QUANTUM SPECIAL ISSUE: 75 Years of Linked Fates and Cats in Limbo

ScienceNews

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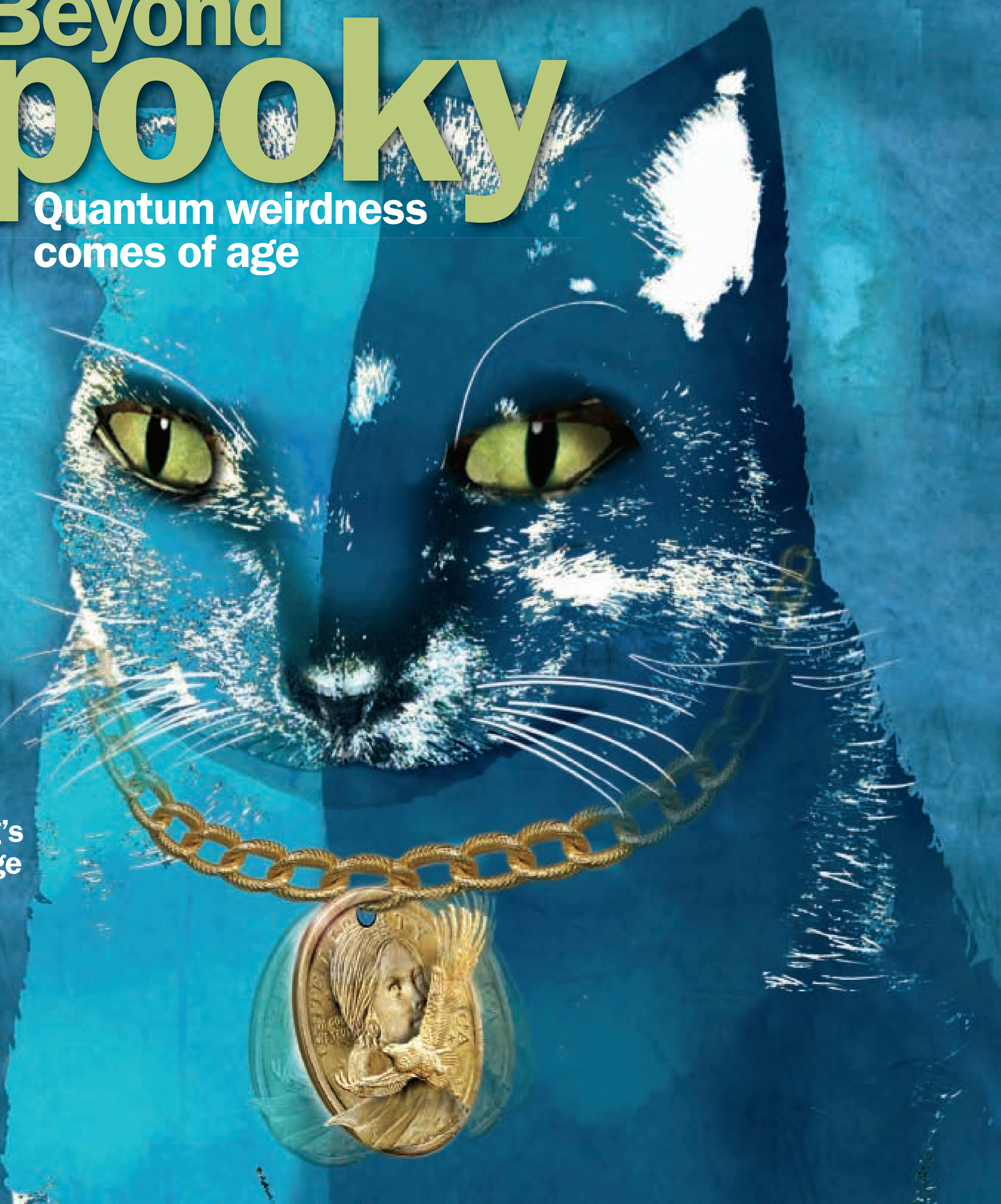
MAGAZINE OF THE SOCIETY FOR SCIENCE & THE PUBLIC ■ NOVEMBER 20, 2010

Beyond Spooky

Quantum weirdness comes of age



In Africa, Toolmaking's Cutting Edge

Gene Therapy for Depression

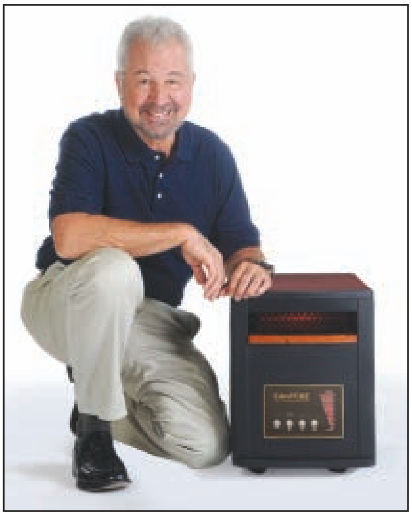
Robots Get a Grip with Coffee Grounds

Bob Vila ranks new 2011 EdenPURE® portable heater #1 in North America

Millions of Americans now saving on their heating bills and raving about the "heavenly heat"

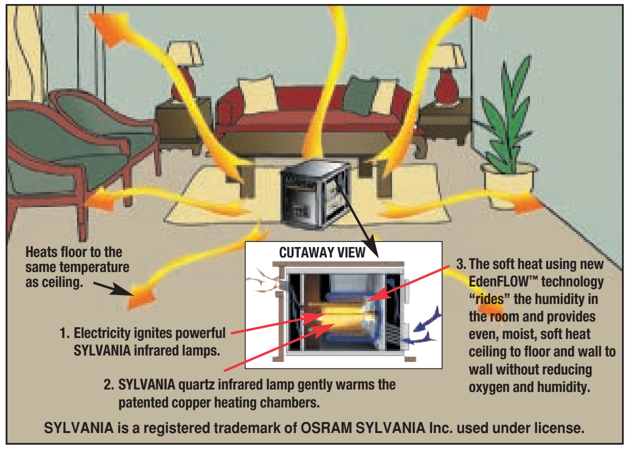
Accept no imitations - portable heaters and fireplaces "dry out" the air with inefficient ceramic heating elements

Never be cold again



Firemen and safety professionals choose EdenPURE®. We all read about space heaters and the danger of fire. The EdenPURE® has no exposed heating elements that can cause a fire. And your pet may be just like my dog that has reserved a favorite spot near the EdenPURE®. *– Bob Vila*

How it works:



Bob Vila, America's Favorite Home Improvement Expert, Canton, Ohio

The famous infrared portable heater, the EdenPURE®, has been greatly improved.

The new EdenPURE® GEN4 heats better, faster, saves more on heating bills and runs almost silent.

And now you can save up to $102 on the new 2011 EdenPURE® GEN4, the finest portable heater in the world.

The new GEN4 was designed and engineered in the USA and has several patented technological breakthroughs to save you money on your heating bill.

The EdenPURE® saves you big money on your heating bill but you will be toasty warm. The heat it produces is unlike any past heating sources. It produces what customers call "heavenly heat".

For over 30 years as your home improvement television host, I have reviewed and experienced thousands of products. I have an EdenPURE® in my Massachusetts home and found it to be a very safe and reliable source of portable heat. This is one of those few comfort investments I can recommend for your home that will truly pay dividends.

We all know heating costs are expected to remain at record levels. The cost of heating our homes will continue to be a significant burden on the family budget. The EdenPURE® GEN4 can cut your heating bills, pay for itself in a matter of weeks, and then start putting a great deal of extra money in your pocket after that.

With over one million satisfied customers around the world, the new EdenPURE® heats better, faster, saves more on heating bills, and runs almost silent.

A major cause of residential fires in the United States is portable heaters. The choice of fire and safety professionals everywhere, the EdenPURE® has no exposed heating elements that can cause a fire.

The outside of the EdenPURE® only gets warm to the touch so that it will not burn children or pets. And your pet may be just like my dog who has reserved a favorite spot near the EdenPURE®.

The EdenPURE® can also help you feel better. Unlike EdenPURE® imitators, it will not reduce humidity or oxygen in the room. These imitators use ceramic plates instead of our patented copper. The EdenPURE® GEN4 has over 1 pound of copper! Cheap ceramic plates reduce humidity, dry out your sinuses and make your skin dry. With other heating sources, you'll notice that you get sleepy when the heat comes on because they are burning up oxygen.

The advanced space-age EdenPURE® GEN4 also heats the room evenly, wall to wall and floor to ceiling. Other heating sources heat rooms unevenly with most of the heat concentrated high and to the center of the room. And as you know, portable heaters only heat an area a few feet around the heater. With the EdenPURE®, the temperature will not vary in any part of the room.

How can a person cut their heating bill with the EdenPURE®? First, the EdenPURE® uses less energy to create heat than many other sources, but that is just part of why it will cut a person's heating bill. The EdenPURE® will heat a room in minutes. You will immediately notice the difference! Therefore, you can turn the heat down in your house to as low as 50 degrees, but the room you are occupying, which has the EdenPURE®, will be warm and comfortable.

Your EdenPURE® GEN4 Portable easily rolls from room to room. Using zone heating keeps you comfortable and reduces your heating bills. This can drastically cut heating bills; in some instances, the savings may be substantial.

With no increase in price, the new EdenPURE® GEN4 has been updated with the latest technology, safety, and comfort features to provide you with even greater comfort, more savings, and years of reliability.

The EdenPURE® GEN4 Portable Heater comes with a comprehensive five year warranty and a 60-day, no questions asked, satisfaction guarantee – EdenPURE® will even pay for the return shipping. There is absolutely no risk. And EdenPURE® is the only portable heater with a National Service Network.

How to order:

There are two models to choose from: the new U.S. engineered GEN4 or our Personal Heater. The GEN4 comfortably heats an area up to 1,000 square feet while the Personal Heater covers up to 300 square feet.

During our special, you are eligible for a $75 DISCOUNT PLUS FREE SHIPPING AND HANDLING FOR A TOTAL SAVINGS OF UP TO $102 on the EdenPURE® GEN4. And now you can save an additional $100 on new Personal Heaters for a total savings of $192. This special offer expires in 10 days. If you order after that, we reserve the right to either accept or reject order requests at the discounted price. See my attached Authorized Discount Coupon to take advantage of this savings opportunity.

The EdenPURE® carries a 60-day unconditional, no-risk guarantee. If you are not totally satisfied, return it at our expense and your purchase price will be refunded. No questions asked. There is also a 5-year warranty on all parts and labor for the GEN4 and a 3-year warranty for the Personal Heater.

BOB VILA'S AUTHORIZED DISCOUNT COUPON

The price of the EdenPURE® GEN4 is $472 plus $27 shipping and handling and $372 plus $17 shipping and handling for the Personal Heater, but, with this Authorized Discount Coupon, you will receive a $75 discount, free shipping and handling and be able to get the EdenPURE® GEN4 for only $397 delivered and the Personal Heater for only $197 delivered. After 10 days we reserve the right to either accept or reject order requests at the discounted price.

Check below which model and number you want:

☐ GEN4 Heater, number ____ ☐ Personal Heater, number ____

☐ I am ordering within 10 days, therefore I get a $75 discount, free shipping and handling and my price is only $397 for GEN4 Heater delivered.

☐ I am ordering within 10 days, therefore I get a $175 discount, free shipping and handling and my price is only $197 for the Personal Heater delivered.

☐ I am ordering past 10 days, therefore I pay full price of $472 plus $27 shipping & handling for GEN4 Heater and $372 plus $17 shipping & handling for the Personal Heater.

- To claim your discount or by phone: call **toll-free 1-800-630-8983**. Operators are on duty Monday - Friday 6am - 3am, Saturday 7am - 12am and Sunday 7am - 11pm, EST. Give operator your Authorization Code on this coupon.
- To claim your discount and order online: visit www.edenpure.com and enter your Authorization Code on this coupon.
- To claim your discount and order by mail: fill out and mail in this Authorized Discount Coupon Form.

____
NAME

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ADDRESS

____
CITY STATE ZIP CODE

Enclosed is $______ in: ☐ Cash ☐ Check ☐ Money Order (Make check payable to EdenPURE) or charge my:

☐ VISA ☐ MasterCard ☐ Am. Exp./Optima ☐ Discover/Novus

Account No. ____________________ Exp. Date ___/___

Signature ______________________

MAIL TO: EdenPURE®
Authorization Code EHS2978
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Canton, OH 44767

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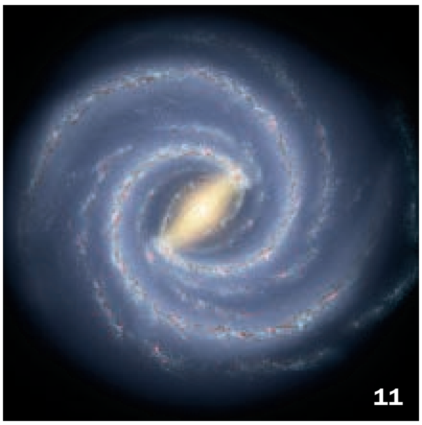
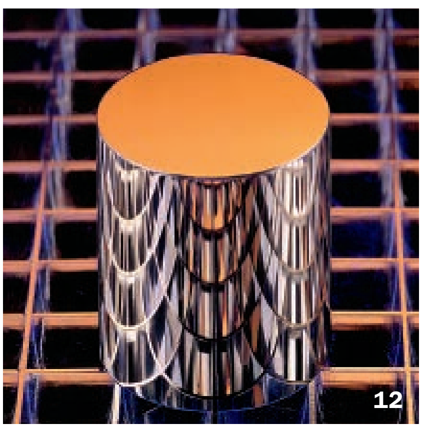


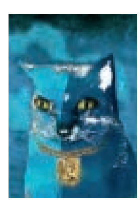


ScienceNews

In The News

Special Issue

Departments



COVER Schrödinger's cat, half alive and half dead, symbolizes the weirdness of quantum physics.
Michael Morgenstern

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FROM THE EDITOR

Like fate of cat, quantum debate is still unresolved

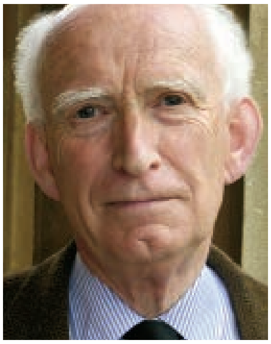
In the tapestry of 20th century physics, virtually every major thread is entangled with the name of Albert Einstein. He was most famous for the theory of relativity, of course, which rewrote Newton's laws and set modern theoretical cosmology in motion. But Einstein also played a major role in the origins of quantum theory and in perceiving its weird implications — including entanglement, a mystery named by Erwin Schrödinger in a paper based on an experiment imagined by Einstein.

Entanglement is now one of the hottest research fields in physics. It is pursued not only for insights into the nature of reality, but also for developing new technologies, as Laura Sanders notes (Page 22) in a special section marking the 75th anniversary of Einstein's entanglement paper (and another quantum legend, Schrödinger's half-dead, half-alive cat).

Despite his contributions to quantum theory, Einstein didn't like it. He believed that its weirdness indicated an incomplete theory that accounted for observed phenomena but was silent on invisible elements of reality that produced the weirdness. As I describe in this issue (Page 15), Einstein clashed with Niels Bohr, who found it meaningless to ascribe reality to anything unobservable. Bohr outdebated Einstein, but adherents to Einstein's views remain vocal today.

Today's debate sometimes gets acrimonious. It was not that way with Einstein and Bohr — their disagreement did not erode their deep mutual respect. Their conflicting ideas simply reflected differences in their worldviews, shaped by their personalities and scientific backgrounds. Einstein valued simplicity and clarity; Bohr embraced ambiguity. Einstein was a loner, working for the most part in isolation; Bohr surrounded himself with the brightest physicists of the day at his Copenhagen institute. Einstein's initial scientific success came from finding unities in phenomena — matter's identity with energy, for instance. Bohr explained the atom by emphasizing the incompatibility of classical and quantum physics.

For Bohr, quantum mysteries such as the dual wave-and-particle nature of light reflected the richness of a complicated universe. Einstein wanted a simpler, unified theory from which complexity would emerge logically, sans weirdness. Physicists have pursued Einstein's goal within a quantum framework, without much success. It's unclear whether future progress will come from avoiding quantum weirdness, or by making it even weirder. *—Tom Siegfried, Editor in Chief*



Scientific Observations

"As scientists, we must be led by curiosity over the mechanism of the natural world, but doing bread-and-butter science, straightforward extensions of what is known in order to elucidate new phenomena, is the main job. We should not spend all our time groping at great problems that may be beyond our capacity. Too often those of great intellect spend all their time so doing, achieve little and become disillusioned when they could have achieved much.... Ideas are not readily described through the positions and motions of particles and fields but, as in philosophy, ideas and questioning are the gist of all science. I am not ashamed to ask questions that others claim are nonsensical.... Knowing how often I have not seen the obvious implications of my own work, I regard all mankind, myself included, as somewhat shortsighted." — ASTROPHYSICIST DONALD LYNDEN-BELL OF THE UNIVERSITY OF CAMBRIDGE IN ENGLAND, IN THE 2010 *ANNUAL REVIEW OF ASTRONOMY AND ASTROPHYSICS*

Science Past | FROM THE ISSUE OF NOVEMBER 19, 1960

MERCURY CAPSULE FAILS — Failure of the test shot of the Mercury space capsule and its pilot escape system will not "necessarily" delay putting a man in space, the National

Aeronautics and Space Administration reported. NASA has scheduled a manned rocket launch for 1961. The Mercury spacecraft, designed to take an astronaut safely into outer space and return him to earth, failed to separate from its Little Joe rocket booster 13 miles from Wallops Island, Va., where it was launched. "If the cause of the malfunction is a minor mechanical failure, I see no reason why the Mercury Project program should be delayed," an NASA spokesman said.... If the design should be at fault, this will be a serious setback to the United States program.

