THE SPARK OF LIFE • SHRIMP FARMING • THE CHEMISTRY OF MISERY

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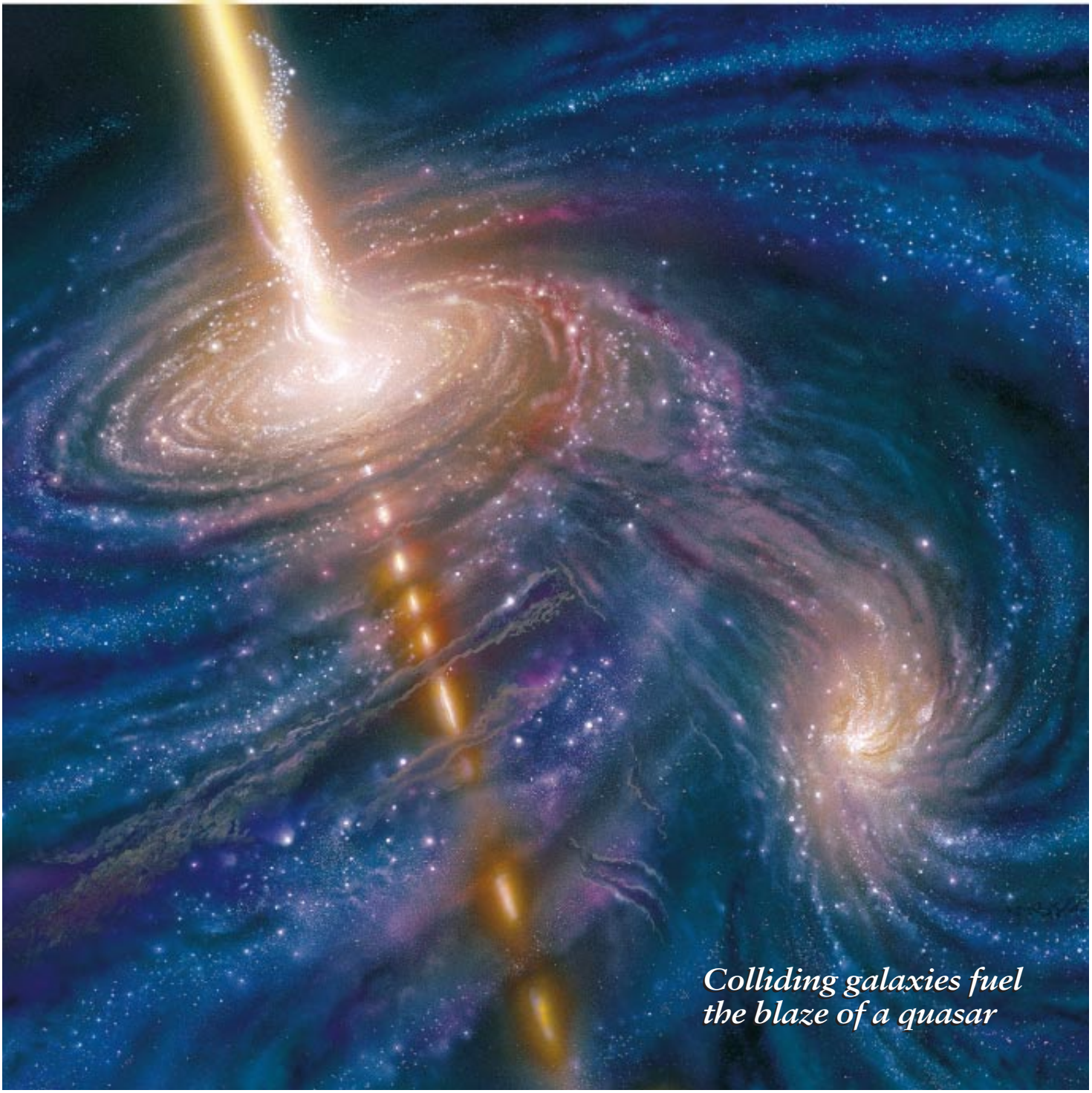
LIQUID COMPUTERS

Magnetic Fields Build a Computer from Drops of Fluid

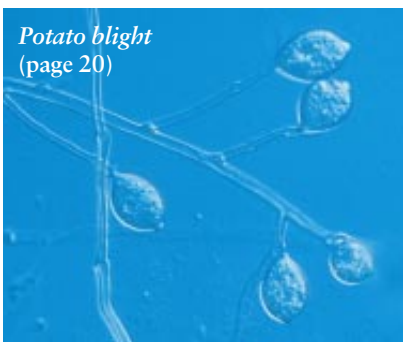


Colliding galaxies fuel the blaze of a quasar

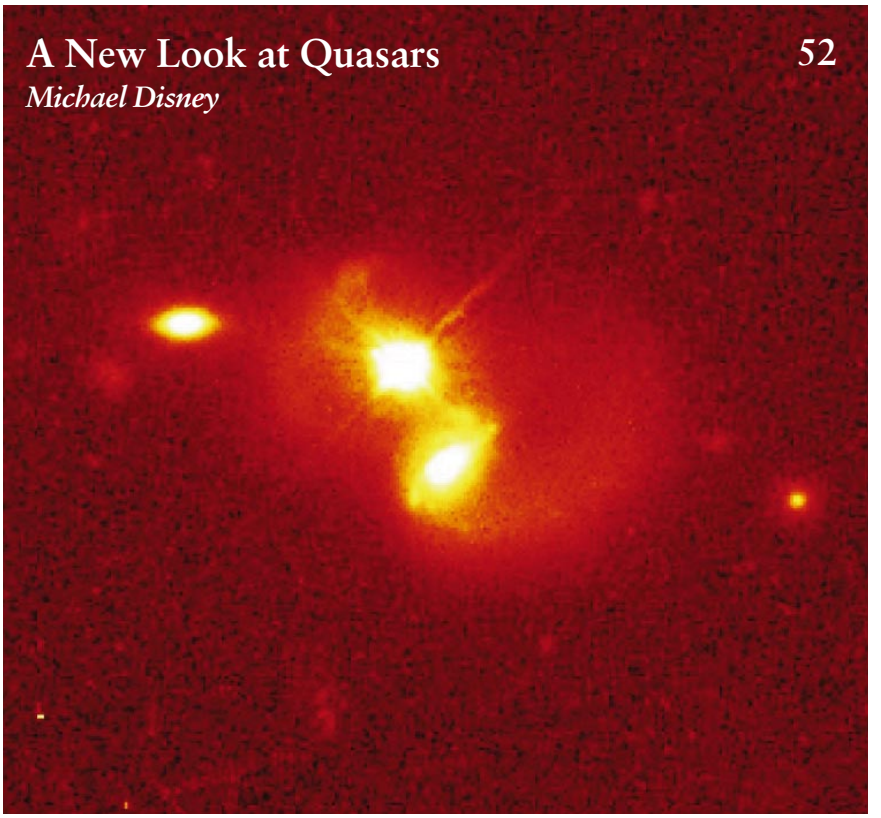
SCIENTIFIC AMERICAN

June 1998 Volume 278 Number 6

NEWS AND ANALYSIS

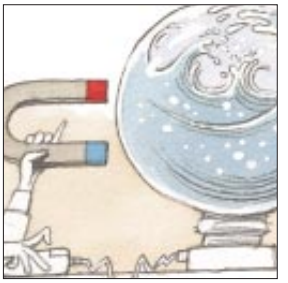


Potato blight
(page 20)



Quasars are the most luminous objects in the universe, not much larger than our solar system but brighter than a trillion suns. Their mere existence challenged physics for years. Black holes swallowing whole stars inside colliding galaxies seem to power most quasars, but many mysteries remain. Newly installed instruments on the Hubble Space Telescope may reveal the answers at last.

Whatever its cause, depression ultimately arises from biochemical shifts in the brain that provoke aching sadness, loss of pleasure, guilt, thoughts of death and other symptoms. The search for those neurological underpinnings is intensifying and raising the prospects of better treatment for one of the most common mental health disorders.



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REVIEWS AND COMMENTARIES

About the Cover

During a collision of two galaxies, gases fall into a monstrous black hole at nearly the speed of light, generating an intense beam of energy that is visible from the earth as a quasar. Painting by Don Dixon.

Visit the SCIENTIFIC AMERICAN Web site (http://www.sciam.com) for more information on articles and other on-line features.

Not Just a Fish Story

Job satisfaction comes in many forms; in the magazine business, it often arrives by mail. While putting the finishing touches on this issue, we received such a note unsolicited from Mike Sipe, the president of Tilapia Aquaculture International in Palmetto, Fla. (*Tilapia* is a genus of freshwater fish, closely related to angelfish and the African cichlids, much prized for its food value.)

His start in aquaculture came after seeing "The Cultivation of Tilapia," by Charles F. Hickling, in the May 1963 issue of *Scientific American*. "After reading it over about four times," Sipe explains, "I wrote to Dr. Hickling asking how I could get involved." Since 1971 he has worked full-time at breeding tilapias. "I have been able to select strains of pure species that can provide almost double the fillet yields of the hybrids depicted in your 1963 article," Sipe continues, "and F1 hybrids that grow from 10 grams to one kilogram in under six months." He has also refined methods for breeding and growing the fish: "Our best systems can now produce upward of 100 pounds per square foot per year, indoors, with zero water exchange."

HANS REINHARD *Bruce Coleman Inc.*

Tilapia

"Tilapia cultivation is the fastest-growing single agriculture or aquaculture industry on the planet Earth," he writes. "I have helped to start projects and supplied breeders in more than 35 countries and in most U.S. states. Recently, after a conference in Veracruz, I learned that almost 100 million pounds of tilapias originating from my red mossambica strains are now grown and consumed annually in rural Mexico, and I have been told that similar amounts are being grown from the same tilapia strain in Brazil."

In short, he says, tilapias are the most cultivated fish in the world (outside China), at reportedly more than a billion pounds last year. And 300 million to 400 million pounds of that came from Sipe-strain red tilapias.

"All of which was as a result of reading your article," Sipe declares.

Readers who would like to know more about tilapias and Sipe's activities should check out his company's World Wide Web site (http://www.cherrysnapper.com). Shrimp farming is another hot aquacultural endeavor, one with a mixed environmental record. Claude E. Boyd and Jason W. Clay offer differing perspectives on "Shrimp Aquaculture and the Environment" (see page 58), but they also find common ground. We hope their collaboration and dialogue here will help that industry live up to its best potential. What a shame if shrimp were the ones that got away.

JOHN RENNIE, *Editor in Chief*
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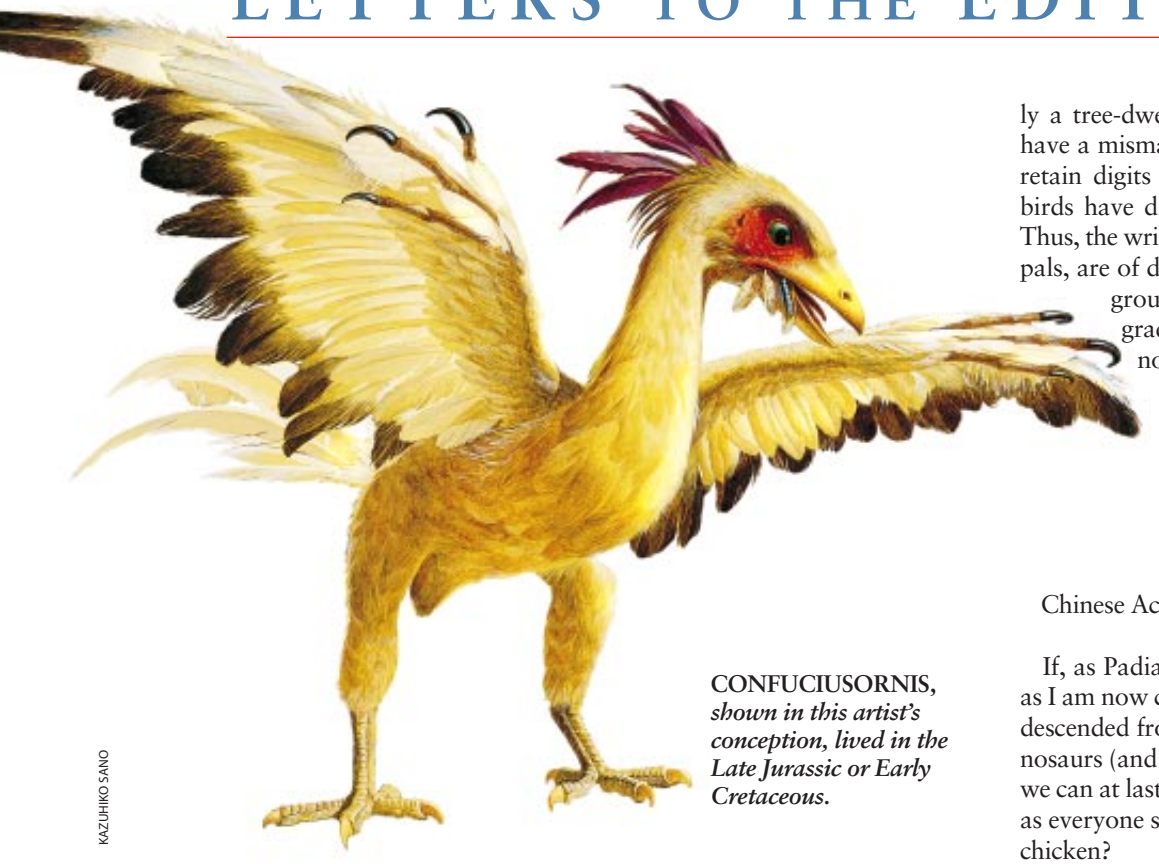


KAZUHIKO SANO

CONFUCIUSORNIS, ***shown in this artist's conception, lived in the Late Jurassic or Early Cretaceous.***

BIRDS OF A FEATHER

As the original describers of *Confuciusornis,* we were astounded to see the cover of the February issue, with its illustration for the article "The Origin of Birds and Their Flight," by Kevin Padian and Luis M. Chiappe. Although *Confuciusornis* is a primitive, sauriurine bird, in life it would have appeared very much like a normal perching bird, such as a small crow, not a feathered dinosaur. The cover illustration has nothing to do with *Confuciusornis,* which, as is now known from literally hundreds of specimens, exhibited dramatic sexual dimorphism and apparently lived in colonies. The illustration would appear to be a resurrection of the "insect-net" hypothesis for the origin of flight feathers proposed by John Ostrom but now almost universally rejected.

What is particularly disturbing is that the bird shown has a vertical, dinosaurian pubis, but the fossils [*see below*] show a backwardly directed pubis, as in modern birds. The authors have no concept of how feathers attach to the hand, and it is not clear if this bird has primary feathers. In the fossils of *Confuciusornis,* a complete set of normal primary feathers and perfectly aligned secondary feathers are clearly evident. The fossils show a perfectly normal reversed first toe (hallux), with strongly curved claws adapted for life in the trees and a short lower leg bone (tarsometatarsus); *Confuciusornis* was clearly a tree-dweller. Birds and dinosaurs have a mismatch of fingers—dinosaurs retain digits one, two and three, and birds have digits two, three and four. Thus, the wristbones, or semilunate carpals, are of different origins in the two groups, thereby grossly degrading the possibility of a dinosaurian origin of birds.

ALAN FEDUCCIA
University of North Carolina
LARRY MARTIN
ZHONGHE ZHOU
University of Kansas
LIAN-HAI HOU
Chinese Academy of Sciences, Beijing

ZHANG JIE

FOSSILIZED REMAINS ***of* Confuciusornis *were found in China.***

If, as Padian and Chiappe state, and as I am now convinced, "birds not only descended from dinosaurs, they are dinosaurs (and reptiles)," could it be that we can at last understand why it is that, as everyone says, rattlesnake tastes like chicken?

ALLEN DODWORTH
Salt Lake City

Padian and Chiappe reply:

Most readers can easily distinguish between science and art. And while some license is necessary in restorations of extinct animals, artist Kazuhiko Sano worked from Feduccia et al.'s own reconstruction published in *Science* in 1996 [*opposite page*]. We reworked this kangaroolike pose, which no known bird has ever plausibly assumed, into the stance seen in all living birds and their dinosaurian ancestors. This stance can be seen in the illustrations in our article and in any dinosaur book or museum gallery, and it is reflected in Sano's painting. Readers can judge for themselves the comparative verisimilitude of the reconstructions.

The other statements that Feduccia and his colleagues make about the pubes, feathers, toes and social habits of *Confuciusornis* and the magazine

cover are misinterpretations of the painting, irrelevant, or possibly true but still unpublished inferences that require scientific substantiation.

Birds and dinosaurs do not have mismatched fingers. Both groups retain the first three fingers, inherited from a common ancestor. Readers can easily see this in our illustrations on page 42 of the February issue and in the references we cited in our article. Feduccia and his colleagues, after 20 years of objecting

COURTESY OF KEVIN PADIAN (*left*); REPRINTED FROM *SCIENCE* (Vol. 274, Nov. 15, 1996) (*right*)

RECONSTRUCTION of* Confuciusornis *in a birdlike stance* (left), *favored by authors Padian and Chiappe, differs significantly from the upright stance* (right) *favored by Feduccia and his colleagues.

to the dinosaurian ancestry of birds, have no alternative ancestry for us to test; they ignore 90 percent of the evidence and refuse to use the methods of analysis that everyone else uses. All their well-worn objections have been answered. This "debate" ceased to be scientific a decade ago.

We take Dodworth's question more seriously, as it is a testable one. Frog legs, crocodiles, rabbits and some rodents are also said to taste like chicken. Could this feature have characterized the earliest tetrapods, and was it later modified into the different, "secondary" forms of beef, lamb, pork and so on? The French gastronome Anthelme Brillat-Savarin, in his famous book, gave us the physiology of taste; Dodworth now offers a possible solution to its genealogy.

DONOR DISCRIMINATION

As a physician whose patients frequently require blood products, I second your plea for donors ["Saving at the Blood Bank," by John Rennie, From the Editors, February]. Personally, I wish that I could donate blood. But because I am a gay man, I am automatically excluded. This is despite the fact that I am not infected with HIV or any other blood-borne pathogen. The practice of donor exclusion originated in the early days of the AIDS epidemic, before the biology of HIV was understood. But we now understand much more about the virus, and many gay men can be completely confident that they are not infected. Yet as a group, we continue to be forbidden from donating blood. This is tragic in the context of our country's continuing shortage of blood products.

PETER SHALIT
University of Washington

Editors' note:

Blood services do ask whether male donors "have had sex with another man even one time since 1977"; men who answer "yes" are not allowed to give blood. In addition, people who have been involved with illegal injected drugs, prostitution or other activities considered high risk are excluded as donors, regardless of their current tested HIV status. The policy reflects the 1992 guidelines from the Food and Drug Administration, the agency that regulates all blood donation practices in the U.S.

JASON AND MEDEA

Somewhat belatedly, I wish to clarify the background of the name "MEDEA" for the scientific project described in Jeffrey Richelson's article "Scientists in Black" [February]. In 1991 the consulting group JASON decided to deemphasize environmental research, much to the disgust of my husband, Gordon MacDonald, who has been a JASON participant since 1962. I therefore suggested, facetiously, that he establish a competing organization focused exclusively on environmental issues and call it MEDEA because of the mythological Medea's antagonism toward Jason.

When Gordon and other scientists began in 1992 to work with representatives of the intelligence community to establish the Environmental Task Force (ETF), he, Linda Zall and I continued to refer to the program as MEDEA. In 1994 Vice President Al Gore accepted this name for the permanent group that would succeed the ETF, but Linda told us that we would need—immediately—to justify the name by inventing a title for which MEDEA could serve as an acronym. As we drove to lunch, I scribbled alternatives on the back page of my address book (I still have it) and came up with "Measurement of Earth Data for Environmental Analysis," a name Linda accepted and has since ably advocated.

MARGARET STONE MACDONALD
International Institute
for Applied Systems Analysis
Laxenberg, Austria

SOMETHING IS ROTTEN

I love your magazine but was a little disappointed to see that you failed to put the Danish capital in its correct place ["The Viking Longship," by John R. Hale, February] on the map on page 60. Last time I checked, wonderful Copenhagen lay around 50 miles north of where you placed it—it should have appeared just below the "s" in "Roskilde," by the small island. A minor detail, but we Danes have to stand up for our geography.

MORTEN ERNEBJERG
Værløse, Denmark

Letters to the editors should be sent by e-mail to editors@sciam.com or by post to Scientific American, 415 Madison Ave., New York, NY 10017. Letters may be edited for length and clarity. Because of the considerable volume of mail received, we cannot answer all correspondence.

ERRATA

"The End of Cheap Oil" [March] states that "only 700 Gbo [or billion barrels of oil] will be produced from unconventional sources over the next 60 years." The sentence should have read "over the next 160 years."

In "Japanese Temple Geometry" [May], an answer on page 91 of the U.S. edition contains an error. For the problem of a cylinder intersecting a sphere, the correct answer is

$$16t\sqrt{t(r-t)}$$

50, 100 AND 150 YEARS AGO

SCIENTIFIC AMERICAN

JUNE 1948

FUNGUS INFECTION—"Histoplasmosis, in 1944, was thought to be extremely rare; even its name was unknown to most physicians. However, since then a new skin test was used in a large-scale survey of thousands of student nurses. The results were astonishing: almost one fourth of all the students reacted positively to the test. It is now thought that millions of Americans are afflicted. Little is known about this ominous fungus. *Histoplasma capsulatum* appears in nature in two varieties, one harmless, the other parasitic and responsible for causing histoplasmosis in man. The parasitic type is believed to be insect-borne, but the method by which the disease is spread is unknown." [*Editors' note: The fungus is associated with bird or bat droppings.*]

OLD AGE—"Within the last 10 years scientific interest in problems of aging has gained momentum. This interest comes in the nick of time, for such disorders as arthritis, nephritis, and cardiovascular disease have become a tremendous problem. As medicine copes more effectively with the diseases of childhood and early maturity, the percentage of our population in older age groups has been mounting steadily. How far deterioration and natural death can be pushed back is still a matter of debate. Conservative physiologists would grant that health and vigor can last to the age of 100. The enthusiastic Russians, who have been probing the secrets of age with great energy, would set the limit above 150."

JUNE 1898

HYDROGEN LIQUEFIED—"Prof. Dewar has recently liquefied hydrogen, which is an unprecedented feat. Fuller accounts of his experiments have now been published. In the apparatus used in these experiments, hydrogen was cooled to –205° Centigrade, and under a pressure of 180 atmospheres, escaped continuously from the nozzle of a coil of pipe at the rate of about 10 or 15 cubic feet per minute, in a vacuum vessel. Liquid hydrogen began to drop from this vacuum vessel into another, and in about five minutes 20 cubic centimeters were collected."

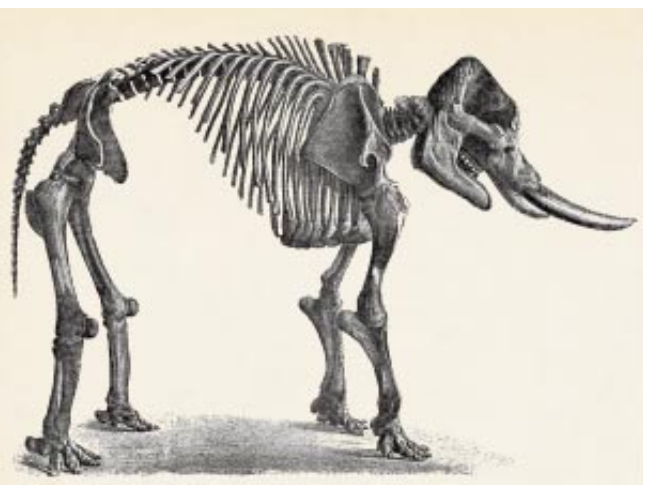
EARTH'S ATMOSPHERE—"By causing green plants to vegetate in nitrogen gas containing some carbonic acid, I became convinced that they are essentially anaerobic, that they can vegetate without free oxygen, that they are the means by which nature has provided the atmosphere with free oxygen and that as the composition of the air gradually changed, becoming more oxygenated with the lapse of centuries, plants of aerobic nature and animals appeared. If I place a green plant, such as *Lysimachia nummularia* (moneywort), over water in a glass bell full of nitrogen containing some carbonic acid, in a few months the atmosphere of the bell will be proved to be even richer in oxygen than the external atmosphere. —Thomas L. Phipson"

BAD SOW DISEASES—"The growing danger of slaughter houses as a factor in spreading infectious disease is at last being appreciated. Ch. Wardell Stiles, Ph.D., in a paper published in 1896, says, 'When the offal of a trichinous hog is fed to hogs which are raised upon the grounds, the latter cannot escape infection with trichinae. Every slaughter house is a center of disease for the surrounding country, spreading trichinosis, echinococcus disease, gid, wireworm, and other troubles caused by animal parasites, and tuberculosis, hog cholera, swine plague and other bacterial diseases.' He recommends: (a) Offal feeding should be abolished; (b) drainage should be improved; (c) rats should be destroyed; and (d) dogs should be excluded from the slaughter houses."

MASTODON SKELETON—"In 1866, when clearing a place to establish the Harmony Knitting Mills, at Cohoes, N.Y., a large pot-hole was found. It appeared as a bog, like many a mountain pond covered with floating moss which has no outlet because it is a bowl in the rock. Excavating disclosed the remains of a mastodon fifty feet below the surface. Evidently in prehistoric times the huge beast had fallen into the hole in the ground, for this one is thirty feet in diameter. The bones of this big fellow are now on exhibition in the New York State Geological rooms."

JUNE 1848

A FEMALE FIRST—"Miss Maria Mitchell, of Nantucket, discoverer of the Comet which bears her name, was unanimously elected an honorary member of the American Academy of Arts and Sciences, at their last general meeting. We believe that this is the first time such an honor has been conferred on any lady in this country; and a similar honor had been conferred on but two ladies in Europe, Miss Caroline Herschell, the sister and assistant of the late Sir William Herschell, the astronomer, and Mrs. Mary Fairfax Somerville, the commentator on Marquis de La Place's 'Celestial Mechanics.'"



Mastodon skeleton from a New York State bog

NEWS AND ANALYSIS

IN FOCUS

CULTURING NEW LIFE

Stem cells lead the way to a new medical paradigm in tissue regeneration

KAY CHERNUSH

KEY HUMAN CELLS THAT MAY DEVELOP INTO A RANGE OF TISSUES have been isolated by Michael Shamblott (left) ***and John D. Gearhart.***

Many killer diseases involve irreversible degeneration of some crucial cell type or tissue: islet cells of the pancreas in diabetes, neurons of the brain in Parkinson's disease, Huntington's disease and other neurological conditions. Researchers have long dreamed of culturing in the laboratory human cells that could colonize and regenerate failing tissue. But biology has been uncooperative. Cancer cells readily grow in a bottle, but healthy, normal ones soon stop propagating outside the body.

Recent discoveries point to a solution. Investigators have been able to identify and culture for many months rare "stem cells" from various crucial tissues. These cells, when implanted in the appropriate type of tissue, can regenerate the range of cells normally found there. Stem cells have been discovered in the nervous system, muscle, cartilage and bone and probably exist in pancreatic islet cells and the liver. More remarkable still, unpublished work has convinced moneyed entrepreneurs that special cells derived originally from a fetus could produce a wide variety of tissue-specific cells.

A type of human stem cell found in bone marrow, which gives rise to the full range of cells in blood, has been known since Irving L. Weissman of Stanford University discovered it in 1991. A cancer patient whose marrow has been destroyed by high doses of radiation or chemotherapy can be saved by a transplant of bone marrow–derived cells. Stem cells in the transplant establish lineages of all the cells in blood.

Researchers have, however, been surprised to learn that stem cells exist in tissues such as the brain, where they can give rise to all three of the common cell types found there: astrocytes, oligodendrocytes and neurons. The discovery "contradicts what is in the textbooks," says Ronald D. G. McKay of the National Institute of Neurological Disorders and Stroke. McKay reports that he has demonstrated that central nervous system stem cells grown in his laboratory can engraft in mouse brains and alleviate behavioral abnormalities in

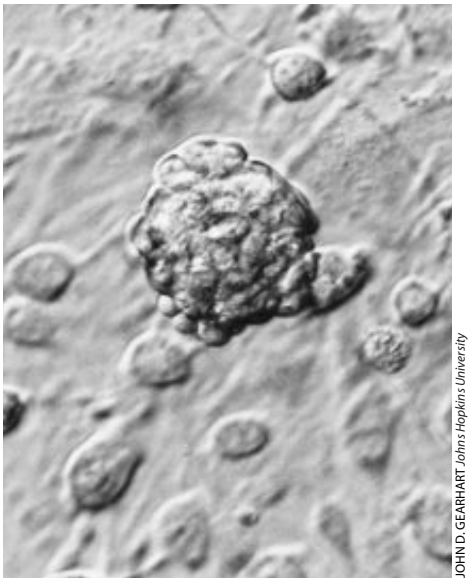
animals genetically engineered to mimic features of Parkinson's disease. Pancreatic islet and liver stem cells were likewise not widely expected to exist in adults, but the evidence for them is "strong," Weissman says.

Although they may constitute only one in every few thousand tissue cells, stem cells can be isolated through specific molecules they display on their surfaces. One way to make use of stem cells would thus be to extract them from a tissue sample given by the patient or a donor, then multiply them in the laboratory. Several companies are studying this approach.

SyStemix in Palo Alto, Calif., a division of Swiss pharmaceutical giant Novartis, is testing its technique for isolating blood-producing stem cells from bone marrow as a means to improve conventional bone marrow transplantation. Such cells taken from a donor can also bring about in a patient immune system tolerance of any of the donor's cells, Weissman notes, suggesting a future for them in preventing rejection of transplants. He has established a company, StemCells, Inc., now part of CytoTherapeutics in Lincoln, R.I., which aims to establish solid-organ stem-cell lines. Osiris Therapeutics in Baltimore, which Novartis partly owns, is testing patient-derived mesenchymal stem-cell preparations for regenerating injured cartilage and other types of tissue.

Yet growing tissue-specific stem cells from donors or patients has a potentially worrisome disadvantage, says Thomas B. Okarma of Geron in Menlo Park, Calif. Blood-producing stem cells have to divide rapidly in order to reengraft a patient's bone marrow successfully. With each division, structures at the end of the chromosomes known as telomeres shorten slightly. As a consequence, the reengrafting cells age prematurely, perhaps limiting their growth potential.

Geron therefore plans to derive tissue-specific stem and other cells from a different source: nonaging cells called embryonic germ cells. These ultimately versatile cells can, Okarma believes, be cultured indefinitely and can give rise to every cell type found in the body. They are similar to what in animals are called embryonic stem cells.



JOHN D. GEARHART *Johns Hopkins University*

HUMAN EMBRYONIC GERM CELLS **(cluster in center)** ***grow on "feeder" cells*** **(background).**

Mouse embryonic stem cells are extracted from live, very early stage embryos. When injected into a developing embryo, they populate and develop into all tissue types. Scientists in the U.S. cannot use the same technique to isolate human embryonic stem cells because of legal restrictions (an institution that allowed such work would most likely lose all federal funding). But John D. Gearhart, a professor of gynecology and obstetrics at Johns Hopkins University, has employed a different approach to establish human cell lines that seem to have characteristics of embryonic stem cells.

Gearhart knew that in mice, gonad-precursor cells in the developing fetus behave like true embryonic stem cells. He and postdoctoral fellow Michael Shamblott therefore established embryonic germ-cell lines from human gonad-precursor cells, which they took from aborted fetuses. Gearhart is now testing whether the cells can indeed develop into a full range of human cell types—by implanting them in mice that have no functioning immune system, where they give rise to tumors. For now, Gearhart will say only that he has seen "several cell types" forming in the tumors and that he aims to publish full details within months. But if Gearhart's cell lines, or others', make cells from all tissue types, they could become a long-lived source for human tissue cells and stem cells.

Several investigators have in the past year or so shown that animal embryonic stem cells can be induced to develop into tissue-specific cells by bioengineering techniques. Loren J. Field and his associates at Indiana University, for example, have made heart muscle cells from mouse embryonic stem cells by adding to them specific DNA sequences. The resulting cells engraft in a developing heart. McKay has been able to create central nervous system stem cells from mouse embryonic stem cells. "Human embryonic stem cells would have profound implications for the treatment of human disease," notes James A. Thomson of the University of Wisconsin.

Okarma says Geron plans to develop techniques to convert Gearhart's cells into medically useful types. Because embryonic germ cells do not age, it should be possible to alter their immunologic characteristics with genetic engineering. Doctors treating a patient in need of new neural tissue, for example, might then convert banked cells that match the patient's into neural precursors and place them in the patient's brain. (Fetal tissue is sometimes used now, but the supply is limited.) If an exact match is needed, a technique known as nuclear transfer could even be used to create tissue that is immunologically identical to the patient's own, Okarma speculates.

Geron also has a keen interest in telomerase, an enzyme that prevents the telomeres at the ends of chromosomes from getting shorter each time a cell divides. Geron scientists showed earlier this year that when human cells that normally do not express telomerase have the gene artificially activated, they divide in culture indefinitely. Okarma says Geron researchers plan to investigate whether telomerase can allow tissue-specific stem cells to be cultured indefinitely.

Isolating and culturing stem cells is still an exacting task. Moreover, stringent safety testing would be needed before physicians could introduce modified cells into a patient, because they could conceivably become cancerous. But the broad, long-term potential of stem-cell therapy is becoming apparent. In the meantime, companies such as Geron hope human stem cells will assist drug-development efforts.

Stem cells could even bring to fruition the long-sought promise of gene therapy. The technique has yet to become a practical mode of treatment, because it has proved difficult to get active therapeutic genes into mature cells. But if therapeutic genes could be introduced into just a few stem cells, they could be cultured and then deployed in quantity.

How long before stem cells are in widespread medical use? Thomson declines to be specific. But he estimates that "we'll know how to make specific cell types within five years."

—Tim Beardsley in Washington, D.C.

ENDANGERED SPECIES

LUPUS IN LIMBO

A special designation leaves open legal challenges to the reintroduction of wolves

This past March the U.S. Fish and Wildlife Service released 11 captive-bred Mexican gray wolves into the Apache National Forest, a tract of greenery extending through eastern Arizona. Extinct from the Southwest for the past two decades, the wolves that were reintroduced received the "nonessential experimental" designation under the Endangered Species Act. This label was meant to appease ranchers; it allows them to defend their livestock against the reintroduced wolves. With the label, the reintroduced animals have less federal protection than the wild ones, which cannot be legally harmed. But that creates a practical problem for ranchers, who can't always distinguish reintroduced wolves from wild ones. Now legal action by the ranchers is challenging the effectiveness of the label and could threaten the future of the program.

Conservationists got their first lesson on the legal quandaries created by the labeling from the controversy surrounding another nonessential experimental animal: the reintroduced gray wolves, *Canis lupus,* of Yellowstone National Park. In the early 1990s the Fish and Wildlife Service trapped wild gray wolves in western Canada and released them in the park. Listed as endangered since 1967, the gray wolf was exterminated from the American Rockies in the early 1900s to quell the fears of ranchers. But populations were allowed to thrive in parts of Canada.

"The gray wolf would've eventually reestablished itself," says Edward E. Bangs, Fish and Wildlife Service coordinator of wolf recovery at Yellowstone. "We knew they were migrating down from Canada into central Idaho and Montana." The service estimates that the northern populations will take 20 to 30 years to migrate into the U.S., whereas the reintroduction program will reestablish the populations in six to seven years.

"But the sooner we get them reestablished," Bangs adds, "the sooner we reap the benefits"—namely, a restoration of the region's precolonial ecological balance. As a result of the reintroduction program, Bangs estimates that between 155 and 170 gray wolves now roam the Rockies; as the dominant predators in the area, they have brought exploding coyote and elk populations under control.

But last December a U.S. district court ruled that the nonessential experimental designation violates the Endangered Species Act because ranchers cannot immediately identify wild wolves from reintroduced ones; they cannot be sure if it's legal to shoot a threatening wolf. So the judge ordered the wolves removed from the park—which in wildlife terms probably means they will be shot.

A similar battle could shape up in the Southwest, where ranchers in New Mexico and Arizona have filed suit to stop the reintroduction of the Mexican wolf, *Canis lupus baileyi,* a subspecies of the gray wolf. It has been listed as endangered since 1976, and the last confirmed sighting of the wolf in the wild was in 1980, according to David R. Parsons, leader of the Mexican Wolf Recovery Program. The Fish and Wildlife Service looks to maintain captive populations in zoos and to reintroduce these animals into the South over the next five years. Eventually, the conservationists hope to establish a minimum population of 100 wolves, which may take eight to 10 years. Parsons reports that the wolves are adapting well: three family groups were released, and the animals are sticking together, remaining within a three-mile radius of their point of release.

The problem stems from studies that estimate that 100 Mexican wolves will kill up to 34 livestock annually. That has ranchers motivated. Nine organizations, led by the New Mexico Cattle Growers Association, have filed suit to stop the reintroduction. They argue that wild Mexican wolves still roam in the Southwest and that reintroduced captive-born animals might breed with the wild wolves, thus threatening to dilute the genes of the native populations.

Parsons and his group had until late May to defend against the lawsuit. Parsons was not worried. "The situation in the Southwest is very different from the one in Yellowstone," he maintains. Contradicting the ranchers' claims, Parsons argues that "the Mexican wolf is completely extinct in the wild, so there isn't the problem of identifying reintroduced and wild animals. The nonessential experimental population isn't threatened by this lawsuit."

In contrast, the Yellowstone gray wolves face a much more uncertain future. The nonprofit group Defenders of Wildlife has appealed the ruling to remove the wolves, and any action against the animals must await a judgment on the appeals. At the moment, that decision lies in the indefinite future, so the fates of the "nonessential experiments" remain in limbo. —*Krista McKinsey*

TOM BRAKEFIELD *Bruce Coleman Inc.*

***GRAY WOLF FROM CANADA** was used to repopulate Yellowstone National Park.*

CLIMATE CHANGE

GOOD NEWS FOR THE GREENHOUSE

Growth of atmospheric methane might soon abate

Last December's climate talks in Kyoto, Japan, helped to keep the world's attention firmly focused on the threat of greenhouse warming posed by emissions of carbon dioxide. And to good effect: if industrial nations can meet the targets they established, the heat-trapping veil of carbon dioxide should thicken less swiftly. But another, more subtle, event occurred last December that might also bode well for future climate. Researchers from the National Oceanic and Atmospheric Administration (NOAA) and the University of Colorado reported that methane, another potent greenhouse gas, appears to be accumulating in the atmosphere more slowly than anticipated. If this trend continues, the concentration of methane might soon stabilize, miraculously stemming some 20 percent of the burgeoning greenhouse problem.

This news from NOAA's Edward J. Dlugokencky and his colleagues (delivered at the last meeting of the American Geophysical Union) represents a departure from previous conceptions. Researchers had known that the growth of atmospheric methane had been ebbing since comprehensive measurements began in the early 1980s. And they were aware of an abrupt decrease in the rising tide of methane and several other trace gases that occurred in 1992. But many, including members of the influential Intergovernmental Panel on Climate Change (IPCC), regarded that sudden downturn as a short-term "anomaly." After all, the main sources of methane—wetlands, rice paddies and livestock—had not gone away. According to their best guesses, the 1992 decline was caused, perhaps, by the drop in natural gas production (and, presumably, methane leakage from pipes) in the former Soviet Union. Or it came from the eruption of Mount Pinatubo the previous year, which reduced stratospheric ozone and allowed more ultraviolet light to reach the lower atmosphere, where it breaks up methane.

So Dlugokencky's observation that the growth of methane has remained comparatively low for years after the atmospheric effects of Pinatubo subsided has sparked some rethinking. Inez Y. Fung, an expert on atmospheric methane at the University of Victoria in British Columbia, regards the new findings as "spectacular data," yet she emphasizes that most scientists are so far at a loss to understand what is behind the change. "Ed has presented for us a tremendous challenge," she notes.

But Dlugokencky and his colleagues did more than just offer up data. They suggested that the slowing growth rate of methane can be explained by viewing the atmosphere as a chemical system approaching equilibrium on a timescale that is on par with the lifetime of methane—about a decade (it is broken down both by ultraviolet light and by certain chemical reactions).

Aslam K. Khalil, an atmospheric scientist at Portland State University, has a different interpretation. He believes that methane is accumulating more slowly now because the long-standing link between methane sources and human population is weakening. But whatever the cause, if the current pattern holds, then stabilization between production and destruction is not far off.

In contrast, the IPCC had projected that atmospheric methane would continue to rise, roughly doubling (in one typical forecast) by 2100. Thus, many of the scenarios for global warming provided in their last assessment may have been overly gloomy. Nevertheless, Fung thinks it is premature to celebrate, because this slowing in the rise of methane might not persist. When pressed for how long one must wait to be optimistic, she answers: "If it goes on for another 10 years, I would be ecstatic."

David S. Schimel of the National Center for Atmospheric Research, one of the authors of the 1995 IPCC report on the topic, admits that the assumptions used at that time were "based on an understanding of methane that was five to 15 years old." He, too, notes that climate researchers are disquieted by their inability to forecast such changes. Still, he regards the recent downturn in the growth of this greenhouse gas as "definitely good news." *—David Schneider*

MICKEY GIBSON *Earth Scenes*

RICE CULTIVATION,
shown here in Bali, is among the activities that release heat-trapping methane.

FIELD NOTES

MESOZOIC MYSTERY TOUR

The annual horseshoe crab procession, as seen from Brooklyn

Flatlands, Brooklyn, is not the kind of place to which one generally travels to reflect, awestruck, on an indescribably ancient natural pageant. But this is exactly what I did last year, on a breezy evening when the moon was full, and the summer solstice was only a day away.

Every year horseshoe crabs and their evolutionary ancestors have crawled shoreward in a mating ritual that is perhaps 400 million years old. The procession starts out on the continental shelves, where the creatures subsist on mussels, worms and other bottom dwellers. Once during their lives, in spring or early summer, the females trek in to shore to lay

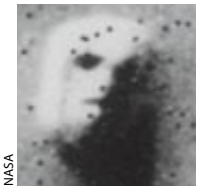
IN BRIEF

Basmati Battle

Ricetec, an American company based in Texas, has patented basmati rice, a staple grain in southern Asia, and has trademarked the word "basmati" as well. Longtime foes India and Pakistan are working together to challenge Ricetec. They argue that nowhere in the U.S. can you grow what is ordinarily called basmati, so that Ricetec has no right to label the product "Kasmati, Indian style Basmati." India and Pakistan maintain that the U.S. Patent Office would not have awarded Ricetec the rights if they had known more about the prior art and use of basmati. Southern Asians are not the only ones worried: Central and South American groups have also protested a patent awarded to a U.S. company for one of their native plants.

The Man on Mars

In 1976 NASA's Viking spacecraft snapped a photograph of a feature on Mars that was startlingly familiar to earthlings: part of the rocky surface looked just like a face. Most interpreted this Martian Mount Rushmore as a trick of light and shadow, but others credited it to alien artisans. Now the 22-year-old mystery is settled once and for all. Last month the Mars Global Surveyor took images of the same spot, and this time, the geologic formations there resembled a footprint (*left*).



NASA

JPL/CALTECH/NASA

Help for Arthritis

Researchers at the University of Pittsburgh got a surprise recently: when they tried gene therapy on a rabbit's right arthritic knee, it helped the left one, too. As reported in the April 14 *Proceedings of the National Academy of Sciences*, Steve Ghivizzani and his colleagues introduced genes producing modified receptors for interleukin-1 (IL-1) and tumor necrosis factor alpha (TNFα)—proteins that inflame arthritic joints. The modified receptors mopped up excess IL-1 and TNFα in the treated knee; moreover, white blood cells distributed the modified genes to other diseased joints, where their products similarly kept inflammation in check.

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ZIG LESZCZYNSKI *Animals Animals*

COME HERE OFTEN?
Mating season for horseshoe crabs—here, on a New Jersey beach.

eggs, linking up with a male somewhere in the intertidal region. The coupling is best viewed during the unusually high tides of a full or new moon, when the females creep to the edge of the waterline, each with a male clinging to her posterior in the tenacious copulative embrace known as amplexus. In Florida the migration peaks in March and April; in Delaware Bay the traffic is usually heaviest around April and May; in the northeast U.S., June and July is generally the best time to view the spectacle.

At the water's edge, the female burrows into the sand, depositing in several locations thousands of tiny, pearly green eggs, on which the male deposits semen. H. Jane Brockmann, a zoologist at the University of Florida, says this form of external fertilization makes horseshoe crabs unique among arthropods. In fact, the creatures are not actually crabs at all. They are closer in evolutionary heritage to scorpions and spiders.

When the high tide retreats, the buried, fertilized eggs are no longer underwater, where they have been safe from aquatic predators. In addition, Brockmann's research has shown that proper development of the eggs demands that they be buried fairly high (but not too high) on the beach. If the eggs are buried too high, they dry out and do not hatch. Too low, and they are killed by the low oxygen content of the sand, she says.

As female horseshoe crabs dig their nests, they often displace the eggs from earlier nests. These eggs often float to the surface and are a major source of nutrition for migratory birds en route, typically, from South America to Arctic breeding grounds. The eggs that somehow remain undisturbed hatch in about a lunar month into so-called trilobite larvae, which are a few millimeters long and resemble tailless horseshoe crabs.

My guide on this Mesozoic mystery tour was Joseph Nemeth, an avid fisherman and amateur naturalist. At the water's edge, horseshoe crabs were dug into the sand every few meters, carrying out the ancient ritual, while above, the brightly lit Gil Hodges Memorial Bridge conveyed a never-ending stream of trucks and cars. As we ambled along the surprisingly litter-free beach, Joe regaled me with horseshoe crab trivia: that their bluish blood, which contains copper-based hemocyanin rather than iron-based hemoglobin, is widely used in medicine to test for the presence of toxins in solutions destined for intravenous use in humans; that horseshoe crabs are capable of swimming upside down; that the *Limulus polyphemus* species is found only off the eastern coast of North America (largely distinct *Limulus* populations live in the Gulf Coast). All of the three other species of horseshoe crab live in Asian waters.

