cigarette, the flow is laminar. A little higher up, it becomes rippled and diffusive.

Turbulence is composed of eddies: patches of zigzagging, often swirling fluid, moving randomly around and about the overall direction of motion. Technically, the chaotic state of fluid motion arises when the speed of the fluid exceeds a specific threshold, below which viscous forces damp out the chaotic behavior.

Turbulence, however, is not simply an unfortunate phenomenon to be eliminated at every opportunity. Far from it: many engineers work hard trying to increase it. In the cylinders of an internal-combustion engine, for example, turbulence enhances the mixing of fuel and oxidizer and produces cleaner, more ef-



**SPACE SHUTTLE SIMULATION was combined with a photograph of the shuttle for reference. In the bottom half of the image, different colors indicate air-pressure values at the vehicle's surface, from blue (low pressure) to red (high).**

ficient combustion. And only turbulence can explain why a golf ball's dimples enable a skilled golfer to drive the ball 250 meters, rather than 100 at most.

Turbulence may have gotten its bad reputation because dealing with it mathematically is one of the most notoriously thorny problems of classical physics. For a phenomenon that is literally ubiquitous, remarkably little of a quantitative nature is known about it. Richard Feynman, the great Nobel Prize–winning physicist, called turbulence "the most important unsolved problem of classical physics." Its difficulty was wittily expressed in 1932 by the British physicist Horace Lamb, who, in an address to the British Association for the Advancement of Science, reportedly said, "I am an old man now, and when I die and go to heaven there are two matters on which I hope for enlightenment. One is quantum electrodynamics, and the other is the turbulent motion of fluids. And about the former I am rather optimistic."

Of course, Lamb could not have foreseen the development of the modern supercomputer. These technological marvels are at last making it possible for engineers and scientists to gain fleeting but valuable insights into turbulence. Already this work has led to technology, now in development, that may someday be employed on airplane wings to reduce drag by several percent—enough to save untold billions of dollars in fuel costs. At the same time, these insights are guiding the design of jet engines to improve both efficiency and performance.

As recondite as it is, the study of turbulence is a major component of the larger field of fluid dynamics, which deals with the motion of all liquids and gases. Similarly, the application of powerful computers to simulate and study fluid flows that happen to be turbulent is a large part of the burgeoning field of computational fluid dynamics (CFD). In recent years, fluid dynamicists have used supercomputers to simulate flows in such diverse cases as the America's Cup racing yachts and blood movement through an artificial heart.

## CFD: 150 Years in the Making

What do we mean when we speak of simulating a fluid flow on a computer? In simplest terms, the computer solves a series of well-known equations that are used to compute, for any point in space near an object, the velocity and pressure of the fluid flowing around that object. These equations were discovered independently more than a century and a half ago by the French engineer Claude Navier and the Irish mathematician George Stokes. The equations, which derive directly from Newton's laws of motion, are known as the Navier-Stokes equations. It was the application of supercomputers to these equations that gave rise to the field of computational fluid dynamics; this marriage has been one of the greatest achievements in fluid dynamics since the equations themselves were formulated.

Although the marriage has been successful, the courtship was a rather long one. Not until the late 1960s did supercomputers begin achieving processing rates fast enough to solve the Navier-Stokes equations for some fairly straightforward cases, such as two-dimensional, slowly moving flows about an obstacle. Before then, wind tunnels were essentially the only way of testing the aerodynamics of new aircraft designs. Even today the limits of the most powerful supercomputers still make it necessary to resort to wind tunnels to verify the design for a new airplane.

Although both computational fluid dynamics and wind tunnels are now used for aircraft development, continued advances in computer technology and algorithms are giving CFD a bigger share of the process. This is particularly true in the early design stages, when engineers are establishing key dimensions and other basic parameters of the aircraft. Trial and error dominate this process, and wind-tunnel testing is very expensive, requiring designers to build and test each successive model. Because of the increased role of computational fluid dynamics, a typical design cycle now involves between two and four wind-tunnel tests of wing models instead of the 10 to 15 that were once the norm.

Another advantage of supercomputer simulations is, ironically, their ability to simulate more realistic flight conditions. Wind-tunnel tests can be contaminated by the influence of the tunnel's walls and the structure that holds the model in

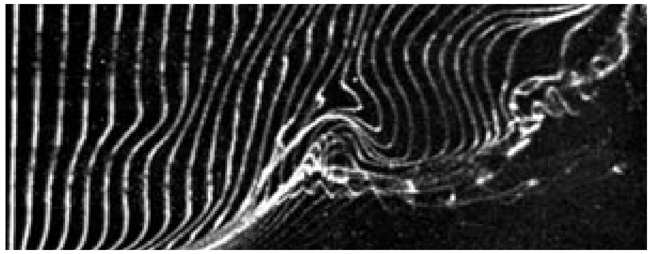

ROGER RESSMEYER *Corbis* (*photograph*); PIETER BUNING (*simulation*); SLIM FILMS (*digital montage*)

## A Simulation Milestone

Until around 1980, few researchers attempted to simulate even very simple turbulent flows in their entirety. That year we and our co-workers at the NASA Ames Research Center used a pioneering parallel computer, the ILLIAC-IV, to perform the largest turbulence simulations achieved until then. The work was well received; soberingly enough, however, it was not the quality of the data that won over many of our colleagues but rather a five-minute motion picture of the simulated flow. The movie showed trajectories of marker particles in a turbulent flow between parallel plates (*left*); remarkably, it resembled similar visualizations made two decades earlier, by filming actual water flow in a laboratory at Stanford University (*right*). —*P.M. and J.K.*

PARVIZ MOIN AND JOHN KIM



STEVEN KLINE

place. Some of the flight vehicles of the future will fly at many times the speed of sound and under conditions too extreme for wind-tunnel testing. For hypersonic aircraft (those that will fly at up to 20 times the speed of sound) and spacecraft that fly both within and beyond the atmosphere, computational fluid dynamics is the only viable tool for design. For these vehicles, which pass through the thin, uppermost levels of the atmosphere, nonequilibrium air chemistry and molecular physics must be taken into account.

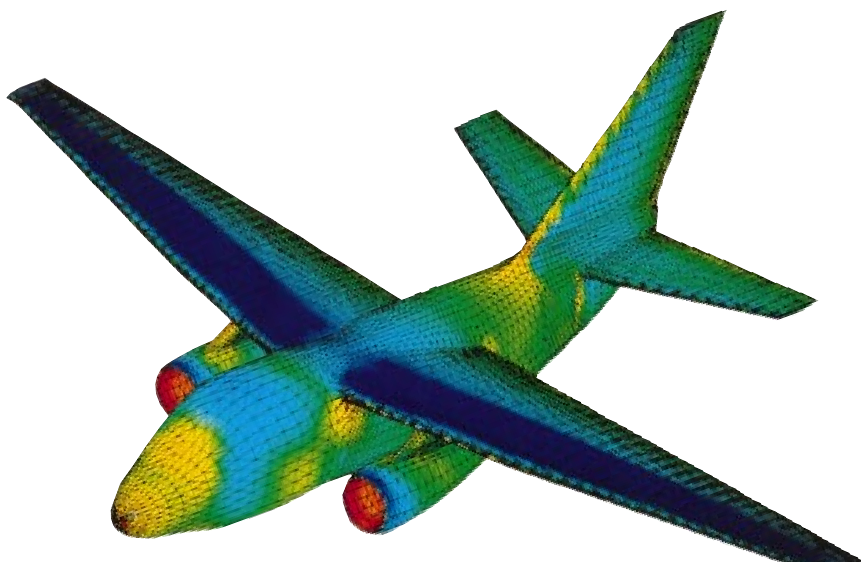
Engine designers also rely extensively on computational techniques, particularly in the development of jet engines. A program called Integrated High Performance Turbine Engine Technology is seeking a 100 percent improvement in the thrust-to-weight ratio of jet engines and a 40 percent improvement in fuel efficiency by 2003. The project is supported by the U.S. Department of Defense, the National Aeronautics and Space Administration and various makers of jet engines.

The flow of air and fuel through a jet engine's various sections and passages is complex. A fan draws air into an internal chamber called a compressor. There multiple rotating and stationary stages increase the pressure about 20-fold. This high-pressure air is fed into a combustor, where it mixes with fuel and is ignited. Finally, the hot, very expanded exhaust drives a turbine. This turbine powers the fan and the compressor and, more important, generates thrust by directing the exhaust out of the rear of the engine at high velocity. Currently engineers use computational fluid dynamics to design turbine blades, inlet passages and the geometry of combustors. Simulations also help engineers shape the afterburner mixers that, in military aircraft, provide additional thrust for greater maneuverability. And they play a role in designing nacelles, the bulbous, cylindrical engine casings that typically hang below the wings.

### Applying the Equations

To understand how the Navier-Stokes equations work, consider the flow of air over an airplane in flight. In reality, it will probably be many decades before computers are powerful enough to simulate in a detailed manner the fluid flows over an entire airplane. In theory, however, the Navier-Stokes equations can reveal the velocity and pressure of the air rushing by any point near the aircraft's surface. Engineers could then use these data to compute, for various flight conditions, all aerodynamic parameters of interest—namely, the lift, drag and moments (twisting forces) exerted on the airplane.

Drag is particularly important because it determines an aircraft's fuel efficiency. Fuel is one of the largest operating expenses for most airlines. Not surprising-



ANTONY JAMESON

**AIR PRESSURE over a Lockheed S-3A airplane in flight is highest near the craft's nose and inside the engine nacelles, which are below the wings. The grid visible on the surface of the image above is the computational mesh; a value of the air pressure was computed for each point at which grid lines intersect. Such simulations are critical means of**

ly, aircraft companies have spent huge sums to reduce drag by even tiny increments. In general, though, lift is relatively easy to calculate, moments are harder, and drag is hardest of all.

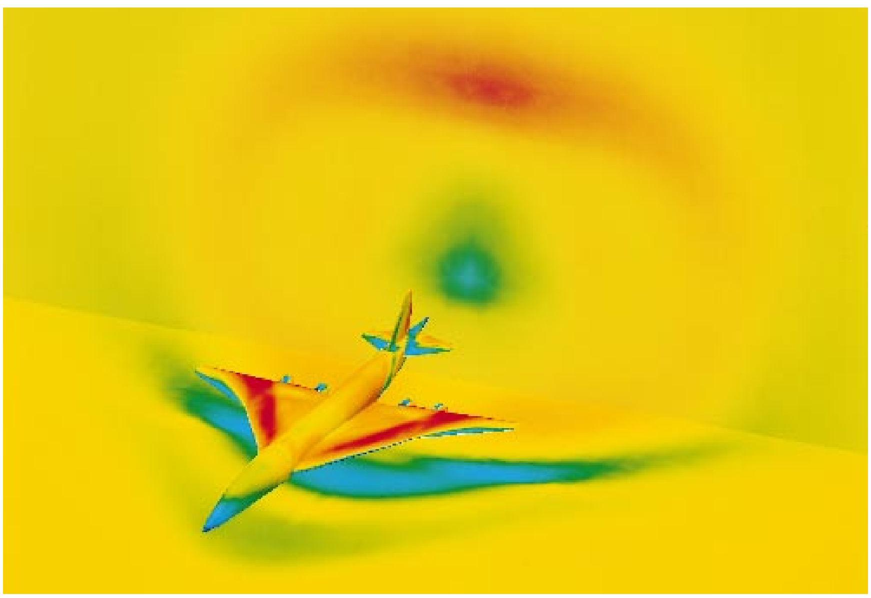
Drag is difficult to compute mainly because it is the parameter most dependent on turbulence. Of course, in this context we are not referring to the bumpiness that provokes the pilot to remind passengers to fasten their seat belts. Even when a plane is flying smoothly, the flow of air within a few centimeters of its surface, in a volume known as the boundary layer, is turbulent. Because of turbulence, the high-speed air several millimeters above the surface of the wings is brought very close to the surface, where it undergoes a more abrupt—and momentum-robbing—deceleration. The equal and opposite reaction to this flow deceleration is drag on the aircraft. A great deal of the work of aerodynamicists involves understanding the mechanics of the generation and destruction of turbulence well enough to control it.

To solve the Navier-Stokes equations, engineers start by entering into the equations certain variables known as initial and boundary conditions. For an airplane in flight, the initial conditions include wind velocity and atmospheric disturbances, such as air currents. The boundary conditions include the precise shape of the aircraft, translated into mathematical coordinates.

Before the equations can be applied to an aircraft, computer specialists must represent the aircraft's surface and the space around it in a form usable by the computer. So they represent the airplane and its surroundings as a series of regularly spaced points, known as a computational grid. They then supply the coordinates and related parameters of the grid to the software that applies the Navier-Stokes equations to the data. The computer calculates a value for the parameters of interest—air velocity and pressure—for each of the grid points.

In effect, the computational grid breaks up (the technical term is "discretizes") the computational problem in space; the calculations are carried out at regular intervals to simulate the passage of time, so the simulation is temporally discrete as well. The closer together—and therefore more numerous—the points are in the computational grid, and the more often they are computed (the shorter the time interval), the more accurate and realistic the simulation is. In fact, for objects with complex shapes, even defining the surface and generating a computational grid can be a challenge.

Unfortunately, entering the initial and boundary conditions does not guarantee a solution, at least not with the computers available today or in the foreseeable future. The difficulty arises from the fact that the Navier-Stokes equations are nonlinear; in other words, the many variables in the equations vary with respect to one another by powers of two or greater. Interaction of these nonlinear variables generates a broad range of scales, which can make solving the equations exceedingly difficult. Specifically, in turbulence, the range of the size of whirling eddies can vary 1,000-fold or even more. There are other complicating factors as well, such as global dependence: the nature of the equations is that the fluid pressure at one point depends on the flow at many other points. Because the different parts of the problem are so interrelated, solutions must be obtained at many points simultaneously.



ANTONY JAMESON

**verifying designs for supersonic (*above*) and hypersonic aircraft, for which wind-tunnel testing is impossible. The simulation of this supersonic aircraft design also shows the sonic boom, visible as a circle behind the vehicle. Such booms are a major issue in ongoing studies of whether the public will accept these aircraft.**

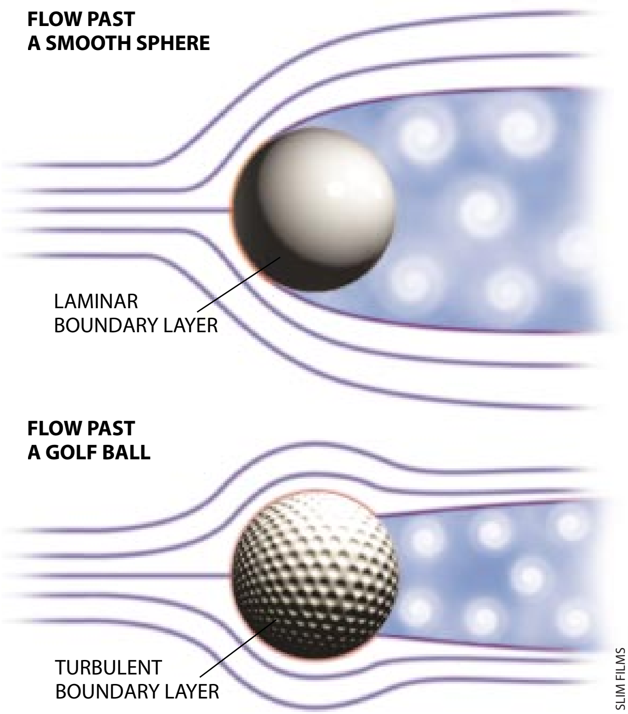
### Computational Bête Noir

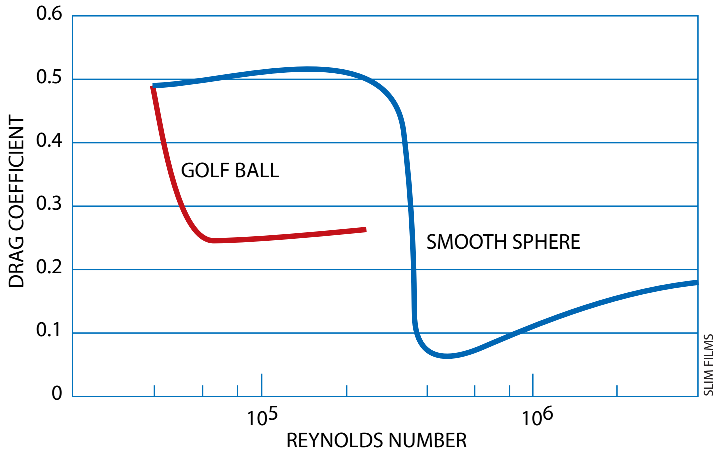
Although the preceding description conveys the basics of a fluid dynamics simulation, it leaves out turbulence, without which a realistic discussion of the capabilities—and limitations—of computational fluid dynamics would be futile. The complexities engendered by turbulence severely limit our ability to simulate fluid flow realistically.

Perhaps the simplest way to define turbulence is by reference to the Reynolds number, a parameter that compactly characterizes a flow. Named after the British engineer Osborne Reynolds, this number indicates the ratio, or relative importance, of the flow's inertial forces to its viscous ones. (A flow's inertial force is calculated by multiplying together the fluid's density and the square of its velocity and dividing this product by a characteristic length of the flow, such as the width of the airfoil, if the flow is over a wing.)

Large inertial forces, relative to the viscous ones, tend to favor turbulence, whereas high viscosity staves it off. Put another way, turbulence occurs when the Reynolds number exceeds a certain value. The number is proportional to both the size of the object and the flow velocity. For example, the Reynolds number for air flowing over the fuselage of a cruising commercial aircraft is in the neighborhood of 100 million. For the air flowing past a good fastball, the Reynolds number is about 200,000. For blood flowing in a midsize artery, it is about 1,000.

As we have seen, a distinguishing characteristic of a turbulent flow is that it is composed of eddies, also known as vortices, in a broad range of sizes. These vortices are continually forming and breaking down. Large eddies break down into smaller ones, which break down into yet smaller eddies, and so on.




**DRAG ON A GOLF BALL comes mainly from air-pressure forces. This drag arises when the pressure in front of the ball is significantly higher than that behind the ball. The only practical way of reducing this differential is to design the ball so that the main stream of air flowing by it is as close to the surface as possible. This situation is achieved by a golf ball's dimples, which augment the turbulence very close to the surface, bringing the high-speed airstream closer and increasing the pressure behind the ball. The effect is plotted in the chart, which shows that for Reynolds numbers achievable by hitting the ball with a club, the coefficient of drag is much lower for the dimpled ball.**

When eddies become small enough, they simply dissipate viscously into heat. The British meteorologist Lewis F. Richardson described this process in verse:

Big whorls have little whorls,
Which feed on their velocity,
And little whorls have lesser whorls,
And so on to viscosity.

To solve the Navier-Stokes equations for, say, the flow over an airplane requires a finely spaced computational grid to resolve the smallest eddies. On the other hand, the grid must be large enough to encompass the entire airplane and some of the space around it. The disparity of length scales in a turbulent flow—the ratio of largest to smallest eddy size—can be calculated by raising the flow's Reynolds number to the $^3/_4$ power. This ratio can be used to estimate the number of grid points that are needed for a reasonably accurate simulation: because there are three dimensions, the number is proportional to the cube of this ratio of length scales. Thus, the required number of grid points for a numerical simulation is proportional to the Reynolds number raised to the $^9/_4$ power. In other words, doubling the Reynolds number results in almost a fivefold increase in the number of points required in the grid to simulate the flow.

Consider a transport airplane with a 50-meter-long fuselage and wings with a chord length (the distance from the leading to the trailing edge) of about five meters. If the craft is cruising at 250 meters per second at an altitude of 10,000 meters, about 10 quadrillion ($10^{16}$) grid points are required to simulate the turbulence near the surface with reasonable detail.

What kind of computational demands does this number of points impose? A rough estimate, based on current algorithms and software, indicates that even with a supercomputer capable of performing a trillion ($10^{12}$) floating-point operations per second, it would take several thousand years to compute the flow for one second of flight time! Such a "teraflops" computer does not yet exist, although researchers are now attempting to build one at Sandia National Laboratories. It will be about 10 times faster than the most powerful systems available today.

### Simulation Shortcuts

Fortunately, researchers need not simulate the flow over an entire aircraft to produce useful information. Indeed, doing so would probably generate much more data than we would know what to do with. Typically, fluid dynamicists care only about the effects of turbulence on quantities of engineering significance, such as the mean flow of a fluid or, in the case of an aircraft, the drag and lift forces and the transfer of heat. In the case of an engine, designers may be interested in the effects of turbulence on the rates at which fuel and oxidizer mix.

The Navier-Stokes equations are therefore often averaged over the scales of the turbulence fluctuations. What this means is that, in practice, researchers rarely calculate the motion of each and every small eddy. Instead they compute the large eddies and then use ad hoc modeling practices to estimate the effects of the small eddies on the larger ones. This practice gives rise to a simulated averaged flow field that is smoother than the actual flow—and thus drastically reduces the number of grid points necessary to simulate the field.

The ad hoc models that this averaging process demands range in complexity from simple enhanced coefficients of viscosity to entire additional systems of equations. All these models require some assumptions and contain adjustable coefficients that are derived from experiments. Therefore, at present, simulations of averaged turbulent flows are only as good as the models they contain.

As computers become more powerful, however, fluid dynamicists are finding that they can directly simulate greater proportions of turbulent eddies, enabling them to reduce the range of scales that are modeled. These approaches are a compromise between a direct numerical simulation of turbulence, in which all scales of motion are resolved, and the turbulence-averaged computations.

For years, meteorologists have used a form of this strategy called large-eddy simulation for weather prediction. In meteorology, the large-scale turbulent motions are of particular interest, so in meteorological applications the relatively large eddies are generally simulated in their entirety. Smaller-scale eddies are important only inasmuch as they may affect the larger-scale turbulence, so they are merely modeled. Recently engineers have begun using these techniques for simulating complex fluid flows, such as the gases inside a cylinder of an internal-combustion engine.

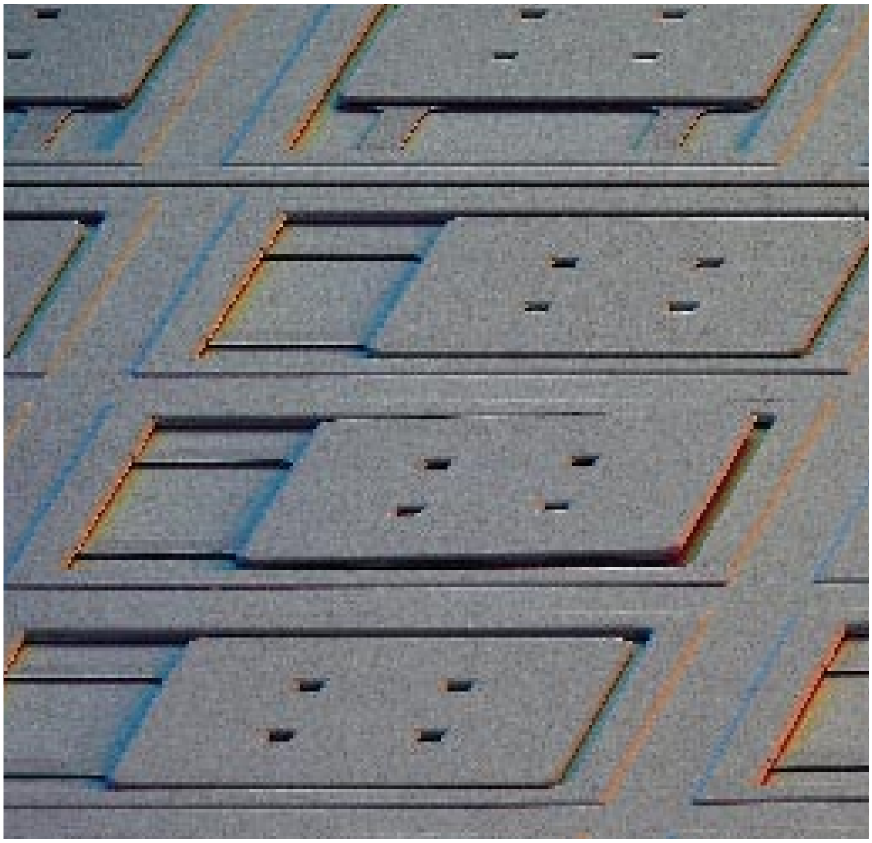
Another current trend in computational fluid dynamics, also made possible by increasing computational speed, is the direct, complete simulation of relatively simple flows, such as the flow in a pipe. Simple as they are, simulations of some of these flows, which have low Reynolds numbers, offer invaluable insights into the nature of turbulence. They have revealed the basic structure of turbulent eddies near a wall and subtleties of their influence on drag. They have also generated useful data that have enabled engineers to validate or fine-tune the ad hoc models they use in practical simulations of complex flows.

Lately the number of engineers and scientists seeking access to these data has swelled to the point that immense data sets have been archived and made available by the NASA Ames Research Center. Although most researchers do not have the computing resources to perform direct simulations of turbulence, they do have sufficient resources, such as powerful workstations, to probe the archived data.

### From Prediction to Control

As supercomputers become faster and faster, fluid dynamicists are increasingly able to move beyond predicting the effects of turbulence to actually controlling them. Such control can have enormous financial benefits; a 10 percent reduction in the drag of civilian aircraft, for example, could yield a 40 percent increase in the profit margin of an airline. In a recent project, researchers at the NASA Langley Research Center demonstrated that placing longitudinal V-shaped grooves, called riblets, on the surface of an aircraft's wing or fuselage leads to a 5 to 6 percent reduction in viscous drag. Drag is reduced despite the increase in the surface area exposed to the flow. For typical transport airplane speeds, the riblets must be very finely spaced, about 40 microns apart, like phonograph grooves; larger riblets tend to increase drag.

During this work, the researchers came across a Soviet study on toothlike structures, called denticles, on the skin of sharks. These denticles strikingly resembled riblets, a fact that has been interpreted as nature's endorsement of the riblet concept. Ultimately, however, it was the direct numerical simulation of turbulent flow along riblets that showed how they work. The riblets appear to inhibit the motion of eddies by preventing them from coming very close to the surface (within about 50 microns). By keeping the eddies this tiny distance



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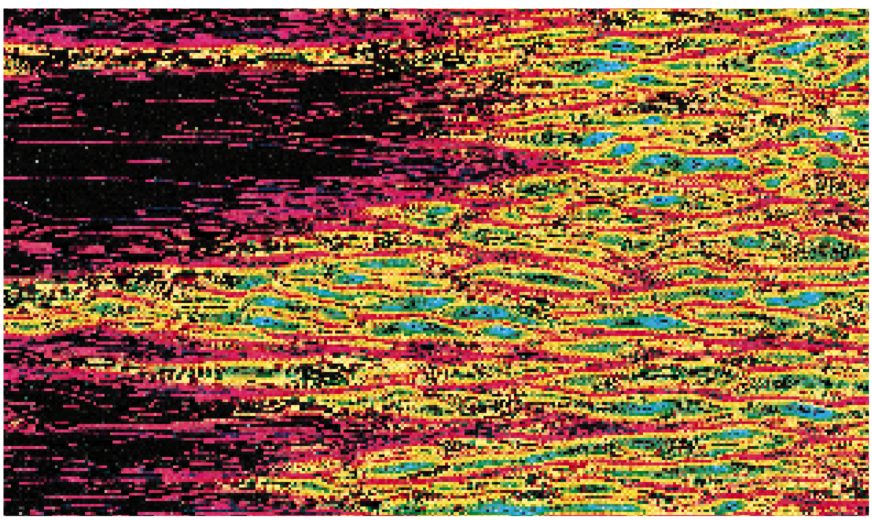
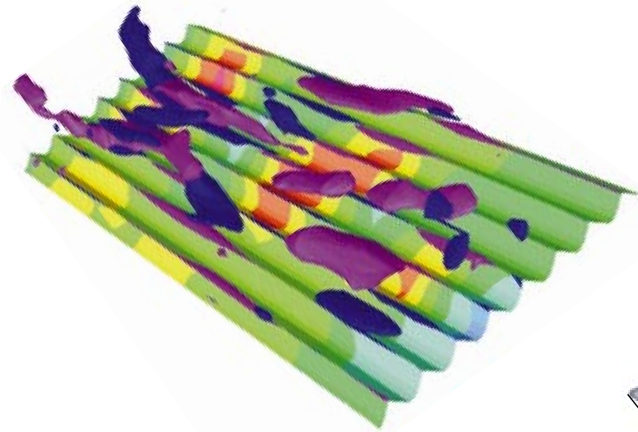
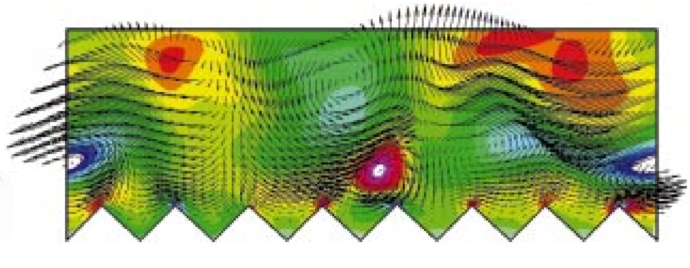


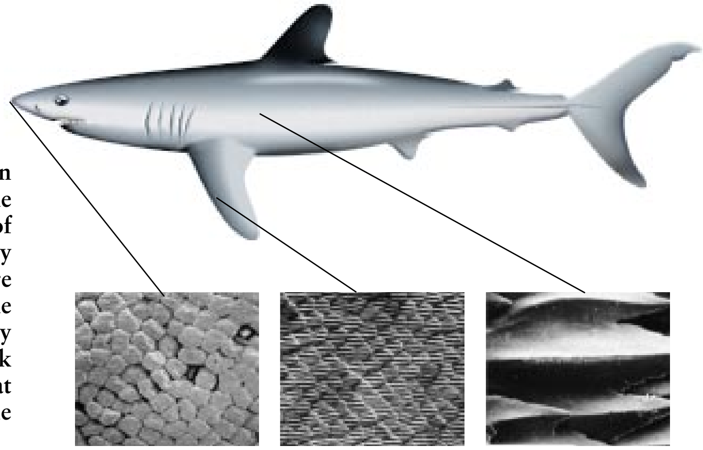
MAN MOHAN RAI AND PARVIZ MOIN

**CLOSE-UP VIEW of the simulated airflow over an airplane wing shows the transition from smooth, or laminar, flow (*dark areas at left*) to turbulence (*rippled areas at right*). Tiny actuators called microflaps (*top photomicrograph*) would tilt upward or remain flat in response to pressure variations to control small eddies on the wing's surface.**





HAECHEON CHOI, PARVIZ MOIN AND JOHN KIM



SLIM FILMS

WOLF-ERNST REIF

**V-SHAPED GROOVES called riblets (*above*) have been found to inhibit the motion of eddies, thereby lessening the drag they can exert on an aircraft's wing. A cross section of the airflow over the grooves (*above, right*) shows the vorticity contours—warm colors are clockwise, and cool colors are counterclockwise. The arrows are velocity vectors for the flow over the riblets. To be effective, the riblets must be very closely spaced, like phonograph grooves. The skin of a shark has tiny, toothlike denticles (*photomicrographs at right*) that seem to serve the same function as the riblets, lessening the drag on the creatures as they move through the water.**

away, the riblets prevent the eddies from transporting high-speed fluid close to the surface, where it decelerates and saps the aircraft's momentum.