Science Future

November 20
New York's American Museum of Natural History opens its interactive brain exhibit. Go to www.amnh.org/exhibitions/brain

December 2
San Francisco's Exploratorium considers sugar, from its bodily functions to art. With cocktails. See www.exploratorium.edu

December 2–3
Howard Hughes Medical Institute airs live classroom webcasts on infectious diseases. See www.holidaylectures.org

SN Online

www.sciencenews.org

DELETED SCENES BLOG
Despite hopeful reports, scientists still can't explain bees' disappearance. Read "Bee mystery not over yet."

EARTH
Tree sap shows isolation didn't hurt India's insect diversity. See "India yields fossil trove in amber."

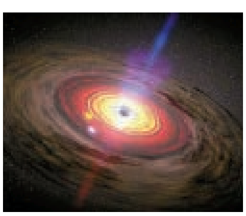
ATOM & COSMOS
The most massive stellar core yet found puts limits on the nature of what's inside. Read "Neutron star breaks mass record."

Astronomers spot what could be recent lava flows on Earth's sister planet. See "Venus, erupting?"

LIFE
Hairy animals shake off water at frequencies optimized for their sizes. Read "Doing the wet-dog wiggle."

How Bizarre

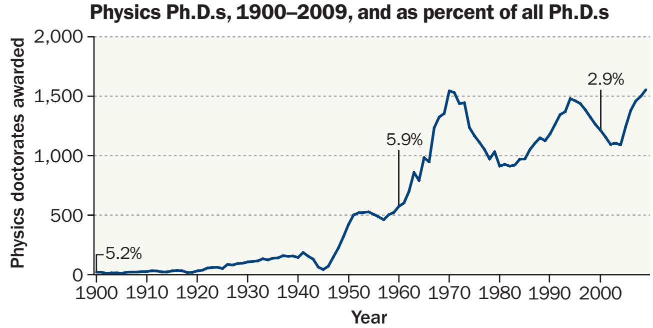
Black holes can help physicists understand strange metals. These compounds have unusual electrical resistance properties and can act as superconductors at very low temperatures. Theoretical methods have trouble explaining their behavior, but black holes may succeed where other models fail, physicists reported in the Aug. 27 *Science* and the Oct. 8 *Physical Review Letters.* Using conceptions of black hole spacetime related to string theory, the authors independently developed frameworks that, they claim, may help scientists tackle strange metals' physical properties.



Science Stats | PHYSICS ON THE BRAIN

The number of physics Ph.D.s awarded in the U.S. each year rose in the last century but now makes up a smaller portion of all Ph.D.s given.

Physics Ph.D.s, 1900–2009, and as percent of all Ph.D.s



SOURCES: ACE (1900–1919), NAS (1920–1961), AIP (1962–2009)

CLOCKWISE, FROM TOP LEFT: AMANDA J SMITH; DAVID GRIMALDI/AMERICAN MUSEUM OF NATURAL HISTORY; NASA/DANA BERRY, SKYWORKS DIGITAL

> “The body is doing one thing and the mind is doing another. What we found was that the fingers knew the truth.” —GORDON LOGAN, PAGE 7

In the News

STORY ONE

Tool finishing technique arose before humans first left Africa

Method may be 55,000 years older than thought

By Bruce Bower

Stone-tool makers living in southern Africa 75,000 years ago pushed the cutting edge in more ways than one. These intrepid folk sharpened the thin tips of heated stone spearheads using a technique previously dated to no more than 20,000 years ago, a new study finds.

This stone-tool making method, called pressure flaking, was invented and used sporadically in Africa before spreading to other continents, according to a team led by archaeologist Vincent Mourre of the University of Toulouse-Le Mirail in France. Having a flexible repertoire of toolmaking methods aided the survival of modern humans who left Africa beginning around 60,000 years ago, the scientists propose in the Oct. 29 *Science*.

The finding fits with the idea that symbolic art, rituals and other forms of modern human behavior developed gradually over hundreds of thousands of years, not in a burst of cultural innovation marked by cave paintings and other creations that appeared after 50,000 years ago in Western Europe. Some researchers have proposed that an intellectually advantageous gene mutation in human populations around that time spurred rapid cultural advances.

Pressure flaking may have been used to fashion the sharp edges at the tip (bottom) of this stone point, which dates to 75,000 years ago.

Excavations of sediment dated to 75,000 years ago in South Africa’s Blombos Cave revealed stone artifacts displaying signs of pressure flaking, Mourre and his colleagues say.

“The Blombos evidence for pressure flaking is the oldest we know,” says anthropologist and study coauthor Paola Villa of the University of Colorado Museum of Natural History in Boulder. “We don’t know how long ago pressure flaking originated.”

Blombos Cave and nearby sites of comparable age previously yielded engraved pigment chunks (*SN Online: 6/12/09*), decorated ostrich eggshells (*SN: 3/27/10, p. 10*) and heat-treated stone artifacts (*SN: 9/12/09, p. 15*).

African Athens Finds from a cave in South Africa suggest that human symbolic culture and technological know-how may have started to emerge much earlier than previously thought.

Southern Africans occasionally made items with symbolic meanings and used special forms of toolmaking beginning 100,000 years ago or more, Villa suspects. These practices flourished in and out of Africa starting about 40,000 years ago, in her view.

Pressure flaking consists of trimming the edges of a finished tool by pressing them with a bone point hard enough to remove thin slices of rock. This process creates the narrow, evenly spaced grooves found on flint tools from Europe’s 20,000-year-old Solutrean culture and from prehistoric Native American groups from more than 10,000 years ago. On these artifacts, the tiny scallop marks roughly resemble serrations on a knife.

Wider, more irregular grooves characterize 36 pressure-flaked Blombos tools, which were made from silcrete, Villa says. This rock is generally of lower quality than flint and requires heating to ready it for pressure flaking.

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SN Today at **www.sciencenews.org**

Villa and her colleagues identified glossy areas on silcrete tools at Blombos that, they surmise, formed when the stones were preheated for pressure flaking. Other marks on the artifacts indicated that they had been attached to handles, probably as spearheads.

By pressure-flaking preheated replicas of the Blombos finds made from silcrete collected near the South African cave, Mourre was able to reproduce marks resembling those on the ancient artifacts.

Toolmakers probably used pressure flaking by 100,000 years ago in East Africa, remarks paleoanthropologist John Shea of Stony Brook University in New York. Several sites there contain stone artifacts, many made from obsidian, that deserve close analysis for pressure flaking marks, Shea says.

Shea, an expert at making replicas of Stone Age tools, notes that pressure flaking can be taught in 30 minutes to a novice. "It is, literally, so easy a caveman can do it," he says.

Curiously, Shea adds, the new study doesn't try to explain why Blombos denizens began to trim and shape the tips of spearheads around 75,000 years ago. Any practical advantages that pressure flaking offered to weapon-toting hunters remain unclear, in his opinion.

Archaeologist Vincent Mourre pressure-flaked modern stone samples to reproduce patterns seen on ancient points.

Pressure flaking doesn't add much sharpness or strength to a cutting instrument, Shea adds. Blombos toolmakers probably employed this technique to advertise their skill or to denote users' social identity, he proposes.

Individuals today who have learned to fashion replicas of Stone Age spearheads like to finish off their handiwork with pressure flaking, mainly because it looks nice and demonstrates the maker's precision skills, according to Shea.

Archaeologist Curtis Marean of Arizona State University in Tempe calls the evidence for pressure flaking at Blombos "suggestive but not completely convincing." Further work needs to confirm that pressure flaking of replicated silcrete artifacts consistently produces marks like those on the Blombos finds, Marean asserts.

Pressure flaking on Solutrean and prehistoric Native American artifacts shows far more refinement than the coarse trimming marks observed on Blombos tools, he notes. Such a great disparity in finished products weakens the authors' argument that the same technique was used in all three cases, Marean contends.

Knowledge of pressure flaking doesn't imply any special mental or toolmaking abilities, he believes. Like Shea, Marean regards pressure flaking as a simple way to finish shaping tools made from certain types of stone.

"If the authors are correct that pressure flaking occurred at Blombos Cave, the result is important in that it extends the time range of the technique," Marean says. "But it's not game-changing in our understanding of the origins of complex cognition." ■

Back Story | CAVES OF INNOVATION

The people who lived at Blombos Cave about 75,000 years ago must have been a pretty impressive bunch. The cave's deposits contain evidence of other advanced technologies and practices besides pressure flaking. Archaeological finds from Blombos and other sites on the South African coast over the last few decades (examples shown below) suggest that the region may have played a key role in the emergence of modern human behavior.

Lines of reason A block of ochre, used by Stone Age cultures as body pigment, is inscribed with crosshatched designs that suggest some degree of abstract or symbolic thinking. Blombos Cave contains pieces like this one dating back 100,000 years.

The first jewelry Shell beads from Blombos Cave are among the oldest known examples of personal ornaments. Excavations at a nearby cave suggest that people in southern Africa harvested shellfish, made specialized stone blades and decorated their bodies with pigment as early as 164,000 years ago.

TOP: C. THIÉBAUT; BACKSTORY, BOTH: C. HENSHILWOOD/WIKIMEDIA

Humans

212 words per minute | Typist Barbara Blackburn's maximum speed on a Dvorak keyboard

60 words per minute | Approximate speed of Guinness World Record for fastest text message

Fingers disclose truth about errors

Brain misplaces blame, credit when assessing typing skills

By Laura Sanders

The brain has more than one way to guard against sloppy copy. By using a doctored word processor to sneak errors into typed words and surreptitiously fix typists' real errors, scientists teased apart the various ways people catch their own mistakes. The findings, published in the Oct. 29 *Science*, highlight the complex ways in which the brain monitors performance.

Psychologist Gordon Logan and his colleague Matthew Crump of Vanderbilt University in Nashville recruited people who typed more than 40 words a minute using all of their fingers and were able to type a paragraph about the merits of border collies with over 90 percent accuracy.

As the typists pecked away, researchers introduced common typing errors into about 6 percent of the words that appeared on a screen (changing *sweat* to *swaet*, *swerat* or *swet*, for instance). The program also corrected about 45 percent of the typists' true errors.

In questionnaires after the test, subjects by and large took the blame for the introduced errors and took credit for the researchers' corrections. No matter what they actually typed, when typists saw that the word on the screen matched the word they had intended to type, they assessed their own performance as accurate.

After hitting the wrong key, though, a typist's fingers slowed down for the next keystroke, even if the researchers had fixed the error so that the typist didn't notice it. In these cases, a typist wasn't explicitly aware of the mistake, but the brain's motor signal still changed.

Logan says that this change in timing reflects a kind of automatic assessment of performance. "The body is doing one thing and the mind is doing another," he says. "What we found was that the fingers knew the truth."

Psychologists had suspected that the mind can detect errors in several ways, but "nobody had pinned it down," says cognitive neuroscientist Jonathan Cohen of Princeton University. "Here, they developed a very clever set of experiments to tease the types of systems apart."

The results may reveal a hierarchical method of error correction — with a "lower" system doing the actual work and a "higher" system assigning credit and blame, Logan suggests. These multiple layers of control may be evident in tasks such as playing music, speaking and walking to a destination. Whether the two types of error-catching systems operate in tandem or if one is subservient to the other isn't yet clear, Cohen says. ■

Convicts subpar at weighing risks

Serious offenders misgauge odds of both gains, losses

By Bruce Bower

Men imprisoned for murder and other serious offenses have a well-earned reputation for taking dangerous risks. But their problems with risk assessment may go much deeper than that.

Relative to men who haven't been incarcerated, prisoners generally have a harder time assessing the probabilities of big gains and harsh losses, says psychologist and study coauthor Thorsten Pachur of the University of Basel in Switzerland. In experimental lotteries, British prisoners displayed little appreciation of benefits that they stood a good chance of winning and often opted for smaller but sure rewards, Pachur and his colleagues conclude in the October *Psychonomic Bulletin & Review*.

If prisoners don't appreciate or consider the consequences of risky options, "increasing punishment will not necessarily be successful in reducing crime," Pachur says. Former prisoners may also find it difficult to appreciate the long-term payoffs of taking a chance on an entry-level job or educational opportunities.

> "Increasing punishment will not necessarily be successful in reducing crime."
>
> THORSTEN PACHUR

Programs to enhance prisoners' thinking skills should include sessions on how to understand the likelihood of various risky decisions to yield gains or losses, Pachur says. Current prison programs in England teach about moral reasoning, empathy and controlling impulses but have had little success in reducing crime.

"This article demonstrates that there is not one factor that makes some people risk takers and others risk avoiders," remarks psychologist Timothy Pleskac of Michigan State University in East Lansing. Reduced sensitivity to the probable outcomes of risky decisions may partly explain criminal behavior, but researchers know little about risk assessment among prisoners, Pleskac cautions.

Men imprisoned for serious offenses may prefer to use intuitive, simplifying rules of thumb to assess risks of all types, leading them to ignore useful information about potential gains and losses, Pachur hypothesizes. It's also possible that prisoners have often encountered situations with potentially big gains or losses — such as collecting millions of dollars in a successful bank robbery or spending decades in prison for a sexual assault — and thus become insensitive to the consequences of such decisions.

Body & Brain

"A 10-second difference in pace per mile could make the difference between success and a dramatic failure." —BENJAMIN RAPOPORT

Bitter air brings better breathing

Taste receptors for acrid gases dilate airways to lungs

By Rachel Ehrenberg

Inhaling bitter fumes may send a breathe-easy message to the lungs. Stimulating bitter-taste receptors can open the airways, a counterintuitive finding that could lead to new asthma medications, a team of Baltimore scientists report online October 24 in *Nature Medicine.*

In people and mice, bitter-taste receptors just like the ones on the tongue abound on the smooth muscle tissue that wraps around the airways leading to the lungs. In mice with asthma, inhaled bitter compounds such as quinine did a better job of relaxing airways than did the standard asthma drug albuterol.

The taste receptors in lung muscles should be good targets for new asthma drugs developed from the multitude of molecules already known to stimulate bitter-taste receptors, says Mathur Kannan, a pharmacologist at the University of Minnesota in St. Paul.

Still puzzling is the lungs' response to the bitter-flavored air. In the mouth, bitter receptors are part of the body's first line of defense against possibly poisonous compounds. Cells lining the upper part of the respiratory tract also have bitter-taste receptors, scientists showed last year. But there, the receptors can trigger an "out, out" reaction, stimulating the feather-like cilia of the airways to push whatever's nearby up and away. So researchers from the University of Maryland and Johns Hopkins expected that muscles controlling air flow to lungs would constrict when stimulated by bitter potential toxins, says Stephen Liggett of the University of Maryland School of Medicine, who led the new work. But it turns out that stimulating the bitter receptors in the airway muscles triggers a "relax, chill out" response in human and mouse cells.

Opening the airways may aid in clearing infection, the scientists speculate. Previous research revealed that some signaling molecules made by bacteria also activate bitter receptors. Perhaps relaxed airways prevent lung infections from festering.

"When you get a lot of gunk in there, it leads to a closed airway," Liggett says. "That would have been fatal in the days before antibiotics."

Making a marathon manageable

Or at least endurable, by calculating a sustainable pace

By Laura Sanders

A marathoner's worst nightmare — hitting "the wall" — may be completely avoidable if athletes adhere to personalized pace limits proposed by biomedical engineer and runner Benjamin Rapoport. His mathematical formula, published online October 21 in *PLoS Computational Biology*, shows the speediest pace a marathoner can sustain for an entire race.

"A 10-second difference in pace per mile could make the difference between success and a dramatic failure," says Rapoport, of Harvard Medical School and MIT, who experienced his own traumatic wall splat in the 2005 New York City Marathon. He started out pushing too hard, he says, and was out of steam by the last few miles. Rapoport finished, but with a slower time than he wanted.

To avoid this scenario, a runner has to maintain a pace that conserves carbohydrates, the body's main source of quick-burn energy. Rapoport calculates the ideal pace from a measure of aerobic fitness called VO_2max, along with a few other variables. VO_2max indicates how efficiently a body consumes oxygen.