As midnight approached, we found we were not the only spectators out gawking at horseshoe crabs. "This is part of the chain of life," declared a wild-eyed young man who identified himself only as "Cowboy," as he gestured toward a mating pair in the water near his feet. Then, as his girlfriend rolled her eyes, he told us that he knows that life is precious because he'd been dead twice, and he shared his view that there will be vast coral reefs off the northeastern U.S. in the foreseeable future. Clearly, the arthropods were not the only odd organisms under the full moon on that Brooklyn beach. —*Glenn Zorpette*

In Brief, *continued from page 18*

Dinosaur Innards

Paleontologists might want to thank Steven Spielberg for making *Jurassic Park*. The film convinced Giovanni Todesco that perhaps the fossil he dug up near Naples a decade ago was not, as he had presumed, that of a bird. Scientists Cristiano dal Sasso of the Museum of Natural History in Milan and Marco Signore of the University of Naples recently confirmed that Todesco's discovery—which they named *Scipionyx samniticus*—is the first fossil of a baby dinosaur in which the soft tissues are well preserved. Researchers are particularly excited about *S. samniticus*'s liver, which retains a dark purple tint. The organ's position might indicate whether the dinosaur's respiratory system was crocodilian or birdlike.

The Cost of Time Travel

In the movies, it looks easy: just cruise warped space-time in a souped-up DeLorean. But in reality, traveling into the past—though not impossible under the laws of physics—would prove incredibly difficult. Princeton University physicists J. Richard Gott and Li-Xin Li estimate that for every microsecond of time travel, you would need a space-warping mass—say, a black hole or decaying cosmic string loop—having a mass one tenth that of the sun. And even if you accessed such a massive object, it might very well suck you into oblivion.

EVERETT COLLECTION

The Big One?

Southern Californians have been waiting for it since 1995, when the Southern California Earthquake Center (SCEC) declared that too few quakes had occurred there since 1850 to relieve the energy built up in the earth's crust. But two new assessments written primarily by David D. Jackson of the University of California at Los Angeles dispute that report. With Jackson, Edward H. Field and James F. Dolan of the University of Southern California modeled California's shifting plates and concluded that less energy had accumulated than was thought. And Thomas C. Hanks and Ross S. Stein of the U.S. Geological Survey determined that more quakes have probably taken place since 1903 than the SCEC study accounted for. So the next big earthquake may be further off in the future than had been thought.

More "In Brief" on page 28

PLANT PATHOLOGY

THE BLIGHT IS BACK

The fungus that caused the Irish potato famine returns with a vengeance

In 1845 a plant disease called late blight swept through potato farms in Europe, causing the historic potato famine and ultimately the starvation of more than one million people in Ireland. Now, 150 years later, aggressive new strains of *Phytophthora infestans*, the fungus responsible for late blight, are rapidly spreading around the world. The strains are so virulent that they not only can destroy a potato field in a matter of days, but they are also resistant to metalaxyl, the only fungicide effective in slowing established infestation.

The fungus, which originated from Mexico's Toluca Valley, comes in two types, called A1 and A2. For reasons not clearly understood, only A1 migrated from Mexico in the mid-19th century, probably on a plant specimen. Late blight became controllable through a combination of fungicides and integrated pest management, a system that combines biological, cultural, physical and chemical tools. But in the early 1980s Europe reported a sharp increase in *P. infestans*–related crop losses. Whereas only the A1 mating type had been previously reported in Europe, investigators are now finding new strains consisting of both mating types.

That, apparently, may be causing the renewed blight. Alone A1 and A2 reproduce asexually, but together they reproduce sexually. Researchers suspect that sexual reproduction has increased the genetic variation, creating strains that are no longer sensitive to potent fungicides and that have overpowered any genetic resistance within the crop. "In an asexual population there can be an accumulation of detrimental mutation," says William E. Fry, a plant pathologist at Cornell University. "For the past 100 years, there had been little or no immigration and no sexual recombination, so the older, resident strains may have just become increasingly less aggressive." As a result, the exotic and more virulent new strains replaced the older ones.

Biologists believe the A2 strain hitched a ride to Europe during the 1970s, when large potato shipments were imported from Mexico and then exported to the rest of the world unintentionally. The strains in North America have proved remarkably prolific. US-8, now the most prominent strain in the U.S., was detected in a single county in upstate New York in 1992; by 1994 it had spread to 23 states and to eastern Canada.

Poor farming practices do not appear to have played a significant role in the strains' development. Fry points out that even though three or four potato cultivars dominate 80 percent of the market, the blight affects all types of potatoes, including several wild cousins. And he does not believe that chemical management has been used indiscriminately, at least not in the U.S. "The strains were already resistant [to metalaxyl] when they arrived here," Fry says. "And we've been using integrated techniques, without heavy reliance on one fungicide."

The fungus, which needs wet weather to thrive, has caused average annual crop losses during the past several years

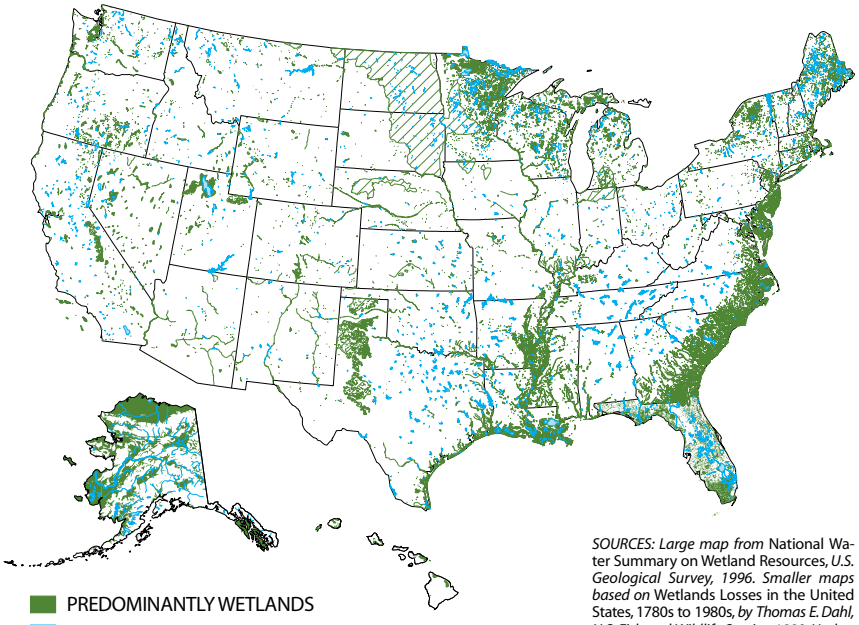
(Continued on page 26)

DEPARTMENT OF PLANT PATHOLOGY, CORNELL UNIVERSITY

INFECTED POTATOES have a reddish, granular rot.

BY THE NUMBERS

U.S. Wetlands

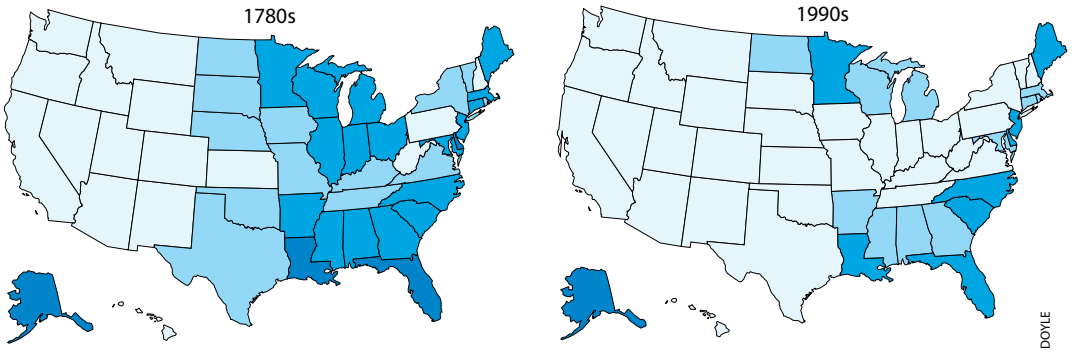


SOURCES: Large map from National Water Summary on Wetland Resources, *U.S. Geological Survey, 1996. Smaller maps based on* Wetlands Losses in the United States, 1780s to 1980s, *by Thomas E. Dahl, U.S. Fish and Wildlife Service, 1990. Updating to 1990s based on data from the National Resources Inventory, USDA.*

Swamps, marshes, bogs and similar watery tracts have long been thought of as dismal, unhealthy places that should be removed in the name of progress. In recent years, however, this view has changed radically as scientists realized that wetlands perform many vital functions. They protect shorelines and remove pesticides and other pollutants from surface waters. They provide a refuge for one half of the fish, one third of the bird and one sixth of the mammal species on the U.S. threatened and endangered lists. By acting as reservoirs for rainfall and runoff, they help to extend stream flow during droughts and to prevent floods. The loss of wetlands contributed to the great floods of 1993 on the upper Mississippi and Missouri rivers, the worst in modern U.S. history.

Wetlands take many forms, including salt marshes, forested swamps, floodplains, peat bogs and prairie potholes (the depressions left after the retreat of the last glacier). The large map shows areas that have been predominantly wetlands since the early 1990s. (Also shown are lakes, which serve some of the same functions as wetlands, such as storage of water and species protection.)

Over the past two centuries, improvements in technology accelerated the conversion of wetlands to cropland. For example, the hand-dug drainage ditch of colonial times was succeeded in the 19th



RODGER DOYLE

century by the steam-powered dredge. New implements such as steel plows and cultivators made possible the development of land previously thought unfit for farming, putting more wetlands at risk. The immense appetite for new farmland was aided by the federal government, which in a series of Swamp Land Acts beginning in 1849 turned over almost 65 million acres of wetlands to the states for reclamation and development.

The cumulative effect has been a 53 percent decline of wetlands in what is now the lower 48 states, from 221 million acres in the 1780s to 104 million in the 1990s. Alaska, which had an estimated 170 million acres of wetlands in the 1780s, has virtually the same amount now. The agricultural states of Ohio, Indiana, Iowa and California suffered the greatest percentage decline, but the most substantial loss in acreage was in Florida, Louisiana and Texas.

Although most of the wetlands gave way to agriculture in earlier years, recently an increasing proportion of the losses has resulted from industrial and housing development. As population grew in the 18th and 19th centuries, the size of wetland conversions increased. In one of the most spectacular cases, the Black Swamp in northwest Ohio—which was almost the size of Connecticut—disappeared between 1859 and 1885. The swamp, it seems, was considered a barrier to travel and settlement and contained a variety of commercially valuable trees. Today the area is mostly farmland.

Federal efforts to restore wetlands have expanded since 1987, but even so, wetland acreage has continued to shrink, although the rate has slowed. This outcome is not surprising, as restoration is a slow, complex process. In February President Bill Clinton announced a clean-water action plan that includes a strategy for increasing wetlands by 100,000 acres a year beginning in 2005. If the plan is successful, wetland acreage will have increased for the first time since record keeping began more than 200 years ago.

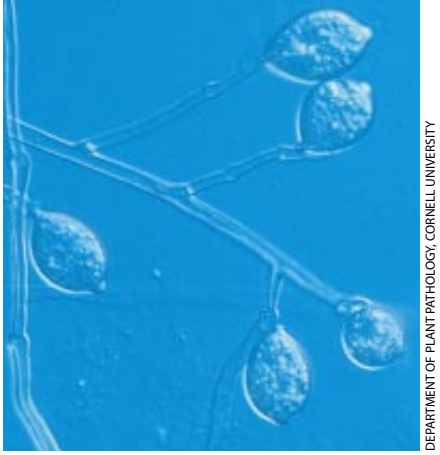
—Rodger Doyle (rdoyle2@aol.com)

(Continued from page 20)
of nearly 14 million tons, equivalent to almost $3 billion; in the U.S., losses are estimated in the hundreds of millions of dollars. The Northeast can expect blight every year, but attacks in drier regions, such as those in North Dakota, vary. The severity of blight depends on the amount of rainfall and the individual farmers' aggressiveness in pest management, including the use of fungicide sprays as a prophylaxis, before infestation takes hold.

But boosting the use of fungicide is expensive, to say nothing of the potential impact on health and environment. So biologists are formulating a different strategy. In 1996 the Lima-based International Potato Center launched a coordinated worldwide research effort called the Global Initiative on Late Blight (GILB). The goal of the $25.5-million program is to develop potato cultivars that resist all forms of the disease.

Researchers in Mexico have already developed blight-resistant potatoes, which are being successfully grown by thousands of subsistence farmers in several countries. But genetically engineering potatoes for the large commercial markets is more daunting. Not only must they resist blight, but they must also meet market standards: much of the commercial crop is destined for processed foods such as potato chips and french fries, so the spuds must have a certain size and a specific sugar consistency, among other qualities. Development of that potato, unfortunately, is still many years down the road. For now, plant pathologists remain out on the front lines, educating growers and investigating improved management activities.

—Roxanne Nelson in Tiburon, Calif.



DEPARTMENT OF PLANT PATHOLOGY, CORNELL UNIVERSITY

***POTATO BLIGHT FUNGUS** has spore-filled sacs called sporangia, about 35 microns long.*

MEDICINE

THE PREVENTION PILL

Tamoxifen cuts the risk of breast cancer, but a newer drug may be better yet

The news in April that tamoxifen, a drug prescribed since the 1970s to treat breast cancer, can also prevent the disease caught many oncologists by surprise. Not least among them were the researchers at the National Cancer Institute (NCI) and the National Surgical Adjuvant Breast and Bowel Project (NSABP) whose six-year clinical trial produced the good news.

The results were not supposed to be announced until 1999. But when scientists took a regularly scheduled peek this past March at how the 13,388 women in the experiment were coming along, they discovered that "the effect [of the drug] was much stronger than we had

expected," recounts Joseph P. Costantino, a biostatistician with the NSABP.

After an average stint of four years in the study, one in 31 of the 6,707 women taking 20 milligrams of placebo tablets each day was diagnosed with breast cancer of some kind, compared to just one in 58 of the 6,681 women on the same amount of tamoxifen. The drug also cut the rate at which the patients—all of whom were selected because of their high risk of breast cancer—developed invasive tumors by the same amount, 45 percent.

"This is the first time there has ever been a medicine that has been shown to prevent breast cancer," beams V. Craig Jordan, who directs breast cancer research at Northwestern University Medical School. Well-rounded diets and sufficient exercise may reduce women's risk of the disease somewhat. "But the evidence there is more circumstantial," says Peter Greenwald, director of the NCI's division of cancer prevention.

Tamoxifen's ability to delay or prevent breast cancer, by contrast, was so clear—99.999 percent certain, according to Costantino—that the study leaders decided it would be unethical to withhold the results any longer from the women receiving placebos. The NCI's implicit public endorsement of tamoxifen as a preventive therapy could cause problems for physicians, however. They may be swamped with requests for the drug, even though the Food and Drug Administration has not yet approved it as a preventive medicine. The NCI estimates that 29 million women in the U.S. alone are at high enough risk of breast cancer to consider taking tamoxifen. All women over age 60 meet the threshold, but physicians need a computer program developed by the NCI to estimate the susceptibility of younger patients.

Such calculations are crucial, Jordan says, because tamoxifen poses its own risks; it is at best a lesser evil. The recent trial demonstrated with 95 percent certainty that tamoxifen raised the rate of uterine cancer per 1,000 women from two to five. The incidence of blood clots forming in the lungs also rose, from nine to more than 25 per 10,000. There may be other risks that show up only after many years. Doctors still cannot say for sure whether tamoxifen will extend lives in the end.

A new trial set to start this autumn should clarify the overall benefits of tamoxifen—and test whether another drug might work even better. Costantino reports that the NSABP has proposed a five-year, 22,000-subject study that will compare the effects of placebo, tamoxifen and raloxifene, a close chemical relative that also reportedly cut breast cancer rates in two recent trials.

Like tamoxifen, raloxifene is able to dock with receptors for the hormone estrogen in breast, bone and uterine cells. Through some mysterious mechanism, tamoxifen mimics the effect of estrogen in the bone and uterus yet has the opposite effect in the breast. There it blocks the action of estrogen and, it is thought, thus starves budding tumors of a hormone they need to grow.

Raloxifene, which was approved last year for preventing osteoporosis, seems to behave similarly in bone and breast tissue. But studies so far suggest that it does not harm the uterus, as both tamoxifen and estrogen replacement therapy sometimes do. As a bonus, raloxifene appears also to lower LDL cholesterol (the bad kind); it may thus reduce the risk of heart attacks. Women interested in participating in the coming trial can sign up at the NSABP's World Wide Web site (www.nsabp.pitt.edu).

—W. Wayt Gibbs in San Francisco

In Brief, *continued from page 20*

Ancient Cosmology

In southern Egypt's Sahara Desert at a site called Nabta, scientists have discovered the oldest collection of astronomically aligned megaliths—some of which reach about three meters (about 10 feet) in height. These stone slabs are about 6,000 to 6,500 years old and predate Stonehenge by about 1,000 years. They were first sighted several years ago by Fred Wendorf of Southern Methodist University and his colleagues, who suspected that the stones bore some cosmological significance. A recent GPS satellite survey, published in the journal *Nature* in April, confirmed that the megaliths are arranged to mark east-west and north-south directions, as well as to provide a line of sight toward the summer solstice horizon. Beneath the structures, researchers found cattle remains and a rock shaped like a cow. Neolithic herders, who may well have sacrificed cows as a religious ritual, first arrived at Nabta some 10,000 years ago.

UNIVERSITY OF COLORADO AT BOULDER

Reforming Sex Offenders

According to a recent review of 61 studies, published in the April issue of the American Psychological Association's *Journal of Consulting and Clinical Psychology*, sex offenders are less likely to have recurring run-ins with the law than was believed. R. Karl Hanson and Monique T. Bussiere of the Corrections Research Department of the Solicitor General of Canada found that among 23,393 cases, only 13.4 percent of sex offenders committed another crime after they had spent four to five years in the community. The psychologists say that although this percentage is surely an underestimate (many sex crimes are never reported), it is still remarkably low considering the popular belief that once a sex offender, always a sex offender. Repeat offenders were the most likely to have deviant sexual preferences, to lead criminal lifestyles or to have dropped out of treatment.

—Kristin Leutwyler

ANTI GRAVITY

Greatness Thrust upon It

Things that were great, but only briefly: the Florida Marlins; *Saturday Night Live;* Lake Champlain. Take the Marlins. They won the World Series last year, then sold or traded most of their best players and ran off 11 straight losses in April. Take *Saturday Night Live*. Please. Finally, take Lake Champlain, a long and lovely seam of freshwater that separates Vermont from upstate New York. On March 6, President Bill Clinton signed a bill containing a bon mot inserted by Vermont Senator Patrick J. Leahy: "The term 'Great Lakes' includes Lake Champlain."

Yes, money was involved. The bill, the National Sea Grant Program Reauthorization Act of 1998, frees up money for research on oceans, coasts or the Great Lakes. Formerly, Vermont colleges interested in researching Lake Champlain were ineligible for a piece of the more than $50 million up for grabs. The Leahy redesignation instantly enabled Vermont schools to compete, because their lake was Great, too.

Now, Lake Champlain does share geologic history and current ecological problems—notably, zebra mussel infestation—with what suddenly were being called the five "traditional" Great Lakes. But Champlain is just $^{1}/_{17}$ the size of Lake Ontario, the smallest Great Lake everyone agrees is Great. Even the *Burlington Free Press* (Vermont), in its front-page story on the local lake's new status, admitted, "Champlain, though sizable, is puny when compared to the real greats." The *Chicago Tribune* was a bit more strident: "We know a little something about Great Lakes. If you can fit it inside Green Bay, it isn't one." (The *Tribune* also responded to Leahy's claim that Vermonters have always considered Champlain to be the sixth Great Lake by saying, "Vermonters may have always considered maple syrup one of the basic food groups, but that doesn't make it so.")

MICHAEL CRAWFORD

The incident brings to mind another attempt by a legislative body to get into the science business. Back in 1897, the Indiana State House decided to legislate the value of pi—irrationally, of course. Not only did their bill assign an incorrect value for pi, but various sections defined different wrong values.

Money was involved here, too. Legislators were led to believe by a crank who came up with this pi in the sky that Indiana textbooks could use his wacky ideas for free but that other states would have to pay royalties. Perhaps providing mathematical proof that providence protects fools, an actual mathematician, one C. A. Waldo, happened to be at the capitol lobbying for the Indiana Academy of Science and saw the bill. He was asked if he would care to meet the bill's author. In an article he wrote years later, Waldo, referring to himself in the third person, recalled, "He declined the courtesy with thanks remarking that he was acquainted with as many crazy people as he cared to know." His explanation got the bill thrown out. Similarly, Champlain's Greatness was revoked a couple of weeks after its promotion. Midwestern representatives were particularly annoyed with Leahy and convinced him that his "puny" lake—"I propose we rename it 'Lake Plain Sham,'" Ohio Representative Steve LaTourette said—didn't hold water. So Leahy retreated.

Discretion, as well as being the better part of valor, may be the fastest route to federal funding, however. New legislation by Leahy and his midwestern colleagues, though annulling Champlain's official eminence, also entitled the lake to Sea Grant funding. The same folks who probably would have fought like wolverines to keep Sea Grant money specific to the Great Lakes before the whole name game got played buckled on the funding in no time to protect the appellative sanctity of their region's waterways. "This is a win-win solution," said Leahy, who may still be snickering about the Vermonter who sold some Midwest boys their own Great Lakes.

—Steve Mirsky

PROFILE

Where the Bodies Lie

To industry's chagrin, epidemiologist Joel Schwartz has argued that particulates in the air shorten human life—his research has helped set tougher air-quality standards

Joel Schwartz is the antithesis of the epidemiologist as public accountant of the medical profession—the cautious record keeper who never goes beyond highly qualified statements about plausible statistical association between pollutant exposure and disease. His method of employing high-powered statistical techniques to find ties between fine combustion particles and premature deaths is coupled with an activist's sensibility. "If you think that all a public health professional should do is to publish papers and pad a CV, then you should get another job," Schwartz says.

Schwartz is one of the scientists most closely associated with the research that led to new Environmental Protection Agency regulations last year to reduce levels of microscopic particles measuring 2.5 microns in diameter or less. These "fine" particles are by-products of combustion from industrial plants, woodstoves and motor vehicles. During the multiyear debate over new rules, the outspoken qualities of the tall, intense figure with the salt-and-pepper beard made him a lightning rod for industry officials who have attacked particulate research as "junk science."

Schwartz's influence, though, relates as much to his technical prowess as to his advocacy. "As the industry started to look at Joel's work and hire their own analysts, it took a while for them to catch up with the sophistication of his statistical analysis," says Daniel Greenbaum, president of the Health Effects Institute, an independent nonprofit group funded by the EPA and industry.

SAM OGDEN

ACTIVIST STYLE OF HARVARD UNIVERSITY'S Joel Schwartz is complemented by prodigious technical acumen and a messy office.

The 50-year-old Schwartz was among a small group of air-pollution researchers during the late 1980s who began to make extensive use of time-series analysis—the examination of how one variable changes in relation to another over time. Time series had been used by econometricians to track inflation or gross national product but was not widely deployed in studying air pollution. These techniques—combined with methods of accounting for nonlinear effects, such as the sharp rise in deaths at temperature extremes—allow one to track sickness and mortality from one day to another as air-pollution levels rise and fall. Using time series, a researcher can discard a host of confounding variables, such as whether a patient was a smoker or had high blood pressure. The amount a person smokes from day to day is unlikely to be correlated with changes in particulate air pollution.

Excluding details such as smoking greatly simplifies the process of obtaining data. A researcher can seek out death certificates, hospital admissions and other readily available public records without having to look for recruits for a multimillion-dollar study. "It makes things cheap," Schwartz says. "All you need is a little money to pay a salary while you're crunching numbers." In the early 1990s Schwartz cranked out a wad of these studies that showed associations between relatively low levels of particulates and death or illness from respiratory or cardiovascular ailments in city after city across the U.S. More recently, he has served as a collaborator on similar studies conducted across Europe.

The innovative qualities that Schwartz brings to his labors may result from his training as a theoretical solid-state physicist and mathematician, not an epidemiologist. "The culture of physics is much more adventurous than the culture of medicine, where you don't want to kill patients," Schwartz says. "In physics, the faster you get out flaky ideas, the faster you find out which ones are right and which ones are wrong." When Schwartz left Brandeis University in the mid-1970s, however, he could not find a job as a physicist. After serving as a congressional aide, he moved to the policy office of the EPA in 1979 as an energy economist.

Schwartz made his mark in the early 1980s at the agency when the Reagan administration tried to halt the phaseout of lead in gasoline as part of a larger regulatory reform effort. His supervi-

JOHN J. GODLESKI AND VICTORIA HATCH *Harvard School of Public Health (photograph);* JOHNNY JOHNSON (*chart*)

STANDARDS FOR PARTICULATE MATTER (MICROGRAMS PER CUBIC METER OF AIR)

	1987 STANDARD	1997 STANDARD
≤10-MICRON-DIAMETER PARTICLES		
24-HOUR AVERAGE	150	150
ANNUAL AVERAGE	50	50
≤ 2.5-MICRON-DIAMETER PARTICLES		
24-HOUR AVERAGE	NONE	65
ANNUAL AVERAGE	NONE	15

FINE PARTICLES MEASURING 2.5 MICRONS or less in diameter* (photograph) *have been regulated under new federal standards.

sors asked him to produce a study to show the savings to industry once the rules on scaling back of lead were eliminated. "I did it, and then I asked what was the other side of the coin," he says. On his own, Schwartz then undertook an analysis that revealed that the $100 million or so savings to industry would be more than offset by health costs that could total more than $1 billion annually. His study helped to convince the agency to reverse its position and actually tighten standards. In 1985, working with his wife, Ronnie Levin, another EPA scientist, Schwartz completed a new cost-benefit study that bolstered the case for additional rules that resulted in totally eliminating lead from gasoline. "Schwartz's work clearly delineated how much people were paying in terms of monetized health costs; it was a revolution to put those things into the thinking about lead," says Herbert Needleman, a University of Pittsburgh professor who is a prominent researcher on health effects of lead.

During the mid-1980s, Schwartz began to fashion a job description for himself as an epidemiologist with a focus on air pollution. He consciously avoided Superfund and the other hazardous-waste issues that occupied many of the agency's resources. "Even if something's going on with hazardous wastes, the number of cases is not going to be very large in terms of the overall public health impact," he says. "It's not where the bodies lie. I view myself as exploring places missed where the overall public health impact is likely to be large."

In 1986 he reassessed a 14-year-long study of air pollution and health data in London. Particulates—not sulfur dioxide—seemed to be linked to early deaths and illness. Schwartz's analysis aided in fashioning a 1987 standard that set a daily and annual average for particulate matter with a diameter of 10 microns or less, called PM 10. But he felt the standard did not suffice, because his investigation had shown that there was no detectable threshold at which people stopped becoming sick. The EPA rule failed to target the smallest particles produced by combustion from power plants, trucks and other sources. So Schwartz plowed on: "I kept turning out studies using U.S. data until people couldn't ignore it anymore."

In 1991 Schwartz's work on lead and particles resulted in his becoming a MacArthur Fellow. Schwartz was the first federal career employee to receive the so-called genius award—an event that prompted EPA administrator William Reilly to remark: "Every time you fill up your car with gasoline, you can think of Joel Schwartz."

The MacArthur Award also provided him with an escape route from his cramped, windowless office at the EPA. "It was clear that the PM [particulate matter] stuff was getting very hot," Schwartz says. "If I had still been a federal employee, I would have been harassed to death." The $275,000, no-strings-attached grant allowed him to take a slight pay cut for an associate professor's job at the Harvard School of Public Health and to afford a home in the Boston area.

Schwartz's expectations about the coming fight over particulates were amply fulfilled. In the several years leading up to the new rules, Schwartz and his colleagues Douglas Dockery of Harvard and C. Arden Pope III of Brigham Young University saw their studies subjected to an onslaught of attacks, often from industry-funded scientists.

One pointed critique came from Suresh Moolgavkar, a University of Washington professor whose investigations were paid for by the American Iron and Steel Institute. Moolgavkar's findings showed that reported links to higher death rates cannot be attributed to particulates alone. Sulfur dioxide, carbon monoxide, ozone and other pollutants may have also contributed to the mortality. Schwartz responds that similar ties between premature death and particulates can be found in cities where one or more of the other confounding pollutants are present at low levels.

The debate's shrillness picked up last year, when Harvard researchers were lambasted for refusing to release to outside scientists raw data from their "Six Cities Study," a widely cited report that found a link between particulates and death rates over a 16-year period. Dockery, the lead researcher, refused because of confidentiality agreements with study subjects. He also expressed an aversion to letting critics pick apart the data. The data were subsequently provided to the Health Effects Institute for reanalysis. Not, however, before Schwartz was quoted in the *Wall Street Journal* defending the study team against scientists he called "industry thugs."

Although the EPA promulgated the new rules last July for ozone as well as 2.5-micron particles, the controversy surrounding the issue means that the policy firestorm will most likely continue. The agency is treading cautiously, taking several years to conduct particle monitoring and scientific studies before states are required to submit implementation plans. The rules, in fact, allow states to take well over a decade to come into full compliance, much to Schwartz's chagrin. "We're going to postpone public health for 14 years," he says. "Meanwhile people are going to die."

Schwartz's pace has not slackened, however. An article he published with his wife and another researcher in the November issue of the journal *Epidemiology* used a time-series analysis that found a relation between the turbidity (cloudiness) of filtered drinking water—a possible indicator of microbial contamination—and emergency visits and admissions for gastrointestinal complaints to a Philadelphia hospital. "I'm getting in trouble in another area," he notes, commenting on an attack from water utilities that came after the article was published.

At times, Schwartz worries that his bluntness may affect support for his endeavors: "I think industry is trying to compromise my ability to get more money to do research, and I think there's a risk they'll succeed." But Schwartz is unlikely to muzzle himself. "When I look at the statistics, I see more people dying of particle air pollution than are dying of AIDS, and I need to call that to people's attention," he says. —*Gary Stix*

DEFENSE POLICY

STAR WARNED

Missile defense remains a shaky proposition, $50 billion later

This year marks the 15th anniversary of the Strategic Defense Initiative, which President Ronald Reagan hoped would one day protect the U.S. from Soviet missiles. Whereas Reagan's vision of a space-based shield has largely faded in the aftermath of the cold war, missile defense remains alive and well funded. A Republican Congress has added more than $2 billion to the Ballistic Missile Defense Organization (BMDO) budget since 1996, and this year the Pentagon plans more tests of so-called Star Wars systems than in any prior year.

But 1998 has also brought renewed criticism of the technology. In February a team of former Pentagon officials, led by one-time Air Force chief of staff Gen. Larry Welch, issued a scathing evaluation of current efforts. Warning of a "rush to failure," the group cautioned that a "perceived" threat was driving the Pentagon to hurry the development of missile defense systems without first proving that they work.

All the principal U.S. missile defense programs rely on "hit-to-kill" interceptors that must score direct strikes on target missiles (imagine a bullet hitting another bullet). Older "blast fragmentation" systems have to explode only in a target's vicinity, which is supposed to be enough to destroy the missile but sometimes merely sends it off course. The major advantage of hit-to-kill mode is that if it works, the target is obliterated, and any warheads are destroyed well before they reach the ground.

The problem is that there is little proof that hit-to-kill is a viable technological proposition. "After more than a dozen flight tests," the Welch panel concluded, "the most obvious and visible consequence of the approach is that we are still on 'step one' in demonstrating and validating hit-to-kill systems." Even after this first step is achieved, the group added, the Pentagon must prove hit-to-kill technology can be fashioned into working weapons that can consistently shoot down "real-world targets."

Yet the enormous cost of these programs has led the Pentagon to reduce the number of planned tests—exactly opposite the Welch panel's recommendations. Critics note that the results of tests conducted to date do not indicate that this is a wise move: in 20 tests of hit-to-kill interceptors conducted since the early 1980s, only six hits have been scored. Recent testing of the most sophisticated system yet produced, the Theater High Altitude Area Defense (THAAD) missile, has been disastrous. THAAD is designed to protect troops and cities abroad from short- and medium-range missile attacks. According to the Welch panel and other evaluations, poor management, inadequate preparation and an overaggressive schedule have conspired to produce four failures in four intercept attempts. Those failures threaten THAAD, which has an annual budget set to exceed $800 million in 1999. (At the time of writing, the fate of the fifth THAAD intercept test, set for May, had not been determined.)

Although the bulk of BMDO spending is devoted to shorter-range missile defense systems such as THAAD, the top priority for Star Wars backers remains a "homeland defense" to protect the U.S. itself: the National Missile Defense (NMD). The Welch report cautions that the Pentagon is headed down a similarly perilous path with its NMD program. Although Defense Department officials say they have implemented some of the panel's recommendations, the NMD schedule remains firm: a limited system is to be ready in six years. Few involved, however, believe this schedule will be easily attainable. Both the Welch panel and the General Accounting Office, citing previous large-scale efforts, have suggested that six years is nowhere near enough time to develop a working NMD system. And BMDO director Lt. Gen. Lester L. Lyles has told Congress and anyone else who has asked that the schedule is "high risk."

Missile defense supporters in Congress remain committed to the six-year goal. Leading BMDO backer Representative Curt Weldon of Pennsylvania, who says he laughed when he first saw the Welch report, wants more money devoted to accelerating certain missile defense programs, including NMD and THAAD.

By year's end, more will be known about the technological feasibility of hitting a bullet with another bullet. More THAAD flights are planned, a new Patriot missile is set to fly, the navy will attempt intercepts at sea, and the Pentagon will try to shoot down an intercontinental ballistic missile in an NMD test. As noted skeptic John E. Pike of the Federation of American Scientists observes, it could be a "make-or-break year" for the BMDO. More failures could cause even hard-core supporters to reevaluate the nearly $4 billion spent every year on missile defense programs.

On the other hand, even a few successes could make the technology issue moot, despite the Welch report and other critics who state that far more testing is needed. "If we hit them all, then we're on a roll," Weldon says of this year's tests, "and we can deploy much sooner than we thought." —*Daniel G. Dupont in Washington, D.C.*

BALLISTIC MISSILE DEFENSE ORGANIZATION

***MISSILE INTERCEPTOR** called THAAD was first flight-tested at the White Sands Missile Range in New Mexico in 1995.*

ENVIRONMENTAL POLICY

RUNNING ON MMT?

The debate on the health effects of a gasoline additive rages on

LIAISON INTERNATIONAL

***CANADIAN GASOLINE** often contains the controversial additive MMT.*

The auto industry despises it, the petroleum industry is avoiding it, the U.S. government was forced to legalize it, and animal studies suggest that its key ingredient can damage health. Yet MMT, a fuel additive that increases octane and reduces oxide emissions, is marketed worldwide as safe, effective and efficient. Its manufacturer, Ethyl Corporation, based in Richmond, Va., is so sure of MMT that it is now suing the Canadian government, which in April 1997 banned for health concerns the import and interprovince trade of MMT, after 20 years of use.

At issue is MMT's main component, manganese. Small amounts in the diet are beneficial and necessary, and large amounts pose no threat because the liver can rid the body of any excess. But inhaled manganese is a different story. Epidemiologist Ellen K. Silbergeld of the University of Maryland points to studies of monkeys that show the dose reaching the brain is consistently higher than when ingested and can cause neurological disorders similar to Parkinson's disease. She cites studies suggesting that airborne metals can travel up the olfactory nerve to the brain. The fear is that vapors of MMT-enhanced gasoline—which does not have to be labeled in the U.S.—might enter the atmosphere.

Air-quality studies around Toronto reveal no risk of high-level exposure. But there have been no examinations of chronic, low-level exposure in humans, mainly because those types of experiments are tough to design. Jerry Pfeifer, a biochemist at Ethyl, points out that MMT is not the only source of airborne manganese. Commuting via the subway, he suggests, where the steel tracks are 12 percent manganese, has a much greater impact than MMT usage does. "Therefore, it is virtually impossible to design a meaningful experiment to determine the long-term effects to low-level manganese from MMT because humans are already exposed to significant and variable amounts of manganese throughout their lives in air, food, water and soil," he said in a statement.

Without human studies, no one can agree on a safe level. The U.S. Environmental Protection Agency set the reference concentration at 0.05 microgram of manganese per cubic meter, and the agency may increase it. In any case, the amount of manganese in air is well below this limit. Only one drop is added to a gallon of gasoline, and both Ethyl and the EPA concur that only 10 to 15 percent of the manganese in MMT becomes airborne. Such a small amount, Ethyl argues, poses no real threat.

The provinces of Alberta, British Columbia, Quebec, Saskatchewan and Nova Scotia apparently agree. Along with Ethyl, they have filed suit against the Canadian government's action against MMT, which is sold under the brand name HiTEC 3000. They argue that the transport ban violates the North American Free Trade Agreement.

The case mirrors the controversy over another fuel additive: tetraethyl lead. Like MMT, it was known to be harmless at low doses when it was approved 75 years ago under pressure from its maker, also Ethyl. As it turned out, the increased use of lead in gasoline, combined with the use of lead in paints, was associated with severe neurological disorders, particularly in children.

After the debacle of leaded gasoline, the EPA has been reluctant to legalize MMT, or methylcyclopentadienyl manganese tricarbonyl. Several times since 1978 Ethyl presented emissions studies to comply with the Clean Air Act, and each time the agency denied Ethyl's request for legalization, asking for more data. In 1995 Ethyl took the EPA to federal court, which decided there was no basis for making MMT illegal. So the additive entered the U.S. bulk market.

Right now the chances of coming across the additive at a U.S. gas station are slim. None of the major oil refineries currently use MMT. According to Ethyl, MMT's unpopularity does not stem from concern over adverse health effects. Jack Graham, an Ethyl spokesperson until this past March, suggests the large refineries have yet to adopt MMT simply because they have other options. "They can afford to make higher-octane gasoline and purchase other fuel additives, such as ethanol," he says. "The fact that they aren't buying it is just part of the ebb and flow of business."

Oil companies may also be avoiding MMT because of pressure from auto makers. Mark Nantais of the Canadian Motor Vehicles Manufacturers Association states that "80 percent of the manganese in MMT stays in the vehicle and clogs the system," coating spark plugs, clogging hoses and impairing emissions-control devices. For those reasons, Ford, General Motors, Chrysler and Toyota discourage MMT use. Ethyl contests the charges, citing its own studies that dispute the auto industry's claims.

Graham, who notes that "MMT is the most studied fuel additive in history," expects a decision in the Canadian lawsuit by the end of this year. Others would just as well see a decision against Ethyl. Most of the studies Ethyl cites were occupational and focused on white males, Silbergeld observes, pointing out that "we have no idea what low doses can do to other populations, including fetuses or children." And Robert G. Feldman, a toxicologist at the Boston University School of Medicine, thinks the parallels between lead and manganese should be taken more seriously: "Why unleash another toxin into the atmosphere only to find out that it causes neurodegenerative diseases many years from now?" —*Krista McKinsey*

COMPUTER SCIENCE

MILLENNIUM BUG ZAPPER

A radical solution for the Year 2000 problem

Like the late Jonas Salk's return to prominence to combat HIV, Bob Bemer's emergence from semiretirement to solve the "Year 2000" computer problem evokes nostalgia. A pioneer in the digital world, Bemer is the man who, among other accomplishments, helped to define ASCII characteristics, which allow otherwise incompatible computers to exchange text. But critics say Bemer's solution, though ingenious, may be too much too late.

The Year 2000, or "Y2K," problem arises from the widespread use of two-digit date fields, which leaves computers confused whether "00" refers to the year 1900 or 2000. According to detailed estimates, fixing this pervasive "bug" will cost companies and governments around the world hundreds of billions of dollars. One brute-force solution calls for finding every instance of a two-digit year and then rewriting the computer code to expand each field to accommodate four digits. This hellishly tedious process has led a cottage industry of vendors to create software tools that help to automate the procedure.

The unique feature of Vertex 2000, Bemer's innovative solution, is that it expands dates "vertically." Bemer realized that each space reserved for two-digit years contains surplus data bits. This tiny excess was enough room to piggyback additional information for denoting the century. He dubbed the vertically expanded characters "bigits," for Bemer digits. This efficient approach offers a huge advantage over the conventional method of "horizontal" expansion (that is, going to four-digit years), which leads to longer files and, as a result, possible computer crashes. How did Bemer know that he could squeeze the century information into existing two-digit years? "I've been in the character-set business since 1960," he declares. "I've eaten, slept, breathed and lived character sets."

To incorporate these new bigits, Vertex 2000 makes the necessary changes in object code, or machine language, which a computer (but not humans) can understand easily. Traditional methods work in the more accessible world of source code, which is written in computer languages such as COBOL and FORTRAN that have comprehensible commands such as "write" and "read."

Because Vertex 2000 is supposed to do much of this conversion inconspicuously and automatically, Bemer asserts that his method will be at least 10 times faster than other solutions, at less than half the cost. To capitalize on these possible benefits, he founded BMR Software in Richardson, Tex. Expecting business to ramp up soon, Bemer says, "We're sitting here in a state of delirious excitement."

Others are also delirious but not with excitement. Making changes at the arcane level of object code gives many programmers conniptions, and not everyone is crazy over bigits. "Bemer has got to be respected for what he's done, but his approach is so advanced in theory that you have to question whether it's practical," asserts Leland G. Freeman, consultant with Management Support Technology in Framingham, Mass. But Bemer contends that extreme approaches are exactly what companies need right now. "It's either tamper with your object code or have your business go belly up," he argues.

Bemer does, however, acknowledge that Vertex 2000 is merely a temporary fix. Adjusted programs will typically run about 20 percent slower. Consequently, Bemer states that companies should use his method to buy time before implementing a permanent solution, such as a conversion to a Julian Day system.

That said, BMR Software had better move fast. At press time, the company had yet to ship Vertex 2000 even after having pushed back the schedule several times already. With only a year and a half left until the new millennium, Freeman says, "by the time Bemer's solution is accepted in the market, the game could be over." —*Alden M. Hayashi*

GUS GUSTOVICH *Michael A. Burns and Associates*

TEACHING COMPUTERS THAT "00" means the year 2000, not 1900, is Bob Bemer, a pioneer in the digital world.

COMPUTER SECURITY

CONFIDENTIALLY YOURS

A novel security scheme sidesteps U.S. data encryption regulations

A new technique to send confidential messages may finally scotch government policies restricting the export of encryption technology. The method—called chaffing and winnowing—was devised by Ronald L. Rivest, a Massachusetts Institute of Technology computer scientist and the "R" in RSA encryption, the popular commercial data-scrambling scheme developed in the 1970s by Rivest and his then colleagues Adi Shamir and Leonard M. Adleman.

Rivest's new scheme depends not on encryption but on authentication, or proofs of the source of the message and its unaltered contents. As such, Rivest says, "it has no decryption key as its back door. The standard arguments for

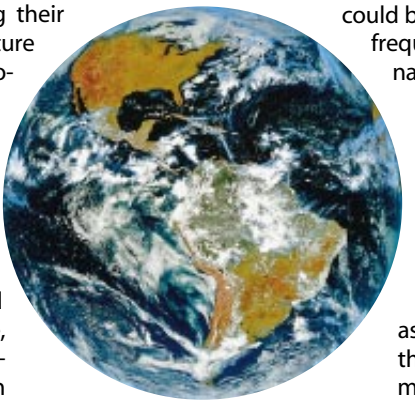
SPACE TECHNOLOGY

Eye in the Sky

Politicians strive tirelessly to find what George Bush, famously but inarticulately, called the "vision thing." Presidential-candidate-in-waiting Al Gore recently had a vision that would—literally—encompass the whole earth and has persuaded the National Aeronautics and Space Administration to make it happen.

The veep wants NASA to launch a spacecraft whose principal (and probably only) purpose would be to beam back to Internet-worked earthlings an image of the globe floating in the blackness of space. The satellite, according to NASA, is to be "a natural beacon for environmental awareness and science education." Agency scientists are now scratching their heads trying to decide how much the venture would cost and whether any nonpolitical rationale can be found to bolster its questionable scientific mission.

The vice president has dubbed the scheme Triana, after the lookout who spied the New World from Columbus's ship the *Pinta*. (Never mind that Columbus had no idea where he was and failed to realize he had found a new continent.) Triana, equipped with a simple eight-inch-diameter telescope, would hover at a point of equilibrium between the earth and the sun, about a million miles away. From that vantage point it would always see the earth's full sunlit disk. Triana could probably be built and launched inside two years, says NASA's earth science head Ghassem R. Asrar. It would update and retransmit its view, which would have the quality of a high-definition television picture, every few minutes.



ESA Photo Library International/Photo Researchers, Inc.

VOTE WINNER? Feel-good mission would periodically snap the earth's picture.

Although pictures might be worth a thousand words, some Republicans in Congress—as well as some scientists—are wondering whether Triana is worth as much as the $50 million NASA has budgeted for it. Weather satellites and other orbiters already provide much higher resolution images, and these could (if anybody wanted to) be patched together now to form a monochrome composite of most of the globe. But such a patchwork could be refreshed only every few hours. The more frequent updates will "open up avenues in dynamic meteorology," Asrar suggests hopefully.

Meteorologists are waiting to find out more. Fred Carr of the University of Oklahoma admits that he is "not really sure" whether Triana would be useful to weather forecasters. And politicians wonder why what some have dubbed "Goresat" has escaped normal scientific peer review.

One plan that has found favor with some astronomers is to add to Triana a solar camera that would continually image the sun. The mission might then be able to provide a truly useful "vision thing": early warnings of solar storms that affect communications.

—Tim Beardsley in Washington, D.C.

key recovery don't apply." At present, Clinton administration officials want surreptitious access to the text of encrypted documents, usually by means of a decryption key.