Another recent and exciting application of direct numerical simulation is in the development of turbulence-control strategies that are active (as opposed to such passive strategies as riblets). With these techniques the surface of, say, a wing would be moved slightly in response to fluctuations in the turbulence of the fluid flowing over it. The wing's surface would be built with composites having millions of embedded sensors and actuators that respond to fluctuations in the fluid's pressure and speed in such a way as to control the small eddies that cause the turbulence drag.

Such technology appeared to be farfetched as recently as three years ago, but the advent of microelectromechanical systems (MEMS), under the leadership of the U.S. Air Force, has brought such a scheme to the brink of implementation. MEMS technology can fabricate integrated circuits with the necessary microsensors, control logic and actuators. Active control of turbulence near the wing's surface also has an encouraging analogue in the form of a marine creature: dolphins achieve remarkable propulsive efficiency as they swim, and fluid dynamicists have long speculated that these creatures do it by moving their skins. It seems that smart aircraft skins, too, are endorsed by nature.

Getting back to those golf balls we mentioned earlier: they, too, present an intriguing example of how a surface texture can advantageously control airflow [*see illustration on page* 66]. The most important drag exerted on a golf ball derives from air-pressure forces. This phenomenon arises when the air pressure in front of the ball is significantly higher than the pressure behind the ball. Because of the turbulence generated by the dimples, a golf ball is able to fly about two and a half times farther than an identical but undimpled ball.

The growing popularity of computational fluid dynamics to study turbulence reflects both its promise, which is at last starting to be realized, and the continued rapid increase in computational power. As supercomputer processing rates approach and surpass a trillion floating-point operations per second over the next few years, fluid dynamicists will begin taking on more complex turbulent flows, of higher Reynolds numbers. Over the next decade, perhaps, researchers will simulate the flow of air through key passages in a jet engine and obtain a realistic simulation of an operating piston-cylinder assembly in an internal-combustion engine, including the intake and combustion of fuel and the exhaust of gases through valves. Through simulations such as these, researchers will finally begin learning some of the deep secrets expressed by the equations uncovered by Navier and Stokes a century and a half ago. SA


### *The Authors*

PARVIZ MOIN and JOHN KIM worked together in the early 1980s at the National Aeronautics and Space Administration Ames Research Center. Moin is now Franklin and Caroline Johnson Professor of Engineering at Stanford University and director of the Center for Turbulence Research there. His work lately has been on turbulence control, on the interaction of turbulence with shock waves and on noise generated by turbulent flows. Kim is Rockwell International Professor of Engineering at the University of California, Los Angeles. Much of his recent work has been in the application of neural networks to the control of turbulence.


### *Further Reading*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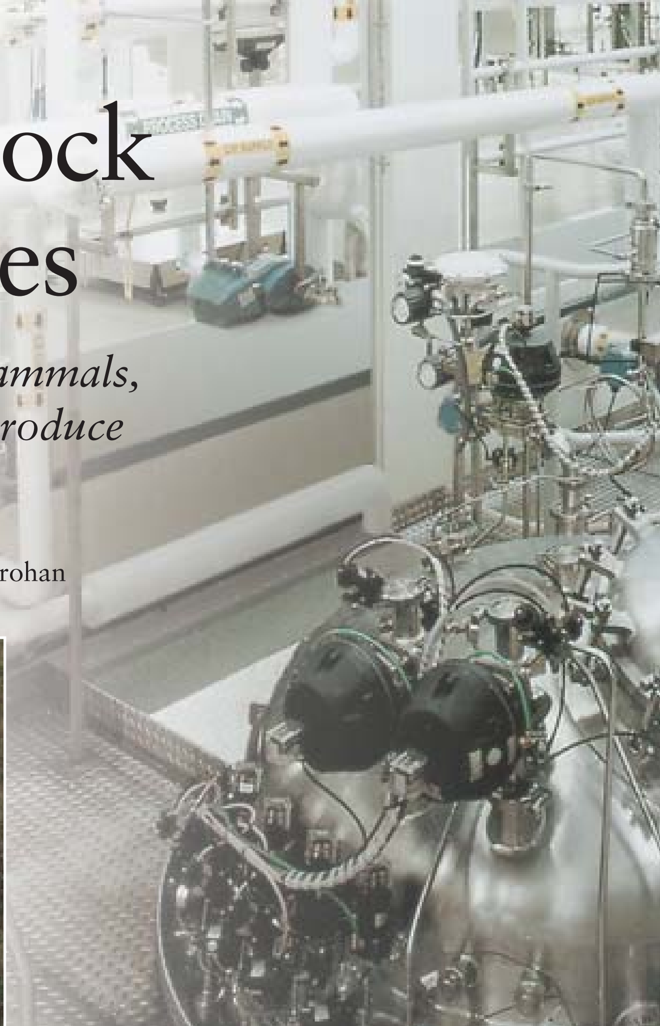
# Transgenic Livestock as Drug Factories

*By introducing key human genes into mammals, biologists can induce dairy animals to produce therapeutic proteins in their milk*

by William H. Velander, Henryk Lubon and William N. Drohan



Exactly one year after her own birth, Genie, our experimental sow, was serenely nursing seven healthy piglets, her milk providing the many nutrients these offspring needed to survive and grow. But unlike other pigs, Genie's milk also contained a substance that some seriously ill people desperately need: human protein C. Traditional methods of obtaining such blood proteins for patients involve processing large quantities of donated human blood or culturing vast numbers of cells in giant stainless-steel reactor vessels. Yet Genie was producing copious amounts of protein C without visible assistance. She was the world's first pig to produce a human protein in her milk.

Genie's ability to manufacture a therapeutic drug in this way was the outcome of a research project conceived almost a decade ago. In collaboration with scientists from the American Red Cross who specialized in providing such blood proteins, we began to consider the possibility of changing the composition of an animal's milk to include some of these critically needed substances. In theory, this approach could generate any required quantity of the various therapeutic blood proteins that are regularly in short supply.

Demand for such drugs comes from many quarters. For instance, hemophiliacs may lack any of several different clotting agents, particularly blood proteins called Factor VIII and Factor IX. Certain people with an inborn deficiency require extra protein C (which acts to control clotting) to supplement their body's meager stores, and patients undergoing joint replacement surgery can benefit from this protein as well. Another important example of the need for therapeutic blood proteins involves people suffering strokes or heart attacks: these cases often demand quick treatment with a protein called tissue plasminogen activator, a substance that can dissolve blood clots. And some people suffering from a debilitating form of emphysema can breathe more easily with infusions of a protein called alpha-1-antitrypsin.

All these proteins are present in donated blood only in tiny amounts, and hence they are currently so difficult to produce that their expense precludes or severely limits their use as drugs. For example, treatment with purified Factor VIII (restricted to those times when someone with hemophilia is actually bleeding) typically costs the patient tens of thousands of dollars every year. The cost of continuous replacement of this blood protein for the same period—a desirable but rarely available option—would exceed $100,000.

Such enormous sums reflect the many problems involved in extracting these proteins from donated blood or establishing specialized production facilities using cultured cells—an enterprise that can require an investment of $25 million or more to supply even modest amounts of a single type of protein. Developing "transgenic" animals such as Genie (that is, creatures that carry genes from other species) demands only a small fraction of such costs. Yet the new breeds simplify procedures enormously and can produce vast quantities of human blood protein. Replacing conventional bioreactors with transgenic livestock thus offers immense economic benefits.

Creating blood proteins in this fashion also stands to better the other cur-


**BIOREACTORS are typically large stainless-steel tanks with complicated controls for maintaining the broth in which countless individual cells are grown. But a new strategy for producing protein-based medicines circumvents the need for such elaborate, and often costly, machinery by using transgenic livestock, such as the pig (*inset*) engineered by the authors to produce one such protein in its milk.**

BARRY L. WILLIAMS (*pig*); JOHN HORNER ARCHITECTURAL PHOTOGRAPHY (*bioreactor*)

rent practice—purifying them from donated blood—because it would circumvent the risk of contamination with infectious agents. Although blood proteins derived from pooled blood plasma are considered relatively safe now that donors are carefully screened and virus inactivation treatments are routinely applied, the threat from some pathogens always looms. For example, the fear of inadvertently spreading HIV (the AIDS-causing agent) and the hepatitis C virus is spurring researchers to seek substitutes for drugs now derived from human blood. Similarly, recent concerns about Creutzfeldt-Jakob disease (a degenerative disease of the nervous system) has caused some blood products to be withdrawn from the U.S. and Europe. Creating human blood proteins with transgenic livestock that are known to be free of such diseases would deftly sidestep these difficulties.

The many gains that would result from the use of transgenic animals as bioreactors gave us ample reason to pursue our vision of tidy stalls occupied by healthy livestock carrying a few key human genes. But at the outset of our work, we had many worries about the technical hurdles facing us in breeding such transgenic animals and garnering usable quantities of protein from their milk. Fortunately, we were able to progress rapidly, benefiting from a body of trailblazing research that had already been done.

### Prior Mousing Around

As early as 1980, Jon W. Gordon and his colleagues at Yale University had determined that a fertilized mouse embryo could incorporate foreign genetic material (DNA) into its chromosomes—the cellular storehouses of genetic material. Shortly afterward, Thomas E. Wagner and his associates at the University of Ohio demonstrated that a gene (a segment of DNA that codes for a particular protein) taken from a rabbit could function in a mouse. Using a finely drawn glass tube of microscopic dimensions, these researchers devised a way to inject a specific fragment of rabbit DNA into a single-cell mouse embryo. Amazingly, that DNA would often become integrated into the mouse's chromosomes, perhaps because it was recognized by the cell as a broken bit of DNA that needed to be repaired.

These researchers then implanted the injected embryos in a surrogate mother mouse and found that some of the mice born to her contained the rabbit gene in all their tissues. These transgenic mice in turn passed the foreign gene on to their offspring in the normal manner, following Mendel's laws of inheritance. The added gene functioned normally in its new host, and these mice made rabbit hemoglobin in their blood.

Another milestone on the road to transgenic animal bioreactors was passed in 1987. Along with their respective colleagues, both Lothar Hennighausen of the National Institute for Kidney and Digestive Diseases and A. John Clark of the Institute of Animal Physiology and Genetics at the Edinburgh Research Station in Scotland established means for activating foreign genes in the mammary glands of mice. Foreign protein molecules created in this way were then secreted directly into a transgenic mouse's milk, where they could be easily collected. These researchers accomplished this feat by combining the foreign gene of interest with a short segment of DNA that normally serves to activate a gene for a mouse milk protein.

Whereas Hennighausen's mice produced the desired human protein (in that case, tissue plasminogen activator) at disappointingly low concentrations, Clark's mice produced 23 grams of a sheep milk protein (known as beta-lactoglobulin) in each liter of milk—approximately matching a mouse's own major milk proteins in abundance. But beta-lactoglobulin was not a human protein in short supply, nor were these tiny mice the proper vehicle to provide useful quantities of milk. So Clark and his colleagues went to work injecting sheep embryos with DNA that contained a medically important human gene.

They used the gene that codes for a blood-clotting factor (Factor IX), along with a segment of sheep DNA that normally switches on the production of beta-lactoglobulin in the mammary gland. Two years later Clark's transgenic sheep secreted Factor IX in their milk—but at barely detectable levels. It was at that juncture that we began our attempts to realize the potential of such pioneering work. But we decided to take a gamble and try a novel strategy.

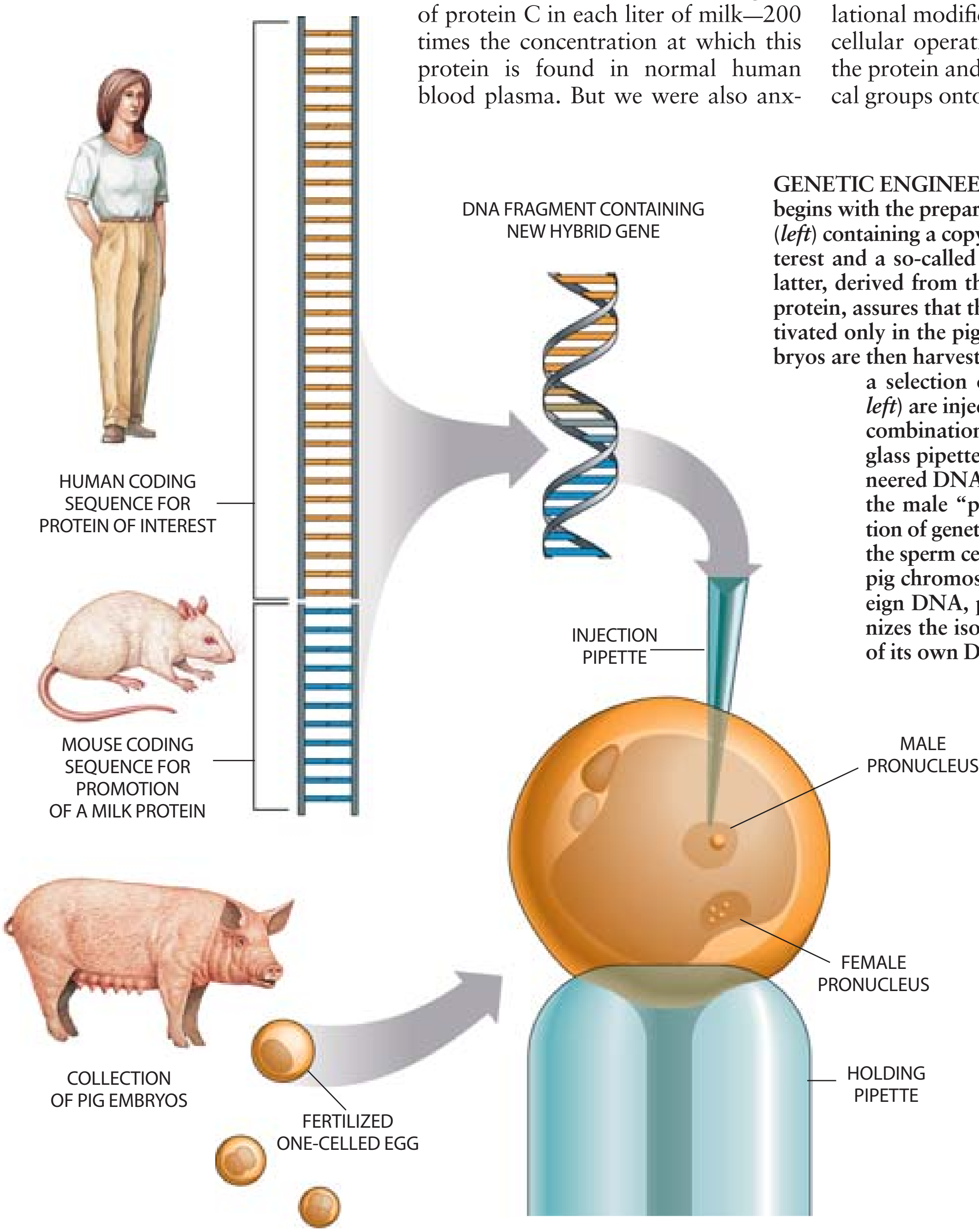
### A Pig in a Poke

Whereas other research groups had picked sheep, goats or cows as suitable dairy animals for producing human proteins, we chose to work with pigs instead. Swine offer the advantages of short gestation periods (four months), short generational times (12 months) and large litter sizes (typically 10 to 12 piglets). Thus, producing transgenic pigs is relatively quick compared with transforming other types of livestock. And despite their lack of recognition as dairy animals, pigs do produce quite a lot of milk: a lactating sow generates about 300 liters in a year. The real question for us was whether this unconventional choice of transgenic animal could in fact be made to produce appreciable levels of human protein in its milk.

Toward that end, we decided to use a DNA segment made up of a human gene and the so-called promoter for a major mouse milk protein (called whey acidic protein) that had been characterized by Hennighausen and his colleagues. By injecting this DNA combination into mouse embryos, those researchers were able to augment a mouse's chromosomes so that the creature would produce the desired human protein in its milk. To take advantage of this approach, we, too, fashioned a fragment of DNA that contained the human gene for the target protein (in our case, protein C) and the mouse promoter for whey acidic protein. But we injected this DNA into a set of pig embryos.

By implanting these fertilized cells in a surrogate mother pig, we could identify—after four months of nervous waiting—a newborn female piglet that carried the foreign DNA in all its cells. But even with this accomplishment, we had to remain patient for another year as our transgenic piglet, Genie, matured. Only then could we find out whether she would indeed produce the human protein in her milk. To our delight, Genie's milk contained protein C. Although the human protein was not as abundant as some of the pig's own milk proteins, it was nonetheless present in substantial amounts, with about one gram of protein C in each liter of milk—200 times the concentration at which this protein is found in normal human blood plasma. But we were also anxious to find out if this pig-made human protein would be biologically active.

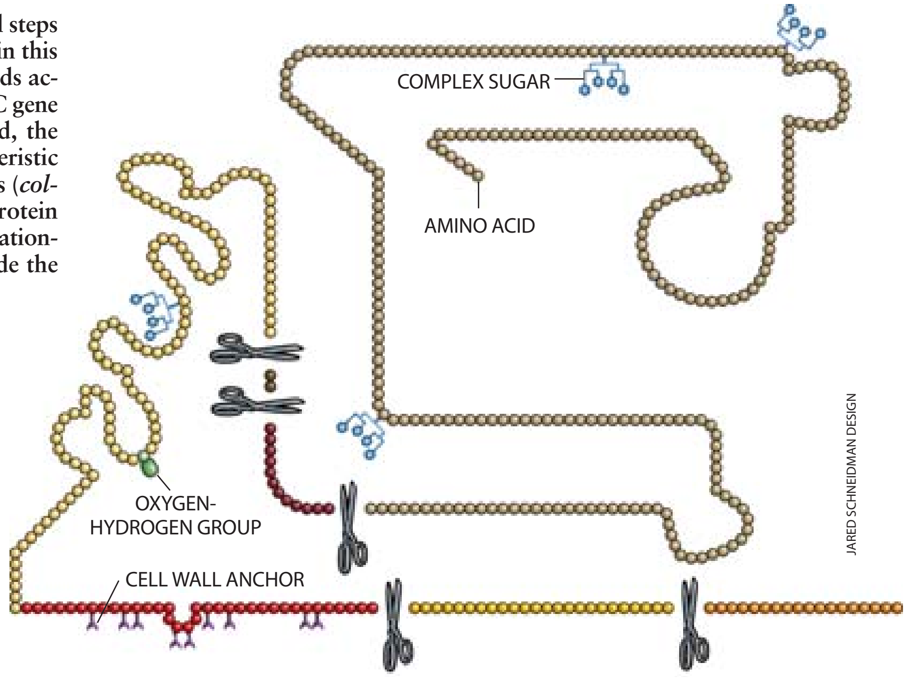
We were concerned because the details of protein synthesis inside cells remain somewhat mysterious. The workings of the cellular machinery for reading the genetic code and translating that information into a sequence of amino acids—the building blocks for protein molecules—is, for the most part, well understood by biologists. But there are some subtle manipulations that need to be done by cells after the amino acids are joined together. These so-called post-translational modifications give a newly constructed protein molecule the final shape and chemical composition it needs to function properly. Post-translational modifications require complex cellular operations to cut off parts of the protein and to paste various chemical groups onto the molecule as it is as-




**GENETIC ENGINEERING of a transgenic pig begins with the preparation of a DNA fragment (*left*) containing a copy of the human gene of interest and a so-called promoter sequence. The latter, derived from the gene for a mouse milk protein, assures that the human gene will be activated only in the pig's mammary tissues. Embryos are then harvested from a donor pig, and a selection of fertilized eggs (*below, left*) are injected with the foreign gene combination using a finely drawn glass pipette (*below, right*). The engineered DNA is added to the region of the male "pronucleus," a concentration of genetic material contributed by the sperm cell that fertilized the egg. A pig chromosome will take up the foreign DNA, perhaps because it recognizes the isolated fragments as pieces of its own DNA in need of repair.**

ROBERTO OSTI (*animals*); JARED SCHNEIDMAN DESIGN (*diagram*); STEPHEN P. BUTLER (*photomicrograph*)

HUMAN PROTEIN C is synthesized in several steps within a cell. The cellular machinery involved in this task starts by stringing together 461 amino acids according to a prescription coded by the protein C gene (a step known as translation). As it is created, the nascent protein molecule folds into a characteristic configuration, forming several distinct domains (*colored regions*). But to function properly, the protein must also undergo several so-called post-translational modifications. These additional steps include the cleaving and removal of certain sections of the protein, as well as the addition of particular chemical groups to specific sites on the amino acid chain.




sembled. Would the cells of Genie's mammary tissue be able to carry out those modifications well enough to make a working version of the human blood protein?

To determine the answer, we had to tackle the new problem of isolating a human blood protein from pig milk. First we removed the milk fat by centrifugation. Then we purified the remaining whey using a procedure that would extract only the biologically active part of the human protein. To our amazement, this component amounted to about one third of the total complement of protein C present. Never before had functional protein C been produced and harvested at such high levels from a transgenic animal—or from a conventional bioreactor. Genie had passed a major test, providing the first practical demonstration that a complex human protein could be produced in the milk of livestock.

### Next Year's Model?

We devoted several years to studying Genie and many of her extant offspring and then began to focus our efforts on increasing the concentration of active human protein in the milk. Our intent was to overcome the limitations of mammary tissue in making the needed post-translational modifications. In principle, breaking through those final barriers could triple the output of useful protein molecules produced.

With some painstaking research into the problem, we discovered that most of the protein C remained in an immature, inactive form because there were insufficient amounts of a key processing enzyme named furin—itself a complex protein—within these cells. Hence, we immediately asked ourselves whether we could improve the situation by introducing another foreign gene, one that would allow more of the needed processing enzyme to be made.

To test this possibility quickly, we switched our efforts temporarily from pig to mouse, the fast-breeding mainstay of most transgenic mammal experiments. In 1995 we succeeded in engineering a line of transgenic mice that contained two human genes—one for protein C and one for furin. We arranged for both of these transgenes to switch on in the mammary gland by attaching them to the DNA promoter we had previously incorporated in Genie.

After months of tedious effort in the lab, we were ecstatic to find that these mice were able to secrete the mature form of protein C in their milk. We have thus started development of a new and improved transgenic pig that contains human genes for both protein C and furin. We expect soon to see a pig that produces three times more active protein C than Genie did, and we anticipate that other researchers working with transgenic livestock will also be able to fashion genetic modifications that cause the manufacture of processing enzymes along with the target protein.

### Chimerical Visions

The notion of obtaining essentially unlimited quantities of scarce human blood proteins at reasonable cost would have seemed pure fantasy just a short time ago. For more than two decades, molecular biologists and biochemical engineers have labored to overcome the problems of producing even modest amounts of human proteins from large-scale cell culture facilities. Yet making biological pharmaceuticals in huge stainless-steel vats of genetically engineered cells seemed destined to remain an awkward and expensive undertaking.

Such bioreactors are enormously costly to construct, and they prove in operation to be extremely sensitive to small changes in the temperature and composition of the broth in which the cells are grown. In contrast, transgenic livestock bioreactors can be created merely by breeding more animals. Transgenic livestock need only routine attention to control their living conditions and nutrient supply, and yet they can easily produce the desired proteins at much higher concentrations than their metallic counterparts.

Although some risk exists that pathogens could be transmitted from livestock to humans, formal procedures are available to establish pedigreed animals that are free of known diseases. Indeed, such specific-pathogen-free herds are a well-established part of the agriculture industry. In addition, decades of the clinical use of pigs to produce insulin for diabetics give us confidence that swine can readily serve as bioreactors for therapeutic human proteins without presenting undue hazard.

Still, like all new medicines, the human proteins produced in this way need to be carefully tested for safety and effectiveness before the government approves them for widespread use. The

## What's Good for Genie…

The advent of transgenic techniques for manipulating livestock also raised legitimate concerns about the health and welfare of the animals altered in this rather unorthodox way. After all, engineered "transgenes" of the kind we implanted in pig embryos can ultimately become part of each and every cell of the mature animals. What if an introduced gene turns on inappropriately and produces the foreign protein in a way that damages the surrounding tissue?

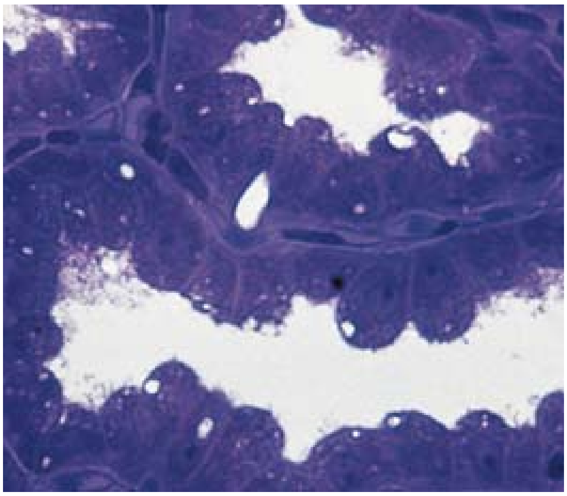
Such worries made it critically important that we design our genetic manipulations so that the foreign gene would be driven into action only in the mammary gland—that is, within tissues that have a natural ability to produce and export protein without harming themselves or their host. We could expect to achieve such targeted control of protein production in our transgenic pigs because we used a promoter from a milk gene—a genetic switch of a type that is present in all mammals.

Yet we recognized that even such well-behaved genes can show some promiscuous activity. The genes we introduced into pigs, for example, also produce small amounts of their foreign proteins in the animals' salivary glands. These tissues are, in fact, quite similar in composition to mammary tissue. So we fully expected this incidental production, and we are quite sure that this minor side effect does not harm the pigs in any way.

The lack of detrimental side effects is crucial—for the animals involved and also for the success of this pioneering method. One of the primary reasons for developing transgenic livestock to supply human proteins is to limit the possibility of transmitting diseases to the recipients of these drugs. Using anything but the healthiest livestock to produce these substances could increase the animals' susceptibility to disease as well as the possibility that they might accidentally pass on some unknown pathogen. Genetically engineering weakened livestock would thus, in the end, only prove self-defeating in the quest to produce safe and plentiful medicines. *—W.H.V.*

first example to be so examined (an anticlotting protein called antithrombin III, manufactured by Genzyme Transgenics Corporation using transgenic goats) began clinical trials just a few months ago.

It is possible that the subtle differences between human and animal cells in the way post-translational modifications are carried out may affect how such proteins function in people. For example, certain modifications cause proteins to be cleared from the blood quickly by the liver, and so we suspect that some of the differences between the animal and human forms of these proteins could actually constitute improvements in the way these substances function as long-lived therapeutic drugs.



ROBERT M. AKERS

**MAMMARY TISSUE from a genetically engineered pig contains a dense array of cells (*purple*) that produce a therapeutic human protein. The structure of the mammary gland allows the human protein produced in this way to flow through the secretory channels (*white*), along with other components in the animal's milk.**

It is tempting to view the development of transgenic livestock bioreactors purely as a triumph of technology. But the history of this science also highlights the limits of what people can do with sophisticated machines. The mammary gland is optimized to maintain a high density of cells, to deliver to them an ample supply of nutrients and to channel the valuable proteins produced into an easily harvested form. Mammary tissue proves far superior to any cell-culture apparatus ever engineered for these tasks. Despite all their efforts to improve industrial cell-culture facilities, it turns out that a generation of biochemical engineers were unable to match the abilities of a tool for making proteins that nature had already honed. SA


### *The Authors*

WILLIAM H. VELANDER, HENRYK LUBON and WILLIAM N. DROHAN have worked together for nearly a decade to develop scarce medicines from transgenic animals. Velander is a professor of biochemical engineering at Virginia Polytechnic Institute and State University. He received his doctorate from the Pennsylvania State University in 1987. Lubon received a Ph.D. from the Agricultural Academy in Lublin, Poland, in 1981 and moved to the U.S. in 1990. Lubon has worked at the National Institutes of Health and at the Jerome H. Holland Laboratory of the American Red Cross, where he is now a staff scientist. Drohan earned a doctoral degree in 1974 from the school of medicine at the University of California, Los Angeles. After working in industry and for the NIH, he joined the Jerome H. Holland Laboratory in 1987. Drohan now serves there as director of the plasma derivatives department.


### *Further Reading*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# How the Blind Draw

*Blind and sighted people use many of the same devices in sketching their surroundings, suggesting that vision and touch are closely linked*

by John M. Kennedy

ABRAHAM MENASHE

**BLIND ARTISTS, such as Tracy (*above*), rely on their sense of touch to render familiar objects. Tracy lost all sight to retinal cancer at the age of two, but by feeling the glass, she determines its shape. By rubbing the paper, placed on a piece of felt, she knows where her pen has scored the page and left a mark. Because the lines in most simple drawings reveal surface edges—features that are discerned by touching as readily as they are by sight—drawings by the blind are easily recognized by sighted people.**

I first met Betty, a blind teenager in Toronto, as I was interviewing participants for an upcoming study of mine on touch perception in 1973. Betty had lost her sight at age two, when she was too young to have learned how to draw. So I was astonished when she told me that she liked to draw profiles of her family members. Before I began working with the blind, I had always thought of pictures as copies of the visible world. After all, we do not draw sounds, tastes or smells; we draw what we see. Thus, I had assumed that blind people would have little interest or talent in creating images. But as Betty's comments revealed that day, I was very wrong. Relying on her imagination and sense of touch, Betty enjoyed tracing out the distinctive shape of an individual's face on paper.