"This is a unique area that hadn't been addressed in the medical literature in any substantial way," says Mark Cucuzzella, a physician and running coach based in Harpers Ferry, W.Va.

Given enough carbs before a race, a man with a VO_2max of 60 — which, after training, is attainable by only the top 10 percent of male runners — can achieve a 3:10 marathon finish time, the model predicts. This time happens to be the cutoff for 18- to 34-year-old men to qualify for the Boston Marathon.

VO_2max is usually measured with specialized equipment while someone exercises at maximum exertion, but it can also be estimated by measuring heart rate at rest or while running at a constant pace.

Rapoport's model also accounts for the slightly faster pace that can be maintained by adding carbs during a race.

On-the-go snacking helps, but it can't win races because the body can store only so much fuel, says Cucuzzella, chief medical consultant for the Air Force Marathon and a marathoner himself.

To help runners calculate their ideal pace, Rapoport put a version of his formula online (endurancecalculator.com). "My primary goal," he says, "is to give any marathon runner a quantitative plan for their training."

Running the numbers A new calculator uses aerobic capacity to tell marathoners the pace to keep to avoid "the wall" late in a race.

Pace comparison

	Runner 1	Runner 2
Age	25 years	25 years
Weight	160 lbs.W	160 lbs.
Carbs eaten before race	1,606 kcal	1,606 kcal
Resting heart rate/estimated VO_2max	40 beats per minute/72	70 beats per minute/41
Finishing time	2:39:22	4:38:54
Pace/mile	6:05	10:38

SOURCE: B. RAPOPORT, ENDURANCECALCULATOR.COM

89 percent Five-year survival rate for breast cancer

15.8 percent Five-year survival rate for lung cancer

5.6 percent Five-year survival rate for pancreatic cancer

Pancreatic cancer develops slowly

Gradual onset raises possibility of screening and treatment

By Nathan Seppa

Cancer of the pancreas takes a while to develop, possibly opening a decade-long window of opportunity for screening and removing tumors on this vital organ, a study in the Oct. 28 *Nature* shows. A companion study finds unusual chromosomal rearrangements in this deadly cancer, a characteristic that might provide insights into how the disease develops.

Scientists have been puzzled by the deadliness of pancreatic cancer. Only about 5 percent of patients survive for five years after diagnosis; by then the cancer has usually spread beyond the pancreas to lymph nodes or other organs.

Some researchers argue that the cancer is so lethal because it is fast-growing and aggressive, while others suggest the cancer's deadliness stems from an ability to remain hidden for years. The new research suggests a slow-growth theory might be on target.

In 2008, cancer geneticist Bert Vogelstein and his colleagues published complete genetic profiles of 24 pancreatic cancers, identifying more than 60 mutations common to the tumors. Now, the team has used those mutation data along with the average proliferation rate of pancreas cells to calculate the pace of cancer growth. The accumulation of mutations serves as a kind of clock that can tell scientists how long it took for the first cancer-related mutation in a pancreas cell to develop into cancer.

In pancreatic tumors obtained in autopsies of seven patients, that interval turned out to be an average of 11.7 years. It took another 6.8 years on average for tumors to appear outside the pancreas.

"We were surprised and very pleased by this result," Vogelstein says. This long lead time might eventually enable doctors to spot genetic or protein abnormalities linked to the cancer, he says.

Doctors might scan the pancreas with ultrasound for signs of a tumor in patients at risk, says coauthor Christine Iacobuzio-Donahue, a pathologist and cancer researcher also at Johns Hopkins. During a routine endoscopy doctors view the stomach with a camera-tipped tube threaded down the throat. Adding an ultrasound attachment would also scan the nearby pancreas for aberrant growths, she says. Cancer confined to the pancreas is often treatable with surgery.

> "It is hoped that such information will … lead to new approaches to early cancer detection."
> E. GEORG LUEBECK

In the other study, Iacobuzio-Donahue and her colleagues explored the nature of chromosomal instability in pancreatic tumors from 13 patients. The researchers found that these patients often had a distinct pattern of chromosomal rearrangements called fold-back inversions, in which strings of DNA loop back upon themselves. The origin and consequences of these rearrangements are unclear, but their pattern appears different from such rearrangements seen in breast cancer, the researchers note.

"The two studies are a bellwether, and are among the first to explore the biological and clinical implications of [genetic] sequence data for individual tumors," says E. Georg Luebeck of the Fred Hutchinson Cancer Research Center in Seattle, writing in the same issue of *Nature*. "It is hoped that such information will not only deepen our understanding of the cancer process, but also lead to new approaches to early cancer detection, better prognosis and, ultimately, prevention."

MEETING NOTES

Infectious Diseases Society of America, Vancouver, British Columbia, October 21–24

Pet frogs transmit salmonella

Pet African dwarf frogs harboring salmonella have sickened at least 113 people, most of them children, Shauna Mettee from the Centers for Disease Control and Prevention reported October 22. Between April 2009 and March 2010, the CDC traced 113 U.S. salmonella cases to the aquarium-dwelling amphibians. Three-fourths of the cases were in children under age 10. The median age of the patients was 5. Symptoms ranged from cramping to severe and bloody diarrhea; about one-third needed hospitalization. There were no fatalities. —*Nathan Seppa*

Anticancer protein may also combat HIV

A protein best known as a cancer suppressor may enable some people infected with HIV to stave off AIDS indefinitely, a new study shows. Copious production of this protein, p21, shows up in a select group of HIV-positive people who rarely develop AIDS, scientists reported October 21. Tests showed that in the most HIV-resistant group of infected subjects, CD4 T cells — the cells targeted by HIV — made 10 to 100 times more p21 than those of people more susceptible to HIV. "It might offer an alternative way to control HIV if we can find a way to manipulate this p21 protein in patients," said Mathias Lichterfeld of Harvard Medical School and Massachusetts General Hospital in Boston.
—*Nathan Seppa*

Technology

For longer versions of these and other Technology stories, visit **www.sciencenews.org**

Coffee grounds give robot a hand

Beanbag-like gripper proves to be versatile picker-upper

By Laura Sanders

A small bag filled with coffee grounds is lending robots a fingerless hand. The new kind of gripper, described in the Nov. 2 *Proceedings of the National Academy of Sciences*, can easily grasp all sorts of different objects.

"This could be game-changing technology," says engineer Peko Hosoi of MIT, who wasn't involved with the new study.

The gripper is made of a vacuum and a bag of coffee grounds, though couscous and sand also work, says study coauthor Eric Brown of the University of Chicago. To pick something up, the bag of loose grounds first melds around the object. As the vacuum sucks air from between the grains, the gripper stiffens into a hard vise molded to the object. Reducing the bag's volume by a teeny amount — less than 1 percent — allows the gripper to latch on.

A robotic gripper made of a stretchy bag of coffee grounds and a vacuum picks up a shock absorber with ease.

Because the gripper conforms to any shape evenly before the vacuum locks its hold, the device is extremely versatile. "Our goal was to pick up objects where you don't know what you're dealing with ahead of time," Brown says.

In experiments, the gripper held a cup of water well enough to pour, a pen well enough to write and, in a more daring feat, hoisted two water-filled gallon jugs tied together with a rope. The gripper was also able to grasp a raw egg, a formidable task for most robotic hands because hard metal pincers or fingers can concentrate force, shattering the fragile shell.

The researchers calculate that a similar gripper 1 meter across would be able to lift an object weighing 1 metric ton.

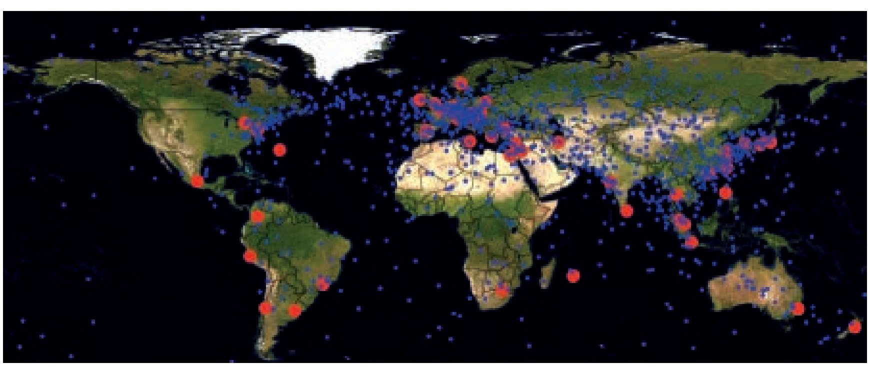
Let a thousand Wall Streets bloom

Study pinpoints optimal spots for playing financial markets

By Rachel Ehrenberg

Forget the trading floor — in the future, an empty lot in Uzbekistan or a barge anchored miles off Chile's southern coast may be the most lucrative spot for playing the financial markets. A new analysis identifies the optimal locations between the world's major securities exchanges for gaming the speed of light.

In today's markets, computers search for and act on relevant information in a flash, sending orders through fiber-optic cables at nearly light speed. By buying or selling shares split seconds ahead of the rest of the market, holding stock for mere moments and then doing it all again, high-frequency traders are turning fractions of pennies into piles of dollars. To trim time, some firms even place their computers as close as possible to an exchange's, a practice called "colocating" that cuts data travel time, giving some traders an edge.



When speed of light is the limiting factor, the best moneymaking locations (blue dots) for some high-frequency trades sit between, not at, big exchanges (red dots).

But to exploit the 50-odd milliseconds it takes for information to cross the Atlantic, the sweet spot isn't always at the exchange's door. For some assets sold on more than one market, such as the New York and London stock exchanges, the moneymaking spot is in the middle of the Atlantic Ocean, researchers report in a paper to appear in *Physical Review E*.

Many of the choice spots "are in the ocean or other poorly connected areas," says study coauthor Alexander Wissner-Gross of MIT. But some, such as Nova Scotia, are already well connected.

It's unlikely, however, that anyone will take advantage of this moneymaking map anytime soon, says Michael Kearns of the University of Pennsylvania in Philadelphia. If you take high-frequency trading to its theoretical limit, then yes — the limiting resource is the speed of light, he says. But right now it's hopping from router to router that slows data down. There are also regulatory issues, notes Kearns. "But if I blur my eyes about those things, well, these guys are doing something that is a sensible exercise," he says. "On Wall Street, never say never."

FROM TOP: JOHN AMEND; A. WISSNER-GROSS AND C. FREER/*PHYS. REV. E*

Atom & Cosmos

"Either this is something or this is a remarkable coincidence. And I think this is something." —DAN HOOPER

Gamma rays may signal detection of dark matter in Milky Way's core

Fermi telescope data analysis matches other experiments

By Ron Cowen

For years, most claims for evidence of dark matter, the ghostly material believed to account for more than 80 percent of the universe's mass, have seemed to dissolve into thin air. But a new claim may have more credibility, scientists say.

JPL/NASA

The Fermi Gamma-ray Space Telescope may have spotted signs of dark matter particles at the core of the Milky Way, illustrated here.

Physicists Dan Hooper of the University of Chicago and the Fermi National Accelerator Laboratory in Batavia, Ill., and Lisa Goodenough of New York University see signs of dark matter in an excess of energetic gamma rays emitted from the core of the Milky Way galaxy. The gamma rays were recorded over the last two years by NASA's Fermi Gamma-ray Space Telescope, launched in 2008. Hooper and Goodenough posted their findings October 15 at arXiv.org.

Dark matter, like ordinary atomic matter, is expected to concentrate at the galaxy's center. That makes the Milky Way's crowded core one of the most promising places to look for signs of the dark stuff. It's also one of the most complex places to search, because the core is riddled with a variety of ordinary but poorly understood sources of gamma rays, notes Fermi scientist Steve Ritz of the University of California, Santa Cruz.

Hooper and Goodenough found a sharply rising gamma-ray signal in data recorded from the innermost 570 light-years of the galaxy. That signal peaked at energies between 2 billion and 4 billion electron volts, about a billion times the energy of visible light. Hooper asserts that the location and energy of the gamma rays can't easily be explained by run-of the-mill sources, such as ultradense spinning stars called pulsars.

"We discussed a number of astrophysical possibilities for the origin of the signal, including a population of pulsars, cosmic ray interactions and emission from our galaxy's supermassive black hole," notes Hooper. "And in the end, no combination of any astrophysical sources could give us the signal we're seeing.… We tried dark matter and it fit beautifully without any special bells or whistles."

Astronomers require some kind of dark matter to explain why galaxies and galaxy clusters don't fly apart, and how the universe evolved from the Big Bang to its present state. The gravitational glue provided by ordinary matter isn't nearly enough to explain how the complex structure of the cosmos came to be. The density of dark matter inferred by Hooper and Goodenough is in the right ballpark to account for the universe's missing material, the team says.

"This is the most confident I have ever been that something we were seeing in an experiment was a signal of dark matter," says Hooper.

In addition, the mass of the proposed dark matter particles that Hooper and Goodenough infer from their analysis is consistent with findings from two terrestrial dark matter detection experiments — COGENT, in the Soudan mine in Minnesota, and DAMA, in the underground Gran Sasso National Laboratory near Rome (*SN: 8/28/10, p. 22*).

Hooper says he's particularly excited by the apparent match with the COGENT and DAMA experiments, results he had been independently considering for several months. "You should have seen the look on my face when those numbers came out of my computer code. I thought, 'No one is going to believe this.' … Either this is something or this is a remarkable coincidence. And I think this is something."

Physicist Neal Weiner of NYU says that the galactic center is a tricky place to study, but that doesn't justify brushing a signal like this aside. "This feature has a dramatic cutoff in its spectrum and a rapid falloff as a function of radius. I don't know of a population of astrophysical objects that has that distribution."

Nonetheless, Weiner cautions, "we need to be careful before making strong claims" that the signal comes from dark matter.

Ritz notes that he and his Fermi collaborators — Hooper and Goodenough are not on the Fermi team — are still trying to better estimate uncertainties in the distribution and identity of ordinary gamma-ray–emitting sources before weighing in on the dark matter issue.

"If you want to claim new physics, the burden of proof is very high," says Ritz. "You have to exclude actively all the standard astrophysical interpretations." ■

Matter & Energy

For longer versions of these and other Matter & Energy stories, visit **www.sciencenews.org**

A standard mass you can count on

Refining Avogadro constant to boost kilogram's precision

By Marissa Cevallos

The kilogram may finally get a break from its yo-yo diet. An international team of scientists is closer to redefining the unit of mass based on fundamental constants, instead of a piece of metal in France that loses weight only to put it back on again.

Since 1889, the international standard for the kilogram has been a cylinder of platinum stored in a vault outside Paris. But despite exceedingly stringent storage conditions, the cylinder (and six exact copies kept with it) gains weight from dust in the atmosphere, requiring regular steam baths to remove the crud. On top of that, the cylinders change mass relative to each other by micrograms per century, for reasons no one can fully explain.

Scientists want to redefine the basic metric unit of mass based on something truly constant, just as the meter is defined as the distance light travels in 1/299,792,458th of a second. Several teams have been trying to define the kilogram in terms of the Avogadro constant, well-known to chemistry students as the number of atoms or molecules in one "mole" (about 6.022 times 10^{23}).

The U.S. standard kilogram is housed at the National Institute of Standards and Technology in Gaithersburg, Md.

German scientists determined the constant by counting the atoms in painstakingly crafted one-kilogram spheres of silicon-28. Because, by definition, one mole of silicon-28 atoms weighs 28 grams, a kilogram of the material should contain 35.7142857 moles of atoms.

In principle, counting the atoms is like estimating how many Coca-Cola cans are in a giant mound of 12-pack cartons, says Arnold Nicolaus of the Physikalisch-Technische Bundesanstalt in Braunschweig, Germany. Simply measure the mound's volume and calculate how many cartons will fit inside, taking into account how the cartons are spaced. The researchers did that for the silicon spheres by measuring the distance between atoms using X-ray interferometry.

The scientists estimated the Avogadro constant at 6.02214084 times 10^{23}, with an uncertainty of only 30 parts per billion, they write in a paper published online October 12 at arXiv.org. The hunk of metal in Paris, for all its faults, is still a little more reliable than that. Its mass is uncertain to 20 parts per billion.

"We're getting very close. It's a big step," said Edwin Williams, an emeritus physicist at the National Institute of Standards and Technology in Gaithersburg, Md.

But the problem now is that not everyone agrees on the true number for the Avogadro constant. American and British teams have tried measuring the constant another way, by balancing gravity's force on a mass with the electrical forces needed to suspend it in midair, but repeated trials gave inconsistent measures of the constant. Currently, the number is set by a committee that considers the results from different experiments.

The beauty of a constant, however, is that it doesn't matter which number you choose, Williams says. As long as the Avogadro constant stays constant, it will be useful for defining the kilogram. ■

Sailing toward the island of stability

Creation of new superheavy isotopes encourages researchers

By Marissa Cevallos

Chemists searching for the island of stability now have a better map. Thanks to the discovery of six new variations, or isotopes, of the superheavy elements on the periodic table's bottom rung, scientists are closer to creating superheavy elements that are stable enough to study in depth.

