SN
SCIENCE NEWS MAGAZINE
SOCIETY FOR SCIENCE & THE PUBLIC
MARCH 19, 2016

Neutrino Ghost Hunters

Lead's Lasting Effects

Chasing Pluto's Shadow

Quantum Heat

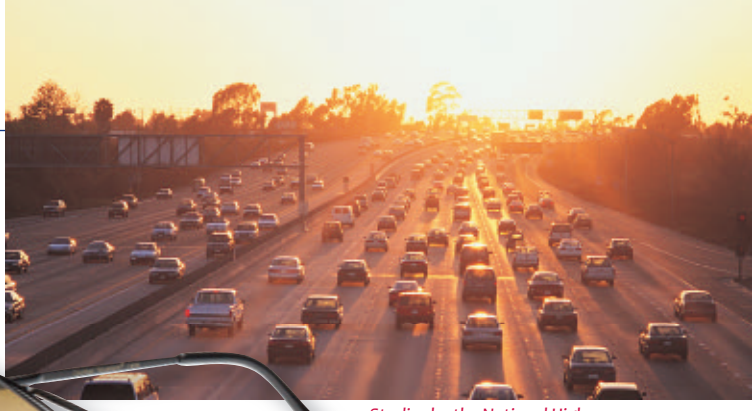
The beauty of FAT

It just may be the ultimate body repair kit

Urgent: Special Driving Notice

To some, sunglasses are a fashion accessory…

But When Driving, These Sunglasses May Save Your Life!



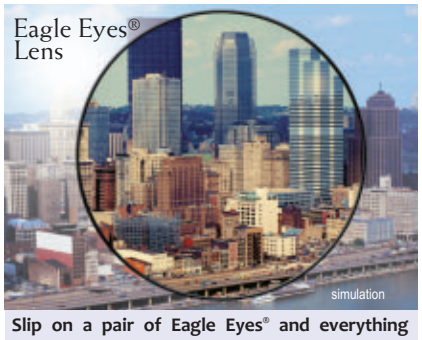
Studies by the National Highway Traffic Safety Administration (NHTSA) show that most (74%) of the crashes occurred on clear, sunny days

Drivers' Alert: Driving in fall and winter can expose you to the most dangerous glare… do you know how to protect yourself?

In the fall and winter, the sun is lower in the sky so it rises and sets at peak travel periods. During the early morning and afternoon rush hours many drivers find themselves temporarily blinded while driving directly into the glare of the sun. Deadly accidents are regularly caused by such blinding glare with danger arising from reflected light off another vehicle or snowy and icy pavement. Yet, motorists struggle on despite being blinded by the sun's glare that can cause countless accidents every year.

Not all sunglasses are created equal. Protecting your eyes is serious business. With all the fancy fashion frames out there it can be easy to overlook what really matters—the lenses. So we did our research and looked to the very best in optic innovation and technology.

Sometimes it does take a rocket scientist. A NASA rocket scientist. Some ordinary sunglasses can obscure your vision by exposing your eyes to harmful UV rays, blue light, and reflective glare. They can also darken useful vision-enhancing light. But now, independent research conducted by scientists from NASA's Jet Propulsion Laboratory has brought forth ground-breaking technology to help protect human eyesight from the harmful effects of solar radiation light. This superior lens technology was first discovered when NASA scientists looked to nature for a means to superior eye protection—specifically, by studying the eyes of eagles, known for their extreme visual acuity. This discovery resulted in what is now known as Eagle Eyes®.



Slip on a pair of Eagle Eyes® and everything instantly appears more vivid and sharp. You'll immediately notice that your eyes are more comfortable and relaxed and you'll feel no need to squint. These scientifically designed sunglasses are not just fashion accessories for the summer; they are necessary to protect your eyes from those harmful rays produced by the sun in the winter.

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SOCIETY UPDATE
Applications open for Advocate Grants program

COVER Fat is not just a storage vessel for extra energy. It's an organ containing cells with healing potential. © *Science Photo Library/Alamy Stock Photo*

CLOCKWISE FROM TOP: M. TELFER; WWW.MORPHOSOURCE.ORG, PETER SCHMID/UNIV. OF THE WITWATERSRAND; TODD MCINTURF/*THE DETROIT NEWS* VIA AP

Finding wonders in fat

Who knew body fat held such hidden treasures? Scientists have found some serious loot in that bemoaned organ, including a vigorous population of flexible stem cells that can be coaxed into acting as new cartilage or tendons for damaged joints. Fat's gems may also find uses in building new bone and repairing hearts, Susan Gaidos reports on Page 22.

One day such research might enable people to avoid hip replacement surgery, instead getting an injection of manipulated stem cells harvested from their own belly blubber — a pretty good deal. Of course, the work is still early, and few of the techniques have been tried in people yet. But the approach has great potential: There are some 200 million stem cells in a pound of fat, many more than in bone marrow. From a scientific perspective, fat is intriguing as well. Too much can obviously harm the body's systems, but it clearly has an important role, carrying its own supply of stem cells, immune cells and blood vessels. Gaidos paints a picture of a dynamic, although still poorly understood, organ that may have yet-undiscovered functions in keeping the body going.

Whether we're talking about fat cells or steam engines, energy follows the laws of thermodynamics. But what happens to those laws at the atomic scale is something that has intrigued physicists for decades. On Page 18, Andrew Grant explores new work in the quantum realm. Despite all the effort to break its well-aged tenets of heat, work and entropy, thermodynamics still rules, Grant reports. Where there might be some flex, though, is in the use of entangled particles to one day "do work."

Not all science is so futuristic. Some is headline news now. Witness recent mainstream coverage of gravitational waves (read our follow-up on Page 10), the Zika virus (tune in next issue) and the Flint, Mich., lead crisis. On Page 8, Meghan Rosen reports on the extensive lead exposure that has hit Flint and what scientists have to say about the expected fallout. Rosen's story is not our usual fare — but it's an important example of the crucial work science does in our everyday lives.
— Eva Emerson, Editor in Chief

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SANDY SCHAFFER

No Contract

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Excerpt from the March 19, 1966 issue of *Science News*

50 YEARS AGO

Understanding memory

Memory is losing its mystery.... A man's brain contains some 10 billion neurons.... How are new memories established in cells, if they are? An explanation may lie in the dendrites [the branching tips of neurons].... Logically [neurons] can send out new branches, though this has never been observed. Man would require far more subtle instruments than he now possesses to find such new dendritic growth among 10 billion neurons.

UPDATE: While our understanding of the brain has dramatically improved, mysteries remain. Those old neuron counts were way off; recent estimates say the number exceeds 85 billion. And researchers now have the tools to watch dendrites as they grow and change over time (*SN: 7/12/14, p. 8*). Dendrites seem to play a key role in memory, but scientists are now exploring on a molecular level how memories form, change and persist. Recent studies have suggested a role for specialized proteins and nets that swaddle brain cells (*SN: 11/14/15, p. 8*).

A 2.5-meter-wide telescope peers through an opening on SOFIA during a 2010 test flight over the Sierra Nevada.

THE SCIENCE LIFE

120 seconds in Pluto's shadow

Pluto's shadow raced across the Pacific Ocean at more than 85,000 kilometers per hour. MIT planetary scientist Michael Person was on a 747 chasing the shadow, which formed as Pluto passed in front of a distant star. Until last summer, everything researchers knew about Pluto's atmosphere came from stellar eclipses like this one. But for this June 2015 run, the analysis would get a reality check from the New Horizons spacecraft, which was speeding through the Kuiper belt toward the dwarf planet.

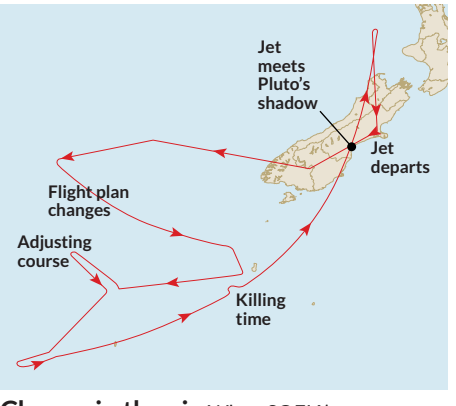
On the night of June 29, Person and his team departed Christchurch, New Zealand, on SOFIA, a jumbo jet fitted with an infrared telescope. Operated by NASA and the German Aerospace Center, SOFIA lofts its telescope, perched within a large hole in the airplane's side, to an altitude of roughly 12,500 meters, high enough to get above most of the molecules in Earth's atmosphere that absorb infrared light.

The rendezvous with Pluto's shadow required precision: The remote world would block the star for just a couple of minutes. And while the entire shadow would be as wide as Pluto — 2,374 kilometers — SOFIA was aiming for a 50-km-wide spot at the shadow's center. In this region, known as the "central flash," researchers can get the fullest sense of Pluto's skies. Partway through the eight-hour flight, plans had to quickly change. Colleagues in Arizona who were monitoring Pluto's position with a telescope in Chile called to tell Person's team it needed to shift the flight path 250 km north.

"We were talking frantically with the navigator," Person says. The plane was headed out to sea but needed a course that would send it back over the southeast coast of New Zealand. After some fancy maneuvering, SOFIA soared through the central flash, its instruments recording how Pluto's atmosphere absorbed the starlight. Person and his team measured properties such as atmospheric pressure and particle sizes in the haze around Pluto.

Fifteen days later, New Horizons got an intimate look at Pluto, providing crucial support for SOFIA's observations (*SN: 12/26/15, p. 16*). New Horizons scoped out the upper and lower levels of Pluto's atmosphere while SOFIA had checked out the middle altitudes. The combined data, presented January 7 at a meeting of the American Astronomical Society, paint a consistent picture of Pluto's multilayered, hazy atmosphere.

Flying on SOFIA is "kind of mind-bending," says Person, who has made five flights on the jet. Looking toward the back of the plane, he'd see the telescope quivering, but in truth, the instrument is steady. "It's the thing you're standing on that's wobbling," he says. SOFIA's next trip: 2017, when Pluto passes in front of another bright star. — *Christopher Crockett*



Change in the air When SOFIA's crew got word that Pluto's shadow would not be where expected, the team drew up a new flight plan, including some zigs, zags and time adjustments, to head back over New Zealand.

FROM TOP: NASA; M. PERSON

SAY WHAT?

Yottawatt \YOT-ah-wat\ n.

1 million billion billion watts

That's a lotta watts. And a lot more — 3.6×10^{49} watts, or 36 septillion yottawatts — blasted out of the black hole collision that the Advanced Laser Interferometer Gravitational-Wave Observatory detected in September (see Page 10). Rather than a flash of light, the power came out as ripples in spacetime. As the black holes merged, three suns' worth of mass transformed into gravitational wave energy in a few milliseconds, researchers report in *Physical Review Letters* on February 12.