I was so intrigued by Betty's ability that I wanted to find out if other blind people could readily make useful illustrations—and if these drawings would be anything like the pictures sighted individuals use. In addition, I hoped to discover whether the blind could interpret the symbols commonly used by sighted people. To bring the blind into the flat, graphical world of the sighted, I turned to a number of tools, including models, wire displays and, most often, raised-line drawing kits, made available by the Swedish Organization for the Blind. These kits are basically stiff boards covered with a layer of rubber and a thin plastic sheet. The pressure from any ballpoint pen produces a raised line on the plastic sheet.

Thanks to this equipment, my colleagues and I have made some remarkable findings over the past 20 years, and this information has revised our understanding of sensory perception. Most significantly, we have learned that blind and sighted people share a form of pictorial shorthand. That is, they adopt many of the same devices in sketching their surroundings: for example, both groups use lines to represent the edges of surfaces. Both employ foreshortened shapes and converging lines to convey depth. Both typically portray scenes from a single vantage point. Both render extended or irregular lines to connote motion. And both use shapes that are symbolic, though not always visually correct, such as a heart or a star, to relay abstract messages. In sum, our work shows that even very basic pictures reflect far more than meets the eye.

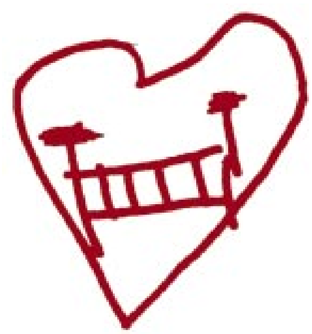
## Outlines

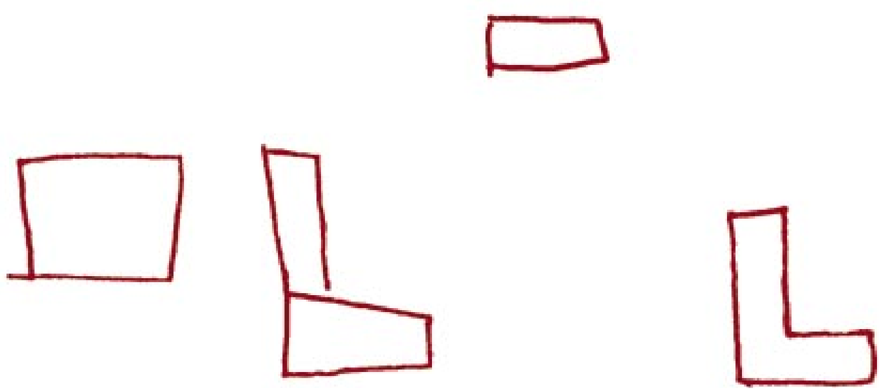
After meeting Betty, I wondered whether all blind people could appreciate facial profiles shown in outline. Over the years, I asked blind volunteers in North America and Europe to draw profiles of several kinds of objects. Most recently, I undertook a series of studies with Yvonne Eriksson of Linköping University and the Swedish Library of Talking Books and Braille. In 1993 we tested nine adults from Stockholm—three men and six women. Four were congenitally blind, three had lost their sight after the age of three, and two had minimal vision. Each subject examined four raised profiles, which Hans-Joergen Andersen, an undergraduate psychology student at Aarhus University in Denmark, made by gluing thin, plastic-coated wires to a flat metal board [*see upper illustration on next page*].

Eriksson and I asked the volunteers to describe the most prominent feature on each display using one of four labels: smile, curly hair, beard or large nose. Five of them—including one man who had been totally blind since birth—correctly identified all four pictures. Only one participant recognized none. On average, the group labeled 2.8 of the four outlines accurately. In comparison, when 18 sighted undergraduates in Toronto were blindfolded and given the same raised-line profiles, they scored only slightly better, matching up a mean of 3.1 out of four displays.

Many investigators in the U.S., Japan, Norway, Sweden, Spain and the U.K. have reported similar results, leaving little doubt that blind people can recognize the outline shape of familiar objects. At first, it may seem odd that even those who have never had any vision whatsoever possess some intuitive sense of how faces and other objects appear. But with further thought, the finding makes perfect sense. The lines in most simple drawings show one of two things: where two surfaces overlap, called an occluding edge, or where two surfaces meet in a corner. Neither feature need be seen to be perceived. Both can be discerned by touching.

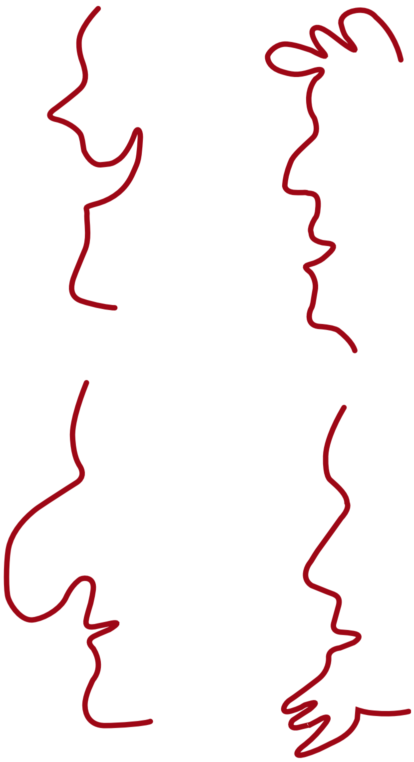
Not all blind people read raised-line drawings equally well, and these individual discrepancies can reflect the age at which someone lost his or her sight.





**OUTLINE DRAWINGS, made by Kathy, totally blind since age three, demonstrate that blind artists use many of the same devices as sighted illustrators do. They use lines to represent surfaces, as Kathy's picture of the eagle on her charm bracelet shows (*top*). Blind people portray objects, such as a house, from a single vantage point (*at right*). Blind artists use shapes to convey abstract messages: Kathy drew a heart surrounding a crib to describe the love surrounding a child (*at right*). And they use foreshortening to suggest perspective: Kathy drew the L-shaped block and the cube to be the same size when they were side by side but made the cube smaller when it was placed farther away from her (*bottom*).**

DRAWINGS COURTESY OF JOHN M. KENNEDY



COURTESY OF JOHN M. KENNEDY

**PROFILES, made from plastic-coated wires mounted on a thin metal board, were given to nine blind subjects in Stockholm. The subjects were asked to describe each display using one of four labels: smile, curly hair, beard or large nose. On average, the group described 2.8 of the four displays accurately, showing that blind people often recognize the outline of simple objects. Blindfolded, sighted control subjects given the same task did only slightly better.**

For example, people who have been blind from birth or infancy—termed the early blind—sometimes find raised-line drawings challenging. But in 1993 Yatuka Shimizu of Tsukuba College of Technology in Japan, with colleagues Shinya Saida and Hiroshi Shimura, found that 60 percent of the early-blind subjects they studied could recognize the outline of common objects, such as a fish or a bottle. Recognition rates were somewhat higher for sighted, blindfolded subjects, who are more familiar with pictures in general.

Interestingly, subjects who lose vision later in life—called the later blind—frequently interpret raised outlines more readily than either sighted or early-blind individuals do, according to Morton Heller of Winston-Salem University. One likely explanation is that the later blind have a double advantage in these tasks: they are typically more familiar with pictures than are the early blind, and they have much better tactile skills than do the sighted.

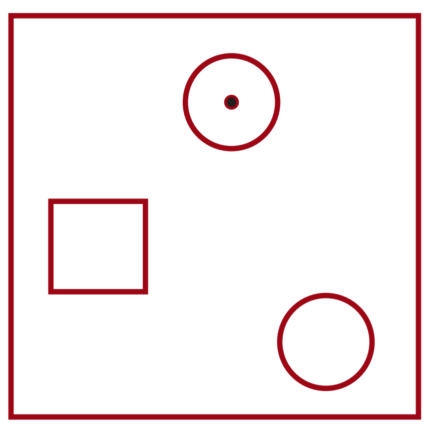
### Perspective

Just as Betty prompted me to study whether the blind appreciate profiles in outline, another amateur artist, Kathy from Ottawa, led me to investigate a different question. Kathy first participated in my studies when she was 30 years old. Because of retinal cancer detected during her first year of life, Kathy had been totally blind since age three and had never had detailed vision. Even so, she was quite good at making raised-line drawings. On one occasion Kathy sketched several different arrangements of a cube and an L-shaped block that I used to test how relative distances appear in line art. When the blocks sat side by side, she made them the same size—as they were in actuality. But when the cube was farther from her than the other block, she made it smaller in her drawing.

This second drawing revealed a fundamental principle of perspective—namely, that as an object becomes more distant, it subtends a smaller angle. (Think about viewing a picket fence at an angle and how its posts appear shorter closer to the horizon.) Kathy's use of this basic rule suggested that some aspects of perspective might be readily understood by the blind. Again the proposition seemed reasonable, given some consideration. Just as we see objects from a particular vantage point, so, too, do we reach out for them from a certain spot. For proof of the theory, I designed a study with Paul Gabias of Okanagan University College in British Columbia, who was then at New York University.

We prepared five raised-line drawings: one of a table and four of a cube [*see upper illustration on opposite page*]. We showed the drawings to 24 congenitally blind volunteers and asked them a series of questions. The table drawing had a central square and four legs, one protruding from each corner. The subjects were told that a blind person had drawn the table and had explained, "I've drawn it this way to show that it is symmetrical on all four sides." They were then told that another blind person had drawn an identical table but had offered a different explanation: "I've shown it from underneath in order to show the shape of the top and all four legs. If you show the table from above or from the side, you can't really show the top and all four legs, too."

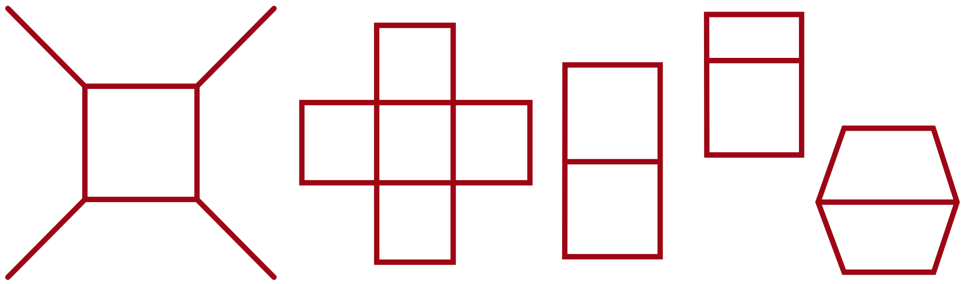
Next we asked our volunteers to pick out the cube drawing that had most likely been made by the person who drew the table from below. To answer consistently, they needed to understand what strategy had been used in drawing the table and each cube. One cube resembled a foldout of a box, showing the front face of the cube in the middle, surrounded by its top, bottom, left and right faces. Another drawing showed



COURTESY OF JOHN M. KENNEDY

**SOLIDS—a sphere, a cone and a cube—arranged on a table are commonly used to test spatial ability. The arrangement is shown from overhead at the far right. Which drawing at the near right shows the solids from the edge of the table facing the bottom of the page? Which drawing shows them from the opposite edge? From the edge facing left? Facing right? Blind and sighted individuals do equally well on this task, proving that the blind can determine how objects appear from particular vantage points.**



COURTESY OF JOHN M. KENNEDY

**PERSPECTIVE is readily understood by the blind. To prove this point, the author and Paul Gabias of Okanagan University College asked 24 congenitally blind volunteers to examine a drawing of a table (*far left*) and four drawings of a cube. They were told that one blind person drew the table in a star shape to show how it appeared from underneath and that another blind person drew an identical table, intending to show its symmetry instead. The subjects were then asked which cube was most likely drawn by the person who drew the table from underneath. Most chose the cube composed of two trapeziums (*far right*), the one that made the most sophisticated use of perspective.**

two squares, representing the front and top of the cube. A third picture depicted the front of the cube as a square and the top as a rectangle—foreshortened because it was receding away from the observer. A fourth illustrated two trapeziums joined along the longest line; the extra length of this line revealed that it was the edge nearest to the observer.

Which cube do you think was drawn by the person who intended to show the table from below? Most of the blind volunteers chose the drawing that showed two trapeziums. That is, they selected the illustration that made the most sophisticated use of perspective. Accordingly, they picked as the least likely match the flat "foldout" drawing—the one that used no perspective whatsoever. The foldout drawing was also the one they judged most likely to have been made by the person who, in drawing the table, had hoped to highlight its symmetry.

Heller and I joined forces to prepare another task for demonstrating that the blind understood the use of perspective. (You might like to try it, too; it appears at the bottom of the opposite page.) We arranged three solids—a sphere, a cone and a cube—on a rectangular tabletop. Our blind subjects sat on one side. We asked them to draw the objects from where they were sitting and then to imagine four different views: from the other three sides of the table and from directly above as well. (Swiss child psychologist Jean Piaget called this exercise the perspective-taking, or "three mountains," task.) Many adults and children find this problem quite difficult. On average, however, our blind subjects performed as well as sighted control subjects, drawing 3.4 of the five images correctly.

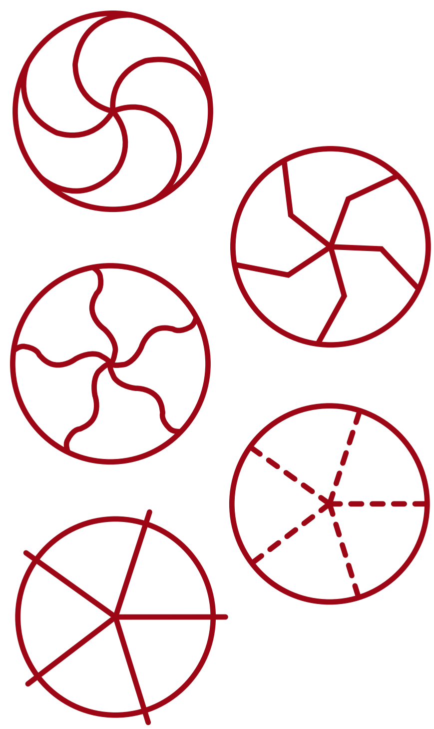
Next, we asked our subjects to name the vantage point used in five separate drawings of the three objects. We presented the drawings to them twice, in random order, so that the highest possible score was 10 correct. Of that total, the blind subjects named an average of 6.7 correctly. Sighted subjects scored only a little higher, giving 7.5 correct answers on average. The nine later-blind subjects in the study fared slightly better than the congenitally blind and the sighted, scoring 4.2 on the drawing task and 8.3 on the recognition task. Again, the later blind probably scored so well because they have a familiarity with pictures and enhanced tactile skills.

## Metaphor

From the studies described above, it is clear that blind people can appreciate the use of outlines and perspective to describe the arrangement of objects and other surfaces in space. But pictures are more than literal representations. This fact was drawn to my attention dramatically when a blind woman in one of my investigations decided on her own initiative to draw a wheel as it was spinning. To show this motion, she traced a curve inside the circle. I was taken aback. Lines of motion, such as the one she used, are a very recent invention in the history of illustration. Indeed, as art scholar David Kunzle notes, Wilhelm Busch, a trendsetting 19th-century cartoonist, used virtually no motion lines in his popular figures until about 1877.

When I asked several other blind study subjects to draw a spinning wheel, one particularly clever rendition appeared repeatedly: several subjects showed the wheel's spokes as curved lines. When asked about these curves, they all described them as metaphorical ways of suggesting motion. Majority rule would argue that this device somehow indicated motion very well. But was it a better indicator than, say, broken or wavy lines—or any other kind of line, for that matter? The answer was not clear. So I decided to test whether various lines of motion were apt ways of showing movement or if they were merely idiosyncratic marks. Moreover, I wanted to discover whether there were differences in how the blind and the sighted interpreted lines of motion.

To search out these answers, Gabias and I created raised-line drawings of five different wheels, depicting spokes



COURTESY OF JOHN M. KENNEDY

**MOTION can be suggested by irregular lines. When blind and sighted volunteers were shown five diagrams of moving wheels (*right*), they generally interpreted them in the same way. Most guessed that the curved spokes indicated that the wheel was spinning steadily; the wavy spokes, they thought, suggested that the wheel was wobbling; and the bent spokes were taken as a sign that the wheel was jerking. Subjects assumed that spokes extending beyond the wheel's perimeter signified that the wheel had its brakes on and that dashed spokes indicated that the wheel was spinning quickly.**

| WORDS ASSOCIATED WITH CIRCLE-SQUARE | AGREEMENT AMONG SUBJECTS (PERCENT) |
|---|---|
| SOFT-HARD | 100 |
| MOTHER-FATHER | 94 |
| HAPPY-SAD | 94 |
| GOOD-EVIL | 89 |
| LOVE-HATE | 89 |
| ALIVE-DEAD | 87 |
| BRIGHT-DARK | 87 |
| LIGHT-HEAVY | 85 |
| WARM-COLD | 81 |
| SUMMER-WINTER | 81 |
| WEAK-STRONG | 79 |
| FAST-SLOW | 79 |
| CAT-DOG | 74 |
| SPRING-FALL | 74 |
| QUIET-LOUD | 62 |
| WALKING-STANDING | 62 |
| ODD-EVEN | 57 |
| FAR-NEAR | 53 |
| PLANT-ANIMAL | 53 |
| DEEP-SHALLOW | 51 |

**WORD PAIRS were used to test the symbolism in abstract shapes—and whether blind and sighted people perceived such meanings in the same way. Subjects were told that in each pair of words, one fit best with circle and the other with square. For example, which shape better describes soft? According to the number given after the soft-hard word pair, everyone thought a circle did. These percentages show the level of consensus among sighted subjects. Blind volunteers made similar choices.**

with lines that curved, bent, waved, dashed and extended beyond the perimeter of the wheel. We then asked 18 blind volunteers to assign one of the following motions to each wheel: wobbling, spinning fast, spinning steadily, jerking or braking. Which wheel do you think fits with each motion? Our control group consisted of 18 sighted undergraduates from the University of Toronto.

All but one of the blind subjects assigned distinctive motions to each wheel. In addition, the favored description for the sighted was the favored description for the blind in every instance. What is more, the consensus among the sighted was barely higher than that among the blind. Because motion devices are unfamiliar to the blind, the task we gave them involved some problem solving. Evidently, however, the blind not only figured out meanings for each line of motion, but as a group they generally came up with the same meaning—at least as frequently as did sighted subjects.

We have found that the blind understand other kinds of visual metaphors as well. Kathy once drew a child's crib inside a heart—choosing that symbol, she said, to show that love surrounded the child. With Chang Hong Liu, a doctoral student from China, I have begun exploring how well blind people understand the symbolism behind shapes such as hearts, which do not directly represent their meaning. We gave a list of 20 pairs of words to sighted subjects and asked them to pick from each pair the term that best related to a circle and the term that best related to a square. (If you wish to try this yourself, the list of words can be found at the left.) For example, we asked: What goes with soft? A circle or a square? Which shape goes with hard?

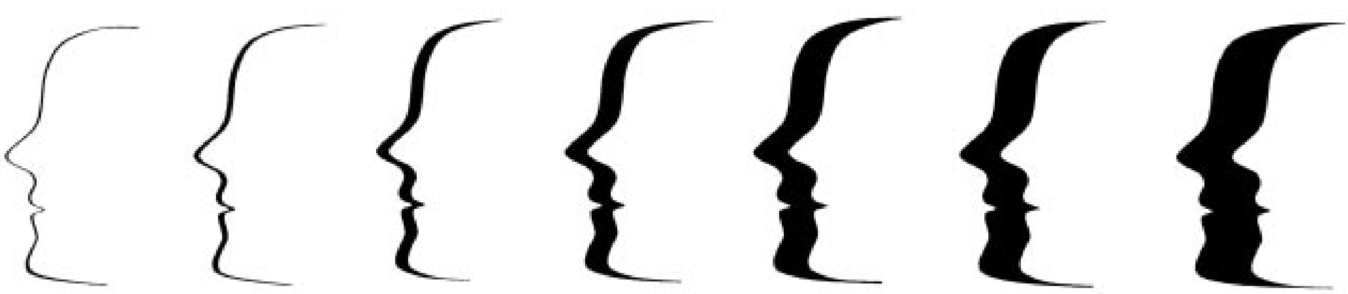
All our subjects deemed the circle soft and the square hard. A full 94 percent ascribed happy to the circle, instead of sad. But other pairs revealed less agreement: 79 percent matched fast and slow to circle and square, respectively. And only 51 percent linked deep to circle and shallow to square. When we tested four totally blind volunteers using the same list, we found that their choices closely resembled those made by the sighted subjects. One man, who had been blind since birth, scored extremely well. He made only one match differing from the consensus, assigning "far" to square and "near" to circle. In fact, only a small majority of sighted subjects—53 percent—had paired far and near to the opposite partners. Thus, we concluded that the blind interpret abstract shapes as sighted people do.

### Perception

We typically think of sight as the perceptual system by which shapes and surfaces speak to the mind. But as the empirical evidence discussed above demonstrates, touch can relay much of the same information. In some ways, this finding is not so surprising. When we see something, we know more or less how it will feel to the touch, and vice versa. Even so, touch and sight are two very different senses: one receives input in the form of pressure, and one responds to changes in light. How is it that they can then interpret something as simple as a line in exactly the same way? To answer this question, we must consider what kind of information it is that outlines impart to our senses.

The most obvious theory is that each border in a basic drawing represents one physical boundary around some surface or shape. But it is not that simple, because all lines, no matter how thin, have two sides or contours—an inside and an outside border, if you will. As a result, thick lines are perceived quite differently from thin ones. Consider a thick line tracing a profile. If it is thick enough, it appears to show two profiles, one per edge, gazing in the same direction [*see illustration below*]. When the line is thin and its two borders are close together, though, an observer perceives only one

**THICKNESS of these outlines determines whether their two contours are viewed as one profile or two. The same ambiguity occurs with touch. Blind subjects interpret raised edges placed near each other as a single surface boundary and those placed farther apart as two.**



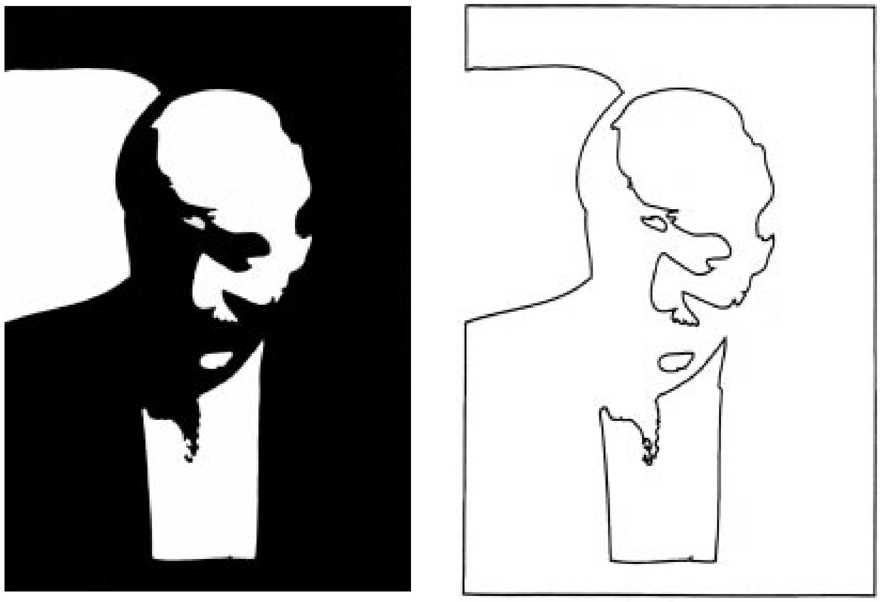
COURTESY OF JOHN M. KENNEDY

face. As it turns out, touch produces a similar effect. I prepared a series of profile drawings in which both edges of the defining line were raised. When the edges were only 0.1 centimeter apart, my blind volunteer, Sanne, a student at Aarhus University, said they showed one face. When they were 0.8 centimeter apart, she reported that they showed two faces.

Another theory of outline drawings suggests that lines substitute for any perceptible boundary, including those that are not tangible, such as shadows. But this theory, too, fails in a very telling fashion. Look at the illustration at the right, which shows two pictures of the author. In one image, shadow patterns, defined by a single contour separating light and dark areas, cross my face. In the second image, a dark line having two contours traces the same shadow patterns. Despite the fact that the shapes in the second picture are identical to those in the first, the perceptual results are vividly different. The first is easily recognized as a face; the second is not.

Again, this example shows that our visual system, like our tactile system, does not read two contours of a line in the same way as it interprets a single contour. The implication is that the brain region responsible for interpreting contours in sensory input from busy environments is a general surface-perception system. As such, it does not discriminate on the basis of purely visual matters, such as brightness and color. Rather it takes the two contours of a dark line and treats them as indicators for the location of a single edge of some surface. Whereas sighted individuals treat brightness borders as indicators of surface edges, the blind treat pressure borders in the same way.



COURTESY OF JOHN M. KENNEDY

**SHADOWS, and other intangible boundaries, are not recognizable in outline—explaining in part why the blind can understand most line drawings made by sighted people. In the picture of the author on the left, a single contour separates light and dark areas of his face. In the picture on the right, a line, having two contours, makes the same division. Note that although the shapes are identical in both images, the perceptual results are quite different. Only the image on the left clearly resembles a face.**

Because the principles at work here are not just visual, the brain region that performs them could be called multimodal or, as it is more commonly termed, amodal. In one account, which I have discussed in my book on drawings by the blind, such an amodal system receives input from both vision and touch. The system considers the input as information about such features as occlusion, foreground and background, flat and curved surfaces, and vantage points. In the case of the sighted, visual and tactile signals are coordinated by this amodal system.

As we have found, the ability to interpret surface edges functions even when it does not receive any visual signals. It is for this very reason that the blind so readily appreciate line drawings and other graphic symbols. Knowing this fact should encourage scholars and educators to prepare materials for the blind that make vital use of pictures. Several groups around the world are doing just that. For instance, Art Education for the Blind, an organization associated with the Whitney Museum of American Art and the Museum of Modern Art in New York City, has prepared raised-line versions of Henri Matisse paintings and of cave art. It may not be long before raised pictures for the blind are as well known as Braille texts. SA

## *The Author*

JOHN M. KENNEDY was born in Belfast in 1942 and was raised in one of the few Unitarian families in Northern Ireland. He attended the Royal Belfast Academical Institution and Queen's University of Belfast, where his interests included fencing and theater. He completed his Ph.D. in perception at Cornell University and began his research with the blind shortly thereafter as an assistant professor at Harvard University. He currently lectures at the University of Toronto, Scarborough College, where he won his college's teaching prize in 1994. Notes from his courses on perception are available through the university's World Wide Web site at http://citd.scar.utoronto.ca/Psychology/PSYC54/PSYC54.html

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# Experimental Flooding in Grand Canyon

*Scientists monitor a controlled deluge that was staged in the early spring of 1996 solely for the benefit of the environment in and around the Colorado River*

by Michael P. Collier, Robert H. Webb and Edmund D. Andrews

For more than three decades, Glen Canyon Dam has impounded the flow of the Colorado River above Grand Canyon, the vast winding chasm in America's southwestern desert that ranks as one of the wonders of the natural world. Although many people recognized that damming the flow would destroy the river upstream, few anticipated that there might be serious environmental consequences downstream. But over the years, scientists, government officials and professional river guides have become increasingly aware of troubling changes within Grand Canyon.

These alterations have occurred because the dam replaced the Colorado's natural pattern of forceful summer flooding with a gentle daily ebb and flow dictated entirely by the electrical power demands of distant cities. The dam thus eliminated the normal seasonal variation in river flow and ended the immense floods that had annually washed through the canyon. Although these floods had lasted only a few weeks of the year, they had been the principal force

sculpting the river corridor. The floodwaters routinely stripped all but the highest vegetation from the channel banks, deposited sandbars and plucked boulders out of rapids. After Glen Canyon Dam went into service, exotic flora encroached, sandbars disappeared and boulder piles clogged the main channel.

So as dozens of scientific observers (including the three of us) made ready, the secretary of the interior, Bruce Babbitt, launched a bold experiment in environmental restoration at 6:20 A.M. on March 26, 1996, opening the first of four giant "jet tubes" at Glen Canyon Dam. Over the next nine hours, the other three tubes and the eight hydroelectric turbines added to the torrent, which grew to 1,270 cubic meters per second—a discharge 50 percent greater than the maximum flow through the turbines alone. As the surge of water mounted, the surface of the river rose five meters higher than usual. In all, 900 million cubic meters of water coursed through the canyon during the weeklong experiment. Never before had an intentional flood been released specifically for environmental benefit, and we were eager to help assess the results.

MICHAEL P. COLLIER

### A Changed River

Along with many other scientists who monitored the experimental flooding, we have been aware that conditions in the canyon had been evolving dramatically since Glen Canyon Dam began operations in 1963. After construction of the dam, virtually all sediment coming from upstream was trapped above the dam, in the newly created Lake Powell, and most sandy beaches in Grand Canyon began slowly but steadily to vanish. By the time the test flood was planned, some rapids in the river had become so obstructed by coarse debris swept down from side canyons that particular stretches had become extremely difficult to navigate. The bridled river did not have sufficient power to clear away the boulder-filled deposits. Many people familiar with the canyon had also observed dramatic alterations to the vegetation since the dam was built. Native coyote willow, as well as exotic tamarisk, camelthorn and even bermuda grass, took root on beaches that had previously been bare. Mature mesquite trees growing at the old high waterline began to die.

But not all changes brought about by the damming of the river were obviously undesirable. Trout—which did not live there before in the relatively warm, turbid waters of the free-running river—flourished in the cold, clear water below the dam. Stabilization of flow favored trees and shrubs on the riverside, which provided new homes for some endangered birds. The green ribbon of new vegetation made the once barren canyon appear more hospitable to other kinds of wildlife as well—and to countless campers who traveled the river for recreation.

Indeed, the many beneficial changes to the canyon ecosystem may have diverted attention from some of the more disturbing trends. It was not until 1983 that many scientists and environmentalists took full notice of the important role that floods originally played in shaping the canyon. In June of that year, a sudden melting of the winter snowpack rapidly filled Lake Powell and forced the operators of Glen Canyon Dam to release water at a rate of 2,750 cubic meters per second. This flow was far smaller than some recorded flood episodes, but it still constituted a momentous event.