Researchers at Lawrence Berkeley National Laboratory in California saw the new isotopes by watching the decay of the synthetic element 114. The isotopes of an element differ in the number of neutrons in the nucleus, a variable that can affect radioactivity and other properties.

Scientists believe that certain combinations of protons and neutrons in a superheavy element's nucleus would place it in an "island of stability" where decay would be much slower than in superheavy elements created so far (*SN: 6/5/10, p. 26*). The new isotopes may help guide theorists to a better understanding of where that island lies.

"The half-lives are picking up in a fashion that's pretty encouraging," says chemist Paul Karol of Carnegie Mellon University in Pittsburgh.

The nuclear chemists created a sample of element 114 by bombarding a plutonium target with a beam of calcium ions. As the atoms decayed, the team saw six previously undiscovered isotopes of other heavy elements, the scientists report in the Oct. 26 *Physical Review Letters*.

Earth

For more Earth stories, visit **www.sciencenews.org**

Siberian lake yields climate record

Winter drilling project also penetrates ancient impact crater

By Alexandra Witze

It took the better part of a decade, $10 million and help from the guys who build ice roads for Canadian truckers. But scientists now have the most continuous record of ancient climate ever extracted from the terrestrial Arctic.

"It's like the difference between having the complete set of encyclopedias versus having a few volumes that provide lots of information but not the whole story," says climate expert Yarrow Axford of Northwestern University in Evanston, Ill., who was not involved in the project.

The record — cored through sediment layers beneath a lake in northeastern Siberia — also illuminates what happened when a kilometer-wide meteorite smashed into the spot 3.6 million years ago. Water filled the resulting crater and formed Lake El'gygytgyn (pronounced EL-gih-git-ghin).

Julie Brigham-Grette, a geologist at the University of Massachusetts Amherst and one of the project's leaders, described the findings on October 31.

Analysis of the cores reveals details of how the Arctic warmed and cooled over the last several million years, she said. Comparing similar data from the Arctic Ocean and Antarctica can show how the two polar regions — which are more sensitive to climate change than temperate or tropical latitudes — react differently to changing temperatures.

Lake El'gygytgyn lies 100 kilometers north of the Arctic Circle and 360 kilometers from the nearest inhabited town: Pevek, Russia. The 12-kilometer-wide lake is too windy and rough to be drilled from a floating rig in the summer, so the researchers decided to drill from an ice platform in the winter.

The team had to ship camp materials and a drill rig to Pevek, then use helicopters or trucks running along an ice road that ended 90 kilometers short of the lake. For the final leg, equipment was hauled with bulldozers through the snow.

After all that, the team had to artificially thicken the lake ice by drilling a small hole and pumping water to the top to freeze again. The ice thickness had to be 2 meters in order to support the weight of the drill rig.

Back when the meteorite hit, temperatures were probably 10 to 14 degrees Celsius warmer than today, Brigham-Grette said. The impact vaporized much of the silica-rich rock, turning it into a jumble known as breccia with fractured quartz grains and other particles melted by the impact's heat.

The core holds no tiny fossils or pollen in the 15 meters just above the layer marking the meteorite impact, Brigham-Grette reported — possibly because the searing heat zapped anything that would otherwise have been preserved.

Researchers drilled a sediment core from Lake El'gygytgyn using the frozen lake as a stable platform.

LAKE EL'GYGYTGYN SCIENTIFIC TEAM

MEETING NOTES

Fossil fangs not so fierce

Anomalocaris, that fearsome predator of ancient seas, may have to return its title. A new analysis suggests that the monstrous shrimplike creature, which lived more than 500 million years ago, couldn't handle crunchy food.

Researchers modeled the stresses that *Anomalocaris* jaws would have undergone while feeding on snacks as hard as lobster tails. The team found that eating hard-shelled prey, such as the trilobites that were ubiquitous at the time, would have fractured the critter's mouth plates, James Hagadorn of the Denver Museum of Nature and Science reported November 1.

Though fierce-looking and up to 2 meters long, *Anomalocaris* may have fed — like a dental patient slurping up applesauce — mostly on tiny, softer prey. —*Alexandra Witze* ■

Old lunar rocks are new

For the first time in decades, researchers have identified a new type of rock found on the moon. Scientists spotted the rock on the moon's farside using a spectrometer aboard the Indian mission Chandrayaan-1. The material is probably very old and was apparently brought up somehow from deep inside the moon, Carle Pieters, a planetary geologist at Brown University in Providence, R.I., reported November 2.

The rock appears in a few places in the Moscoviense basin, and preliminary work suggests that it also lurks in a second basin. For the moment the rock bears the name OOS, because it is rich in the minerals orthopyroxene, olivine and spinel. —*Alexandra Witze*

Genes & Cells

Gene therapy might ease depression

Boosting protein in key brain region shows promise in mice

By Laura Sanders

Scientists have pinpointed a brain region where scarcity of a key protein may contribute to depression. Published in the Oct. 20 *Science Translational Medicine*, the findings could pave the way to treating some depression with gene therapy.

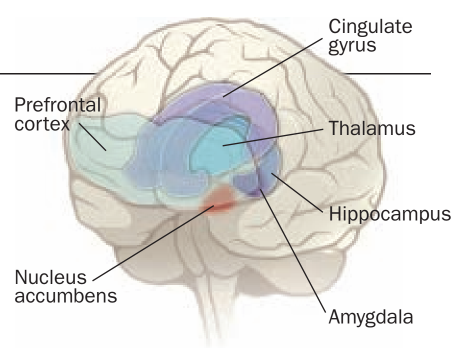
A team led by Michael Kaplitt of Weill Cornell Medical College in New York City found that levels of the protein, called p11, were lower in the brains of 17 people diagnosed with major depression than in the brains of matched controls. This difference was seen in the brain's nucleus accumbens, a structure involved in pleasure, drug addiction and depression.

When Kaplitt's team lowered levels of p11 in the nucleus accumbens of mice, the animals showed behaviors akin to those seen in depressed humans. These mice quit struggling sooner when held by their tails, swam less in water when escape was impossible and drank less sugar water.

Finding that p11 is required specifically in the nucleus accumbens makes sense, Kaplitt says. "We're not saying it's the only area that matters," he says. "But it did say to us that this particular site is important for p11 action."

The scientists could reverse the mice's depression-like behavior with gene therapy. The team injected a virus carrying the p11 gene into the nucleus accumbens of mice with no p11. Cells in the region began producing p11, and the mice no longer displayed elevated signs of despair.

"We believe that low levels of p11 may be one of the causes of depression in at least some patients," Kaplitt says. "If we can restore it to normal levels, we can potentially reverse the process."



Using gene therapy to deliver a gene encoding the protein p11 to the human nucleus accumbens (red) might provide a new way to treat depression.

A human clinical trial testing the efficacy and safety of a similar gene therapy technique to treat Parkinson's disease has just ended, Kaplitt says, so he is hopeful that a gene therapy trial for human depression might be ready to start in one to two years.

Kaplitt cofounded and is a consultant for the Fort Lee, N.J., gene therapy company Neurologix Inc., which has licensed rights to develop p11 gene therapy treatments for behavioral disorders.

To 1,000 genetic blueprints or bust

Project identifies millions of new variations in human DNA

By Tina Hesman Saey

The average person walks around with defective copies of 250 to 300 genes, a new close-up snapshot of human genetic diversity reveals, including about 75 DNA variants associated with disease.

Those disquieting figures come from data gathered during the pilot phase of the 1000 Genomes Project and reported in the Oct. 28 *Nature* along with a companion paper in the Oct. 29 *Science*.

Despite its name, the project is an effort to catalog genetic variation in about 2,500 people, with special emphasis on finding more of the relatively rare variants present in less than 5 percent of the population. The information can be used to search for links between DNA variation and disease, and to study events in human prehistory that have left a genetic footprint.

Analyzing the chemical letters of DNA, the project found about 15 million different one-letter variations, 1 million small insertions or deletions of portions of chromosomes, and about 20,000 larger missing or duplicated chunks of DNA in the human genetic instruction book. Among these are about 8 million newly identified genetic variants.

In addition, researchers report in the *Science* paper that they have discovered about 1,000 genes that are duplicated in many people, including 44 gene families whose extra copies were previously unknown. Most of the duplicated genes the researchers found varied between zero and five copies per person, but a few extreme examples had ranges between five and 368 per person.

About five years ago, roughly half of the variants discovered each time that researchers deciphered another person's genetic blueprint were new, says David Altshuler, a geneticist at the Broad Institute in Cambridge, Mass., and one of the leaders of the 1000 Genomes Project. "Now, about 95 percent of what you'll find in the next person's genome is already in the database," he says.

In this early stage of the project, researchers closely read the entire genome of six people from two families. Each family consisted of a mother, father and daughter. One of the families belongs to the Yoruba tribe in Ibadan, Nigeria; the other is a family of European descent living in Utah. In addition, researchers skimmed the genomes of 159 people from Nigeria, Utah, Japan and China. Researchers also read the genetic equivalent of CliffsNotes of 697 other people by examining just the protein-producing parts of 906 genes.

Y. HAMMOND, C. BICKEL/*SCIENCE TRANSLATIONAL MEDICINE*

Clash of the Quantum Titans

After decades of debate, disputes over the mathematical rules governing reality remain unresolved

By Tom Siegfried

Schrödinger's cat was born 75 years ago. Its date of death remains uncertain. Science's most famous feline remains perpetually both alive and dead, a mythological zombie symbolizing an enduring enigma at the heart of modern physics.

It's an imaginary cat, of course, invented by Austrian physicist Erwin Schrödinger in 1935 to emphasize the weirdness of quantum mechanics, the mathematical constitution governing the microworld. An experiment could be devised, Schrödinger showed, to put a cat in a box into a live-dead limbo (technically, a "superposition" of states) until somebody looked inside. In the same paper, Schrödinger described another quantum conundrum, known as entanglement, in which measuring one particle seemed to affect the properties of another a great distance away. Entanglement was the feature of quantum physics that Einstein lamented as "spooky action at a distance."

Semighostly cats and spooky long-distance influences both reflected the radical new view of reality that quantum theory imposed on 20th century physics. Quantum reality is ruled by probabilities. Instead of the rock-solid cause-and-effect world of Newtonian physics, humans occupy a casino universe with an undetermined future, a state of affairs that evoked Einstein's famous complaint that God does not play dice.

Although both Einstein and Schrödinger helped give birth to quantum physics, they believed something was seriously amiss about it. Yet its predictions have always come true, no matter how absurd. Experiments have confirmed the Schrödinger-cat superposition, for instance, with atoms in multiple locations or simultaneous high- and low-energy states playing the role of the cat. And entanglement, though it remains mysterious, is no longer ghostly. It is now regarded as an information and communication resource, sort of the way the electromagnetic spectrum offers channels for TV stations and cell phone signals. Entanglement provides for an entirely novel type of communication involving "quantum" information, useful for sending secret codes, enabling computers to perform otherwise impossible calculations and promising new kinds of messaging networks.

"This is a huge effort worldwide now to develop quantum

Quantum special section

The world got much weirder 75 years ago, when linked fates and zombie cats infiltrated the culture of physics.

Web edition For pdfs of this section and past quantum stories, visit www.sciencenews.org/quantum75 information," says Anton Zeilinger, a leading quantum experimentalist. "It is probably the fastest-expanding subfield of physics right now ... not only because of the technical promise but also because of the fundamental questions still being very interesting."

Those same fundamental questions that concerned Einstein and Schrödinger continue to disturb many physicists today. What quantum mechanics really means, where it ultimately comes from, why it denies the cause-and-effect certainty of traditional physics are all questions that haunt the deepest scientific thinkers — and divide them almost as badly as 21st century political parties. Physicists simply can't agree on how to interpret quantum physics. They fight like cats and dogs over it.

"There are different views," says physicist Nino Zanghì of the University of Genoa in Italy. "And the different views are defended by sensible people."

At the heart of these disputes is the very nature of reality itself, and whether quantum physics is the last word on how to describe it. Zeilinger, of the University of Vienna, advocates the standard quantum view of reality's fuzziness. "It turns out that the notion of a reality 'out there' existing prior to our observation ... is not correct in all situations," he points out.

"It turns out that the notion of a reality 'out there' existing prior to our observation … is not correct in all situations."
ANTON ZEILINGER

Yet some physicists cling to the prejudice that cause-and-effect determinism will someday be returned to its privileged status, and physics will restore objectivity to reality.

"I basically understand why people have this position," Zeilinger responds. "But the evidence is overwhelming that this approach would not succeed."

Both particle and wave

That evidence has been accumulating for more than a century. Quantum theory's first success came in 1900, when Max Planck invented it to solve a problem about the colors of light emitted from hot objects. Energy from such objects had to be emitted in packets (called quanta) to explain the observed colors, Planck determined. In 1905 Einstein used quantum reasoning to explain the emission of electrons from certain substances exposed to light (the photoelectric effect). He concluded that light itself was composed of particles (later called photons), but few believed him at the time, the wave nature of light having been conclusively established a century earlier.

In 1913, though, the quantum concept gained credibility when the Danish physicist Niels Bohr used it to explain the colors emitted by hydrogen atoms. A dozen years later, Bohr's German mentee Werner Heisenberg (and then shortly thereafter, Schrödinger himself) showed how to apply the quantum concept to more complicated atoms, and quantum mechanics was born.

One small snag remained: Heisenberg's math treated an atom's electrons as particles; Schrödinger's equation described waves. Both approaches produced identical results, though, and Heisenberg's professor, Max Born, then showed that the wave math could be interpreted as a measure of probabilities for a particle's properties. At the same time, new experiments revealed that electrons did indeed sometimes behave like waves — and for that matter, light sometimes behaved like particles, just as Einstein had declared two decades earlier.

Out of this morass emerged two principles. One was Bohr's principle of complementarity. No one picture of nature provides a complete description of quantum phenomena, Bohr asserted. Rather, mutually exclusive but complementary pictures must be invoked, depending on the experimental situation. In other words, if you design an experiment to see if electrons are waves, you get waves. If you design an experiment to test whether electrons are particles, you get particles.

Bohr's philosophical principle was complemented by the hard mathematics of Heisenberg's uncertainty principle, which declared that you couldn't precisely measure some pairs of properties simultaneously. (You could not, for example, determine both the exact position and the momentum of an electron in any one experiment.) Heisenberg's limit had nothing to do with human capabilities; an electron simply does not possess a well-defined position or momentum before a measurement. Unobserved, an electron exists in multiple locations at once, just as Schrödinger's cat is both alive and dead until somebody opens the box. All physics can provide are the odds of spotting the electron in any given place (or finding an expired feline).

Both Bohr's complementarity and Heisenberg's uncertainty were proposed in 1927. For the next several years, Einstein and Bohr engaged in a titanic debate over the implications — Einstein attempting to show that the uncertainty principle had exceptions, Bohr refuting Einstein's arguments at every turn. Finally Einstein acknowledged that the uncertainty principle was unavoidable with respect to what could be observed. But he began to believe that the observable was not all there was to reality.

In 1935, Einstein and two collaborators proposed a thought experiment designed to illustrate a mismatch between reality itself and its quantum description. Suppose, they wrote, that two particles interacted with each other and then flew far apart. Quantum math describes the pair as a single system, such that measuring the momentum of particle A would instantly reveal the momentum of particle B. Similarly, measuring particle A's position instead would instantly reveal the position of particle B. (Other properties, such as spin or polarization, would be similarly linked.)

Zombie cat In 1935, Austrian physicist Erwin Schrödinger developed a cat-killing thought experiment to illustrate his annoyance with one of the oddest features of quantum mechanics: its insistence on the existence of multiple simultaneous realities. Imagine a sealed box, he said, in which a cat exists along with a sealed flask of hydrocyanic acid. Next to the acid is a hammer, attached to a box that contains a radioactive substance. A Geiger counter is rigged to release the hammer when the radioactive substance decays, smashing the flask and releasing cyanide gas to kill the cat. After an hour, chances are about 50–50 that one of the radioactive atoms will have decayed. So the cat, according to quantum mechanics, exists in a half-live, half-dead quantum state, until somebody opens the box to see. Schrödinger disliked the idea that the "real" condition of the cat was determined by someone's observation, but at the subatomic level the basic idea has been experimentally demonstrated, with atoms simultaneously occupying multiple positions until observed. —*Alexandra Witze*

MICHAEL MORGENSTERN

Einstein and friends (Boris Podolsky and Nathan Rosen) did not deny that a measurement on particle A, no matter how distant, could provide information about particle B. But it seemed to them that if either the position or momentum of particle B could be determined, it must have possessed both: There should be no way that an action at one place could change the "reality" at another place far away. Yet the uncertainty principle allowed measuring only one property or the other, not both. Therefore quantum mechanics must be an incomplete theory. There has to be something more.

Einstein's thought experiment inspired Schrödinger's paper describing the spooky entanglement. It also inspired a critical reply from Bohr. He declared that it made no sense to ascribe "reality" to something before it was measured. In any actual experiment, he pointed out, you could measure only momentum or position, not both. Position and momentum could not be simultaneously real.