"[It] created a violent storm in the fabric of space and time," Caltech astrophysicist Kip Thorne said at a February news conference announcing the discovery. The storm's power, he said, "was 50 times greater than all of the power put out by all of the stars in the universe put together." — *Christopher Crockett*

$1 = 10^{24}$

yottawatt watts

3.6×10^{25}

yottawatts

Amount of power blasted out of the collision of black holes detected in September by Advanced LIGO

FOR DAILY USE

Stinkbugs add protein to African diets

One continent's nuisance is another's nutrition.

In parts of rural Zimbabwe and South Africa, the stinkbug *Encosternum delegorguei* is shaken out of trees, braised with salt and eaten as a spicy delicacy. With their defensive stink glands removed, the insects pack a high-protein punch, according to a study published January 5 in *PLOS One*.

Chemical analyses of ground, freeze-dried stinkbugs revealed the insects have lots of protein and nine essential amino acids. The stinkbugs also contain cholesterol-lowering fatty acids and several antioxidants that come from a flowering plant that the bugs eat.

E. delegorguei is a good protein supplement to the kind of grain-based diets that are common in developing countries, the researchers conclude. As with most edibles, however, proper food safety is important. Stinkbugs that are collected in traditional wooden baskets or in grain bags pick up low levels of a cancer-causing fungus toxin. Storing the bugs in clean ziplock bags keeps the snack toxin-free, the researchers found. — *Sarah Schwartz*

Before *Encosternum delegorguei* stinkbugs are cooked, their defensive stench is washed away. The bugs can become contaminated, however, with a fungus toxin when kept in reusable grain bags (left); clean ziplock bags are better.

STINKBUGS: R. MUSUNDIRE *ET AL/PLOS ONE* 2016; CHAMELEON: T. DAVENPORT/WCS

The *Kinyongia msuyae* chameleon has an unusual snout that may be important in courtship.

INTRODUCING

New chameleon doesn't mind the gap

Males of a newly described chameleon species sport a distinctive double-tipped snout. The raised snout portion (called a rostral appendage) of *Kinyongia msuyae* splits and sticks out several millimeters at the front in a hint of horns. The appendage's function is unclear, says species codiscoverer Tim Davenport of the Wildlife Conservation Society, but it might have evolved under the pressures of wooing and winning females. The new chameleon comes from biologically rich Tanzania, where its range intrigues scientists who puzzle over how species end up where they do. The four known forest fragments where the chameleons live are separated, two on each side, by the dry, forbidding Makambako Gap, report Davenport and colleagues in the current *Acta Herpetologica*. The divided habitats of the chameleon and several other animals, including the kipunji monkey (*SN: 5/21/05, p. 324*), suggest that the gap is not as isolating as scientists once thought. — *Susan Milius*

GENES & CELLS

Human DNA found in Neandertal bone

Genetic mingling pushes back timeline of ancient interbreeding

BY TINA HESMAN SAEY

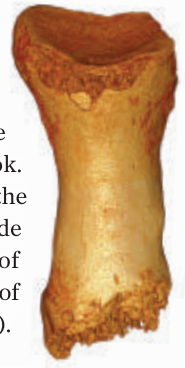
Excavations at Denisova Cave in Siberia turned up a fossil that has yielded the most complete DNA from a Neandertal ever analyzed. That DNA contains signs that humans and Neandertals interbred roughly 100,000 years ago, much earlier than scientists previously thought.

Humans and Neandertals may have hooked up much earlier than previously thought.

Early modern humans interbred with Neandertals about 100,000 years ago, an international group of researchers reports in the Feb. 25 *Nature*. That genetic mixing left its mark on the DNA of a Siberian Neandertal, the researchers have discovered. While many humans today carry bits of Neandertal DNA, this is the first time human DNA has been found embedded in a Neandertal's genes.

If the finding is correct, it indicates that the relationship between humans and Neandertals goes further back and is more complicated than scientists supposed, says Sarah Tishkoff, an evolutionary geneticist at the University of Pennsylvania who was not involved in the study.

Geneticists knew that early modern humans and Neandertals mated about 47,000 to 65,000 years ago (*SN: 6/13/15, p. 11*). Evidence of that Stone Age interbreeding was uncovered when researchers found traces of Neandertal DNA slipped into the pages of the human genetic instruction book. Today, about 1.5 to 4 percent of the genomes of non-Africans is made up of Neandertal DNA. Some of that DNA may increase the risk of certain diseases (*SN: 3/5/16, p. 18*).



A 50,000-year-old Neandertal toe bone holds evidence that humans left a genetic mark on Neandertals.

Scientists had been puzzled about why they hadn't found signs of the interbreeding in the Neandertal genome, says Graham Coop, an evolutionary geneticist at the University of California, Davis. No one could say why there was a lack of human DNA in Neandertals. Perhaps biology or cultural practices — such as shunning hybrid children — prevented human DNA from mixing into the Neandertal gene pool. Or maybe the lack of human DNA was simply a product of missing data, as DNA from very few Neandertals is available. The new finding indicates that DNA traveled both ways, Coop says.

About 1 to 7.1 percent of a 50,000 year-old Siberian Neandertal woman's DNA is human DNA, Adam Siepel, a computational biologist at Cold Spring Harbor Laboratory in New York, and colleagues discovered. That woman's toe bone, found in the same cave in the Altai Mountains as the only known fossils of extinct human cousins called Denisovans, yielded some of the most well-preserved Neandertal DNA ever analyzed (*SN: 1/25/14, p. 17*).

Siepel and colleagues lined up the Siberian Neandertal's DNA from chromosome 21 and compared it with chromosome 21 DNA from modern humans and from two other Neandertals, one from Spain and one from Croatia. The Siberian Neandertal shared more DNA with modern humans than the two European Neandertals did, the team found. That result indicates that there was little, if any, mixing between early human groups and populations that led to the European Neandertals, Siepel says.

Early humans must have left their DNA in the Siberian genome after the Neandertal woman's ancestors and the European Neandertals went their separate ways. That split occurred between 68,000 and 167,000 years ago, probably after around 110,000 years ago.

Exactly who the humans were who mated with the Siberian Neandertal's ancestors isn't clear. Those humans appear to be equally related to all present-day Africans. They could be direct ancestors of all Africans. Or they could have belonged to a group that split off from the population that would give rise to today's Africans, but didn't leave any modern descendants. "Perhaps we're getting a glimpse of populations that just didn't make it," Tishkoff says.

Also unknown is where the early interbreeding happened. "This is all sort of reading tea leaves," Siepel says. More Neandertal DNA could help pinpoint where and when humans and Neandertals first mixed.

Siepel says some hypotheses about human migration may now need rethinking in light of the new genetic evidence. "The timeline is hard to reconcile with a dominant model of human evolution with a single major migration out of Africa about 50,000 to 60,000 years ago," Siepel says. His group's finding "points fairly strongly to an earlier migration out of Africa." ■

BOTH: BENCE VIOLA

EARTH & ENVIRONMENT

FDA to test foods for glyphosate

Evidence is still mixed on herbicide's health effects

BY RACHEL EHRENBERG

The U.S. government will test various foods for the presence of glyphosate, the active ingredient in several herbicides.

Tests on foods including soybeans, corn, milk and eggs are set to begin this year, says U.S. Food and Drug Administration spokesperson Lauren Sucher. In 2014, the Government Accountability Office called for stronger monitoring of glyphosate, the world's most widely used herbicide. Previously, methods for such testing would have been too costly and labor intensive, Sucher says, but new methods now make it more feasible.

Evidence for glyphosate's ill effects is mixed and clouded by spin on both sides. But there is little doubt that human exposure has increased along with a sharp rise in the herbicide's use (*SN: 2/6/16, p. 22*).

Introduced in 1974 in Monsanto's Roundup, glyphosate soon dominated the market; today, over 275 million pounds are applied yearly to U.S. agricultural lands. Initially, farmers used the herbicide, which interferes with an essential enzyme in plants, to clear weeds from fields before planting. In the 1990s, the development of crops genetically engineered to tolerate glyphosate, and the expiration of patents, led to a dramatic increase in its use, including applications to fields during the growing season.

Regulatory agencies have concluded that the herbicide has low toxicity, and there is no routine testing for glyphosate in food or people. A onetime study by the U.S. Department of Agriculture in 2011 found glyphosate residues in 90 percent of tested soybeans and a glyphosate metabolite in over 95 percent of soybean samples. The levels were below the acceptable dietary level established by the U.S. Environmental Protection Agency of 20 parts per million, although the highest concentration reached 18.5 ppm.

Numerous toxicology studies, many conducted by industry, have found that glyphosate is relatively harmless. Animals don't have the enzyme that glyphosate acts on and shouldn't be directly affected. Other research suggests ill effects. Yet evidence of harm isn't clear-cut and has been stained by a few highly publicized, discredited studies. Such a muddled research history is all the more reason for independent studies and general monitoring, says Ana Soto, an expert in endocrine-disrupting chemicals at Tufts University School of Medicine.

In 2015, the World Health Organization's International Agency for Research on Cancer reviewed over 400 studies and rated glyphosate as "probably carcinogenic." This designation is in part due to limited evidence from real-world exposures in humans. Studies in Canada, Sweden and the United States have shown that people who work with glyphosate-based herbicides have increased risks for non-Hodgkin's lymphoma, although one large U.S. study found no such link.

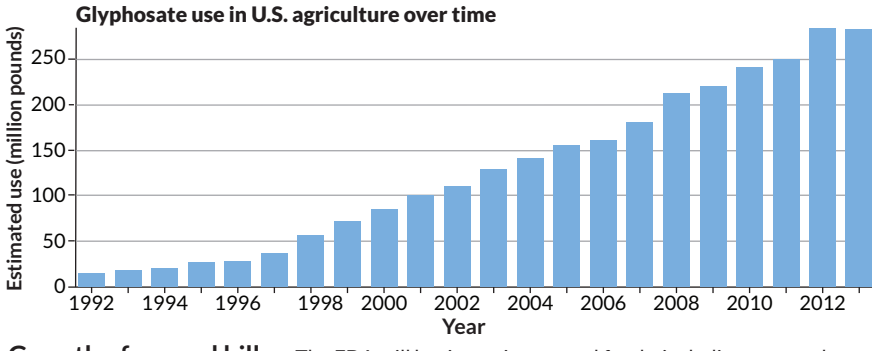
The designation also rests on evidence from animal experiments and evidence of how damage from glyphosate might occur at the cellular level. Other agents classified by the IARC as having similar strength of evidence for cancer-causing capabilities include indoor emissions from wood-burning stoves and red meat (*SN: 11/28/15, p. 9*).

The IARC assessment included only studies that are in the public domain and can be independently reviewed, says IARC toxicologist Kathryn Guyton, lead author of a paper summarizing the findings in the May 2015 *Lancet Oncology*. Many unpublished industry studies, which are accepted by U.S. regulatory agencies, were excluded. Also excluded were studies that don't provide enough data for independent analysis, such as a retracted study that linked Roundup to kidney problems and tumors in rats.