This emergency release in 1983 required the first use of the "spillways"—giant drain tunnels carved into the walls of Glen Canyon alongside the dam. The operators of the dam had at first been dismayed—and then gravely concerned—to see the outflow turn red as swiftly moving water plucked first concrete and then great blocks of sandstone from the spillway tunnels. Some feared that destruction of the spillways could catastrophically undermine the dam. Fortunately, the crisis passed, and engineers were able to redesign the spillways to minimize "cavitation." This phenomenon (formation of a partial vacuum within a moving liquid) had sucked material from the tunnel walls and caused them to erode with startling speed.

The downstream effects of the 1983 flood also took others by surprise. When the waters receded from the flooded banks, scientists and guides familiar with the river were stunned to see many of the formerly shrunken beaches blanketed with fresh sand. The flood had killed some exotic vegetation that had grown artificially lush and had also partially restored riverine animal habitats in many spots. Had several years of ordinary dam operations followed, many people would have hailed the 1983 flood for improving conditions in the canyon. Instead runoff in the Colorado River basin during the next three years remained quite high, and the operators of Glen Canyon Dam were forced to release huge amounts—an average of 23 billion cubic meters of water every year. Flows commonly reached 1,270 cubic meters per second, for at least brief periods, each

MICHAEL P. COLLIER

**JETS OF WATER (*opposite page*) emerge during the experimental flood from four steel drainpipes built into the base of Glen Canyon Dam (*right*). The water stored in the adjacent reservoir, Lake Powell, can also flow through the hydroelectric turbines situated underneath the dam or, if there is urgent need to lower the lake, through the two "spillway tunnels" carved into the canyon walls (*visible at right, below the dam*).**

year through 1986. The beaches that had been built up in 1983 soon washed away. A single flood, it seemed, could create beaches; frequently repeated floods could destroy them.

### Time for Another Flood?

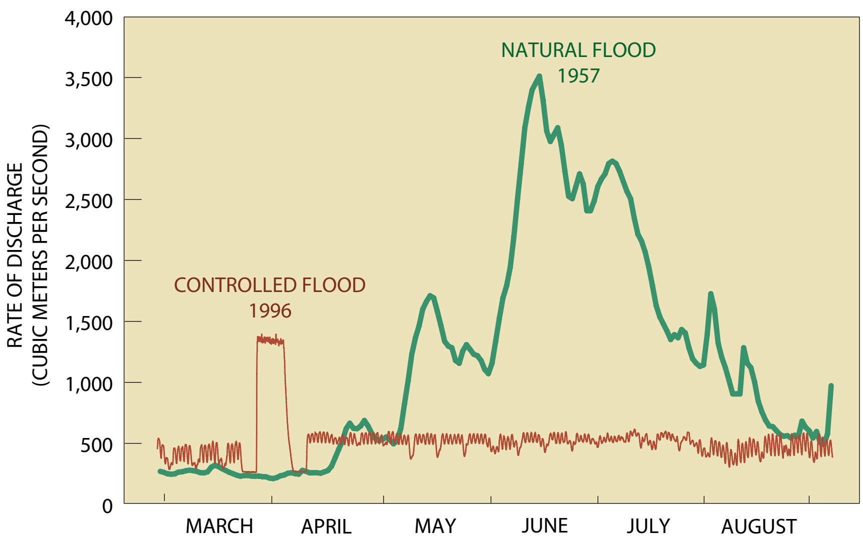
As scientists learned more about risks and benefits of flooding in the canyon, many of those interested in the fate of the river began to recognize the need to restore flooding of some type. Most geologists who had studied the movement of sediment by the Colorado River were convinced that an artificial flood would benefit the canyon, and they began championing that idea within the scientific community in 1991. But during discussions, some biologists worried aloud that a flood would jeopardize the gains that had been made within the canyon by several endangered species. A few geologists, too, were concerned that the beaches nearest Glen Canyon Dam might be inadvertently washed away. And anthropologists working in the canyon expressed concern that new flooding would accelerate erosion and threaten the integrity of archaeological sites next to the river.

Yet the overall sentiment was that purposeful flooding would be more beneficial than harmful and should be arranged. By 1993 the murmurs in favor of a flood had turned to shouts. Some of the loudest voices came from river guides who were being forced to find camping sites on smaller and smaller beaches—despite the fact that millions of metric tons of sand were reaching the Colorado every year by way of its two main tributaries below the dam, the Paria and Little Colorado rivers. Under the normal operating regime of Glen Canyon Dam, only 450,000 metric tons of this sand wash downstream and out of Grand Canyon. So sand was filling the canyon, but it was not accumulating on the banks. Rather it was settling out of sight on the bottom of the river.

Along with others at the U.S. Geological Survey (USGS) and the Bureau of Reclamation's Glen Canyon Environmental Studies program, we were certain that a flood would stir up these deposits and drape them along the banks, just as the river had done before the dam had reined it in. But what sort of flood would be most appropriate? The people debating that question agreed that the best time of year for an initial test would be during a narrow window in late March, when fish were least likely to be spawning and troublesome tamarisk plants would not yet be able to germinate. A date at that time would also assure that most bald eagles and waterfowl that had wintered in the canyon would have already left. Still, the optimum choice for the size of the flood remained elusive.

One reason for that difficulty was that the quantity of sand moved by a river varies quite strongly with the rate of discharge: when the discharge rate doubles, the flux of sand increases eightfold. Consequently, for a given flood volume, more sand will be stirred up and deposited on the banks by a large flood that runs for a short time than by a lesser flood of longer duration. One of us (Andrews) argued for a release at the rate of 1,500 cubic meters per second, which would have been close to two thirds the size of the typical annual flood before the dam was built. After all, if the goal was to restore a critical natural process, why not try roughly to approximate that level?

But there was an important logistical constraint: flows greater than 1,270 cubic meters per second through the dam would require the use of the spillways. Despite having made repairs and improvements, officials at the Bureau of Reclamation were reluctant to risk repetition of the frightening experience of 1983. Restricting the flood to 1,270 cubic meters per second would also minimize the threat to an endangered species of snail that lived near the dam. Most proponents of flooding felt that this level was a reasonable compromise. They




SOURCE: Robert H. Webb

JENNIFER C. CHRISTIANSEN

MICHAEL P. COLLIER

**DISCHARGE of water during the experimental flood of 1996 may have appeared extremely powerful (*photograph*), but the flow maintained for that one week is dwarfed by natural events of the past, such as the flood of 1957 (*chart*), which endured for much of the spring and summer.**

agreed that the flood would last one week—enough time to redistribute a considerable amount of sand but not so long as to deplete all sand reserves at the bottom of the river.

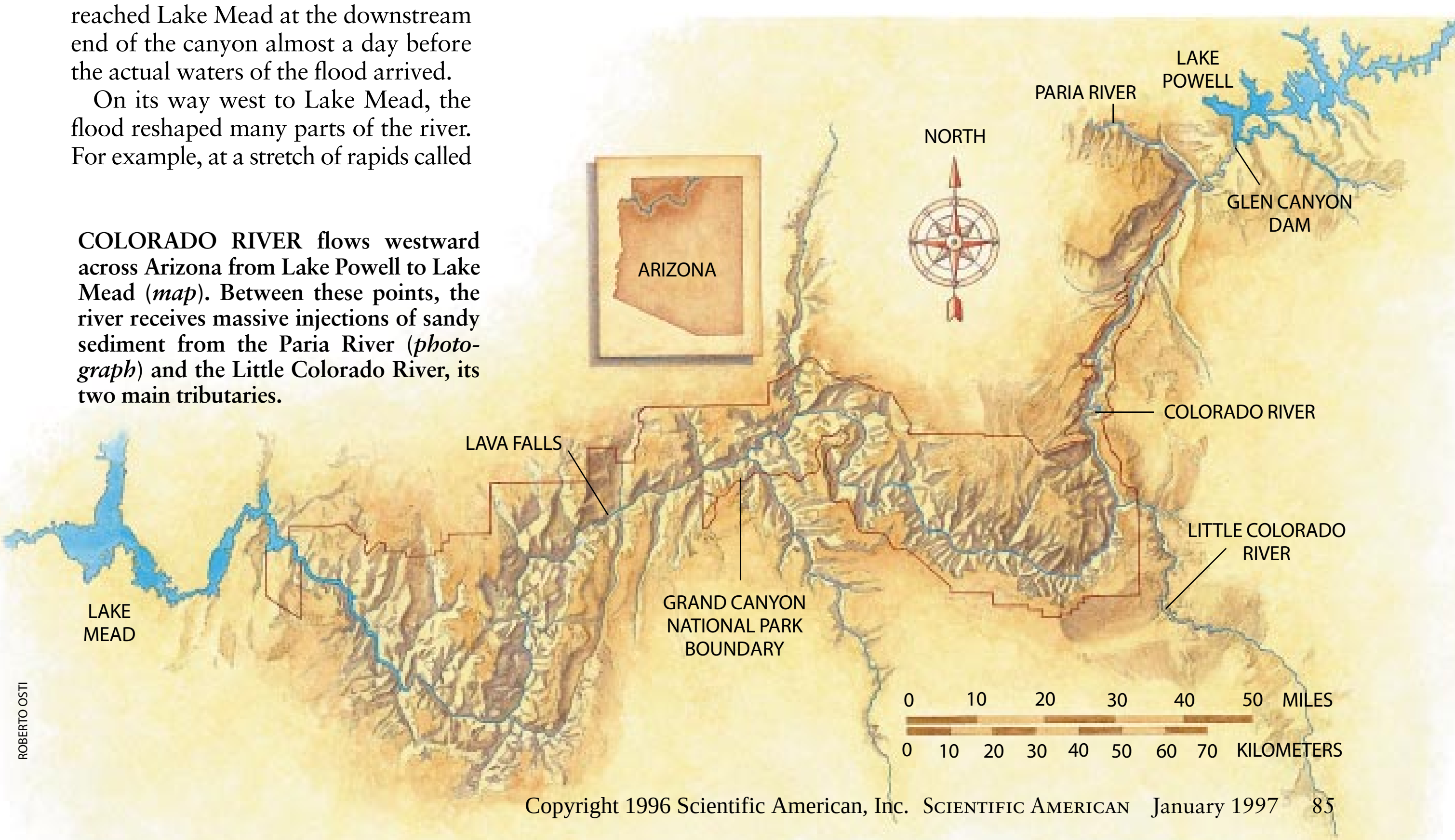
On the eve of the test, our biggest fear was that the water would not have the power needed to build sizable beaches. But John C. Schmidt, a geologist at Utah State University who had also favored the flooding experiment, had a bigger concern. He worried that something might unexpectedly go wrong: Would scientists in their arrogance ruin what was left of the heart of Grand Canyon?

### On a Rising Tide

On March 26 the flood began on schedule. The waters of the river rose and raced down the canyon. On signal, scientists from the USGS released 30 kilograms of a nontoxic fluorescent dye into the river a short distance downstream from the dam. They used the chemical to track the velocity of the water by measuring the arrival of this dye at six sites spaced throughout the canyon, where they had placed sensitive fluorometers. A numerical model developed by researchers at the USGS accurately predicted the progress of the flood. The model and measurements showed that the floodwaters accelerated as they ran through the canyon, pushing riverwater so far ahead that the first crest reached Lake Mead at the downstream end of the canyon almost a day before the actual waters of the flood arrived.

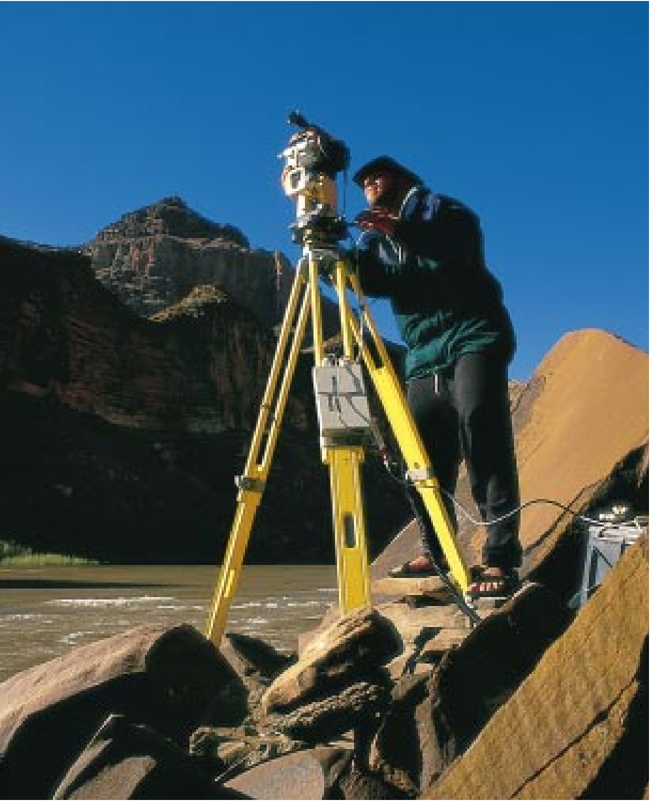
On its way west to Lake Mead, the flood reshaped many parts of the river. For example, at a stretch of rapids called


MICHAEL P. COLLIER



ROBERTO OSTI

**COLORADO RIVER flows westward across Arizona from Lake Powell to Lake Mead (*map*). Between these points, the river receives massive injections of sandy sediment from the Paria River (*photograph*) and the Little Colorado River, its two main tributaries.**



PHOTOGRAPHS BY MICHAEL P. COLLIER

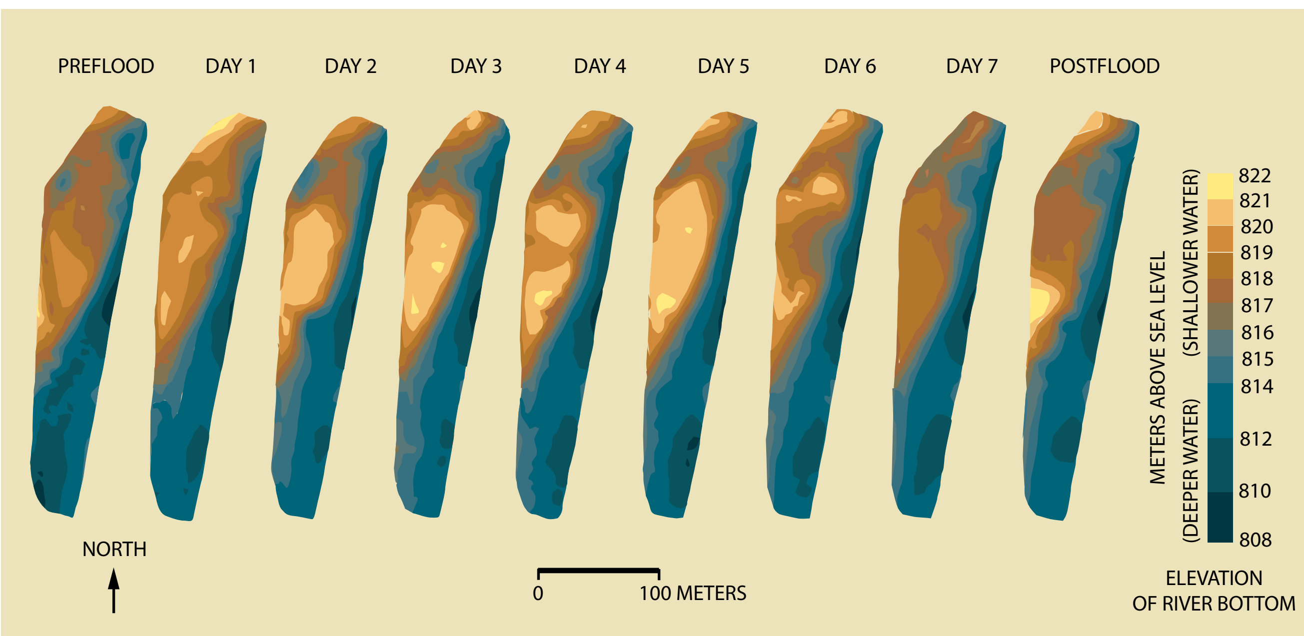
Lava Falls, about 300 kilometers below the dam, the river rose against a fan-shaped bank of loose mud and boulders that had been formed one year earlier after a debris flow roared down a small side canyon. The material deposited by that cascade of rock and mud had narrowed the Colorado—normally 50 meters wide there—by almost 20 meters. Although some geologists had previously concluded that very large floods would be required to clean out such constrictions, we believed this flood would be sufficient to do the job.

And so we were quite pleased to see just how effective the experimental flood proved. As discharge of the river surpassed 850 cubic meters per second at Lava Falls on March 27, the energized water quickly cut through the new debris fan, reducing its size by one third. We studied that event by placing radio transmitters in 10 large stones positioned originally near the top of the rapids. Despite their considerable size (up to 0.75 meter across), all 10 rocks traveled downstream during the flood. Using directional antennas, we subsequently located eight of the boulders. The great stones had moved, on average, 230 meters.

Besides tracking boulders at Lava Falls, we worked with several colleagues to measure the deposition of sand at some other key locales. For those studies, we chose five eddies—places where the river widens abruptly, and water swirls upstream near the banks. Employing laser tracking equipment and a small boat equipped with a sonar depth finder, we charted the sandy bottom during the flood. The results were quite surprising. We found that a great deal of sand accumulated in the first 36 to 48 hours. But as the influx of sand slowed, the bottom of the eddy began to lose sand back into the main channel.

This behavior initially puzzled us, but after we examined the measurements more carefully, we realized that much of the sediment had originally settled above its so-called angle of repose, an unstable configuration that resulted in some newly deposited sand slumping

**SAND DEPOSITION within an eddy, a place where water swirls in the upstream direction near the banks, raised the bed of the river along one margin (*tan areas in diagrams*) in the first days of the flood. Later during the flood, much of that sand escaped back into the main channel (*blue areas in diagrams*). To collect this record of sediment accumulation and removal, a boat fitted with an acoustic echo sounder (*photograph at left*) measured the depth of the water, and surveying equipment on land tracked the position of the boat (*photograph at top*).**

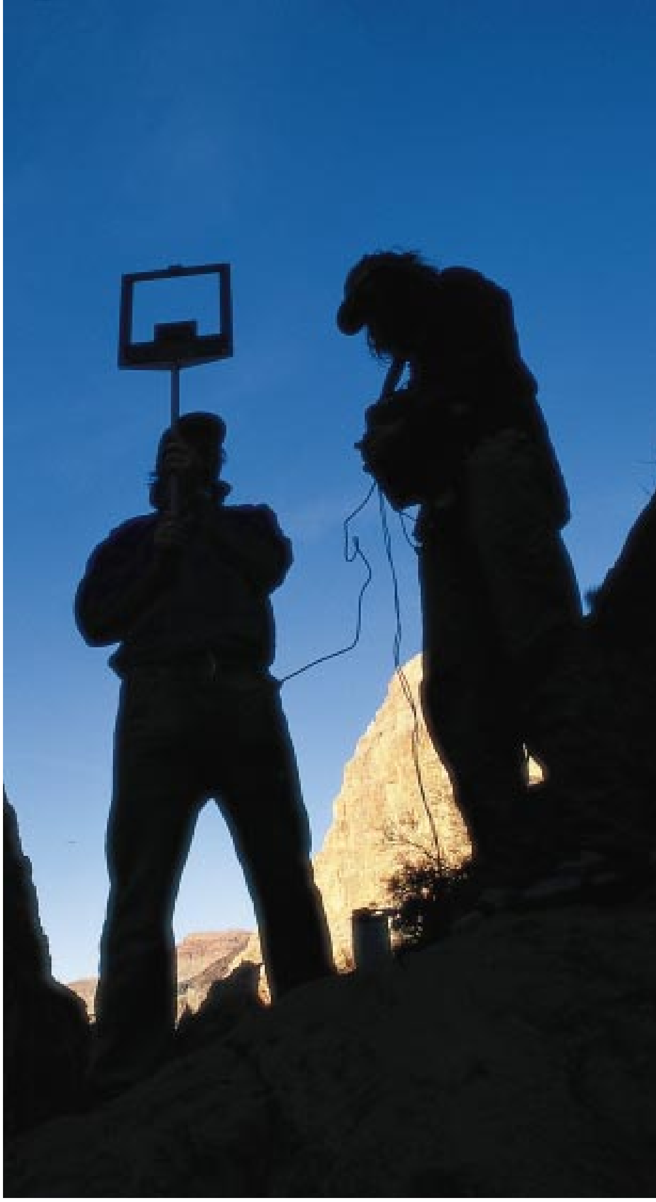



JENNIFER C. CHRISTIANSEN; SOURCE: CHRISTOPHER E. JOHNSTON back into the main channel. Still, we found that the overall amount of sand after the flood had increased in all five places we mapped.

Many other scientists made important observations during the course of the flood. Near the lower end of Grand Canyon, our colleague J. Dungan Smith measured the velocity of the river and concentration of sediment held in suspension by the turbulent water. His goal is to compare the quantity of sediment washed out of the canyon during the flood with the amount normally delivered into the canyon by the Paria and Little Colorado rivers. Smith is still analyzing his data, but he should soon be able to predict how often floods could be staged without depleting the existing sand reserve.

Several other scientists took special interest in the movement of sand. Using optical sensors and sonar equipment borrowed from his oceanographer colleagues at the USGS, David M. Rubin studied the sediment concentration of water entering an eddy and characterized the fine-scale patterns in the deposition of this sand. Working at the same site, Jon M. Nelson documented the curious behavior of swirling vortices that form in a line where the main downstream current rushes past a slower, upstream-flowing eddy. Nelson observed that as the main current pushes these vortices downstream, the vortices tip over, because flow is slowed near the channel bottom where friction is greatest. In this canted position, he reasoned, the vortices should then act to sweep sediment out of the main current and into the eddy.

But sediment came and went within the eddy at rates far greater than anticipated. With a sinking feeling, Rubin and Nelson watched as $70,000 worth of borrowed equipment was first buried, then excavated and finally carried away by the water. They were fortunate enough to have collected sufficient data to show that the vortex "sediment pump" operated as they had predicted. So their ideas withstood the test flood, even though much of their equipment did not.



**SCIENTIFIC STUDIES carried out during the experimental flood included documentation of fine-scale patterns of sand deposition using plaster molds (*bottom right*), time-lapse videography of the floodwaters (*bottom left*) and measurement, by means of a directional antenna (*top right*), of the displacement of boulders that were fitted with radio transmitters.**

PHOTOGRAPHS BY MICHAEL P. COLLIER

As expected, a good deal of the newly deposited sand quickly eroded, but months later much of it still remained at those sites monitored by scientists—and at many other places as well. During the summer of 1996, many longtime observers believed the Colorado River had taken on something of its original appearance. Those impressions echoed the more careful assessment of Lisa H. Kearsley, a biologist working for the Bureau of Reclamation. She tracked the fate of almost 100 beaches throughout the canyon and concluded that 10 percent of them were diminished by the flood, whereas 50 percent were augmented, and the remainder were unaffected. Six months after the flood, she found that much sand had slipped back into the river, but there was still more beach area than before.

The expanded beaches should please campers in years to come, but scientists are also anxious to know how the flood might have affected many less vocal residents of the canyon. Because the earlier unintentional flood of 1983 had hurt the trout fishery, some biologists were particularly concerned that the experimental flood of 1996 would wash many fish far downstream. To find out, biologists stationed below Lava Falls during the experimental flood placed nets in the river. These scientists captured a few more trout than they would have otherwise done, but their tests did not show any flushing of native fishes, whose ancestors had, after all, survived many larger natural floods. The biologists surmised that the native species (and most of the trout) must have quickly retreated to protected areas along the riverbank. Other investigators determined that the floodwaters had hardly disturbed the ubiquitous cladophora algae and associated invertebrates, which constitute an important source of food for fish.

But the effects on other components of the local biota are still a matter of intense debate. Lawrence E. Stevens, a biologist with the Bureau of Reclamation, has studied the river for 25 years as an entire suite of animals—some endangered—migrated into the canyon and survived in the artificial environment created by Glen Canyon Dam. He is concerned that intentional flooding may threaten the existence of some species protected by the Endangered Species Act, such as the humpback chub (a fish), the southwestern Willow Flycatcher (a bird) or the Kanab ambersnail. But we would argue that floods were part of the natural cycle of the Colorado River in the past, and many species, both common and endangered, have adapted to this process as long as there has been a Grand Canyon—for about five million years. Restoration of flooding may be detrimental to some organisms, but we and many of our colleagues hypothesize that in the long run a collection more resembling the native fauna will return.

## Epilogue

Did the flood work? It deposited significant amounts of sand above the normal high-water line and rejuvenated some backwater habitats important to spawning fish. The flood widened the two largest rapids on the river. Archaeological sites along the edge of the river were neither helped nor hurt by the high water; most of the encroaching vegetation was similarly unaffected.

So in our view the environmental benefits outweighed any damage. But one needs to consider other costs as well. Five months after the flood, David A. Harpman, an economist with the Bureau of Reclamation, was analyzing factors that bear on the final price tag. Because power had been continuously generated during the flood even at times when demand was low, and because the huge quantity of water sent through jet tubes produced no electricity at all, he

MICHAEL P. COLLIER

GLEN CANYON ENVIRONMENTAL STUDIES

**LAVA FALLS, a stretch of rapids in the Colorado, was narrowed by coarse, rocky material that had washed down a side canyon and spread into a fan-shaped deposit. An aerial photograph taken before the flood (*top left*) shows an obvious constriction in the river. A matching photograph taken after the flood (*bottom left*) reveals that much of the debris has been cleared away.**

**REJUVENATED BEACHES, such as the one enjoyed by these kayakers, signal that the flood restored habitats along the river's edge to a more natural configuration. Such changes should, for example, benefit native fish, which spawn in the shallows.**

estimates that the Bureau of Reclamation has foregone about $1.8 million in lost revenue (about 1 percent of the total yearly income from the sale of electricity). Add to this expense the price of the scientific studies, and the total cost of the experiment almost doubles.

Because similar expenditures will be incurred during future floods, the Bureau of Reclamation will want to know precisely how big and how often floods will be needed to support the environment. The answers are far from clear. All scientists involved agree that a future flood need not last seven days. Smith believes Grand Canyon beaches can be improved by floods staged perhaps every year, as long as incoming sediment from the Paria and Little Colorado rivers is at least as great as the amount of sediment carried out of the canyon during a flood. One of us (Webb) argues for an initial release of as much as 2,800 cubic meters per second to scour debris fans, followed by an immediate drop to more moderate beach-building levels. Andrews emphasizes that under any scenario, artificial floods should be made to vary in magnitude from year to year, the better to mimic natural variability.

Will there be more floods? Probably—both in Grand Canyon and elsewhere. We have studied several other American rivers controlled by dams, and they, too, would benefit from periodic floods. So the ideas and instrumentation developed by scientists working within Grand Canyon during the 1996 experimental flood could soon help restore natural conditions within and around many other rivers across the nation and, perhaps, throughout the world. SA

## *The Authors*

MICHAEL P. COLLIER, ROBERT H. WEBB and EDMUND D. ANDREWS have long cherished the splendor of Grand Canyon. Collier, who considers himself a writer and photographer rather than a true scientist, also maintains an active medical practice in Flagstaff, Ariz. He earned a master's degree in geology from Stanford University in 1978 and worked for six years as a river guide in Grand Canyon before he began collaborating with U.S. Geological Survey scientists. Webb received a doctorate from the University of Arizona in 1985 and then joined the staff of the USGS as a hydrologist. Since 1989 he has also taught at the University of Arizona. Andrews worked as a river guide in Grand Canyon from 1969 to 1974. Three years later he earned a doctorate from the University of California, Berkeley, and has since done research for the USGS in its water resources division. Andrews also maintains an ongoing affiliation with the University of Colorado at Boulder.

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# The Einstein-Szilard Refrigerators

*Two visionary theoretical physicists joined forces in the 1920s to reinvent the household refrigerator*

by Gene Dannen

In July 1939 Leo Szilard visited Albert Einstein to discuss the danger of atomic bombs. Szilard was alarmed by the recent discovery of uranium fission: he had realized almost six years earlier how a "chain reaction" could dangerously multiply such a process. Szilard's warning that nuclear weapons might be possible—and that Nazi Germany might build them—convinced Einstein to write his famous letter to President Franklin D. Roosevelt urging faster research efforts.

When Szilard visited Einstein on Long Island, N.Y., that day, he was also reviving a collaboration dating from Berlin's golden age of physics. It is part of the lore of physics that Szilard and Einstein held many joint patents, filed in the late 1920s, on ingenious types of home refrigerators without moving parts. But little information beyond the patents was thought to survive.

In the process of researching Szilard's life, I have been able to piece together almost the full story of this partnership. In Stockholm, I discovered that appliance manufacturer AB Electrolux still keeps files on two patents purchased from Einstein and Szilard. And in Budapest, the primary engineer for the inventions, Albert Korodi, shared cherished memories of the enterprise. Korodi, who died recently at the age of 96, had preserved copies of engineering reports—including the only known photographs of the Einstein-Szilard prototypes—that were long believed lost.

From these sources and from correspondence in the Leo Szilard Papers at the University of California at San Diego and from the Albert Einstein Archives at Princeton University (originals of the latter are at the Hebrew University of Jerusalem), a detailed picture of the Einstein-Szilard collaboration has emerged. The project was more extensive, more profitable and more technically successful than anyone guessed. The story illuminates Einstein's unlikely role as a practical inventor.

### Inventing with Einstein

Szilard and Einstein met in Berlin in 1920. Einstein, then 41, was already the world's most renowned physicist. Szilard, at 22, was a brilliant and gregarious Hungarian studying for his doctorate in physics at the University of Berlin. For his dissertation, Szilard extended classical thermodynamics to fluctuating systems, applying the theory in a way that Einstein had said was impossible. The "Herr Professor" was impressed, and a friendship grew.

After graduation, Szilard later recalled, Einstein advised him to take a job in the patent office. "It is not a good thing for a scientist to be dependent on laying golden eggs," Einstein said. "When I worked in the patent office, that was my best time of all."

Despite this suggestion, Szilard chose an academic career at his alma mater and soon solved the problem of Maxwell's Demon. This imp, first imagined by James Maxwell, could seemingly violate the second law of thermodynamics by sorting fast and slow molecules, thus confounding their natural tendency to become disordered. The demon could then power a perpetual-motion machine. Szilard showed that this was false: the apparent gain in order was supplied by the information used to produce the effect. His solution included the idea of a "bit," later to be recognized as the cornerstone of information theory. In late 1924 Nobel laureate Max von Laue selected Szilard to be his assistant at the university's Institute for Theoretical Physics.