To use the technique, the sender first breaks the message into packets and authenticates each packet with a secret key—essentially stamping it with a digital signature. To these packets—the "wheat"—the user adds "chaff"—fake packets with bogus authentication that are randomly intermingled with the good packets.

"It's a clever hack," says Bruce Schneier, author of the well-regarded text *Applied Cryptography*. "You have one person speaking plus 1,000 other people shouting. If you don't know the recognition-validation codes, you can't hear my voice."

Chaffing and winnowing bears some relation to a confidentiality method called steganography, in which a sender hides the secret message within a larger one—for instance, in sound files. With chaffing and winnowing, the adversary may suspect that two types of packets are streaming past but will be unable to separate them without the secret authentication key.

Users can create this key with any standard technique, Rivest writes on the World Wide Web page announcing his scheme (http://theory.lcs.mit.edu/~rivest/chaffing.txt). For his examples, Rivest uses common message authentication codes (MACs), but he points out that MACs can be replaced by some newer digital signatures. "As usual, the policy debate about regulating technology ends up being obsoleted by technological innovations," he writes.

Rivest expects his scheme to draw scrutiny from the government. "What's new in the scheme," he says, "is that it has two parts. One part is authentication, with secret authentication keys—that part has been routinely approved for export. The other part, chaff, is new, but that, too, is not considered encryption by export control."

Schneier does not think Rivest's scheme will succeed in derailing the current export rules: "It's an interesting research idea, but it can't get around export control. The rules are not about sneaking around ITAR [International Traffic in Arms Regulations]—they're about preventing the export of cryptography. This is not a verbal game."

The scheme, if applied successfully, may force the government to fight for access to all authentication keys, which the government had always left alone, Rivest says. He adds that "the prospect of legislators controlling back doors for encryption pales next to the prospect of their controlling back doors for authentication. If the government had a back door to a bank's authentication key, for instance, rogue officials could forge bank transactions in your name." In contrast, access to decryption keys would only enable someone to view the transactions, not alter them. Back-door authentication "would wreak havoc on the integrity of the Internet," Rivest exclaims.

Rivest wants his paper to be as much a contribution to cryptographic policy debate as to technology. "One shouldn't misunderstand the point of the paper as entirely a technical contribution," he says. "I am very concerned about the risk we take in installing back doors for law enforcement."

—Anne Eisenberg in New York City

CYBER VIEW

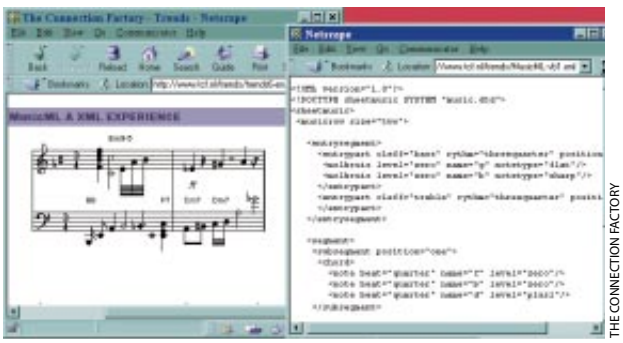
The Web Learns to Read

Imagine lifting up a page arriving from the World Wide Web to watch the computers beneath negotiate their transfers over the Internet. You would see them conversing in four distinct languages. Three of those four tongues are extremely terse and rigid; they are spoken only by machines. It is the fourth one, HyperText Markup Language (HTML), that has made the Web such a phenomenon. HTML is similar enough to English that masses of people have learned to use it to annotate documents so that almost any kind of computer can display them. But HTML is still rigid; a committee must approve every new addition to its narrow vocabulary.

In February a fifth language was approved for use on the Web—one that could have consequences nearly as profound as the development of HTML did seven years ago. Extensible Markup Language (XML), like HTML, is surprisingly easy for humans to read and write, considering that it was developed by an international group of 60 engineers. But XML is much more flexible than HTML; anyone can create words for the language. More than that, devices that can understand XML (within a few years, probably almost all the machines hooked to the Internet) will be able to do more intelligent things than simply display the information on Web pages. XML gives computers the ability to comprehend, in some sense, what they read on the Web.

To understand how, imagine that you want to rent a dacha on the shores of the Black Sea for a vacation, but you cannot read Russian. A friend in Odessa e-mails you the classified rental listings from the local paper. Even if he inserts descriptions of how the ads appeared in the newspaper—there was a line here, this word was in boldface—that hardly helps. But what if he annotated the Russian text to indicate which numbers referred to prices and which to bedrooms? Or if he highlighted each reference to a view and noted that •чень х•р•ш• means "very good"? Suddenly the listings would be useful.

To browser programs, Web pages today are typically long stretches of gibberish (what we humans would see as English or Russian), with a few intelligible HTML words that describe how to arrange the chunks of gibberish on the page and what typeface to put them in. Publishers can use HTML to make Web pages pretty, but getting the pages to *do* anything semi-intelligent—to reorder a list of properties according to price, for example—requires a separate program. Then readers must wait while that program generates a whole new page on some distant, overburdened server and sends it to them. That costly, inefficient process is what makes the Web so clumsy and slow at providing services such as travel reservations, customized news or useful searches—and why so few companies offer such services on-line.



THE CONNECTION FACTORY

XML TEACHES browsers how to read data—and music.

XML should fix those problems. It allows authors to annotate their pages with labels that describe what pieces of text are, rather than simply how they should appear. The *Odessa Tribune,* for example, could mark up its classifieds so that Web browsers can distinguish ads for vodka from those for dachas and can identify within each dacha listing the price, size and view of the property.

Now that XML has been certified as a Web standard, both Microsoft and Netscape have announced that the next major releases of their browsers will understand the new language. Using so-called style sheets, the programs will be able simply to display XML documents much as they format HTML pages now. But if snippets of code, known as scripts and applets, are embedded in an XML page, the browsers could also act on the information it contains. The Odessa listings could be culled to remove properties costing over 2,000 rubles or even combined with dacha listings from five other on-line newspapers.

In essence, XML offers the first universal database translator, a way to convert information in virtually any repository into a form that almost any other computer can manipulate. As such, it should eventually make Internet searches dramatically more useful, in two ways. First, surfers could limit their searches to specific kinds of Web pages: recipes, say, or news stories or product descriptions. Second, many of the most useful bits of information on the Web remain tucked inside databases that are hidden from the search robots traversing the Net in search of text for their indexes. With XML, Medline could open up its database of medical journal abstracts so that any program could search them. General Motors could do the same for its spare-parts catalogue.

XML is universal because authors are free to define new words to describe the structure of their data. Such liberty could lead to chaos were everyone to make up a new lingo. But people and companies with a common interest have a strong incentive to settle on a few choice terms. Chemists, for example, have already used XML to redefine their Chemical Markup Language, which now enables browsers to display the spectra of a molecule and its chemical structure given only a straightforward text describing the compound. Mathematicians used the standard to create a Math Markup Language, which makes it easy to display equations without converting them to images. More important, MathML formulas can be dropped directly into algebra software for computation.

Perhaps the most impressive demonstration so far of XML's flexibility is MusicML, a simple set of labels for notes, beats and rests that allows compositions to be stored as text but displayed by XML-enabled Web browsers as sheet music. With a little more programming, the browsers could probably play MusicML on synthesized instruments as well. After all, now that the Web can read data, it may as well learn to read music.

—W. Wayt Gibbs in San Francisco

The Neurobiology of Depression

The search for biological underpinnings of depression is intensifying. Emerging findings promise to yield better therapies for a disorder that too often proves fatal

by Charles B. Nemeroff

In his 1990 memoir *Darkness Visible,* the American novelist William Styron—author of *The Confessions of Nat Turner* and *Sophie's Choice*—chillingly describes his state of mind during a period of depression:

> He [a psychiatrist] asked me if I was suicidal, and I reluctantly told him yes. I did not particularize—since there seemed no need to—did not tell him that in truth many of the artifacts of my house had become potential devices for my own destruction: the attic rafters (and an outside maple or two) a means to hang myself, the garage a place to inhale carbon monoxide, the bathtub a vessel to receive the flow from my opened arteries. The kitchen knives in their drawers had but one purpose for me. Death by heart attack seemed particularly inviting, absolving me as it would of active responsibility, and I had toyed with the idea of self-induced pneumonia—a long frigid, shirt-sleeved hike through the rainy woods. Nor had I overlooked an ostensible accident, à la Randall Jarrell, by walking in front of a truck on the highway nearby.... Such hideous fantasies, which cause well people to shudder, are to the deeply depressed mind what lascivious daydreams are to persons of robust sexuality.

As this passage demonstrates, clinical depression is quite different from the blues everyone feels at one time or another and even from the grief of bereavement. It is more debilitating and dangerous, and the overwhelming sadness combines with a number of other symptoms. In addition to becoming preoccupied with suicide, many people are plagued by guilt and a sense of worthlessness. They often have difficulty thinking clearly, remembering, or taking pleasure in anything. They may feel anxious and sapped of energy and have trouble eating and sleeping or may, instead, want to eat and sleep excessively.

Psychologists and neurobiologists sometimes debate whether ego-damaging experiences and self-deprecating thoughts or biological processes cause depression. The mind, however, does not exist without the brain. Considerable evidence indicates that regardless of the initial triggers, the final common pathways to depression involve biochemical changes in the brain. It is these changes that ultimately give rise to deep sadness and the other salient characteristics of depression. The full extent of those alterations is still being explored, but in the past few decades—and especially in the past several years—efforts to identify them have progressed rapidly.

At the moment, those of us teasing out the neurobiology of depression somewhat resemble blind searchers feeling different parts of a large, mysterious creature and trying to figure out how their deductions fit together. In fact, it may turn out that not all of our findings will intersect: biochemical abnormalities that are prominent in some depressives may differ from those predominant in others. Still, the extraordinary accumulation of discoveries is fueling optimism that the major biological determinants of depression can be understood in detail and that those insights will open the way to improved methods of diagnosing, treating and preventing the condition.

Pressing Goals

One subgoal is to distinguish features that vary among depressed individuals. For instance, perhaps decreased activity of a specific neurotransmitter (a molecule that carries a signal between nerve cells) is central in some people, but in others, overactivity of a hormonal system is more influential (hormones circulate in the blood and can act far from the site of their secretion). A related goal is to identify simple biological markers able to indicate which profile fits a given patient; those markers could consist of, say, elevated or reduced levels of selected molecules in the blood or changes in some easily visualizable areas of the brain.

After testing a depressed patient for these markers, a psychiatrist could, in theory, prescribe a medication tailored to that individual's specific biological anomaly, much as a general practitioner can run a quick strep test for a patient complaining of a sore throat and then prescribe an appropriate antibiotic if the test is positive. Today psychiatrists have to choose antidepressant medica-

OLD MAN WITH HIS HEAD IN HIS HANDS **was sketched (*right*) by Vincent van Gogh in 1882 and resembles *Old Man in Sorrow,* painted in 1889. The image may reflect van Gogh's own depression, with which he grappled for much of his life. He committed suicide in 1890.**

VAN GOGH MUSEUM/VINCENT VAN GOGH FOUNDATION, AMSTERDAM; EXCERPT FROM *DARKNESS VISIBLE* ©1990 RANDOM HOUSE (*opposite page*)

The Symptoms of Major Depression

The American Psychiatric Association considers people to have the syndrome of clinical depression if they show five or more of the following symptoms nearly every day during the same two-week span. The symptoms must include at least one of the first two criteria, must cause significant distress or impairment in daily functioning, and cannot stem from medication, drug abuse, a medical condition (such as thyroid abnormalities) or uncomplicated bereavement. For the formal criteria, see the association's *Diagnostic and Statistical Manual of Mental Disorders,* fourth edition. —*C.B.N.*

- ☐ Depressed mood most of the day (in children and adolescents, irritability may signify a depressed mood)
- ☐ Markedly diminished interest or pleasure in all or most activities most of the day
- ☐ Large increase or decrease in appetite
- ☐ Insomnia or excessive sleeping
- ☐ Restlessness (evident by hand wringing and such) or slowness of movement
- ☐ Fatigue or loss of energy
- ☐ Feelings of worthlessness or excessive or inappropriate guilt
- ☐ Indecisiveness or diminished ability to think or concentrate
- ☐ Recurrent thoughts of death or of suicide

JENNIFER C. CHRISTIANSEN

tions by intuition and trial and error, a situation that can put suicidal patients in jeopardy for weeks or months until the right compound is selected. (Often psychotherapy is needed as well, but it usually is not sufficient by itself, especially if the depression is fairly severe.)

Improving treatment is critically important. Although today's antidepressants have fewer side effects than those of old and can be extremely helpful in many cases, depression continues to exact a huge toll in suffering, lost lives and reduced productivity.

The prevalence is surprisingly great. It is estimated, for example, that 5 to 12 percent of men and 10 to 20 percent of women in the U.S. will suffer from a major depressive episode at some time in their life. Roughly half of these individuals will become depressed more than once, and up to 10 percent (about 1.0 to 1.5 percent of Americans) will experience manic phases in addition to depressive ones, a condition known as manic-depressive illness or bipolar disorder. Mania is marked by a decreased need for sleep, rapid speech, delusions of grandeur, hyperactivity and a propensity to engage in such potentially self-destructive activities as promiscuous sex, spending sprees or reckless driving.

Beyond the pain and disability depression brings, it is a potential killer. As many as 15 percent of those who suffer from depression or bipolar disorder commit suicide each year. In 1996 the Centers for Disease Control and Prevention listed suicide as the ninth leading cause of death in the U.S. (slightly behind infection with the AIDS virus), taking the lives of 30,862 people. Most investigators, however, believe this number is a gross underestimate. Many people who kill themselves do so in a way that allows another diagnosis to be listed on the death certificate, so that families can receive insurance benefits or avoid embarrassment. Further, some fraction of automobile accidents unquestionably are concealed suicides.

The financial drain is enormous as well. In 1992 the estimated costs of depression totaled $43 billion, mostly from reduced or lost worker productivity.

Accumulating findings indicate that severe depression also heightens the risk of dying after a heart attack or stroke. And it often reduces the quality of life for cancer patients and might reduce survival time.

Genetic Findings

Geneticists have provided some of the oldest proof of a biological component to depression in many people. Depression and manic-depression frequently run in families. Thus, close blood relatives (children, siblings and parents) of patients with severe depressive or bipolar disorder are much more likely to suffer from those or related conditions than are members of the general population. Studies of identical twins (who are genetically indistinguishable) and fraternal twins (whose genes generally are no more alike than those of other pairs of siblings) also support an inherited component. The finding of illness in both members of a pair is much higher for manic-depression in identical twins than in fraternal ones and is somewhat elevated for depression alone.

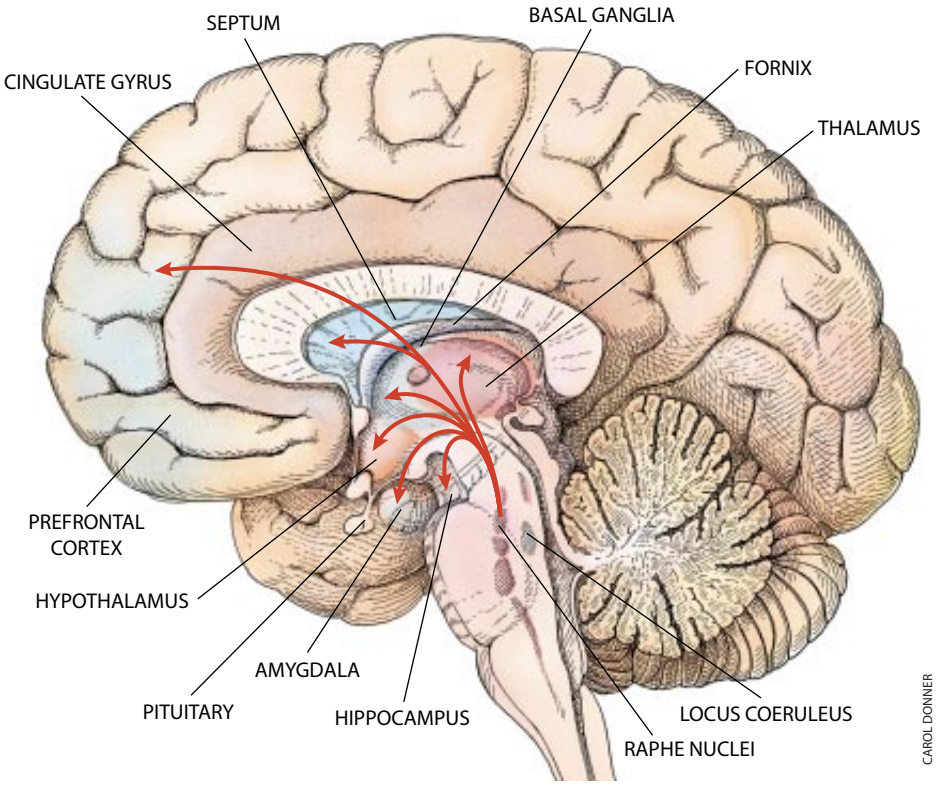
In the past 20 years, genetic researchers have expended great effort trying to identify the genes at fault. So far, though, those genes have evaded discovery, perhaps because a predisposition to depression involves several genes, each of which makes only a small, hard-to-detect contribution.

Preliminary reports from a study of an Amish population with an extensive history of manic-depression once raised the possibility that chromosome 11 held one or more genes producing vulnerability to bipolar disorder, but the finding did not hold up. A gene somewhere on the X chromosome could play a role in some cases of that condition, but the connection is not evident in most people who have been studied. Most recently, various regions of chromosome 18 and a site on chromosome 21 have been suggested to participate in vulnerability to bipolar illness, but these findings await replication.

As geneticists continue their searches, other investigators are concentrating on neurochemical aspects. Much of that work focuses on neurotransmitters. In particular, many cases of depression apparently stem at least in part from disturbances in brain circuits that convey signals through certain neurotransmitters of the monoamine class. These biochemicals, all derivatives of amino acids, include serotonin, norepinephrine and dopamine; of these, only evidence relating to norepinephrine and serotonin is abundant.

Monoamines first drew the attention of depression researchers in the 1950s. Early in that decade, physicians discovered that severe depression arose in about 15 percent of patients who were treated for hypertension with the drug

reserpine. This agent turned out to deplete monoamines. At about the same time doctors found that an agent prescribed against tuberculosis elevated mood in some users who were depressed. Follow-up investigations revealed that the drug inhibited the neuronal breakdown of monoamines by an enzyme (monoamine oxidase); presumably the agent eased depression by allowing monoamines to avoid degradation and to remain active in brain circuits. Together these findings implied that abnormally low levels of monoamines in the brain could cause depression. This insight led to the development of monoamine oxidase inhibitors as the first class of antidepressants.



SEVERAL BRAIN AREAS involved in mood and other functions commonly disturbed in depressed individuals—such as appetite, sleep, sexual desire and memory—are highlighted. Except for the pituitary, all are broadly considered to be part of the so-called limbic system, and all normally receive signals from neurons that secrete serotonin or norepinephrine or from neurons of both types. Reductions in the activity of circuits that use serotonin and norepinephrine apparently contribute to depression in many people. Some serotonin pathways (*arrows*) are indicated. Norepinephrine-producing cells project from the locus coeruleus.

The Norepinephrine Link

But which monoamines were most important in depression? In the 1960s Joseph J. Schildkraut of Harvard University cast his vote with norepinephrine in the now classic "catecholamine" hypothesis of mood disorders. He proposed that depression stems from a deficiency of norepinephrine (which is also classified as a catecholamine) in certain brain circuits and that mania arises from an overabundance of the substance. The theory has since been refined, acknowledging, for instance, that decreases or elevations in norepinephrine do not alter moods in everyone. Nevertheless, the proposed link between norepinephrine depletion and depression has gained much experimental support. These circuits originate in the brain stem, primarily in the pigmented locus coeruleus, and project to many areas of the brain, including to the limbic system—a group of cortical and subcortical areas that play a significant part in regulating emotions.

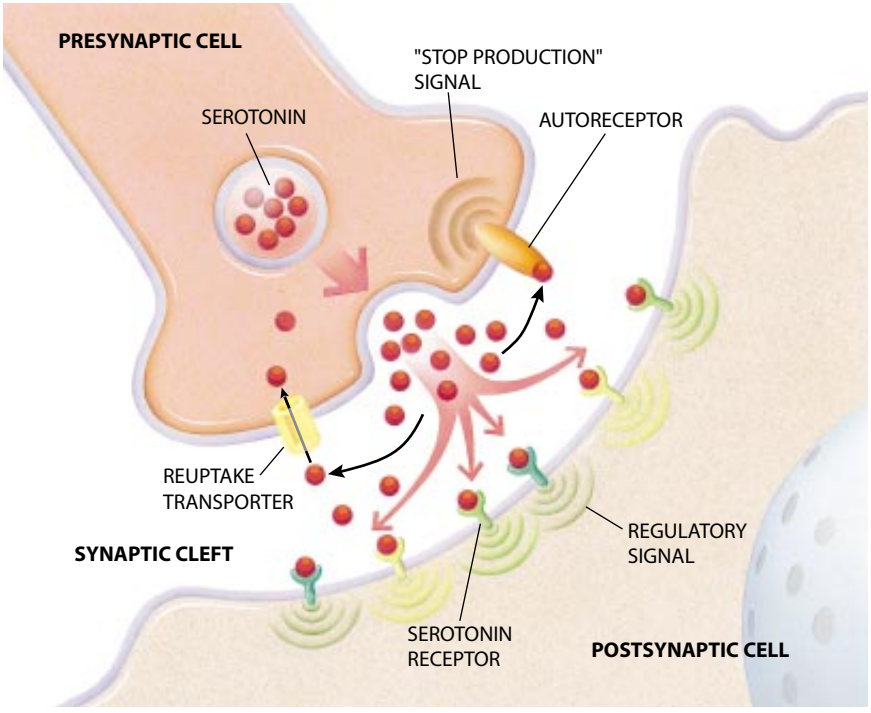
To understand the recent evidence relating to norepinephrine and other monoamines, it helps to know how those neurotransmitters work. The points of contact between two neurons, or nerve cells, are termed synapses. Monoamines, like all neurotransmitters, travel from one neuron (the presynaptic cell) across a small gap (the synaptic cleft) and attach to receptor molecules on the surface of the second neuron (the postsynaptic cell). Such binding elicits intracellular changes that stimulate or inhibit firing of the postsynaptic cell. The effect of the neurotransmitter depends greatly on the nature and concentration of its receptors on the postsynaptic cells. Serotonin receptors, for instance, come in 13 or more subtypes that can vary in their sensitivity to serotonin and in the effects they produce.

The strength of signaling can also be influenced by the amount of neurotransmitter released and by how long it remains in the synaptic cleft—properties influenced by at least two kinds of molecules on the surface of the releasing cell: autoreceptors and transporters. When an autoreceptor becomes bound by neurotransmitter molecules in the synapse, the receptors signal the cell to reduce its firing rate and thus its release of the transmitter. The transporters physically pump neurotransmitter molecules from the synaptic cleft back into presynaptic cells, a process termed reuptake. Monoamine oxidase inside cells can affect synaptic neurotransmitter levels as well, by degrading monoamines and so reducing the amounts of those molecules available for release.

Among the findings linking impoverished synaptic norepinephrine levels to depression is the discovery in many studies that indirect markers of norepinephrine levels in the brain—levels of its metabolites, or by-products, in more accessible material (urine and cerebrospinal fluid)—are often low in depressed individuals. In addition, postmortem studies have revealed increased densities of certain norepinephrine receptors in the cortex of depressed suicide victims.

Observers unfamiliar with receptor display might assume that elevated numbers of receptors were a sign of more contact between norepinephrine and its receptors and more signal transmission. But this pattern of receptor "up-regulation" is actually one that scientists would expect if norepinephrine concentrations in synapses were abnormally low. When transmitter molecules become unusually scarce in synapses, postsynaptic cells often expand receptor numbers in a compensatory attempt to pick up whatever signals are available.

A recent discovery supporting the norepinephrine hypothesis is that new drugs selectively able to block norepi-



SEROTONIN (*red spheres*) secreted by a presynaptic cell binds to receptors (*shades of green*) on a postsynaptic cell and directs the postsynaptic cell to fire or stop firing. The cell's response is influenced by the amount of serotonin in the cleft and by the types of receptors; serotonin receptors come in at least 13 "flavors." Serotonin levels in synapses are reduced by two kinds of presynaptic molecules: autoreceptors (*orange*), which direct the cells to inhibit serotonin production, and reuptake transporters (*yellow*), which absorb the neurotransmitter. Several antidepressants, including Prozac and Paxil, increase synaptic serotonin by inhibiting its reuptake.

nephrine reuptake, and so increase norepinephrine in synapses, are effective antidepressants in many people. One compound, reboxetine, is available as an antidepressant outside the U.S. and is awaiting approval here.

Serotonin Connections

The data connecting norepinephrine to depression are solid and still growing. Yet research into serotonin has taken center stage in the 1990s, thanks to the therapeutic success of Prozac and related antidepressants that manipulate serotonin levels. Serious investigations into serotonin's role in mood disorders, however, have been going on for almost 30 years, ever since Arthur J. Prange, Jr., of the University of North Carolina at Chapel Hill, Alec Coppen of the Medical Research Council in England and their co-workers put forward the so-called permissive hypothesis. This view held that synaptic depletion of serotonin was another cause of depression, one that worked by promoting, or "permitting," a fall in norepinephrine levels.

Defects in serotonin-using circuits could certainly dampen norepinephrine signaling. Serotonin-producing neurons project from the raphe nuclei in the brain stem to neurons in diverse regions of the central nervous system, including those that secrete or control the release of norepinephrine. Serotonin depletion might contribute to depression by affecting other kinds of neurons as well; serotonin-producing cells extend into many brain regions thought to participate in depressive symptoms—including the amygdala (an area involved in emotions), the hypothalamus (involved in appetite, libido and sleep) and cortical areas that participate in cognition and other higher processes.

Among the findings supporting a link between low synaptic serotonin levels and depression is that cerebrospinal fluid in depressed, and especially in suicidal, patients contains reduced amounts of a major serotonin by-product (signifying reduced levels of serotonin in the brain itself). In addition, levels of a surface molecule unique to serotonin-releasing cells in the brain are lower in depressed patients than in healthy subjects, implying that the numbers of serotonergic cells are reduced. Moreover, the density of at least one form of serotonin receptor—type 2—is greater in postmortem brain tissue of depressed patients; as was true in studies of norepinephrine receptors, this up-regulation is suggestive of a compensatory response to too little serotonin in the synaptic cleft.

Further evidence comes from the remarkable therapeutic effectiveness of drugs that block presynaptic reuptake transporters from drawing serotonin out of the synaptic cleft. Tricyclic antidepressants (so-named because they contain three rings of chemical groups) joined monoamine oxidase inhibitors on pharmacy shelves in the late 1950s, although their mechanism of action was not known at the time. Eventually, though, they were found to produce many effects in the brain, including a decrease in serotonin reuptake and a consequent rise in serotonin levels in synapses.

Investigators suspected that this last effect accounted for their antidepressant action, but confirmation awaited the introduction in the late 1980s of Prozac and then other drugs (Paxil, Zoloft and Luvox) able to block serotonin reuptake transporters without affecting other brain monoamines. These selective serotonin reuptake inhibitors (SSRIs) have now revolutionized the treatment of depression, because they are highly effective and produce much milder side effects than older drugs do. Today even newer antidepressants, such as Effexor, block reuptake of both serotonin and norepinephrine.

Studies of serotonin have also offered new clues to why depressed individuals are more susceptible to heart attack and stroke. Activation and clumping of blood platelets (cell-like structures in blood) contribute to the formation of thrombi that can clog blood vessels and shut off blood flow to the heart and brain, thus damaging those organs. Work in my laboratory and elsewhere has shown that platelets of depressed people are particularly sensitive to activation signals, including, it seems, to those issued by serotonin, which amplifies platelet reactivity to other, stronger chemical stimuli. Further, the platelets of depressed patients bear reduced numbers of serotonin reuptake transporters. In other words, compared with the platelets of healthy people, those in depressed individuals probably are less able to soak up serotonin from their environment and thus to reduce their exposure to platelet-activation signals.

Disturbed functioning of serotonin or

norepinephrine circuits, or both, contributes to depression in many people, but compelling work can equally claim that depression often involves dysregulation of brain circuits that control the activities of certain hormones. Indeed, hormonal alterations in depressed patients have long been evident.

Hormonal Abnormalities

The hypothalamus of the brain lies at the top of the hierarchy regulating hormone secretion. It manufactures and releases peptides (small chains of amino acids) that act on the pituitary, at the base of the brain, stimulating or inhibiting the pituitary's release of various hormones into the blood. These hormones—among them growth hormone, thyroid-stimulating hormone and adrenocorticotropic hormone (ACTH)—control the release of other hormones from target glands. In addition to functioning outside the nervous system, the hormones released in response to pituitary hormones feed back to the pituitary and hypothalamus. There they deliver inhibitory signals that keep hormone manufacture from becoming excessive.

Depressed patients have repeatedly been demonstrated to show a blunted response to a number of substances that normally stimulate the release of growth hormone. They also display aberrant responses to the hypothalamic substance that normally induces secretion of thyroid-stimulating hormone from the pituitary. In addition, a common cause of nonresponse to antidepressants is the presence of previously undiagnosed thyroid insufficiency.

All these findings are intriguing, but so far the strongest case has been made for dysregulation of the hypothalamic-pituitary-adrenal (HPA) axis—the system that manages the body's response to stress. When a threat to physical or psychological well-being is detected, the hypothalamus amplifies production of corticotropin-releasing factor (CRF), which induces the pituitary to secrete ACTH. ACTH then instructs the adrenal gland atop each kidney to release cortisol. Together all the changes prepare the body to fight or flee and cause it to shut down activities that would distract from self-protection. For instance, cortisol enhances the delivery of fuel to muscles. At the same time, CRF depresses the appetite for food and sex and heightens alertness. Chronic activation of the HPA axis, however, may lay the ground for illness and, it appears, for depression.

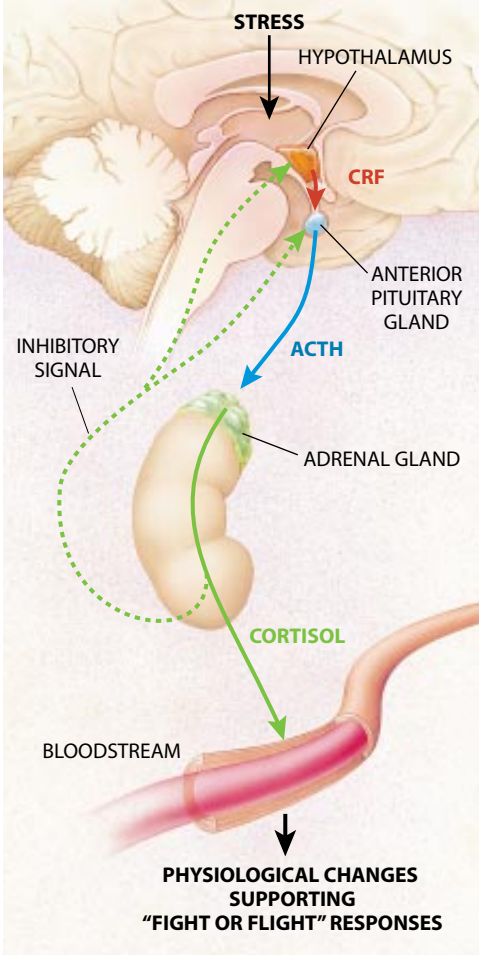
As long ago as the late 1960s and early 1970s, several research groups reported increased activity in the HPA axis in unmedicated depressed patients, as evinced by raised levels of cortisol in urine, blood and cerebrospinal fluid, as well as by other measures. Hundreds, perhaps even thousands, of subsequent studies have confirmed that substantial numbers of depressed patients—particularly those most severely affected—display HPA-axis hyperactivity. Indeed, the finding is surely the most replicated one in all of biological psychiatry.

Deeper investigation of the phenomenon has now revealed alterations at each level of the HPA axis in depressed patients. For instance, both the adrenal gland and the pituitary are enlarged, and the adrenal gland hypersecretes cortisol. But many researchers, including my colleagues and me at Emory University, have become persuaded that aberrations in CRF-producing neurons of the hypothalamus and elsewhere bear most of the responsibility for HPA-axis hyperactivity and the emergence of depressive symptoms.

Notably, study after study has shown CRF concentrations in cerebrospinal fluid to be elevated in depressed patients, compared with control subjects or individuals with other psychiatric disorders. This magnification of CRF levels is reduced by treatment with antidepressants and by effective electroconvulsive therapy. Further, postmortem brain tissue studies have revealed a marked exaggeration both in the number of CRF-producing neurons in the hypothalamus and in the expression of the CRF gene (resulting in elevated CRF synthesis) in depressed patients as compared with controls. Moreover, delivery of CRF to the brains of laboratory animals produces behavioral effects that are cardinal features of depression in humans, namely, insomnia, decreased appetite, decreased libido and anxiety.

Neurobiologists do not yet know exactly how the genetic, monoamine and hormonal findings piece together, if indeed they always do. The discoveries nonetheless suggest a partial scenario for how people who endure traumatic childhoods become depressed later in life. I call this hypothesis the stress-diathesis model of mood disorders, in recognition of the interaction between experience (stress) and inborn predisposition (diathesis).

The observation that depression runs in families means that certain genetic traits in the affected families somehow



TOMO NARASHIMA

Effects of CRF Application to Brain in Animals

DECREASED	INCREASED
Eating	Restless activity in familiar environments
Sleeping	Withdrawal in unfamiliar environments
Reproductive activity	

HORMONAL SYSTEM known as the hypothalamic-pituitary-adrenal axis is active (*solid arrows in diagram*) in response to stress. Mounting evidence suggests that chronic overactivity of the axis, and particularly overproduction of corticotropin-releasing factor (CRF), contributes to depression. For instance, application of CRF to the brain of laboratory animals produces symptoms (*above*) similar to those often displayed by depressed individuals.

lower the threshold for depression. Conceivably, the genetic features directly or indirectly diminish monoamine levels in synapses or increase reactivity of the HPA axis to stress. The genetically determined threshold is not necessarily low enough to induce depression in the absence of serious stress but may then be pushed still lower by early, adverse life experiences.

My colleagues and I propose that early abuse or neglect not only activates the stress response but induces persistently increased activity in CRF-containing neurons, which are known to be stress responsive and to be overactive in depressed people. If the hyperactivity in the neurons of children persisted through adulthood, these supersensitive cells would react vigorously even to mild stressors. This effect in people already innately predisposed to depression could then produce both the neuroendocrine and behavioral responses characteristic of the disorder.

Support for a Model

To test the stress-diathesis hypothesis, we have conducted a series of experiments in which neonatal rats were neglected. We removed them from their mothers for brief periods on about 10 of their first 21 days of life, before allowing them to grow up (after weaning) in a standard rat colony. As adults, these maternally deprived rats showed clear signs of changes in CRF-containing neurons, all in the direction observed in depressed patients—such as rises in stress-induced ACTH secretion and elevations of CRF concentrations in several areas of the brain. Levels of corticosterone (the rat's cortisol) also rose. These findings suggested that a permanent increase in CRF gene expression and thus in CRF production occurred in the maternally deprived rats, an effect now confirmed by Paul M. Plotsky, one of my co-workers at Emory.

We have also found an increase in CRF-receptor density in certain brain regions of maternally deprived rats. Receptor amplification commonly reflects an attempt to compensate for a decrease in the substance that acts on the receptor. In this case, though, the rise in receptor density evidently occurs not as a balance to decreased CRF but in spite of an increase—the worst of all possibilities. Permanently elevated receptor concentrations would tend to magnify the action of CRF, thereby forever enhancing the depression-inducing effects of CRF and stress.

In an exciting preliminary finding, Plotsky has observed that treatment with one of the selective serotonin reuptake inhibitors (Paxil) returns CRF levels to normal, compensates for any gain in receptor sensitivity or number (as indicated by normal corticosterone production lower down in the axis) and normalizes behavior (for instance, the rats become less fearful).

We do not know exactly how inhibition of serotonin reuptake would lead to normalization of the HPA axis. Even so, the finding implies that serotonin reuptake inhibitors might be particularly helpful in depressed patients with a history of childhood trauma. Plotsky further reports that all the HPA-axis and CRF abnormalities returned when treatment stopped, a hint that pharmaceutical therapy in analogous human patients might have to be continued indefinitely to block recurrences of depression.

Studies of Bonnet macaque monkeys, which as primates more closely resemble humans, yielded similar results. Newborns and their mothers encountered three foraging conditions for three months after the babies' birth: a plentiful, a scarce and a variable food supply. The variable situation (in which food was available unpredictably) evoked considerable anxiety in monkey mothers, who became so anxious and preoccupied that they basically ignored their offspring. As our model predicts, the neonates in the variable-foraging condition were less active, withdrew from interactions with other monkeys and froze in novel situations. In adulthood, they also exhibited marked elevations in CRF concentrations in spinal fluid.

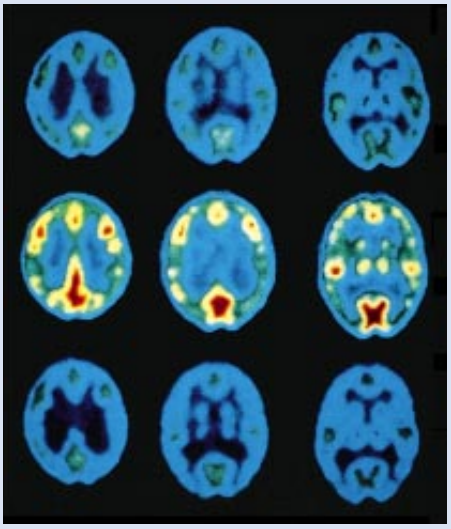
The rat and monkey data raise profound clinical and public health questions. In the U.S. alone in 1995, more than three million children were report-

Contributions from Imaging

The remarkable advances in brain imaging that have occurred over the past 15 years are now enabling noninvasive visualization to complement other approaches for identifying the neurobiological abnormalities that underlie depression. These techniques may also help reveal anatomical or functional markers of susceptibility to the disorder.

So far magnetic resonance imaging and other tools that assess brain structure have produced several provocative findings, although the practical implications are not always clear. Views of the subcortical white matter in manic-depressive (bipolar) patients, especially elderly ones, reveal an unexpectedly high number of bright spots in certain brain regions known to be involved in mood (such as the basal ganglia, thalamus and brain stem). "Hyperintensities" usually reflect neuronal loss, but which kinds of nerve cells might be missing from these regions remains obscure.

Also, the volume of various brain structures is reduced in long-term sufferers of depression. Among these is the hippocampus, a part of the limbic system (a suite of structures involved in emotion and memory). For instance, in a study of elderly women whose depression was in remission, the hippocampus was smaller than in other women of the same age. This finding is consistent with animal data suggesting that chronic oversecretion of cortisol (as occurs in many depressed individuals) can destroy hippocampal cells. Still uncertain is how neuronal loss in the hippocampus and other regions would foster depression, but it is reasonable to guess that some of the affected neurons may include ones that respond to serotonin or



LEWIS R. BAXTER, JR., University of Alabama at Birmingham, © 1985 Archives of General Psychiatry

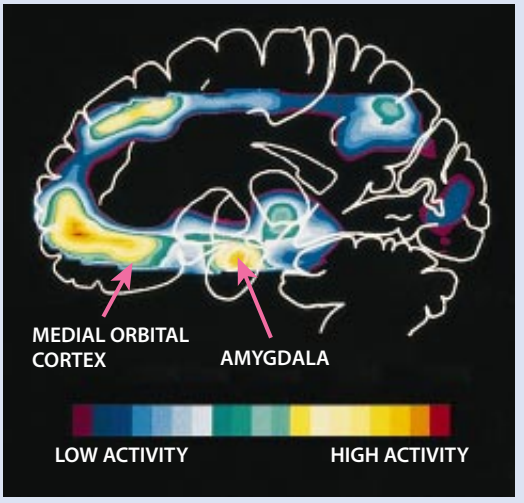
PET SCAN "SLICES" from the brain of a patient who cycled from depression (*top row*) to abnormally elevated mood (*middle*) and back (*bottom*) reveal different patterns of activity in the two states. Activity levels are indicated by a spectrum ranging from blue (low) through green to yellow and red (high).

norepinephrine. As the main text notes, declines in these signaling molecules, or neurotransmitters, contribute to many cases of depression.

Imaging studies that look at brain function—specifically at which areas are active (firing) when a person is resting or engaged in some task—have produced other insights. For example, positron emission tomography (PET) has shown that patients with major depression and normal controls evince different patterns of activity in several limbic and cortical brain areas. Further, in one patient who cycled rapidly between depression and mania over several days, the global activation pattern varied dramatically in the two states. Such work offers clues to the brain regions most important in each state. In addition, one PET analysis hints that increased activity in a region of the limbic system—the amygdala of the left hemisphere—might be an indicator of heightened vulnerability to future depression.

Functional imaging technology can also reveal the concentrations of the target molecules of neurotransmitters, so that densities of those targets can be compared in different people and in various areas of the brain. Traceable substances that bind to the serotonin reuptake transporter (which removes serotonin from synapses) and to one type of serotonin receptor have now been developed and should provide valuable information about exactly which brain areas show depleted serotonin activity in depressed patients. Moreover, functional imaging should help clarify where various antidepressants exert their effects in the brain.

Imaging tools are just beginning to be applied to study of the causes and best ways to treat depression. As the technology advances, understanding of mood disorders should take another giant step ahead. —*C.B.N.*



WAYNE C. DREVETS *University of Pittsburgh Medical Center*

INCREASED ACTIVITY has been found by PET imaging in parts of the prefrontal cortex and in the amygdala in the left hemisphere of depressed patients. Some work suggests that elevated activity in the amygdala can signal vulnerability to future depression.

edly abused or neglected, and at least a million of those reports were verified. If the effects in human beings resemble those of the animals, the findings imply that abuse or neglect may produce permanent changes in the developing brain—changes that chronically boost the output of, and responsiveness to, CRF, and therefore increase the victims' lifelong vulnerability to depression.

If that conclusion is correct, investigators will be eager to determine whether noninvasive techniques able to assess the activity of CRF-producing neurons or the number of CRF receptors could identify abused individuals at risk for later depression. In addition, they will want to evaluate whether antidepressants or other interventions, such as psychotherapy, could help prevent depression in children who are shown to be especially susceptible. Researchers will also need to find out whether depressed adults with a history of abuse need to take antidepressants in perpetuity and whether existing drugs or psychotherapy can restore normal activity in CRF-producing neurons in humans.

The stress-diathesis model does not account for all cases of depression; not everyone who is depressed has been neglected or abused in childhood. But individuals who have both a family history of the condition and a traumatic childhood seem to be unusually prone to the condition. People who have no genetic predisposition to depression (as indicated by no family history of the disorder) could conceivably be relatively protected from serious depression even if they have a bad childhood or severe trauma later in life. Conversely, some people who have a strong inherited vulnerability will find themselves battling depression even when their childhoods and later life are free of trauma.

More work on the neurobiology of depression is clearly indicated, but the advances achieved so far are already being translated into ideas for new medications. Several pharmaceutical houses are developing blockers of CRF receptors to test the antidepressant value of such agents. Another promising class of drugs activates specific serotonin receptors; such agents can potentially exert powerful antidepressive effects without stimulating serotonin receptors on neurons that play no part in depression.

More therapies based on new understandings of the biology of mood disorders are sure to follow as well. As research into the neurobiological underpinnings progresses, treatment should become ever more effective and less likely to produce unwanted side effects. SA

The Author

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A New Look at Quasars

Recent observations from the Hubble Space Telescope may reveal the nature and origin of quasars, the mysterious powerhouses of the cosmos

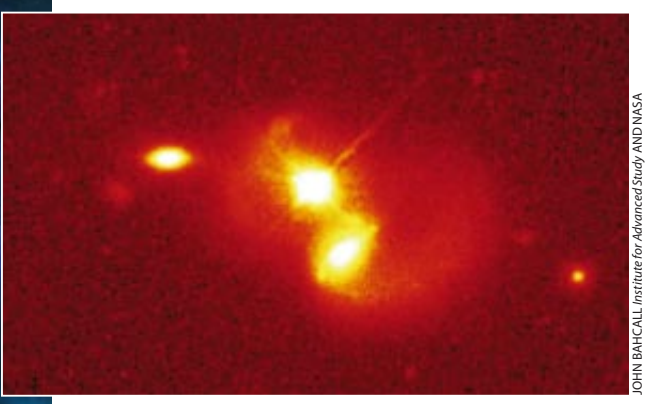
by Michael Disney

Quasars are the most luminous objects in the universe. They give off hundreds of times as much radiation as a giant galaxy like our own Milky Way, which is itself as luminous as 10 billion suns. Nevertheless, by astrophysical standards, quasars are minute objects, no more than a few light-days in diameter, as compared with the tens of thousands of light-years across a typical galaxy. How in heaven can they generate so much energy in such tiny volumes? What are they, and can they be explained by the ordinary laws of physics? To answer these questions, astronomers are training their most advanced instruments—the Hubble Space Telescope in particular—on these celestial superstars.

The first quasar was discovered in 1962, when Cyril Hazard, a young astronomer at the University of Sydney, began to study a powerful source of radio waves in the Virgo constellation. Hazard could not pinpoint the source, because the radio telescopes of the time were not precise enough, but he realized that the moon would occult the unknown object when it passed through Virgo. So he and John Bolton, the director of a newly built radio telescope in Parkes, Australia, pointed the instrument's giant dish toward the radio source and waited for the moon to block it out. By timing the disappearance and reappearance of the signal, they would be able to pinpoint the source of radio emissions and identify it with a visible object in the sky. Unfortunately, by the time the moon arrived the great dish was tipped so far over that it was running into its safety stops. Apparently unperturbed by the risk, Bolton sheared off the stops so that the telescope could follow the occultation downward until the rim of the dish almost touched the ground.