In more picturable terms, the dispute boils down to something like this: Suppose a quantum leather factory in Las Vegas sends out two boxes — one to Sue in Ohio and one to Jim in Texas. Sue opens her box and finds a left-handed glove; she then knows instantly that Jim has received a right-handed glove. But suppose Sue had opened the box and found a right-footed shoe. Then she would know for sure that Jim now possessed a left shoe.

Einstein believed that the shoes or gloves were inside the boxes from the time they left the factory. Bohr believed that both boxes contained formless leather until Sue opened her box (or Jim — it doesn't matter who goes first). Instead of causes and effects all operating at specific locations, Bohr's view implies a holistic aspect of reality, with "nonlocal" influences defying the ordinary limits of space and time.

For decades afterward, the Einstein-Podolsky-Rosen paper remained irrelevant to the practice of physics, since most physicists accepted Bohr's response or believed no real-life experiment could settle the dispute. But then in 1964, John Bell, a physicist at the CERN laboratory in Geneva, analyzed a variant of the EPR idea. Bell showed that, in principle, experiments could in fact distinguish between quantum mechanics and theories that proposed additional "hidden" features that would restore locality to reality. Twenty years later, various experiments had been conducted to test Bell's math, and quantum mechanics, like Perry Mason, won every time.

Einstein was no Hamilton Burger, though, and his appeal is still posthumously pending. Even though the experiments all turn out exactly as Bohr would have predicted, sympathy for Einstein's position has been increasing in recent years, along with growing antipathy toward Bohr.

Some physicists claim (simultaneously) that it's impossible to understand what Bohr meant and that he was wrong (perhaps a curious example of complementarity in itself). Bohr had repeatedly insisted that experiments had to specify a clear distinction between the measuring apparatus, described in ordinary nonquantum language, and the quantum system to be observed — say, electrons or photons. Modern anti-Bohrians argue, though, that quantum mechanics applies to experimental instruments (and everything else), so any such division of the world into classical instruments and quantum phenomena is arbitrary and illogical.

As Maximilian Schlosshauer and Kristian Camilleri point out in a recent paper, Bohr understood very well that instruments also obeyed quantum mechanics. But he insisted that distinguishing the instrument from the object of observation was essential to doing science. Otherwise everything becomes a mixed-up mess of quantum fuzz, with no way to find out anything definite. "If everything is just gobbled up by ever-spreading entanglement and homogenized into one gargantuan maelstrom of nonlocal quantum holism, and if we can't conceptually isolate and localize a system and regard it as causally independent from some (potentially distant) other system, then there are no systems that could be the object of empirical knowledge," Schlosshauer and Camilleri write in a paper posted online in September at arXiv.org. To get knowledge about a quantum system, Bohr averred, an observer had to probe it with an external apparatus and report the results in ordinary language.

Bohr's view prevailed for decades. But two nagging issues continued to plague physicists and philosophers alike: How one single reality emerges from the multiple quantum possibilities, and how quantum physics applies to the whole universe, with no outside observer to conduct an experiment.

One early attempt to address those issues was developed by Hugh Everett III at Princeton University in the 1950s (see Page 31). Everett took quantum math at face value — if it contains multiple possible realities, he reasoned, then all the possible realities exist. When you make an observation, you get one result, of course, not a cloud of multiple quantum possibilities. Another of those possibilities actually does occur, however, in a sort of parallel universe occupying the same space. You just somehow split into different versions of yourself, each unaware of the other, occupying separate realms of existence with different experimental outcomes.

John Wheeler, Everett's thesis adviser, initially supported the multiple-reality idea but later dismissed it as requiring "too much metaphysical baggage." Nevertheless Everett's view, later designated the "Many Worlds" interpretation of quantum mechanics, inspired further efforts to address the issues that Bohr's approach had not resolved. One popular approach involved a peculiar phenomenon called quantum decoherence.

A puzzling paradox

In 1935, Albert Einstein and colleagues Boris Podolsky and Nathan Rosen of Princeton University collaborated on a paper arguing that the description of physical reality provided by the math of quantum mechanics was incomplete.

They proposed a thought experiment in which two particles have interacted and then separated. Without further measurement, a quantum description can be formulated only for the state of both particles together; it would be impossible, for instance, to use quantum math to predict the momentum of either one of them. But once the momentum of one is measured, the momentum of the other would be known with certainty without the need for another measurement.

Einstein and colleagues insisted that because quantum mechanics could not predict the momentum of a particle — even though its momentum could in fact be measured — the theory must be incomplete. Einstein's adversary on this issue, Niels Bohr, replied that neither particle possessed a momentum until one was measured.

In recent decades, experiments using variants of what has come to be called the "EPR paradox" have confirmed Bohr's view. Distant particles can in fact be linked even when information can't pass between them. This distant linkage, called entanglement, reveals an "inherent nonlocality" in nature. —*Alexandra Witze*

Decoherent reality

Decoherence offers a simple solution to the paradox of Schrödinger's cat. In principle, the quantum description of the cat comprises both life and death, just as a rock could, in principle, simultaneously occupy different locations. But air molecules and dust particles and light beams bounce off of rocks. After a fraction of a second, only one location for the rock will be consistent with the paths of the deflected particles — a coherent wave describing multiple possibilities has thus "decohered" into just one outcome. Something similar would happen to the cat: Environmental interactions guarantee the cat to be either dead or alive before anybody looks in the box.

One especially elaborate variant of the decoherence theme has been developed over the past two decades by physics Nobel laureate Murray Gell-Mann and his collaborator James Hartle. In their approach, multiple realities in the quantum fog condense into various chains of events, each chain approximately observing the cause-and-effect rules of classical physics. In other words, people perceive the world as classical and predictable, rather than quantum and probabilistic, because they occupy a realm where predictable patterns have decohered from the coherent cloud of quantum possibilities. Each such chain of events would constitute a "consistent history." More than one consistent history might emerge from the quantum cloud, similar to the many worlds of Everett's interpretation.

Using the math describing decoherence, physicists can calculate the probabilities of the various consistent histories, says Gell-Mann, of the Santa Fe Institute in New Mexico. He and Hartle, of the University of California, Santa Barbara, emphasize that these consistent histories arise naturally in any "coarse-grained" view of reality. Quantum weirdness persists in the fine-grained view of nature at the subatomic scale, but decoheres into ordinary physics in the coarser-grained realm of macroscopic objects. It's much like the way coarse-grained (and predictable) properties of a gas, like temperature and pressure, emerge from the unpredictable and unobservable behavior of tiny molecules bouncing off each other.

Throughout their lives, Albert Einstein and Niels Bohr (shown in 1927 at a conference in Brussels) disputed the implications of quantum mechanics for the nature of reality.

PAUL EHRENFEST, COURTESY AIP EMILIO SEGRÈ VISUAL ARCHIVES, EHRENFEST COLLECTION

Viewed in this way, quantum physics can accommodate an entire universe with no reference to an outside observer — consistent histories decohere from within. "Our way of doing it … for a given initial condition of the universe, as well as a given unified theory, would give predictions for the probabilities of alternative coarse-grained decoherent histories of the universe," Gell-Mann says.

Gell-Mann and Hartle's approach is similar in some respects to Everett's, and it incorporates Bohr's view as well. Bohr's analyses involved measurements by observers experimenting on systems within the universe. That approach wasn't wrong, Gell-Mann says — just not general enough to deal with the universe as a whole.

"It's correct in a sense, but it can't be general, it can't be the deep way to look at quantum mechanics," Gell-Mann observed in a 2009 interview. "It's a special case.... If you look at 13 billion years of the history of the universe, you can't describe it that way until very recently."

Gell-Mann and Hartle's view also offers natural explanations for the counterintuitive results of some quantum experiments. Multiple possible outcomes of such experiments are simply different results in different histories.

Consider a typical entanglement paradox similar to the Einstein-Podolsky-Rosen experiment. Two entangled photons fly away from a common source toward distant laboratories set up to measure polarization — the orientation of the light's vibrations. When photon A arrives at its destination, detectors can record either a horizontal or vertical alignment. The experiment can be set up so that if "horizontal" is the answer for photon A, then photon B, no matter how far away, will be horizontal also. If the first photon was vertical, then so is the second. But no magic message was instantly sent from one photon to the other. In the Gell-Mann–Hartle view, one measurement simply reveals which consistent history you are in. If your measurement of photon A is vertical, you are in the history where both photons turn out to be vertical. In another consistent history, the photons are both horizontal.

"Those are two different branches of history — two different alternative coarse-grained decoherent kinds of history," says Gell-Mann. "They have nothing to do with each other.... If it had been explained that way to Einstein, he might have accepted it."

Desperate measures

Or maybe Einstein was right in the first place. Paul Dirac, one of the pioneers of quantum mechanics, considered that to be a possibility. "I think that it is quite likely that at some future time we may get an improved quantum mechanics in which there will be a return to determinism," Dirac said in a 1975 public lecture. "But such a return to determinism could only be made at the expense of giving up some other basic idea which we now assume without question."

Few experts today believe that a future quantum physics will restore determinism, and most efforts in that direction meet dead ends when confronted with experimental results. But one among those yearning for a return to determinism — the Dutch Nobel physics laureate Gerard 't Hooft — has looked more deeply into the issue than most and sees some hope. He accepts the validity of experiments showing that hidden variables cannot explain quantum outcomes deterministically. To restore cause and effect, 't Hooft believes, will require digging even deeper into reality than quantum mechanics has so far penetrated.

When James Clerk Maxwell developed the idea of electromagnetic fields in the mid-19th century, he pictured reality in the microcosm as a mesh of tiny gears that transmitted forces described by deterministic equations. Suppose, says 't Hooft, that the reality underlying experience is not so much like gears and switches, but more like the bits and bytes processed by computers. Information on this subquantum level, at the root of reality, might be processed deterministically after all, just at a level beyond the reach of any conceivable mathematical description.

"The general consensus is that the amount of information that nature can store in a very tiny volume of space and time is gigantic, it is so tremendously big that there is no hope whatsoever to follow this thing with any rigorous mathematics at all," 't Hooft said in July at the Euroscience Open Forum conference in Turin, Italy.

But mathematical tools are available to deal with such situations — namely, the math of probability and statistics. In fact, 't Hooft's investigations suggest that statistical equations describing this world of information too small to be seen would reproduce the features of quantum mechanics, including superposition and entanglement. But as Dirac suspected, achieving this return to determinism would come at a cost — in this case, abandoning the idea that particles and fields are ultimately real.

"The particles and fields are very, very crude statistical descriptions," 't Hooft says. "Those particles and those fields are not true representatives of what's really going on."

Zeilinger, on the other hand, does not expect the future to return physics to the past. It is more likely, he suggested at the Turin conference, that an advanced theory going beyond today's quantum mechanics will be even more counterintuitive.

"In the end of the day," he says, "the situation is such that when we ever succeed — and I think we will succeed to build a new theory even beyond quantum physics — when we have the new theory, people who attack quantum theory today ... would love to have quantum mechanics back." ■

Explore more

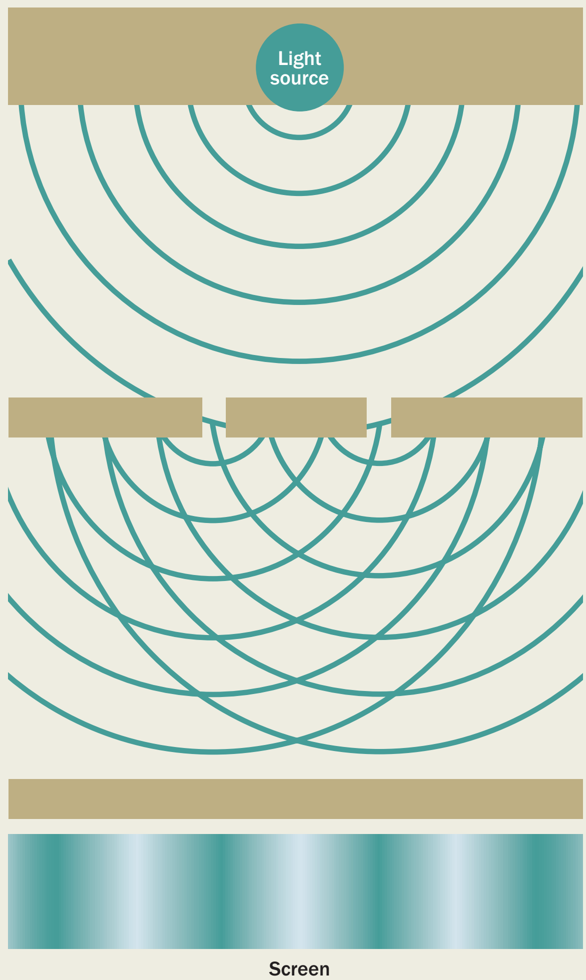
- Max Born. *The Born-Einstein Letters: Friendship, Politics and Physics in Uncertain Times*. Macmillan, 2004.
- University of Vienna's quantum institute: www.quantum.at

Quantum weirdness

Some key concepts in quantum mechanics lead to rather startling results. In the quantum world, objects can be in two states at once and the outcomes of experiments can change depending on when, how and how often scientists make their measurements.

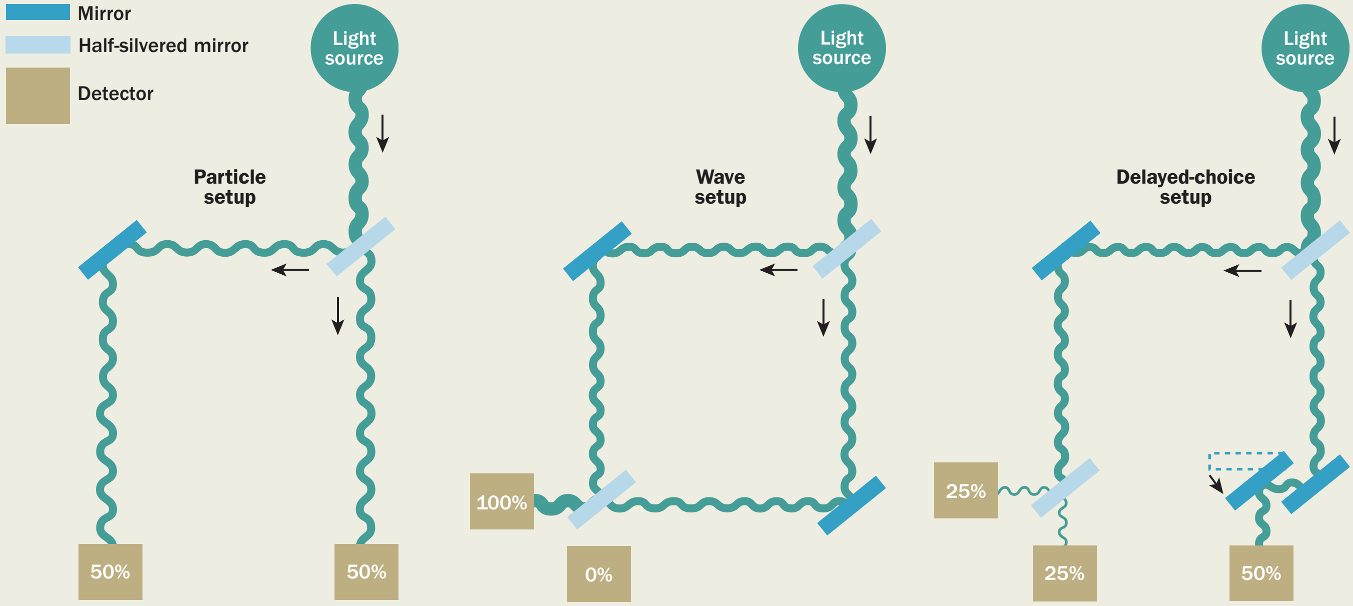
Double-slit experiment

An electron can be either a wave or a particle depending on the design of the experiment. If electrons pass through a single slit in a barrier and then strike a phosphorescent screen, they make patterns indicating the arrival of particles. But if two slits are available, an electron "wave" interferes with itself, producing the alternating bands of an interference pattern on the screen (bottom). This wave-particle duality is a fundamental feature of quantum physics and applies to all "particles" (including photons, particles of light) and even to atoms and molecules. Experiments have, for instance, shown the wavelike nature of fullerene molecules composed of as many as 70 carbon atoms.



Delayed-choice experiment

The delayed-choice experiment permits an observer to change the outcome of an event after it has already happened.



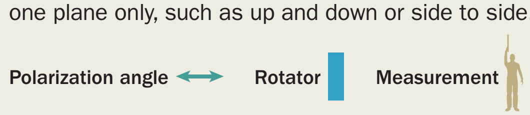
In an experimental setup designed to detect particles, a single photon is shot at a half-silvered mirror. The photon must choose one of two paths—reflecting off of the mirror or passing through it. There's a 50 percent chance the photon will strike the detector at the end of one path and an equal chance that the photon will hit a detector along the other path.