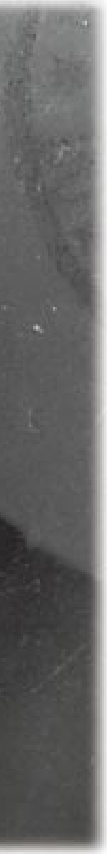
LEO SZILARD PAPERS, MANDEVILLE SPECIAL COLLECTIONS LIBRARY *University of California, San Diego*

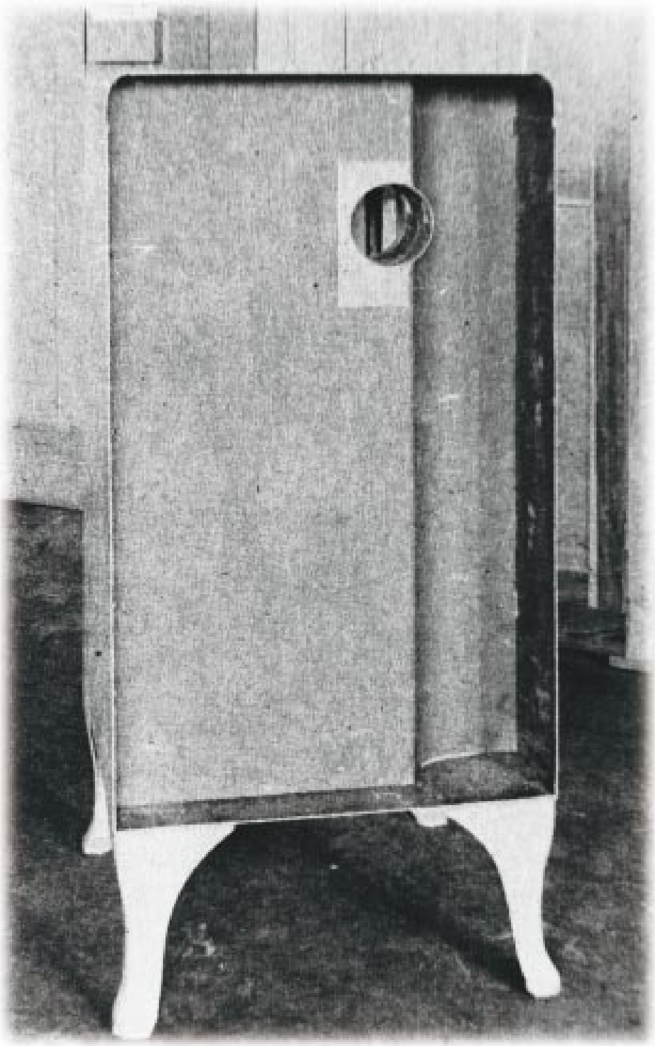
**REFRIGERATOR CABINET (*center*), seen from the rear, awaits installation of an electromagnetic pump invented by Leo Szilard (*left*)**

By the mid-1920s, Szilard had become a frequent visitor to Einstein's home. In some ways, the two men were opposites. Szilard was outgoing and self-confident (some said arrogant); Einstein was modest and retiring. In more important ways, however, they were kindred spirits. They shared a joy in ideas, a strong social conscience—and a fondness for invention.

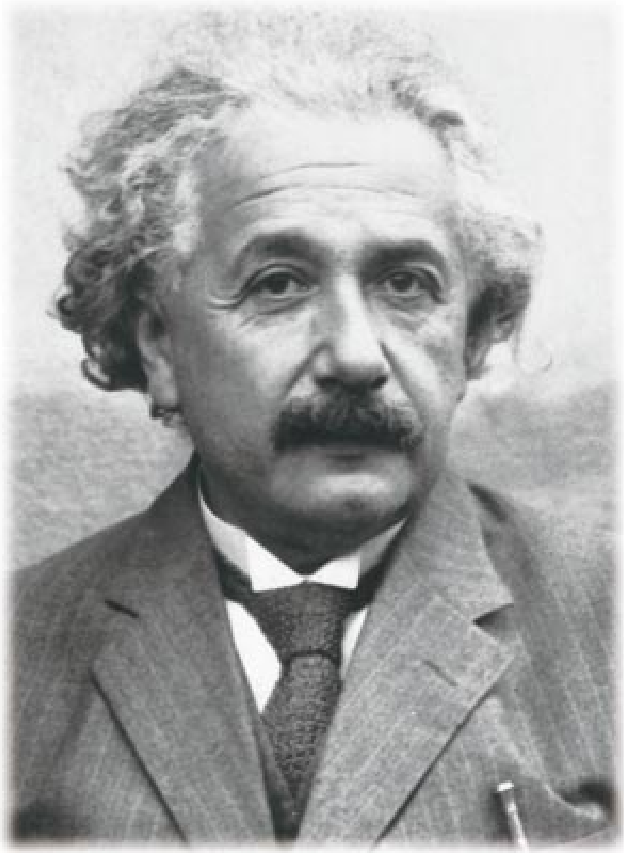
According to the late Massachusetts Institute of Technology physicist Bernard Feld, who heard the story from Szilard, the refrigerator collaboration began with a newspaper article. One day Einstein read about an entire family—parents and several children—who had been killed in their beds by the poisonous gases leaking from the pump of their refrigerator. At the time, such accidents were a growing hazard. Mechanical home refrigerators were starting to replace traditional iceboxes. Chemistry, however, had yet to produce a nontoxic





COURTESY OF ALBERT KORODI, © A.E.G.



UPI/CORBIS-BETTMANN

**and Albert Einstein (*right*). The refrigerator, developed at the A.E.G. Research Institute in Berlin, was never marketed, partly because of the Great Depression.**

refrigerant. The three cooling gases then commonly used—methyl chloride, ammonia and sulfur dioxide—were all toxic, and the quantities in a refrigerator could kill.

Einstein was distressed by the tragedy. "There must be a better way," he said to Szilard. The two scientists reasoned that the problem was not just the refrigerant. Such leakages, from bearings and seals, were inevitable in systems with moving parts. From their knowledge of thermodynamics, however, they could derive many ways to produce cooling without mechanical motion. Why not put these to use?

There was personal incentive to try. At that time, evidently the winter of 1925–1926, Szilard was preparing to take the next step in a German academic career—to become a privatdocent, or instructor. As an assistant, he received a salary; as an instructor, however, he would be forced to scrape by on small fees collected from students. The inventions, if successful, could support Szilard's budding career.

Einstein, who wanted to help his gifted young friend, agreed to a collaboration. A letter from Szilard to Einstein preserves the terms of their agreement. All inventions by either of them in the field of refrigeration would be joint property. Szilard would have first claim on profits if his income fell below the salary of a university assistant. Otherwise, all royalties would be shared equally.

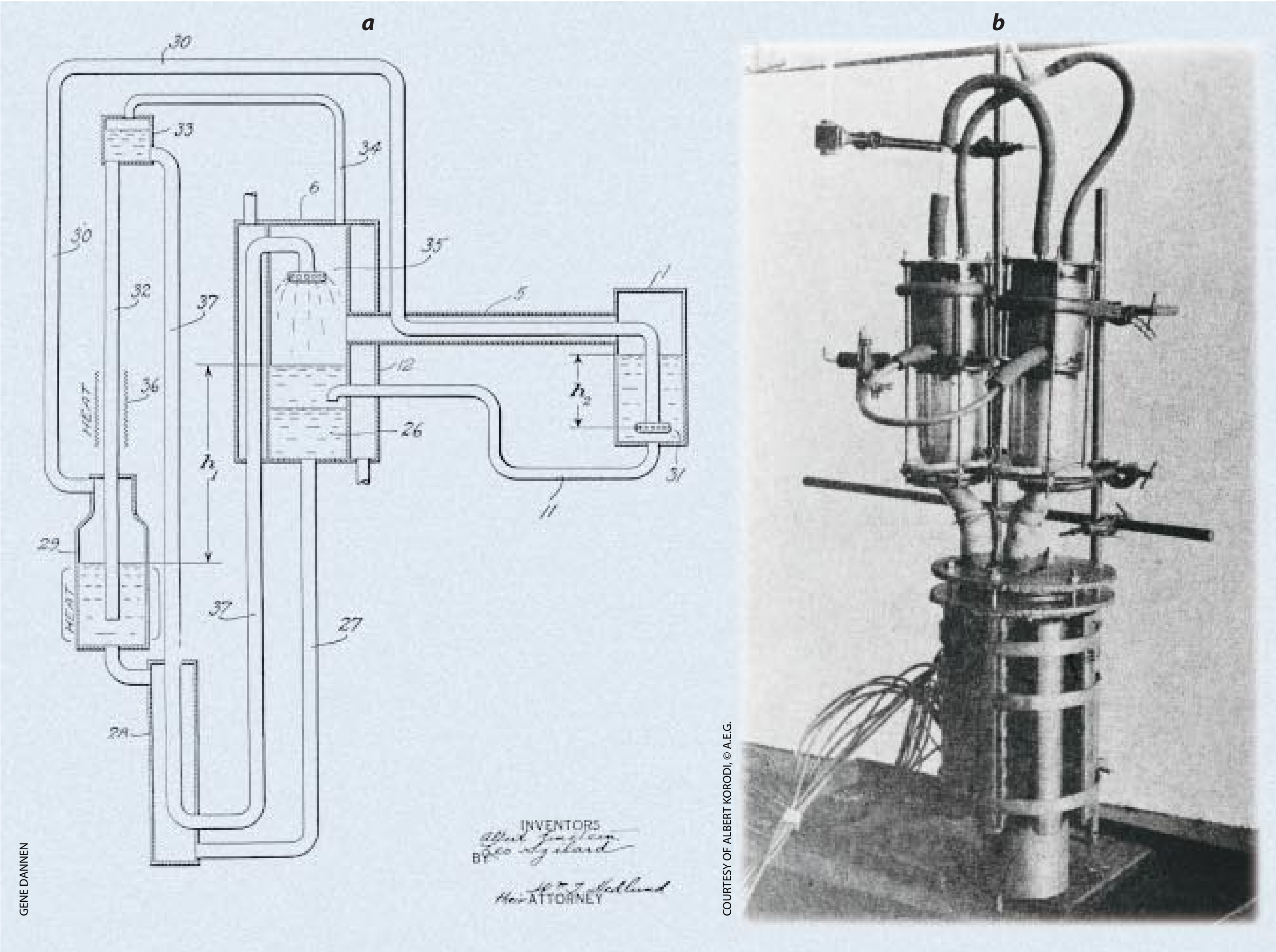
### Early Designs

Then, as now, most refrigerators used mechanical compressor motors. A refrigerant gas is compressed, liquefying as its excess heat is discharged to the surroundings. When the liquid is allowed to expand again, it cools and can absorb heat from an interior chamber. Einstein and Szilard considered a different concept, used in so-called absorption refrigerators, to be the safer. In these devices, heat from a natural gas flame—rather than the push of a piston—drives the cooling cycle. One new design, by Swedish inventors Baltzar von Platen and Carl Munters, and marketed by AB Electrolux, was considered a breakthrough. Szilard devised an improvement.

In fact, the entrepreneurs did not stop with a single design; they came up with many. Einstein's experience as a patent examiner allowed them to do without the usual attorneys, and in early 1926 Szilard began filing a series of patent applications on their inventions. By the fall, they had decided on the three most promising designs.

Each refrigerator, it seems, was based on an entirely different physical concept—absorption, diffusion or electromagnetism. In a letter to his brother, Bela, written in October, Szilard described their progress. "The matter of the refrigerator patents, which I applied for together with Professor Einstein, has now come so far that I feel it is a reasonable time to get into contact with industry," he wrote. "All three machines work without moving parts, and are hermetically sealed.... One of these three types is nearly identical with one of the Electrolux company's machines (in my opinion the best at the moment).... The other two types are completely different from




**DIVERSE PRINCIPLES lie behind the Einstein-Szilard refrigerators. An absorption design (*a*) purchased by AB Electrolux uses a heat source and a combination of fluids to drive the refrigerant, butane, through a complex circuit. The butane, initially a liquid, vaporizes in the presence of ammonia in the refrigerant chamber 1 (*at right*), taking up heat. The gaseous mixture passes to chamber 6 (*center*), where water absorbs the ammonia, freeing liquid butane to be recirculated. The electromagnetic pump (*b*) developed by A.E.G. pushes a liquid metal through a cylinder; here it is using mercury for test purposes. The**

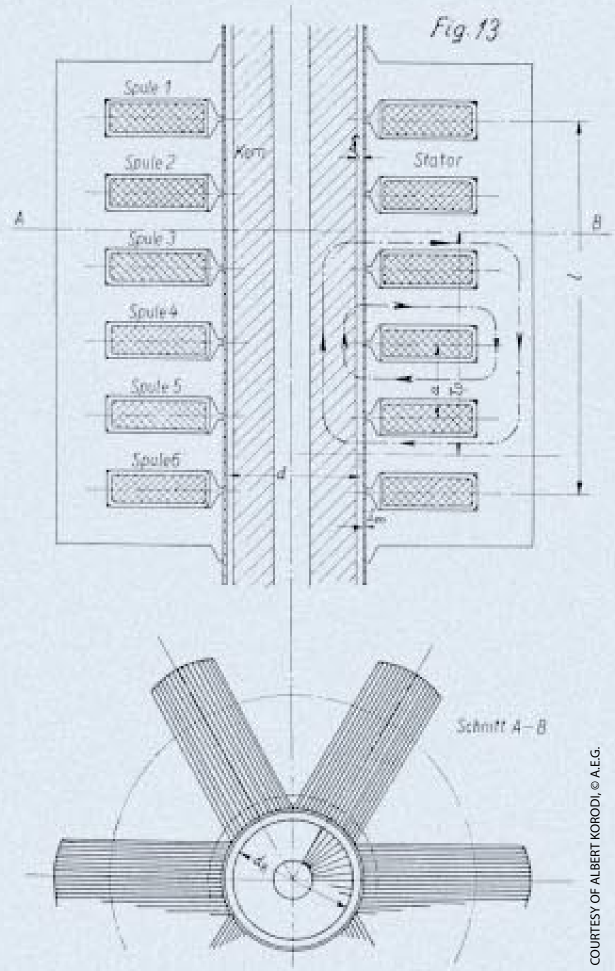
any other machines known until now."

Szilard quickly negotiated a contract with the Bamag-Meguin company, a large manufacturer primarily of gaswork equipment with factories in Berlin and Anhalt. In late 1926 Szilard began to supervise the development of prototypes at the laboratories of the Institute of Technology in Berlin. Albert Kornfeld, a Hungarian graduate from the electrical engineering department of the institute, started working on the refrigerators at this time. (Kornfeld later changed his name to Korodi, and I will use that name hereafter.) In 1916 Korodi had won the Eötvös Prize, the prestigious Hungarian mathematics competition for 18-year-old students. After meeting Szilard through the Eötvös competition, Korodi had studied with him at the Budapest Technical University. Later he followed Szilard to Berlin, where they lived in the same apartment building and became close friends.

Unfortunately, the agreement with Bamag-Meguin lasted less than a year. "Bamag-Meguin got in difficulties at that time. I think they dropped all uncertain projects," Korodi recalled. Within months, however, the inventors reached agreements with two other companies, one Swedish and one German.

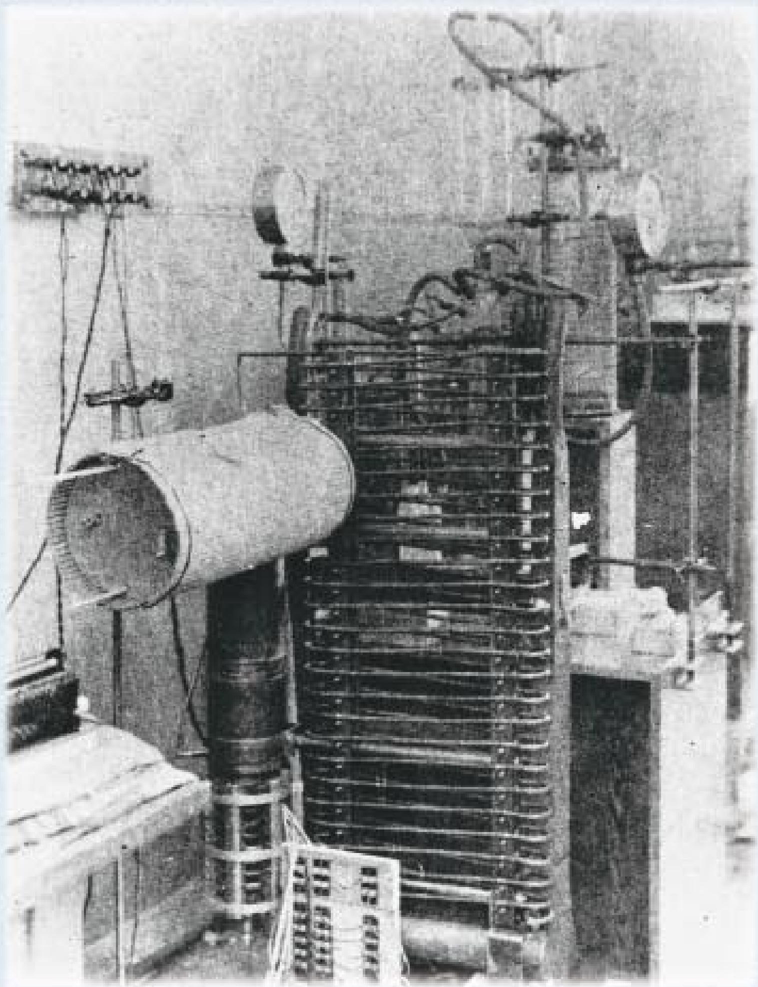
The Swedish company was AB Electrolux. On December 2, 1927, Platen-Munters Refrigerating System, a division of Electrolux in Stockholm, bought a patent application for an absorption refrigerator from the two inventors for 3,150 reichsmarks, or $750. Both parties were pleased with the transaction. Electrolux's files show that it considered the purchase price "very cheap"; even so, Szilard and Einstein earned roughly $10,000 in today's dollars.

The application for a U.S. patent on the absorption device caused some polite consternation. "I would be interested to know if Albert Einstein is the same person who propounded the theory of relativity," wrote back the American patent attorney responsible for the case. If so, he continued, the patent office should not object to Einstein's unusual claim of dual Swiss-German citizenship: "Albert Einstein is listed in the Standard Dictionary under the word 'Einstein' as an adjective denoting a theory of relativity. The dictionary explains that the name is derived from Albert Einstein, a citizen of both Switzerland and Germany. With this designation in one of the accepted dictionaries, I think the Patent Office will not object c




COURTESY OF ALBERT KORODI, © A.E.G.

d



COURTESY OF ALBERT KORODI, © A.E.G.

**blueprint (*c*) shows the cylinder lengthwise (*above*) and in cross section (*below*). Alternating current flowing through coils (arranged like spokes of a wheel) provides electromagnetic induction to drive the liquid, which acts as a piston to compress a refrigerant. A nearly complete refrigerator assembly (*d*) uses a potassium-sodium alloy—the pump is the dark vertical cylinder near the bottom—and a pentane refrigerant. The prominent array of condenser coils operates the same way as in modern refrigerators. The two photographs, from 1932, were recently discovered by the author.**

to the statement that Prof. Einstein is a citizen of two different countries."

Electrolux also later purchased the diffusion design; the patent it took out on this invention, however, does not mention Einstein or Szilard. Nor did Electrolux ever develop either of the two patents. The documents show that, despite admiration for their ingenuity, the firm bought the designs mostly to safeguard their own pending applications.

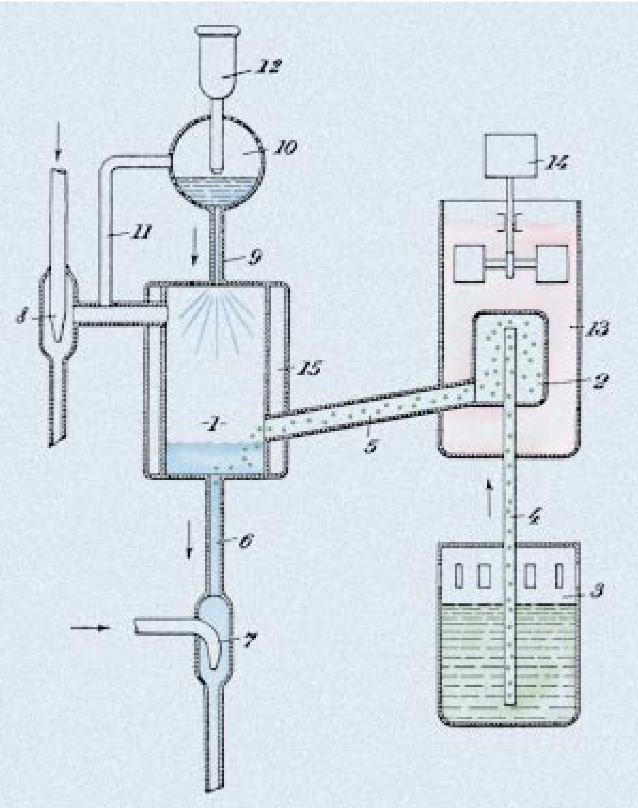
Another, much different Einstein-Szilard design produced a partnership with the Citogel company in Hamburg (the company's name means "quick freeze" in Latin). According to Korodi, the invention was Einstein's response to the diabolical complexity of absorption designs: "[He] proposed a quite simple and cheap system especially suited for small refrigerators."

The device, Korodi recalled, was "a small immersion cooler that could be dipped for instance in a cup of some beverage to be cooled." Requiring no conventional power source, it operated solely off the pressure of a water tap. The pressure powered a water-jet pump, producing a vacuum in a chamber from which water and a small amount of methanol were evaporated. The methanol was slowly used up, but the liquid was cheap and readily available. It could be expended and replaced, Korodi explained: "That was the idea of Einstein."

The cooler worked well, and a prototype was demonstrated under the Citogel name at the Leipzig Fair in early 1928. Korodi, who moved to Hamburg to work with Citogel on the invention, remembered Szilard's exasperation at the eventual outcome. Methanol in retail quantities did not turn out to be as cheap as expected. But more important, the ingenious cooler, which required reliable water pressure, met its match in the haphazard German water system. At the time, the pressure of tap water varied between buildings as well as from floor to floor within a building. In the end the variations proved too great, and the invention was not marketed.

### The Einstein-Szilard Pump

The most revolutionary, and most successful, invention would become known as the Einstein-Szilard electromagnetic pump. It was a fully functional pump without mechanical moving parts. Instead a traveling electromagnetic field caused a liquid metal to move. The metallic fluid, in turn, was used as




**WATER PRESSURE from a tap drives this small cooling device, developed (in simpler form) by Citogel in Hamburg. Methanol contained in chamber 3 evaporates in chamber 2, cooling the surrounding compartment 13. Turbine 14 churns ice cream or other frozen foods. The methanol dissolves in water in chamber 1 and flows out, so it has to be replenished. The device was not marketed because of variable water pressure in German buildings.**

LEO SZILARD PAPERS, MANDEVILLE SPECIAL COLLECTIONS LIBRARY *U.C.S.D.*

a piston to compress a refrigerant. (The refrigerant cycle, after that point, was the same as in standard refrigerators.)

Korodi remembered vividly that the device was first envisioned as an electromagnetic conduction pump, with an electric current passing through the liquid metal. Mercury was an obvious first choice, but its low conductivity would provide very poor efficiency. Szilard then suggested an alternative liquid metal—a potassium-sodium alloy with much better conductivity. Although potassium and sodium were both solids at room temperature, an optimal mixture of the two was liquid above its melting point of –11 degrees Celsius. Unfortunately, the metals were chemically aggressive and would attack the insulation of the wires carrying current to the mixture.

Szilard and Korodi considered different insulating materials, then Szilard took the problem back to Einstein. "Einstein thought a few minutes," Korodi related, and proposed eliminating the need for such wires by applying indirect force from exterior coils, by induction.

The invention therefore became an induction pump. Korodi, who calculated the expected efficiency of the pump for potassium-sodium alloys, found that it was still much less efficient than standard compressors. What it lacked in efficiency, however, it gained in reliability. "It was worthwhile to make such a compressor," he stated: an Einstein-Szilard pump would not leak or fail.

In the fall of 1928 the Allgemeine Elektrizitäts Gesellschaft (German General Electric Company), or A.E.G., agreed to develop the pump for refrigeration. The A.E.G. was a prosperous Berlin firm with its own research institute, where it established a special department led by two full-time engineers. Korodi was hired to develop electrical aspects of the invention. Another Hungarian engineer friend of Szilard's, Lazislas Bihaly, was taken on to develop the mechanical side. Szilard, with the title of consultant, directed the team.

Korodi and Szilard received salaries of 500 reichsmarks a month, the equivalent of $120. "It was a good salary," Korodi observed, at a time when "a car, a Ford, cost $300." For Szilard, the A.E.G. contract was even more lucrative. Patent royalties, in addition to his consulting fees, eventually brought his income to a comfortable $3,000 a year (worth roughly $40,000 today).

Szilard and Einstein kept a joint bank account, but the sum Einstein actually accepted from the partnership remains unknown. Korodi described Einstein as far from a silent partner, however: he visited the laboratory at each stage of construction to check on the prototypes. Korodi also remembered visiting Einstein's Berlin apartment with Szilard, perhaps a dozen times, to talk about new inventions. "I didn't talk to Einstein about physics," he recalled with a laugh.

For Szilard, who did discuss physics with Einstein, the collaboration was funding an increasingly productive career. At the University of Berlin, Szilard was teaching seminars in quantum theory and theoretical physics with John von Neumann and Erwin Schrödinger. His other inventions during this period included the linear accelerator, cyclotron and electron microscope. Einstein, meanwhile, continued his tireless pursuit of the Unified Field Theory but also worked with other inventors on a gyrocompass and a hearing aid.

Even as the refrigerator advanced, however, dark clouds were gathering. In the Reichstag elections of September 14, 1930, the tiny Nazi party received almost 20 percent of the vote. Szilard, with his legendary foresight, saw what others did not. On September 27 he wrote to Einstein with a prophetic warning: "From week to week I detect new symptoms, if my nose doesn't deceive me, that peaceful [political] development in Europe in the next ten years is not to be counted on.... Indeed, I don't know if it will be possible to build our refrigerator in Europe."

### A Working Refrigerator

Until recently, the only known detail of the Einstein-Szilard electromagnetic pump prototype was its objectionable noise. Although expected to be silent, the pump suffered from cavitation—the expansion and collapse of tiny voids or cavities—as the liquid metal was forced through the pump. Physicist Dennis Gabor, who was one of Szilard's best friends in Berlin, once commented that the pump "howled like a jackal." Another "earwitness," according to American physicist Philip Morrison, said it wailed "like a banshee."

Korodi, on the other hand, described the sound as resembling that of rushing water. Furthermore, as detailed in the A.E.G. final report, the noise depended on the force and speed of the pump. A combination of tricks—reducing the voltage at the start of each stroke, for example—eventually lowered the noise to acceptable levels.

From an engineering viewpoint, the noise problem was mostly cosmetic. The truly interesting challenges arose in working with chemically reactive metals. Special equipment was developed to fill the pump without the (possibly explosive) oxidation of the sodium and potassium. Despite this difficulty, Korodi emphasized that there would have been no danger to refrigerator owners. The Einstein-Szilard refrigerator was a sealed system, with the liquid metals fully contained in welded stainless steel.

Many problems had been solved, but the noise was still under attack, when a full prototype was constructed. "In two years," Korodi stated, "a complete refrigerator was built, which worked—operated—as a refrigerator." On July 31, 1931, an Einstein-Szilard refrigerator went into continuous operation at the A.E.G. Research Institute. For comparison with existing units, the apparatus was mounted in the cabinet of a four-cubic-foot (120-liter) General Electric model G40 refrigerator. With a potassium-sodium alloy as its liquid metal and pentane as a refrigerant, the prototype operated at 136 watts, consuming 2.3 kilowatt-hours a day.

"The efficiency was as good as it was calculated," Korodi insisted. But for the A.E.G., battered by the growing worldwide depression, the refrigerator was not good enough. Improvements in conventional refrigerators, in addition to the economic slump, were shrinking the potential market. The 1930 American demonstration of a nontoxic "Freon" refrigerant, in particular, promised to eliminate the danger of leaks. (Only decades later, of course, would it be realized that such chlorofluorocarbons might endanger the ozone layer of the entire planet.)

Work continued in the A.E.G. laboratory for another year, resulting in improved pump prototypes and a change in liquid metals. The internal heat of the pump had proved sufficient to keep pure potassium above its melting point of 63 degrees C. A four-month-long test operation with potassium was successful, increasing the electrical efficiency from 16 to 26 percent. The Depression-ravaged A.E.G., however, was not persuaded to continue the research.

Szilard tried to interest manufacturers in Britain and America, also to no avail. In 1932 the A.E.G. Research Institute was reduced by half, eliminating all but essential projects. Korodi helped to write the 104-page final report on the Einstein-Szilard refrigerator development: *A.E.G. Technischer Bericht 689,* dated August 16, 1932. (It is fortunate that Korodi kept a copy of this manuscript, because the A.E.G.'s files were destroyed in World War II.)

Only months later Adolf Hitler's appointment as chancellor ended Berlin's golden age of physics. Szilard fled to Britain and then to America. Einstein found refuge at the Institute for Advanced Study in Princeton, N.J. Korodi returned to Budapest, where he found work with the Hungarian division of Philips and built a successful career in telecommunications. He died in Budapest on March 28, 1995.

**Applied Physics**

In the seven years of their collaboration, Szilard and Einstein filed more than 45 patent applications in at least six countries. Although none of their refrigerators reached consumers, the designs were ingenious applications of physical principles. The Einstein-Szilard pump, in particular, eventually proved its value. The built-in safety of its design later found a more critical task in cooling breeder reactors.

As intended, the inventions had supported Szilard's academic career in Germany. His savings, moreover, saw him through two more years in Britain. After selflessly helping fellow refugee scholars find university positions, he turned to nuclear physics and conceived the neutron chain reaction in the autumn of 1933. Szilard's early research on atomic energy was in fact made possible by this money.