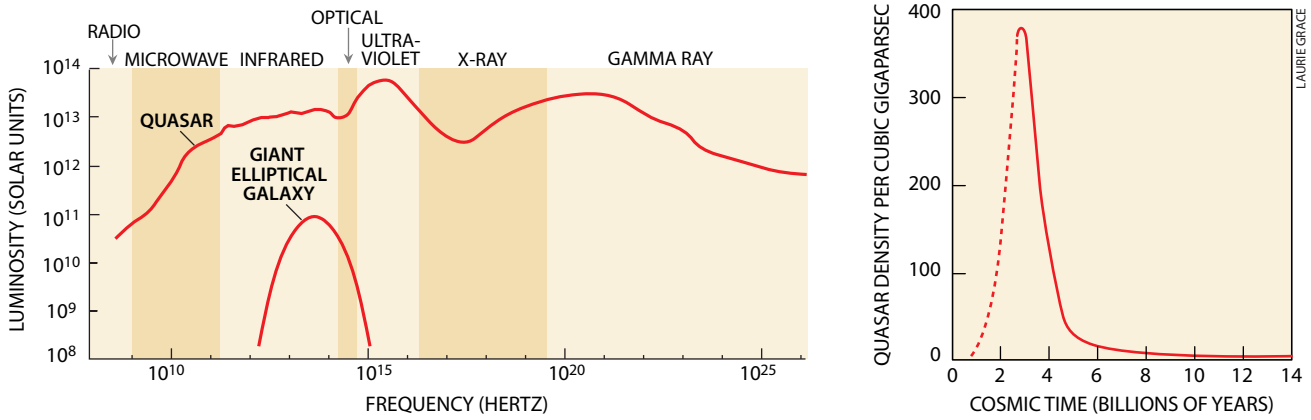
His daring was to be rewarded. From their measurements Hazard was able to calculate the first accurate position for such a cosmic radio source and then identify it with a comparatively bright, starlike object in the night sky. The position of that object—dubbed 3C273—was sent to Maarten Schmidt, an astronomer at the Mount Palomar Observatory in California, who had the honor of taking its optical spectrum. After some initial puzzlement, Schmidt realized he was looking at the

DON DIXON



JOHN BAHCALL, *Institute for Advanced Study* AND NASA

GALACTIC COLLISIONS may sometimes result in the birth of a quasar. A massive black hole at the core of one of the galaxies sucks in stars and gas from the other galaxy, and the maelstrom of infalling matter generates a beam of intense radiation. Such a process may be occurring in quasar PG 1012+008 (*inset*), as observed by the Hubble Space Telescope. The quasar is 1.6 billion light-years from the earth.



QUASAR SPECTRUM of 3C273—one of the brightest quasars and the first to be discovered—is far broader than the spectrum of a typical giant elliptical galaxy (*left*). In the optical range, the quasar is hundreds of times more luminous. Quasars were most numerous when the universe was two to four billion years old (*right*). Today quasars are 1,000 times less common. Quasars were also rare in the very early history of the universe, but the exact numbers are uncertain.

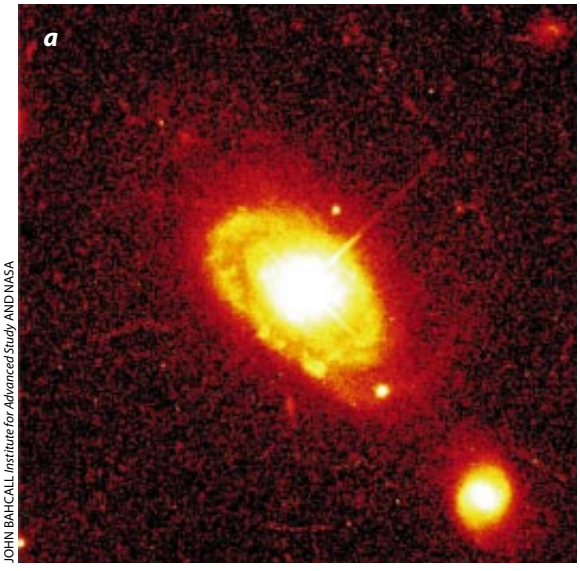
spectrum of hydrogen shifted redward by the expansion of the universe. The 16 percent redshift meant that 3C273 was about two billion light-years from the earth. Given the distance and the observed brightness of the object, Schmidt calculated that it had to be emitting several hundred times more light than any galaxy. The first quasistellar radio source—or quasar—had been discovered.

Spurred by Hazard's and Schmidt's work, astronomers identified many more quasars in the following years. Observers discovered that the brightness of many quasars varied wildly; some grew 10 times as bright in just a matter of days. Because no object can turn itself on and off in less time than it takes for light to travel across it, the astonishing implication was that these highly luminous objects must be a mere light-week or so across. Some reputable astronomers refused to believe that the enormous distances and luminosities implied by the redshifts could be so great. The controversy spilled over to the popular press, where it attracted a younger generation of scientists, like myself, into astronomy.

Since then, astronomers have catalogued thousands of quasars, some with redshifts as large as 500 percent. They are not difficult to find, because unlike stars, and unlike galaxies composed of stars, they emit radiation of all energies from gamma rays to radio. Ironically, the radio emissions by which they were first discovered turn out to be, in energetic terms, the least significant portion of their output. For that reason, some astronomers argue that the name "quasar" should be superseded by QSO, for quasistellar object.

There are four big questions facing the quasar astronomer. First, how are quasars related to galaxies and stars? Second, how long does each quasar pour out its enormous energy? In our immediate cosmic neighborhood—within one billion light-years from the earth—there is only one quasar for every million galaxies. But that does not necessarily mean that quasars are much rarer than galaxies; they could be just as common but have much shorter luminous lifetimes. This brings us to the third question: Why were quasars far more numerous in the past? At a redshift of 200 percent—about 10 billion light-years away—the number of quasars jumps 1,000-fold. In the early universe, apparently, quasars were 1,000 times more common than they are today. And last, the most perplexing question: How do quasars generate their prodigious energy?

None of these questions can be easily



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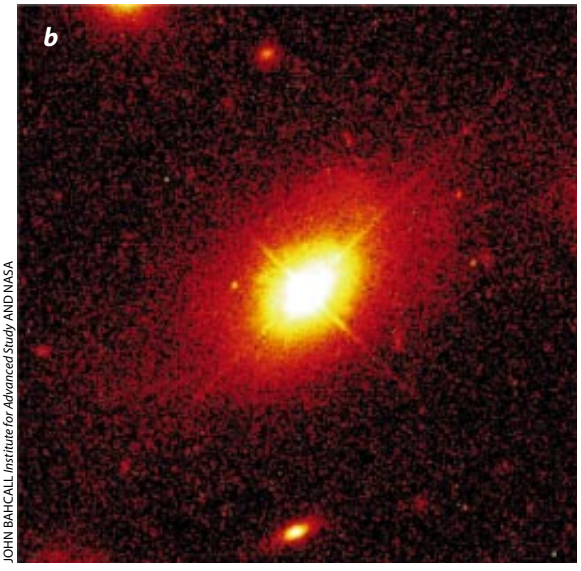

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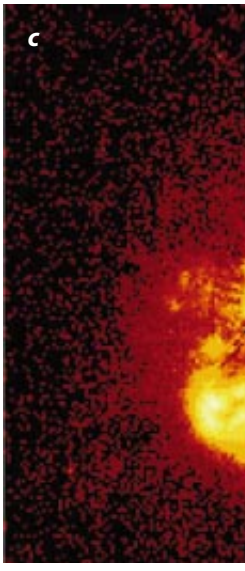


MICHAEL DISNEY AND NASA

answered. The typical quasar is so far from the earth that its image on the largest ground-based optical telescope would be 100 million times too small to be resolved. From the outset, one school of astronomers felt that quasars had to be sited in galaxies, probably in their nuclei. They gathered evidence to show that all the phenomena observed in quasars were manifested, albeit in a far weaker form, in the nuclei of about 1 percent of the giant galaxies near the Milky Way. A whole zoo of active galactic nuclei were revealed, including radio galaxies, Seyferts, blazars, optically violent variables, superluminal sources and so on. But astronomers could not tell whether these objects were separate classes of galactic nuclei or representations of the same phenomenon viewed from different angles or at different stages of development. Nor could astronomers explain the exact relation between the active galactic nuclei and quasars. Critics of the theory linking the two types of objects argued that the luminosity of the active nuclei did not even approach that of quasars. And the sheer power of quasars is their most distinctive and mysterious characteristic.

A more direct approach was taken by Jerry Kristian, another astronomer at Mount Palomar, in 1973. He argued that if quasars were inside giant host galaxies, then the images of the closest quasars should show a fuzzy halo of light from the stars in the host galaxy. It would not be an easy observation, because light from the brilliant quasar, scattered by the earth's atmosphere, would swamp the light from the much fainter host. Nevertheless, Kristian was able to demonstrate that the lowest redshift quasars did exhibit this faint, fuzzy halo. His evidence was not very satisfactory, though, because virtually nothing could be discerned about the host galaxies, not even whether they were elliptical or spiral.

Troubles with Hubble

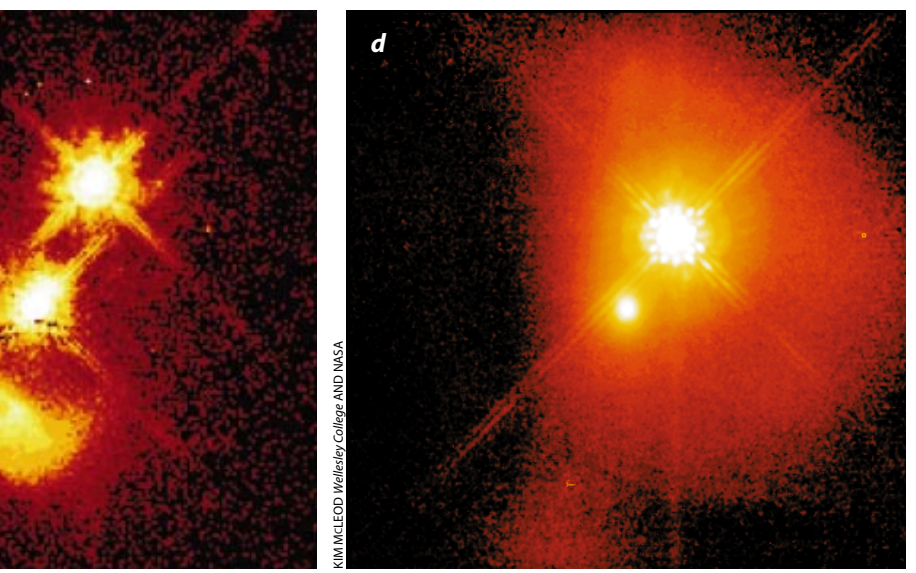
When the Hubble Space Telescope was proposed in the mid-1970s, most quasar observers expected it to provide the first clear images of host galaxies, if they really existed. Indeed, finding host galaxies became one of the primary objectives of the telescope. We on the European space telescope team designed the Hubble's Faint Object Camera with quasars very much in mind. For instance, we built in a high-magnification focus and a coronograph specially designed to block off the brilliant light from quasars and thus make the surrounding hosts more visible.

By then, astronomers suspected that the only way a quasar could produce so much energy out of such a tiny volume was if the object contained a massive black hole at its core. Such a monster hole, weighing as much as a billion suns, would suck in all the gas and stars in its vicinity. Gas would swirl into the hole at almost the speed of light, generating intense magnetic fields and huge amounts of radiation. Donald Lynden-Bell, then an astronomer at the California Institute of Technology, calculated that a massive black hole could convert up to 40 percent of the infalling matter's rest-mass energy into radiation. Such a process would be 400 times more efficient than the production of thermonuclear energy in stars. For this reason, massive black holes became the favored theoretical explanation for quasars. (All the other plausible models would rapidly evolve into black holes anyway.)

One problem with the model, though, was explaining how these monsters could be fed. A black hole of such enormous mass would tend to swallow up all the nearby stars and gas and then go out for lack of fuel. To explore this mystery, the European space telescope team also built a special long-slit spectrograph into the Faint Object Camera. This instrument was designed to measure the rotation speed of material in active galactic nuclei and thus weigh the putative black holes at their cores.

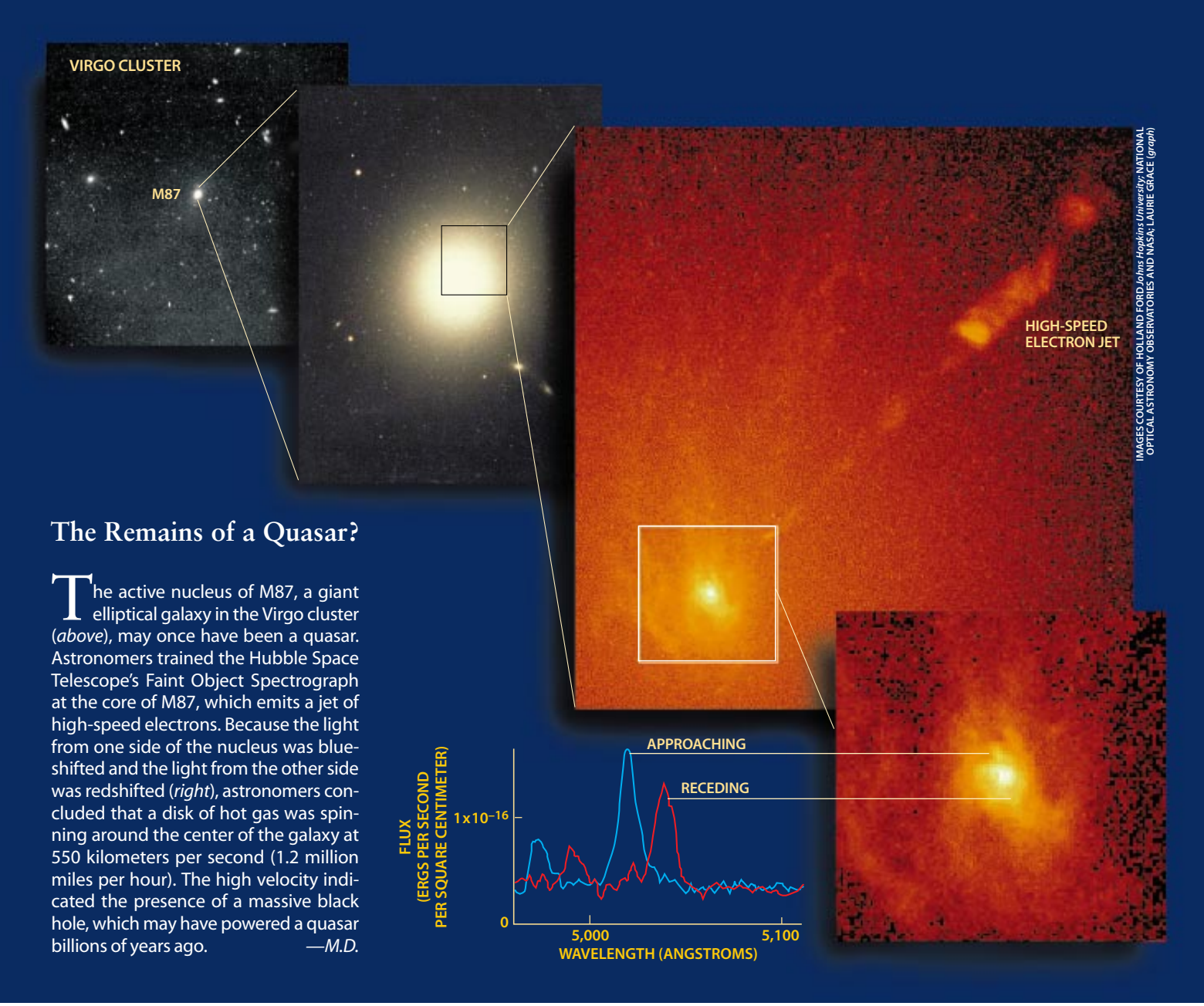
After the much delayed launch of Hubble in 1990, it was soon discovered that the telescope's main mirror had been incorrectly manufactured. The images were such a travesty that quasar astronomers were devastated. I, for one, felt that five to 10 of the most productive years of my astronomical life had been thrown away through unforgivable incompetence. And many others felt likewise. To its credit, however, the National Aeronautics and Space Administration had designed Hubble to be repairable, and astronauts installed new cameras with corrective optics in 1993. Unfortunately, none of the special instruments in the original cameras for observing quasars was recoverable. If we were still going to search for quasar host galaxies, we would have to use the new Wide-Field Planetary Camera, which was not designed for the job. Nevertheless, two teams set out to try: a European team headed by myself and an American team led by astronomer John Bahcall of the Institute for Advanced Study in Princeton, N.J.

Observing quasar hosts with the Hubble's new camera was akin to looking into the headlights of an oncoming car in a snowstorm and trying to identify its



KIM MCLEOD *Wellesley College* AND NASA

HOST GALAXIES surround most of the quasars observed by the Hubble Space Telescope. The spiral galaxy around PG 0052+251 (*a*) and the elliptical galaxy around PHL 909 (*b*) appear to be undisturbed by collisions. But a galactic crash seems to be fueling IRAS 04505-2958 (*c*). A spiral ring torn from one of the galaxies is below the quasar; the object above it is a foreground star. Hubble's new infrared camera observed another galactic smashup (*d*). The dots around quasar PG 1613+658 were caused by diffraction; the colliding galaxy is below it and to the left.



The Remains of a Quasar?

The active nucleus of M87, a giant elliptical galaxy in the Virgo cluster (*above*), may once have been a quasar. Astronomers trained the Hubble Space Telescope's Faint Object Spectrograph at the core of M87, which emits a jet of high-speed electrons. Because the light from one side of the nucleus was blueshifted and the light from the other side was redshifted (*right*), astronomers concluded that a disk of hot gas was spinning around the center of the galaxy at 550 kilometers per second (1.2 million miles per hour). The high velocity indicated the presence of a massive black hole, which may have powered a quasar billions of years ago. —*M.D.*

manufacturer. Astronomers had to take several shots of each object, subtract the high beam—the light from the quasar—and play with the remaining images on their computers. In most cases, the final result contained enough detail to make out a galactic structure. Sadly, Jerry Kristian, who pioneered this field, was killed in an ultralight airplane crash in California just before the Hubble results were published.

What did the space telescope reveal? Of the 34 quasars observed, about 75 percent showed the faint, fuzzy halo indicating a host galaxy. The remaining 25 percent showed no such halo, but it is possible that the quasar's dazzling beam is blocking the image in those cases. About half of the host galaxies were elliptical, and half were spiral. The quasars with the strongest radio signals were located primarily in elliptical galaxies, but no other patterns were discernible. Most intriguing, about three quarters of the host galaxies appeared to be colliding with or swallowing other galaxies.

This finding had already been reported by John Hutchings and his co-workers at Dominion Astrophysical Observatory in Victoria, Canada, who had used a ground-based telescope with adaptive optics to observe quasars. But the Hubble, with its greater resolution, provided much more vivid evidence of the galactic interactions. The images suggest that colliding galaxies supply the fuel for the quasar's energy production. Stars and gas shaken loose by the violence of the impact may be funneling into a massive black hole at the heart of one of the galaxies. The infalling matter then generates the intense radiation.

This process would explain the relative numbers of quasars at different stages in the universe's history. Immediately after the big bang, there were no galaxies and hence no galactic collisions. Even if black holes existed then, there was no mechanism to funnel material toward them and turn them into quasars. Consequently, few quasars are observed at very high redshifts—that is, more than 11 billion years ago. But in the following aeons, galaxies began to assemble and collide, producing the relatively large number of quasars observed 10 billion light-years from the earth. Finally, the expansion of the universe carried most galaxies away from one another,

reducing the number of galactic collisions—and the number of quasars.

Nevertheless, about one quarter of the host galaxies observed by Hubble—such as the spiral galaxy surrounding the quasar PG 0052+251—show no sign that they are colliding with another galaxy. It is possible that a faint companion galaxy is present in these cases, but the quasar's beam is preventing astronomers from seeing it. Or perhaps there is an alternative mechanism that can provide enough fuel to transform a massive black hole into a quasar. What we do know for certain is that the vast majority of galactic interactions do *not* seem to produce quasars; if they did, quasars would be far more common than we observe.

The scarcity of quasars seems to suggest that massive black holes are a rare phenomenon, absent from most galaxies. But this supposition is contradicted by recent evidence gathered by a team of astronomers led by Douglas Richstone of the University of Michigan. Combining observations from Hubble with spectroscopic evidence from ground-based telescopes, the team weighed the nuclei of 27 of the galaxies closest to the Milky Way. In 11 of the galaxies Richstone's group found convincing evidence for the presence of massive dark bodies, most likely black holes.

Furthermore, some of those massive black holes may once have been quasars. In 1994 a group of astronomers led by Holland Ford of Johns Hopkins University used Hubble to look into the heart of M87, a giant elliptical galaxy in the Virgo cluster, about 50 million light-years from the earth. The active nucleus of M87 emits a broad spectrum of radiation, similar to the radiation produced by a quasar but with only a thousandth the intensity. The astronomers discovered that the light from one side of the nucleus was blueshifted (indicating that the source is speeding toward the earth), whereas light from the other side was redshifted (indicating that the source is speeding away). Ford concluded that they were observing a rotating disk of hot gas. What is more, the disk was spinning so rapidly that it could be bound together only by a black hole weighing as much as three billion suns—the same kind of object that is believed to be the quasar's power source. Billions of years ago the nucleus of M87 may well have been a quasar, too.

The Quasar Quest

The recent observations have led astronomers to construct a tentative theory to explain the origin of quasars. According to the theory, most galaxies contain massive black holes capable of generating vast amounts of energy under very special circumstances. The energy production rises dramatically when gas and stars start falling into the black holes at an increased rate, typically about one solar mass a year. This huge infall occurs most often, but not always, as a result of galactic collisions or near misses. Quasars were thus far more prevalent in the epoch of high galaxy density, when the universe was younger and more crowded than it is now.

What can be said of the individual lifetimes of these beasts? Not much for certain. The observed host galaxies show no evidence that the quasars have been radiating long enough to damage them. The hydrogen gas in the host galaxies, for example, has not been substantially ionized, as it might be if quasars were long-lived. The observation that so many of the host galaxies are interacting—and the fact that such interactions typically last for one galactic rotation period or less—indicates a quasar lifetime shorter than 100 million years. And if the existence of massive black holes in most galaxies implies a past epoch of quasarlike activity in each case, then the small number of observed quasars—only one for every 1,000 galaxies during their most abundant era—suggests a quasar lifetime of 10 million years or less. If that number is correct, the quasar phenomenon is but a transient phase in the 10-billion-year lifetime of a galaxy. And although the amount of energy generated by each quasar is tremendous, it would account for only about 10 percent of the galaxy's lifetime radiant output.

Obviously, more observations are needed to test the theory. The Hubble Space Telescope must be trained on a wider sample of nearby quasars to search for host galaxies. The existing samples of nearby quasars are too small and too narrowly selected for reliable conclusions to be drawn, and the distant host galaxies are too difficult to observe with the current instruments.

Astronomers expect to make new discoveries with the help of two devices recently installed on Hubble: the Near Infrared Camera and Multi-Object Spectrometer (NICMOS), which will allow scientists to peer into the nuclei of galaxies obscured by clouds of dust, and the Space Telescope Imaging Spectrograph (STIS), which has already demonstrated its usefulness by detecting and weighing a black hole in a nearby galaxy in one fortieth the time it would have taken previously. In 1999 NASA plans to install the Advanced Camera, which will contain a high-resolution coronograph of the kind that was always needed to block the overwhelming quasar light and unmask the host galaxies.

On the theoretical side, we need to understand how and when massive black holes formed in the first place. Did they precede or follow the formation of their host galaxies? And we would like a convincing physical model to explain exactly how such black holes convert infalling matter into all the varieties of quasar radiation, from gamma rays to superluminal radio jets. That may not be easy. Astronomer Carole Mundell of Jodrell Bank Observatory in England once remarked that observing quasars is like observing the exhaust fumes of a car from a great distance and then trying to figure out what is going on under the hood. SA

The Author

MICHAEL DISNEY is a professor of astronomy at the University of Wales in Cardiff, U.K. For 20 years he was a member of the European Space Agency's Space Telescope Faint Object Camera team. He received his Ph.D. from University College London in 1968. His other scientific interests include hidden galaxies, bird flight and the environmental dangers posed by oil supertankers.

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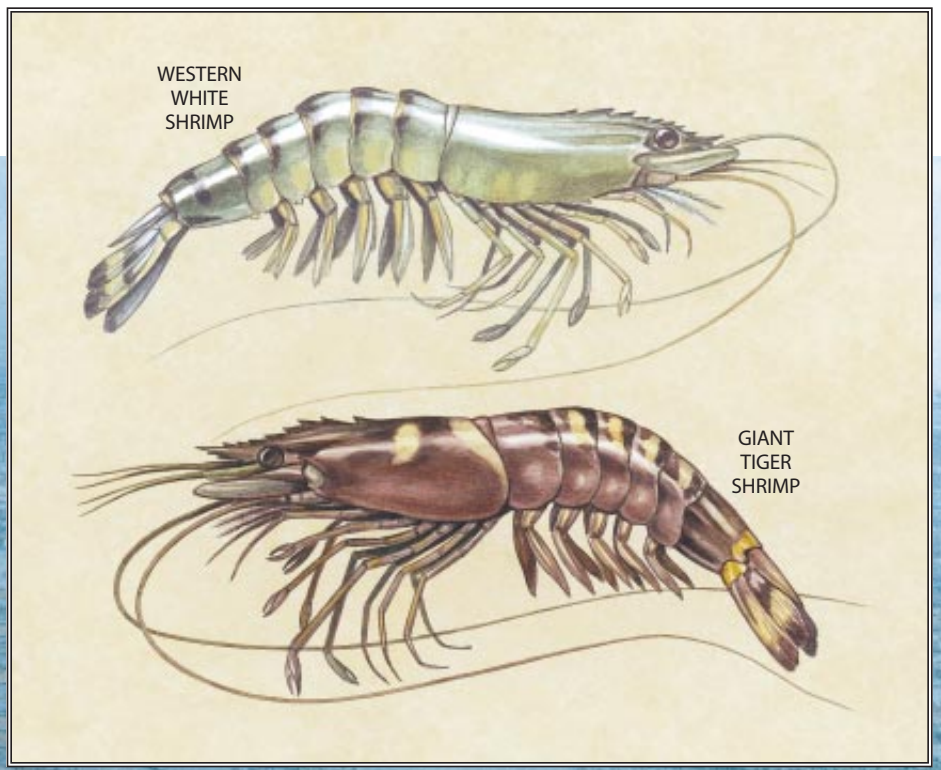
Shrimp Aquaculture and the Environment

An adviser to shrimp producers and an environmentalist present a prescription for raising shrimp responsibly

by Claude E. Boyd and Jason W. Clay



Shrimp aquaculture, or farming, first became profitable during the 1970s and has since mushroomed into a widespread enterprise throughout the tropical world. Thailand, Indonesia, China, India and other Asian nations now host about 1.2 million hectares (three million acres) of shrimp ponds on their soil, and nearly 200,000 hectares of coastline in the Western Hemisphere have been similarly transformed. Though rare in the U.S., where fewer than 1,000 hectares are devoted to shrimp farming, at least 130,000 hectares of Ecuador are covered with shrimp ponds. The seafood produced in this fashion ends up almost exclusively on plates in the U.S., Europe or Japan.

Hailed as the "blue revolution" a quarter century ago, raising shrimp, like many other forms of aquaculture, appeared to offer a way to reduce the pressure that overfishing brought to bear on wild populations. Shrimp farming also promised to limit massive collateral damage that trawling for these creatures did to other marine species, 10 kilograms of marine life being caught routinely for each kilogram of shrimp taken from the sea. Unfortunately, neither of these benefits has, as of yet, fully materialized. And as the record of the past two decades of shrimp farming clearly shows, aquaculture often creates its own set of environmental problems.

Down on the Farm

Normally, shrimp mate in the ocean. A single female spawns 100,000 or more eggs at a time, and within 24 hours the eggs that are fertilized hatch into larvae, which soon start feeding on plankton. After the larval period ends (about 12 days later), the young shrimp migrate from the open ocean into nutrient-rich estuaries, where they grow into more robust juveniles. Later they return to the sea to mature and mate.

For the most part, shrimp farming attempts to duplicate this natural life cycle. Aquaculturists induce adult broodstock to spawn in hatcheries by manipulating lighting, temperature, salinity, hormonal cycles and nutrients. After the eggs hatch, the managers of the hatcheries quickly transfer the offspring to rearing tanks where they can mature. During the early stages of this process, the tiny shrimp feed on microscopic algae. After the larvae grow bigger, they receive brine shrimp and manufactured feed. The managers keep the young shrimp in rearing tanks for an additional three weeks or so before releasing them into larger ponds.

In southeast Asia, most shrimp ponds are stocked with such hatchery-produced young. But in Latin America, many shrimp farmers prefer to raise larvae caught in the wild, because they are thought to be stronger and survive better in ponds. So the price for wild progeny may be more than twice that of shrimp conceived in a hatchery, and armies of collectors take to the water with nets to capture young shrimp for sale to the farmers. It is not clear whether fishing out so many larvae has depleted populations of wild shrimp. Still, in Central America, some commercial shrimp trawlers report that their catches declined noticeably when people began collecting larvae in large numbers from nearby estuaries.

Although fishing for shrimp larvae provides much needed work for many locals, their fine-mesh nets harvest essentially everything in their path, and inadvertent taking, or "bycatch," becomes a serious problem. The statistics are difficult to verify, but some workers believe that for every young shrimp snared in the wild, 100 other marine creatures will be killed.

Other environmental problems can arise from the ponds themselves. These shallow bodies are usually built by constructing earthen embankments along their perimeter. They vary in size from a few hundred square meters to many hectares, with average depths that are typically less than two meters. Usually, shrimp farmers pump seawater into canals from where it can then flow by gravity into ponds located somewhat inland, although some small-scale operations rely on the tide for filling ponds perched close to the sea.

The location of shrimp ponds is perhaps the most critical factor in controlling their impact on the surrounding environment. In Ecuador, ponds were initially constructed on salt flats and some other areas well suited to this use. That is, they were situated in places that were not particularly important for the proper functioning of the local ecosystem or for maintaining biodiversity. Yet as these expendable lands became scarce, shrimp ponds began to invade what was, from an environmental standpoint, more valuable property—wetlands and coastal thickets of salt-tolerant mangrove trees. In Thailand and many parts of Asia, shrimp aquaculture was never limited to salt flats. Although larger operations tended to avoid mangroves, about 40 percent of the small-scale farms—facilities set up with little forethought or investment capital—displaced mangroves.

Mangroves and wetlands are extraordinarily important both for the environmental services they provide and for the many plant and animal species that depend on them. For instance, mangroves soak up excess nutrients that would otherwise pollute coastal waters, and they provide protective nurseries for young marine animals. So the estimate of the United Nations Food and Agriculture Organization that about half the world's original endowment of mangrove forest has already been lost is quite troubling.

In most countries, the destruction of mangroves is driven primarily by people seeking wood for building or for fuel. Some mangrove-lined shores, like other kinds of forests, succumb to the pressures of development, which are often greatest along the coast. Shrimp farming alone appears to be responsible for less than 10 percent of the global loss. Yet in some countries shrimp aquaculture has caused as much as 20 percent of the damage to mangroves, and in some local watersheds shrimp farming accounts for nearly all the destruction.

Intensive Care Units

There are three primary methods for raising shrimp in ponds. These systems are classified according to the density of shrimp they contain, but they differ also in the nature of the feed used and in the rate of exchange of water between the ponds and the nearby ocean.

So-called extensive systems of aquaculture raise fewer than five shrimp for each square meter of pond water, whereas intensive systems grow 20 or more shrimp for each square meter of pond. Somewhere in between are the "semi-intensive" operations. The people who manage extensive systems of aquaculture nourish their charges by treating

WESTERN WHITE SHRIMP (*Penaeus vannamei*) and the giant tiger shrimp of Asia (*P. monodon*) respectively comprise 22 and 58 percent of the shrimp grown in shallow ponds (*aerial photograph*) in much of the tropical world.

ROBERTO OSTI (*illustration*); CONNER BAILEY (*photograph*)

C. C. LOCKWOOD *Bruce Coleman Inc.*

"BYCATCH," marine creatures inadvertently caught and killed while trawling the sea, typically exceeds the haul of wild shrimp harvested in fishing nets. In some cases, the ratio of bycatch to shrimp approaches 10 to one.

their ponds with fertilizers or manure to promote growth of algae. No other feed is given. In contrast, pellets made from plant and fish meals, nutritional supplements and a binder to enhance the stability of the feed in the water are applied daily to ponds undergoing semi-intensive and intensive management. Production during a 100- to 120-day crop is less than 1,000 kilograms per hectare (892 pounds per acre) in extensive ponds. Semi-intensive methods might produce as much as 2,000 kilograms per hectare, and intensive cultures can, in some cases, provide a phenomenal 8,000 or more kilograms per hectare.

On average, nearly two kilograms of food are needed to produce a kilogram of shrimp. Part of the reason for the inequality is that shrimp, like other animals, are not 100 percent efficient in converting food to flesh. Also, even in the best regulated feeding systems, up to 30 percent of the feed is never consumed. Consequently, a considerable amount of waste accumulates in the ponds in the form of uneaten feed, feces, ammonia, phosphorus and carbon dioxide. Usually, no more than a quarter of the organic carbon and other nutrients provided in the feed is recovered in the fattened shrimp at harvest. The excess nutrients stimulate the growth of phytoplankton, which eventually die, sink and decompose on the bottom of the ponds, consuming large amounts of oxygen in the process.

In traditional systems of aquaculture, the operators periodically remove the unwanted nutrients, dissolved gases, phytoplankton and pathogens by flushing them out to sea. In past decades, from 10 to as much as 30 percent of the water in the ponds was disgorged into the ocean each day. Today most shrimp farmers do better, exchanging daily from 2 to 5 percent of the pond water with the sea. Some shrimp farmers are attempting to eliminate this exchange completely. They have reduced the amount of wasted feed and also kept diseases in check by taking care not to stock their ponds too densely or with any infected larvae. In intensively operated ponds, mechanical aerators inject supplemental oxygen to prevent hypoxia from harming the shrimp.

The main chemicals put into ponds are fertilizer (to stimulate the growth of plankton on which the shrimp can feed), agricultural limestone and burnt lime (for adjusting the acidity of the water and underlying soil). In Asia, shrimp farmers also routinely add porous minerals called zeolites to remove ammonia, and they sometimes dose their ponds with calcium hypochlorite, formalin and some other compounds to kill pathogens and pests.

In some areas, the pollutants released from shrimp farms have exceeded the assimilative capacities of nearby coastal waters. Even if the quality of effluents from individual ponds falls within reasonable standards, too many farms in one area will eventually overwhelm natural ecosystems nearby, frequently causing unwanted fertilization (eutrophication) of coastal waters. The problem immediately spills over to all the coastal inhabitants—including the aquaculturists themselves, who must then struggle with the contamination of their own water supply.

But eutrophication is not the only threat. Viral diseases also haunt locales where concentrated shrimp aquaculture has degraded coastal waters. These diseases have sparked the collapse of much of the shrimp farming in China and Taiwan, and they have caused serious difficulties in Thailand, India and Ecuador. The pathogens at fault can travel from country to country—even from hemisphere to hemisphere—in shipments of infected hatchery-produced shrimp. Diseases of shrimp can also be spread through uncooked, processed frozen shrimp.

Shrimp farmers have learned to fight these diseases in several ways. For example, they can now test the larvae they buy from hatcheries for dangerous viruses. And they have figured out how to dispose of shrimp from infected ponds so as to contain outbreaks. Certain hatcheries are using carefully bred broodstock to ensure that the larvae they produce are disease-free. Such advances are welcome, but some shrimp farmers also turn to using medicated feeds, a tactic for combating disease that may foster the proliferation of antibiotic-resistant bacteria or otherwise upset the local microbial ecology in worrisome ways.

Running a Tighter Vessel

Shrimp aquaculturists have recently started to address environmental concerns. Many of the rules of environmental etiquette are obvious. For example, ponds should not be constructed in sandy soil (unless impermeable clay or plastic liners are used) to prevent seepage of saltwater into freshwater aquifers. Discharge of effluents into predominately freshwater bodies or onto dry land should also be prohibited.

Making the proper choice of sites for the ponds is perhaps one of the easiest ways for shrimp farmers to limit environmental damage—at least for ponds that have not yet been built. There is no defense for putting shrimp ponds in mangrove forests or even in tidal wet-

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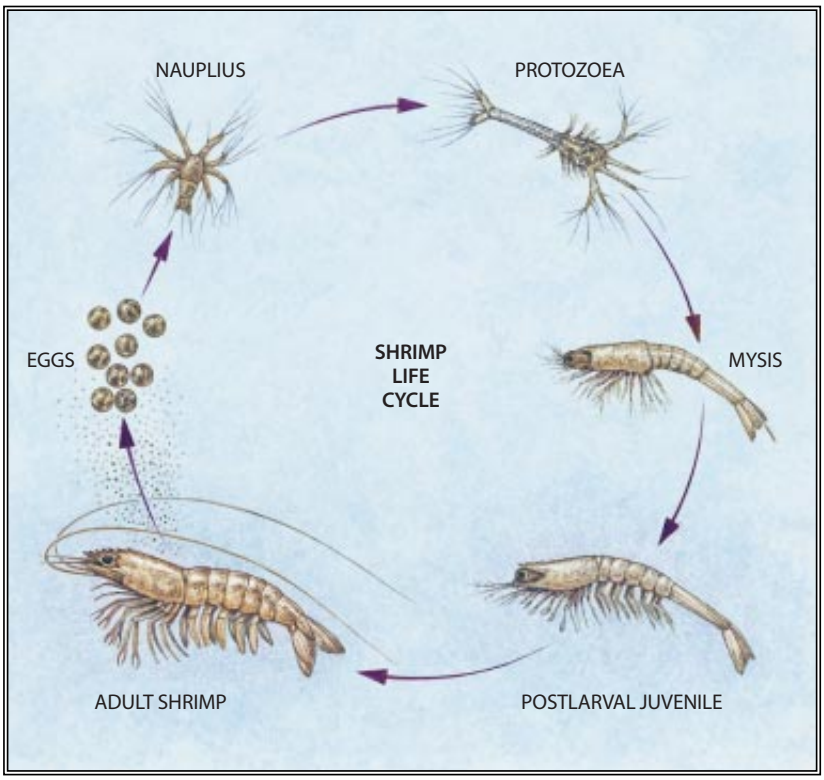


ROBERTO OSTI

COURTESY OF HARLINGEN SHRIMP FARMS

SHRIMP LIFE CYCLE (*above*), in which the eggs hatch and the shrimp grow through several stages before becoming adults, can be entirely duplicated by farmers. In the most environmentally responsible operations, shrimp are initially raised in hatchery tanks (*left*) and then grown to full size in ponds that are situated well away from ecologically valuable mangrove forests (*lower left*). But many farmers raise young shrimp taken from the wild (*right*) instead of a hatchery, and some of them build ponds where mangrove trees formerly stood (*lower right*), practices that risk considerable damage to the environment.

CONNER BAILEY

ALFREDO QUARTO

MICKEY GIBSON *Earth Scenes*

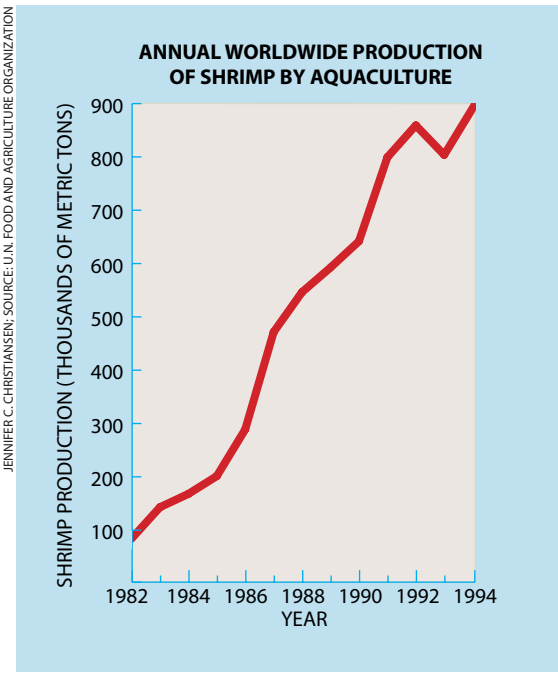
lands. These areas are not suited for sustained shrimp farming: they often have soils that are incompatible with long-term shrimp production and, more troubling, are vulnerable to coastal storms.

Most large-scale aquaculturists have learned to do better, for themselves and for the environment, than to displace mangroves with their facilities. Instead they construct canals or pipelines to bring ocean water through the coastal mangroves to sites farther inland. And many smaller-scale shrimp farmers are forming cooperatives to pool the resources and knowledge needed for responsible operations. In Indonesia, some large producers are required by law to help small-scale shrimp farmers manage their ponds. It is imperative that such efforts expand so that shrimp farming neither causes nor takes advantage of the epidemic loss of mangroves.

Even shrimp farmers preoccupied with profitability should be able to understand the benefits of adopting better practices. It costs anywhere from $10,000 to $50,000 per hectare to build proper shrimp ponds. Abandoning these works after only a few years because they have been located inappropriately not only causes considerable environmental damage, it also proves needlessly expensive. So shrimp farmers would do well to pick suitable locations away from mangroves.

And there are other simple changes that would help both the environment and the bottom line. For example, farm managers commonly broadcast large amounts of food over their ponds once or twice a day; however, many smaller feedings at more frequent intervals, combined with the use of feeding trays, would require less food and cause less waste. Improved feeds—formulations that use greater amounts of vegetable protein and less fish meal—are more digestible, appear to last longer in the water and also produce less waste. Investing in these practices would discourage overfishing of the seas for shrimp food, and it would save shrimp farmers money on feed, limit pollution and diminish the cost of cleaning up problems later. So it would also boost profits.

Another way to reduce water pollution is to avoid stocking ponds with too many juveniles and to restrict the amount of water exchanged with the sea. When the density of shrimp is right, natural processes within the ponds will assimilate much of the waste into the underlying soil. And although current technology requires ponds to be drained



JENNIFER C. CHRISTIANSEN; SOURCE: U.N. FOOD AND AGRICULTURE ORGANIZATION

SHRIMP AQUACULTURE has been practiced for centuries, but only in the past two decades have people raised shrimp in massive quantities (*right*). The top shrimp-producing nations (*far right*) straddle the equator in Asia and the Americas.

ALFREDO QUARTO

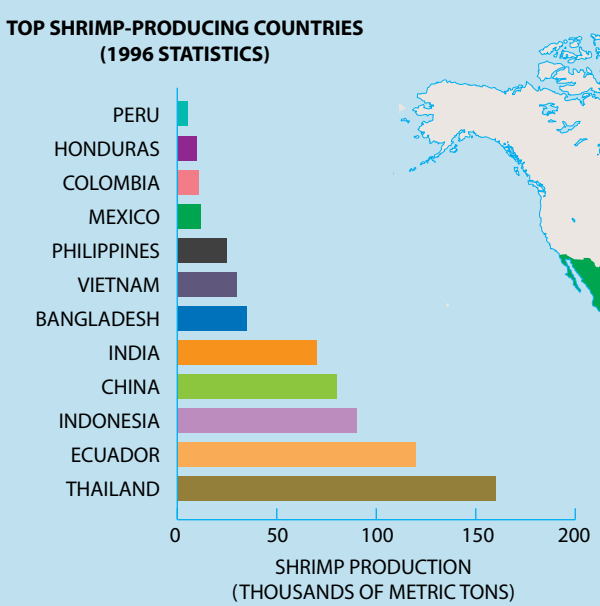
SALT-TOLERANT MANGROVE TREES (*left*) still line many tropical shores, although people have destroyed about half the world's original inventory. The fraction of that damage brought on specifically by irresponsible shrimp farming (*right*) probably accounts for less than 10 percent of the global loss, but in some localities shrimp aquaculture is the chief threat to mangroves.

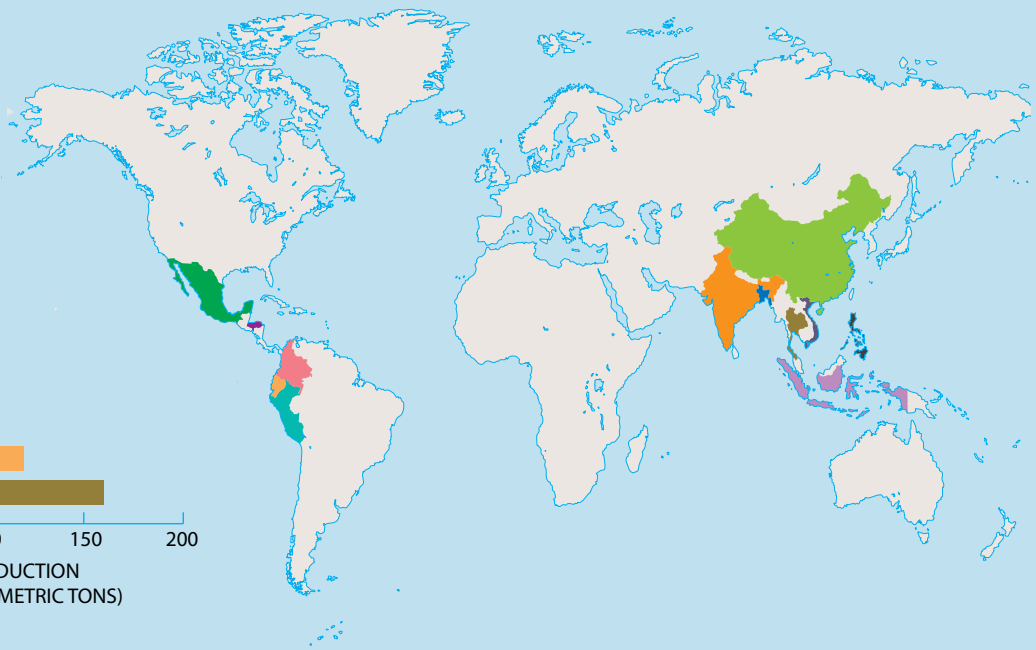
for harvest, operators could easily pass the water through settlement ponds to encourage denitrification and to remove many other pollutants associated with the suspended solids. Shrimp farmers should also refrain from mixing freshwater with the seawater in the ponds to reduce salinity. This practice (which, thankfully, has been abandoned by almost all shrimp farmers) is unnecessary and should be prohibited to avoid excessive drain on freshwater supplies.