A second setup tests for waves. In this case, the single photon interferes with itself in a way that is possible only if the light consists of waves. One detector always records the entire signal because the recombining waves reinforce each other. The photon appears to know that it should behave as a wave, taking both paths when it gets to the first mirror.

In 1978 physicist John Wheeler had an insight: Adding a movable mirror to the wave-detecting setup could make the light choose one of two paths (particle, shown above) or both paths (wave) *after* it had passed through the first mirror. Delayed-choice experiments were first performed in the 1980s and Wheeler's version was confirmed in 2007.

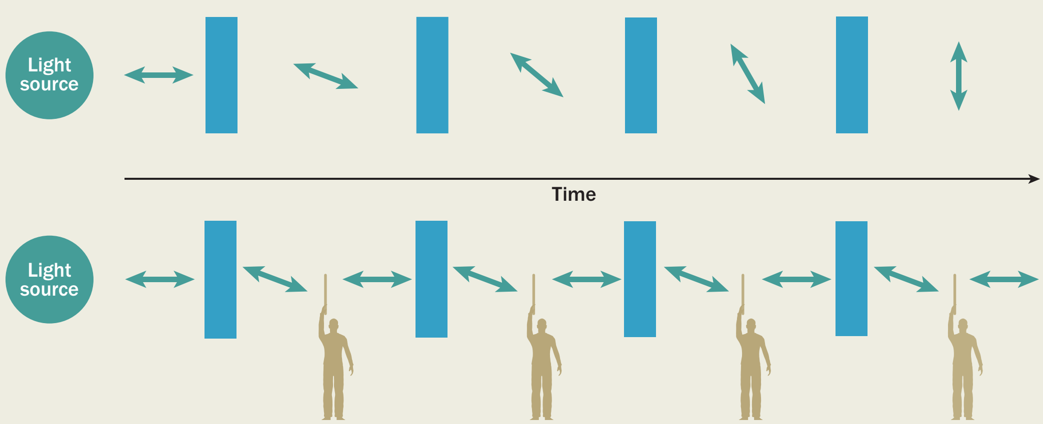
Quantum Zeno effect

The quantum Zeno effect gives truth to the adage that a watched pot never boils. Under some circumstances, repeatedly observing an unstable particle that would normally decay away quickly actually prevents it from decaying. The effect gets its name from the Greek philosopher Zeno, who held that an arrow in flight could not actually be moving because it seems to be standing still at each individual moment of observation. The quantum Zeno effect can be demonstrated with an apparatus that rotates the polarization of light. Polarized light waves oscillate in one plane only, such as up and down or side to side.



Repeatedly rotating the side-to-side oscillations of a light wave by just a bit should eventually transform the wave into an up-down polarization.

But measuring the polarization immediately after each slight rotation restores the light to its original side-to-side polarization.



E. FELICIANO

MICHAEL MORGENSTERN

Everyday entanglement

Physicists take quantum weirdness out of the lab

By Laura Sanders

If the Manning brothers were quantum physicists as well as NFL quarterbacks, one of them could win his game's opening coin toss every time. The night before they played, the brothers would take two coins from a special quantum box to use the next day. If Peyton's game came first, after learning the outcome of his coin toss, he would know without a doubt how his brother's coin would land. Say Peyton's came up heads; he could text "tails" to his little brother. Eli would correctly call tails in his later game and win the toss (not that it would do the Giants much good).

Such a creepy connection of the fates of far apart coins does not yet threaten the integrity of football. But in the microworld, where the players are atoms and photons, this long-distance connection — technically called quantum entanglement — is as real as instant replay. In fact, entanglement is at the very heart of reality. No mere quantum quirk of interest only to physicists, its peculiar possibilities have caught the attention of investment bankers and information entrepreneurs.

"We believe that there's a second quantum revolution going on right now," says physicist Chris Monroe of the Joint Quantum Institute at the University of Maryland in College Park.

The first revolution peaked when Austrian physicist Erwin Schrödinger introduced the term entanglement (a translation of the German *Verschränkung*) in a 1935 paper, inspired by a thought experiment proposed the same year by Albert Einstein and collaborators Boris Podolsky and Nathan Rosen. The thought experiment demonstrated that when two objects interact in a particular way, quantum physics requires them to become connected, or entangled, so that measuring a property of one instantly reveals the value of that property for the other, no matter how far away it is.

"No reasonable definition of reality" could permit two objects to be mysteriously entwined across great distances, Einstein and his collaborators complained in *Physical Review* (*SNL: 5/11/35, p. 300*). There must be more to reality, Einstein believed, than quantum theory described. But rather than undermining quantum physics, the EPR paper, as it became known, became fodder for other scientists who showed that this unreasonable connection was in fact real. If quantum rules applied in everyday life, as soon as Peyton saw his quantum coin land in Seattle, he would know the outcome of Eli's toss — even if Eli's game were across the country or on the moon.

For decades, though, few physicists worried about entanglement. It was regarded as a hypothetical concept with no real prospects for ever being tested. "Initially it was a pure theory — quasi-philosophy," says physicist Nicolas Gisin of the University of Geneva.

That's no longer the case. Now, laboratories around the world routinely create and study entanglement, pushing the limits on the types and sizes of objects that can be entangled. Some studies are attempting to clarify the mysterious boundary separating the strange realm of quantum weirdness from the macroscopic world of football. Others focus on entanglement itself, particularly how it changes over time. Much of the new work is building a base for powerful technologies that operate in the real world, from manipulating information in futuristic quantum computers to sending secret messages with unbreakable security.

Yet despite all the progress, there remains a deep mystery at the core of entanglement. "I want to be able to tell a story," Gisin says, "and I cannot tell you a story of how nature manages the trick."

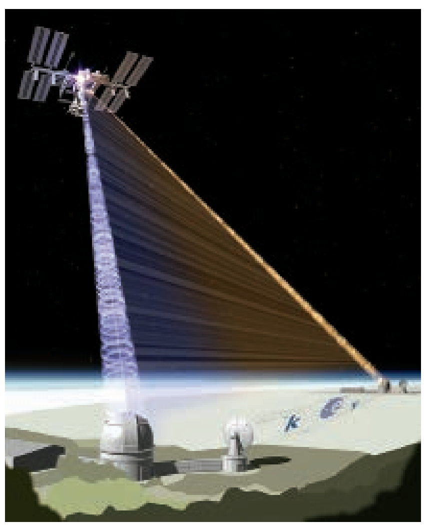
The Bell goes off

With no way to actually perform the EPR experiment, entanglement languished in philosophical obscurity for nearly 30 years. But that all changed in 1964, when Irish physicist John Bell devised an ingenious mathematical trick that allowed physicists to rule out mundane explanations for entanglement. One such physicist was Alain Aspect, now at the Institut d'Optique's campus in Palaiseau, France. When he saw Bell's paper, Aspect was immediately struck by its implications.

"This is the most important experiment I've ever heard of," he recalls thinking. Undeterred by Bell's warning that such a pursuit might brand him a crackpot, Aspect figured out a way to perform Bell's test on twin photons emitted by calcium atoms. Aspect and his colleagues measured the light waves' orientation — a property called polarization (the feature of light exploited by sunglasses for reducing glare).

Aspect and his collaborators reported in 1982 that the two detectors, when aligned in the same way, gave results closely matching the scenario Bell had outlined if the bizarre quantum link were true. It was as if the photons were in cahoots, with each instantly deciding what to do as soon as its partner made a choice (see Page 24). Entanglement had been demonstrated (*SN: 1/11/86, p. 28*).

In the years since Aspect's experiment, physicists have been extending entanglement's reach in a number of ways. They've confirmed its existence over and over, and shown that it may one day be put to work. Researchers are creating entanglement that can be sent across the globe, entanglement that can link new kinds of objects and even entanglement that can connect gaggles of objects instead of just two. And physicists are upsizing objects that exhibit what Einstein dismissed as "spooky action at a distance."



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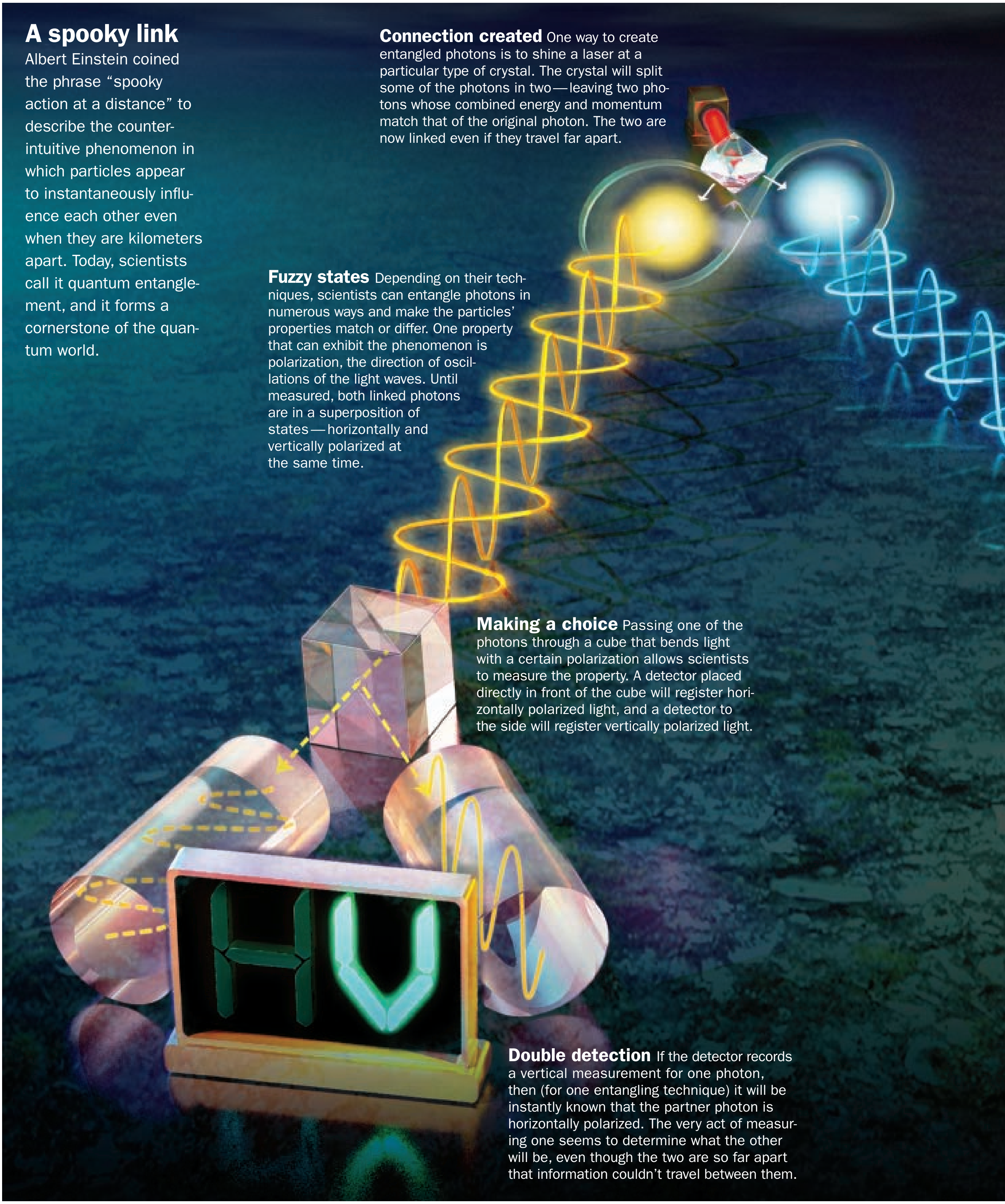
A pair of entangled photons beamed from the International Space Station could allow for secret communication between faraway locales on Earth.

- In 2008, for instance, Gisin and colleagues measured entangled photons 18 kilometers apart at exactly the same time and calculated that any secret signal between the two would have to travel 10,000 times faster than the speed of light. The long-distance record is held by a team of physicists including Anton Zeilinger of the University of Vienna, who measured entangled photons 144 kilometers apart on two Canary Islands. A plan to break that record involves sending an entangled photon from Earth to the International Space Station. Quantum information beamed by satellites orbiting the planet might ultimately lead to new, powerful ways to communicate across the globe.

- So far, photons are the only elementary particles that have been entangled, but Lucas Lamata of the Max Planck Institute of Quantum Optics in Garching, Germany, and his colleagues have devised a way to entangle electrons, which would be more stable. Other types of objects — including dissimilar ones — have been entangled as well, and these systems could offer more mix-and-match options for the design of new devices, such as quantum computers. "We're very interested in entangling new systems," Lamata says.

- It's not all just about extending the kinds of things to be entangled — numbers matter too. "If you go to more than two parties, the number of ways the systems can be entangled becomes much more rich," Gisin says. Today, the formulas that describe two entangled particles are easy to understand. "Two particles is too simple," he says. "It took a long time for me to say that."

  Researchers have succeeded in entangling three different-colored beams of light, entangling six photons and entangling eight calcium ions, revealing much more complex kinds of entanglement. "These experiments are confirming entanglement, but confirming it in more subtle ways than people had thought about," says



A spooky link

Albert Einstein coined the phrase “spooky action at a distance” to describe the counter-intuitive phenomenon in which particles appear to instantaneously influence each other even when they are kilometers apart. Today, scientists call it quantum entanglement, and it forms a cornerstone of the quantum world.

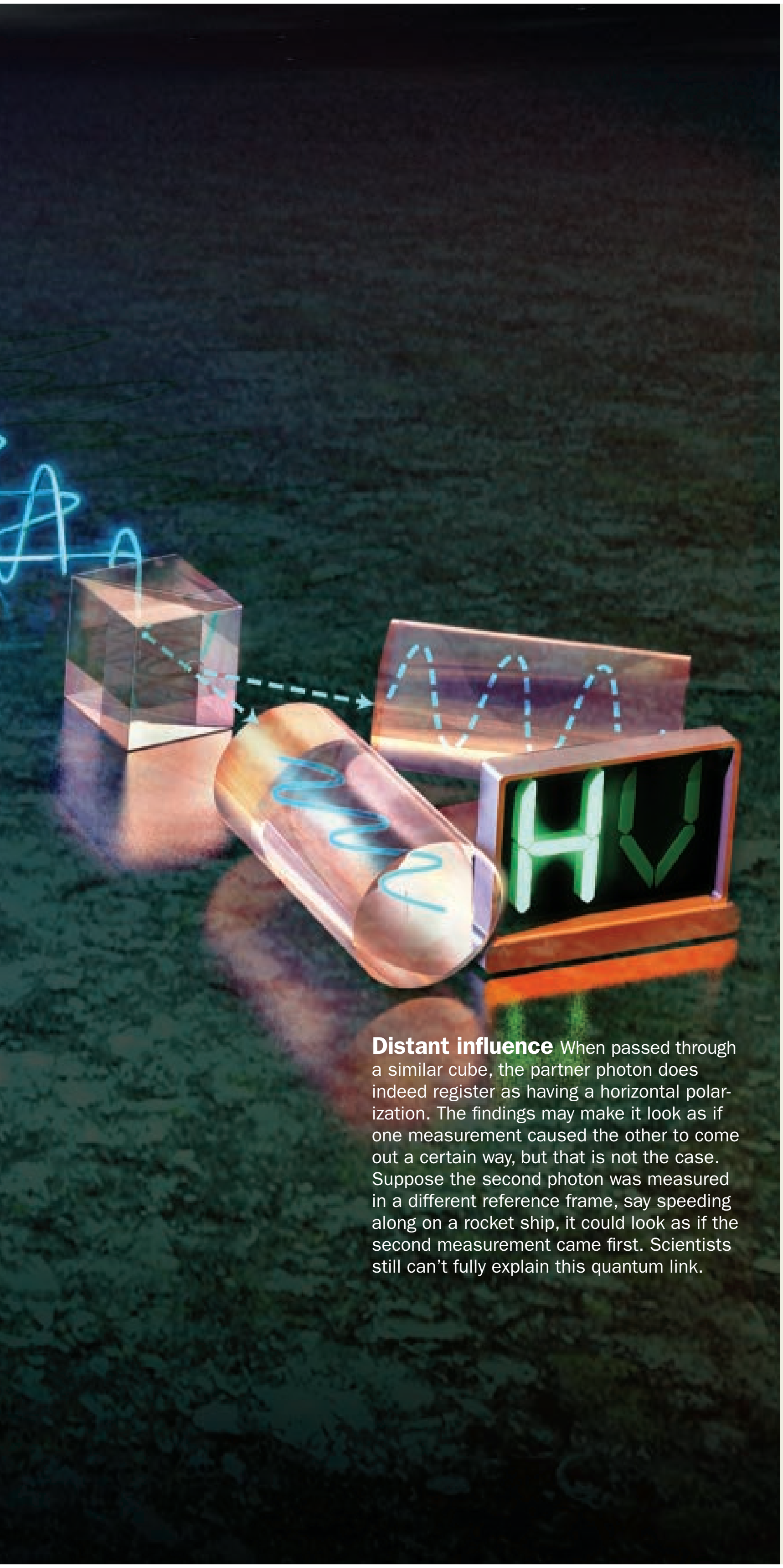
Connection created One way to create entangled photons is to shine a laser at a particular type of crystal. The crystal will split some of the photons in two—leaving two photons whose combined energy and momentum match that of the original photon. The two are now linked even if they travel far apart.