Following the designation, the European Food Safety Authority reassessed glyphosate's risks. The EFSA assessment, which was more narrowly focused and included some studies not reviewed by the IARC, was published in November 2015. It concluded that glyphosate "is unlikely to pose a carcinogenic hazard," and it raised the acceptable daily intake of glyphosate from 0.3 milligrams per kilogram of body weight per day to 0.5 mg/kg. It also established for the first time an "acute reference dose" — the maximum amount that can be ingested in a short time period without being a health risk — based on new toxicity data from rabbit studies (also 0.5 mg/kg).

The FDA's decision to monitor food coincides with a statement of concern over glyphosate exposure published online February 17 in *Environmental Health*. The statement cites some dubious science (such as the retracted rat study). But given the conflicting evidence, its recommendations seem sound, Soto says. These include routine testing for glyphosate in human fluids.

Monsanto spokesperson Charla Lord says that if the FDA tests for glyphosate residue, the company is confident that the monitoring will reaffirm the product's safety. ■



Growth of a weed killer The FDA will begin testing several foods, including corn and soybeans, for traces of glyphosate. The use of the herbicide in U.S. agriculture, and around the world, has skyrocketed in recent years. SOURCE: U.S. GEOLOGICAL SURVEY

BODY & BRAIN

Lead's health effects can last a lifetime

Tainted water for kids in Flint could mean problems in adulthood

BY MEGHAN ROSEN

The people of Flint, Mich., are drinking bottled water now, if they can get it. Volunteers deliver it door-to-door and to local fire stations.

The goal is to keep the city's residents from ingesting too much lead. Success — or lack thereof — could have consequences not just now, but for generations to come.

Late last year, scientists raised alarms over a link between the city's lead-tainted water and the growing number of children with high lead levels in their blood. It's a serious problem. Lead is toxic to the brain, something scientists have known for years.

"Lead is probably the most well-known neurotoxin to man," says Mona Hanna-Attisha, the pediatrician who first connected lead in Flint's water to lead exposure in kids. And as scientists are beginning to find out, the damage that lead inflicts on children could contribute to disorders that develop later in life, such as Alzheimer's disease or schizophrenia. Lead's reach could extend even further — beyond those who drank the contaminated water to their children and grandchildren.

Flint's kids "will have to be followed throughout their whole life, and maybe into the next generation or two," says Douglas Ruden, a neural toxicologist at Wayne State University in Detroit.

A few months of drinking clean water will help bring the kids' lead levels back down, he says. "But the damage is done." And it's permanent.

In the United States, lead is everywhere. Decades of burning leaded gasoline spewed lead into the air, and the element settled in the upper layer of soil, clinging to particles of dirt.

"Lead never goes away," says David Bellinger, an environmental epidemiologist at Boston Children's Hospital. "It doesn't degrade. It just stays where it is."

Indoors, old lead-based paint still flakes from walls and window frames. And in many U.S. cities, lead remains in old water pipes. In April 2014, a change in Flint's water source (from Lake Huron to the corrosive water of the Flint River) dissolved lead in the city's pipes, letting the toxic metal seep into tap water. After the switch, the number of kids with elevated blood lead levels doubled; in some neighborhoods, it tripled, Hanna-Attisha, of Hurley Medical Center in Flint, reported in the February *American Journal of Public Health*.

A mom in Flint, Mich., uses bottled water to bathe her 3-week-old baby. Scientists have linked high levels of lead in the city's tap water to elevated blood lead levels in children.

TODD MCINTURF/*THE DETROIT NEWS* VIA AP

Now, Hanna-Attisha is working with Ruden to examine lead levels in blood from babies born during the water crisis. The known spike in lead levels "grossly underestimates the risk," Hanna-Attisha says. The analyses didn't include newborns whose mothers had been drinking the contaminated water.

Flint's crisis garnered national attention, in part because lead exposures in the United States have become less common over the last few decades.

"It's actually a great public health success," Bellinger says.

Since the United States banned lead in paint in 1978 and in gasoline in 1996, the amount of lead in young children's blood has fallen hard and fast: from around 16 micrograms per deciliter of blood on average in the late 1970s to just over 1 µg/dl in 2010. Today, 5 µg/dl is the benchmark for high blood lead levels, according to the U.S. Centers for Disease Control and Prevention.

Most cases of lead exposure in children come from eating lead particles or paint.

Children playing outside or on the floor can end up licking lead dust that's stuck to their hands or toys — it tastes sweet. From the mouth, lead travels to the gut, into the bloodstream and on to the brain and other organs. Then lead moves into the bones, where it can hide out for decades.

Scientists have linked chronic lead exposure to lowered IQ, shortened attention spans, antisocial behavior and having less gray matter — the nerve cell bodies that make up much of the brain.

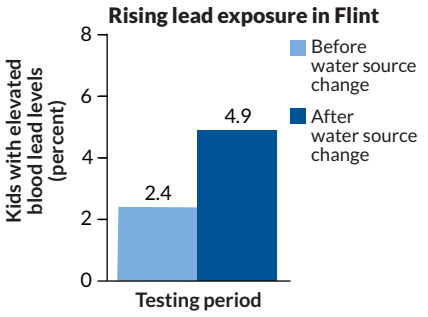
"We know now that no amount of lead is good for children," says Columbia University neurotoxicologist Tomas Guilarte.

He and others have spent years puzzling out what lead does to the brain. It's a grim picture. Chronic exposure can kill nerve cells and make it hard for new ones to survive and talk to each other. The mark that lead leaves on the brain might even show up when people age.

"I think in the next 15 to 20 years," Guilarte says, "if people look closely, they'll find that many of these lead-exposed children are going to have mental issues."

In recent years, scientists have linked lead exposure to diseases that strike in adulthood, such as Alzheimer's, Parkinson's and schizophrenia.

Some evidence comes from animal studies. In 2015, Guilarte and colleagues chronically exposed young rats to lead and then dissected their brains. The rats showed signs of schizophrenia, the researchers reported in *Translational*



Source switch After Flint, Mich., changed its water source from Lake Huron to the Flint River in 2014, the percentage of kids with elevated blood lead levels doubled.
SOURCE: M. HANNA-ATTISHA *ET AL/AJPH* 2016

Psychiatry. The rats had lost PVG neurons, nerve cells essential for attention and memory. And the rats had gained dopamine receptors, proteins that might be overactive in schizophrenia .

At the molecular level, one way that lead might do its dirty work is by masquerading as zinc. One of zinc's jobs is to anchor floppy sections of protein together, forming a shape that plugs into DNA. This lets proteins flip genes on and off like a light switch. When lead takes the place of zinc, the protein switch might not work the same way, says bioinorganic chemist Rachel Austin of Barnard College in New York City.

Scientists know that several of these switches go out of whack in schizophrenia, Alzheimer's and Parkinson's. Lead could bear some of the blame, Austin and Jacqueline Ordemann of Bates College in Lewiston, Maine, proposed online January 8 in *Metallomics*. "It's certainly chemically possible," Austin says.

Lead exposure during youth also seems to leave chemical fingerprints on future generations. Ruden and colleagues examined blood collected from 35 Michigan mothers and babies at birth. The newborns' DNA carried an atypical set of chemical tags, or methyl groups, the researchers reported in *Scientific Reports* last September. Some of the mothers themselves had been born with high blood lead levels, which means that *their* mothers had been exposed to lead. The researchers proposed that if grandma had lead in her blood, her grandkids could show it.

If DNA is the hardware of the cell, says Ruden, then the chemical tags are the software that tells cells what to do. Lead seems to rewrite cells' software — for generations. "We don't know if that's good, bad or indifferent," he says. "But it's more than likely not good."

Massive public health campaigns have tried to scrub lead from the environment, but there's still no cure for lead poisoning. Some treatments, called chelation therapies, can draw lead from the body, but they don't seem to help the brain. And dietary supplements, such as iron, calcium or zinc, could potentially keep lead from entering the blood, but "the evidence is not that great," Bellinger says.

Still, Hanna-Attisha says the situation in Flint isn't hopeless. Thousands of kids drank contaminated water, "but it doesn't mean every kid is going to have every problem," she says. And stimulating children's learning might be one way to lessen lead's damaging effects.

A 2013 study found a link between the home environments of lead-exposed first-graders and their thinking ability and behavior. Lead seemed to have less of an effect on kids whose mothers helped out with schoolwork and extracurricular activities, Katarzyna Kordas and colleagues reported in *NeuroToxicology*.

"It's certainly very suggestive, but we're not claiming causality," cautions Kordas, an environmental epidemiologist at the University at Buffalo in New York.

Ultimately, preventing exposure to lead in the first place is key, says Hanna-Attisha. "You don't mess around with lead," she says. "It can change a child's whole life trajectory." ■

JIE YANG/YUNNAN UNIV., CHINA

LIFE & EVOLUTION

Fossil reveals arthropod's nervous system

The fossilized remains of a roughly 520-million-year-old creepy-crawly provide an exquisite portrait of an ancient arthropod's nervous system.

Researchers first described *Chengjiangocaris kunmingensis* — an extinct relative of spiders, insects and crustaceans unearthed in southern China —in 2013. Further imaging and investigation of five new fossilized specimens reveal exceptionally well-preserved soft tissue and a ropelike structure running down the animal's belly. That structure is the remains of a ventral nerve cord, Xi-guang Zhang of Yunnan University in Kunming, China, and colleagues explain in an upcoming *Proceedings of the National Academy of Sciences*. A partial nerve cord is preserved in the specimen above (dark brown horizontal line in the head area).

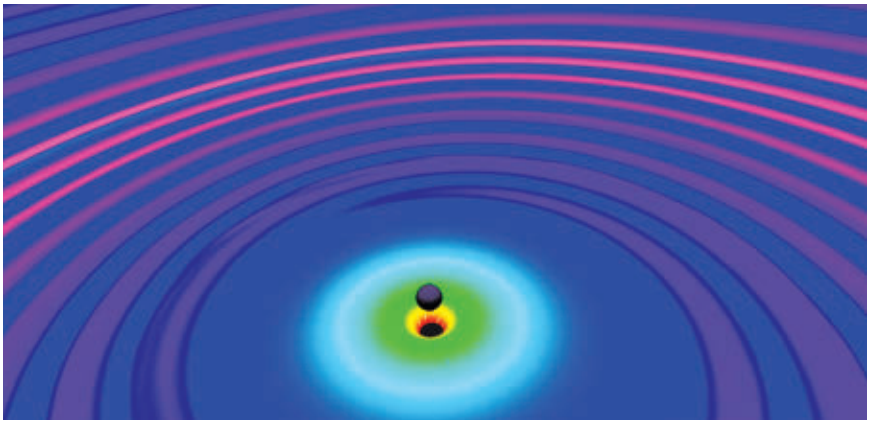
In invertebrates, a nerve cord serves the same function as a vertebrate's spinal cord. In *C. kunmingensis*, bundles of ganglia and connective tissue formed the cord similar to today's arthropods and tardigrades. Each bundle probably controlled a pair of itty-bitty legs, the researchers say. What appear to be individual peripheral nerves shoot off from the nerve cord, resembling the segmented nerve roots seen in penis worms and velvet worms. — *Helen Thompson*

ATOM & COSMOS

New details about LIGO's black holes

Many more gravitational wave detections expected this year

BY CHRISTOPHER CROCKETT



In the wake of a black hole collision, one bigger black hole (middle) forms as gravitational waves (blue and purple bands) ripple away, as seen in this computer simulation. The colors near the black hole illustrate how gravity slows time (clocks would tick slower in the orange zone).