Addressing threats to biodiversity is more difficult. But many problems could be eliminated if farmers raised only shrimp procured from hatcheries, carefully regulated the importation of broodstock and young shrimp, and cultured only native species. They could also prevent larger aquatic animals from being caught in their pumps by using intake screens.

Shrimp farmers should also pay more attention to the chemical additives they employ. Although most of the chemicals used in shrimp farming have a history of safe use, the application of chemicals other than agricultural limestone, burnt lime and fertilizers is usually unnecessary. In those rare instances where antibiotics are required, government regulators should evaluate the chemicals employed and prohibit potentially harmful ones—or at least make sure that they are used in a safe manner.

These governments should also require that careful studies of environmental and social impact precede the construction of new shrimp farms. That way, the communities involved could gauge the likelihood of damage to the local environment and identify conflicts





SOURCE: SHRIMP NEWS INTERNATIONAL

Notes from an Adviser to the Shrimp Industry

It cannot be denied that a great deal of environmental damage has arisen from poor planning and management by shrimp farmers and lax government agencies in countries where this form of aquaculture is widespread. But shrimp farming is not always harmful to the environment. Unfortunately, some environmentalists have unfairly made sweeping condemnations of the entire industry.

One charge leveled against shrimp farming is that rich investors make quick profits and then abandon farms. Here the critics are just plain wrong. Although some shrimp farms have proved unsustainable and been abandoned, these farms usually were small, often consisting of only one or two cheaply constructed ponds, which were situated on unsuitable sites and operated without sufficient capital and expertise. Properly sited and well-constructed shrimp farms cost from $10,000 to $50,000 per hectare of pond and are expensive to operate. Such large investments cannot be recovered quickly, so owners want to make sure that their farms are productive for many years.

Shrimp farming is an interesting example of a situation in which a disproportionate amount of the environmental damage has resulted from smaller operators rather than from bigger ones. But it is possible for small-scale farmers to pool their resources in cooperatives or producer associations and greatly improve their management. Well-run operations require many workers up and down the line—for hatcheries, farms and processing plants—typically creating one or two jobs for each hectare of pond in production. Shrimp farming also stimulates local economies and provides import earnings for many developing nations.

So it would be a sad loss for many people if shrimp aquaculture disappeared. The trick is to manage these operations sensibly. Many shrimp farmers are, in fact, acutely aware of the damage that shrimp farming can do. They have learned that their long-term success depends on maintaining healthy conditions for their shrimp and that their prosperity is linked directly to environmental quality along nearby coasts. Degradation of the coastal zone makes aquaculture more difficult, so it is easy to convince most shrimp farmers that they have a vested interest in being good environmental stewards.

Several recent developments indicate that shrimp farmers are indeed moving toward "environmentally friendly" forms of production. The Australian Prawn Farmers Association established a formal code of practice for its members; the Association of Southeast Asian Nations Fisheries Network published a manual of good shrimp farm procedures; and the Food and Agriculture Organization of the United Nations presented technical guidelines for responsible fisheries that apply to shrimp farming. In addition, the Network of Aquaculture Centers in Asia-Pacific has created a detailed plan to improve the sustainability of aquaculture in general.

What is more, several recent scientific and trade meetings have focused on the connection between shrimp farming and the environment. Most countries now require environmental impact assessments for new shrimp farms. Thailand has instituted regulations in an effort to make sure that shrimp farmers adopt the best management practices possible. A particularly important development is the recent formation of the Global Aquaculture Alliance. This industry group is fostering responsible shrimp aquaculture, developing an elaborate code of practice and promoting consumer awareness with an "eco-label" for environmentally friendly shrimp. —*Claude E. Boyd*

COURTESY OF CLAUDE E. BOYD

CHECKING THE SOIL and water of shrimp ponds requires the kind of expertise that author Boyd shares with shrimp producers around the world through workshops and consulting tours.

in the use of land and water. Governments must also find ways to ensure that these initial efforts to protect the environment remain effective over time.

Although environmental impact studies would be valuable for new projects, many existing shrimp farmers will clearly need to change their practices. Here both a carrot and a stick are necessary. Some shrimp producers will see the wisdom of adopting more sustainable approaches themselves. In some instances, however, governments must impose regulations.

In all, shrimp farmers should welcome the changes on the horizon. Technological innovations promise to aid them in reducing the discharge of wastewater and extending the life of their ponds. Better breeding programs should offer varieties of shrimp with greater resistance to disease. The adoption of better practices will cost producers somewhat more in the short term. But in the long run these changes will pay for themselves by improving the efficiency and durability of their operations.

The shrimp industry seems to be responding to criticisms from environmentalists, and we are hopeful that shrimp aquaculture will prove much less harmful to the environment in the future. In fact, many of today's operations are better than those of the recent past in this regard. Yet the shrimp industry as a whole still has to evolve substantially before it attains standards that might allow shrimp aquaculture to flourish on the same site indefinitely. Only at that point will shrimp aquaculture join most other kinds of farming in achieving widespread acceptance. SA

Comments from an Environmental Advocate

Many businesspeople see natural resources as free for the taking. They count as costs only the labor and investment to extract them. There is no thought given to the cost of replacement or maintenance for the resources they use. Nowhere is this blindness more true than with shrimp aquaculturists, who often depend on access to public resources that, traditionally, have been used by many different groups.

Shrimp farmers must decide if they indeed want to address the environmental problems their industry has created. True, all economic activities have environmental consequences. Nevertheless, the goal of shrimp producers should be to reduce the deleterious effects on the environment as much as possible.

Some practices that would make shrimp farming more sustainable are already used by more progressive and well-financed shrimp producers. Around the world, however, there are hundreds of thousands of shrimp farmers. Each one makes decisions that affect his or her own future as well as those of others in this business. Shrimp aquaculture as it is conducted today in most parts of the world is not sustainable for very many decades into the future.

Perhaps an ideal, indefinitely sustainable system for shrimp farming is not possible, at least with current knowledge. Yet most shrimp farmers and others affected by this industry could agree that some practices are better than others, and the industry as a whole would benefit from the swift adoption of these improved techniques.

There are a number of business reasons to adopt more efficient and sustainable methods of shrimp production. For example, increasing the survival rates of young shrimp from less than 50 to 75 percent or more will reduce the initial outlays required for each crop. Similarly, more effective ways of feeding shrimp can reduce expenditures on food by a quarter to a half. These two simple changes would reduce the cost of cleaning effluents and moving ponds periodically. Ecuadorian shrimp farmers have been able to double their profits by such means.

Although other improvements may be more expensive, the boost to income in many instances will compensate for the required expenditures. Yet it is important to understand that some investments will not result in increased efficiency. These costs will have to be passed on to consumers, who are, after all, the ultimate polluters in the economic system. Regulations might bring increased prices. Or perhaps "green" shrimp will prove to command a premium from environmentally conscious consumers.

But producers who try to differentiate their product to gain market advantage must be able to prove their claims. People will pay more only if a reliable third party has verified assertions about the product being environmentally benign. Because there are no "name brands" of shrimp, such assurances will be difficult to judge.

Who should establish the guidelines for sustainable shrimp production? Today environmentalists, producers and some governments are each developing their own guidelines for sustainable shrimp aquaculture. But no single group, certainly not the producers themselves, will be able to create a credible system. Attaining that goal will require that these diverse groups agree on general principles, which can then be adapted to specific local conditions. Only through the adoption of such sustainable production systems will shrimp aquaculture be part of the solution for the next millennium rather than just another environmental problem that must be put right. *—Jason W. Clay*

COURTESY OF JASON W. CLAY

PROTECTING INDIGENOUS PEOPLE through responsible business practices is a passion for author Clay, who trained in anthropology and economics before joining the World Wildlife Fund.

The Authors

CLAUDE E. BOYD and JASON W. CLAY can represent widely differing perspectives on shrimp aquaculture with good authority. Boyd received a Ph.D. in water and aquatic soil chemistry from Auburn University in Alabama in 1966 and is currently a professor there in the department of fisheries and allied aquacultures. He also works regularly as an adviser for shrimp aquaculturists around the globe. Clay obtained a Ph.D. in anthropology and international agriculture from Cornell University in 1979. Now a senior research fellow at the World Wildlife Fund in Washington, D.C., Clay has taught at Harvard University, conducted social science analysis for the U.S. Department of Agriculture and has served as the director of research for Cultural Survival, a human-rights organization working with indigenous peoples throughout the world.

Further Reading

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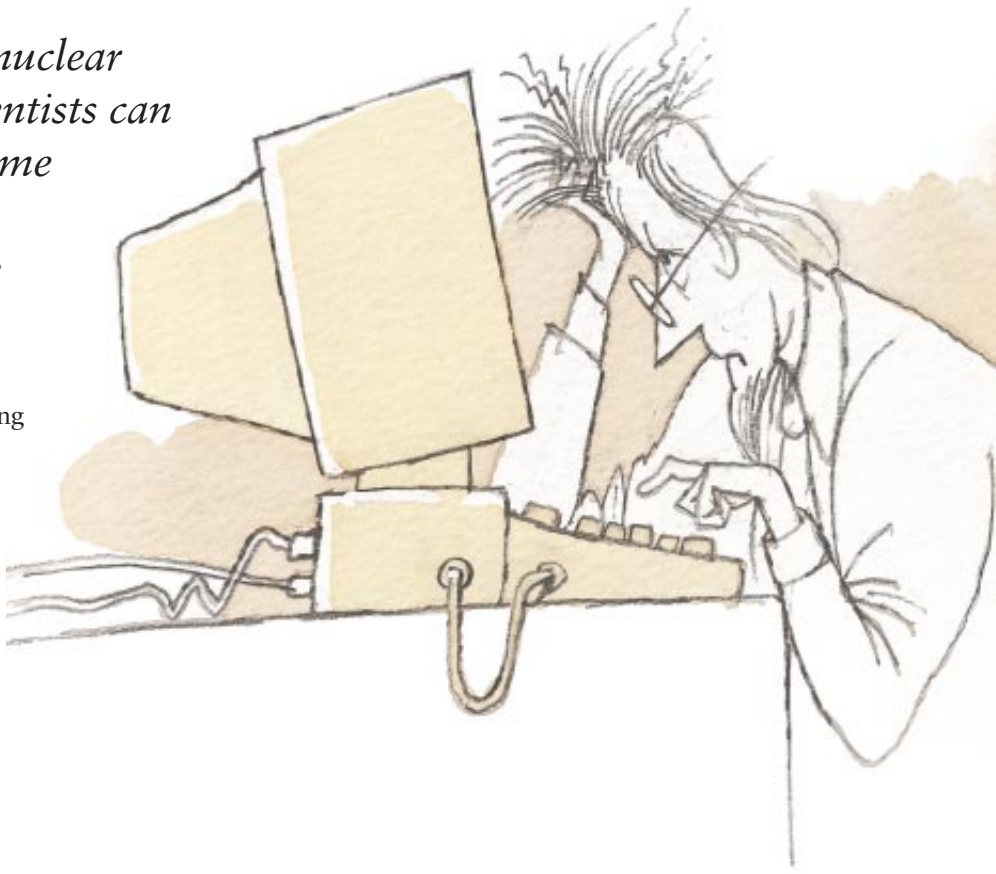
Quantum Computing with Molecules

By taking advantage of nuclear magnetic resonance, scientists can coax the molecules in some ordinary liquids to serve as an extraordinary type of computer

by Neil Gershenfeld and Isaac L. Chuang



Factoring a number with 400 digits—a numerical feat needed to break some security codes—would take even the fastest supercomputer in existence billions of years. But a newly conceived type of computer, one that exploits quantum-mechanical interactions, might complete the task in a year or so, thereby defeating many of the most sophisticated encryption schemes in use. Sensitive data are safe for the time being, because no one has been able to build a practical quantum computer. But researchers have now demonstrated the feasibility of this approach. Such a computer would look nothing like the machine that sits on your desk; surprisingly, it might resemble the cup of coffee at its side.

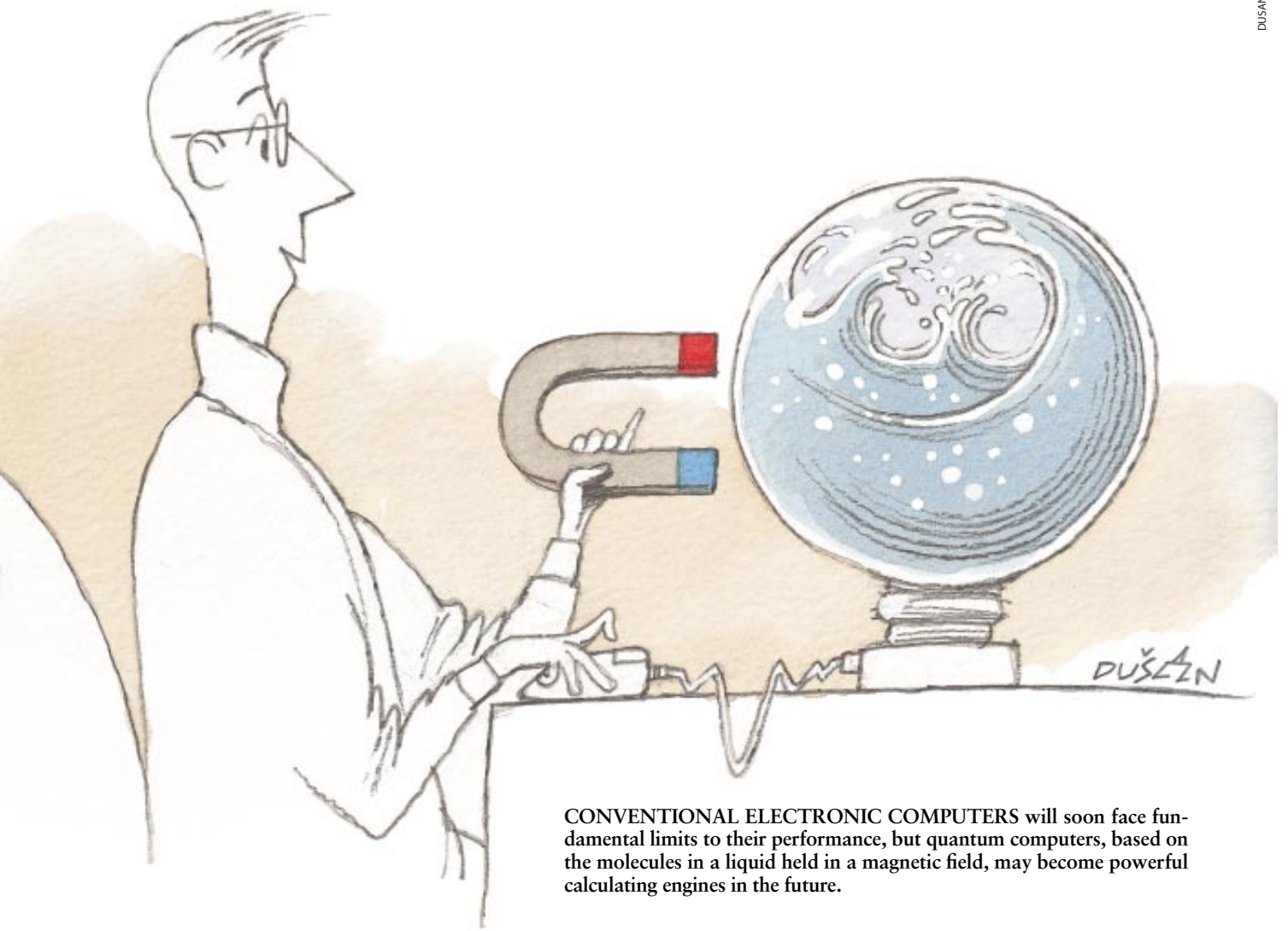
We and several other research groups believe quantum computers based on the molecules in a liquid might one day overcome many of the limits facing conventional computers. Roadblocks to improving conventional computers will ultimately arise from the fundamental physical bounds to miniaturization (for example, because transistors and electrical wiring cannot be made slimmer than the width of an atom). Or they may come about for practical reasons—most likely because the facilities for fabricating still more powerful microchips will become prohibitively expensive. Yet the magic of quantum mechanics might solve both these problems.

The advantage of quantum computers arises from the way they encode a bit, the fundamental unit of information. The state of a bit in a classical digital computer is specified by one number, 0 or 1. An *n*-bit binary word in a typical computer is accordingly described by a string of *n* zeros and ones. A quantum bit, called a qubit, might be represented by an atom in one of two different states, which can also be denoted as 0 or 1. Two qubits, like two classical bits, can attain four different well-defined states (0 and 0, 0 and 1, 1 and 0, or 1 and 1).

But unlike classical bits, qubits can exist simultaneously as 0 and 1, with the probability for each state given by a numerical coefficient. Describing a two-qubit quantum computer thus requires four coefficients. In general, *n* qubits demand 2^n numbers, which rapidly becomes a sizable set for larger values of *n*. For example, if *n* equals 50, about 10^{15} numbers are required to describe all the probabilities for all the possible states of the quantum machine—a number that exceeds the capacity of the largest conventional computer. A quantum computer promises to be immensely powerful because it can be in multiple states at once—a phenomenon called superposition—and because it can act on all its possible states simultaneously. Thus, a quantum computer could naturally perform myriad operations in parallel, using only a single processing unit.

Action at a Distance

Another property of qubits is even more bizarre—and useful. Imagine a physical process that emits two photons (packets of light), one to the left and the other to the right, with the two photons having opposite orientations (polarizations) for their oscillating electrical fields. Until detected, the polarization of each of the photons is indeter-



DUSAN PETRICIC

CONVENTIONAL ELECTRONIC COMPUTERS will soon face fundamental limits to their performance, but quantum computers, based on the molecules in a liquid held in a magnetic field, may become powerful calculating engines in the future.

minate. As noted by Albert Einstein and others early in the century, at the instant a person measures the polarization for one photon, the state of the other polarization becomes immediately fixed—no matter how far away it is. Such instantaneous action at a distance is curious indeed. This phenomenon allows quantum systems to develop a spooky connection, a so-called entanglement, that effectively serves to wire together the qubits in a quantum computer. This same property allowed Anton Zeilinger and his colleagues at the University of Innsbruck in Austria to perform a remarkable demonstration of quantum teleportation last year.

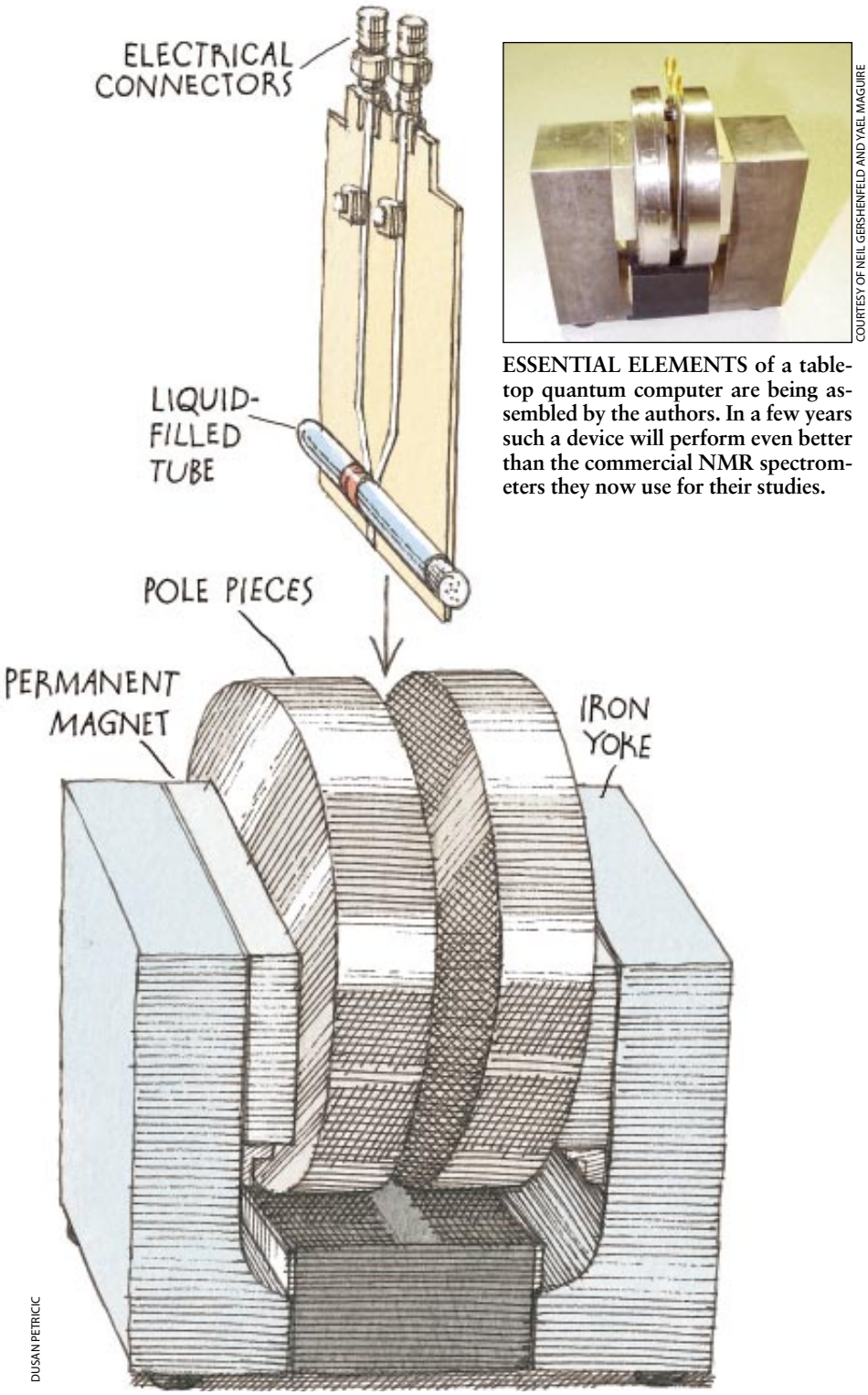
In 1994 Peter W. Shor of AT&T deduced how to take advantage of entanglement and superposition to find the prime factors of an integer. He found that a quantum computer could, in principle, accomplish this task much faster than the best classical calculator ever could. His discovery had an enormous impact. Suddenly, the security of encryption systems that depend on the difficulty of factoring large numbers became suspect. And because so many financial transactions are currently guarded with such encryption schemes, Shor's result sent tremors through a cornerstone of the world's electronic economy.

Certainly no one had imagined that such a breakthrough would come from outside the disciplines of computer science or number theory. So Shor's algorithm prompted computer scientists to begin learning about quantum mechanics, and it sparked physicists to start dabbling in computer science.

Spin Doctoring

The researchers contemplating Shor's discovery all understood that building a useful quantum computer was going to be fiendishly difficult. The problem is that almost any interaction a quantum system has with its environment—say, an atom colliding with another atom or a stray photon—constitutes a measurement. The superposition of quantum-mechanical states then collapses into a single very definite state—the one that is detected by an observer. This phenomenon, known as decoherence, makes further quantum calculation impossible. Thus, the inner workings of a quantum computer must somehow be separated from its surroundings to maintain coherence. But they must also be accessible so that calculations can be loaded, executed and read out.

Prior work, including elegant experiments by Christopher R. Monroe and David J. Wineland of the National Institute of Standards and Technology and by H. Jeff Kimble of the California Institute of Technology, attempted to solve this problem by carefully isolating the quantum-mechanical heart of their



DUSAN PETRICIC

COURTESY OF NEIL GERSHENFELD AND YAEL MAGUIRE

ESSENTIAL ELEMENTS of a tabletop quantum computer are being assembled by the authors. In a few years such a device will perform even better than the commercial NMR spectrometers they now use for their studies.

computers. For example, magnetic fields can trap a few charged particles, which can then be cooled into pure quantum states. But even such heroic experimental efforts have demonstrated only rudimentary quantum operations, because these novel devices involve only a few bits and because they lose coherence very quickly.

So how then can a quantum-mechanical computer ever be exploited if it needs to be so well isolated from its surroundings? Last year we realized that an ordinary liquid could perform all the steps in a quantum computation: loading in an initial condition, applying logical operations to entangled superpositions and reading out the final result. Along with another group at Harvard University and the Massachusetts Institute of Technology, we found that nuclear magnetic resonance (NMR) techniques (similar to the methods used for magnetic resonance imaging, or MRI) could manipulate quantum information in what appear to be classical fluids.

It turns out that filling a test tube with a liquid made up of appropriate molecules—that is, using a huge number of individual quantum computers instead of just one—neatly addresses the problem of decoherence. By representing each qubit with a vast collection of molecules, one can afford to let measurements interact with a few of them. In fact, chemists, who have used NMR for decades to study complicated molecules, have been doing quantum computing all along without realizing it.

Nuclear magnetic resonance operates on quantum particles in the atomic nuclei within the molecules of the fluid. Particles with "spin" act like tiny bar magnets and will line up with an externally applied magnetic field. Two alternative alignments (parallel or antiparallel to the external field) correspond to two quantum states with different energies, which naturally constitute a qubit. One might suppose that the parallel spin corresponds to the number 1 and the antiparallel spin to the number 0. The parallel spin has lower energy than the antiparallel spin, by an amount that depends on the strength of the externally applied magnetic field. Normally, opposing spins are present in equal numbers in a fluid. But the applied field favors the creation of parallel spins, so a tiny imbalance between the two states ensues. This minute excess, perhaps just one in a million nuclei, is measured during an NMR experiment.

In addition to this fixed magnetic backdrop, NMR procedures also utilize varying electromagnetic fields. By applying an oscillating field of just the right frequency (determined by the magnitude of the fixed field and the intrinsic properties of the particle involved), certain spins can be made to flip between states. This feature allows the nuclear spins to be redirected at will.

For instance, protons (hydrogen nuclei) placed within a fixed magnetic field of 10 tesla can be induced to change direction by a magnetic field that oscillates at about 400 megahertz—that is, at radio frequencies. While turned on, usually only for a few millionths of a second, such radio waves will rotate the nuclear spins about the direction of the oscillating field, which is typically arranged to lie at right angles to the fixed field. If the oscillating radio-frequency

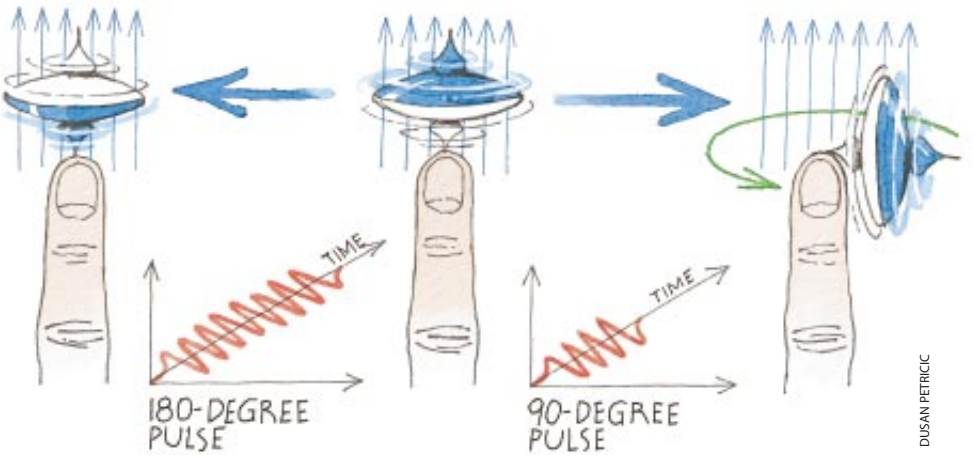
pulse lasts just long enough to rotate the spins by 180 degrees, the excess of magnetic nuclei previously aligned in parallel with the fixed field will now point in the opposite, antiparallel direction. A pulse of half that duration would leave the particles with an equal probability of being aligned parallel or antiparallel.

In quantum-mechanical terms, the spins would be in both states, 0 and 1, simultaneously. The usual classical rendition of this situation pictures the particle's spin axis pointing at 90 degrees to the fixed magnetic field. Then, like a child's top that is canted far from the vertical force of gravity, the spin axis of the particle itself rotates, or precesses, about the magnetic field, looping around with a characteristic frequency. In doing so, it emits a feeble radio signal, which the NMR apparatus can detect.

In fact, the particles in an NMR experiment feel more than just the applied fields, because each tiny atomic nucleus influences the magnetic field in its vicinity. In a liquid, the constant motion of the molecules relative to one another evens out most of these local magnetic ripples. But one magnetic nucleus can affect another in the same molecule when it disturbs the electrons orbiting around them both.

Rather than being a problem, this interaction within a molecule proves quite useful. It allows a logic "gate," the basic unit of a computation, to be readily constructed using two nuclear spins. For our two-spin experiments, we used chloroform ($CHCl_3$). We were interested in taking advantage of the interaction between the spins of the hydrogen and carbon nuclei. Because the nucleus of common carbon, carbon 12, has no spin, we used chloroform containing carbon with one extra neutron, which imparts an overall spin to it.

Suppose the spin of the hydrogen is directed either up or down, parallel or antiparallel to a vertically applied magnetic field, whereas the spin of the carbon is arranged so that it definitely points up, parallel to this fixed magnetic field. A properly designed radio-frequency pulse can rotate the carbon's spin downward into the horizontal plane. The carbon nucleus will then precess about the vertical, with a speed of rotation that depends on whether the hydrogen nucleus in that molecule also happens to be parallel to the applied field. After a certain short time, the carbon will point either in one direction or exactly the opposite, depending on whether the spin of the neighboring hydrogen was up or down. At that instant, we apply another radio-frequency pulse to rotate the carbon nucleus another 90 degrees. That maneuver then flips the carbon nucleus into the down position if the adjacent hydrogen was up or into the up position if the hydrogen was down.



DUSAN PETRICIC

MAGNETIC NUCLEUS acts like a spinning top. The spin axis will normally align along the direction of a magnetic field applied constantly (*center*). A suitable oscillatory field can then induce the spin to reorient. For example, a 180-degree pulse (*left*) causes a spinning nucleus to flip entirely over. A 90-degree pulse (*right*) would force it to tip perpendicular to the constant magnetic field (*vertical arrows*). After it tips over, the spin axis will itself rotate slowly around, just as with a child's toy.

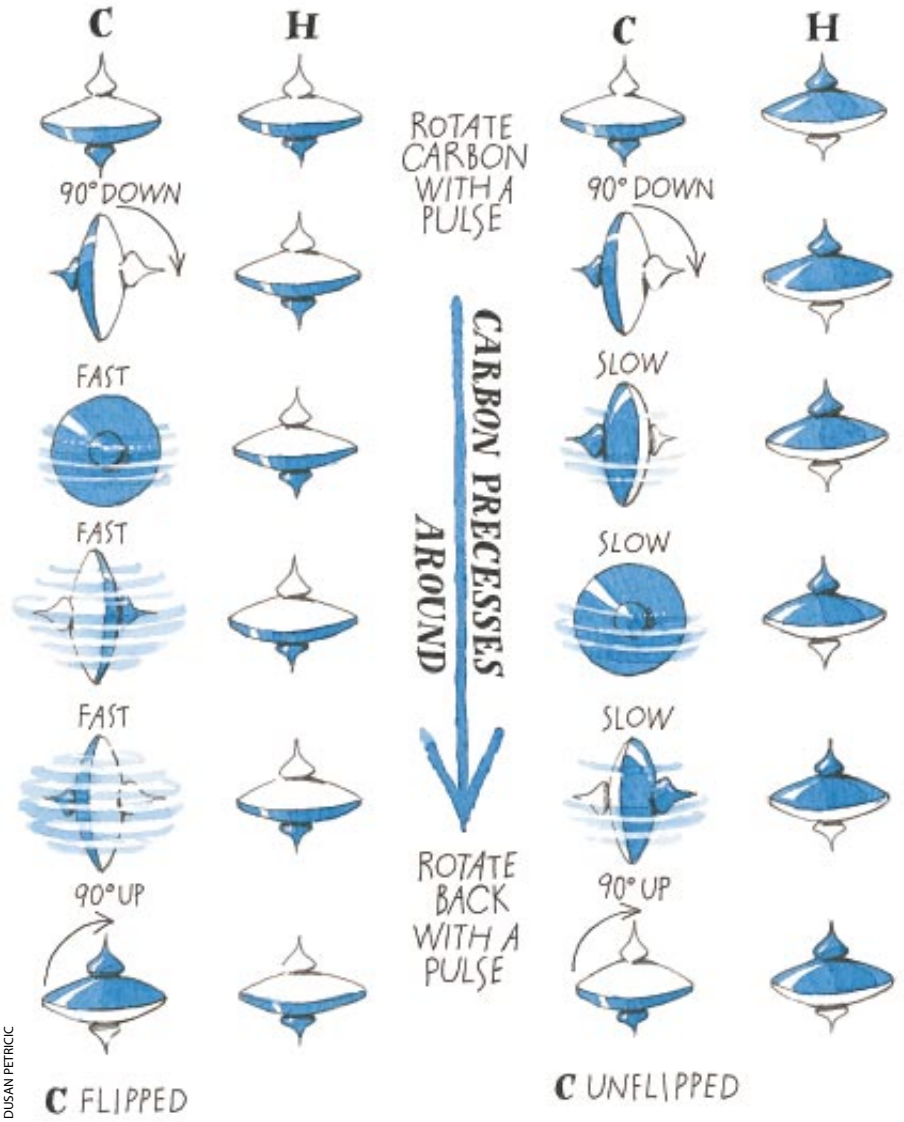
This set of operations corresponds to what electrical engineers call an exclusive-OR logic gate, something that is perhaps better termed a controlled-NOT gate (because the state of one input controls whether the signal presented at the other input is inverted at the output). Whereas classical computers require similar two-input gates as well as simpler one-input NOT gates in their construction, a group of researchers showed in 1995 that quantum computations can indeed be performed by means of rotations applied to individual spins and controlled-NOT gates. In fact, this type of quantum logic gate is far more versatile than its classical equivalent, because the spins on which it is based can be in superpositions of up and down states. Quantum computation can therefore operate simultaneously on a combination of seemingly incompatible inputs.

Two Things at Once

In 1996 we set out with Mark G. Kubinec of the University of California at Berkeley to build a modest two-bit quantum-mechanical computer made from a thimbleful of chloroform. Preparing the input for even this two-bit device requires considerable effort. A series of radio-frequency pulses must transform the countless nuclei in the experimental liquid into a collection that has its excess spins arranged just right. Then these qubits must be sequentially modified. In contrast to the bits in a conventional electronic computer, which migrate in an orderly way through arrays of logic gates as the calculation proceeds, these qubits do not go anywhere. Instead the logic gates are brought to them using various NMR manipulations. In essence, the program to be executed is compiled into a series of radio-frequency pulses.

The first computation we accomplished that exercised the unique abilities of quantum-mechanical computing followed an ingenious search algorithm devised by Lov K. Grover of Bell Laboratories. A typical computer searching for a desired item that is lost somewhere in a database of n items would take, on average, about $^n/_2$ tries to find it. Amazingly, Grover's quantum search can pinpoint the desired item in roughly $\sqrt{n}$ tries. As an example of this savings, we demonstrated that our two-qubit quantum computer could find a marked item hidden in a list of four possibilities in a single step. The classical solution to this problem is akin to opening a two-bit padlock by guessing: one would be unlikely to find the right combination on the first attempt. In fact, the classical method of solution would require, on average, between two and three tries.

A basic limitation of the chloroform computer is clearly its small number of



DUSAN PETRICIC

CONTROLLED-NOT LOGIC GATE inverts one of two inputs conditionally on the state of the second. The authors created a quantum controlled-NOT gate using the interaction between the nuclear spins of hydrogen and carbon in chloroform molecules. First, an oscillatory pulse selectively rotates the carbon nucleus 90 degrees. This nucleus then precesses rapidly (if the adjacent hydrogen is in one state) or slowly (if the hydrogen is in the opposite state). Waiting a suitable amount of time and then applying another 90-degree pulse causes the carbon to invert (*left*) or to remain the same as it was originally (*right*), depending on the state of the neighboring hydrogen.

qubits. The number of qubits could be expanded, but *n* could be no larger than the number of atoms in the molecule employed. With existing NMR equipment, the biggest quantum computers one can construct would have only about 10 qubits (because at room temperature the strength of the desired signal decreases rapidly as the number of magnetic nuclei in the molecule increases). Special NMR instrumentation designed around a suitable molecule could conceivably extend that number by a factor of three or four. But to create still larger computers, other techniques, such as optical pumping, would be needed to "cool" the spins. That is, the light from a suitable laser could help align the nuclei as effectively as removing the thermal motion of the molecules—but without actually freezing the liquid and ruining its ability to maintain long coherence times.

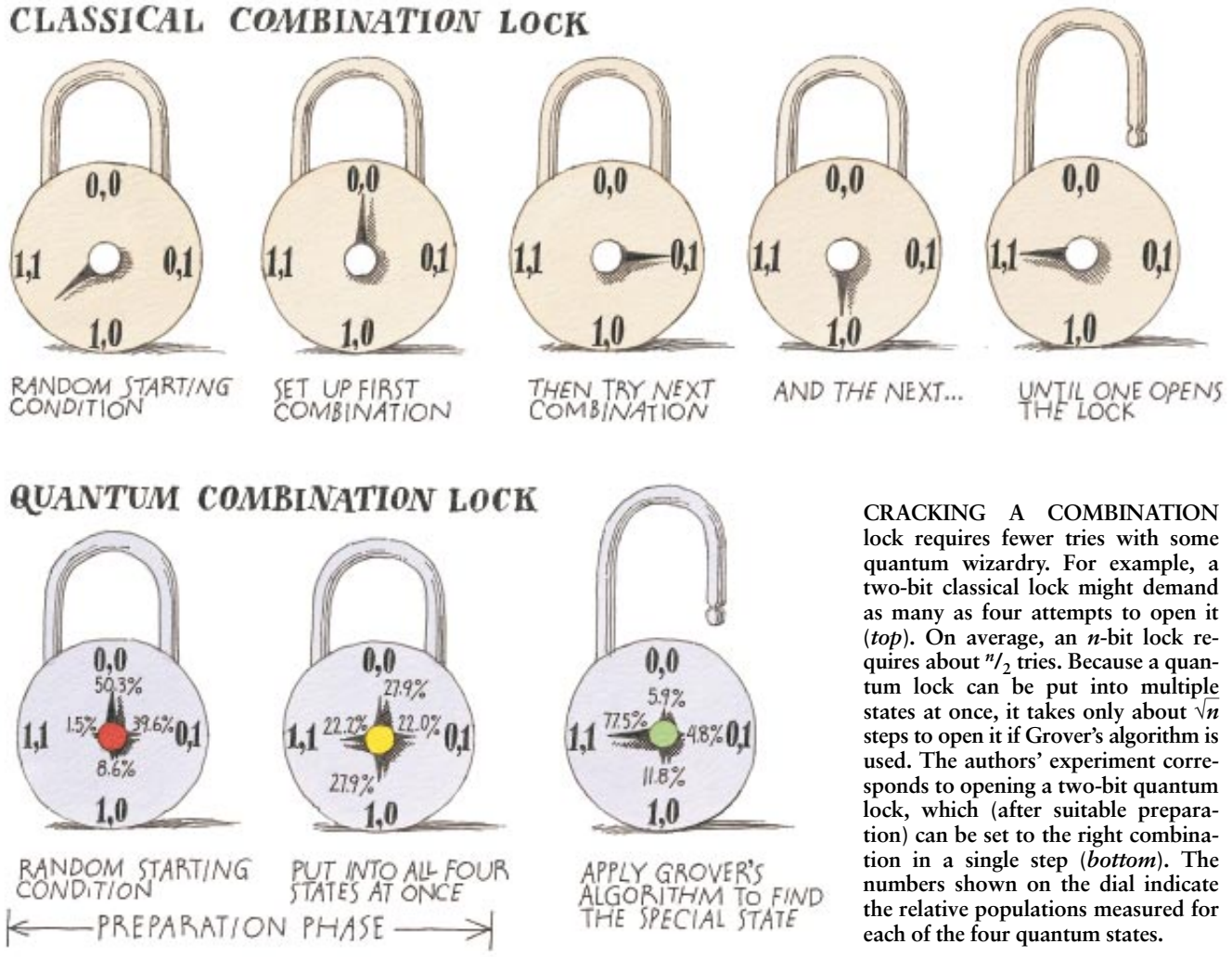
So larger quantum computers might be built. But how fast would they be? The effective cycle time of a quantum computer is determined by the slowest rate at which the spins flip around. This rate is, in turn, dictated by the interactions between spins and typically ranges from hundreds of cycles a second to a few cycles a second. Although running only a handful of clock cycles each second might seem awfully sluggish compared with the megahertz speed of conventional computers, a quantum computer with enough qubits would achieve such massive quantum parallelism that it would still factor a 400-digit number in about a year.

Given such promise, we have thought a great deal about how such a quantum computer could be physically constructed. Finding molecules with enough atoms is not a problem. The frustration is that as the size of a molecule increases, the interactions between the most distant spins eventually become too weak to use for logic gates. Yet all is not lost. Seth Lloyd of M.I.T. has shown that powerful quantum computers could, in principle, be built even if each atom interacts with only a few of its nearest neighbors, much like today's parallel computers. This kind of quantum computer might be made of long hydrocarbon molecules, also using NMR techniques. The spins in the many atomic nuclei, which are linked into long chains, would then serve as the qubits.

Another barrier to practical NMR computation is coherence. Rotating nuclei in a fluid will, like synchronized swimmers robbed of proper cues, begin to lose coherence after an interval of a few seconds to a few minutes. The longest coherence times for fluids, compared with the characteristic cycle times, suggest that about 1,000 operations could be performed while still preserving quantum coherence. Fortunately, it is possible to extend this limit by adding extra qubits to correct for quantum errors.

Although classical computers use extra bits to detect and correct errors, many experts were surprised when Shor and others showed that the same can be done quantum-mechanically. They had naively expected that quantum error correction would require measuring the state of the system and hence wrecking its quantum coherence. It turns out, however, that quantum errors can be corrected within the computer without the operator ever having to read the erroneous state.

Still, reaching sizes that make quantum computers large enough to compete with the fastest classical computers will be especially difficult. But we believe the challenge is well worth taking on. Quantum computers, even modest ones, will provide superb natural labo-



DUSAN PETRICIC

CRACKING A COMBINATION lock requires fewer tries with some quantum wizardry. For example, a two-bit classical lock might demand as many as four attempts to open it (*top*). On average, an *n*-bit lock requires about $^{n}/_{2}$ tries. Because a quantum lock can be put into multiple states at once, it takes only about $\sqrt{n}$ steps to open it if Grover's algorithm is used. The authors' experiment corresponds to opening a two-bit quantum lock, which (after suitable preparation) can be set to the right combination in a single step (*bottom*). The numbers shown on the dial indicate the relative populations measured for each of the four quantum states.

ratories in which to study the principles of quantum mechanics. With these devices, researchers will be able to investigate other quantum systems that are of fundamental interest simply by running the appropriate program.

Ironically, such quantum computers may help scientists and engineers solve the problems they encounter when they try to design conventional microchips with exceedingly small transistors, which behave quantum-mechanically when reduced in size to their limits.

Classical computers have great difficulty solving such problems of quantum mechanics. But quantum computers might do so easily. It was this possibility that inspired the late Richard Feynman of Caltech to ponder early on whether quantum computers could actually be built.

Perhaps the most satisfying aspect is the realization that constructing such quantum computers will not require the fabrication of tiny circuits of atomic scale or any other sophisticated advance in nanotechnology. Indeed, nature has already completed the hardest part of the process by assembling the basic components. All along, ordinary molecules have known how to do a remarkable kind of computation. People were just not asking them the right questions. SA

The Authors

NEIL GERSHENFELD and ISAAC L. CHUANG have worked together on problems of quantum computing since 1996. Gershenfeld first studied physics at Swarthmore College and Bell Laboratories. He went on to graduate school at Cornell University, where he obtained a doctorate in applied physics in 1990. Now a professor at the Massachusetts Institute of Technology, Gershenfeld also serves as director of the physics and media group of the institute's renowned Media Lab. Chuang studied at M.I.T. and at Stanford University, where he obtained a Ph.D. in 1997. He now studies quantum computation as a research staff member at the IBM Almaden Research Center in San Jose, Calif.

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Gravity Gradiometry

A formerly classified technique used to navigate ballistic-missile submarines now helps geologists search for resources hidden underground

by Robin E. Bell

During the cold war, submarine crews from both sides of the iron curtain were faced with the problem of guiding their vessels through the dark reaches of the ocean. Although they could always switch on their sonars to sense obstacles ahead or the depth of water below the keel, that act would send out acoustic signals, loud "pings," which would quickly reveal their presence to enemies—something right-thinking submariners hesitate to do.

In an effort to devise more stealthy aids to underwater navigation, U.S. and Soviet navies designed sensitive instruments that could measure tiny variations in the pull of gravity caused by underwater ridges or mountains. Yet with the exception of Tom Clancy's fictional submarine *Red October,* no Soviet vessel actually carried such elaborate gear. Only the U.S. ballistic-missile submarines benefited from these sophisticated devices, called gravity gradiometers. This equipment was a well-kept military secret for many years, but now I and other civilian geologists are making use of similar gravity gradiometers to pinpoint the location of oil and gas deposits deep underground.