For decades, it seemed a mere curiosity that Szilard and Einstein should have chosen to design refrigerators. Today, with refrigeration technology again a priority—this time the earth's ozone layer might be at stake—the challenge of the problem has become clear. For Szilard and Einstein, the inventions were more than a brief interlude. From their first collaboration in physics to their later efforts in controlling the threat of nuclear weapons, Szilard's and Einstein's scientific accomplishments and their commitment to humanity were closely intertwined. SA

CAROL GRAM PAULSON

**ALBERT KORODI (1898–1995) was the primary engineer for the inventions. He is holding the Tivadar Puskás Award of the Hungarian Scientific Society for Telecommunications, which he received in 1993.**

*The Author*

GENE DANNEN is an independent scholar who has been researching the life of Leo Szilard for 15 years. This article is adapted from his forthcoming book on Szilard's role in the birth of the nuclear age. He owes special thanks to the Mandeville Special Collections Library at the University of California, San Diego; the department of rare books and manuscripts at Princeton University Libraries; Egon Weiss for permission to use Szilard's unpublished letters; Henry Throop and Carol Paulson for conducting interviews with Albert Korodi; and Mihály Korodi. Dannen can be reached by e-mail at danneng@peak.org

*Further Reading*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# Science versus Antiscience?

*Movements lumped under the term "antiscience" have disparate causes, and not all pose as much of a threat as has been claimed*

by the staff of *Scientific American*

Science has long had an uneasy relationship with other aspects of culture. Think of Galileo's 17th-century trial for heresy before the Catholic Church, which formally admitted its error just four years ago, or poet William Blake's rants against the mechanistic worldview of Isaac Newton. The schism between science and the humanities has, if anything, deepened in this century, as C. P. Snow documented in his classic 1959 essay *The Two Cultures and the Scientific Revolution*.

Until recently, the scientific community was so powerful that it could afford to ignore its critics—but no longer. As funding for science has declined, scientists have denounced "antiscience" in several books, notably *Higher Superstition,* by Paul R. Gross, a biologist at the University of Virginia, and Norman Levitt, a mathematician at Rutgers University; and *The Demon-Haunted World,* by Carl Sagan of Cornell University.

Defenders of science have also voiced their concerns at meetings such as "The Flight from Science and Reason," held in New York City in 1995, and "Science in the Age of (Mis)information," which assembled last June near Buffalo. And last spring the physicist Alan D. Sokal of New York University re-

## Postdiluvian Science

In an industrial park set in the arid hills 15 miles east of the San Diego waterfront, there is a tourist attraction usually bypassed by the hordes who descend every year on Sea World and the San Diego Zoo. The Museum of Creation and Earth History is a creationist's version of a natural history museum. Each exhibit displays a milestone in the Christian creationist interpretation of history: the six days when God made the earth, the Fall of Man, the Flood, the Tower of Babel, the rise of nonmonotheistic religions and the emergence of Darwinian theory.

The low-slung building is a monument to the life's work of Henry M. Morris, the 78-year-old patriarch of creation science. Morris came to the world's attention in 1961 with the publication of *The Genesis Flood*. With co-author John C. Whitcomb, Morris popularized the notion of early 20th-century creationist George McCready Price that the earth's major geological features were formed by the effects of Noah's flood only a few thousand years ago.

Morris's advocacy of the Biblical account as historical fact helped to foster a creationist revival in the 1960s. During this time, the federal government poured millions of dollars into biology teaching as part of an effort to bolster science education after the Soviet launch of the *Sputnik* satellite. Until then, the teaching of evolution had been largely absent from high school curricula because of fears of controversy it might engender.

The intricate rewriting of science by Morris and his colleagues—an exegesis of radiometric dating, of estimates of the distance to stars and of the fossil record—represents creationism at its most extreme and perhaps the most radical incarnation of antiscientific thought as well. Morris, in his teachings, expropriates the ideas of science and the authority that society accords scientific rationalism to make the case for a literal interpretation of the Biblical account in the book of Genesis. Anthropologist Christopher P. Toumey has written of the Institute for Creation Research, the educational and research organization founded by Morris, "It [ICR] gives conservative Christians the creation stories they want to hear with the moral meanings they require, and it sets them upon a stage of scientific sanctification decorated with test tubes, Kuhnian paradigms, white lab coats, monographs, geological expeditions, quotes from Karl Popper and secular credentials."

Geological expeditions and Kuhnian paradigms are in full view at the ICR museum, which expanded in 1992 to fill its current 4,000-square-foot space. The antithesis of a powerful cultural institution, the museum emanates a homespun quality that mirrors its grassroots following. Its reported $50,000 price tag roughly matches the cost a better-endowed institution might pay for a dinosaur skeleton. A room depicting the fifth through seventh days of creation houses an array of live animals, including finch-

**FALL FROM EDEN is illustrated at the Museum of Creation and Earth History near San Diego, where religious and scientific themes mix. The creationist museum describes death and decay in terms of both original sin and thermodynamics.**

vealed that an article he had written for the journal *Social Text* was a parody intended to expose the hollowness of postmodernism, which at its most extreme depicts the big bang theory as just another creation myth.

Antiscience clearly means different things to different people. Gross, Levitt and Sokal find fault primarily with sociologists, philosophers and other academics who have questioned science's objectivity. Sagan is more concerned with those who believe in ghosts, alien abductions, creationism and other phenomena that contradict the scientific worldview.

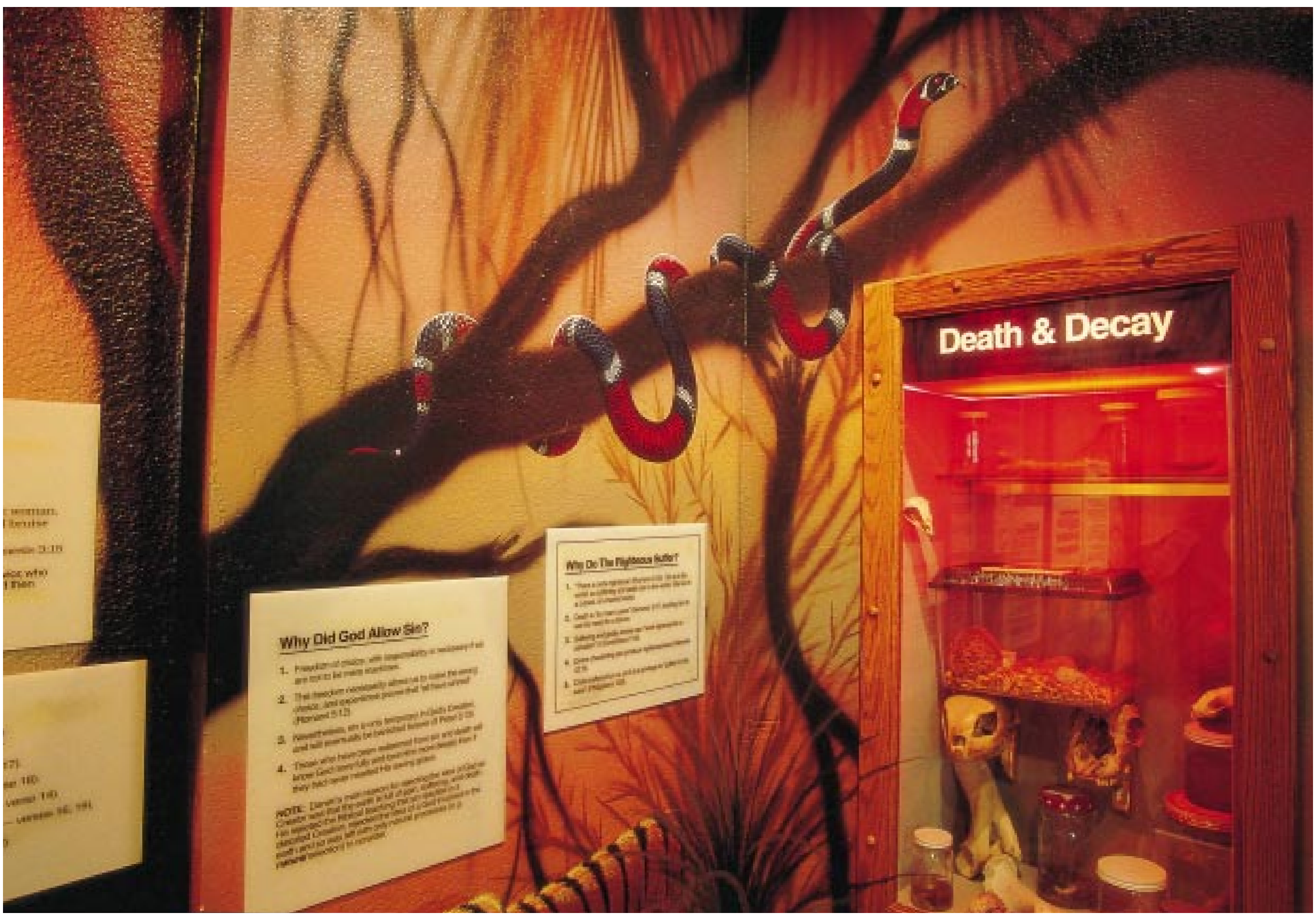
A survey of news stories in 1996 reveals that the antiscience tag has been affixed to many other groups as well, from authorities who advocated the extermination of the last remaining stocks of smallpox virus to Republicans who advocated decreased funding for basic research.

Few would dispute that the term applies to the Unabomber, whose manifesto, published in 1995, excoriates science and yearns for a return to a pretechnological utopia. But surely that does not mean that environmentalists concerned about untrammeled industrial growth are antiscience, as an essay in *U.S. News & World Report* last May seemed to suggest.

The environmentalists, inevitably, respond to such critics with the venerable "I'm rubber and you're glue" defense. The true enemies of science, argues Paul Ehrlich of Stanford University, a pioneer of environmental studies, in his just published book *The Betrayal of Science and Reason,* are those who question the evidence supporting global warming, the depletion of the ozone layer and other consequences of industrial growth.

Indeed, some observers fear that the antiscience epithet is in danger of becoming meaningless. "The term 'antiscience' can lump together too many, quite different things," notes Harvard University philosopher Gerald Holton in his 1993 work *Science and Anti-Science,* "that have in common only that they tend to annoy or threaten those who regard themselves as more enlightened."

In this article, *Scientific American* looks at three topics selected from among the most prominent trends tarred with the antiscience brush. First, Gary Stix visits the Institute for Creation Research, one of the oldest centers of anti-Darwinian thinking in the country, which tries to undermine noncreationist accounts of nature with idiosyncratic scientific theories. Sasha Nemecek then weighs the threat posed by feminist critiques of how science is conducted. Finally, Philip Yam lifts the lid on the rise of television programs such as *The X-Files,* which may promote belief in pseudoscience and the occult, as well as the commercial forces driving their proliferation. Readers can ponder for themselves what kinds of challenges to science these phenomena pose and how useful the antiscience label is in understanding them. —*The Editors*




JAMES ARONOVSKY *Zuma*

es, their presence an allusion to the birds Charles Darwin studied. A ball python doubles as a product of God's sixth-day labors and a symbol of temptation.

The Fall room highlights the second law of thermodynamics, one of the creationists' favorite physical laws. Just as postmodernist theorists invoke Heisenberg's uncertainty principle as a symbol of metaphysical uncertainties, so does the creationist camp view the tendency of things to drift toward disorder as representing Adam and Eve's fall from grace. This leaning toward disarray "precludes any natural evolution toward higher order," the ICR maintains.

JAMES ARONOVSKY Zuma

**FLOOD GEOLOGY, the notion that Grand Canyon formed about the time of Noah's flood, is explained to visitors at the Museum of Creation and Earth History.**

The second law's effects are demonstrated with a broken record, a shattered beaker and a picture of the *Titanic.*

The makeshift atmosphere extends to the "laboratories" in the ICR offices adjoining the museum where the institute's eight full-time scientists carry out their research. Larry Vardiman, a former cloud-seeding expert with the Department of the Interior who now runs the ICR's astrogeophysics program, is trying to analyze the meteorological conditions associated with the Flood. Vardiman notes that the aging IBM personal computer running a public-domain program from the National Center for Atmospheric Research needs six weeks to simulate a year's worth of global atmospheric changes; the task would take less than a day on a larger computer. "I really need access to a Cray [supercomputer]," Vardiman laments.

Applying numerical-modeling methods to Biblical history can produce unexpected consequences. A mural at the museum's entrance shows a 40-foot-deep canopy of water vapor hovering above the newly created earth. Hoping to demonstrate that the condensation of this huge cloud might have contributed to Noah's flood, Vardiman found instead that it would have created a greenhouse effect so severe that it would have "cooked" every living thing on the planet. Vardiman's work now focuses on how the polar ice caps could have formed immediately after the Flood.

Down the hall from Vardiman's computers, Henry Morris still maintains a book-lined office, although his son, John, has assumed day-to-day management of the ICR. On a shelf in Morris's office is his 1972 textbook, *Applied Hydraulics in Engineering*. Still in print, it recalls this portly, avuncular figure's former career as a professor and chair of the department of civil engineering at the Virginia Polytechnic Institute and State University.

As his working years draw to a close, Morris seems undaunted by the fact that many of the battles he helped to inspire over the past 35 years have concluded with a court barring the teaching of creation science on constitutional grounds. To Morris, these losses vindicate his advocacy of a grassroots strategy that bypasses the political system entirely. Morris may have judged correctly by making his appeal at such a down-home level: pollsters say that currently almost half the American public believes God created humans sometime within the past 10,000 years.

Morris maintains that outreach should be accomplished through books and pamphlets or ICR conferences. The ICR mailing list exceeds 100,000 names, and Morris points to societies of scientists and engineers who remain steadfast advocates. "When I started this 55 years ago, I couldn't find any other scientists who were creationists. Now there are thousands of them," he says.

Morris does not fret either that he and his colleagues may even be out of step with other creationists. In recent years the most dynamic segment of the movement has moved away from the literalist interpretations put forward by the "young earth" school. Proponents of so-called intelligent design—some of whom even eschew the creationist title—do not waste their time on critiques of radiometric dating. Instead they question whether random mutations coupled with natural selection could have given rise to complex biological processes such as blood clotting.

Morris believes intelligent design is a bid by creationists for broader acceptance that will ultimately fail. "I don't think we'll ever get the approbation of the majority of mainstream scientists," he says. But intelligent-design proponents owe a debt of thanks to Morris. He was a leader in the early 1970s in casting creationism in the guise of "creation science" as an alternative theory to evolution—and one that could describe the details of physical origins without any direct reference to the Scriptures. Other creationists used Morris's arguments to get state laws passed mandating equal time for their views in the classroom. The legislation was subsequently overturned by federal courts, including, in one case, the U.S. Supreme Court. But even today the intelligent-design community pursues a similar strategy, reducing evolution to a speculative theory that needs to be examined against other hypotheses.

It is true that creationists on local school boards will continue to goad science educators. But the prospects for creationism as a larger political force—a Christian version of the Taliban, the religious fundamentalists who have wrested political control in Afghanistan—are relatively bleak.

The societal mainstream pays creationists little heed. A recent *Time* magazine cover story on a nationwide revival of interest in the stories recounted in Genesis mentioned literal creationism only to discredit it. Among the clergy, Pope John Paul II recently endorsed evolution as "more than just a hypothesis." Even the Christian right would rather devote its lobbying effort to abortion and school prayer. "Creationism, like loyalty to Taiwan or fear of rock music, has been more a sideshow," writes Toumey in his book *God's Own Scientists: Creationists in a Secular World*.

In this environment, Morris's tiny museum near the cowboy bar and the drive-in movie theater may serve as a model for an entire movement that chooses to guard its precious isolation on the outskirts of town. *—Gary Stix*

# The Furor over Feminist Science

In *Higher Superstition,* their call to action against the forces of antiscience in academia, Paul R. Gross and Norman Levitt take on what they call a "new academic industry"—feminist critiques of science. Gross and Levitt contend that this highbrow assault, along with related branches of the field known as science studies, challenges whether science has a legitimate claim to truth and objectivity. "The new criticism is sweeping: it claims to go to the heart of the methodological, conceptual, and epistemological foundations of science," they write of the feminist camp.

Critics who accuse feminist science studies of being antiscience often cite the most radical scholarship—such as philosopher Sandra Harding's charge that Isaac Newton's *Principia Mathematica* is a "rape manual." Although feminists have taken a particularly hard hit in recent skirmishes between "the two cultures," they certainly have not held up a white flag.

Feminists began their scrutiny of science in the 1960s and 1970s by concentrating primarily on inequalities in science education and employment; their arguments opened eyes as well as doors. In 1994 women received approximately 25 percent of the Ph.D.'s awarded in the U.S. in engineering, physical sciences and biological sciences, compared with roughly 6 percent in 1970.

By the late 1970s, feminist critiques of science began to touch on the material of science itself, asking whether and how various disciplines might have been molded by the exclusion of women. For instance, medical researchers once relied on data drawn solely from male subjects when studying a disease or a new drug—a practice that certainly skewed their understanding of women's health. But today women are included in drug studies more routinely. Ailments such as heart disease, once seen primarily as a male affliction, are now recognized as important problems for women as well.

Digging deeper into the philosophy of science, feminist scholars considered how scientists' choices of topics and descriptive terminology reflect prevailing cultural attitudes about gender—and, in the process, ignited some spectacular rhetorical fireworks. One prominent practitioner of feminist scholarship is the historian and philosopher of science Evelyn Fox Keller of the Massachusetts Institute of Technology.

Keller, who trained as a theoretical physicist, has been "looking at how traditional ideologies of gender got into science through gendered metaphors." By gender, she does not mean how many X and Y chromosomes a person has but rather stereotypes about what is "masculine" and "feminine." For instance, she points to a long tradition in Western culture of viewing rational thinking as a masculine trait, while seeing intuition as feminine.

Keller emphasizes that she is not suggesting that women in fact think intuitively or that all men are purely rational, only that certain traits have been historically associated with one or the other sex. And historically, it seems that traits labeled as feminine were often undervalued.

This theme pervades Keller's most famous work, *A Feeling for the Organism,* a 1983 biography of the Nobel Prize–winning biologist Barbara McClintock. Keller argues that McClintock's different approach to genetic research—her intuitive, empathic style of "getting to know" the corn plants she studied—made her a scientific oddball whose research was ignored and even ridiculed for much of her career. McClintock received the Nobel in 1983 at the age of 81, shortly after Keller published the book.

More recently, Keller and others have pondered the emphasis given to DNA as the "master molecule," particularly in the early years of genetics and molecular biology in the 1950s. This terminology, Keller asserts, reflects science's tendency to frame problems in terms of a linear sequence of cause and effect—elevating control (to some, a stereotypically masculine trait) over interaction (often seen as feminine). But scientists have come to appreciate that DNA is just part of a complex system for expressing genetic information.

Bonnie B. Spanier, a professor of women's studies at the State University of New York at Albany, who holds a doctorate in microbiology, has examined whether scientific metaphors have changed in response to this new understanding. In her recent book, *Im/partial Science: Gender Ideology in Molecular Biology,* Spanier surveyed current biology textbooks and journal articles and found that many of the old metaphors were still in place. "Despite the significance of proteins and other complex macromolecules," she concludes, "scientists were still using the language of genes being in control, at the top of the hierarchy of the cell."

Spanier expresses concern that more than semantics may be at stake: some scientific ideas might be overlooked because they do not fit into this hierarchy. As an example, she cites research into the causes of cancer. "By focusing on the genetic basis of cancer, for example, researchers tend to be deflected from studying other aspects, such as environmental causes," she says.


AP/WIDE WORLD PHOTOS

**ACTIVISTS have encouraged researchers to focus more attention on women's health issues, such as breast cancer.**

Human reproduction has also proved to be fertile ground for feminists such as Emily Martin, an anthropologist at Princeton University. For years, she notes, biologists viewed sperm as the active party in fertilization and the egg as passive; it turns out that both participate equally in the process. Martin argues that cultural stereotypes of men as aggressive and women as passive influenced the original choice of imagery. Although these stereotypes oversimplify human nature as well as biology, Martin sees their persistence as significant:

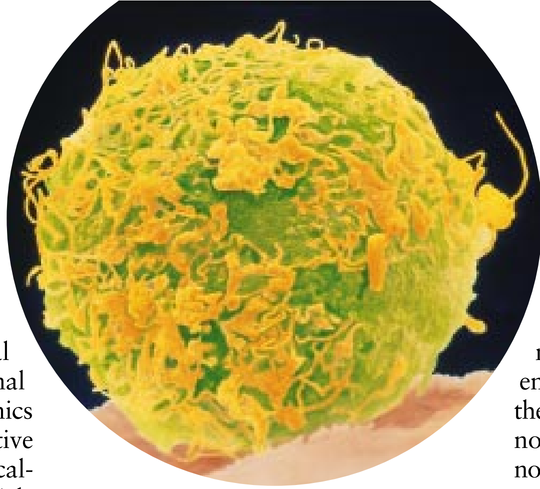
  

"We want to bring them into the light—find out where they came from and what work they do now."

Feminists have tackled nonbiological disciplines as well. For instance, Karen M. Barad, a physicist and philosopher of science at Pomona College, has written about the influence of gender on theoretical physics. Barad argues that traditional presentations of quantum mechanics tend to overlook a more interpretive mode of thinking in favor of brute calculations. She points out that Niels Bohr, one of the founders of quantum theory, originally championed the more philosophical approach, but she claims Bohr's message has simply not been passed on to today's students.

Like most of her colleagues, Barad insists that her work is intended to enhance rather than to deny science's ability to uncover genuine truth. "There is a way to think that science is getting at physical phenomena," she suggests, "without that being seen as a rejection of the idea that culture can influence science. It's not an either/or option."

Even Harding, whose description of Newton's *Principia* and other statements have sparked so much controversy, maintains that her criticisms are meant to strengthen science. In fact, she says she is sorry she used the term "rape manual" in her 1986 book, *The Science Question in Feminism:* "I had no way of knowing how it would be used and repeated out of context. I wish it weren't in there." Now at the University of California at Los Angeles, Harding argues that science should aim for what she calls "strong objectivity"—a means of evaluating not only the usual scientific evidence but also the social values and interests that lead scientists toward certain questions and answers.



**EGG AND SPERM have been described with language that feminist science studies scholars term "gendered."**

K. H. KJELDSEN *SPL/Photo Researchers*

Still, some scholars, such as Noretta Koertge, a historian and philosopher of science at Indiana University and co-author (with Daphne Patai) of *Professing Feminism,* fear that applying feminist theory to science could have an unintended consequence. By painting science as a strongly "masculine" enterprise, Koertge says, feminists risk turning women away from science.

"The debilitating argument is made that there is something different with the way women understand the world—that women are intrinsically not suited to science" as it is practiced now, she explains. "Feminists want more women in science," she continues, "but they say science should be changed to accommodate women"—for example, by emphasizing qualitative over quantitative methods.

Others reject Koertge's assessment. "I never argued that women would do a different kind of science," protests Keller, who acknowledges that her work has often been interpreted in this manner. "My point has always been to liberate both science and women," she says.

Martin, similarly, thinks exposure to the ideas of feminism will help today's students: "They aren't going to be the same sort of scientists, doctors and so on. They'll be asking new questions." Of course, not every idea in feminist science studies will stand the test of time—but then again, neither will all current scientific theories. *—Sasha Nemecek*

# The Media's Eerie Fascination

Chris Carter is in the hot seat. The creator of *The X-Files,* a hit television show about two federal agents who investigate paranormal mysteries, is giving a luncheon address at the first World Skeptics Congress, held last June on the Amherst campus of the University of Buffalo. The Fox network program, which focuses on extraterrestrials, witchcraft, precognition, telekinesis and other artifacts of popular culture, has become a lightning rod for many bemoaning the rise of paranormal beliefs and the decline of rational, critical thinking. "I'm anticipating some very tough questions, but I feel I should face my accusers," Carter said by way of introduction.

He turns out to have an easier time than anticipated: the majority of the audience at the luncheon seem to enjoy his program. And in a sense, it's hard to see what the fuss is about. Dramatists have long relied on spooks and spirits to propel a story, and some observers find it silly to demand that television be more hardheaded. "No one gets history from Shakespeare," remarks Wayne R. Anderson, a physics and astronomy professor at Sacramento City College.

Still, skeptics grumble because *The X-Files* belongs to a larger spate of new programs emphasizing the paranormal, some of which cloak themselves as documentaries. *Alien Autopsy,* also shown on Fox, presented footage allegedly showing a dissection of an extraterrestrial that crash-landed in Roswell, N.M., in 1947; the NBC network aired *The Mysterious Origins of Man,* which asserted that humans lived on the earth with dinosaurs. Besides relying on questionable evidence, these programs are also conspiracy-minded, arguing that governments and mainstream scientists have been covering up the information.

"People understand science through the media, largely. They should get it in school, but it's not required" in many cases, comments Paul Kurtz, head of the Committee for the Scientific Investigation of Claims of the Paranormal (CSICOP), which organized the skeptics congress, "Science in the Age of (Mis)information." One third of Americans watch four or more hours of television daily, and studies show that most people get their science information from TV.

Yet in that medium, real science and critical thinking continue to suffer image problems. According to William Evans, a communications professor at Georgia State University, who has surveyed the content of film and television programming, in most shows scientists produce something dangerous, and skeptical thinking hinders problem solving.

The skeptics community has attempted to combat these prejudices. Organized efforts began in 1976, when a group of academics and magicians formed CSICOP. In its battle, CSICOP chastises the networks, complaining about "balance"—the tendency of producers, for example, to book more believers than skeptics on talk shows and to allot little time for rebuttals of extraordinary assertions. Along with a younger, second organization called the Skeptics Society, based in Altadena, Calif., CSICOP also investigates astonishing claims, issues press releases and publishes magazines.

Distressingly, the rise in paranormal programming suggests those approaches have failed. "We thought that if you just provide information, people would reject [paranormal claims]," Kurtz laments. "The problem is more massive and complicated than we imagined."

More disturbing than the increase in supernatural claims are the changing demographics of the believers. Hard numbers are not available, but observers agree that interest in the paranormal has begun to seep more deeply into well-educated and higher-income households. Such an audience is attractive to advertisers, Evans notes: "Finally, they can market conspiracy theories to people with disposable incomes."

That new marketability suggests that pseudoscience in the mass media will become even more prevalent. Pressure to fatten the coffers with more salable products has increased as media companies continue to merge. All the traditional major networks are owned by larger corporations: ABC by Disney/Capital Cities, CBS by Westinghouse, NBC by General Electric. And cable giants Time-Warner and Turner Broadcasting System have combined forces.

The tendency to merge was blessed with the Telecommunications Act of 1996, which, in addition to reworking long-distance telephone rules, removes many antitrust provisions. "In effect, it unleashes global monopolies," argues George Gerbner, a communications expert formerly at the University of Pennsylvania. In their competitive drive for profits, he says, the conglomerates have "a lot to sell but little to tell."

The broad appeal of the paranormal therefore makes it an alluring addition to the usual staples, violence and titillation. Cross-promotional opportunities resulting from the mergers are also likely to exacerbate matters; for instance, ABC aired a program about extraterrestrial encounters that urged viewers to visit Tomorrowland at Disney World as preparation for alien meetings.

"Publishing used to be based on a 6 percent profit," but now, notes Mark Crispin Miller, a media expert at Johns Hopkins University, the firms are pressured to clear 12 to 16 percent. "As huge companies become more competitive with one another, they resort more to retrograde superstitious pap," he insists. "Take a guy like Rupert Murdoch," he says of the international media magnate. "He made his fortune by degrading newspapers with, among other things, pseudoscience, superstition, horoscopes, stories of wonders and marvels. Murdoch always includes a hefty dose of this kind of weird baloney. So when the guy moved to television"—Murdoch created the Fox network in 1986—"he used the same kind of formula."

The drive for ratings and profits has blurred the line between entertainment and information, Miller argues: "It's no longer possible to say with confidence where the dividing line is."

Notwithstanding its apparent failures in the past, CSICOP plans to be more aggressive by preparing specific countermeasures to pseudoscience. Last year it founded the Council for Media Integrity, which consists of members from the world of science and academia (including the editor-in-chief of *Scientific American*). The council will respond quickly to irresponsible stories. Popular advocacy coalitions, such as Gerbner's Philadelphia-based Cultural Environment Movement, will call for a more responsible and independent media. Finally, researchers have proposed television programs that present science in a more positive way—Nobel laureate Leon Lederman has been lobbying for a science drama series, and Carl Sagan has urged the development of a nonfiction series that shows how skepticism can debunk paranormal claims, for instance.

Although noble, these efforts are unlikely to work anytime soon. "It's just so hard to imagine mass appeal for shows that are skeptical," Evans remarks. Indeed, Isaac Asimov's series *Probe,* which featured scientifically plausible solutions to purportedly supernatural phenomena, died after a few episodes in 1988. And network executives have thus far given Lederman the cold shoulder.

The crux of the matter is that people need faith as they seek comfort or try to make sense out of a complex world. "You need to understand why they believe in this nonsense," Evans points out.

Hope for a more critical audience is not all lost. Studies reveal that a disclaimer before a pseudoscience-based program—saying that it is for entertainment—affects viewers' perception: they become more discriminating about what they see (viewers were most amenable to a show's premise when there was no notice of any kind). In addition, a study released last November by the Department of Education reports that science and math scores among high school students reached highs not seen in 25 years.

If critical thinking is taught more effectively, then perhaps dramatists such as Chris Carter can accomplish without controversy what they do best. As he put it, "What I wanted to do in a very smart way was to scare the pants off people every Friday night." *—Philip Yam*

EVERETT COLLECTION

**PARANORMAL MYSTERIES are investigated by actors Gillian Anderson and David Duchovny on the popular television series *The X-Files.***

# THE AMATEUR SCIENTIST

by Shawn Carlson

## Catch a Comet by Its Tail

On March 9, beginning 41 minutes after midnight Universal Time, a few hardy souls willing to brave the Siberian winter will witness a total eclipse of the sun. As the lunar shadow rushes northward across the subzero landscape, intrepid observers will see, in addition to the usual spectacular solar corona, a streak of light painting the darkened sky. Comet Hale-Bopp (known to astronomers as C/1995 O1), predicted to be the brightest comet in more than two decades, will be just 22 days away from perihelion and only 13 days short of its closest approach to the earth. Its brilliantly illuminated tails should produce a dazzling display.