The recent detection of gravitational waves is a stunning confirmation of Albert Einstein's theories and the start of a new way of observing the universe. And at the center of it all is a celebrity couple: the first known pairing of black holes and the most massive ones formed from the collapse of a star.

On September 14, the Advanced Laser Interferometer Gravitational-Wave Observatory, or LIGO, sensed a disturbance in spacetime caused by two massive black holes smashing together (*SN: 3/5/16, p. 6*). "It's quite an incredible discovery," says Vikram Ravi, an astrophysicist at Caltech. "They've seen objects that I guess none of us outside the collaboration imagined they might see." With masses of 29 and 36 suns, these black holes were roughly twice as massive as the previous record holders.

Those masses actually aren't too shocking, says astrophysicist Jeffrey McClintock of the Harvard-Smithsonian Center for Astrophysics. Black holes such as those detected by LIGO are born when a massive star dies. Very massive stars, though rare, should give rise to very massive black holes. What would have been more surprising, he says, is if LIGO failed to turn up any black holes this large. "If the nearest 1,000 stars had been investigated and we hadn't found any planets, I would go back to church," he says. "I feel the same way about two 30-solar-mass black holes."

There are heavier black holes. Those monsters live in the centers of galaxies and can weigh billions of times as much as the sun. They are different beasts entirely, probably built up as galaxies collide. Given the masses of the black holes that LIGO found, "they likely formed in a fairly different environment than the Milky Way," Ravi says.

How much mass a star ends up with at the end of its life depends partly on its store of elements heavier than helium. Atoms such as carbon, magnesium and iron present larger targets to the light that's escaping a star. As light races outward, it bumps into these atoms, which in turn shove the surrounding gas along. The heavy elements behave like little snowplows attached to the photons, whittling away at the star's mass as the light radiates into space. To make black holes as massive as LIGO's, the original stars must have had fewer of these heavy elements than typical stars in our neighborhood, the LIGO team reports in the Feb. 20 *Astrophysical Journal Letters*.

One possibility is that the stars formed early in the universe, before heavy elements had a chance to accumulate. At the other extreme, the stars could have formed more recently in a relatively nearby and pristine pocket such as a dwarf galaxy. "With one observation, it's impossible to say if it's on one side of the continuum or the other," says Vicky Kalogera, a LIGO astrophysicist at Northwestern University in Evanston, Ill.

The best estimates put the collision in a galaxy about 1.3 billion light-years away (give or take a few hundred million light-years) in the southern sky, roughly in the direction of the Magellanic clouds, two satellites of the Milky Way. A third LIGO facility, such as the one recently approved for India, will help narrow down precise positions of future detections. So would a simultaneous burst of electromagnetic radiation from the location of a collision. LIGO has agreements with telescopes around the world (and in space) to keep an eye out for any flashes of light that occur at the same time as a gravity wave detection. For LIGO's debut, no observatories reported anything definitive. But the Fermi gamma-ray satellite did see something interesting, astrophysicist Valerie Connaughton and colleagues report online February 14 at arXiv.org.

"We found a little blip that's weaker than anything we'd normally look at," says Connaughton, of the Universities Space Research Association in Huntsville, Ala. At 0.4 seconds after LIGO's detection, Fermi recorded a very faint flash of gamma rays. "We'd normally never pick it out of the data," she says. Researchers can't pinpoint precisely where the burst came from, but the direction is roughly consistent with LIGO's.

If the black hole collision did blast out gamma rays, theorists are going to have some explaining to do. Merging black holes shouldn't release any electromagnetic radiation. It's only when neutron stars get involved that telescopes should see flashes of light. During a recent phone call with colleagues about the Fermi data, "the theorists were already arguing with each other," Connaughton says.

Perhaps the black holes were born within a single whirling star whose core split in two, Harvard astrophysicist

SXS

Abraham Loeb suggests online February 15 at arXiv.org. The gamma rays could have come from a gas fountain fueled by infalling debris from the parent star.

But before the theorists get too worked up, researchers need to figure out if what Fermi saw had anything to do with LIGO's black holes. "We're definitely not saying we saw an [electromagnetic] counterpart," Connaughton says. It could be just a coincidence. During nearly 67 hours of observation in September, Fermi saw 27 similar gamma-ray bursts. The only way to be certain is to wait for more LIGO detections. "If it's real, it's not going to be a one-off," she says.

LIGO's debut detection appeared during a engineering run in September; researchers are analyzing LIGO data accumulated during the four months that followed, and another science run is planned for later this year. The team is optimistic about its chances of finding more events. LIGO could have sensed a collision between two 30-solar-mass black holes out to about 6 billion light-years away. Given that researchers found one (so far) in 16 days of data, and assuming that's a typical couple of weeks in the universe, then researchers estimate that between two and 53 similar collisions occur per cubic gigaparsec per year. (One cubic gigaparsec is the volume of a sphere roughly 4 billion light-years across.)

If those estimates are correct, scientists think LIGO could have detected up to about 10 more similar collisions in its first four months of operation, and possibly will record hundreds once the facility is running at full sensitivity. And that's not including collisions of black holes with different masses, smashups of neutron stars or any other cosmic calamities that could rattle spacetime.

As more collisions are found, astronomers should get a better handle on where binary black holes form. "We may find they're all in the local universe and none in the early universe," Kalogera says. And that would tell researchers something about how massive star formation has changed throughout cosmic history. "We have high expectations now for a bigger sample in the near future." ■

HUMANS & SOCIETY

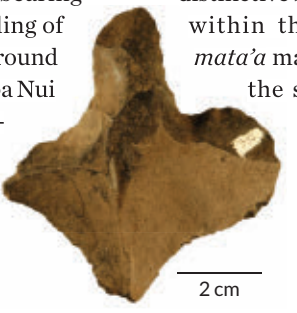
Easter Islanders made tools, not war

Artifacts challenge idea that violence led to Rapa Nui collapse

BY BRUCE BOWER

Sharpened stones previously viewed as spearpoints wielded by warring Easter Islanders actually served as general-purpose tools, researchers say.

Early European visitors to Easter Island, or Rapa Nui, wrote in the late 1700s that the islanders carried spears topped with sharp, triangular pieces of glassy lava, or obsidian. In the last 20 years, some researchers have suggested that fighting among spear-bearing groups — following the leveling of resource-rich palm forests around 1550 — largely destroyed Rapa Nui civilization before Europeans arrived.



Obsidian artifacts from Easter Island, including this one, served as tools for planting and other daily activities, a new study finds.

But instead the islanders probably used the alleged spearpoints in a variety of ways that had nothing to do with killing, say archaeologist Carl Lipo of Binghamton University in New York and colleagues. These sharp rocks, known as *mata'a*, would have been useful for tasks such as cutting sweet potato plants into pieces for cultivation, cutting bananas off trees, stripping bark for rope and cutting ritual designs into people's skin, perhaps to create tattoos, the scientists report in the February *Antiquity*.

Evidence of versatile uses for *mata'a* "adds to our understanding of how ancient Rapa Nui society flourished until well after initial European contact in 1722," says anthropologist Mara Mulrooney of the Bernice Pauahi Bishop Museum in Honolulu. Recent research suggests that farming on the island continued long after palm forests had been cleared (*SN: 1/25/14, p. 9*).

Mata'a had no standardized shape and rarely sported long, spearlike tips, Lipo's team finds. These tools must have been fashioned with nonviolent purposes in mind, the scientists contend.

That conclusion rests on shape and size measurements taken from photographs of 423 *mata'a*. Most artifacts are in museums on Rapa Nui or in Hawaii. There are no precise age estimates for the finds, but *mata'a* date to before Europeans reached Rapa Nui, Lipo says.

A statistical analysis identified no consistent tool shape among these finds. *Mata'a* feature narrow stems and wide blades, but vary considerably within that format. Neither did Lipo's group detect a distinctive set of spear-shaped *mata'a* within the larger sample. Even *mata'a* made from rock gathered at the same Rapa Nui obsidian quarries — of which five existed — and fashioned at the same toolmaking locations lacked signature forms.

Microscopic studies published 20 years ago suggested that scratches, polish and chipping on *mata'a* resulted from woodworking, Lipo adds.

Previous research indicated that obsidian tools resembling *mata'a* were used to cut up root crops, carve wood and perform other daily tasks on the Melanesian island of New Britain several thousand years ago.

Robin Torrence, an archaeologist at the Australian Museum in Sydney who codirected the work in New Britain, says Lipo's new study can't definitively rule out the use of *mata'a* as weapons. Although *mata'a* don't look like spearpoints, she says, "these stone implements would be very dangerous if used as axes or clubs in close-combat fighting."

Lipo considers that scenario unlikely. While any sharp-edged stone can be used on occasion to hurt others, no remains of hilltop forts or other defensive structures linked to warfare have been found on Rapa Nui, he says. *Mata'a* "were sharp rocks on sticks designed not as lethal weapons but for peaceful purposes." ■

C. LIPO, FATHER SEBASTIAN ENGLERT ANTHROPOLOGICAL MUSEUM/RAPA NUI

GENES & CELLS

‘Selfish’ DNA flouts rules of inheritance

Although harmful, *R2d2* can sweep through mouse populations

BY TINA HESMAN SAEY

In the *Star Wars* movies, the droid R2-D2 is a heroic rebel. In living animals, a selfish bit of DNA called *R2d2* is an outright lawbreaker. It violates laws of both genetic inheritance and Darwinian evolution. *R2d2* can sweep through mouse populations by mimicking helpful mutations while actually damaging fertility, researchers report online February 15 in *Molecular Biology and Evolution*.

The new finding suggests that even genes that hurt an organism’s evolutionary chances can cheat their way to the top. That could be good news for researchers hoping to use engineered “gene drives” to eliminate mosquito-borne diseases and invasive species (*SN: 12/12/15, p. 16*). But it’s also a cautionary tale for scientists looking for signs that natural selection has picked certain genes because they offer an evolutionary benefit.

If researchers aren’t careful, they may be hoodwinked into thinking that a selfish gene has some evolutionary advantage, says Daven Presgraves, an evolutionary geneticist at the University of Rochester in New York. The genetic signatures are the same, he says. But what looks like survival of the fittest may actually be a cheater prospering.