Curiously, the current effort by geologists to exploit this formerly classified technology harks back to some of the earliest research in measuring the force of gravity. In 1890 Hungarian physicist Baron Roland von Eötvös used a simple instrument to measure gravity in a novel way. Other 19th-century physicists had timed the swinging of a pendulum to measure the tiny changes in the magnitude of gravity brought about by lunar and solar tides. But Eötvös's instrument was more sensitive: it could measure minute variations in gravity at one place—the gravity gradient—caused by the presence of a massive object nearby.

His instrument consisted of a metal beam with weights at both ends. If gravity varied with position, the force exerted on the weight attached to one side of the beam would not be identical to the force applied to the opposite weight. Differences in gravity could thus give rise to a rotational force on the beam, which was suspended in the middle by a thin wire. By measuring the amount of twist, Eötvös could determine how the force of gravity varied with position. His device, called a torsion balance, was the first instrument to measure such gravity gradients successfully.

As it happened, the head of the Hungarian geologic survey, Hugo de Boeckh, was following Eötvös's work. He realized that if he could coax Eötvös to move his delicate balance out of the laboratory and into the field, they might employ gravity gradients to detect interesting geologic structures hidden below the surface of the ground. After some discussion, Eötvös and de Boeckh instituted a series of experiments in 1901.

At the outset, their primary concern was whether natural gravity gradients would be sufficiently large to affect the torsion balance. For an initial test, they made measurements on a frozen lake. They reasoned that if the instrument worked properly, the resulting map of gravity gradients should reflect the configuration of the underlying lake basin, a shape that was well known from soundings made during previous summers with a line and sinker. The geologist and the physicist were pleased when they plotted the results from the torsion balance on a map and found a pattern that matched the contours of the lake floor. They then tackled more difficult geologic surveys in the region and soon began to attract the attention of oil prospectors around the globe.

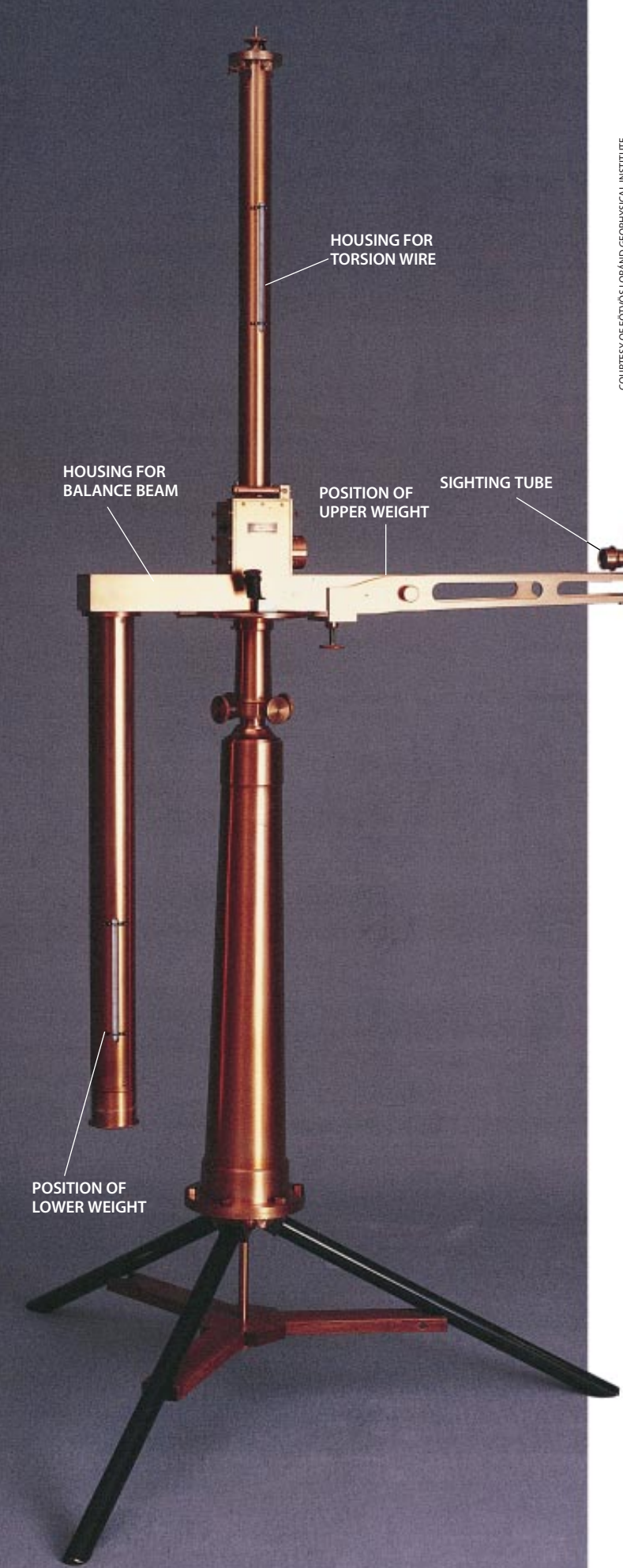
A Taste for Salt

After considerable delay caused by the dislocations of World War I, American geologists decided to try Eötvös's instrument in their searches for oil. In particular, they hoped the apparatus could detect one of their favorite targets, geologic structures called salt domes. These mushroom-shaped underground bodies, which are sometimes more than a kilometer (0.6 mile) thick, commonly hold huge oil and gas deposits along their flanks. But because the salt does not necessarily come all the way to the surface, such domes can be difficult to find. Salt is, however, less dense than most rock, and so it exerts a relatively weak gravitational pull. Shifts to abnormally low values of gravitational force—that is, gravity gradients—can thus delineate the outline of a buried salt body.

In 1924 geologists working for Amerada Hess Corporation made a historic first: they used measurements of gravity gradients with an Eötvös balance to find a hidden salt dome. And many other discoveries followed in rapid succession. Geologists enlisted gravity gradiometers to map more complicated underground formations as well. The geologic structure on which the city of Houston now rests (dipping sedimentary rock deformed by a shifting salt formation and cut by faults) was first mapped with a torsion balance. By 1935 probing the subsurface by measuring gravity gradients had become routine practice in exploring for oil.

Despite this early success, the heyday of gravity gradiometry proved short-lived. One problem was that the measurements were exceedingly difficult to make. Teams operating a torsion balance would have to level a swath of real estate extending for 100 meters in eight different directions. At the center of these star-shaped clearings, a survey crew would

COURTESY OF EÖTVÖS LORÁND GEOPHYSICAL INSTITUTE



COURTESY OF EÖTVÖS LORÁND GEOPHYSICAL INSTITUTE

EARLY GRADIOMETER (*left*), **of a type known as a torsion balance, was devised by Hungarian physicist Baron Roland von Eötvös in the late 19th century. He and his colleagues tested the ability of this instrument to survey the distribution of mass within the earth in the winter of 1901 on the frozen surface of Lake Balaton** (*above*), **which is situated near Budapest.**

have to erect a small building around the instrument to prevent it from being disturbed by wind or changing temperatures. Other sources of erroneous readings included heavy belt buckles, low-hanging telephone wires and adjacent cellars. In contrast, instruments that registered just the overall strength of gravity (devices that had also come into vogue with petroleum geologists during the 1930s) proved much less sensitive to nearby objects. And measurements of the overall strength of gravity did not require the effort of cutting down trees or setting up a small house.

The popularity of surveying gravity gradients also suffered because the results were often difficult for geologists to understand. Most of them preferred to work with straightforward contour maps of the strength of gravity rather than with the detailed gradiometry charts, which were invariably festooned with enigmatic lines and arrows. Their fondness for the simple strength maps, combined with the relative simplicity of collecting such measurements, soon led to the complete abandonment of work with gravity gradients.

Then and Now

As with many geophysicists working today, my knowledge of gravity gradiometry initially came only from reading the historical overview chapters in textbooks. Still, I was well versed in measuring the strength of gravity. I had, for example, installed a rather sophisticated electronic gravity meter in an aircraft and flown with it over West Antarctica to investigate the geology hidden underneath the thick ice sheet there. Yet my involvement with gravity gradiometry came quite by happenstance.

Four years ago my scientific feet were itchy. My second child was due to be born in October, at the beginning of the Antarctic summer field season, and so I was looking for a problem that would not involve extended fieldwork. Seeking some advice, I stopped by the office of Roger N. Anderson, a co-worker who had been studying flat-lying salt bodies in the

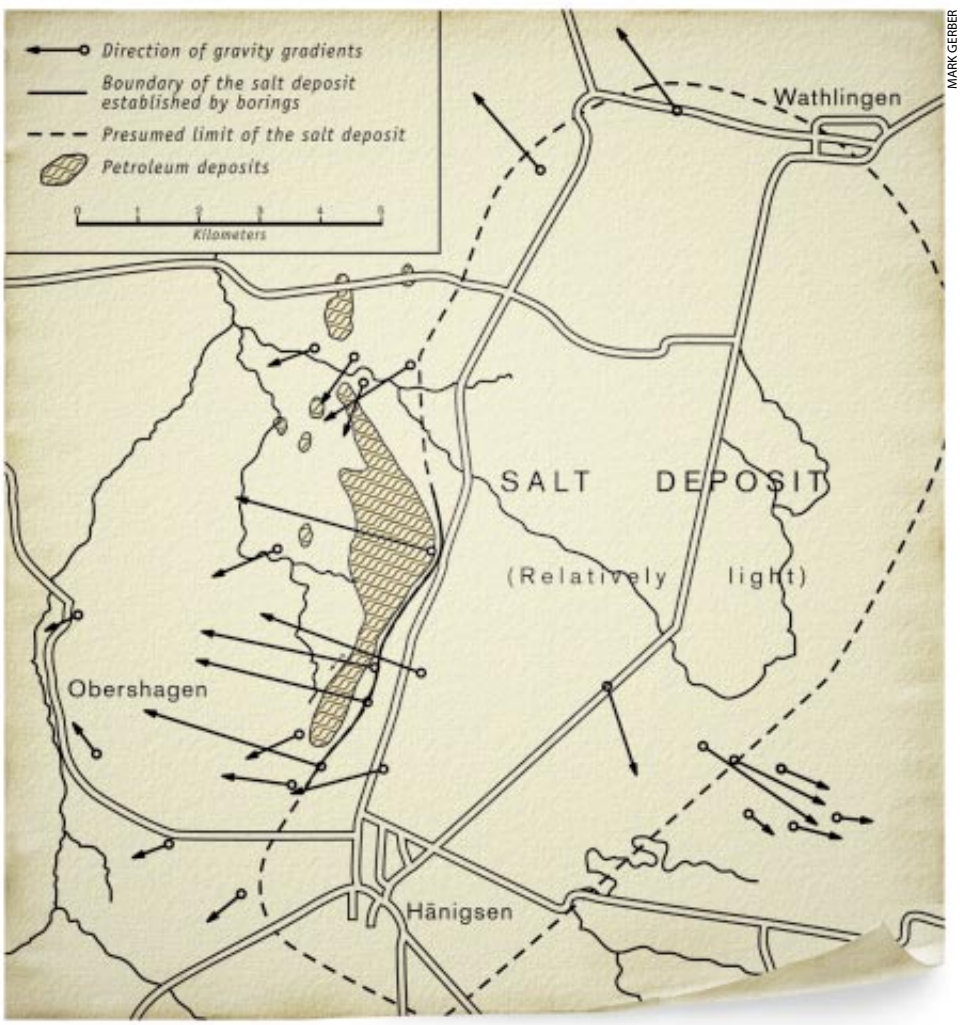
Gulf of Mexico, which sometimes form vast sheets. These widespread salt layers, resembling fluffy down comforters, often obscure underlying features of interest to oil-exploration geologists when they try to map the geologic structures below them using standard seismic methods. (Seismic techniques, like the acoustic depth sounders used at sea, rely on penetrating sound waves.) Anderson asked whether I could fly my airborne gravity meter over his study area and compare the results with similar gravity measurements collected from a ship. The idea was to examine how the gravity changed with height—a form of gravity gradiometry.

Although that approach seemed to be a good one in theory, I knew from practice how difficult it would be to make measurements from an aircraft with the necessary accuracy. Even on the smoothest flight, airborne measurements of gravity are somewhat unreliable, because an airplane always jitters up and down a little bit. So I quickly explained to my colleague that extracting gradients from such noisy measurements would very likely be impossible. Yet later that night, it occurred to me that the gravity gradiometers used in submarines might solve the problem. I had learned of these instruments from the manufacturer of the gravity meter I had been using in Antarctica. The modern military instruments use a set of six rotating pairs of gravity sensors to measure the complete gravity gradient (a three-dimensional quantity with five independent components). The real question was whether a few eager geologists could penetrate the veil surrounding this secret military technology.

Within a week, a group of us flew to Buffalo, N.Y., and visited the factory where Bell Aerospace (now a part of Lockheed Martin) had been manufacturing gradiometers for submarines. In prior years, activity in that plant must have been much greater, but at that time, with fewer than 100 employees on staff, the cavernous building seemed to echo with our footsteps. Without a steady stream of orders from the military, the instruments this company produced seemed destined to collect dust. Some of the resident engineers had thought of using these sensitive meters to monitor the load of passing trucks, but they had not had much success selling that idea. So our notions of employing these devices to search for oil sparked considerable interest.

With the aid of John J. Brett (then a retired engineer who was well versed in secret military projects), we soon convinced officials at Bell Aerospace, the U.S. Navy and several oil companies to help us find out whether gravity gradiometers could provide new information about oil-bearing geologic formations below the Gulf of Mexico. For our tests, we selected a field area about 130 kilometers (81 miles) southeast of New Orleans, which contained a huge, boot-shaped body of salt. Geologists from Texaco provided subsurface geologic maps, which they had constructed previously from seismic surveys in the region. And the navy agreed to measure gravity gradients over the area with a military gradiometer installed in one of its research ships. Any difference between the gravity signals we predicted on the basis of the seismic data and the result of the new gradiometer survey would constitute an important discovery about the geology of the region.

Then came the most difficult part of the experiment. Because the submarine gradiometer system was still a classified military technology, much of the work designing the experimental protocols and assessing the raw data took place behind a door that was closed and barred to the civilian geologists involved. So we turned our attention to developing techniques that would help us interpret the gravity gradients. In a sense, we were being forced to grapple with some of the same problems that faced our predecessors of the 1930s. Fortunately, we had the luxury of desktop computers to aid in the task. And over the next few months, as "sanitized" sets of data (ones from which the informa-



MARK GERBER

GEOPHYSICAL SURVEY performed with a torsion balance gradiometer near Hannover, Germany, in 1917, showed that measurements of gravity gradients could delineate buried salt, which is less dense than the surrounding rock. The formation of such salt bodies disturbs adjacent sedimentary layers, allowing oil and gas to accumulate in nearby deposits (*hatched areas*).

MODERN GRADIOMETER (*right*), of the type carried by some U.S. ballistic-missile submarines (*below*), contains six pairs of electromechanical gravity sensors, called accelerometers. The difference between two accelerometers, which are offset a small distance from one another, reflects the local gravity gradient. But the output from such sensors also tends to shift erratically over time. So the positions of paired sensors are swapped repeatedly using three spinning platforms inside the instrument to reveal the true gravity gradient.

MARK RANKIN *Arms Communications*

COURTESY OF LOCKHEED MARTIN FEDERAL SYSTEMS

tion presented would not reveal any military secrets) began to emerge from behind locked doors in Buffalo, the power of gravity gradiometry became clear.

Our first results showed that gravity gradients measured by the navy ship resembled those predicted from the seismic data, but later analysis showed curious differences. Although the discrepancy was subtle in the chart of overall gravity, it was stunningly obvious when we looked at the pattern produced by the gradients. Those measurements indicated that there was more mass in the region than we had predicted from the seismic survey. The gradients told us precisely where the mass was located and revealed its shape in excellent detail. The newly discovered formation was a dense unit of rock shaped somewhat like a hat.

After convincing ourselves that our interpretation of the gradients was correct, we sought to test our conclusion. A direct examination was out of the question because it would require millions of dollars to drill into the buried salt. So we contacted Bryant E. Korn, a geophysicist working for Texaco, to see whether our result agreed with his latest appraisal of the geology of the subsurface. He examined a new seismic survey that his company had just collected over this same region and, without prompting from us to focus on any one locale, identified a previously overlooked geologic feature in the same spot we had inferred from our measurements of the gravity gradient. His independent analysis also suggested that the newly discovered structure looked like a hat. This demonstration, showing that measurements of the gravity gradient could map out a buried salt body as effectively as a detailed seismic survey, made the prospect of finding oil with submarine technology appear surprisingly good.

A High-Tech Plowshare

Following what has been a general trend since the end of the cold war to commercialize technology developed for defense, the government has declassified information about military gravity gradiometers, and oil companies are now free to use this method to complement their seismic soundings. So far seven oil companies have begun working with gravity gradiometry to help investigate what may be oil reservoirs underneath the Gulf of Mexico. For example, Edward K. Biegert, a geologist at Shell, has found that by mapping gravity gradients around a salt dome, he can better determine the geologic structures below. In his earlier charts of the subsurface around one dome, the base of the salt had appeared fuzzy and poorly defined. But with the information gleaned from gravity gradients, the underside of the salt body came into sharp focus.

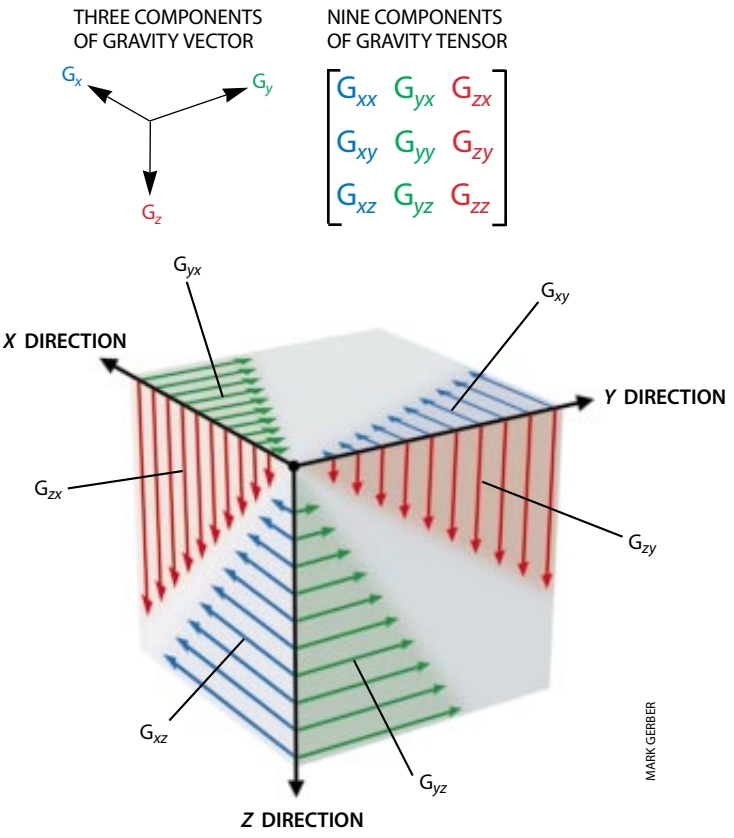
The mining industry is also keen to test whether gravity gradiometers might help discover small ore bodies buried in inaccessible or treacherous terrain. Mining companies had previously spent millions of dollars on airborne gravity meters in hopes of using them to pinpoint ore bodies from the air, but the problem of aircraft jitter had thwarted their best efforts. The measurement of gravity gradients offers a way to circumvent this difficulty: accelerations caused by

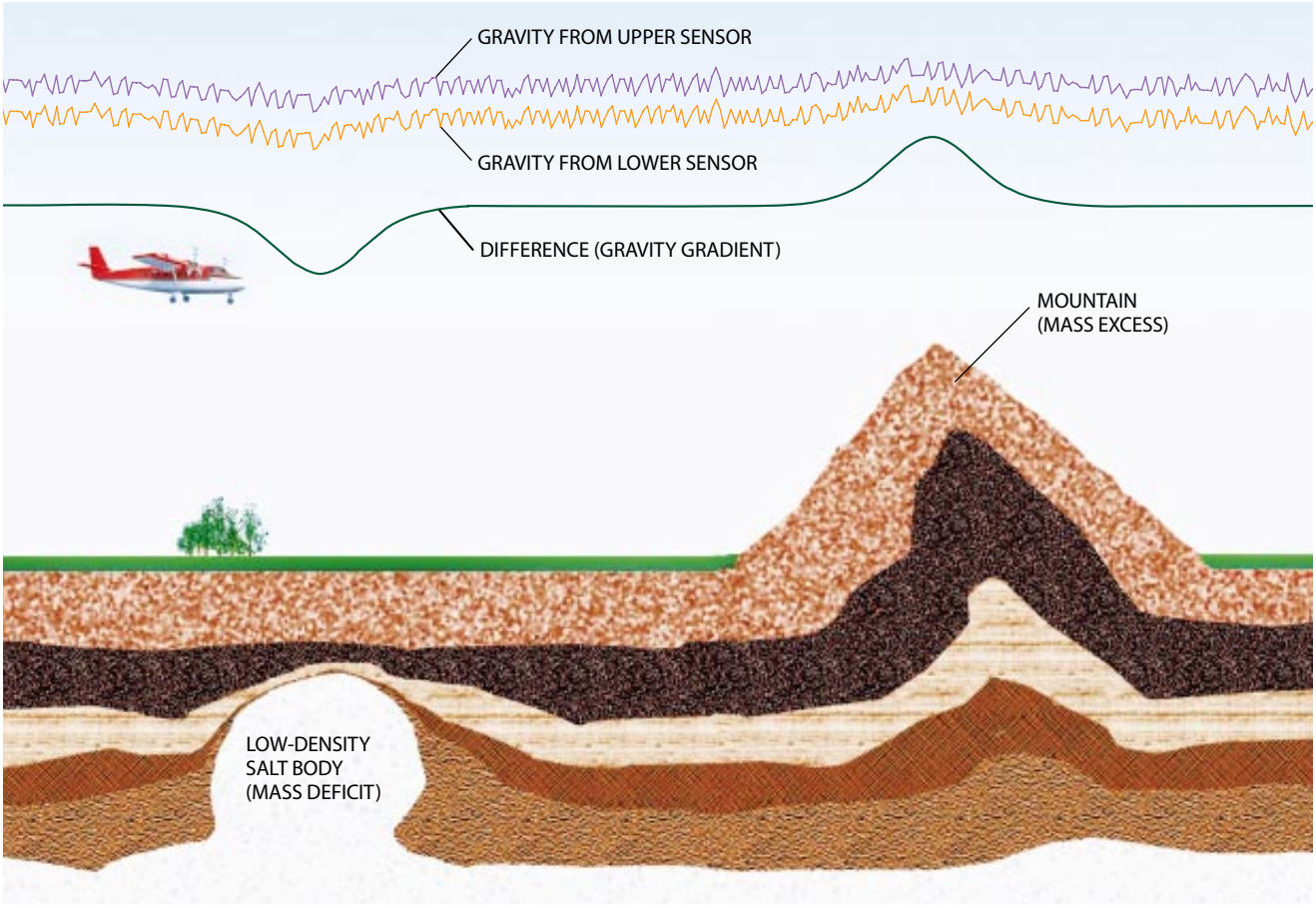
Seeking a Sharper Image

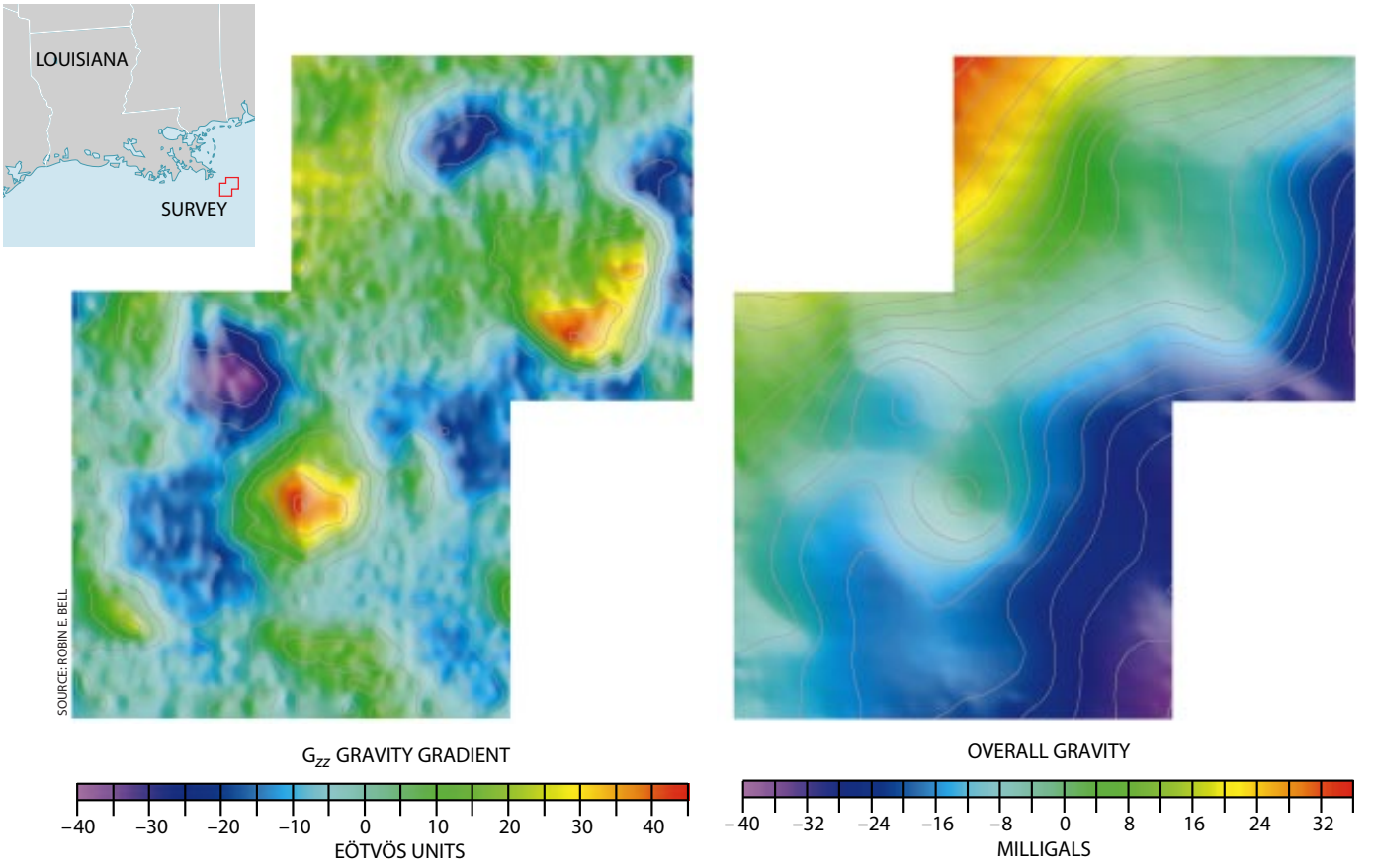
To glean more information about hidden masses buried underground, geologists can measure gravity gradients rather than just the overall force of gravity. Whereas the force of gravity (G) is described mathematically with only three elements (representing the components of gravity in the *x, y* and *z* directions), the gradient requires nine separate quantities. These nine elements form a square matrix, representing the gravity field in so-called tensor form (*right*).

The G_{xy} element of the gradient tensor, for example, is a measure of how rapidly the *x*-directed component of gravity (G_x) changes as one moves in the *y* direction. The G_{yz} element corresponds to the change of the *y*-directed component of gravity (G_y) in the *z* direction, and so forth. Because G_{xx}, G_{yy} and G_{zz} must sum to zero, and because the other elements must match (for example, G_{xy} equals G_{yx}), only five measurements are needed to determine the complete gradient tensor.

Mapping gravity gradients improves on conventional gravity surveying by providing a more detailed picture of the subsurface. For instance, flying a properly outfitted aircraft over a mountain (a mass excess) or a low-density underground salt body (a mass deficit) will show only subtle variations in the overall tug of gravity. Yet the corresponding measurements of the gravity gradient will reveal these features immediately (*below*). Erratic motion of the aircraft creates considerable "noise" in any single gravity profile, whereas measuring the difference between two sensors to obtain the gradient automatically eliminates this source of error. —*R.E.B.*







GRAVITY MAPS help petroleum-exploration geologists in their quest to hunt down buried oil and gas deposits. For example, measurements of the G_{zz} component of the gravity gradient over a part of the Gulf of Mexico provide a detailed depiction of underground salt formations (*left*). Yet conventional gravity measurements obtained for the same area reveal only broad outlines of the buried salt (*right*). This survey was made offshore from the Mississippi River delta in 1995 (*top left*).

turbulent air may mimic the overall tug of gravity, but such buffeting does not create spurious gravity gradients.

This possibility may open a new frontier of applied research. Engineers in Australia have already developed a superconducting version of Eötvös's rotating instrument suitable for carrying in a plane. Bell Geospace, a company that Anderson and I helped to found in 1994, is using the technology devised for submarines to build a gravity gradiometer that can be used in an aircraft.

These efforts may make gravity gradiometry as appealing to some geologists as it once was to submarine captains. Whereas the old methods of taking these measurements would threaten to disturb large swaths of ground as geologic field crews crisscrossed the landscape with trucks and bulldozers, gravity gradiometry from an aircraft does not harm the land surveyed in any way. So just as the submarine *Red October* was supposed to have navigated undetectably with a gravity gradiometer, geologists may soon have a new tool to help them search for scarce resources without leaving environmental disturbance in their wake. SA

The Author

ROBIN E. BELL initially became interested in gravity in 1980, after sailing in a homebuilt boat from Middlebury College in Vermont to her first job at the U.S. Geologic Survey in Woods Hole, Mass. There she made gravity measurements from ships off the eastern coast of the U.S. for several years before moving to Lamont-Doherty Earth Observatory of Columbia University to pursue a Ph.D. degree. For her doctoral thesis, which she completed in 1989, Bell used gravity observations to examine the submerged edges of continents. Currently she works as a research scientist at Lamont-Doherty and as the co-director of the support office for aerogeophysical research, a research facility based in Austin, Tex. Among other topics, she has studied the collapse of the West Antarctic ice sheet and the use of gravity to map geologic structures containing oil and gas. Bell has traveled to all seven continents and has served as chief or co-chief scientist on eight research expeditions. She still sails, though not in her first boat, which has lately become her kids' clubhouse.

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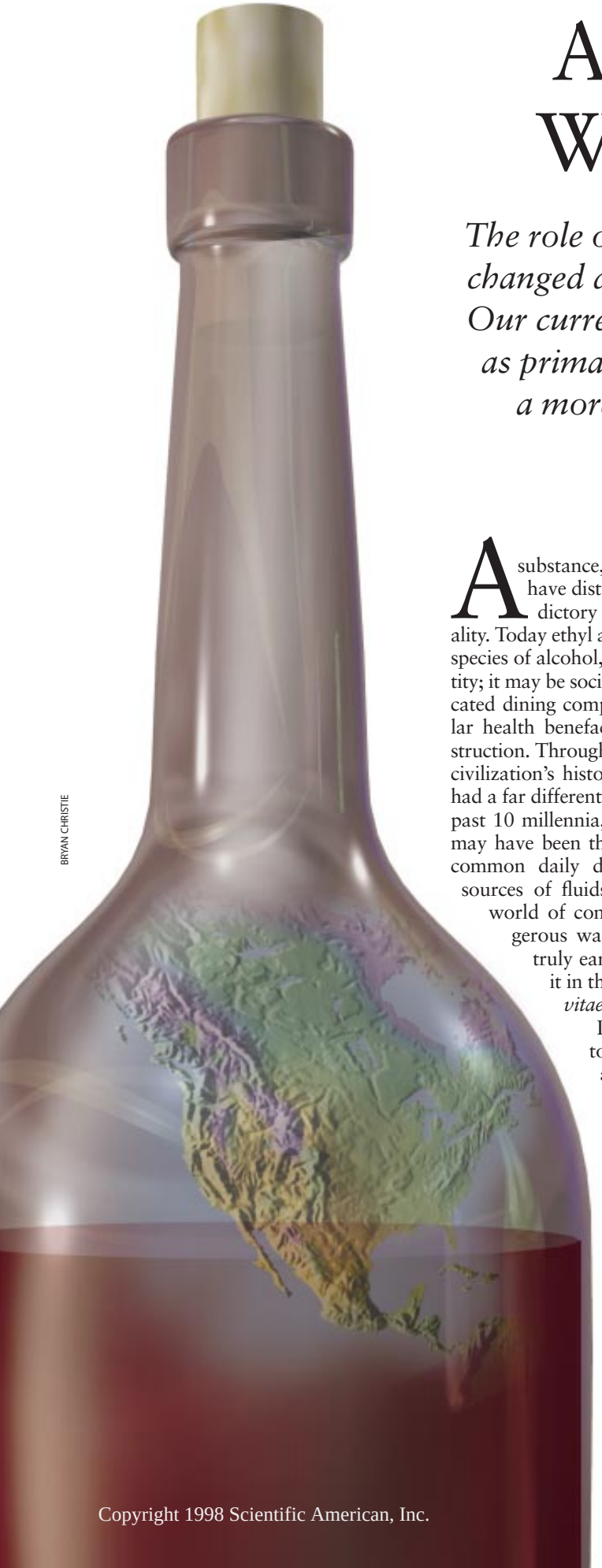


BRYAN CHRISTIE

Alcohol in the Western World

The role of alcohol in Western civilization has changed dramatically during this millennium. Our current medical interpretation of alcohol as primarily an agent of disease comes after a more complex historical relationship

by Bert L. Vallee

A substance, like a person, may have distinct and even contradictory aspects to its personality. Today ethyl alcohol, the drinkable species of alcohol, is a multifaceted entity; it may be social lubricant, sophisticated dining companion, cardiovascular health benefactor or agent of destruction. Throughout most of Western civilization's history, however, alcohol had a far different role. For most of the past 10 millennia, alcoholic beverages may have been the most popular and common daily drinks, indispensable sources of fluids and calories. In a world of contaminated and dangerous water supplies, alcohol truly earned the title granted it in the Middle Ages: *aqua vitae*, the "water of life."

Potent evidence exists to open a window into a societal relationship with alcohol that is simply unimaginable today. Consider this statement, issued in 1777 by Prussia's Frederick the Great, whose economic strategy was threatened by importation of coffee: "It is disgusting to notice the increase in the quantity of coffee used by my subjects, and the amount of money that goes out of the country as a consequence. Everybody is using coffee; this must be prevented. His Majesty was brought up on beer, and so were both his ancestors and officers. Many battles have been fought and won by soldiers nourished on beer, and the King does not believe that coffee-drinking soldiers can be relied upon to endure hardships in case of another war."

Surely a modern leader who urged alcohol consumption over coffee, especially by the military, would have his or her mental competence questioned. But only an eyeblink ago in historical time, a powerful head of government could describe beer in terms that make it sound like mother's milk. And indeed, that nurturing role may be the one alcohol played from the infancy of the West to the advent of safe water supplies for the masses only within the past century.

Natural processes have no doubt produced foodstuffs containing alcohol for millions of years. Yeast, in metabolizing sugar to obtain energy, creates

WESTERN CIVILIZATION has wine and beer to thank for nourishment and hydration during most of the past 10,000 years. Before the very recent availability of clean, pure water, alcoholic beverages may have been the only safe liquids to drink.

ethyl alcohol as a by-product of its efforts. Occasionally animals accidentally consume alcohol that came into being as fruit "spoiled" in the natural process of fermentation; inebriated birds and mammals have been reported. Humans have a gene for the enzyme alcohol dehydrogenase; the presence of this gene at least forces the conjecture that over evolutionary time animals have encountered alcohol enough to have evolved a way to metabolize it. Ingestion of alcohol, however, was unintentional or haphazard for humans until some 10,000 years ago.

About that time, some Late Stone Age gourmand probably tasted the contents of a jar of honey that had been left unattended longer than usual. Natural fermentation had been given the opportunity to occur, and the taster, finding the effects of mild alcohol ingestion provocative, probably replicated the natural experiment. Comrades and students of this first oenologist then codified the method for creating such mead or wines from honey or dates or sap. The technique was fairly simple: leave the sweet substance alone to ferment.

Beer, which relies on large amounts of starchy grain, would wait until the origin and development of agriculture. The fertile river deltas of Egypt and Mesopotamia produced huge crops of wheat and barley; the diets of peasants, laborers and soldiers of these ancient civilizations were cereal-based. It might be viewed as a historical inevitability that fermented grain would be discovered. As in the instance of wine, natural experiments probably produced alcoholic substances that aroused the interest of those who sampled the results. Before the third millennium B.C., Egyptians and Babylonians were drinking beers made from barley and wheat.

Wine, too, would get a boost from agriculture. Most fruit juice, even wild grape juice, is naturally too low in sugar to produce wine, but the selection for sweeter grapes leading to the domestication of particular grape stock eventually led to viniculture. The practice of growing grape strains suitable for wine production has been credited to people living in what is now Armenia, at about 6000 B.C., although such dating is educated guesswork at best.

The creation of agriculture led to food surpluses, which in turn led to ever larger groups of people living in close quarters, in villages or cities. These municipalities faced a problem that still vexes, namely, how to provide inhabitants with enough clean, pure water to sustain their constant need for physiological hydration. The solution, until the 19th century, was nonexistent. The water supply of any group of people rapidly became polluted with their waste products and thereby dangerous, even fatal, to drink. How many of our progenitors died attempting to quench their thirst with water can never be known. Based on current worldwide crises of dysentery and infectious disease wrought by unclean water supplies, a safe bet is that a remarkably large portion of our ancestry succumbed to tainted water.

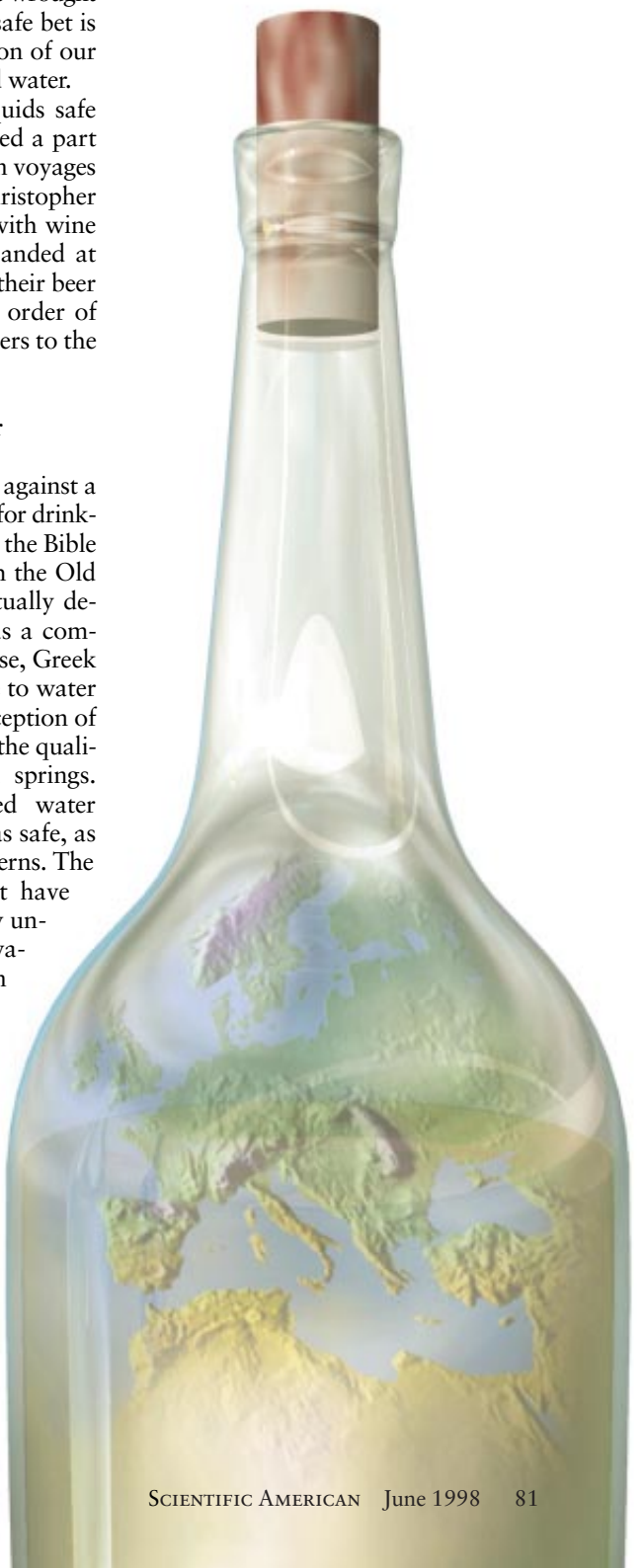
In addition, the lack of liquids safe for human consumption played a part in preventing long-range ocean voyages until relatively recently. Christopher Columbus made his voyage with wine on board, and the Pilgrims landed at Plymouth Rock only because their beer stores had run out. An early order of business was luring brewmasters to the colonies.

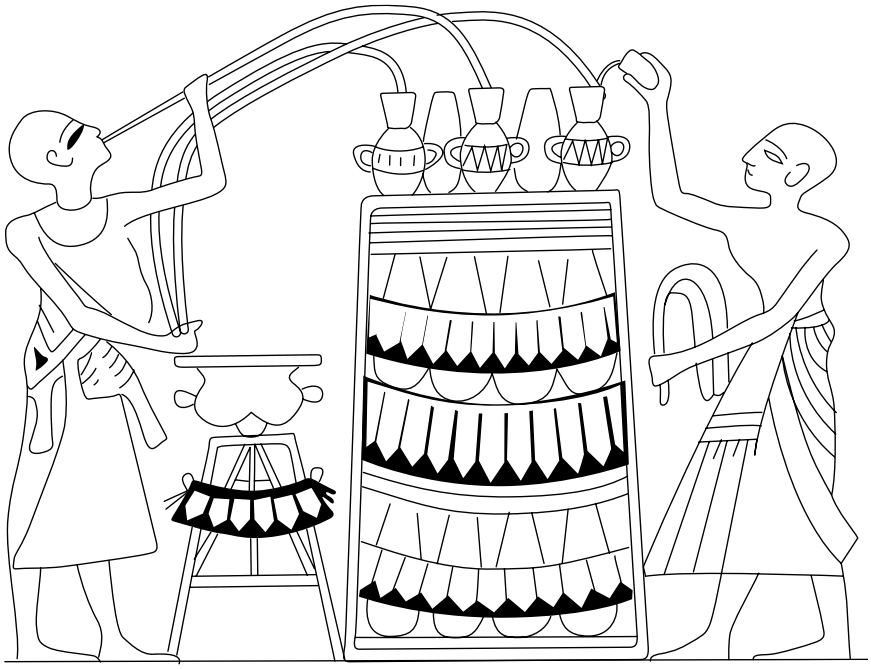
Alcohol versus Water

Negative evidence arguing against a widespread use of water for drinking can be found in perusal of the Bible and ancient Greek texts. Both the Old and New Testaments are virtually devoid of references to water as a common human beverage. Likewise, Greek writings make scant reference to water drinking, with the notable exception of positive statements regarding the quality of water from mountain springs. Hippocrates specifically cited water from springs and deep wells as safe, as was rainwater collected in cisterns. The ancients, through what must have been tragic experience, clearly understood that most of their water supply was unfit for human consumption.

In this context of contaminated water supply, ethyl alcohol may indeed have been mother's milk to a nascent Western civilization. Beer and wine were free of pathogens. And the antiseptic power of alcohol, as well as the natural acidity of wine and beer, killed many pathogens when the alcoholic drinks were diluted with the sullied water supply. Dating from the taming and conscious application of the fermentation process, people of all ages in the West have therefore consumed beer and wine, not water, as their major daily thirst quenchers.

Babylonian clay tablets more than 6,000 years old give beer recipes, complete with illustrations. The Greek *akratidzomai,* which came to mean "to breakfast," literally translates as "to drink undiluted wine." Breakfast ap-





BRYAN CHRISTIE; SOURCE: *Food: The Gift of Osiris, Vol. 2*, Academic Press, 1977

EGYPTIAN PAINTINGS show alcohol as integral to the lives of the nobility. This depiction of wines being blended is from Amanemhat's Tomb, circa 1400 B.C.

parently could include wine as a bread dip, and "bread and beer" connoted basic necessity much as does today's expression "bread and butter."

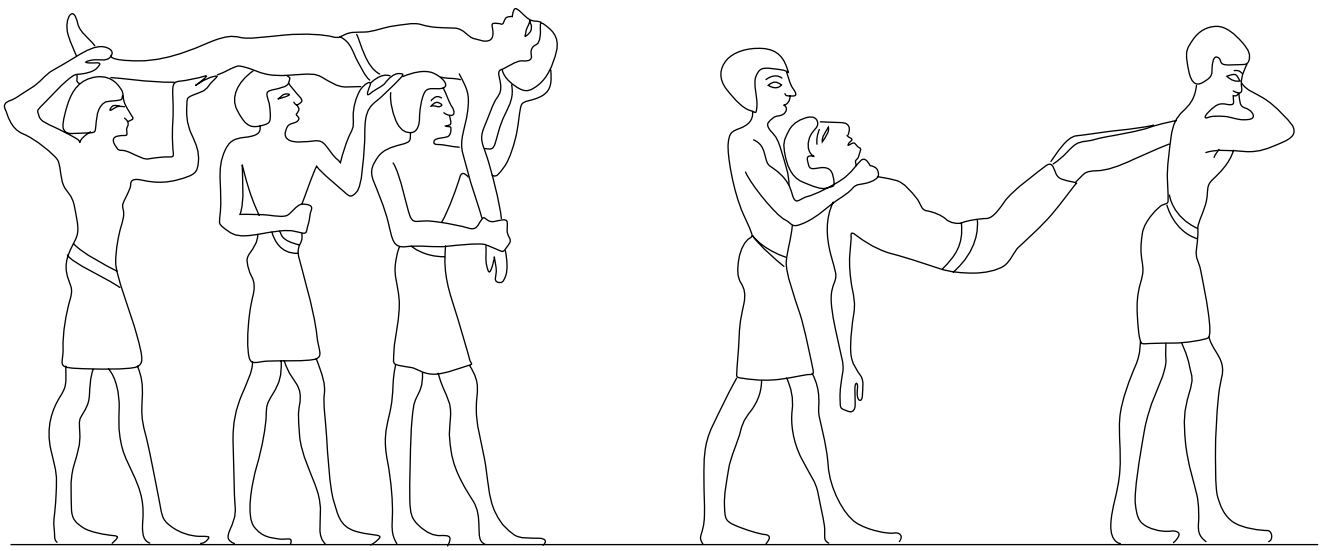
The experience in the East differed greatly. For at least the past 2,000 years, the practice of boiling water, usually for tea, has created a potable supply of nonalcoholic beverages. In addition, genetics played an important role in making Asia avoid alcohol: approximately half of all Asian people lack an enzyme necessary for complete alcohol metabolism, making the experience of drinking quite unpleasant. Thus, beer and wine took their place as staples only in Western societies and remained there until the end of the last century.