If a trek to subarctic Siberia doesn't fit your plans, don't worry. Hale-Bopp promises sensational views from anywhere on the planet. It also offers amateurs a chance to contribute to cometary research: the Harvard-Smithsonian Center for Astrophysics in Cambridge, Mass., is coordinating a global net of observers, and anyone can participate.

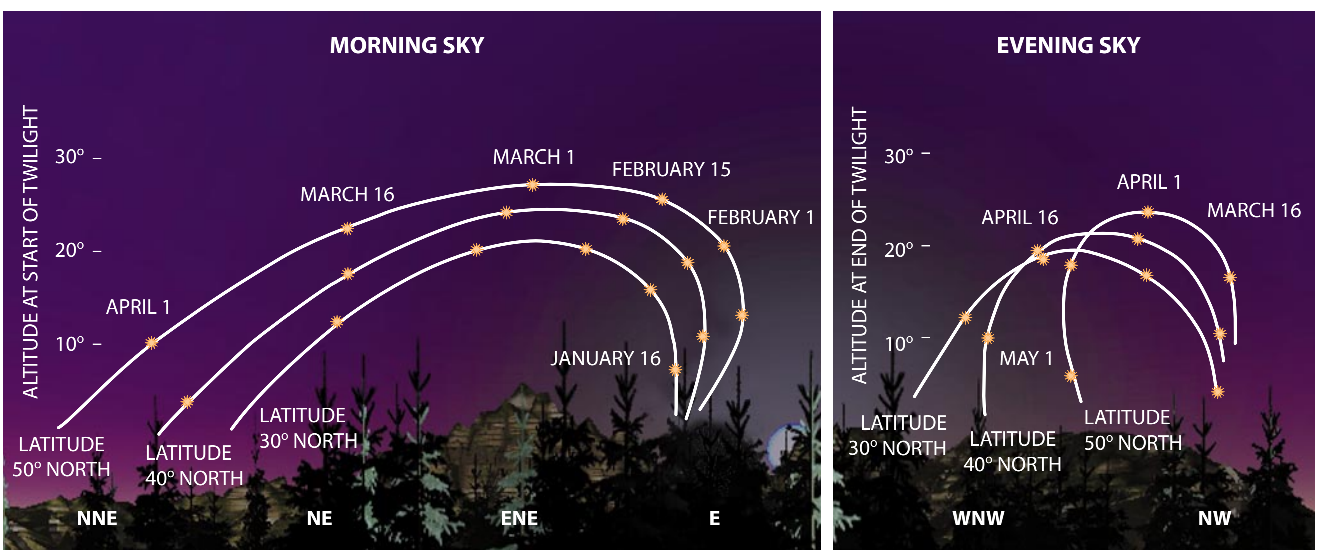
Astronomers are agog over Hale-Bopp because its nucleus seems particularly active. A cometary nucleus is a fluffy ball of ice and rock whose surface evaporates as the wanderer nears the sun. The resulting streams of dust and gas make up the comet's tails. (The glowing dust traces a curved path; ionized gas travels in a straight line away from the sun.) Hale-Bopp's nucleus first began spurting out visible jets of debris as it passed the orbit of Jupiter, roughly seven astronomical units from the sun (1 AU is the average distance from the sun to the earth, or about 150 million kilometers). Experienced naked-eye observers have been watching Hale-Bopp since May 1996 (most comets are visible to the unaided eye only a few months before perihelion), and the rest of us should be able to see it starting this month.

A comet's tails (one dust, the other gas) reveal some of its most intimate secrets of composition and structure. They also give earthbound watchers a fine traveling laboratory to chart the solar wind. Tails are sometimes decorated with feathery features that flow outward under the solar wind's influence. Comet Kohoutek delighted astronomers in 1974 with at least two prominent examples of these skirting disturbances.

Any amateur can record these and other features of the comet's tails. First, you'll need a good star atlas that maps stars in terms of right ascension and declination. (*Norton's 2000.0 Star Atlas and Reference Handbook,* 18th edition, by Ian Ridpath, is probably best for this purpose.) You'll also need a drafting compass and a large bow-shaped angular scale. The bow, made from a flexible meter stick or yardstick and a long piece of scrap wood, will let you locate the tails' features to about 0.1 degree of arc.

Sketch the tails directly on the appropriate page of the star atlas (or on a good photocopy). Locate the comet's head by measuring the angular separation between the head and the three nearest stars in the atlas. Celestial maps mark the positions of stars in terms of declination and right ascension; to convert from angles to distance on the page, note that one hour of right ascension equals 12 degrees at the celestial equator. Elsewhere in the sky, divide the distance at the equator by the cosine of the declination.

For each measurement, set the compass to the appropriate opening and scribe a small arc through where you expect the head to be. The precise location of the head is where the arcs intersect. Follow the same procedure to mark all the other major features in the tails




EDWARD BELL; ADAPTED FROM *SKY & TELESCOPE*

***COMET HALE-BOPP** will be visible for more than four months in the morning sky (before perihelion) and evening sky (after perihelion). The farther north of the equator one is, the better the comet can be seen.*

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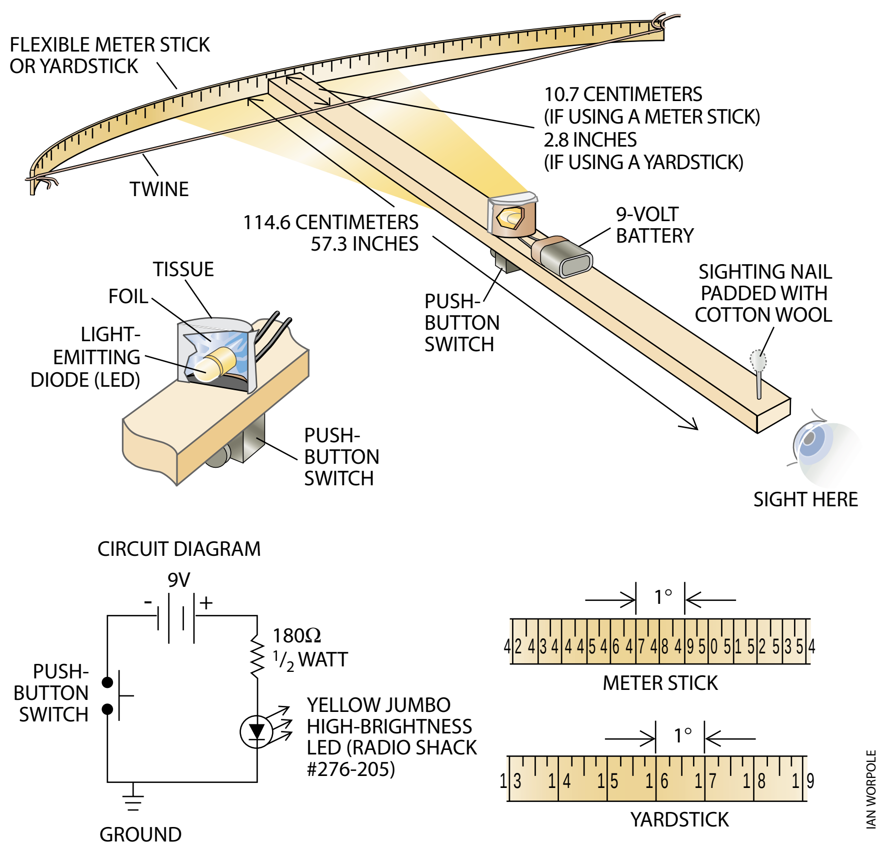
## Building the Bow

If you use a meter stick, place the sighting nail 114.6 centimeters away. Viewed from the nail, each two-centimeter division will span precisely one degree. Paint thin white lines to mark off degrees and half degrees. A slit cut in a playing card makes a perfect stencil. If you use a yardstick, place the nail at 57.3 inches and paint degree marks along the scale every inch. A light-emitting diode illuminates the scale for easy night reading.




and then fill in the finer details. Use a telescope or binoculars for this part. By carrying out this procedure every clear night, you can document the evolution of the tails.

The comet's fuzzy head, or coma, also changes over time in size, brightness and degree of condensation. The best way to measure its size is to use an eyepiece with a calibrated scale etched into the lens. They're a bit pricey, but for accuracy they can't be beat. Check out the micro guide eyepiece from Celestron in Torrance, Calif.; call (800) 237-0600 or (310) 328-9560 to find a local dealer—mine sells the eyepiece for $189.

Those with more limited resources can use a less direct method to measure angular size. Center a telescopic sight on the coma and let the earth's rotation carry the comet across the field of view. Rotate the sight's crosshairs so that the comet drifts straight along the horizontal line, then count how many seconds it takes the coma to pass completely across the vertical crosshair. If you know the comet's declination (from position measurements with the star atlas), the width of the coma in minutes of arc is simply one quarter the cosine of the declination times the number of seconds. Repeat the measurement at least three times and average the results.

With a small telescope and a little practice, you can also estimate the comet's brightness, or visual magnitude, by comparing it with stars of known magnitude. Put the comet in sharp focus using a low-magnification eyepiece (no more than 2× magnification per centimeter of telescope aperture) and commit its image to memory. Point your telescope to a nearby star of known magnitude and defocus the image until the star appears the same size as did the comet. Then mentally compare the brightness of the defocused star and the comet. Find one star just slightly dimmer than the comet and another just slightly brighter—recalling that smaller magnitudes mean brighter stars—and you should be able to estimate where the comet's brightness falls in the interval between them. For more information about the magnitude scale, consult any basic astronomy text.

There are a few cautions to observe when estimating magnitudes. The atmosphere absorbs much more light when a star—or comet—is close to the horizon, so if the comet is at an elevation of less than 30 degrees, compare it only with stars that are at about the same elevation. Don't use red stars for comparison, because your eyes aren't very sensitive to red. If your catalogue lists a star as type K, M, R or N, or if the listing for V-B (visible-minus-blue) magnitude exceeds 1.0, find a bluer star. You will probably find it useful to practice this technique by estimating the brightness of stars of known magnitude. Experienced observers can achieve a precision of 0.1 or 0.2 magnitude.

To find out more about observing comets or to learn how to contribute your observations, contact the Harvard-Smithsonian Center for Astrophysics at icq@cfa.harvard.edu, or visit their World Wide Web site at http://cfa-www.harvard.edu/cfa/ps/icq.html or write to Daniel W. E. Green, Smithsonian Astrophysical Observatory, 60 Garden St., Cambridge, MA 02138. I gratefully acknowledge informative conversations with Dan Green. You can purchase the center's newly published *Guide to Observing Comets,* the definitive resource on the subject, by sending $15, payable to International Comet Quarterly, to the same address. And do contribute your observations. Information is useless if it is not shared. SA

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# MATHEMATICAL RECREATIONS

by Ian Stewart

## Alphamagic Squares

The magic square, in which every row, column and diagonal sums to the same total number, has long been a staple of recreational mathematics. According to Chinese legend, the simplest example

| | | |
|---|---|---|
| 4 | 9 | 2 |
| 3 | 5 | 7 |
| 8 | 1 | 6 |

was revealed to the emperor Yü on the back of a turtle in the 23rd century B.C. The common total, or "magic constant," of this square is 15, and its size, or "order," is three. Magic squares of all the larger orders exist, as well as a plethora of generalizations—magic cubes, hexagons, octagons, circles.

One would think that everything that can be said about such constructs was said long ago. But 10 years ago Lee Sallows invented an entirely new breed, the alphamagic square. Sallows, an expert on word games, specializes in combining these with recreational mathematics. (Another of his inventions, "new merology," was described in this column in March 1994.)

My account is based on two of Sallows's articles in *The Lighter Side of Mathematics,* edited by Richard K. Guy and Robert E. Woodrow (Mathematical Association of America, 1994). The concept is intriguing. Here is an example:

| | | |
|---|---|---|
| five | twenty-two | eighteen |
| twenty-eight | fifteen | two |
| twelve | eight | twenty-five |

If the words are transcribed into numbers, we have a conventional magic square (constant 45). But if instead we count the number of letters in each word (ignoring hyphens), we get

| | | |
|---|---|---|
| 4 | 9 | 8 |
| 11 | 7 | 3 |
| 6 | 5 | 10 |

which is also magic, this time with a constant of 21.

Sallows has developed a general theory of such constructions. He begins by defining log($x$), the "logorithm" of a number $x$, to be the number of letters contained in the verbal equivalent for $x$. (Sallows combined the Greek *logos,* meaning "word," and *arithmos,* meaning "number," into a neat pun on "logarithm.") A number has different logorithms in different languages; for the moment, we'll stick to English.

So can we find any more alphamagic squares? Yes, for a rather trivial reason: just append "one million" to the front of each entry. The magic constant of the numerical square increases by three million, and that of its "logorithmic derivative"—the result of replacing each number by its logorithm—increases by thrice the number of letters in "one million and," namely, by $3 \times 13 = 39$. Hence, infinitely many such extensions of alphamagic squares (of order three) exist. Sallows calls such squares "harmonics" of the original one and reasonably dismisses them as minor variants.

Are there any more interesting variants? In the 19th century the French mathematician Édouard Lucas devised a formula for any $3 \times 3$ magic square:

| | | |
|---|---|---|
| $a + b$ | $a - b - c$ | $a + c$ |
| $a - b + c$ | $a$ | $a + b - c$ |
| $a - c$ | $a + b + c$ | $a - b$ |

This has a constant of $3a$. Whatever values are substituted for $a$, $b$ and $c$, the result is always magic—and every third-order magic square arises in this manner. Observe that each line through the central square forms an arithmetic series, one that has a constant difference between successive terms. So a reasonable strategy for finding alphamagic squares is to look for triples of numbers in arithmetic series, such that the corresponding sequence of logorithms also forms an arithmetic series.

For a first attempt, choose 15 for the number in the central position, because we know there is at least one such alphamagic square. Then the logorithm table reveals five suitable triples, namely, (2,15,28), (5,15,25), (8,15,22), (11,15,19) and (12,15,18). We now try out all possible pairs of these in the two diagonals. For example, if we use the first two, we get

| | | |
|---|---|---|
| 2 | | 25 |
| | 15 | |
| 5 | | 28 |

Lucas's formula tells us that the magic constant of any third-order square is three times the central entry, so any square with 15 at the center has magic constant 45. Therefore, we can complete the square in only one way:

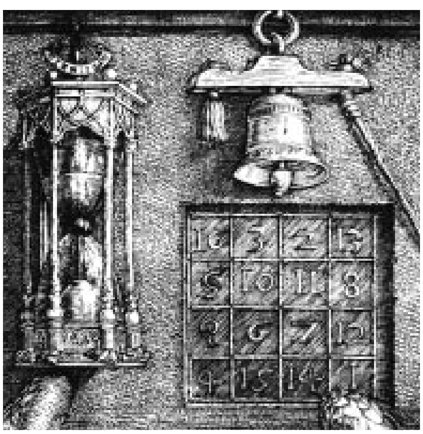
| | | |
|---|---|---|
| 2 | 18 | 25 |
| 38 | 15 | –8 |
| 5 | 12 | 28 |

We can either reject this case because of the negative entry –8, or we can write it as "minus eight," with logorithm 10. In the latter case, we get the logorithmic derivative

| | | |
|---|---|---|
| 3 | 8 | 10 |
| 11 | 7 | 10 |
| 4 | 6 | 11 |

which, alas, is not magic. Experimentation with other pairs of sequences quickly reveals a new alphamagic square; it makes an excellent warm-up problem (the answer is given at the end).

VICTORIA AND ALBERT MUSEUM, LONDON / ART RESOURCE, NEW YORK



*MAGIC SQUARE of order four is from Albrecht Dürer's famous engraving* Melencolia I.

What if the central entry is not 15? Sallows wrote a computer program to search for other third-order squares and found many. An example is

| | | |
|---|---|---|
| 15 | 72 | 48 |
| 78 | 45 | 12 |
| 42 | 18 | 75 |

The same game can be played using other languages. The box below shows examples in Swahili, Welsh, French and German. Using numbers up to 100, Sallows has found third-order alphamagic squares in 19 languages—though none in Danish or Latin.

In French there is exactly one alphamagic square involving numbers up to 200, but a further 255 squares can be found if the size of the entries is increased to 300. Three of these have logorithms forming a sequence of consecutive numbers. One is given below.

In German there are a massive 221 examples using numbers under 100—one of which appears in the box. The basic principle of construction can be seen if we chop out the syllables "und" and "zig" and replace the resulting words by numbers, to get

| | | |
|---|---|---|
| 45 | 62 | 58 |
| 68 | 55 | 42 |
| 52 | 48 | 65 |

I have written the first digit in red because it must be multiplied by 10 to get its true contribution to the numerical value—for example, "fünf-und-vierzig" means five-and-forty. Now split this up into its blue and red components:

| | | |
|---|---|---|
| 4 | 6 | 5 |
| 6 | 5 | 4 |
| 5 | 4 | 6 |

| | | |
|---|---|---|
| 5 | 2 | 8 |
| 8 | 5 | 2 |
| 2 | 8 | 5 |

Each is a so-called Latin square, in which the same three numbers occur in every row and every column, so rows and columns are trivially magic. Moreover, the diagonals happen to be magic, too. This is still the case when the entries of the red square are multiplied by 10 and when the two squares are "added" together. Because every number in the square has the same logorithm, 14, the original square is automatically alphamagic.

What about higher orders? The trick with orthogonal Latin squares works very well. For example, in English the square with numerical values

| | | | |
|---|---|---|---|
| 26 | 37 | 48 | 59 |
| 49 | 58 | 27 | 36 |
| 57 | 46 | 39 | 28 |
| 38 | 29 | 56 | 47 |

is alphamagic. The blue digits form a Latin square of order 4, and so do the red ones, and the regularity of English number-names between 20 and 99 does the rest. Sallows calls such examples "fool's gold" because they are too easy to find. For real gold, you must seek out more exceptional cases, such as

| | | | |
|---|---|---|---|
| 31 | 23 | 8 | 15 |
| 17 | 5 | 21 | 34 |
| 26 | 38 | 13 | 0 |
| 3 | 11 | 35 | 28 |

What of the unsolved questions in the field? Here are three; you can tackle them in any alphabetical language.

1. A "normal" square uses consecutive integers starting from one. For order three, there is only one normal magic square (apart from rotations and reflections), and it is not alphamagic. What about order four? The total number of letters in the number-words "one, two, . . . , sixteen" turns out to be 81. The magic constant of the logorithmic derivative must therefore be $^{81}/_{4}$, which is not an integer, so a normal fourth-order alphamagic square cannot exist. The same argument shows that the smallest possible order for a normal alphamagic square in English is 14, and its magic constant must be 189. No one seems to know whether any such square actually exists, and this is the first open question.

2. Does there exist a 3 × 3 × 3 alphamagic cube?

## International Alphamagic

The first number in parentheses is the numerical value, the second its logorithm.

**SWAHILI**

| | | |
|---|---|---|
| arobaini na tano (45,14) | sitini na saba (67,12) | hamsini na tisa (59,13) |
| sabini na moja (71,12) | hamsini na saba (57,13) | arobaini na tatu (43,14) |
| hamsini na tano (55,13) | arobaini na saba (47,14) | sitini na tisa (69,12) |

**WELSH**

| | | |
|---|---|---|
| chwech deg dau (62,12) | wyth deg (80,7) | saith deg pedwar (74,14) |
| wyth deg pedwar (84,13) | saith deg dau (72,11) | chwech deg (60,9) |
| saith deg (70,8) | chwech deg pedwar (64,15) | wyth deg dau (82,10) |

**FRENCH**

| | | |
|---|---|---|
| quinze (15,6) | deux cent six (206,11) | cent quinze (115,10) |
| deux cent douze (212,13) | cent douze (112,9) | douze (12,5) |
| cent neuf (109,8) | dix-huit (18,7) | deux cent neuf (209,12) |

**GERMAN**

| | | |
|---|---|---|
| fünfundvierzig (45,14) | zweiundsechzig (62,14) | achtundfünfzig (58,14) |
| achtundsechzig (68,14) | fünfundfünfzig (55,14) | zweiundvierzig (42,14) |
| zweiundfünfzig (52,14) | achtundvierzig (48,14) | fünfundsechzig (65,14) |

3. The logorithmic derivative leads from one square array of numbers to another and so can be iterated to give second logorithmic derivatives, and so on. How far can this process continue with every square being magic? Without further conditions, the answer is “forever.” To see why, consider the German alphamagic square analyzed earlier. In its logorithmic derivative, every entry is 14, trivially magic; in its second logorithmic derivative, every entry is 8, and so on. But are there any examples of such “recursively magic” squares in which the logorithmic derivative does not have the same entries throughout? SA

### SOLUTION TO WARM-UP PROBLEM

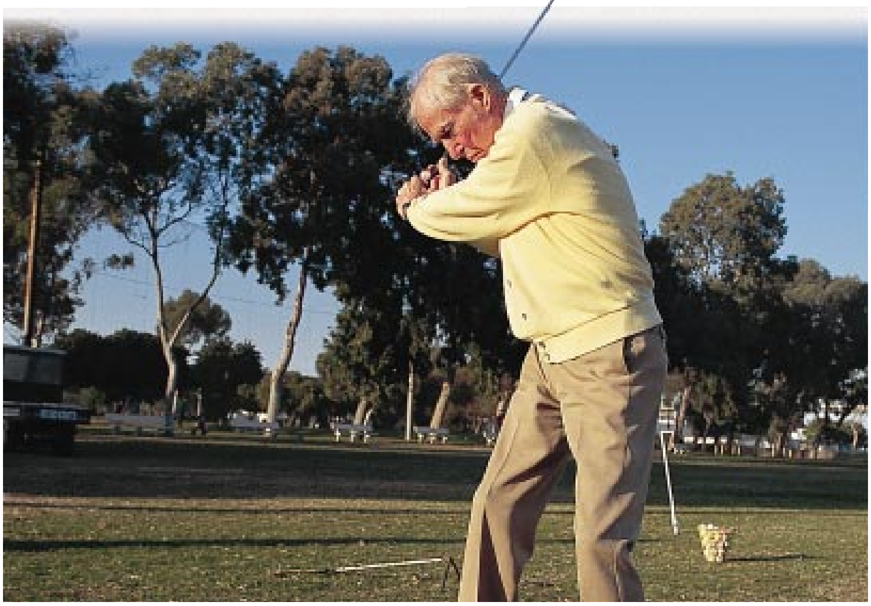
| | | |
|---|---|---|
| 8 | 19 | 18 |
| 25 | 15 | 5 |
| 12 | 11 | 22 |

### FEEDBACK

I keep getting mail on Padovan numbers [June], so I am going to pick up the topic again. Recall that these numbers are those in the series 2, 2, 3, 4, 5, 7, 9, 12, 16, 21, . . . in which each number is obtained by skipping the previous one and adding the two before that. They resemble the better known Fibonacci numbers 1, 1, 2, 3, 5, 8, 13, 21, . . . in which each is the sum of the previous two. I asked whether any numbers other than 2, 3, 5 and 21 could be both Padovan and Fibonacci.

In August, I received an e-mail from Benjamin de Weger in Barcelona, saying he was sure he could prove that there were no others, and did I think it worth spending two days to do this? Before I could reply, he informed me that he had spent three days and figured out how to list all the cases in which a Fibonacci number differs from a Padovan number by less than a million. The proofs, he says, are “routine applications of Baker’s method of linear forms in logarithms of algebraic numbers and a computational diophantine approximation technique.” Routine for some, I’d say. —*I.S.*

# REVIEWS AND COMMENTARIES



JAMES ARONOVSKY *Zuma*

## MYTHS OF AGING

*Review by Leonard Hayflick*

**The Clock of Ages**
BY JOHN J. MEDINA
Cambridge University Press, 1996 ($24.95)

**Reversing Human Aging**
BY MICHAEL FOSSEL
William Morrow, 1996 ($25)

Either you are already old, or the odds are better than even that you will become old. This statistic became true only 40 years ago. Aging is an artifact of a highly developed civilization. For more than 99.9 percent of the time that human beings have inhabited this planet, life expectancy at birth has been no more than 30 or 40 years. It is only after we learned how to avoid animal predators, massive homicides, starvation, most causes of accidents and infectious diseases that it has become possible for a substantial portion of the population of developed nations to grow old.

Although the desire for long life or even immortality has been a common theme in human thought throughout recorded history, it is just in the past 20 years or so that biogerontology—the biology of aging—has become an important area of interest to both the scientific community and the public at large. Earlier neglect of biogerontology was motivated in significant part by ageism—negative stereotypes about old people—even among ostensibly objective scientists. The potential political, social and economic impact of large numbers of older persons, however, has galvanized studies of how people and animals age.

Aging is a complex process, but its foundation is simple: Soon after animals reach sexual maturity and live long enough to raise progeny to the stage of independence—thereby ensuring the survival of the species—the forces of natural selection diminish. The energy that organisms expend is better directed toward reproductive success than toward greater individual longevity. Eventually, the molecular disorder that occurs outpaces a body's usual repair mechanisms, and aging takes place.

The complexity of the topic has not been well served by many books written about aging for the layperson. These texts have, with only one or two exceptions, been authored by reporters who have interviewed a few biogerontologists or by biomedical scientists who have an interest in aging but neither strong professional qualifications nor a solid commitment to the field. *The Clock of Ages* and *Reversing Human Aging* fall into the latter category. Lacking a full grasp of the complexities of biogerontology, nonprofessionals frequently are unaware of its many pitfalls and may ignore alternatives to hypotheses that they present as fact.

John J. Medina, a molecular biologist, devotes about a third of *The Clock of Ages* to a course on fundamental biology. The primer is illustrated with many diagrams and drawings such as those typically found in an introductory biology text; this background may be interesting to some readers, but it is not directly concerned with aging. The most relevant material is a catalogue of changes that occur with age in major organ systems. Medina tells us that a particular organ "deteriorates," "secretes less," "declines," "weakens," "incurs losses" or "has an alteration" in its function. But most of us already know that much about aging. What we want to know is why these changes occur, and that question is substantially neglected. Furthermore, some of the items on the list are simply wrong: for instance, cardiac function does not decrease with age in healthy subjects.

Another significant proportion of the book goes to vignettes, often appearing at the beginning of chapters, that describe the aging of such people as Florence Nightingale, Jane Austen, Napoléon Bonaparte, Giovanni Casanova, Ludwig van Beethoven and Billy the Kid, along with others whose names the reader may or may not recognize. Each vignette is intended to illustrate a scientific point, but the result is more often contrived than informative.

Conceptual errors abound: the author does not distinguish, for example, between the effects of aging and those of disease. He also overlooks the importance of the difference between aging and longevity determination—the former concerns itself with physical decline, the latter with mortality. More crucially, Medina misses the distinction between individual and population immortality in microorganisms, promulgating the mistaken belief that there exist immortal unicellular forms. "Immortal" strains of cells continue dividing forever, but the individual cells die just as surely as you or I will. Cell death is an essential process in the early development of complex organisms like ourselves, but it is not a major factor in aging.

Finally, there is no "clock of ages." There is no evidence for a biological mechanism that measures time. Cells may contain mechanisms that tally events such as cell division, but they do not record the passage of time according to clock or calendar.

Most biogerontologists agree not only that cells must contain multiple biological event counters but also that these counters determine an organism's maximum potential life span, not the random misadventures of age-related change. In *Reversing Human Aging,* Michael Fossel, originally a neurobiologist, takes speculation about molecular event counting to an extreme. He focuses on the important, recent discovery of a mechanism that appears to limit the number of times a cell can reproduce; he suggests that further understanding and manipulation of this mechanism might allow us to increase our longevity significantly.

The scientific story that underpins Fossel's speculations starts 35 years ago at the Wistar Institute of Anatomy and Biology in Philadelphia, when Paul S. Moorhead and I showed that, contrary to the dogma then widely held in cell biology, all cells are not potentially immortal. Cultures of normal human fetal fibroblasts divide about 50 times and no more—eventually the last cells die, and that is the end of the test-tube population. We found that only populations of abnormal or cancerous cells are immortal. Until our discovery, biogerontologists believed aging had nothing to do with events within individual cells.

Since our findings were published, scientists have sought the molecular mechanism that determines the replicative limit of normal human and animal cells. In the past few years, many researchers have come to believe that the answer is in the telomere, a stretch of thousands of repeated nucleotide sequences of the form *TTAGGG* (where *T, A* and *G* are chemical "letters" in the genetic code) that is found at both ends of all 46 human chromosomes. At each cell division, some telomere sequences are lost, until the shortened stretch triggers events that cause the cell to stop dividing. Immortal cells produce an enzyme called telomerase, which adds new sequences to the chromosome each time the cell divides, thus maintaining a constant telomere length. Recently sensitive assays have found that much smaller amounts of telomerase are also present in cells from embryos and in tissues whose cells divide regularly.

This exciting story has persuaded Fossel that science has discovered the mechanism that determines aging and that the molecular clock can soon be turned back. I believe Fossel has overinterpreted this discovery, important as it is. I also believe telomere shortening may tell us a great deal about ultimate limits to the human life span but little about aging.

I have always worried about the enormous power that humans will have if we ever learn how either to tamper with the aging process or to extend our lon-

**ON THE SCREEN**

**L5: First City in Space**
At IMAX 3D theaters
Dentsu Prox, Inc., 1996

We may be making only halting moves toward the colonization of space, but we are making tremendous progress in picturing what it would be like. The 3-D film *L5: First City in Space* imagines a future, one century hence, in which 10,000 people live on board a space station perched between the earth and the moon. The detailed renderings of the station's structure and internal environment, aided by the IMAX 3D technology, make the fantasy future almost tangible—and in a notable advance, the mandatory 3-D movie goggles do not induce headaches.

The plot, involving a water shortage on *L5,* is marred by flat dialogue and some factual lapses (did the space age really begin with the launch of the space shuttle?). Best to ignore the verbiage and enjoy *L5* as eye candy, a stirring visual exhortation to venture into space. —*Corey S. Powell*


COSMIC CITY PRODUCTIONS, LTD.

gevity—it is unclear whether people could cope with the psychological, economic, medical and cultural changes that would accompany vastly extended life spans, even should they prove physiologically possible. Fossel gives a thoughtful overview of his conviction that humans will benefit by possessing this awesome capability. Many other writers and philosophers disagree. Although aging and death put an end to the lives of good citizens, they also make finite the lives of tyrants, murderers and a broad spectrum of other undesirables. Much of the continuing massive destruction of this planet and the consequent ills that this destruction produces for humans can be traced to overpopulation, a phenomenon that appears to show no sign of abating. Extending the life of a population that already strains global resources is, in the view of many, unconscionable.