Geneticist John Didion and colleagues examined DNA samples from wild mice from Europe, the United States and elsewhere to determine how widespread *R2d2* has become. The researchers also bred strains of mice in the lab to determine how quickly *R2d2* is capable of spreading. The selfish DNA could blaze through populations, reports Didion, formerly of the University of North Carolina at Chapel Hill. The proportion of mouse chromosomes with the selfish gene — called the allele frequency — more than tripled in one laboratory population from 18 to 62 percent within 13 generations, the researchers found.

In another breeding population, *R2d2* shot from being in 50 percent of the lab mice’s chromosomes to 85 percent in 10 generations. By 15 generations, the selfish element reached “fixation” — all the mice in the population carried it. That rate of spread was much faster than Didion, now at the National Human Genome Research Institute in Bethesda, Md., and colleagues predicted. Computer simulations had projected it would take 184 generations.

Such wildfire spread of a gene variant that eventually wipes out all other versions is known as a selective sweep. Sweeps are hallmarks of a gene that helps an organism adapt to its environment. But this study suggests that what looks like adaptation may actually be selfish genetics at work, says Nitin Phadnis, an evolutionary geneticist at the University of Utah in Salt Lake City.

R2d2 is a “selfish element,” a gene or other piece of DNA that causes itself to be inherited preferentially, researchers at UNC Chapel Hill and colleagues reported last year. The droid’s namesake is a stretch of DNA on mouse chromosome 2 that contains multiple copies of the *Cwc22* gene. When seven or more copies of that gene build up on the chromosome, *R2d2* gets selfish. In female mice, it elbows aside the chromosome that doesn’t contain the selfish version of the element and is preferentially incorporated into eggs. That’s a violation of the laws of inheritance spelled out by Gregor Mendel, in which each gene or chromosome is supposed to have a fifty-fifty chance of being passed on to the next generation. But there is a cost to *R2d2*’s selfishness: Female mice that carry one copy of the selfish element have small litter sizes compared with mice that don’t carry the greedy DNA.

Under evolutionary laws, that loss of fertility should cause natural selection to weed out *R2d2*. But the selfish element’s greed is greater than the power of natural selection to combat it, the lab experiments show.

Even the most successful cheat can get caught, though. Wild mice in Europe and at other sites, including two U.S. locations, had widely varying allele frequencies of the selfish gene, Didion and colleagues found. In a population of German mice, *R2d2*’s frequency was 67 percent, but only 8 percent in Greek mice. In Maryland, where mice carrying *R2d2* were first found, 21 percent of chromosomes carried it. The selfish element may not have crossed the country yet. None of the tested mice from California had *R2d2*.

Based on lab experiments, the researchers might have expected all the wild mice would carry the deceptive DNA. The relatively low proportion of wild mice carrying *R2d2* could mean that some mice have developed ways to suppress the gene’s selfishness, says evolutionary geneticist Matthew Dean of the University of Southern California. ■

A selfish bit of DNA called *R2d2* was first discovered in Maryland in mice called Watkins Star Line B (one shown). Selfish DNA’s ability to sweep through populations challenges traditional views of evolution.

JACKSON LABORATORY PHOTO BY JENNIFER L. TORRANCE

EARTH & ENVIRONMENT

Seafloor cables don't disrupt life

Animals will cross, colonize high-voltage power lines

BY THOMAS SUMNER

High-voltage electricity surging through undersea power cables doesn't bother local sea life, three new studies suggest. The work eases concerns that planned offshore power production from wind turbines and tidal generators would disrupt marine communities along the lines that ferry power to shore.

Tracking the movements of fish and crabs around underwater power cables, the new studies reveal that marine critters don't shy away from the magnetic fields put off by the cables. One study even found that the thick cables can serve as artificial habitats for undersea communities.

"There's much less of a concern now," said Ann Bull, a marine biologist at the Bureau of Ocean Energy Management in Camarillo, Calif., who presented two of the studies February 26.

Underwater telecommunications cables have clashed with marine life in the past: Sharks have gnawed on the cables, for example, often leaving teeth behind. Wrapping the cables in insulating material blocks the electric fields and stems shark bites, but magnetic fields generated by the cables remain. Lab experiments show that many marine creatures can sense even relatively weak magnetism, sparking fears that the cables create underwater "fences" that disrupt sea life.

Commercial fishers particularly worried that crabs wouldn't cross undersea cables to find bait in crab traps. Bull and colleagues tested this concern in the Santa Barbara Channel off California and near the San Juan Islands off Washington. The team built cages with two baited traps, one of which required crabs to pass over an active power line. Both Dungeness crabs (*Metacarcinus magister*) and rock crabs (*Romaleon antennarium*) had no problem crossing the line: In hundreds of trials, the crabs chose each trap in about equal numbers.

In another study, Bull and colleagues monitored the marine life around three parts of the seafloor over three years. One area had a powered cable, another had an unpowered cable and the third had no cable at all. Both cabled areas attracted similar kinds and numbers of anemones and other sea life. In fact, more than twice as many fish and four times as many invertebrates hung around the cables than in the area with unaltered seafloor.

Measuring the magnetic field generated by the powered cable, Bull and colleagues found that the field quickly weakened with distance. By a meter away, the magnetic field was too meager for the team to distinguish from background noise, Bull said. Even where the magnetic field was strongest, right on top of the cable, sea creatures didn't seem bothered.

In the third study, also presented February 26, Megan Wyman, an animal behaviorist at the University of California, Davis, and colleagues looked at an 85-kilometer-long, high-voltage power cable that bisects the San Francisco Bay. The team found that the activation of this cable in 2010 did not hinder young Chinook salmon (*Oncorhynchus tshawytscha*) from migrating through the bay from inland rivers.

"It's great to hear that they don't seem to see any impact," said Genevra Harker-Klimes, a marine scientist at the Pacific Northwest National Laboratory in Sequim, Wash. "There are a few loose ends that need to be tied up, but overall this is very positive." ■

MEETING NOTES

Corals need to take their vitamin C

Hard corals may need a dose of vitamin C when building their skeletons. New research finds that when free-floating larvae settle down and form their skeletons through calcification, genes associated with the transport of vitamin C get busy. Without enough of the vitamin, corals might even get scurvy.

The work will help scientists better understand how such environmental shifts as climate change will impact coral calcification (*SN Online: 10/8/15*), said Joshua Rosenthal, a neurobiologist at the University of Puerto Rico in San Juan. Rosenthal presented the work February 22.

Rosenthal and colleagues measured which genes switched on when mustard hill corals (*Porites astreoides*) transitioned out of their larval stage. The gene associated with shuttling vitamin C across cell membranes had the biggest jump in activity. Rosenthal proposed that corals use vitamin C similarly to humans, to help weave together strands of cartilage. — *Thomas Sumner*

Gulf oil spill could speed up corrosion of shipwrecks

Lingering oil from the Deepwater Horizon spill could hasten the destruction of historical shipwrecks in the Gulf of Mexico. Tracking the activities of metal-corroding microbes, researchers found that oil mixed into seawater roughly doubled the amount of observed metal corrosion. The scientists reported their findings February 22.

Over 2,000 sunken ships dot the Gulf's seafloor. These wrecks provide historical insights as well as homes for deep-sea communities.

Marine ecologist Jennifer Salerno of George Mason University in Fairfax, Va., and colleagues placed high-carbon steel wafers near sunken ships for four months and in special water tanks for 16 weeks. Wafers in oil-polluted water corroded significantly more than those in pristine seawater and hosted different kinds of microbes. Salerno speculated that the oil may support a microecosystem for metal-chomping microbes or may trap metal-degrading hydrogen sulfide released by the microbes. — *Thomas Sumner*

ROY KALTSCHMIDT

ATOM & COSMOS

New hints of a fourth neutrino found

Reactors' antiparticle output defies theoretical expectations

New results of experiments at the Daya Bay neutrino detector (walls lined with photomultiplier tubes, shown) hint at the existence of a lightweight sterile neutrino, about one-millionth the mass of an electron.

BY RON COWEN

In tunnels deep inside a granite mountain at Daya Bay, a nuclear reactor facility some 55 kilometers from Hong Kong, sensitive detectors are hinting at the existence of a new form of neutrino, one of nature's most ghostly and abundant elementary particles.

Neutrinos, electrically neutral particles that sense only gravity and the weak nuclear force, interact so feebly with matter that over 100 trillion zip unimpeded through your body every second. They come in three known types: electron, muon and tau. The Daya Bay results suggest the possibility that a fourth, even more ghostly type of neutrino exists — one more than physicists' standard theory allows.

Dubbed the sterile neutrino, this phantom particle would carry no charge of any kind and would be impervious to all forces other than gravity. Only when shedding its invisibility cloak by transforming into an electron, muon or tau neutrino could the sterile neutrino be detected. Definitive evidence "would open up a whole new avenue of research," says Stephen Parke, a particle physicist at the Fermi National Accelerator Laboratory in Batavia, Ill.

Possible evidence for the sterile particle comes from a mismatch between theory and experiment. If a nuclear reactor produces a beam of just one type of neutrinos, theory predicts that some should change their identity as they travel to a far-off detector (*SN: 10/31/15, p. 16*). Analyzing more than 300,000 electron antineutrinos (the antimatter counterpart of the electron neutrino) collected from the Daya Bay nuclear reactors during 217 days of operation, researchers found 6 percent fewer of the particles than predicted by the standard particle physics model. Particle physicist Kam-Biu Luk of the University of California, Berkeley and the Lawrence Berkeley National Laboratory and colleagues report the findings in the Feb. 12 *Physical Review Letters*.

One explanation for the deficit is that some of the electron antineutrinos have transformed into an undetectable, lightweight sterile neutrino, about one-millionth the mass of an electron, says Luk. Other nuclear reactor studies, including an experiment at the Bugey reactor in Saint-Vulbas, France, have seen similar electron antineutrino deficits, he notes. Studies with muon antineutrino beams at some particle accelerators have seen an excess of electron antineutrinos, which might be attributed to a different kind of sleight of hand by unseen sterile neutrinos.

The Daya Bay result provides the most precise measure yet of the energies of electron antineutrinos at a nuclear reactor. Even so, the statistical significance of the deficit is not high enough to rate the finding a discovery. The result is a "three-sigma" finding, meaning that there's about a 0.3 percent probability that such a paucity of electron antineutrinos would have occurred if no sterile neutrino exists. Physicists generally want a discrepancy to have a significance of five-sigma, or a 0.00003 percent chance of being a fluke, before they will label it a discovery.

Besides the hint of sterile neutrinos, the Daya Bay results reveal a second strange feature — an excess of electron antineutrinos (compared with theoretical predictions) at an energy of around 5 million electron volts. That could be a sign of completely new physics awaiting discovery (or it could simply mean that scientists don't have a detailed enough grasp of the output of nuclear reactors). A revised understanding of that feature might even do away with the need for a lightweight sterile neutrino to explain the overall deficit in electron antineutrinos.