Fuzzy states Depending on their techniques, scientists can entangle photons in numerous ways and make the particles’ properties match or differ. One property that can exhibit the phenomenon is polarization, the direction of oscillations of the light waves. Until measured, both linked photons are in a superposition of states—horizontally and vertically polarized at the same time.

Making a choice Passing one of the photons through a cube that bends light with a certain polarization allows scientists to measure the property. A detector placed directly in front of the cube will register horizontally polarized light, and a detector to the side will register vertically polarized light.

Double detection If the detector records a vertical measurement for one photon, then (for one entangling technique) it will be instantly known that the partner photon is horizontally polarized. The very act of measuring one seems to determine what the other will be, even though the two are so far apart that information couldn’t travel between them.

NICOLLE RAGER FULLER



Distant influence When passed through a similar cube, the partner photon does indeed register as having a horizontal polarization. The findings may make it look as if one measurement caused the other to come out a certain way, but that is not the case. Suppose the second photon was measured in a different reference frame, say speeding along on a rocket ship, it could look as if the second measurement came first. Scientists still can't fully explain this quantum link.

75 years of entanglement

Though it has been confirmed numerous times since 1935, entanglement is as spooky as ever.

1935: Physicists Albert Einstein, Boris Podolsky and Nathan Rosen publish a paper in *Physical Review* asking "Can quantum-mechanical description of physical reality be considered complete?" Their answer: no.

The same year, in the journal *Naturwissenschaften*, Erwin Schrödinger coins the term *Verschränkung*, meaning "entanglement," and develops his famous thought experiment of a cat that exists simultaneously in a state of being alive and dead.

1952: Building on earlier work by French physicist Louis de Broglie, theoretical physicist David Bohm suggests a deterministic interpretation of quantum theory that incorporates "hidden variables." He claims that the initial state of a system, like a particle's position, can determine its future evolution.

1964: Irish physicist John Bell proposes his inequality, which lays out math that would allow researchers to experimentally rule out any hidden variables operating locally to determine quantum entanglement outcomes. If the inequality holds, then entanglement could be explained through purely local effects. If violated, some amount of nonlocality must be occurring, as standard quantum mechanics would predict.

1972: Berkeley researchers Stuart Freedman and John Clauser experimentally test Bell's theorem by measuring the polarizations of a pair of photons. Though the team found that the inequality is indeed violated, some loopholes exist in the experiment.

1982: French physicist Alain Aspect performs an even stronger test of entanglement, confirming that nonlocal effects do exist.

1984: Charles Bennett and Gilles Brassard propose a theoretical system for quantum cryptography, which would use photons in a superposition of states to create a secure key.

1990: Bennett and colleagues report the first experimental quantum key distribution.

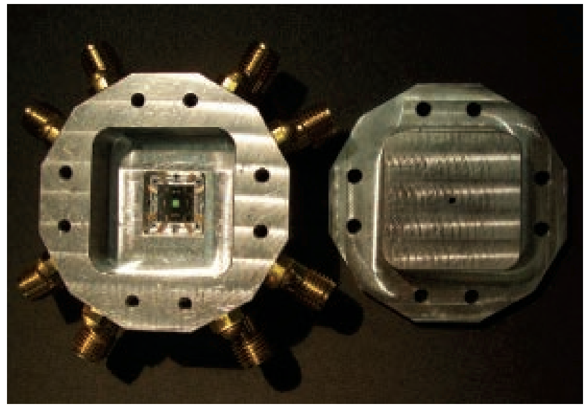
1993: Bennett and collaborators propose that entanglement can, in principle, be used to teleport a particle's quantum information from one place to another.

1997: Austrian quantum physicist Anton Zeilinger and colleagues report in *Nature* the first experimental verification of quantum teleportation.

2007: Zeilinger and colleagues set a distance record by sending entangled photons across 144 kilometers, between two of the Canary Islands. Chao-Yang Lu and colleagues also entangle six photons, a record number.

2010: Researchers observe new kinds of entanglement when linking multiple objects quantumly, quantum information is teleported a record 16 kilometers and teams find better ways to create and control entangled objects. —*Alexandra Witze*

Researchers recently entangled three superconducting chips big enough to be seen with the naked eye. Crisscrossed connections link the three chips (immediate right), along with a fourth chip that was not used. An aluminum box 4 centimeters wide (far right) enclosed the experiment.



John Martinis of the University of California, Santa Barbara. In a paper appearing September 30 in *Nature,* Martinis and colleagues show how entanglement between three superconducting chips might give quantum computers more oomph.

■ The fact that quantum mechanics is so good at describing diminutive particles implies that it should also be good at describing bigger "catlike" states, says Tony Leggett of the University of Illinois at Urbana-Champaign. (In a nod to Schrödinger's creepy cat that was simultaneously alive and dead — see Page 17 — physicists use "catlike" to describe large quantum objects.) "Most of us, at least in the year 2010, are prepared to live with the weird properties of quantum mechanics at the level of single atoms or electrons," Leggett says. "Most people are much less happy to live with it at the level of Schrödinger's cat."

Like the heft of NFL players, the size of entangled objects is steadily creeping upward. The superconductors entangled by Martinis' team are large enough to see with the naked eye. And a blob of thousands of photons and a centimeter-long crystal have, in separate experiments, been entangled with a single photon.

No one knows how to describe the separation between the bizarre quantum world where entanglement exists and the everyday world where nature appears to operate via easy-to-spot causes and effects. Creating entanglement on a larger scale may help clarify this mysterious division.

"Most of the experiments so far have been done with photons, which have no mass," Gisin says. "Some experiments have also been done with atoms or ions, and already there are some experiments going to ensembles of atoms. But a few atoms are still extremely light."

Entanglement evolves

Creating entanglement in multiple shapes and forms isn't that useful if the connection can't be preserved. Entanglement is notoriously finicky, fading away with even slight external disturbance. The motion of a quantum coin jangling in Peyton's pocket, for instance, could ruin the quantum connection long before the toss. A new area of research called entanglement dynamics aims to figure out how entanglement appears, disappears and morphs over time.

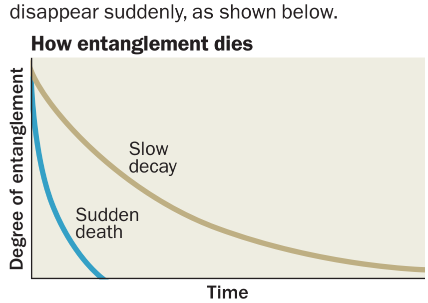
"We really want to go beyond static entanglement, which means you only care about a state without time evolution," says theoretical physicist Ting Yu of the Stevens Institute of Technology in Hoboken, N.J. "We know in nature, we really don't have that kind of thing."

Yu and collaborator Joseph Eberly of the University of Rochester in New York reported that entanglement can disappear abruptly, a phenomenon called "entanglement sudden death," in a 2009 review paper in *Science*. This instant demise has been observed in other places since, including in experiments with the three entangled light beams conducted by Paulo Nussenzveig of the University of São Paulo and colleagues. The team is now trying to understand when and why this collapse happens, and whether particular starting states make it more probable.

Physicists aren't in agreement on what sudden death means. Some think it's nothing surprising, similar to well-studied phase transitions, such as the abrupt disappearance of liquid when water freezes into ice. But Yu thinks the phenomenon represents a previously unknown property of entanglement, one that is closely related to its environment.

A carefully tuned environment can also generate entanglement. Given just the right surroundings, energy leaving clouds of cesium atoms can actually cause atoms to become linked, a study posted June 22 on arXiv.org showed (*SN Online: 6/29/10*). This feat was accomplished at room temperature and lasted for the (relatively) long time of about 0.015 seconds.

Entanglement begone Scientists studying how entanglement changes over time have found that the effect can fade away or disappear suddenly, as shown below.



TOP, BOTH: MATTHEW NEELEY; T. YU AND J. EBERLY/*SCIENCE* 2009

Information encoded in the entanglement can leak out into a noisy environment and then leak back into the objects to reentangle them, Yu says, a process called "revival." In a paper posted online September 16 at arXiv.org, he and his colleagues mathematically describe how this ghostly effect works in different environments. And a group of physicists led by Chuan-Feng Li of the University of Science and Technology of China in Hefei recently witnessed such a revival, watching entanglement between two photons reemerge after it was completely gone. The findings appeared March 12 in *Physical Review Letters*.

Killer apps

Physicists have lots of ideas for what they would do with the power to create, demolish and resurrect entanglement on demand. Although some of the schemes are esoteric, entanglement has a few "killer apps," says Monroe. Chief among these are harnessing entanglement to shuttle information around in powerful quantum computers, across power lines and through the air, and distributing impenetrable coding keys to keep information secure.

Entanglement is at the heart of what physicists call teleportation — in which two entangled objects serve as a link that moves quantum information from one physical location to another. The setup is simple: One object (say a photon) holds the information to be teleported. When that photon interacts with one of a pair of entangled photons, new information is created, allowing the original photon to be reconstructed at a distant location with the help of the other member of the entangled photon pair. (The information needed to reconstruct the original photon must be sent over a normal communication network, though.) Teleportation was proposed in 1993 and was first experimentally demonstrated in 1997.

Such relocation could play a key role in quantum computers, which get their allure from the power of quantum information processing. One unit of quantum information, or qubit, can represent multiple possibilities simultaneously, a vast improvement over typical bits that are restricted to either a 0 or 1. This information abundance could prove to be extremely useful. If a football historian were looking for the most beneficial coin flip in the history of the NFL, a computer made of qubits could search all of the outcomes simultaneously instead of sifting through each toss one by one.

Nearby qubits, such as those in a working quantum computer, often become entangled, says physicist David Hanneke of the National Institute of Standards and Technology's Boulder, Colo., campus. This fortuitous entanglement is a naturally occurring resource that can be used to shuffle information from one location to another in a quantum processor. "You can use entanglement to move the information without physically moving the qubit that stores the information," Hanneke says.

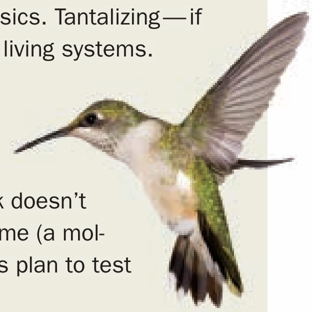
Martinis says his group has come up with a new (unpublished) version of a quantum computer with entangled superconductors as the qubits. Though the research is still under way, he thinks the team has hit upon a "good hardware architecture" that seems to work well.

Teleportation can be used to move information much farther than within the confines of a computer processor. Chinese researchers report in the June *Nature Photonics* a record-setting teleportation distance. For the experiment, the team went wireless, sending entangled photons through the air, whizzing over 16 kilometers of roads, factories and even Guanting Lake. Using the entangled photons, the researchers teleported a piece of information. Performing the feat at such great distances could one day enable satellites to communicate with ground stations quantumly.

Other researchers are figuring out ways to send entangled photons through existing wires. Thomas Jennewein of the University of Waterloo in Canada and his colleagues sent entangled photons

Colliding with biology

Quantum effects may not be limited to the realm of physics. Tantalizing — if unconfirmed — hints of entanglement have appeared in living systems.



Avian navigation

Some studies suggest that migrating birds may exploit quantum effects in their visual systems to boost sensitivity to Earth's magnetic field. Though theoretical work doesn't show a benefit to entangling the electrons of cryptochrome (a molecule thought to be important in navigation), researchers plan to test the idea in other molecules (*SN Online: 4/30/10*).

DNA's double helix

Entanglement, another study suggests, may help hold the genetic building blocks of life together. In DNA, two complementary nucleotides meet up to form a base pair, creating the core of the double helix structure. After constructing a simplified model of the pairing, Elisabeth Rieper of the National University of Singapore and her colleagues conclude that entangling the electron clouds of two nucleotides would give DNA more stability.

Photosynthesis

During photosynthesis, light hits a pigment molecule and boosts one of the molecule's electrons into an excited state, kicking off a series of electron transfers. Some scientists have turned to quantum physics to explain the unexpected efficiency of this process (*SN: 5/9/09, p. 26*). A study earlier this year also found evidence of entanglement at work in the light-harvesting protein of a type of bacteria. — *Laura Sanders*

MIKE TRUCHON/SHUTTERSTOCK

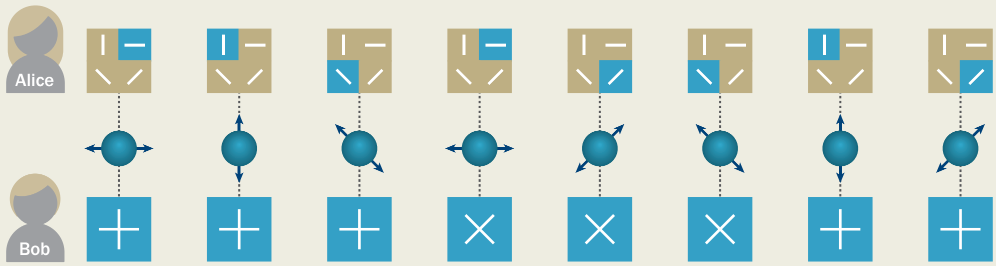
Quantum weirdness in action

Physicists can't explain what lies behind weird quantum effects, such as the ability of particles to exist in two states at once and the mysterious connection between a pair of far apart particles. But that doesn't stop researchers from taking advantage of the bizarre quantum properties.

Quantum cryptography

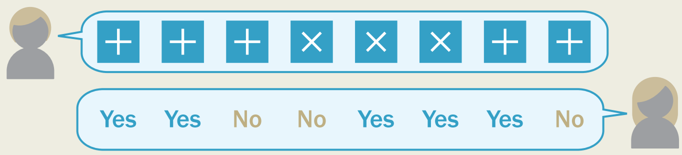
Quantum weirdness allows for the creation of eavesdropper-proof coded messages. In the most widely used setup, two partners (referred to as Alice and Bob) can create a secret coding key that they can later use to send secret messages. Though the concept works with just a stream of photons (shown below), quantumly linked photons, or entangled photons, can lend extra security.

Alice sends Bob a stream of photons that she has randomly put through one of four filters so the photons take on a particular orientation.

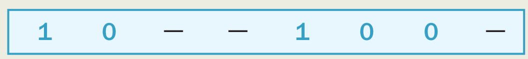


Bob chooses one of two filters to look at the photons, and he writes down the states he measures.

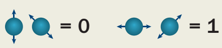
Alice then tells Bob which filters were "correct," meaning they lined up with the filters she used.



Each state corresponds to a bit value, either 0 or 1, allowing Alice and Bob to create their key.

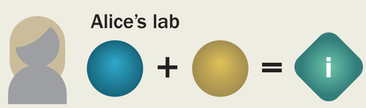


Pre-established bit value:



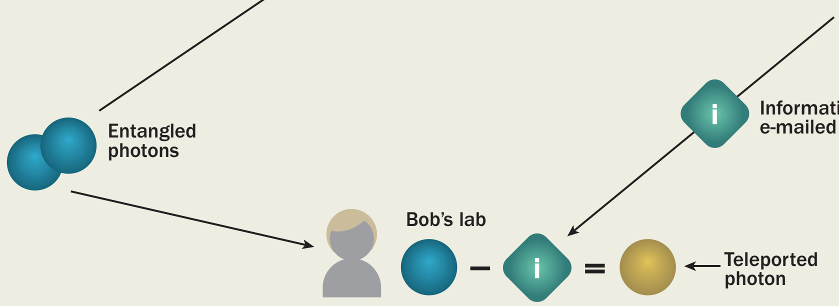
Quantum teleportation

In quantum teleportation, the information stored in a quantum particle (typically a photon of light) is transferred from one location to another. In effect, that means that the information in one photon is destroyed while an identical photon, containing the same quantum information, appears in a new location.



To teleport another photon containing unknown information, Alice must allow it to interact with her entangled photon, then measure the property of interest, such as spin or polarization orientation. That measurement destroys the information stored in the photon.

To accomplish this task, a sender and receiver must each obtain one photon of an entangled pair. Such photons have the peculiar property that measuring one reveals the state of the other. If Alice, the sender, sneaks a peek at her photon and finds its spin axis points up, for example, Bob will know that his has a spin pointing down without even looking at it.



But when Alice sends the result of that measurement to Bob via ordinary communications channels, he can use that result to transform his entangled photon into a replica of the photon that Alice destroyed.