The traditional production of beer and wine by fermentation of cereals and grapes or other fruits produced beverages with low alcohol content compared with those familiar to present-day consumers. The beverages also contained large amounts of acetic acid and other organic acids created during fermentation. Most wines of ancient times probably would turn a modern oenophile's nose; those old-style wines in new bottles would more closely resemble today's vinegar, with some hints of cider, than a prizewinning merlot.

As the alcohol content of daily staple drinks was low, consumers focused on issues of taste, thirst quenching, hunger satisfaction and storage rather than on intoxication. Nevertheless, the "side effects" of this constant, low-level intake must have been almost universal. Indeed, throughout Western history the normal state of mind may have been one of inebriation.

The caloric value of nonperishable alcoholic beverages may also have played a significant role in meeting the daily energy requirements of societies that might have faced food shortages. In addition, they provided essential micronutrients, such as vitamins and minerals.

Alcohol also served to distract from the fatigue and numbing boredom of daily life in most cultures, while alleviating pain for which remedies were nonexistent. Today people have a plethora of handy choices against common aches and pain. But until this century, the only analgesic generally available in the West was alcohol. From the Book of Proverbs comes this prescription: "Give strong drink unto him that is ready to perish, and wine unto them that be of heavy hearts. Let him drink, and forget his poverty, and remember



BRYAN CHRISTIE; SOURCE: *Food: The Gift of Osiris, Vol. 2*, Academic Press, 1977

INEBRIATED REVELERS have accompanied the presence of alcoholic beverages for millennia. This painting from Khety's Tomb, circa 2100 B.C., shows guests being carried away from a banquet after too much wine. Although drinking to excess was, and is, an unsafe practice, drinking any quantity of water 4,100 years ago was probably a much riskier undertaking.

his misery no more." A Sumerian cuneiform tablet of a pharmacopoeia dated to about 2100 B.C. is generally cited as the oldest preserved record of medicinal alcohol, although Egyptian papyri may have preceded the tablet. Hippocrates' therapeutic system featured wines as remedies for almost all acute or chronic ailments known in his time, and the Alexandrian School of Medicine supported the medical use of alcohol.

Religion and Moderation

The beverages of ancient societies may have been far lower in alcohol than their current versions, but people of the time were aware of the potentially deleterious behavioral effects of drinking. The call for temperance began quite early in Hebrew, Greek and Roman cultures and was reiterated throughout history. The Old Testament frequently disapproves of drunkenness, and the prophet Ezra and his successors integrated wine into everyday Hebrew ritual, perhaps partly to moderate undisciplined drinking custom, thus creating a religiously inspired and controlled form of prohibition.

In the New Testament, Jesus obviously sanctioned alcohol consumption, resorting to miracle in the transformation of water to wine, an act that may acknowledge the goodness of alcohol versus the polluted nature of water. His followers concentrated on extending measures to balance the use and abuse of wine but never supported total prohibition. Saint Paul and other fathers of early Christianity carried on such moderating attitudes. Rather than castigating wine for its effects on sobriety, they considered it a gift from God, both for its medicinal qualities and the tranquilizing characteristics that offered relief from pain and the anxiety of daily life.

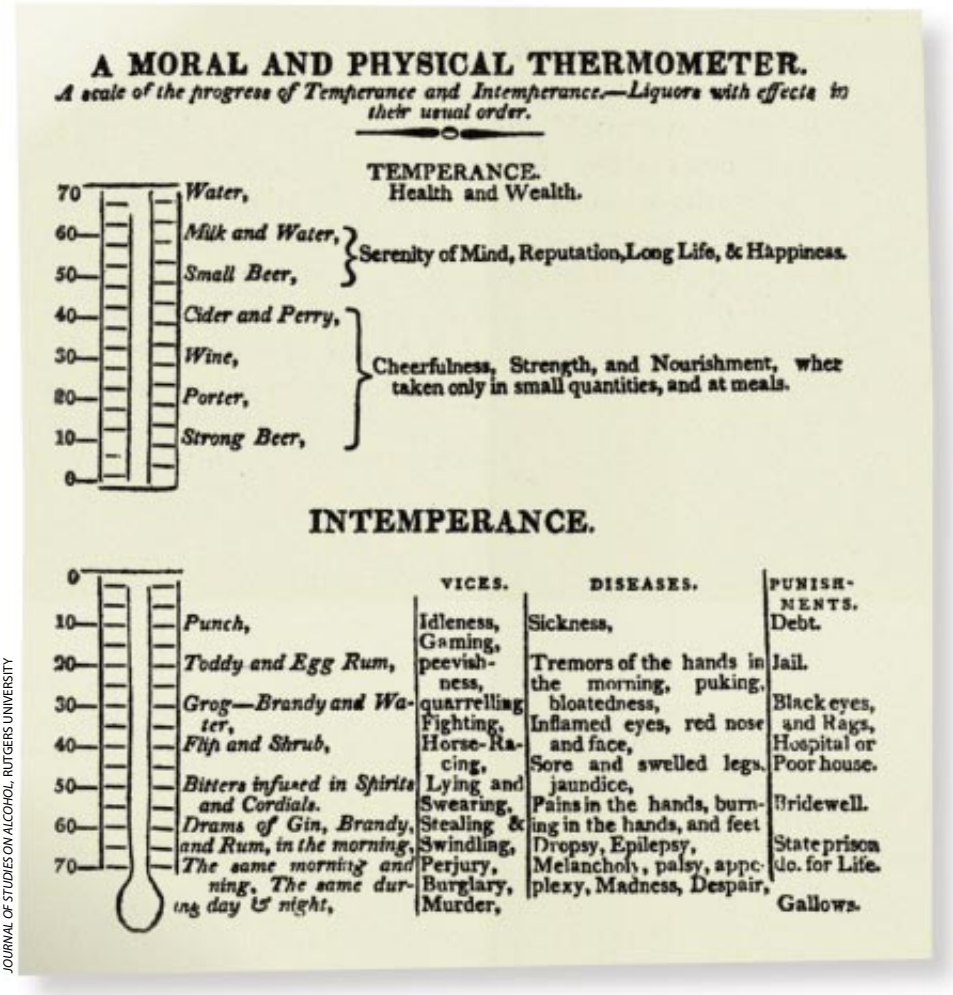
Traditionally, beer has been the drink of the common folk, whereas wine was reserved for the more affluent. Grape wine, however, became available to the average Roman after a century of vineyard expansion that ended in about 30 B.C., a boom driven by greater profits for wine grapes compared with grain. Ultimately, the increased supply drove prices down, and the common Roman could partake in wine that was virtually free. Roman viniculture declined with the empire and was inherited by the Catholic Church and its monasteries, the only institutions with sufficient resources to maintain production.

For nearly 1,300 years the Church operated the biggest and best vineyards, to considerable profit. Throughout the Middle Ages, grain remained the basic food of peasants and beer their normal beverage, along with mead and homemade wines or ciders. The few critics of alcohol consumption were stymied by the continuing simple fact of the lack of safe alternatives. Hence, despite transitions in political systems, religions and ways of life, the West's use of and opinion toward beer and wine remained remarkably unchanged. But a technological development would alter the relationship between alcohol and humanity.

After perhaps 9,000 years of experience drinking relatively low alcohol mead, beer and wine, the West was faced with alcohol in a highly concentrated form, thanks to distillation. Developed in about A.D. 700 by Arab alchemists (for whom *al kohl* signified any material's basic essence), distillation brought about the first significant change in the mode and magnitude of human alcohol consumption since the beginning of Western civilization. Although yeasts produce alcohol, they can tolerate concentrations of only about 16

STEVE BORACK (*photograph of 1512 edition*); F. A. COUNTWAY LIBRARY OF MEDICINE

DISTILLATION created alcoholic drinks of unprecedented potency. This distillation apparatus appeared in Hieronymus Brunschwig's *Liber de arte distillandi,* the first book published on the subject, in A.D. 1500. The book featured these claims for distilled alcohol: "It causes a good colour in a person. It heals baldness … kills lice and fleas…. It gives also courage in a person, and causes him to have a good memory."



JOURNAL OF STUDIES ON ALCOHOL, RUTGERS UNIVERSITY

THERMOMETER ANALOGY was an attempt by physician and political figure Benjamin Rush to illustrate the effects of alcohol. Even after realizing that alcohol abuse was a disease, Rush did allow for the benefits of moderate drinking, seen in the "Temperance" section of his chart.

percent. Fermented beverages therefore had a natural maximum proof. Distillation circumvents nature's limit by taking advantage of alcohol's 78 degree Celsius (172 degree Fahrenheit) boiling point, compared with 100 degrees C for water. Boiling a water-alcohol mixture puts more of the mix's volatile alcohol than its water in the vapor. Condensing that vapor yields liquid with a much higher alcohol level than that of the starting liquid.

The Arab method—the custom of abstinence had not yet been adopted by Islam—spread to Europe, and distillation of wine to produce spirits commenced on the Continent in about A.D. 1100. The venue was the medical school at Salerno, Italy, an important center for the transfer of medical and chemical theory and methods from Asia Minor to the West. Joining the traditional alcoholic drinks of beer and wine, which had low alcohol concentration and positive nutritional benefit, were beverages with sufficient alcohol levels to cause the widespread problems still with us today. The era of distilled spirits had begun.

Knowledge of distillation gradually spread from Italy to northern Europe; the Alsatian physician Hieronymus Brunschwig described the process in 1500 in *Liber de arte distillandi,* the first printed book on distillation. By the time Brunschwig was a best-selling author, distilled alcohol had earned its split personality as nourishing food, beneficent medicine and harmful drug. The widespread drinking of spirits followed closely on the heels of the 14th century's bouts with plague, notably the Black Death of 1347–1351. Though completely ineffective as a cure for plague, alcohol did make the victim who drank it at least feel more robust. No other known agent could accomplish even that much. The medieval physician's optimism related to spirits may be attributed to this ability to alleviate pain and enhance mood, effects that must have seemed quite remarkable during a medical crisis that saw perhaps two thirds of Europe's population culled in a single generation.

Economic recovery following the subsidence of the plague throughout Europe generated new standards of luxury and increased urbanization. This age witnessed unprecedented ostentation, gluttony, self-indulgence and inebriation. Europe, apparently relieved to have survived the pestilence of the 14th century, went on what might be described as a continentwide bender. Despite the obvious negative effects of drunkenness, and despite attempts by authorities to curtail drinking, the practice continued until the beginning of the 17th century, when nonalcoholic beverages made with boiled water became popular. Coffee, tea and cocoa thus began to break alcohol's monopoly on safety.

In the 18th century a growing religious antagonism toward alcohol, fueled largely by Quakers and Methodists and mostly in Great Britain, still lacked real effect or popular support. After all, the Thames River of the time was as dangerous a source of drinking water as the polluted streams of ancient cultures. Dysentery, cholera and typhoid, all using filthy water as a vehicle, were major killers and would remain so in the West as recently as the end of the 19th century, rivaling plague in mass destruction.

Only the realization that microorganisms caused disease and the institution of filtered and treated water supplies finally made water a safe beverage in the West. Religious antialcohol sentiment and potable water would combine with one other factor to make it finally possible for a significant percentage of the public to turn away from alcohol. That other factor was the recognition of alcohol dependence as an illness.

Diseases of Alcohol

Throughout the 19th century the application of scientific principles to the practice of medicine allowed clinical symptoms to be categorized into diseases that might then be understood on a rational basis. Alcohol abuse was among the earliest medical problems to receive the attention of this approach. Two graduates of the Edinburgh College of Medicine, Thomas Trotter of Britain and Benjamin Rush of the colonies and then the U.S., made the first

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WOMEN'S AUXILIARY of the Keeley League supported Keeley's "Gold Cure," which claimed to cure alcoholism at the end of the last century. Dr. Leslie Keeley announced that gold salts effectively ended an alcoholic's cravings for drink. His talent was in fact marketing, not biochemistry. The Women's Auxiliary may have been responsible for whatever success Keeley had, as they provided a social support network for alcoholics struggling with their addiction. Keeley died in 1900, and his cure soon met its demise.

important contributions to the clinical recognition of alcoholism as a chronic, life-threatening disease. The influence of moralistic antialcohol Methodism may have driven their clinical research, but their findings were nonetheless sound.

In an 1813 essay on drunkenness, Trotter described alcohol abuse as a disease and recognized that habitual and prolonged consumption of hard liquor causes liver disease, accompanied by jaundice, wasting and mental dysfunction, evident even when the patient is sober. Rush published similar ideas in America and to greater effect, as he was a prominent member of society and a signer of the Declaration of Independence. His personal fame, behind his correct diagnosis of a societal ill, helped to create viewpoints that eventually culminated in the American Prohibition (1919–1933).

Nineteenth-century studies detailed the clinical picture and pathological basis of alcohol abuse, leading to today's appreciation of it as one of the most important health problems facing America and the rest of the world. Alcohol contributes to 100,000 deaths in this country annually, making it the third leading cause of preventable mortality in the U.S. (after smoking and conditions related to poor diet and a sedentary way of life). Although the exact number of problem drinkers is difficult to estimate accurately, America is probably home to between 14 and 20 million people whose lives are disrupted by their relationship with alcohol.

The overall alcohol problem is far broader. Perhaps 40 percent of Americans have been intimately exposed to the effects of alcohol abuse through a family member. And every year some 12,000 children of drinking mothers are robbed of their potential, born with the physical signs and intellectual deficits associated with full-blown fetal alcohol syndrome; thousands more suffer lesser effects. Pharmaceutical treatments for alcoholism remain impractical and inadequate, with total abstinence still the only truly effective approach.

Society and science are at the threshold of new pharmaceutical and behavioral strategies against alcoholism, however. As with any other disease, whether of the individual or the society, a correct diagnosis is crucial to treatment. Alcoholism, in historical terms, has only just been understood and accepted as a disease; we are still coping with the historically recent arrival of concentrated alcohol. The diagnosis having been made and acknowledged, continuing research efforts can be counted on to produce new and more effective treatments based on the growing knowledge of the physiology of alcohol abuse and of addictive substances in general.

Humanity at any moment of history is inevitably caught in that time, as trapped as an insect in amber. The mores, traditions and attitudes of an era inform the individuals then living, often blinding them to the consideration of alternatives. Alcohol today is a substance primarily of relaxation, celebration and, tragically, mass destruction. To consider it as having been a primary agent for the development of an entire culture may be jolting, even offensive to some. Any good physician, however, takes a history before attempting a cure. SA

The Author

BERT L. VALLEE received his M.D. from New York University in 1943 and held positions at the Massachusetts Institute of Technology before joining the faculty of Harvard Medical School in 1945. He is currently that institution's Edgar M. Bronfman Distinguished Senior Professor. Vallee's primary research has been in zinc enzymology, a field he is credited with establishing. His work on alcohol dehydrogenase, a zinc enzyme, led to his interest in the history of alcohol. The author of more than 600 scientific publications, Vallee is a Fellow of the National Academy of Sciences and holds numerous honorary degrees and professorships.

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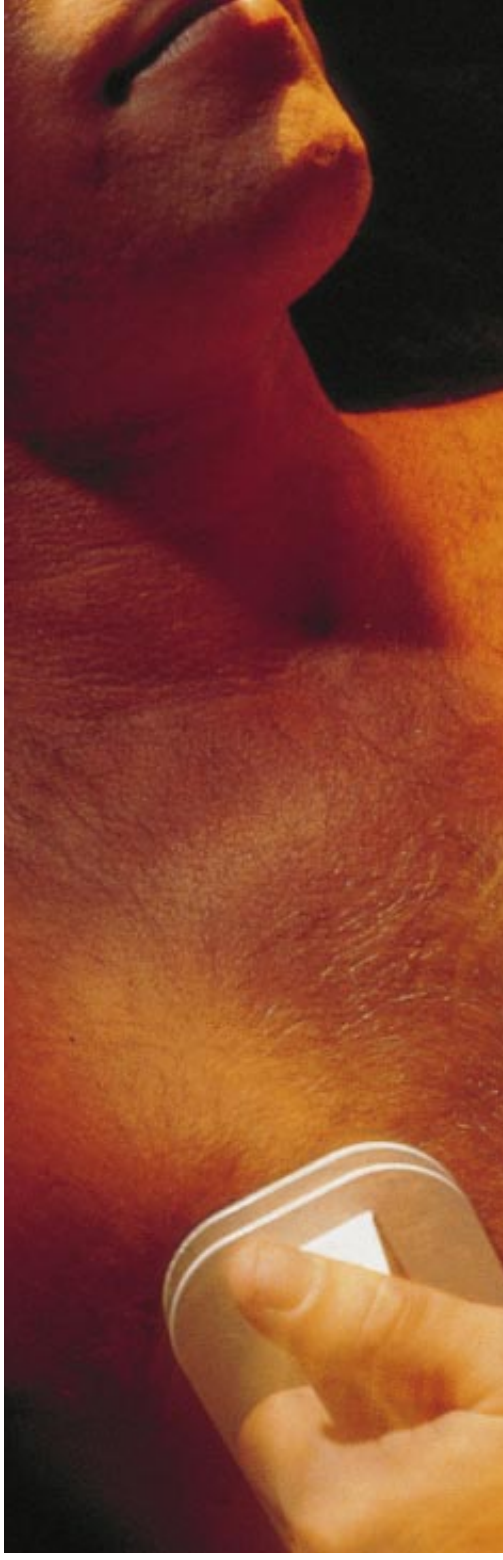
Defibrillation: The Spark of Life

In the 50 years since doctors first used electricity to restart the human heart, we have learned much about defibrillators and little about fibrillation

by Mickey S. Eisenberg



The operation had gone well. There was a brief period of fast heart rate, when the ether was given, but that was easily controlled with digitalis. The two-hour surgery had been technically demanding. The 14-year-old boy's congenitally deformed chest allowed respiration only 30 percent of normal. The task of the attending surgeon, Claude S. Beck, was to separate the ribs along the breastbone and repair nature's botched work. Beck relaxed as the easy part began. But as the 15-inch wound was being closed, triumph abruptly turned to crisis: the boy's heart stopped. Beck grabbed a scalpel, sliced through his sutures, enveloped the heart in his hand and rhythmically squeezed. He could feel the heart's ineffective quivering and knew at once that it had gone into the fatal rhythm called ventricular fibrillation. In 1947 no one survived this rhythm disturbance, but that did not deter Beck.

He called for epinephrine and digitalis to be administered and calmly asked for an electrocardiograph and a defibrillator, all the while continuing to massage the boy's heart. It took 35 minutes to obtain an electrocardiogram, which—wavering and totally disorganized—confirmed the distinctive appearance of ventricular fibrillation. Ten minutes later assistants wheeled in an experimental defibrillator from Beck's research lab adjoining the University Hospitals of Cleveland. Beck positioned the machine and placed its two metal paddles directly on the boy's heart. The surgical team watched the heart spasm as 1,500 volts of electricity crossed its muscle fibers. Beck held his breath and hoped.

The goal of a defibrillatory shock is to jolt the heart into a momentary standstill. With the chaotic pattern of contractions interrupted, the cardiac muscle cells have the chance to resume work in an orderly sequence again. The first shock did not work, and Beck began open-heart massage again while calling for additional medications. Twenty-five minutes passed, and Beck ordered a second shock. This time the shock blasted away the fibrillatory waves, and a normal rhythm ensued. Three hours later the boy responded appropriately to questions and went on to make a full recovery.

Beck realized the significance of this first successful human defibrillation. In the 1940s the nation was in the midst of an epidemic of coronary artery disease—an epidemic that continues today and one that remains the leading cause of death in adults. Beck knew most coronary deaths, especially from sudden cardiac arrest, were triggered by ventricular fibrillation. Ventricular fibrillation is the fatal rhythm in some 65 percent of cardiac arrests. About 3 percent of arrests are caused by ventricular tachycardia (a very fast heart rate), which usually deteriorates into fibrillation, and the remainder is the consequence of an asystolic (flat line) rhythm or a rhythm called pulseless activity (a flaccid heart unable to contract).

The exact cause of ventricular fibrillation is poorly understood. In many instances, it is triggered by a partially or completely occluded coronary artery causing an ischemic—and irritable—area of muscle in the heart. But sometimes the heart goes directly into ventricular fibrillation without an obvious cause. At the instant of fibrillation, the heart pumps no blood, so the pulse ceases and the blood pressure falls to zero. This is called clinical death, and it will turn into irreversible biological death if circulation is not restored within minutes.

Ventricular fibrillation, though it occasionally happens during surgery, most often occurs outside a hospital setting, during routine activities. Of the 350,000 sudden cardiac deaths a year in the U.S., 75 percent happen at home, striking

LIEN/NIBAUER PHOTOGRAPHY *Liaison International*

DEFIBRILLATION REMAINS the first, last and best hope for victims of ventricular fibrillation. Paddles coated with a conduction gel send a shock through the heart muscle, which, for reasons still not clearly understood, allows its internal timing mechanism to reset and return to normal.

people who are in the prime of their lives.

In 1947 Beck's only option was to reopen the chest and manually compress the heart. Cardiopulmonary resuscitation (CPR), as we know it today, would not be invented until 1960. Beck knew that manually compressing the heart only bought time—electricity was (and remains) the only means for treating ventricular fibrillation. For a decade, Beck had developed and perfected his machine, defibrillating hundreds of dogs, but he needed to demonstrate its lifesaving potential on a human. One case was all he needed. He published a report in the *Journal of the American Medical Association* and immediately proselytized physicians to recognize fibrillation and learn how to use defibrillators.

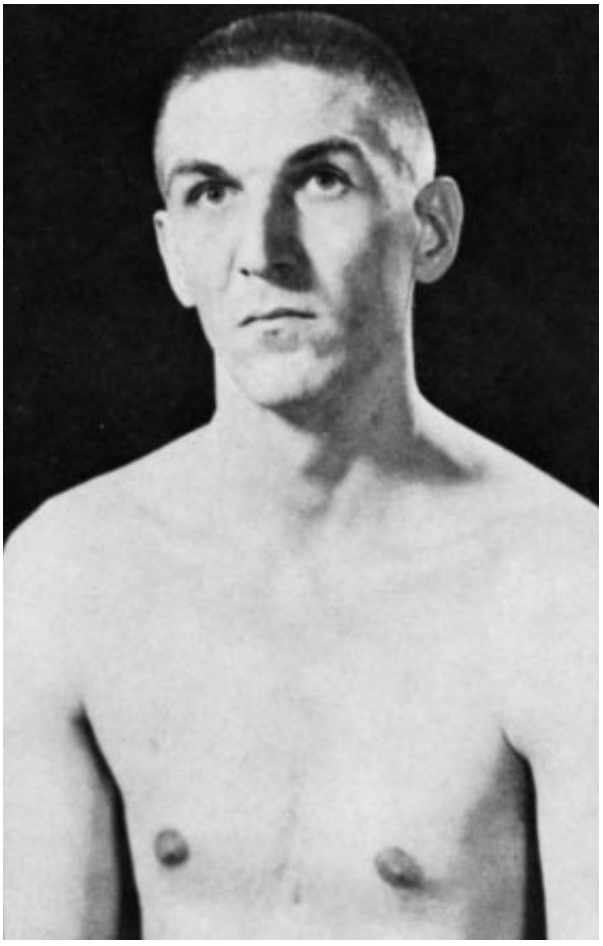
Beck envisioned being "at the threshold of an enormous potential to save life." He saw the defibrillator as the tool for dealing with, to use his expression, "hearts too good to die"—hearts that would remain undamaged if the defibrillation could occur quickly enough. His expression is apt because a heart that is successfully defibrillated usually has many years of mileage left; a heart that fibrillates is like a million-dollar piece of equipment failing because of a 20-cent fuse.

Fifty years later is a good time to ask whether Beck's vision has been achieved. Did the world embrace his invention? Has its huge potential been realized? What does the future hold?

Beck's defibrillator was a large, ponderous machine. It used alternating current directly from a wall socket and required a bulky and heavy step-up transformer. The voltage, usually 1,000 volts, was applied for a quarter or half of a second. The machine was barely portable, although wheels gave it some mobility. Its biggest drawback was the supposed need to place its metal paddles directly on the ventricles, because not enough was known about how much electricity to use to shock through the chest. But it was a start. From such humble beginnings, defibrillators have grown smaller, smarter and far more sophisticated. As the technology developed, so did the clinical applications.

Shortly after Beck's 1947 report, defibrillators were placed in operating rooms throughout the Western world. But they would remain in operating rooms and have very limited use so long as the chest had to be opened and the paddles placed directly on the heart. This problem was solved in 1956 by Paul M. Zoll of Harvard Medical School, who demonstrated that defibrillation could successfully occur across an intact chest. Now the device could move to the rest of the hospital. Defibrillators began appearing in emergency departments as well as coronary care units.

Because defibrillators were large and inherently stationary and required alternating current to operate, they were confined to hospitals. To leave the hospital, defibrillators had to become portable, and there had to be a way of bringing them to patients where they lived. The obstacles were overcome in 1960 by Bernard Lown of the Harvard School



ARIZONA MEDICINE

UPI/CORBIS-BETTMANN

FIRST HUMAN TO RECEIVE DEFIBRILLATION (***shown at left 20 years later***) **went into ventricular fibrillation while undergoing surgery in 1947 to expand his congenitally deformed chest. At that time, ventricular fibrillation was invariably fatal. But the surgeon, Claude S. Beck (*above*), was able to revive his patient using a defibrillator similar to the one shown at the top on the opposite page.**

of Public Health and K. William Edmark of the University of Washington. They demonstrated not only that defibrillators could be powered by direct current but also that these DC machines were, in fact, safer because there were fewer postshock complications such as heart blocks or other difficult-to-treat rhythm disturbances. Also, direct current allowed relatively portable batteries to power the device and used capacitors for collecting and concentrating the charge. Although these first-generation battery-powered devices weighed 35 pounds, portable defibrillators could at last enter the community. Now all that was needed was a means to transport them to the patient.

At Royal Victoria Hospital in Belfast, Northern Ireland, two cardiologists saw the mounting toll from coronary artery disease—an almost invisible carnage because it was occurring before their patients were admitted, usually within an hour of symptoms. J. Frank Pantridge and his colleague John S. Geddes reasoned that the only way to reach patients dying from ventricular fibrillation was to go after them directly in their homes. Resurrecting an old ambulance, they established the world's first mobile intensive care unit in 1966. The unit was staffed with a doctor and nurse and equipped with a jerry-rigged defibrillator powered by two 12-volt car batteries.

Success came slowly, but within 18 months they had accumulated enough experience to publish their findings in the international medical journal *Lancet*. Of groundbreaking importance: information on 10 patients with cardiac arrest. All had ventricular fibrillation, and all were resuscitated and admitted to the hospital. Five were subsequently discharged alive.

An Evolving Technology

The concept spread rapidly. By the late 1960s programs to implement mobile intensive care units were established in several cities. The U.S. version replaced the doctor and nurse with specially trained individuals called paramedics. For the first time in history, people dying suddenly in the community were being brought back to life. Paramedic programs delivering advanced emergency care are now found in virtually every urban and suburban area of the U.S. and in many Western countries.

But paramedics and ambulances are not enough. When a person goes into defibrillation, every minute counts, and waiting for an ambulance to arrive eats away at precious time. Clearly, it would be beneficial to have defibrillators in the hands of a still wider group of laypeople or emergency service personnel.

Up into the 1970s defibrillators were manually operated. The operator—doctor, nurse or paramedic—had to interpret the cardiac rhythm on a small oscilloscope and then, if ventricular fibrillation was present, apply the paddles and shock the patient. To bring defibrillators to a larger audience, the device would have to become easier to use. The next technological evolution provided just that. In the 1980s the defibrillator grew "brains." Computer algorithms, able to detect ventricular fibrillation, were incorporated into standard defibrillators. Such "smart" defibrillators, known as automatic external defibrillators, interpret the patient's rhythm and will deliver a shock only if ventricular

fibrillation is present. Using voice-chip technology, automatic external defibrillators, some weighing as little as four pounds, "talk" to the operator and coach him or her through the procedure. Smart defibrillators spread the technology to another level of emergency care, namely, the hundreds of thousands of medical technicians who staff basic ambulance services.

Each new technological breakthrough has seen a corresponding increase in the number of defibrillators and the situations in which they are used. Today there are more than 250,000 defibrillators in the U.S. Some 110,000 are deployed outside hospitals, and perhaps half of those are automatic external defibrillators.

The American Heart Association launched a public-access defibrillation effort in 1994, advocating automatic external defibrillators in the hands of first responders and other public personnel (such as police and security guards). Clearly, we are on the cusp of another surge in defibrillator availability. There is no question that efforts to place more defibrillators in the community and into the hands of public personnel will be useful. But the payoff will be small because most cardiac arrests do not happen in stadiums or shopping malls; they happen in bedrooms and living rooms. In Seattle and King County, Washington, for instance, only 15 percent of cardiac arrests occur in public locations.

The promise for defibrillators will most probably be realized only when they become consumer products and can be purchased at the neighborhood pharmacy. For this to happen, the price must be made affordable, and the Food and Drug Administration would have to allow companies to market defibrillators to consumers. Currently automatic external defibrillators are prescription devices that cost $3,000, although it is likely that mass production (on the scale of one million units a year) could lower the selling price to $350. There is nothing inherently dangerous about an automatic home defibrillator, because the device shocks only for ventricular fibrillation and will not allow a shock to be delivered if the condition is not present. One day consumer automatic external defibrillators may be as common as fire extinguishers in the home.

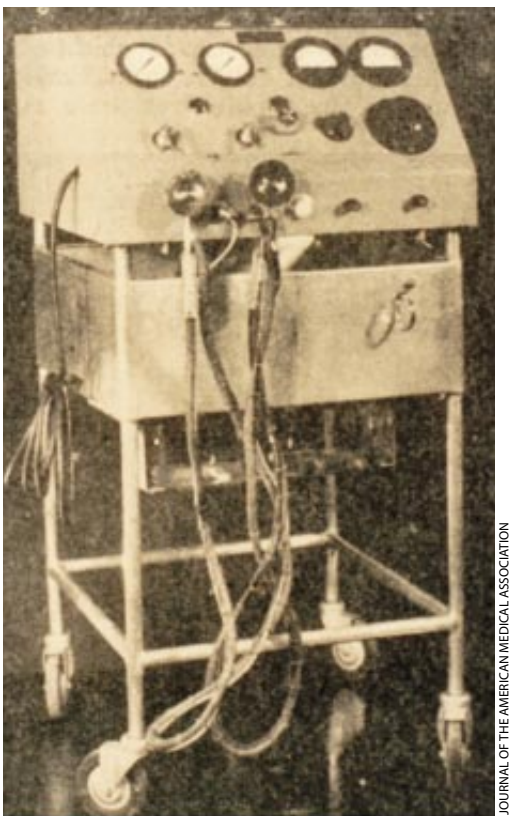
Small Enough to Implant

The concept of building smaller, more intelligent defibrillators and moving them from the operating room to people's living rooms can be logically carried even further. Why not place the defibrillator in the person's chest? This is exactly what Michel Mirowski of Sinai Hospital of Baltimore did after a tragic personal experience in 1966. His mentor and friend was hospitalized for recurrent heart arrhythmias unresponsive to medications and required constant monitoring and repeated defibrillatory shocks in the coronary care unit. The friend chose not to live his life in the hospital and, against advice, checked himself out. He died days later. Although there was nothing anyone could do then, Mirowski vowed to solve the problem.

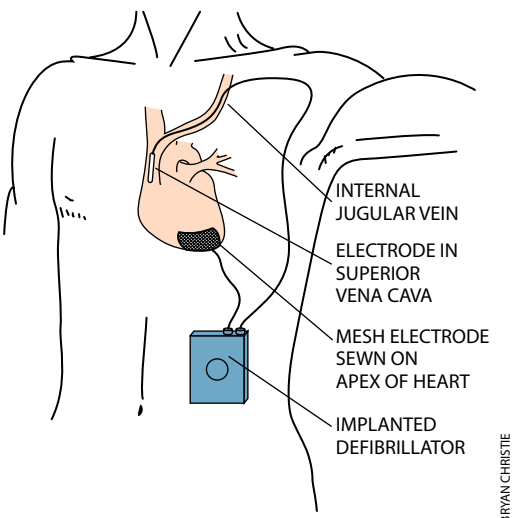
Working in a basement laboratory at Sinai and without research funding, Mirowski and his colleague Morton M. Mower set out to miniaturize defibrillators and implant them in the chests of high-risk patients. After prototypes were tested on dogs, the first human implantation occurred in 1980 at Johns Hopkins Hospital. It was a success. Another five years of clinical testing passed before the device received FDA approval.

The first marketable implantable defibrillators were the size of a Walkman and weighed 12 ounces. Because of their size and weight, they had to be placed in a skin pocket in the abdomen with wires and electrodes running to the heart. Open-heart surgery was required because the electrodes had to be sewn directly onto the heart's ventricle. The device constantly monitored the heart's rhythm, and if it detected fibrillation, it charged its capacitors and its battery delivered a shock of 34 joules. The lower energy, compared with 200 or 300 joules for standard external defibrillation, was sufficient because it was applied directly to the heart and did not have to travel through the chest.

Implanting a defibrillator was major surgery, to be undertaken only in the most dire circumstances. But it was a start, and it demonstrated that lives could be saved. From 1985 until today, several generations of implantable cardioverter defibrillators have been developed. Each generation has resulted in a smaller and more sophisticated device. The latest version weighs only three

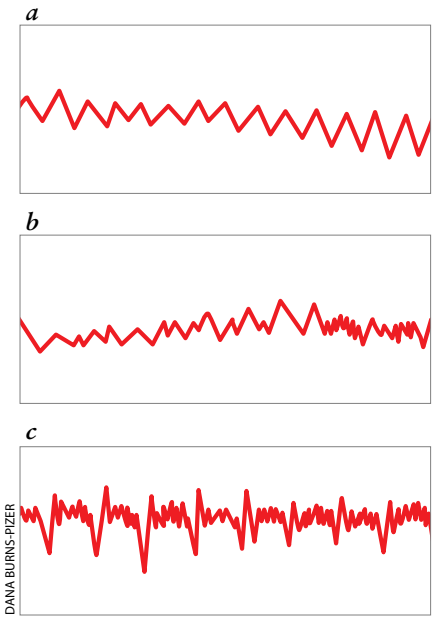


JOURNAL OF THE AMERICAN MEDICAL ASSOCIATION



BRYAN CHRISTIE

FIRST DEFIBRILLATOR to be used on a human looked like the one shown here (*top*). Consisting mainly of a step-up transformer, monitoring instruments and two suction-cup devices that were placed directly on the heart, the defibrillator measured roughly 18 inches by 18 inches by 24 inches. It was powered by alternating current from a wall socket. The earliest implantable defibrillators (*right*) were relatively bulky affairs of 12 ounces implanted in the abdomen, with electrodes running directly to the apex of the heart and the superior vena cava.



ACTUAL CARDIAC RHYTHM of the first person to be defibrillated reveals the wavering, disorganized rhythm of ventricular fibrillation (*a* and *b*). The final panel (*c*) shows the more normal rhythm following a defibrillatory shock.

ounces, small enough to be placed under the skin in the upper chest, similar to a pacemaker. The titanium can housing the device serves as one of the electrodes, and a single wire, threaded through a large vein directly into the heart, acts as the other. Thus, open-heart surgery is not needed, and placement is a simple, one-hour outpatient procedure. The most recent designs have a battery life of eight years. They can also store hours of sensing and electrocardiographic information that can then be downloaded through the skin, enabling the cardiologist to diagnose and troubleshoot ongoing problems. Such technology does not come cheap: these defibrillators cost $30,000, plus another $15,000 to $20,000 for implantation. In the U.S., more that 100,000 such devices have been implanted to date. At a projected rate of 30,000 a year, it is a $1-billion-a-year industry.

The Definitive Solution

Claude Beck would be amazed if he could see today's defibrillators. Smart defibrillators and three-ounce devices implanted in patients are advances inconceivable in 1947. But have these 50 years of development achieved defibrillation's promise for saving lives? The answer is a resounding no. Despite hundreds of emergency medical service programs and thousands of paramedics trained in defibrillation, only a tiny proportion of cardiac arrest victims are saved every year in the U.S. The small number (at best a few thousand) is not higher because defibrillation occurs too late. A strategy based on rushing defibrillators to collapsed individuals is destined to achieve minimal success.

The sad reality is that we do not understand the cause of fibrillation and cannot predict it, and therefore we cannot put defibrillators in the hands, and chests, of everyone who might benefit from them. (Twenty percent of ventricular fibrillation cases occur in people who have not been diagnosed with heart disease.) We can only speculate that its triggers include ischemia (insufficient blood to part of the heart muscle, making it irritable); electrolyte abnormalities; autonomic imbalances, caused by abnormal surges in hormones such as adrenaline; drugs; and inherited disorders.

In fact, we know very little about why defibrillation works in the first place. It is believed that the electrical shock simultaneously depolarizes every muscle fiber in the heart, allowing its internal timing mechanism to reset and return to normal. In a way, it is like rebooting a computer that has suddenly and mysteriously seized. Not only can we not predict it, but we also cannot prevent it. Whether the future brings widespread availability of consumer automatic external defibrillators or liberalized indications for implantable devices, it is important to realize that the only definitive solution to the problem of ventricular fibrillation lies in prevention.

For now, rapid defibrillation offers the only hope for victims of sudden cardiac death. Defibrillators seem to epitomize medical high technology and offer thousands of patients the promise of extended life. Yet within that promise lies a paradox first described by essayist and physician Lewis Thomas. What we think of as high technology—in this case, defibrillation—is really low technology, because we have only a rudimentary understanding of the disease.

The highest level of medical technology is the least expensive and comes about only with a good understanding of the disease—vaccination, for example. The lowest level is very expensive and results from treatment of the ravages of the disease rather than its prevention. We can miniaturize defibrillators and place them in people's chests. But we do not yet know what causes the heart suddenly to fibrillate. And we cannot yet define the harbingers of ventricular fibrillation.

Fifty years have witnessed astounding technological and clinical progress in defibrillation. Yet the problem of ventricular fibrillation still looms as the leading cause of death in adults. I would have to say Beck's vision is only 50 percent achieved. When home defibrillators are approved, perhaps the enormous potential of defibrillation will finally be attained. But this will be a false victory. The true victory will occur when we understand ventricular fibrillation and can prevent its occurrence. Wouldn't it be nice one day to view a defibrillator as an outdated piece of low technology? SA

The Author

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Further Reading

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If You Don't Have a Defibrillator

by Carl E. Bartecchi

Cardiopulmonary resuscitation, commonly known as CPR, can save the lives of victims of ventricular fibrillation and its common predecessor, ventricular tachycardia. Nationwide, however, the technique successfully salvages fewer than 5 percent of out-of-hospital cardiac arrests. The reasons are sobering. The elderly, who need it most often, are least likely to have CPR training. Bystanders are unlikely to respond because of concern for their own health in this era of AIDS, hepatitis and drug-resistant tuberculosis. Also, although cardiac arrest tends to occur in the home, most family members of cardiac patients remain unfamiliar with CPR techniques. And the hyperacute atmosphere surrounding cardiac arrest does not lend itself to the clear, methodical process taught in CPR courses.

There is an alternative to CPR that is simple and easily learned, especially by the elderly. It features maneuvers that can be performed quickly—during the four- to six-minute window of opportunity for restoring circulation and oxygenation. As with basic CPR, one should not expect these steps to be successful in a high percentage of cases. The nature of cardiac arrest itself, together with age and underlying problems, may make saving the victim impossible. Yet simply doing *something* can sometimes save a life. Chest compressions alone, for example, can keep a person alive for a few minutes until trained medical help arrives. The important lesson to remember is to do something and to do it fast.

What to Do

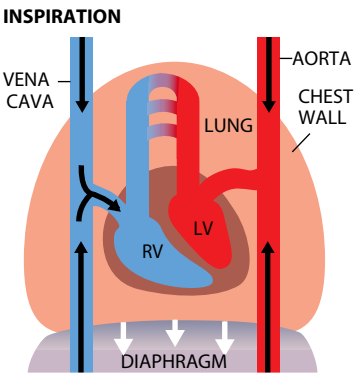
When an individual suddenly collapses, first quickly check for pulse or heartbeat. If one is present, raise the victim's legs two feet above the plane of the reclining body (to augment fluid return to the central circulation); then, call for medical assistance.

If there is no pulse, immediately suspect cardiac arrest. Check the airway for obstruction and clear it. Because most victims resuscitated from cardiac arrest have ventricular tachycardia or ventricular fibrillation, assume that is the problem and follow one of these two procedures:

Cough

If the victim is conscious and capable, he or she should be encouraged to cough vigorously once or twice. Forceful coughs have been shown to transmit a small amount of current to the heart capable of terminating these catastrophic dysrhythmias and allowing for an effective cardiac rhythm to be reestablished. This maneuver is especially suited for self-administration; a patient with known cardiac disease who suddenly feels palpitations in the chest followed by lightheadedness and the feeling of impending loss of consciousness could do little harm by bringing forth one or two vigorous coughs.

ILLUSTRATIONS BY DANA BURNS-PIZER



During the cough's inspiratory phase, the downward movement of the diaphragm facilitates the return of blood from the body to the heart's right ventricle and even oxygenates the blood flowing through the lungs at that time. During the expiratory phase, contraction of the abdominal muscles forces the diaphragm into the chest cavity, generating high pressures that are applied to the heart and its associated large blood vessels, which in turn propels blood through the open heart valves to the brain and other organs.

Regular, repeated, forceful coughs—at a rate of up to 60 per minute—can be as effective as classical CPR in providing blood flow to critical organs, thus supplementing the stricken heart. Cough CPR has proved effective for approximately 90 seconds, although isolated cases for up to five minutes have been reported. The only problem is that the patient is certain to develop fatigue. But cough CPR can buy time.

Thump

If the patient is not capable of coughing, one or two thumps to the midchest can be given with a clenched fist within no more than one minute of collapse. The thump should be applied from six to eight inches above the chest and directed at an area about two thirds of the distance down the breastbone. Should the first blow not result in a pulse, a second, stronger blow should be given immediately. The thump can also be self-administered.

It is not known how the thump procedure works, although it is suspected that the thump causes a mechanoelectrical stimulus that terminates the undesirable rhythm disturbance.

CARL E. BARTECCHI is clinical professor in the department of medicine at the University of Colorado Health Sciences Center.

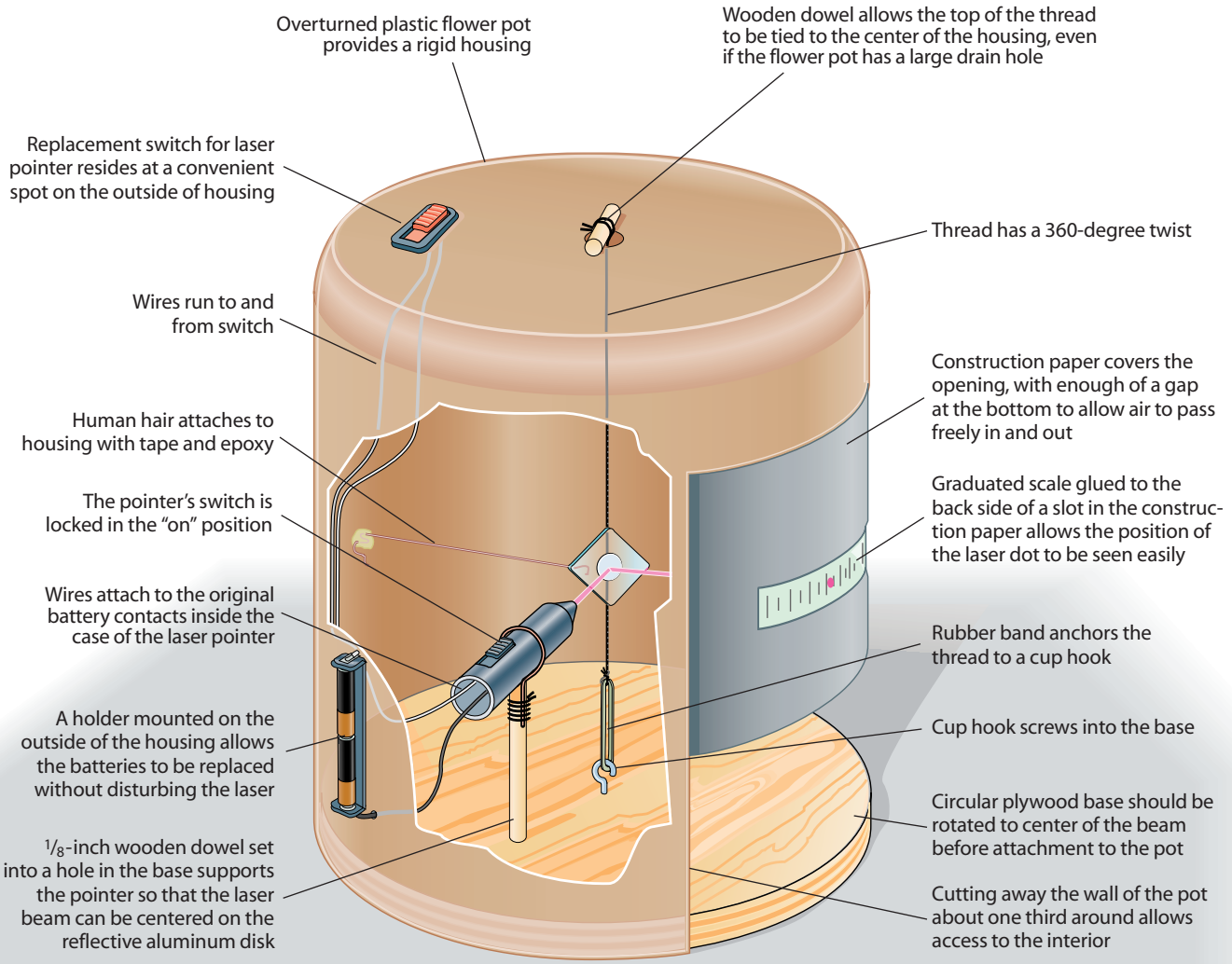
by Shawn Carlson

Waiter, There's a Hair in My Hygrometer

Depending on where you live, you may already contemplate humidity more than you care to. In the U.S., for instance, the hot summer air across the Southeast is thick and oppressive, whereas in the western deserts it is so dry that it greedily soaks up all moisture. The differences in the wildlife inhabiting these two regions shows that humidity has deeper consequences than just the daily weather. The water content in the atmosphere has shaped evolution every bit as much as the water content in the ground, which suggests many fascinating avenues for exploration by amateur scientists.