If definitive evidence for a light sterile neutrino is eventually found, it "would turn the theory community on its head," says Parke, and could have a bigger

impact than the discovery of the Higgs boson, the Nobel-winning finding that explains why elementary particles have mass (*SN: 7/28/12, p. 5*).

"Finding a sterile neutrino is extremely important because it would be the first discovery of a particle which cannot be accommodated in the framework of the so-called standard model," says particle physicist Carlo Giunti of the University of Turin in Italy.

One of the earliest experiments that suggested the presence of sterile neutrinos was the Liquid Scintillator Neutrino Detector, which operated at the Los Alamos National Laboratory in New Mexico from 1993 to 1998. The LSND found that muon antineutrinos beamed into 167 tons of mineral oil had morphed into electron antineutrinos in a way that seemed to require a fourth type of neutrino to exist. A follow-up experiment at Fermilab, called MiniBooNE, ran from 2002 to 2012, with equivocal results. Another Fermilab experiment, MicroBooNE, began operation last October. MicroBooNE is the first of three liquid argon detectors, spaced at different distances near neutrino sources at Fermilab, that will track with unprecedented precision the transformation of neutrinos from one type to another.

Located 470 meters from Fermilab's Booster Neutrino Beamline, MicroBooNE is the middle of the trio, to be joined in 2018 by ICARUS, the farthest detector, at a distance of about 600 meters from the beamline, and the Short-Baseline Near Detector, placed about 100 meters from the source. First results from the trio are expected in 2021, says experimental particle physicist Peter Wilson of Fermilab.

The detectors will also serve as a prototype for the Deep Underground Neutrino Experiment, a large-scale experiment that will send Fermilab-generated neutrinos on a 1,300-kilometer journey to the Sanford Underground Research Facility near Lead, S.D.

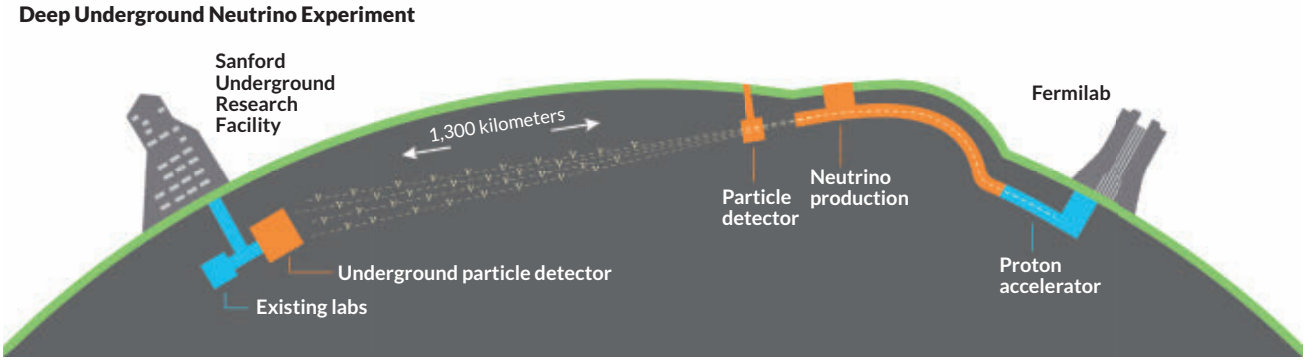
In the meantime, the Daya Bay collaboration has teamed up with another Fermilab experiment, the Main Injector Neutrino Oscillation Search, to continue to seek signs of sterile neutrinos. Although data from accelerator and reactor experiments do not yet paint a consistent picture, "we will know better whether a light sterile neutrino is waiting for us to unveil," Luk says.

If a light sterile neutrino exists, it might have siblings about 1,000 times heavier. These particles could contribute to the as-yet-unidentified dark matter, the invisible gravitational glue that keeps galaxies from flying apart and shapes the large-scale structure of the universe. Fingerprints of these particles will be sought with an experiment called KATRIN, which examines the radioactive decay of tritium, a heavy isotope of hydrogen, at the Karlsruhe Institute of Technology in Germany.

Sterile neutrinos that are even more massive, more than a trillion times heavier than the electron, could explain an even bigger cosmic mystery — the mismatch between the amounts of matter and antimatter in the universe. Possessing an energy at least a million times greater than can be produced at the Large Hadron Collider, the world's most powerful particle accelerator, a superheavy sterile neutrino in the early universe would have made a smidgen more matter than antimatter. Over time, the tiny imbalance, reproduced in countless nuclear reactions, would have generated the matter-dominated universe seen today (*SN: 1/26/13, p. 18*).

"For cosmology, the [lightweight] sterile neutrino that we are talking about cannot solve the problem of the matter-antimatter asymmetry, but it is likely that the sterile neutrino is connected with other new particles that can solve the problem," Giunti says.

Scientists see another, more practical, benefit of studying neutrinos. By recording the antineutrino output of nuclear reactors, detectors can discern the relative amounts of plutonium and uranium, the raw materials for making nuclear weapons. Gram for gram, fissioned plutonium and uranium have distinctive fingerprints in both the energy and rate of antineutrinos they produce, says physicist Adam Bernstein of the Lawrence Livermore National Laboratory in California. Closeup monitoring of reactors, from a distance of 10 to 500 meters, has already been demonstrated; detectors capable of monitoring weapons activity from several hundred kilometers away is possible but will require additional research and funding, Bernstein says. ■



FERMILAB

Incredible journey In the Deep Underground Neutrino Experiment, slated to begin in the next decade, neutrinos (ν) produced at Fermilab in Batavia, Ill., will journey 1,300 kilometers to the Sanford Underground Research Facility near Lead, S.D. There, underground detectors will record how these ghostly particles have morphed from one type to another.

LIFE & EVOLUTION

Ancient armadillo look-alikes are related to modern armadillos

Charles Darwin returned from his travels aboard the *Beagle* in 1836 with several curious fossils from South America, including the remains of what appeared to be a giant armored mammal. He thought the extinct animal, later dubbed a glyptodont, must have looked like a supersized armadillo. DNA evidence published in the Feb. 22 *Current Biology* suggests Darwin was right to make that connection.

Paleontologists have long suspected that glyptodonts (illustrated above) are related to modern armored mammals. To figure out where glyptodonts fit on the family tree, researchers extracted mitochondrial DNA from the roughly 14,000-year-old fossilized carapace of a *Doedicurus* specimen found in Argentina.

Based on comparisons with DNA from modern armadillos and their relatives, the researchers determined that glyptodonts' closest living relatives are fairy armadillos (*SN: 11/16/13, p. 4*) and a group that includes giant armadillos. By the researchers' calculations, the glyptodonts diverged from these armadillos about 35 million years ago, from a common ancestor that weighed six kilograms. Glyptodonts later ballooned to an estimated 2,000 kilograms, about as heavy as a large sedan. — *Helen Thompson*

GENES & CELLS

Ministomachs brew insulin in mice

Ministomachs grown in a lab could one day supply insulin to people with diabetes.

Loss of insulin-producing beta cells in the pancreas is a hallmark of diabetes. But researchers see a solution in tissues in the lower stomach, which regenerate often via local stem cells and regularly employ many of the same genes that are active in pancreatic beta cells. By flipping on three key genes in these stomach stem cells, scientists have engineered what may be a viable replacement for beta cells. In experiments with genetically engineered mice that lacked beta cells, reprogrammed stomach stem cells pumped out insulin and helped the mice maintain normal blood glucose levels.

Using these engineered cells, researchers grew and implanted ministomachs in diabetic mice. In five of 22 mice, glucose levels dropped. That fraction might seem low, but the work shows that the method could be used as a model for diabetes therapies, the scientists say online February 18 in *Cell Stem Cell*. — *Helen Thompson*

BODY & BRAIN

Vaginal ring somewhat effective at preventing HIV infection

A vaginal ring infused with an antiviral drug appears to protect against HIV, although not as much as doctors had predicted. Women who used the ring had a 27 percent lower incidence of HIV infection than women who received a placebo, scientists report online February 22 in the *New England Journal of Medicine*. A second separate study had similar results, finding a nearly 31 percent reduction. Both studies were released during the Conference on Retroviruses and Opportunistic Infections in Boston.

The trials involved women in sub-Saharan Africa. Public health officials hope that this discreet, long-lasting protection will help women prevent infection (*SN: 11/14/15, p. 14*).

The ring delivers dapivirine and lasts for a month. The larger of the two studies involved 2,629 women. After a median follow-up of 1.6 years, 71 women using the ring became infected, compared with 97 using a placebo. Women from two of the 15 study sites had low adherence rates; when the data were analyzed without those sites, infection rates were 37 percent lower for women who used the ring than for those on a placebo. The ring also was less protective among women younger than 21, a finding correlated with less consistent use. — *Laura Beil*

MATTER & ENERGY

Carbon honeycomb could store gas

Researchers have identified a mysterious lab-made material as a new form of carbon.

Carbon honeycomb, a three-dimensional cluster of carbon sheets, can trap large amounts of gas within six-sided cells. The structure could be used to store gases or liquids, or as a building material for more complex compounds, researchers report in the Feb. 5 *Physical Review Letters*.

Electron microscope images helped uncover the new structure, which was first created in 2009 by vaporizing thin carbon spindles in a vacuum. Subsequent tests of the nanometers-thick film revealed that the substance has different density and light-scattering properties than known forms of carbon, such as graphite. Carbon honeycomb cells might link up with cylindrical carbon nanotubes, the researchers say. But unlike nanotubes, the new structure holds up for months in a vacuum without degrading. The honeycomb can also absorb about twice as many gas molecules, such as carbon dioxide, as nanotubes can.

Future research should aim to produce a more uniform carbon honeycomb, says study coauthor Nina Krainyukova of the National Academy of Sciences of Ukraine. Some chambers are five-sided and their arrangement is random. — *Sarah Schwartz*

PETER SCHOUTEN

King Solomon's Secret Treasure: FOUND

Ancient beauty trapped in mines for centuries is finally released and available to the public!

King Solomon was one of the wealthiest rulers of the ancient world. His vast empire included hoards of gold, priceless gemstones and rare works of art. For centuries, fortune hunters and historians dedicated their lives to the search for his fabled mines and lost treasure. But as it turns out, those mines hid a prize more beautiful and exotic than any precious metal: chrysocolla.