T. DUBÉ

Quantum computing

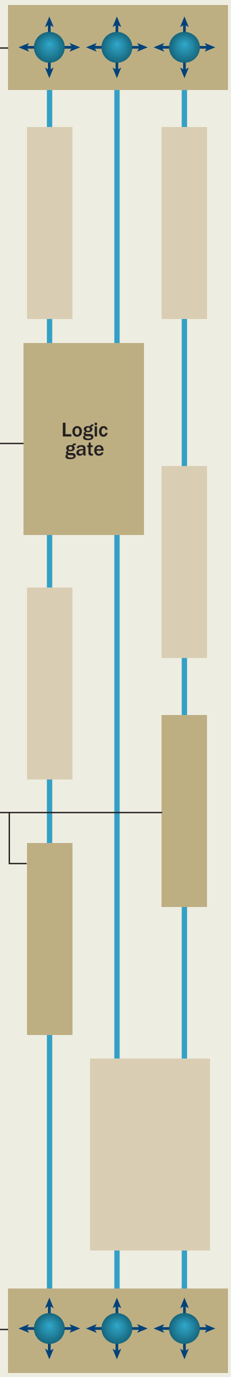
Like traditional computers, a quantum computer is made up of a network of logic gates (brown) that operate on information. Though current versions can perform only rudimentary operations, scientists hope future devices will be powerful alternatives for solving some types of problems.

While the pieces of information, or bits, inputted into an ordinary computer can exist in only two states — 0 or 1 — the qubits of a quantum computer can exist in both states simultaneously. Photons carrying the information (blue) are in a "superposition" of states.

Because of a qubit's ability to occupy multiple states, it is possible to perform an operation on two qubits that evaluates multiple scenarios simultaneously, allowing for improved processing power.

With the help of entanglement, two qubits at distant places in a quantum computer can be linked and operated on together.

Reading out the information in a qubit returns it to a definite state, a process known as "decoherence," making the extra analyses inaccessible to researchers. But scientists have found ways to avoid this limitation for certain types of problems.



through standard telecom lines designed to carry a particular wavelength of light. One of the entangled photons traveled six kilometers between two labs in Waterloo, using lines that normally carry information such as cable television programming.

The researchers thought that this entanglement would be so fragile that the photons would be lost to the noisy telecom environment in the wires. But the entangled photons survived the trip, the team reported online July 22 in *Applied Physics Letters*. "It's very easy to put the quantum signal on top of the telecom signal, and pick it off again," Jennewein says.

To be truly useful, quantum information must also be stored. Photons fly through the air at quite a clip, so holding the information they carry is a challenge. Gisin's group at the University of Geneva has developed a device capable of storing the information carried by an entangled photon. The method, reported online September 6 at arXiv.org, hinges on a crystal that can catch one of a pair of entangled photons and hold its quantum information, while the other photon "idles" by traveling through a 50-meter-long fiber. The crystal can store the information for up to 200 nanoseconds before it emits another photon carrying the exact same information.

Another way to store quantum information was detailed in a paper published online September 26 in *Nature Physics*. Researchers from Georgia Tech in Atlanta managed to hold information from an entangled photon in a gas of cold rubidium atoms.

Manageable entanglement has caught the interest of security firms as a new way to encrypt data. For several years now, researchers have been using quantum properties to generate unbreakable keys that can disguise and then decode messages. The original technique relied on sending a stream of single photons between two parties. But some people see entangled photons as a better way.

In the entanglement scheme, one photon flies off to a destination and its partner flies somewhere else. Measurements made on the distant photons can be used to generate a key, known only to the measurers. Unlike the single photon plan, where the sender knows the state of a particle before sending it, the entanglement-based code is secret to everyone initially. "The beauty is, due to entanglement, this random key reaching the two receivers is not preexisting," says Jennewein, reducing the chances that someone can eavesdrop on the signal.

With all the grand promise that entanglement has for changing the way information is handled, the biggest question around it — why it happens — remains unanswered. It's easy to explain why an egg changes as it fries and why a car runs, Gisin says. Even though scientists can measure it, at its heart, the disconcerting quantum effect remains a mystery. "There is simply no story in spacetime that can tell us how this happens," he says.

But not having the complete story isn't stopping anyone from using entanglement. "It's in real use, every day," Gisin says. The quantum process is proving its worth outside of thought experiments that require quarterbacks to have quantum coins and advanced physics degrees.

A consortium of research institutes and technology companies has set up a quantum network in Tokyo and, on October 18, demonstrated a leak-proof security system. Entangled photons were distributed across a one-kilometer portion of the network and generated a key used to encrypt audio and video data.

Though such schemes are in their infancy, "entanglement has a more important role to play in the future," says Momtchil Peev of the Austrian Institute of Technology in Vienna, who worked on the project.

Since entanglement was first described, it has morphed from a philosophical debate to an experimental oddity to a potentially powerful way to communicate, showing itself to be even weirder than Einstein didn't want it to be. ■

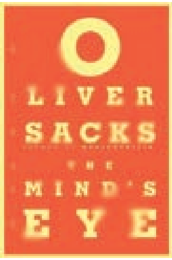
Explore more

- For more on the Tokyo demonstration: www.uqcc2010.org

The Mind’s Eye

Oliver Sacks

True story: A novelist gets up one morning and snatches the newspaper off his doorstep only to find the words appear



to be written in some unintelligible script, perhaps Cyrillic. He suspects a practical joke but soon realizes he has lost the ability to read. The novelist finds he can still write, but can’t proofread what he’s just set down. Determined, he finds a way to produce another novel.

In his latest book, Sacks, a neurologist, explores the loss of various kinds of visual perception, including this real-life example of a condition called alexia, and how people compensate for it.

As in his previous books, Sacks excels at tracking down fascinating case studies. He describes a concert pianist who sits down to play a Mozart concerto in front of an audience but, like the novelist, she finds the sheet music unrecognizable. She plays it from memory. As months pass objects seem to hide in plain sight, yet she retains the ability to play piano for years.

The most stunning vignette concerns Sacks himself, who lacks the ability to recognize faces. He struggles to identify even his coworkers but finds ways to manage. “When I see a youngish woman with a Rhodesian ridgeback hound, I realize that she lives in the apartment next to mine,” Sacks writes. Many people suffer from this problem, called prosopagnosia, and most just live with it, he says.

Sacks gives the reader a guided tour of the brain areas where defects or damage can cause these perception problems in people with otherwise normal vision. In closing, he discusses the loss of binocular vision — which Sacks himself has had to endure — and blindness, exploring how people who have lost all sight rely on the mind’s eye. *— Nathan Seppa*

Knopf, 2010, 288 p., $26.95.

Eels

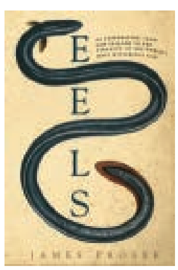
James Prosek

What many people in the West view as vile, slimy creatures are, according to Prosek, the world’s most mysterious fish. (Yes, despite often being mistaken for snakes, eels are fish.) They can live for a century, they spend most of their lives in fresh water but must return to sea to spawn, and they can travel up to a quarter of the globe to do that spawning.

In a captivating account, Prosek takes readers though the scientific, cultural and culinary worlds of eels. In the South Pacific, eels figure prominently in creation myths, even being worshipped by some family clans on one small island. While historians still debate whether the Pilgrims ate turkey at their first Thanksgiving, one account from the era indicates that Native Americans taught starving colonists to fish for eels.

Though now largely shunned in the West, the sweet buttery flesh of the eel is highly prized in Asia. Worldwide, freshwater eels bring in billions of dollars and account for about one-eighth of global aquaculture production.

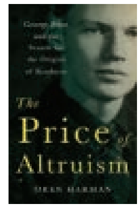
In a style more travelog than tome, Prosek also relates stories of people whose lives are intimately entwined with the slithery fish: the Maori of New Zealand who revere eels as guardians, an



eccentric New Yorker who traps eels using traditional methods and scientists who troll the seas in search of unknown spawning grounds.

Prosek gives readers a new appreciation for eels, whose populations are dropping precipitously. Besides overfishing, eels face habitat degradation and climate change, but the largest threat may be immense dams that block eels headed upstream to mature or seaward to breed. *— Sid Perkins*

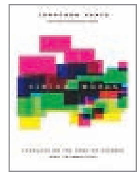
Harper, 2010, 304 p., $25.99.



The Price of Altruism

Oren Harman

A biography of George Price follows the eccentric and reclusive scientist in his quest to explain altruism in a Darwinian world. *W.W. Norton & Co., 2010, 451 p., $27.95.*



Virtual Words

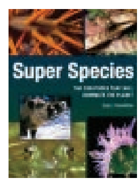
Jonathon Keats

Twenty-eight essays trace the births and lives (sometimes short) of *blog*, *qubit* and other science- and technology-inspired words. *Oxford Univ., 2010, 177 p., $19.95.*

Atlas of Science

Katy Börner

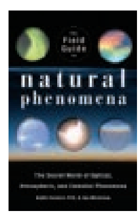
A large-format book highlights attractive and informative illustrations of a variety of science topics, and creators of the images describe how they were made. *MIT, 2010, 254 p., $29.95.*



Super Species

Garry Hamilton

In this cautionary tale, a journalist profiles 20 of the invasive organisms that may one day dominate the planet. *Firefly, 2010, 271 p., $35.*



The Field Guide to Natural Phenomena

Keith Heidorn and Ian Whitelaw

An illustrated tour of everyday events and amazing spectacles, from mirages and meteors to ball lightning. *Firefly, 2010, 223 p., $24.95.*

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PHYSICS ROUNDUP

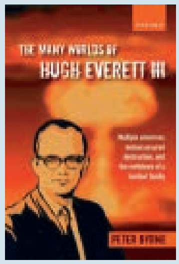
The Many Worlds of Hugh Everett III: Multiple Universes, Mutual Assured Destruction, and the Meltdown of a Nuclear Family

Peter Byrne

In histories of quantum physics, Hugh Everett III's name appears frequently, but without much about the life of the man behind the name. He did not pursue a career in academic physics, opting instead to work as an analyst for secret military projects, and he died young, in 1982 at age 51.

In Everett's 1957 Ph.D. dissertation, he introduced a radical view of quantum mechanics, the mathematics that governs reality with unfathomable weirdness. Standard quantum math describes multiple possible realities; in any given circumstance one of those possibilities becomes "real" when an observation is made. But Everett believed that all the possibilities exist. An observer "splits" each time an observation is made, he insisted, creating a multiplex of parallel realities corresponding to all the possibilities in the quantum math.

Bizarre, of course, but also plausible enough to persuade many physicists that Everett's view, later

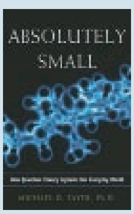


labeled the Many Worlds Interpretation, should be the preferred way of understanding quantum mechanics — a view still widely debated. That debate has been illuminated by Byrne, an investigative reporter. With access to Everett's personal papers, Byrne has re-created the full story of Everett's troubled life, frequently with more private details than some readers may care for.

While Byrne probes personal matters (alcoholism, financial and marital issues) insightfully, his grasp on science is shaky; descriptions of mixed strategies in game theory, entropy and various quantum concepts are vague, muddled or misleading. And much of the book consists of long block quotations, regurgitated from various sources without much digestion.

Nevertheless the book as a whole offers a valuable source of primary information about Everett's life and work, with much material not available elsewhere. With allowances for Byrne's often acerbic point of view (including unconcealed disdain for several of the 20th century's most prominent physicists), this book fleshes out an important part of the quantum physics story. *— Tom Siegfried*

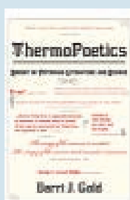
Oxford Univ., 2010, 436 p., $45.



Absolutely Small

Michael D. Fayer

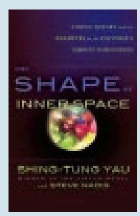
In clear and mostly math-free language, a chemist describes quantum theory in everyday life, relating such tidbits as why blueberries are blue and how a photon can be in two places at once. *AMACOM, 2010, 383 p., $24.*



ThermoPoetics: Energy in Victorian Literature and Science

Barri J. Gold

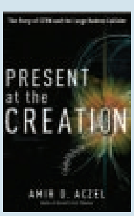
For the literary-minded physics aficionado, this book examines literature's role in shaping and wrestling with emerging ideas of energy and thermodynamics in the Victorian age. *MIT, 2010, 343 p., $30.*



The Shape of Inner Space

Shing-Tung Yau and Steve Nadis

Taking another angle on the string theory genre, a Harvard mathematician and a science writer join up to explore the geometry of curled-up universes too small to see. *Basic Books, 2010, 377 p., $30.*



Present at the Creation

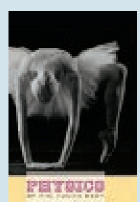
Amir D. Aczel

The story of the Large Hadron Collider—the biggest and most powerful machine ever built—is told in part from its control room, where scientists are working to re-create the moments immediately after the Big Bang. *Crown, 2010, 271 p., $25.99.*

The Instant Physicist

Richard A. Muller

In this collection of physics-related curiosities, every page flip reveals a basic principle of physics and a humorous cartoon by Joey Manfre. Examples include why wine is radioactive and how much plutonium it takes to build a bomb (enough to fill a coffee mug). *W.W. Norton, 2010, 144 p., $16.95.*



Physics of the Human Body

Richard P. McCall

Looking at the body as a physics laboratory lends a fresh perspective, from how the properties of light affect eyesight to the fluid dynamics of the circulatory system. A good resource for doctors or the general reader. *Johns Hopkins Univ., 2010, 301 p., $45.*

Albert Einstein

For more Comment, visit Columns at **www.sciencenews.org**

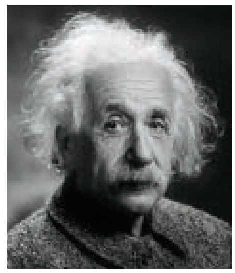
A skeptic of quantum theory explains his misgivings

In a 1905 paper, Albert Einstein proposed that light could travel in the form of particles later called photons. It was one of the pioneering papers in the research that led to quantum mechanics, the mathematical framework for describing matter and energy on a fundamental level. But in his later years, Einstein expressed grave dissatisfaction with quantum mechanics. He was especially unhappy with its description of reality in terms of probabilities, a view developed by the German physicist Max Born. Einstein preferred the deterministic cause-and-effect rigor of classical physics, expressing his displeasure by saying "God does not play dice." But Einstein's views on quantum mechanics are often oversimplified. For observable phenomena, he accepted the statistical view of quantum mechanics; his main concern was its incompleteness (in his view) in describing reality. To investigate those views, Science News *Editor in Chief Tom Siegfried conducted an "interview" with Einstein via of a number of the physicist's writings and statements.*

In a nutshell, what's wrong with quantum mechanics?
Some physicists, among them myself, cannot believe that we must abandon, actually and forever, the idea of direct representation of physical reality in space and time; or that we must accept the view that events in nature are analogous to a game of chance.

Why were you so upset about quantum theory when much of it was based on your own work?
Yes, I may have started it but I always regarded these ideas as temporary. I never thought that others would take them so much more seriously than I did.

Do you believe the world is totally deterministic, so each effect follows from its causes with complete predictability?
From the point of view of immediate experience there is no such thing as exact determinism.... The question is whether or not the theoretical description of nature must be deterministic. Beyond that, the question is whether or not there exists generally a conceptual image of reality (for the isolated case), an image which is in principle completely exempt from statistics.



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Some physicists, among them myself, cannot ... accept the view that events in nature are analogous to a game of chance.

Quantum mechanics has been extremely successful. How can you oppose a theory that always gets the right answers?
I consider the methods of quantum mechanics fundamentally unsatisfactory. I want to say straight away, however, that I will not deny that this theory represents an important, in a certain sense even final, advance in physical knowledge.... Probably never before has a theory been evolved which has given a key to the interpretation and calculation of such a heterogeneous group of phenomena of experience.... In spite of this, however, I believe that the theory is apt to beguile us into error in our search for a uniform basis for physics, because, in my belief, it is an *incomplete* representation of real things, although it is the only one which can be built out of the fundamental concepts of force and material points (quantum corrections to classical mechanics). The incompleteness of the representation leads necessarily to the statistical nature (incompleteness) of the laws.

So then are you saying that a statistical interpretation is necessary for observable "material points"?
Experiments lead to the conclusion that energy values lying between the quantum values do not exist.... It seems to be clear, therefore, that Born's statistical interpretation of quantum theory is the only possible one.

David Bohm proposed a deterministic interpretation of quantum mechanics in 1952 — what about that?
That way seems too cheap to me.

You say that quantum statistics apply only to ensembles of systems rather than individual particles. Is it possible that nature allows no deeper insight into single systems than quantum mechanics provides?
To believe this is logically possible without contradiction; but, it is so very contrary to my scientific instinct that I cannot forgo the search for a more complete conception.

So do you believe quantum mechanics is not the final word as a basis for physical theory?
There is no doubt that quantum mechanics has seized hold of a good deal of truth, and that it will be a touchstone for any future theoretical basis.... If one wants to consider the quantum theory as final (in principle), then one must believe that a more complete description would be useless because there would be no laws for it. If that were so then physics could only claim the interest of shopkeepers and engineers; the whole thing would be a wretched bungle. ■

For sources of Einstein's comments, visit www.sciencenews.org/einstein