But whether your interests are in meteorology or biology, to undertake amateur investigations of humidity you'll need some means to measure it. This column describes a way to monitor relative humidity, which is the ratio of the amount of water actually present in the atmosphere to the maximum amount that it could support at the prevailing temperature and pressure.

One of the most sensitive gauges of relative humidity is, believe it or not, human hair. Hair stretches when water fills the tiny pores within it, and it shrinks as it dries (which explains the cause of at least some bad-hair days). The length of a hair thus tracks relative humidity, and it does so with impressive accuracy. You can take advantage of this phenomenon to build a humidity meter, or hygrometer, that is both sensitive and inexpensive. The one described here uses a single human hair to rotate a tiny mirror, which then reflects a shaft of laser light onto a scale. The final position of a laser beam indicates the rela-



IAN WORPOLE

tive humidity. Although this hygrometer won't work at temperatures below freezing, it is otherwise quite versatile.

To start, you'll need one human hair, preferably straight and reasonably long. Wash it thoroughly with soap and water to remove the natural oils. You will also require a housing for your instrument. This enclosure must be rigid, but it should be made from a material that is easy to cut and drill. I used a plastic pot of the kind used to hold a large houseplant.

The reflector must remain stiff yet be as lightweight as possible. A glass coverslip (the thin wafer normally placed over a specimen on a microscope slide) is ideal, except that it is not very reflective. You can remedy this situation by using aluminum foil. Rest a layer of foil on some stiff paper and punch through both sheets using a standard hole punch. Then separate a small, undamaged disk of shiny aluminum. Secure it (dull side down) to the center of the coverslip with a dab of epoxy, gently rubbing the foil smooth with a handkerchief.

Use a toothpick to draw a bead of epoxy across one diagonal on the back side of the coverslip. It helps to turn a drinking glass upside down and place the coverslip on top, with the epoxy bead facing upward. Next drape a generous length of fine thread along the line of epoxy and hang small weights from either side as the epoxy sets to pull the thread taut. Then attach the hair with a dollop of epoxy placed between the center of the coverslip and one free corner. The sensitivity of this instrument depends on exactly where you attach the hair: the closer it is to the thread, the larger the angle through which the mirror will rotate. Because some people's hair responds more to humidity than others', no one prescription will work for all hygrometers. Therefore, you will need to experiment to find the best place on the coverslip to attach the hair.

After the epoxy hardens, secure your glass reflector into the instrument housing by affixing one end of the thread to the top and the other to the bottom, using a rubber band to maintain some tension. Make sure that when you look directly at the reflector, the hair is on the back of the slide cover and left of center. That way your humidity scale will increase from left to right. Before you

attach the free end of the hair to the instrument case, you must rotate the reflector clockwise around the string once. The resulting torque should cause the reflector to pull the hair taut as the thread tries to untwist.

A laser pointer makes an ideal light source because it produces an extremely bright spot that can be readily seen, even in daylight. Such pointers are available for less than $50 from many sources, including Radio Shack and Jameco Electronics (telephone: 650-592-8097). But it is vital that you rig the pointer initially so that you never have to touch it again, because the slightest inadvertent nudge will upset the calibration of your instrument. The trick is to put a switch and batteries for the pointer on the outside of the hygrometer housing.

To mount the pointer itself, trim a wooden dowel to the appropriate length and attach the laser to one end. If your laser pointer has a flat case, epoxy it directly to the end of the dowel. If the case is round, gird it with a loop of coat-hanger wire and lash the ends to the dowel as shown in the illustration on page 92. Secure this assembly with a liberal coating of epoxy.

To make a scale, use a photocopier to transfer the markings from a fine ruler onto a sheet of paper, then snip out these graduations in a strip approximately two inches (five centimeters) wide. Glue this scale behind a long, rectangular hole in some dark-colored construction paper and attach the paper to the housing so that the laser beam illuminates the scale from the back side. If you intend to use your instrument in very moist environments, you should protect the paper parts from warping with a plastic coating. Spray plastic can be purchased from any well-stocked hardware store.

Your completed hygrometer should be easy to calibrate. First, take it into your bathroom and turn on the shower. As the humidity rises, you will see the bright spot shift to the right. (If you haven't coated the paper parts with plastic, turn off the shower as soon as your bathroom mirror is covered with a thin film of condensation so as not to overload the air with moisture.) When the air is saturated, mark the location of the dot on the scale. Hair-based hygrometers respond sluggishly to changes in humidity, so wait at least 20 minutes before marking your scale. This point represents 100 percent humidity.

You can attain almost zero humidity by placing a substance that readily absorbs moisture at the base of the hygrometer and sealing the instrument inside a transparent plastic bag. Any number of things will absorb water from the air: for example, powdered gelatin, activated charcoal and those little silica gel packets often found bundled with new purchases. Cobalt chloride, which you may be able to obtain from a chemical supplier, is the desiccant of choice, because it changes from blue to pink as it absorbs moisture. If, when the dot of light stops drifting to the left, you have plenty of blue crystals remaining in the bag, you can be confident that the air inside is at near-zero humidity. Be sure to bake whatever drying material you use at 300 degrees Fahrenheit (about 150 degrees Celsius) for at least an hour to remove any water already absorbed before you place it in the bag.

In general, the humidity scale will not be linear between your zero and 100 percent marks, so you should check several intermediate points against a well-calibrated instrument. One easy way to do so (albeit indirectly) is to put the unit outside and compare your measurements with readings from the local weather department.

Once properly calibrated, this device will allow you to perform diverse experiments. You can, for example, measure the rate of evaporation from different kinds of soil into dry air at a variety of temperatures. Or you can monitor how quickly different species of plants transpire under various conditions of light and temperature. To carry out those tests more efficiently, you may want to modify the hygrometer to produce an electronic signal, which will be easier to record than the position of the laser dot. The Society for Amateur Scientists will post suggestions for such modifications on its Web site. SA

For information about this and other projects for amateurs, visit the Forum section of the Society for Amateur Scientists at http://web2.thesphere.com/SAS/WebX.cgi on the World Wide Web. You may also write the society at 4735 Clairemont Square, Suite 179, San Diego, CA 92117, or call (619) 239-8807.

by Ian Stewart

What a Coincidence!

Some years ago a friend of mine was on his honeymoon, camping in a remote part of Ireland. He and his wife were walking along a deserted beach when in the distance they saw two people coming toward them. The other couple turned out to be my friend's boss and his new wife. Neither couple knew of the other's plans: it was a coincidence. Such a striking coincidence, in fact, that it always makes a good story.

People seem endlessly fascinated by coincidences, but should we be impressed by these fluky events, especially when they seem to happen to everyone? Robert Matthews, a British journalist and mathematician whose work has been noted in this column before ("The Anthropomurphic Principle," December 1995; "The Interrogator's Fallacy," September 1996), thinks not. In a recent issue of *Teaching Statistics* (Spring 1998), he and co-author Fiona Stones examine one of the most common types of coincidence: people who share the same birthday. Their conclusion is that we are too impressed by coincident birthdays because we have a very poor intuition of how likely such events are.

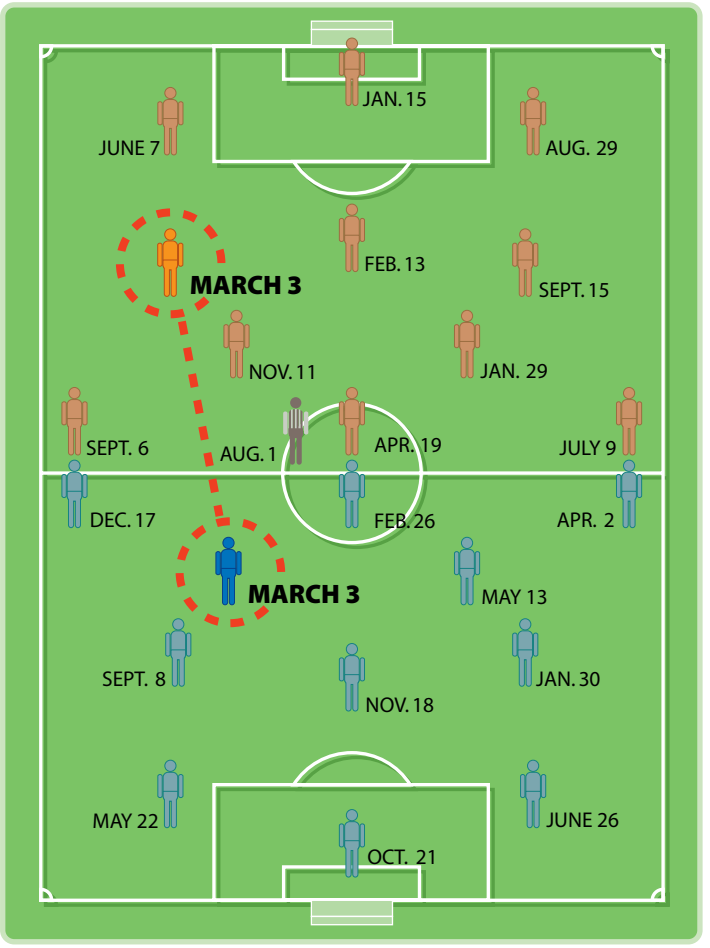
How many people must be in a room to make it more likely than not that at least two of them will have the same birthday? By "birthday" I mean day and month but not year. To keep things simple, I'll ignore February 29, so there are 365 different birthdays. I'll also assume that each birthday is equally likely to occur, which is not entirely true: more children are born at some times of the year than at others. Taking these extra factors into account would complicate the analysis without greatly changing the conclusions.

Okay, how many people are in the room? A hundred? Two hundred? When researchers posed this question to university students, the median of their estimates was 385. The popular guess is obviously too high, because as soon as the room contains 366 people (or 367 if we include February 29) a coincidence is guaranteed. In fact, the correct number is much lower: only 23 people.

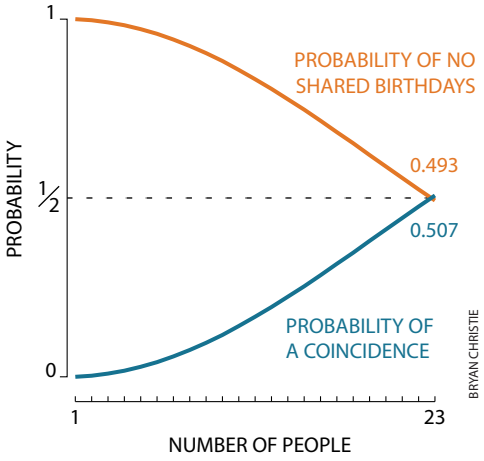
When doing these kinds of calculations, it is often easier to determine the probability that an event does *not* happen. If we know this number, then all we have to do to get the probability that the event *does* happen is to subtract the number from 1. For instance, when does the event "at least two people share the same birthday" not happen? When all their birthdays are different. Suppose we start with just one person in the room and then bring in more people one at a time. We can calculate the probability that the new person has a different birthday from all the previous ones. As people enter the room, the probability that all their birthdays differ steadily decreases—and the probability of a coincidence increases. Now, an event that is more likely to happen than not has a probability greater than $1/2$. As soon as the probability of no differing birthdays drops below $1/2$, we know that a coincidence—at least two people sharing the same birthday—has become more likely than not.

With only one person—let's call him Alfred—there is no possibility of a coincidence, so the probability of unique birthdays is certain, or 1. Now Betty enters the room. There are 365 possible birthdays, but Alfred has used up one of them. That leaves 364 possibilities for Betty if their birthdays are to be different. So the probability that their two birthdays differ is $^{364}/_{365}$. Next, Carla comes in. Now there are only 363 unused birthdays, so the probability that Carla has a birthday that differs from the other two is $^{363}/_{365}$. The combined probability that all three birthdays are different is $(^{364}/_{365}) \times (^{363}/_{365})$.

We're starting to see a pattern. When Diogenes comes into the room, the probability of differing



HYPOTHETICAL SOCCER MATCH includes two players who share the same birthday. Every game is likely to have at least one birthday coincidence among the 22 players and the referee.



***BIRTHDAY COINCIDENCE** becomes more likely than not when the number of people rises to 23.*

birthdays is $(^{364}/_{365}) \times (^{363}/_{365}) \times (^{362}/_{365})$. In general, after the nth person has entered the room, the probability that all n birthdays are different is $(^{364}/_{365}) \times (^{363}/_{365}) \times \ldots \times (^{(365\,-\,n\,+\,1)}/_{365})$. All we have to do now is compute successive values of this expression and see when it drops below $^1/_2$. The graph above shows the results. With 22 people the probability of all birthdays being different is 0.524, but with 23 people it is 0.493. So when the 23rd person enters, the probability that at least two of the people present have the same birthday becomes 1 – 0.493 = 0.507, or slightly more likely to happen than not.

Test the theory at parties of more than 23 people. Take bets. In the long run, you'll win. At big parties you'll win easily. Most partygoers will guess that a coincidence is unlikely because they focus on a misleading aspect of the problem: the number of people in the room. Although 23 is small, there are 253 different pairings among 23 people. (If n is the number of people, the number of pairings is $n \times {}^{(n-1)}/_2$.) That's a lot larger and a lot more relevant to the probability of a coincidence.

Matthews and Stones tested the prediction in another way. In a soccer match there are 23 people on the field: two teams of 11 players each, plus the referee. So the prediction is that among such a group, more often than not, two birthdays will coincide. Matthews and Stones looked at soccer matches in the U.K.'s Premier Division played on April 19, 1997. Out of 10 games, there were six with birthday coincidences, four without.

In fact, in two of the matches there were two coincidences! In the game pitting Liverpool against Manchester United, two players had birthdays on January 21, and two had birthdays on August 1. In the showdown between Chelsea and Leicester City, the two shared birthdays were November 1 and December 22. But this fluke is also predicted by probability theory—the chance of two shared birthdays among 23 people is 0.111, so it is likely to happen in one out of nine soccer matches. The chance of three shared birthdays is 0.018, and the chance of a triple coincidence—three people out of 23 sharing the same birthday—is 0.007, or likely to happen in one out of 143 games.

Now for a slightly different question: How many people, in addition to yourself, must be in a room to make it more likely than not that one of them will share *your* birthday? One might guess the answer is $(^{364}/_2) + 1$, or 183, because there are 364 birthdays that are different from yours, and if more than half that number of people are in the room, you're likely to share a birthday with someone. But the correct answer is 253.

To calculate the number, use the same technique as before: find the probability that the birthdays remain different from yours and then subtract from 1. Suppose that you're already in the room and that other people come in one by one—Alfred, Betty, Carla, Diogenes and so on. The probability that Alfred has a different birthday from yours is $^{364}/_{365}$. The probability that Betty has a different birthday is also $^{364}/_{365}$. And the same goes for Carla, Diogenes and everyone else. We're not interested in the coincidences shared by other people—say, Alfred and Carla both have birthdays on May 19. Doesn't matter: all that counts is whether a birthday is the same as yours. So after n people have entered the room, the probability that they all have different birthdays from yours is $(^{364}/_{365})$ to the nth power. The first value of n for which this number is less than $^1/_2$ is $n = 253$; $(^{364}/_{365})^{253} = 0.499$.

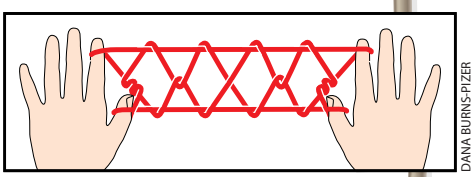
Incidentally, the fact that the answer to the second problem is the same as the number of pairings in the first problem (253 pairings for 23 people) seems not to have any mathematical significance. It seems to be a coincidence.

What do such calculations teach us? First, not to be unduly impressed by things that seem unlikely: maybe they're not. A pair of soccer players with the same birthday would probably be amazed by the coincidence, even though every soccer match is likely to have one. The players would probably remember the coincidence for years. But the 252 other pairs of players would not marvel at the fact that their birthdays did *not* coincide. Because we notice coincidences and ignore noncoincidences, we make the coincidences seem more significant than they really are. My friend's honeymoon encounter seems less striking if you think of how many other people he must have encountered during his life who were *not* his boss and spouse. SA

FEEDBACK

In the column "Cat's Cradle Calculus Challenge" (December 1997), I asked readers to devise a mathematical theory that would explain some aspects of string figures. Mark A. Sherman, editor of the *Bulletin of the International String Figure Association,* sent me several copies of his journal and its predecessor, the *Bulletin of String Figures Association,* containing articles that head in the right direction. Among them are an entire special issue devoted to the mathematical principles of string figures (*B.S.F.A.*, 1988), including a chapter on the beautiful pattern known as Indian diamonds (*below*), and an article on using string figures to teach math skills (*B.I.S.F.A.*, 1997).

This topic deserves a fuller exposition, and I hope to return to it in a future column. Meanwhile, readers may wish to contact the International String Figure Association at P. O. Box 5134, Pasadena, CA 91117, or at http://members.iquest.net/~webweavers/isfa.htm on the World Wide Web. —*I.S.*



AN ATTEMPT TO LINK THE SCIENCES AND HUMANITIES

Review by Robert M. May

Consilience: The Unity of Knowledge
BY EDWARD O. WILSON
Alfred A. Knopf, New York, 1998 ($26)

Edward O. Wilson's first "big book" was a slim volume, *The Theory of Island Biogeography,* written in collaboration with Robert H. MacArthur and published in 1967. It is one of the canonical texts of theoretical ecology. It helped to push the study of populations, communities and ecosystems from a foundation of largely descriptive studies to today's richer mixture of descriptive natural history, manipulative experiments in the field and laboratory, and mathematical analyses (often of complicated nonlinear systems).

Sadly, cancer killed MacArthur a few years later. In 1973 a group of his friends and colleagues gathered in Princeton, N.J., for a memorial meeting. At that time, Wilson was about to send the manuscript of *Sociobiology* to his publisher. Wilson, Richard Levins and Richard C. Lewontin were staying in the overlarge house that I, recently arrived, was renting from Princeton University, and as we and others walked back to dinner there someone asked Wilson, "What is this sociobiology all about?" Dick Lewontin enthusiastically answered something like: "It is a big book, bringing a lot together, and defining sociobiology as whatever is in Ed's book."

Much has happened since then. *Sociobiology: The New Synthesis* appeared—26 chapters on empirical and theoretical advances in understanding the evolutionary origins of the social behavior of nonhuman animals and a final speculative chapter suggesting that many aspects of human behavior and social organization might be understandable in broadly similar terms. Wilson had looked forward to an academic battle with anthropologists, psychologists and others who had little use for Darwinian interpretations of human culture. But he had (perhaps naively) not foreseen the political battle that erupted, with its epicenter at Harvard University and its apogee the infamous letter from Lewontin and others to the *New York Review of Books,* comparing Wilson's ideas with those of the Nazis.

Wilson's subsequent books have ranged from a magisterial overview of his favorite animals (*The Ants,* with Bert Hölldobler, which won a Pulitzer Prize in 1990), through definitive statements about "biodiversity," a word that he made common coin (*The Diversity of Life,* 1992), to a wonderful autobiography (*Naturalist,* 1994). Far from backing off his sociobiological claims that evolutionary biology can illuminate aspects of human behavior and culture, Wilson's agenda has, if anything, enlarged over time.

Which brings me to *Consilience*. The word is borrowed from William Whewell, who in his 1840 synthesis *The Philosophy of the Inductive Sciences* spoke of consilience as a "jumping together" of knowledge by linking facts and theory across disciplines to create a common groundwork of explanation.

I love the clear, calm and often cruel phrases that drive his lance through black knight after black knight.

The book's opening chapter, aptly called "The Ionian Enchantment," sets forth Wilson's conviction that the world is orderly and can be explained by a small set of natural laws. The next two chapters take us on a quick tour through "The Great Branches of Learning" and "The Enlightenment," making clear Wilson's enthusiasm for the attitudes of the Enlightenment: "The assumptions they made of a lawful material world, the intrinsic unity of knowledge, and the potential of indefinite human progress are the ones we still take most readily into our hearts, suffer without, and find maximally rewarding through intellectual advance. The greatest enterprise of the mind has always been and always will be the attempted linkage of the sciences and humanities. The ongoing fragmentation of knowledge and resulting chaos in philosophy are not reflections of the real world but artifacts of scholarship." Off to such a start, I approached the rest of the book with considerable trepidation.

JON CHASE *Harvard Gazette*

EDWARD O. WILSON with his favorite animal

The middle part of the book, however, is an exceptionally insightful account of the sciences, including (as do the U.K. Research Councils) the social sciences. Wilson gives a good account of how our still growing understanding of the physical world has given us the power to reshape our environment, deferring to later chapters his observations on the often unintended consequences. Looking beyond today's spectacular advances in unraveling the structure and function of neural processes or in reading the molecularly coded book of life, Wilson points to a future in which this biological understanding will give us the power to reshape ourselves (again deferring the implications to his final chapters).

The essential difficulty is in asking individuals today to make sacrifices that benefit communities tomorrow.

He cuts through much polarized nonsense about nature versus nurture or genes versus culture, showing with many examples how both are as relevant to us as to other animals. These sociobiological ideas about kin selection, parental investment, mating behavior, territorial expansion and defense, status and other strategies are shown to have firm roots in evolutionary biology and clear applications to human institutions.

As we move on to "The Social Sciences," "The Arts and Their Interpretation" and "Ethics and Religion," things get blurrier. Wilson continually and properly emphasizes patterns that are more or less universal: incest taboos (everything to do with inbreeding depression, and nothing to do with Freud); snakes and serpents in dreams (everything to do with real risks from snakes, and nothing to do with penises). Although I am in sympathy with Wilson's basic premise, I think these illustrative universals are more subtly textured: consanguinity rules, in all their variety, are possibly better understood in economic terms, and I am with the Freudians on serpents.

The suggestion that the magically beautiful cave art of Chauvet and elsewhere was born literally of magic—prescientific attempts to explain and influence one's world—I find compelling. I would even agree that "the dominating influence that spawned the arts was the need to impose order on the confusion caused by intelligence." But to suggest this kind of explanation for contemporary art markets may be foolish: I think instead they are to be explained in largely economic terms (which themselves are ultimately, but remotely, grounded on evolution). The reason the annual turnover on paintings alone by Sotheby's, Christie's and the world's other auction houses is larger than the total annual spending on taxonomic and systematic biological research—and why we have synoptic inventories of the world's art and not of the world's living species—is not simply because we favor human handiwork over nature's. The reasons are essentially economic: we have created markets in art (and there is a lesson for conservationists here!).

In short, I share Wilson's view that the ultimate basis for art, and even for ethics, lies in the chances and necessities of our evolutionary history. But I think these origins are often deeper and subtler than they are sketched by Wilson. This being said, I love the clear, calm and often cruel phrases that drive his lance through black knight after black knight.

On schools within the social sciences: "Each of these enterprises has contributed something to understanding the human condition. The best of the insights, if pieced together, explain the broad sweep of social behavior, at least in the same elementary sense that preliterate creation myths explain the universe, that is, with conviction and a certain internal consistency. But never—I do not think that too strong a word—have social scientists been able to embed their narratives in the physical realities of human biology and psychology, even though it is surely there and not some astral plane from which culture has arisen."

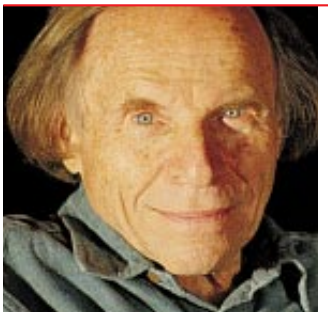
On religion: "For centuries the writ of empiricism has been spreading into the ancient domain of transcendentalist belief, slowly at the start but quickening in the scientific age. The spirits our ancestors knew intimately first fled the rocks and trees, then the distant mountains. Now they are in the stars, where their final extinction is possible."

Wilson, however, completes this quotation with "but we cannot live without them." Greatly to oversimplify, Wilson offers us a clear-eyed view of the wonders of our evolutionary past, shared with other living creatures, as a satisfying creed to live by. As his final chapter makes plain, acceptance of this view of life carries a call to action. This last chapter summarizes our current plight: teeming population growth; climate change; extinction rates running 100 to 1,000 times above average rates in the evolutionary record and set to accelerate. Wilson, encouraged by his vision of the emerging unity of knowledge, which he hopes will help us rise above outdated irrationalities and short-term selfishness, offers a message of hope.

I would like to share his optimism, but I cannot. Insofar as much of Wilson's *Consilience* is grounded on evolutionary biology, it emphasizes the short term and the individual. The classic problems surrounding the "evolution of altruism" or cooperative behavior—of behavior that puts the good of the group above the interest of the individual—are, as yet, ill understood (excepting for groups of sufficiently close relatives). These questions do not loom large in *Consilience,* yet they are utterly crucial to humanity's future. Whether the problem is population growth, or climate change, or diminishing biological diversity, the essential difficulty is in asking individuals today to make sacrifices that benefit communities tomorrow.

In essentials, I agree with Wilson's hope that we are moving toward a unification of all knowledge, based ultimately on understanding evolutionary processes. But I do not share his optimism that this unity may be our salvation. I fear that the inflexibility of social institutions, rooted in the past evolutionary history of our species, will ineluctably continue to put their emphasis on the interests of individuals and of the short term.

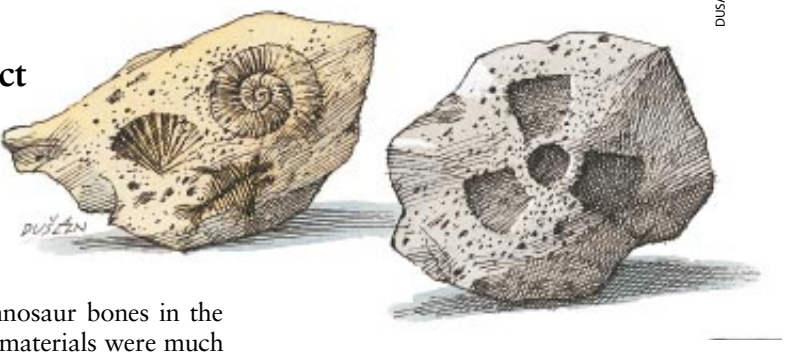
ROBERT M. MAY is Chief Scientific Advisor to the U.K. government and head of its Office of Science and Technology. He is on leave from his Royal Society research professorship at the University of Oxford.



WONDERS

by Philip Morrison

Where Fiction Became Ancient Fact



DUSAN PETRICIC

A lank sunburnt person in tweeds with a yellow-brown hatchet face and one faded blue eye," the explorer Gordon-Nasmyth appeared before London tycoon Ponderevo, to tempt him into a faintly illegal venture. "Fifteen hundred percent on your money in a year … Sir … the most radioactive stuff in the world … a festering mass of earths and heavy metals, polonium, radium … as if some young creator had been playing about … in a sort of rotting sand … the world for miles about it is blasted and scorched… .You can have it for the getting … worth three pounds an ounce, if it's worth a penny."

So runs a vivid scene in H. G. Wells's novel of 1909, named for Mr. Ponderevo's miracle tonic, *Tono-Bungay.* The scientist-narrator soon sails furtively to West Africa, amid whitened mangroves "within the thunderbelt of Atlantic surf." A dozen ship hands spend a few toilsome weeks loading tons of a sand dune worth its weight in gold. On the homeward journey, their laden old brig begins to leak "everywhere" and promptly sinks, its "ligneous fibers destroyed" by radiation. The entire flotilla of the too daring Ponderevo enterprises founders soon enough on the stock exchanges. Our hero and crew are picked up at sea, enabling the story to climax with the final voyage of the bankrupt promoter, an airborne fugitive on a blimp of the narrator's design.

The tale came out the year after Ernest Rutherford won the Nobel Prize in Chemistry, his nuclear atom a few years into the future. *Tono-Bungay,* both Edwardian and steadfastly modern, stands very high on my list of the best science-related novels of the century.

Astonishingly, in 1972 there was found on a West African upland just such a deposit, tons of minerals into which fierce radioactivity had been induced. This old find was a fossil, not of life but of the mineral kingdom, its inner fury as thoroughly stilled by time as any tyrannosaur bones in the rocks. Indeed, its materials were much older than dinosaurs. Flowing north from the border with the Congo Republic, among outcrops of the ancient granite that underlies the sandstone-covered plateau, is the Oklo River, a small tributary to the principal river of Gabon. A strip mine named Oklo grades steeply down from the surface like an open road, wandering 1,000 feet into the past. Pockets of rich, black uranium oxide ore are excavated from the rocky side wall. Twenty-six years ago French scientists—chemists, geologists and physicists—encountered the unique "phenomenon of Oklo" and soon explained it. (See an illustrated account in the July 1976 issue of *Scientific American*.)

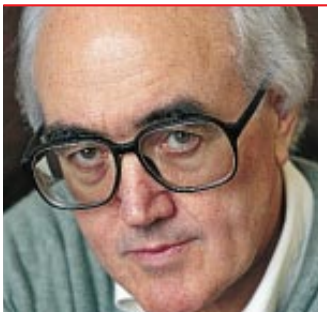
On an African upland are tons of minerals into which fierce radioactivity had been induced long ago.

Recall that the element uranium, nuclear charge 92, has two major species: an isotope of mass 238, the heaviest and longest-lived of natural uranium isotopes, present as 99.3 percent of the element; and a lighter, rarer isotope of mass 235, fissionable even by slow neutrons. Uranium 235, expensively enriched to four or five times its meager natural amount, is the main fuel of power reactors today in France, supplying two thirds of that country's electrical power. All over the earth and on the moon, too, the valued uranium 235 isotope makes up about 0.720 percent of natural uranium. A routine sample from the Oklo mine first showed a small but surprising discrepancy, 0.717 percent of uranium 235, off by several times the expected error of the scrupulous mass-spectrographic analysis. The obvious suspicion was adulteration; after all, uranium much depleted in isotope 235 was the main by-product of their well-run industry. Could someone be watering their rich soup?

Within a few years a large team of scientists of the French Atomic Energy Commission solved the case, step by documented step. The sampling of the Oklo ore body disclosed clear relics of "infectious radioactivity," even in undisturbed places, all fission-born activity spent by lengthy natural decay. Both main isotopes of uranium are naturally radioactive and slowly decay by alpha-particle emission, uranium 235 decaying the faster. Extrapolate today's normal mixture back in time: the easily fissionable uranium 235 becomes more and more abundant the farther back you go. In distant Oklo time, uranium 235 was as abundant in uranium everywhere on the earth as it is now in the enriched fuel fed to nuclear power reactors.

A working neutron chain reaction using *unenriched* uranium today requires a sophisticated arrangement of well-purified uranium and some light moderator rich in hydrogen, carbon, oxygen or deuterium. To achieve that design took the insight of a Fermi and many another. But at a time so ancient that all life was still microbial, any random heap of natural uranium oxide, maybe concentrated chemically by slow bacterial action, then immersed in fresh water to

Continued on page 101



CONNECTIONS

by James Burke

Scribble, Scribble

DUSAN PETRICIC

One of the *real* pains about the kind of historical research I get involved with is that when you go to primary sources, much of the time you have to read somebody's scribble if he or she lived back before the typewriter was invented. You know: research notes, letters, diaries, that stuff. And most of the time, comprehension-wise, it's double Dutch. Recently, in my case, just that.

Which is why what little I know about a 19th-century scientist from Holland named Christoph Buys Ballot is strictly secondary source material. In more senses than one, given that his primary work produced a law that says the angle between the wind and the pressure gradient is a right angle. What I found more intriguing involved Buys Ballot's riding with a trainload of brass players, on a railroad out of Utrecht, Holland, in 1845. The task of these traveling trumpeters was to blow a steady note as the train approached (and then passed) a group of Buys Ballot's pals. Who then confirmed that they had heard the note rise as the train neared them and then fall as it moved away down the track.

Three years earlier an obscure Austrian professor of math, Christian Doppler, had predicted this would happen. In fact, his scientific paper had principally been about how the light from approaching and receding stars moved, respectively, toward the blue (higher frequency) and red (lower frequency) ends of the spectrum. For "light," read "sound." This phenomenon became known (after the now no longer obscure Austrian) as the Doppler effect. And in 1859 it was turned to practical use when German experimental mavens Gustav Kirchoff and Robert Bunsen (he of the burner) used their new spectrograph to show that the shift in the spectral lines of the light from these moving stars enabled you to measure their velocity. Hot stuff.

Unlike the obsession of one of their lab students, who spent the winter of 1871 with them in Heidelberg. Heike Kammerlingh Onnes by name (another Dutchman), he became fascinated with the strange things that happened to objects when they got very cold. Like superconductivity, which he discovered by chilling materials, using liquid gases, to within a few degrees of absolute zero. Onnes was aided in his endeavors by the work of a Frenchman, Louis-Paul Cailletet (recently mentioned in this column), who in 1877 succeeded in liquefying oxygen. Cailletet was also an aeronautics buff and at one point invented a new breathing mask connected to a container of liquid oxygen, so that balloonists at high altitudes could get even higher. In more senses than one.

Nitrous oxide made Davy a bit of a laughingstock.

As it happens, the effect of sniffing excessive amounts of pure oxygen was the experimental concern of one of Cailletet's contemporaries, French physiologist Paul Bert. Also known for his seminal work on how the sensitive mimosa flower reacts to touch (try it), Bert spent many happy hours in a pressure chamber of his own design, finding out about stuff like the bends, hypoxia and other such mind- and body-altering experiences. From time to time his happiness might possibly have been attributed to the fact that he was also trying to find out what pressures of different gases you needed to provide just the right amount of anesthesia for a surgical operation. One of these gases was nitrous oxide, a.k.a. "laughing gas."

The bible on N_2O had been written back in 1800 by Humphry Davy, while he was working at the Clifton Pneumatic Institution in the west of England. Davy was soon to become England's premier scientist, a knight, role model to Mary Wollstonecraft Shelley of *Frankenstein* fame, and winner of all known honors. Including, it is said, a prize from Napoleon, despite the fact that the Brits were fighting the French at the time. Nitrous oxide made Davy a bit of a laughingstock (in the nicest sense of the term) at the newly fashionable N_2O parties, where researchers would get stoned, strictly in the interests of science. Alas, on a (slightly) more serious note, Davy failed to prove that the gas would cure all diseases.

As is often the case with scientists back in those days, Davy also dabbled about in poetry. About which little further need be said. Mind you, when he became a famous lecturer at the Royal Institution in London, admirers of his versification included such Romantic biggies as Samuel Taylor Coleridge and Robert Southey, a couple of scribblers Davy had met during his sojourn at Clifton.

In 1819 Southey spent some time touring the Highlands of Scotland with another eminent self-made type, Thomas Telford. This guy built more roads and bridges than anybody this side of the Romans and two of the greatest engineering achievements of all time: the unparalleled aqueduct at the unpronounceable Pontcysyllte in Wales and the Caledonian Canal in Scotland (about which Southey enthused poetically). In a life of success piled on success (well, structure was Telford's thing), the only failure of his entire career was in 1800, when he designed a bridge to cross the Thames

in London. The top engineers and scientists of the time thought it was a winner. Sadly, a real-estate reality check revealed that the government of the day could not afford to buy the land on either side of the river, on which the bridge approach ramps would have to be built.

Among the regretful members of the bridge commission that turned Telford down was a young genius called Thomas Young. A perfect person to hate. He knew every known ancient Biblical language, cracked the mystery of Egyptian hieroglyphics, lectured at the Royal Institution on you-name-it and conducted the famous experiment that seemed to prove that light beams from different sources produced interference patterns because light traveled in waves. No problem, but—waves traveling in what?

This mysterious luminiferous medium became known as ether, and the search for it bedeviled Victorian science as did little else. Hermann von Helmholtz, the harrumphest German scientist of the time, delegated this minor matter to a pupil (Heinrich Hertz, whose investigations, to see if electromagnetic radiation also moved through ether in waves, made possible the invention of radio).

Helmholtz himself had bigger fish to fry, namely, nailing the prevalent "vitalist" theory, which held that life processes involved some kind of immeasurable "force." Which Helmholtz disproved by showing that the passage of a signal down a frog's sciatic nerve was an entirely measurable 27 meters a second. But the logical thing about a vitalist theory has to be its ability to survive, right? So by 1900 vitalism was still alive and kicking, thanks above all to one Ludwig Klages, psychologist and founder of the science of "characterology" (if it wasn't offered at your institute of higher learning, don't blame me).

The other thing Klages did (which endeared him to the National Socialists a little too much for his taste, whereupon he left for Switzerland) was to develop a technique for analyzing character so accurately that the Nazis would use it in their officer selection programs. I could have done with Klages's trick when I was trying to make head or tail (it could have been "tail or head") of the scribblings of Christoph Buys Ballot. Because Klages's key contribution to the sum of human knowledge was to systematize the study of handwriting. Signing off. SA

Wonders, *continued from page 99*

act as moderator to slow the neutrons, was rich enough in the fissionable isotope to antedate Fermi and his Chicago team by 1.8 billion years. In each of half a dozen locations in the Oklo ore body, about a ton of uranium 235 instead of decaying naturally had fissioned away with a million times the power of natural decay. At each site a fitful five or 10 kilowatts of heat was generated in a pool-size volume over a time of 500 or 1,000 centuries. In a few spots the burn-up transmuted more than half of the original uranium 235 in the oxide: the more the burn-up, the greater the amount of fission products produced. The characteristic pattern of a dozen elements, the rare "earths and heavy metals," is preserved in full. The only culprit at Oklo was Father Time.

The whole mineral system then lay a mile or two deep in the earth within a long-buried aquifer, at modest temperature and high pressure in an old and stable geologic setting. Enriched-uranium, pressurized-water reactors of modest size turn out to be quite natural events. An American radiochemist, Paul K. Kuroda, first suggested in 1956 that such natural reactors might be found, and uranium deposits have been examined worldwide, but no find save in Oklo, and one other small patch 20 miles away.

Still deeper results emerged. We now know more about the nuclear processes in old Oklo than about most other ancient events. A clever physicist in St. Petersburg, Alexander I. Shlyakhter, now at Harvard, showed how to check with astonishing accuracy the energy levels of many nuclei within those reactors. Jointly revisiting the issue, two theorists (Thibault Damour and Freeman J. Dyson) have lately confirmed his most fundamental result.

The very force that drives fission, the mutual electrostatic repulsion among nuclear protons, is the same today as for the nuclei transmuted at Oklo to about one part in 10 million. The physicists, so their critics often say, have worked in the simple faith that the laws of nature are unchanging. That assumption has been hard to test, but now we have some firm limits: some major constants of nature have not noticeably changed in two billion years. Newest results from precision spectra of distant galaxies may reopen this conclusion. SA

WORKING KNOWLEDGE

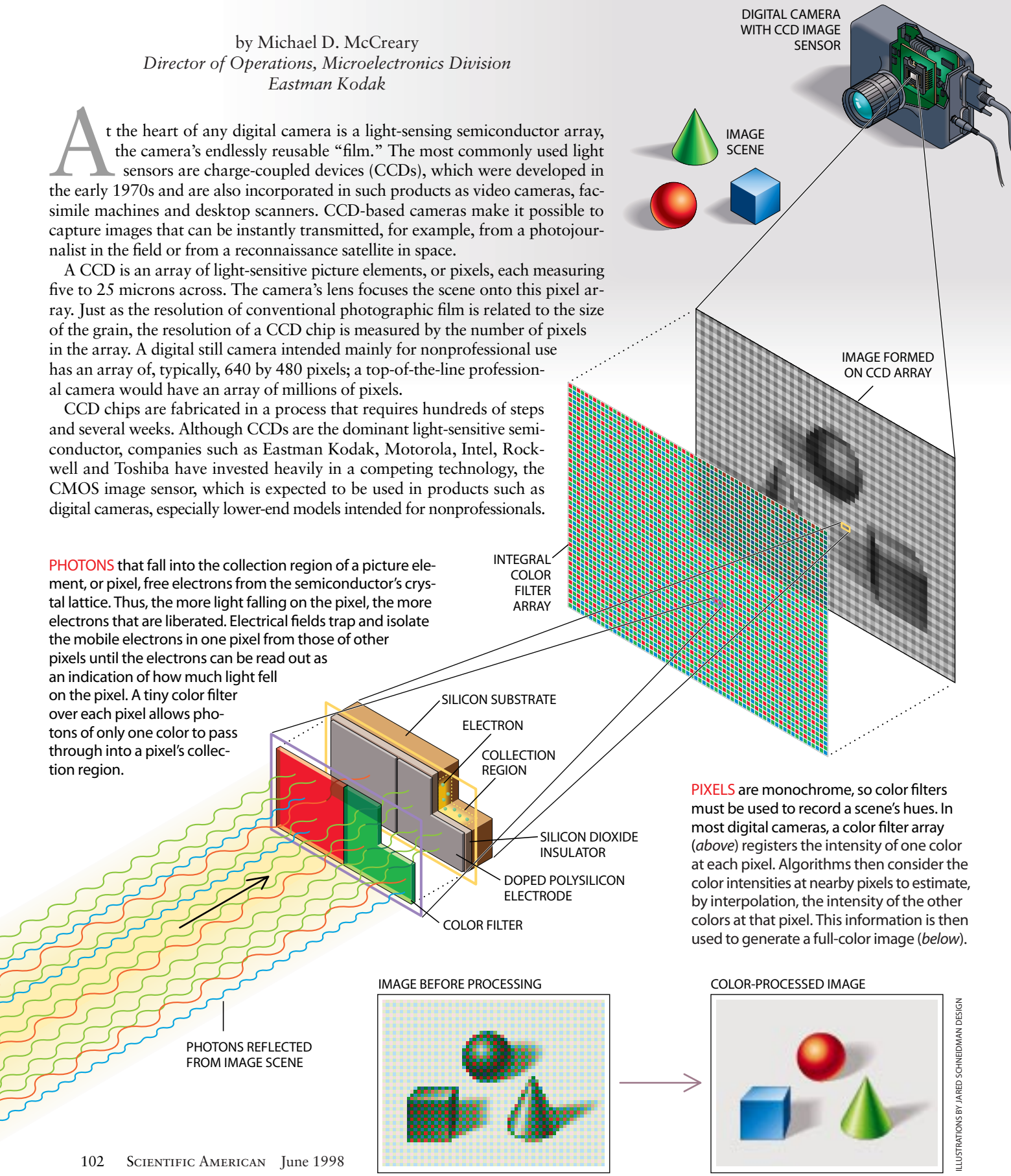
DIGITAL CAMERAS

by Michael D. McCreary
Director of Operations, Microelectronics Division
Eastman Kodak

At the heart of any digital camera is a light-sensing semiconductor array, the camera's endlessly reusable "film." The most commonly used light sensors are charge-coupled devices (CCDs), which were developed in the early 1970s and are also incorporated in such products as video cameras, facsimile machines and desktop scanners. CCD-based cameras make it possible to capture images that can be instantly transmitted, for example, from a photojournalist in the field or from a reconnaissance satellite in space.

A CCD is an array of light-sensitive picture elements, or pixels, each measuring five to 25 microns across. The camera's lens focuses the scene onto this pixel array. Just as the resolution of conventional photographic film is related to the size of the grain, the resolution of a CCD chip is measured by the number of pixels in the array. A digital still camera intended mainly for nonprofessional use has an array of, typically, 640 by 480 pixels; a top-of-the-line professional camera would have an array of millions of pixels.

CCD chips are fabricated in a process that requires hundreds of steps and several weeks. Although CCDs are the dominant light-sensitive semiconductor, companies such as Eastman Kodak, Motorola, Intel, Rockwell and Toshiba have invested heavily in a competing technology, the CMOS image sensor, which is expected to be used in products such as digital cameras, especially lower-end models intended for nonprofessionals.



PHOTONS that fall into the collection region of a picture element, or pixel, free electrons from the semiconductor's crystal lattice. Thus, the more light falling on the pixel, the more electrons that are liberated. Electrical fields trap and isolate the mobile electrons in one pixel from those of other pixels until the electrons can be read out as an indication of how much light fell on the pixel. A tiny color filter over each pixel allows photons of only one color to pass through into a pixel's collection region.

PIXELS are monochrome, so color filters must be used to record a scene's hues. In most digital cameras, a color filter array (*above*) registers the intensity of one color at each pixel. Algorithms then consider the color intensities at nearby pixels to estimate, by interpolation, the intensity of the other colors at that pixel. This information is then used to generate a full-color image (*below*).

ILLUSTRATIONS BY JARED SCHNEIDMAN DESIGN