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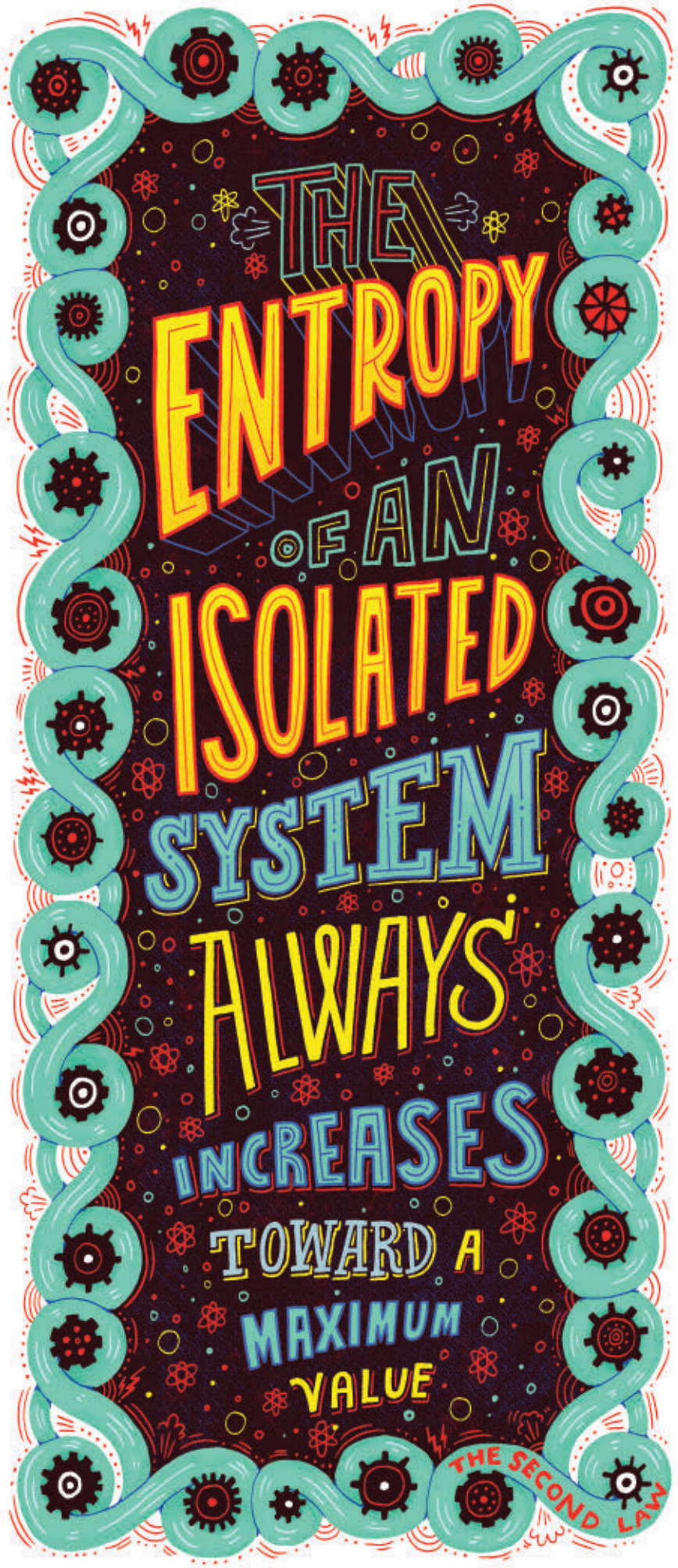


THE LAWS OF HEAT GO SMALL

Physicists explore thermodynamics in the quantum realm

By Andrew Grant

When French engineer Sadi Carnot calculated the maximum efficiency of a heat engine in 1824, he had no idea what heat was. In those days, physicists thought heat was a fluid called caloric. But Carnot, later lauded as a pioneer in establishing the second law of thermodynamics, didn't have to know those particulars, because thermodynamics is insensitive to microscopic details. Heat flows from hot to cold regardless of whether it consists of a fluid or, as it turns out, the collective motion of trillions of trillions of molecules. Thermodynamics, the laws and equations governing energy and its usefulness to do work, concerns itself only with the big picture.

It's a successful approach. As thermodynamics requires, energy is always conserved (the first law), and when it flows from hot to cold it can do work, limited by the generation of disorder, or entropy (the second law). These laws dictate everything from the miles per gallon a car engine gets to the battery life of a smartphone. They help physicists better understand black holes and why time moves forward but not backward (*SN: 7/25/15, p. 15*).

Yet the big picture approach, considering the forest rather than the trees, has made physicists wonder if thermodynamics holds at all scales. Would it work if an engine consisted of three molecules rather than the typical trillion trillion? In the realm of the very small, governed by the quirky rules of quantum mechanics, perhaps the thermodynamic code is not so rigid.

The second law of thermodynamics is showing early signs that it may hold up in the ultrasmall world of quantum mechanics.

MARY KATE MCDEVITT

"Thermodynamics was designed for big stuff," says Janet Anders, a theoretical physicist at the University of Exeter in England. "We haven't really integrated

thermodynamics with quantum mechanics."

Over the last few decades, physicists have gradually explored heat flow at the quantum level, intrigued by the possibility of finding violations of thermodynamics' second law. So far, the second law has held strong. But new precision experimental techniques are allowing physicists to explore the quantum foundations of thermodynamics more fully. Testing the limits set by theorists, researchers are building tiny engines, some powered by a single atom, and measuring the devices' feeble oomph.

Even if physicists can't break the thermodynamic rules, recent evidence suggests ways to bend them — especially by exploiting the way quantum entanglement weaves together the fates of a few particles. Techniques used in processing quantum information could prove useful for squeezing extra energy out of miniature engines, for instance. These lessons could help scientists build nanomachines that harvest heat and use it to deliver medicine inside the body, or help reduce energy loss in the tiny components of traditional computers.

Quantum engines

Any future practical applications of this work will depend on understanding how basic thermodynamic principles operate at ultrasmall scales.

It goes back to statistics, says University College London quantum theoretical physicist Jonathan Oppenheim. If the trillion trillion gas molecules in a steam engine were represented by that many coins, then the result of flipping all those coins would be a homogenous mixture of heads and tails, the equivalent of stable temperature and maximum entropy. That's why steam engines always follow the rules. But flip three minicoins inside a tiny quantum engine and all three could easily land on heads, as if all the fast molecules stayed in one compartment rather than mixing with the other — a violation of the second law.

Experiments over the years had suggested that if the second law of thermodynamics does break down at small scales, the violation is not very drastic. Last year, Oppenheim and colleagues got more specific, publishing a detailed analysis in the *Proceedings of the National Academy of Sciences*. Their results indicate that not only does the second law actually hold at the quantum scale, it is also more demanding.

Rather than analyzing entropy directly, Oppenheim's team looked at how much energy a system has available to do work, a quantity called free energy. In our macroscopic world, the amount of free energy depends only on a system's temperature and entropy. But by zooming in toward smaller and smaller collections of particles, the researchers found that they had to take into account several more varieties of free energy. Every one of them decreases over time. In other words, the second law requires adherence to even more rules at the quantum level.

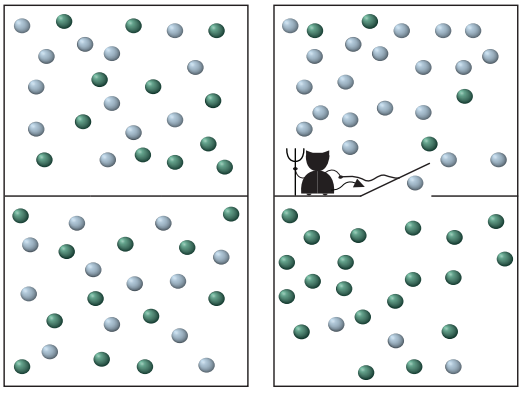
> "Thermodynamics was designed for big stuff."
> JANET ANDERS

Recent experiments have made it clear that attempts to circumvent the second law at any scale are doomed. In the Dec. 31 *Physical Review Letters*, Jonne Koski, a physicist at Aalto University in Finland, and colleagues created the laboratory equivalent of the heat-manipulating "demon" conjured by Scottish physicist James Clerk Maxwell in 1867.

Maxwell wondered whether a hypothetical microscopic entity tracking the particles flitting around two adjacent containers could separate the fast-moving particles from the slow ones. The demon's actions would minimize the system's total entropy, a violation of the second law, and create a temperature difference that could be exploited to do work for free.

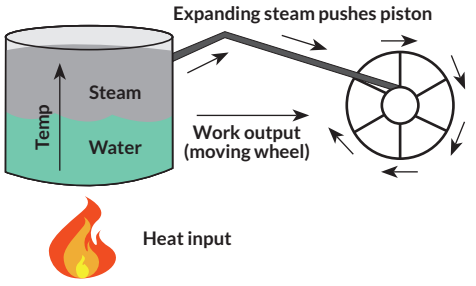
Koski's team built a demonic device that deprived an electronic circuit of heat and thus its entropy as well. The demon did its job: A visitor to the lab observing the experiment would think the circuit was violating the second law. But the researchers also noticed that the demon paid a price for its transgressions. As it performed its dirty deed, the demon itself heated up. The total entropy of the circuit and the demon together actually increased, just as the second law requires (*SN Online: 12/1/15*).

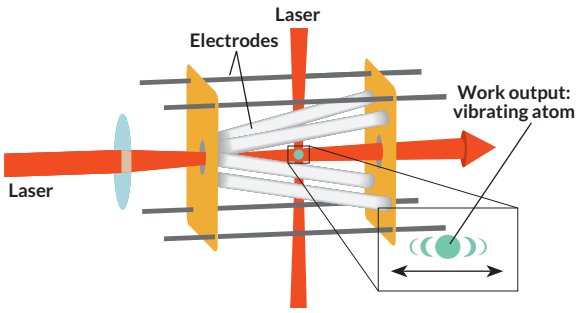
Koski's electronic demon failed because of its reliance on information about individual particles. The connection between information and thermodynamics dates back to 1929. That's when Hungarian physicist Leo Szilard dug deeper into



Tiny failure
Maxwell's demon, which tries to violate thermodynamics' second law by sorting fast (blue) from slow (green) molecules to avoid equilibrium (left), would inevitably fail at the quantum level, a new experiment shows.

J. HIRSHFELD





Incredible shrinking engine A typical engine (left) uses energy from heat to drive a turbine or perform some other task. Reduce the engine's size enough and it can drive a single atom (right, green dot) to vibrate and do a tiny amount of work.

SOURCES: RACHEL CASIDAY AND REGINA FREY/WASHINGTON UNIV. IN ST. LOUIS; J. ROßNAGEL, *ET AL*/ARXIV.ORG OCT. 2015

Maxwell's thought experiment and drew up a blueprint for exploiting information about particles, such as their position and velocity, to perform tasks. Szilard's work demonstrated that in physics, information isn't merely a stock quote or a baseball player's batting average — it's physical.

More than three decades later, IBM physicist Rolf Landauer showed that Szilard's approach came with a cost. Maxwell's demon may capitalize on its knowledge about one particle, Landauer said, but the demon must use up the energy it gained when it scrubs that information from its finite memory and turns its attention to the next particle. Erasing information costs energy. That's why the sophisticated demonic circuit failed to circumvent the second law.