If the price to be paid for the beneficial results of aging and death is its universal applicability, we should all pay that price—as we always have.

*LEONARD HAYFLICK is professor of anatomy at the University of California, San Francisco, School of Medicine, a past president of the Gerontological Society of America and author of* How and Why We Age *(Ballantine Books, 1996).*

## THE ILLUSTRATED PAGE

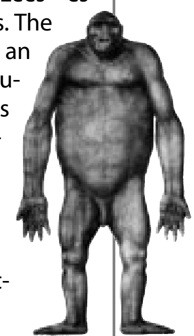
DAVID BRILL

**From Lucy to Language**
BY DONALD JOHANSON AND BLAKE EDGAR
Principal photography by David Brill
Simon & Schuster Editions, 1996 ($50)

Open this book and take history into your hands: the 137 years since Charles Darwin's *On the Origin of Species* and the four million years since the appearance of the first direct hominid ancestors. Donald Johanson and Blake Edgar pull the reader in with a riveting overview of modern anthropology. Then they step back and review the fossil sequence that leads up to *Homo sapiens,* pointing out the forms that document the evolutionary changes. All the players are here, including the famed *Australopithecus afarensis* "Lucy" (discovered by Johanson in 1974), *H. ergaster* (*above*) and *H. heidelbergensis,* whose mixture of traits boldly refutes creationism. The photographic documentation is as gorgeous as it is meticulous: the ancient bones, glowing against matte-black backgrounds, look chillingly frail and familiar. —*Corey S. Powell*

## BRIEFLY NOTED

**DEMONIC MALES: APES AND THE ORIGINS OF HUMAN VIOLENCE,** *by Richard Wrangham and Dale Peterson. Houghton Mifflin, 1996 ($22.95).*
A worthy companion to Frans de Waal's *Good Natured* (reviewed in these pages in September 1996), *Demonic Males* offers a probing inquiry into the violent behavior etched into the nature of humans and chimpanzees—especially males of the species. The authors lead the reader on an intriguing tour through human history, primate studies and anthropological reconstructions; they even offer lessons from the peacemaking behavioral adaptations of bonobo chimps. The science is clearly told, the writing literate throughout.



ORION PUBLISHING GROUP, INC.

**DARWIN'S BLACK BOX: THE BIOCHEMICAL CHALLENGE TO EVOLUTION,** *by Michael J. Behe. Free Press, 1996 ($25).*
The earliest stages in the history of life—including its origin and the development of the basic biochemical pathways—are shrouded in mystery. Michael J. Behe holds that evolutionary theory will never solve the mystery, because some of the components are "irreducibly complex" and so must be the product of "intelligent design"—maybe God's, maybe not. It is an old argument, both arrogant and deeply unsatisfying. Theologians as well as scientists might blanch at the notion that we owe our inner workings to an ambiguous designer who controlled only those aspects of evolution that Behe deems inexplicable.

**THE ILLUSTRATED A BRIEF HISTORY OF TIME,** *by Stephen Hawking. Bantam Books, 1996 ($37.50).*
Stephen Hawking's mind-bending best-seller returns in an updated and lavishly illustrated edition. The text seems more accessible than before, and it includes a lively new chapter on the possibility of time travel, along with several scientific updates. The artwork sometimes sacrifices clarity for style, however, and the captions contain some small but jarring errors that belie the book's premium price.

MOON*RUNNER* DESIGN, U.K.

*Continued on page 115*

## REMEMBRANCE OF FUTURE PAST

*Review by Paul Wallich*

**HAL's Legacy: 2001's Computer as Dream and Reality**
EDITED BY DAVID G. STORK
Foreword by Arthur C. Clarke
MIT Press, 1997 ($22.50)

"I became operational at the HAL Plant in Urbana, Ill., on January 12, 1997," the computer HAL tells his interlocutors in Arthur C. Clarke's 1968 novel, *2001: A Space Odyssey.* That day is upon us, but nothing resembling an intelligent computer is ready to be switched on in Urbana or anywhere else. Clarke was in many respects an acute visionary: he predicted the existence of communications satellites—and their effect as cultural cement mixers—so accurately that life may well have imitated art. But artificial intelligence (AI) remains the same "four to 400 years" away that the field's namer, John McCarthy, estimated some 30 years ago.

Many computer scientists have given up entirely on AI, and *HAL's Legacy*—both in its text and as an object lesson—may help lay readers understand why. Machine-intelligence researcher David G. Stork has enlisted a dozen computer scientists (plus a mathematician and a philosopher) to consider, at heart, a question he was asked at a dinner party: "How realistic was HAL?" The authors tackle a variety of topics in hardware, software and cognitive science with a firm conviction that they are discussing the building blocks of an intelligent machine like HAL, but, tellingly, no underlying coherence emerges. Much as the expert systems of the 1980s were full of "brittle" knowledge that proved useless outside narrowly specialized applications, so human experts in supercomputer design, fault tolerance or computer chess seem unable to step outside the boundaries of their disciplines.

A discussion of the subnanosecond "clock speeds" (the time necessary to carry out each operation) that are potentially possible using gallium arsenide integrated circuits offers a prime example. Ultrafast circuits may be useful for the kind of supercomputing that tackles complex physical simulations, such as predicting weather or modeling the interior of a hydrogen bomb, but it is not at all clear that this kind of computing has anything to do with intelligence and self-awareness as cognitive scientists are beginning to understand it. Similarly, the state of the art of fault tolerance for computer hardware and software is only minimally relevant to the story of HAL's "mental" breakdown in *2001;* Clarke attributed HAL's troubles to a fundamental and quite emotional contradiction in its duties to its crew and to its mission.

Even those contributors who recognize that standard microchips and operating systems are unlikely to yield intelligence can succumb to technological tunnel vision. Inventor Raymond Kurzweil makes the remarkable assertion that increases in the resolution of brain-imaging technology will shortly enable researchers to map human neurons into silicon. That bold leap is a little like imagining that a simultaneous readout of the speedometers in all the cars on Boston's streets would let you predict the results of its next mayoral election.

So many aspects of everyday life as depicted in *2001* have receded over the technological horizon that it should come as no surprise that even the most basic of HAL's abilities—carrying out simple conversation—is beyond modern computers. They cannot reliably convert sounds to an internal representation of meaning; they cannot even generate naturally inflected speech. Machines still lack the enormous, implicit base of knowledge about the world and the intuitive understandings of emotion or belief most people take for granted.

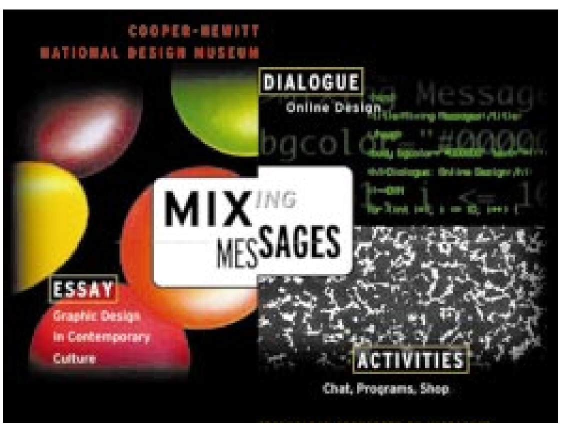
Joseph P. Olive of Bell Laboratories does a good job of explaining the complexities underlying effective speech synthesis. Not only must a computer know what it is saying to produce the proper inflections, but it must also mimic the vagaries of a human vocal tract with surprising precision. Visual cues, too, are important in conveying meaning. Olive and his colleagues have found that displaying an animated, expressive face synchronized with the voice can make the result significantly more intelligible. "If HAL had had a real face, rather than one large eye," he asks, "would it have been so easy to kill him?"

### MULTIMEDIA

**Mixing Messages: Graphic Design in Contemporary Culture**
At Cooper-Hewitt, National Design Museum
in New York City (through February 16)
On the World Wide Web at http://mixingmessages.si.edu
Exhibit catalogue. Princeton Architectural Press, 1996 ($35)

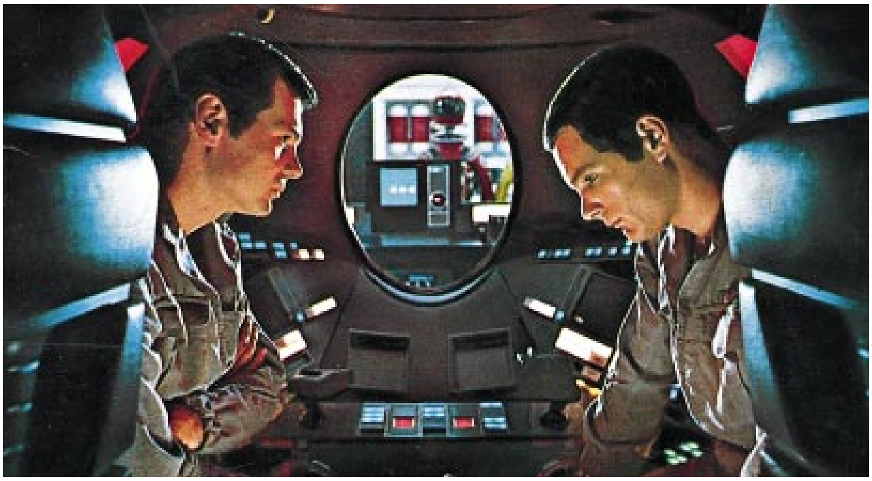
The inaugural exhibit of the renovated National Design Museum offers a rare opportunity to compare new media against old: it exists not only on the wall and in a catalogue but in cyberspace as well. The show itself is a provocative but unfocused examination of the cultural messages buried within ordinary posters and typefaces. Personal computers carry the power of design to nearly every desktop, so it is only fitting that they also bring "Mixing Messages" to everyone wired into the World Wide Web. The brief exhibit essays feel more appropriate on-line, and the overall construction of the Web site is outstanding—swift and smartly hyperlinked. And if the interactive features are not perfect (spoiled by software glitches and low attendance), they do make a point about the interdependence of technology and design.

*—Corey S. Powell*




COOPER-HEWITT, NATIONAL DESIGN MUSEUM



EVERETT COLLECTION; from *2001: A Space Odyssey*

There are always pitfalls in reading too much into the technology or psychology of a fictional entity. Arguments over what kind of being HAL was are ultimately even less resolvable than questions of the true intentions of Clarke or Stanley Kubrick (who collaborated on the screenplay in addition to directing the movie version of *2001*). Murray S. Campbell of the IBM Thomas J. Watson Research Center delivers an interesting discussion on the way that human chess-playing styles differ from computer ones. He goes astray, however, by indulging in a tediously detailed examination of the 1913 chess match between two undistinguished German tournament players from which the closing moves shown in the film were taken.

Perhaps a dark side of HAL's legacy is to have fixed an anthropomorphic view of artificial intelligence so firmly in the minds of a generation of researchers that one of them would take such a throwaway detail so seriously. During the 1980s, those anthropomorphic visions found some kind of fruition in computer programs that demonstrated near-human and occasionally superhuman autonomous abilities in a range of fields from medical diagnosis to ore prospecting or financial analysis.

But these idiot savants did not show even the slightest signs of achieving general competence. In the subsequent AI winter—brought on by the end of a military research spree as well as the inevitable collision between venture capital and reality—only the mechanical cockroaches survived. Researchers scaled back their ambitions and aimed at achieving the cognitive and survival skills of a lobster or a cricket rather than a virtuoso surgeon or an ace fighter pilot.

If mechanical evolution proceeds a million times faster than its natural predecessor, we might expect the emergence of a digital dog in a century or two. Some stalwarts of the AI establishment, however, are calling for a reevaluation of the essential goal of artificial-intelligence research. They contend that trying to create a thinking machine—for the time being, at least—is like asking the Wright brothers for an artificial bird, complete with feathers and flapping wings. Patrick Hayes of the Beckman Institute (who did not contribute to *HAL's Legacy*) has coined the term "cognitive prosthesis" to embrace a range of software tools, including automated memory aids and job-scheduling systems, that help people think more effectively, much as cars help them to move from place to place or hydraulic presses help them to bend and form metal.

No one expects to get into a car and sleep at the wheel while being conveyed automatically to the correct destination, and perhaps no one should expect a computer program to diagnose patients infallibly or to command a major battle. But even now software written using the techniques developed by AI researchers reminds doctors of possibilities they might have missed or schedules the transport aircraft that deliver supplies to combatants in far-off lands. The programs are nothing like HAL, but without people working toward the same vision expressed by Clarke and Kubrick, even these limited intellectual tools would not exist.

*PAUL WALLICH is a staff writer for* Scientific American.

## BRIEFLY NOTED

*Continued from page 113*

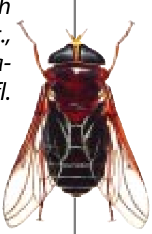
**THE PEENEMÜNDE WIND TUNNELS: A MEMOIR,** *by Peter P. Wegener. Yale University Press, 1996 ($30).*

As a young physicist in Hitler's Germany, the author was assigned to work in the supersonic wind tunnels at Peenemünde. There Wernher von Braun was developing the V2 rocket—research that later proved crucial in establishing a U.S. space program. Peter P. Wegener tells a fascinating tale, full of adventure, romance and science. Nor does he shrink from some of the uglier aspects, frankly discussing what he knew of the use of slave labor in producing the rockets and the Nazi politics of some of his colleagues.

**THE INVENTION THAT CHANGED THE WORLD,** *by Robert Buderi. Simon & Schuster, 1996 ($30).*

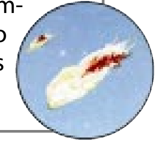
It is only now, after almost all the graduates of M.I.T.'s Radiation Laboratory have died, that one can appreciate the full scope of their contributions. A few hundred young engineers and physicists (guided by their remarkable elders, including financier-physicist Alfred Loomis) developed radar and a host of other electronic gadgets that turned the tide of World War II. They also set the stage for the technological revolution that followed—including the birth of radio astronomy, microwave ovens and the military-industrial complex. Although many parts of the story are long known, Robert Buderi retells it well and brings out its essentially human face.

**THAT GUNK ON YOUR CAR,** *by Mark Hostetler. Illustrations by Rebekah McClean. Brazen Cockroaches, Inc., 1996 ($10). For ordering information, send e-mail to hos@zoo.ufl.edu or call 1-888-BUG-GUNK.*

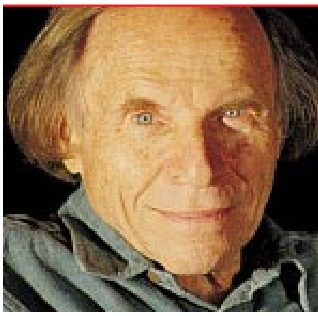


REBEKAH MCCLEAN

It is lighthearted, but Mark Hostetler's unique wildlife guidebook is no joke. A set of color illustrations provides a detailed guide for identifying the insects that produce the splats and streaks on a speeding windshield. The text that follows provides a lively natural history of two dozen common insects, along with suggestions for some simple research projects to do with the various creatures while they are still alive.





## WONDERS

*by Philip Morrison*

# Doing the Poincaré Shuffle

DUSAN PETRICIC

Happy New Year! On 1 January 1997, at about 6 P.M. Eastern Standard Time, Earth will come nearer to the sun than at any other time that year. The elliptical orbit we all travel is no flattened figure but a near circle. The main mark of its ellipticity is that off-center sun. The simplest Newtonian orbital system comprises two bodies, like our sun and planet, free to move under mutual gravity alone, with a unique result: once they begin to circle each other, their orbit will remain for all time a closed ellipse.

Planetary orbits are not all so orderly—or so boring?—as this closed ellipse. Only for the case of two bodies does the eternally fixed ellipse work. For three (or more) interacting bodies, we cannot in general predict for very long even the overall shape of the orbits. How can such a difference appear between two bodies and three? You can grasp why without mathematics, by an appeal to the mechanical intuitions of our life on Earth.

We know that planets are minute actors seen against the wide stage of their spacious orbits. Take an example: heavy central sun; planet moving around it in a big circle; and a third body, a small asteroid or comet, so low in mass that its effect on the other two can almost always be ignored. Set the comet into orbit in the same plane as the planetary circle, but not at all in a circular orbit. Put it rather into a long, narrow ellipse, with the focus at the sun. The comet rounds the sun close in, then goes far out—well past the circular orbit of the planet—to return and repeat. The planet circles smoothly enough, inducing small ripples in the comet's elliptical path. The comet must repeatedly cross the orbit of the planet, although most times planet and comet will be far apart. But sometime in a myriad of passages, a close encounter will take place.

The gravitational force can easily rise a millionfold during an encounter without any physical contact. Such a spike of force takes over the motion. The comet will be pulled into quite a new orbit, first curving near the planet, to depart with its direction and speed forever changed. The moving planet may give energy to or take it away from the deflected comet. Or the comet may be lost, never to return, once it gains speed enough to escape the pull of the distant sun. Plainly, no simple formula can predict such a delicately contingent outcome.

I dub any long string of orbital encounters the "Poincaré shuffle," after the turn-of-the-century French mathematician Jules-Henri Poincaré. He proved before 1900 that even the longest-standing record of punctuality cannot guarantee that the best-tested almanac will hold up. For two bodies, all such misadventures are forbidden, because there is no handy third party to broker some energy. Prediction in the simple case can be perfect, secured by the few overall conservation laws, such as that of energy. There are too few mechanical laws of conservation for the general many-body problem.

*Familiar Mercury now shows signs of orbital instability—it may well become the next planet to depart!*

A calculation in the 1960s by three Russian mathematicians showed that a planetary system will remain stable *if* it starts out closely resembling the simplest case—of low-mass planets moving in co-planar, well-spaced and circular orbits. Our real system does not lie in the narrow band of proved gravitational tranquillity, although it is not far from it.

The most likely popular explanation for our endurance is evolutionary. A real survivor, our solar system has combed itself out over four billion years into the present near-stable state. No one can now say for sure what further simplification, if any, is to come. Add another familiar idea: resonance. Repetitive but distant encounters between orbiters may add up sequentially until small effects grow large, just as the march of soldiers across a suspension bridge can set it swinging. In a system of many orbiting bodies, such fine-tuned patterns of motion are possible even by chance. They offer a wide opening to change more gradual than the shuffle.

The lesson is plain. Most systems with multiple, unkempt orbits have finite lives, if long ones. Lighter bodies cross at their own risk the rights-of-way of any much heavier ones. The clever orbit designers at the Jet Propulsion Laboratory have long known this, as they practice their own art of planetary billiards. Gravitationally caroming by human design, the probe *Galileo* skittered past Earth (with an encore) and then by Venus, ending right on station by looping within Jupiter's sway.

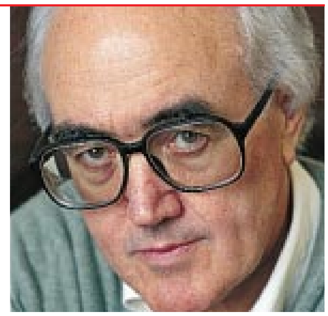
Many rocks among the ejecta from old cratering impacts on planet surfaces are now shuffling from one occupied orbit to another, through millions of orbit crossings. That natural Poincaré shuffle has already brought a few celebrated samples from Mars to Earth, and perhaps some went the other way once. In early times the pull of the big planets strongly stirred the light, icy comets either to merger or banishment. A few of the trillion exiled comets return every year, dangerously crossing orbits again, in response to random attraction from galactic matter far outside our system.

*Continued on page 118*

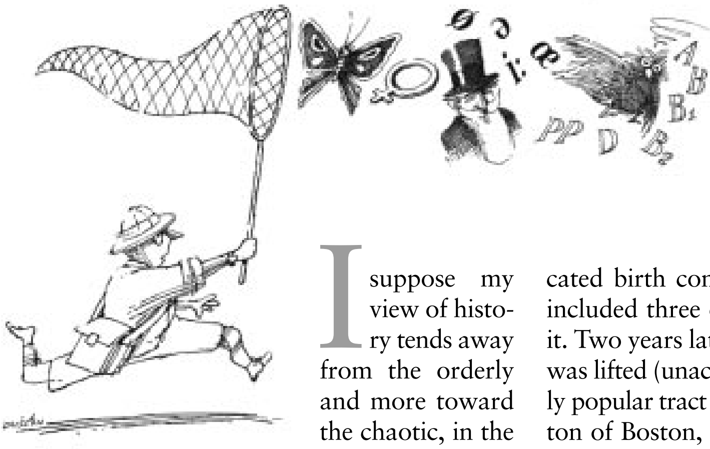
  

# CONNECTIONS

*by James Burke*



## A Bit of a Flutter



DUSAN PETRICIC

I suppose my view of history tends away from the orderly and more toward the chaotic, in the sense of that much overused phrase from chaos theory about the movement of a butterfly's wing in China causing storms on the other side of the world. So, not to be outdone, I decided to have a go at reproducing the butterfly effect on the great web of knowledge across which I travel in these columns.

That thought came at the sight of a giant cabbage white in a Lepidoptera exhibit at the Natural History Museum in London, reminding me of the other great natural history museum, the Smithsonian. Which owes its life to one Robert Dale Owen. The two-term Democrat from Indiana almost single-handedly pushed through Congress the 1846 bill accepting the Englishman James Smithson's bequest of $10 million and change (in today's money) that helped to set up the esteemed institution.

Owen's efforts also involved unraveling one of the shadier deals in American financial history: most of Smithson's money, which had arrived in the U.S. a few years before, was at the time in the dubious grip of a foundering real-estate bank in Arkansas, into which the U.S. Treasury had thoughtlessly placed it for safekeeping.

Owen was a liberal thinker, the son of a famous British reformer who had earlier started an unsuccessful utopian community in New Harmony, Ind. Well ahead of his time, Owen championed the use of plank roads, women's rights, emancipation and family planning. This last he espoused in a pamphlet in 1830. Subtitled "A Brief and Plain Treatise on the Population Question" (which gives you a feel for the cut of his jib), it advocated birth control by everybody and included three examples of how to do it. Two years later much of Owen's text was lifted (unacknowledged) for a wildly popular tract by a Dr. Charles Knowlton of Boston, "The Fruits of Philosophy," which went into greater physiological detail.

Forty years on (which is telling as to the speed of reform), Knowlton's work was republished by activist Annie Besant in England, where it was judged obscene and likely to pervert morals. Ms Besant conducted her own defense at the trial and in doing so became the first woman to speak publicly about contraception. It earned her a fine and a sentence. Undeterred, Besant took up larger causes: Indian independence (she was president of the first Indian National Congress), vegetarianism and comparative religion. This was some years after she'd broken off a romantic interlude with another left-winger, a penniless nobody called George Bernard Shaw, with whom Annie played piano duets at the regular meetings of William Morris's Socialist League in London.

*One day the chickens suddenly got better. What kind of fowl play was going on here?*

Later Shaw would become fairly well known as the author of *Pygmalion* and then world famous when it was remade as the Hollywood musical *My Fair Lady.* It was a play all about talking proper (which Eliza Doolittle didn't, you may recall) and featured a professor of elocution, Henry Higgins, whom Shaw modeled on a real-life linguistic academic named Henry Sweet.

In the 1880s Sweet was one of the inventors of the phonetic alphabet, stemming from the contemporary craze for ancient languages kicked off by William Jones, a Welsh judge in Calcutta. In 1786 Jones had revealed the extraordinary similarities between the Indian language of Sanskrit and Greek. The revelation revved up early 19th-century Romantic nationalistic Germans (who'd not long before lost a war with the French and were going through a period of cultural paranoia) because it gave them the idea that they might be able to trace their linguistic roots back into the Indo-European mists of time, thus proving they had a heritage at least as Paleolithic as anybody in Paris.

This mania for reviving the nation's pride might have been why German graduate students were also getting grants for such big-science projects as sending out 40,000 questionnaires to teachers all over the country asking them how local dialect speakers pronounced the sentence "In winter the dry leaves fly through the air." On the basis of such fundamental data, pronunciation atlases were produced, and dialectology became respectable. So much so that at the University of Jena, a guy called Edward Schwann even got the money to do a phonometric study of zee French accent. Nice work if you can get it.

Schwann was aided in his task by the eminent German physicist Ernst Pringsheim. In 1876 Pringsheim was one of the science honchos visited by Franz Boll, a researcher who was working on the process by which the human eye is able to see in low light, thanks to the presence of a particular chemical. Or not, in the case of its absence. The whole business of such deficiency was taken a stage further by a sharp-eyed Dutch medical type, Christiaan Eijkman.

Eijkman happened to be in Java with a Dutch hospital unit, sent there in 1886 to grapple with the problem of beriberi, a disease that was laying low large numbers of colonial administrators and army people. He noticed some chickens staggering about the hospital yard with symptoms not unlike those he was studying in humans. But these were chickens, so he did nothing about it. Until one day the chickens suddenly got better. What kind of fowl play was going on here?

Turned out, the new cook at the hospital had decided that what was good enough for the local Javanese workers was good enough for birds. So he had stopped feeding the chickens gourmet leftovers from the table of the European medical staff. Difference being in the rice. Europeans were given polished rice ("military rice"); locals and the chickens got the stuff with the hulls left on ("paddy"). Months of chicken-and-rice tests by Eijkman garnered an important result: something in the rice hulls was curing the chickens. Or, to put it more meaningfully, without this "something" the chickens got the staggers. So was that why people did the same?

A few years later, in England, Frederick Gowland Hopkins, an insurance broker turned biochemist, observed that baby rats wouldn't grow, no matter what they were fed, if their diet didn't include milk. He became convinced there was something essential for health in normal food that wasn't protein, carbohydrate, fat or salt. He labeled these mystery materials "accessory food factors" and went on to share the 1929 Nobel Prize for Physiology or Medicine with Eijkman, because between them their work would lead to the discovery of what these accessories actually were: vitamins. (In the case of the chickens, thiamine, vitamin $B_1$.)

Now, why all this made me think that the way the knowledge web works might remind you distantly of chaos theory was because of what Hopkins had been doing before he got into nutrition. He was able to work with pure proteins and their role in nutrition once new techniques had been developed (at Guy's Hospital in London, where Hopkins had trained) to analyze uric acid proteins in urine. And he was interested in uric acid because his very first scientific project had been with insects, and he had conjectured (wrongly, as it turned out) that uric acid was involved in producing the white pigment of the wings of certain butterflies. SA

*Wonders, continued from page 116*

They, too, face eventual capture or exile.

The only satisfying means of study in deep time has become trial by computer. Simulate gravitational forces accurately among the many bodies, and their interactions play out step by step, over orbits galore. One solar system can hardly show how others must behave, for diversity is apt to be their most common property. Generous dynamical friends have shown me some recent experimental printouts of a special three-body case—two planets of adequate mass orbiting too near their sun in closely spaced concentric circles. They execute their more or less unchanging orbits through long, long runs, tens of simulated "millennia." Then, all in one bad season, each planet abandons its accustomed path to move a considerable way toward the other, until both withdraw to their original neighborhoods.

Somewhat later the attraction becomes irresistible; the two draw speedily together and then merge. In another trial one of the errant pair is ejected, to be flung far away. Perhaps this is a clue to the real history of one extrasolar near-Jupiter we have newly found, circling alone, surprisingly close to its own sun?

Our computer-armed dynamicists currently report rather gloomy expectations close at home. The grand experiential almanac is growing, but for billions of years ahead it is hardly conclusive. Few orbital radii within our sun's system remain vacant where additional planets could permanently circle. Most likely many of the sun's earlier planets, a dozen or two more once orbiting right among us, crossed orbits to merge or fly off. Familiar Mercury now shows signs of orbital instability hard to disregard. It may well over the long term become the next planet to depart!

In the meantime, instability may bring beauty, not disaster. Spring 1997 offers a strong hope of seeing one such errant body, Comet Hale-Bopp, named after the two experienced observers who found it independently in 1995. If we luck out, it may grow as bright to the unaided eye as any star, a sight unmatched for a generation [see "The Amateur Scientist," page 102]. U.S. sky watchers can find it in the northwest, a quarter of the way up from the horizon an hour or so after dusk, on any evening from a week before to a week after April 1. No kidding. SA

# WORKING KNOWLEDGE

## MAN-MADE SNOW

SNOWFLAKES, despite their varied geometries, all have a sixfold symmetry. The micrograph at the left shows the hexagonal shape of an ice crystal magnified 4,200 times. The dark speck at the flake's center is Snomax, a protein produced by a nontoxic, nonpathogenic, freeze-dried strain of the bacterium *Pseudomonas syringae.* It attracts water molecules and helps them nucleate into crystals.

by Rich Brown

So that winter-sports enthusiasts can enjoy prime conditions, most ski resorts blanket their slopes with man-made snow. Freezing water to make snow might seem easy, but it is a fascinating manufacturing process. Natural snowflakes usually crystallize around dust motes or pollution—particles on which water molecules can condense. These "ice nucleators" are essential; pure distilled water can otherwise remain liquid even at –40 degrees Celsius, a phenomenon known as supercooling. So resort snowmakers sometimes add nucleators to their recipes.

The nucleator at the heart of many man-made snowflakes is a natural protein named Snomax [*see box*]. Steve Lindow, a professor of plant pathology at the University of California at Berkeley, first noted the properties of Snomax in 1975, when he was a graduate student at the University of Wisconsin investigating ways to protect plants from frost damage. Today about half the ski resorts in North America use his discovery, which, on average, increases snow production by 50 percent and yields lighter, drier flakes. At the 1994 Winter Olympics in Lillehammer, Norway, all the man-made snow on the competition routes was produced with Snomax.

*RICH BROWN is general manager of Snomax Technologies in Rochester, N.Y.*


COMPRESSORS AND PUMPS move the main ingredients of snow—water and air—through vast networks of pipes to hydrants on the mountainside. In most snowmaking operations, the water comes from rivers or creeks or from reservoirs installed near ski areas.

SNOWGUN, connected to a hydrant by way of a hose, atomizes and propels the water, which contains particles that seed forming ice crystals, over the trail. When the water hits the cold air, it crystallizes and falls to the ground. These heaps, or "whales," of accumulating snow are later spread over the slopes.

ILLUSTRATION BY JACK UNRUH; JANA BRENNING (*snowflake*); SNOMAX TECHNOLOGIES (*micrograph*)