Information is clearly important for understanding thermodynamics, and it's also downright essential for making sense of the stranger parts of quantum mechanics. Tiny bits of matter can essentially exist in two places at once, a phenomenon called superposition. Two or more particles can be wrangled into what's known as an entangled state, intricately linking the particles' properties regardless of the distance between them.

Many physicists are trying to exploit superposition, quantum entanglement and other quantum trickery to perform information-heavy tasks that are impossible under the rules of classical physics. Researchers envision supersecure communication networks and quantum computers that exploit entangled photons or ions to solve complex problems with ease (*SN: 11/20/10, p. 22*).

But information means much more than just exchanging and processing 1s and 0s. As a result, physicists pondering quantum computing and communication have turned their attention to thermodynamics. They've begun asking whether properties such as entanglement could also offer an advantage in converting heat into work.

In the October–December 2015 *Physical Review X*, a European team demonstrated that a system of several entangled particles stores more usable energy than the same particles without quantum connections. The advantage, which quickly disappears as the number of particles increases, boils down to the notion that information is a resource. Entangled particles essentially provide information for free, because knowing something about one particle reveals something about its entangled partners (*SN: 1/9/16, p. 9*).

Even though the second law holds strong, says study coauthor Marcus Huber, the ability to exploit information from quantum effects "also helps you to do things that you couldn't do classically."

Information advantage

Obtaining information at a discount may enable technology that bends the second law and outperforms the best life-size engines. "What we can hope for are machines that run faster, refrigerators that get cooler or batteries that store more or charge faster," says Huber, a quantum information theorist at the University of Geneva.

Huber compares the challenge ahead to playing a game, much like the one Carnot played in the 19th century. Carnot essentially turned dials controlling variables such as temperature and pressure until he had squeezed the maximum efficiency out of a steam engine. Today's physicists have different goals — perhaps creating a microscopic refrigerator to cool their instruments to unfathomably low temperatures. To achieve such goals, physicists plan to turn the dials for variables like entanglement and see what happens.

Soon scientists may be able to start playing those games with engines exploiting quantum effects in the lab. German researchers took a step toward that goal in October by building a heat engine consisting of a single atom. Johannes Roßnagel, a quantum physicist at the University of Mainz, and colleagues built a cone-shaped enclosure around a calcium ion. After using a laser and electric field to heat up the ion to about one degree above absolute zero, the researchers measured the work performed by the ion as it exerted a subtle push toward the top of the cone.

The nanoscopic engine worked just as the laws of thermodynamics say it should, the researchers

J. HIRSHFELD

reported in a paper posted online at arXiv.org. Adjusting for the tiny weight of the ion, the power was comparable to that of a car engine, Roßnagel says. "It's quite interesting to see that you can drive heat machines with a single atom," he says.

Despite the measurable power output of the single-ion engine, Roßnagel warns that nano-sized engines for practical use are decades away at best. Instead, the usefulness of quantum thermodynamics will probably happen under the hood of other technologies.

Some researchers have their eyes on the multi-billion-dollar computer chip industry. In the drive to build ever-faster computers, engineers keep shrinking transistors to pack more and more onto chips. The transistors, some just tens of nanometers wide, tend to leak electrons and heat up. That heat ruins the energy efficiency of the computer and damages components. Quantum thermodynamics could help physicists learn tricks to reduce the amount of wasted heat or perhaps even harvest it with small devices inside the computer.

Heat management is even more crucial for physicists seeking to build practical quantum computers. Such a device needs to operate at extremely low temperatures to exploit quantum effects and potentially outperform traditional computers.

Next, Roßnagel and his colleagues plan to chill their single atom until it's capable of maintaining delicate quantum states including superposition and entanglement. Such an experiment would put Huber's theoretical results to the test and expose the potential of adjusting those "quantumness" knobs to better exploit heat to do work.

A few contrarians in the physics community say that such experiments could finally violate the vaunted second law of thermodynamics. But don't bet on it. Early 20th century English astrophysicist Arthur Eddington is still looking good with his prediction that any theory attempting to defy the second law will "collapse in deepest humiliation." But he didn't say anything about moving the goalposts a bit. ■

> "It's quite interesting to see that you can drive heat machines with a single atom."
>
> JOHANNES ROßNAGEL

Explore more

- Jonathan Oppenheim *et al*. "The second laws of quantum thermodynamics." bit.ly/secondlaw
- Martí Perarnau-Llobet *et al*. "Extractable work from correlations." *Physical Review X*. October 22, 2015.

FAT AS A FIXER

Adipose tissue is a natural storehouse of healing cells

By Susan Gaidos

Most people would be happy to get rid of excess body fat. Even better: Trade the spare tire for something useful — say, better-functioning knees or hips, or a fix for an ailing heart or a broken bone.

The idea is not far-fetched, some scientists say. Researchers worldwide are repurposing discarded fat to repair body parts damaged by injury, disease or age. Recent studies in lab animals and humans show that the much-maligned material can be a source of cells useful for treating a wide range of ills.

At the University of Pittsburgh, bioengineer Rocky Tuan and colleagues extract buckets full of yellow fat from volunteers' bellies and thighs and turn the liposuctioned material into tissue that resembles shock-absorbing cartilage. If the cartilage works as well in people as it has in animals, Tuan's approach might someday offer a kind of self-repair for osteoarthritis, the painful degeneration of cartilage in the joints. He's also using fat cells to grow replacement parts for the tendons and ligaments that support the joints.

Foremost among fat's virtues is its richness of stem cells, which have the ability to divide and grow into a wide variety of tissue types. Fat stem cells — also known as adipose-derived stem cells — can be coerced to grow into bone, cartilage, muscle tissue or, of course, more fat.

The stem cells in fat share the medical-worthy spotlight with a few other cells. Along with the fat-filled adipocytes that store energy, fat tissue has its own blood supply and supporting connective tissue, called stroma. The stroma contains blood cells, immune cells, endothelial cells that line the inner surface of blood vessels and pericytes, which line the outer surface. These other fat-derived cells are proving to have therapeutic value as well.

Plastic surgeon J. Peter Rubin, also at Pitt, says that the multitalented cells found in fat could prove to be the ultimate body repair kit, providing replacement tissue or inspiring repair of body parts that can't mend themselves.

Much of the research — more than a decade of studies — has been in lab animals, but a few applications are being tested in human volunteers. Current clinical studies under way aim to provide replacement tissue to treat chronic wounds and diabetic sores, or conditions such as Parkinson's disease, multiple sclerosis, chronic obstructive pulmonary disease and type 1 diabetes.

Adipose tissue, a collection of fat-storing cells (red) surrounded by connective tissue (yellow), has its own supply of blood and immune cells.

STEVE GSCHMEISSNER/SCIENCE SOURCE

Most clinical studies use the simplest approach: Harvest cells from a patient, then inject them in a single procedure. In more complex approaches still in lab and animal testing, various cells in fat are extracted and manipulated to create custom treatments for worn-out or damaged tissues or to generate blood flow after a heart attack or replace bone in large fractures.

Questions remain, however, about how the cells do their regenerative magic. Scientists and regulators still have plenty to figure out, such as what cell characteristics work best for each application.

A lush source

Stem cells can develop into various cell types, which makes them the focus of studies that aim to replace cells that fail because of disease, accident or age. Stem cells taken from embryos are more versatile than other types of stem cells, but their use is controversial. For that reason, researchers have studied stem cells from sources other than embryos, including bone marrow, muscle and blood.

Fat tissue comes from the same embryonic tissue as bone marrow, a traditional stem cell source, so scientists reasoned that fat might contain similar cells. In 2002, UCLA researchers discovered stem cells in human fat. They were surprised to find vast quantities.

Stem cells make up 2 to 10 percent of fat tissue. A cubic centimeter of liposuctioned fat (about one-fifth of a teaspoon) yields 100 times as many stem cells as does the same amount of bone marrow, Tuan says. And fat cells are easy to harvest — much easier than bone marrow. One pound of fat removed from a patient's abdomen can yield up to 200 million stem cells, a more than adequate supply for treatments.

Why fat produces so many stem cells isn't clear, but Rubin points out that fat tissue serves several important functions. In addition to storing and releasing energy, it helps insulate and protect the body's internal organs. "Like most tissues in the body, fat has a reservoir of stem cells to replenish cells as they die off or create new cells in response to growth or the need for more cells," he says.

Fat produces so many stem cells, in fact, that for some applications — such as tissue-replacement or "fat grafting" — there's no need to grow more of them in the lab.

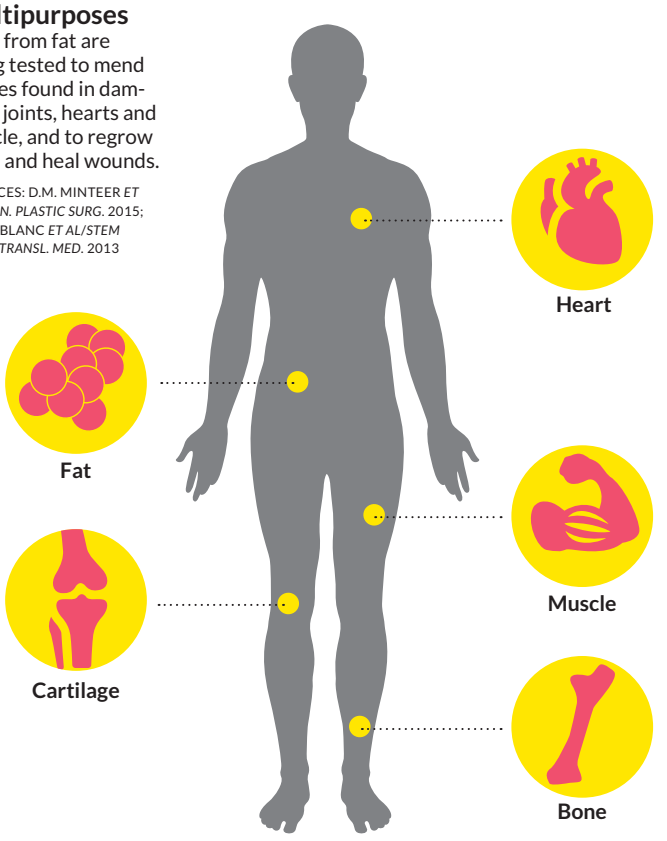
Once harvested, liposuctioned material is treated with enzymes to remove cells from the surrounding tissue, then put into a centrifuge to separate the stem cells from other cell types. In about an hour, the stem cells are ready to be injected back into the patient to plump skin or round out fat tissue lost to injury or disease. Rubin has used this method to treat patients who have lost tissue during breast cancer surgery or have been injured in war. His lab is conducting a clinical trial on the use of fat stem cells to plump up tissue at the site of an amputation to improve the comfort and fit of a prosthetic arm or leg or to make it easier to tolerate sitting for long periods in a wheelchair.

Already, Rubin's team has treated five military patients, extracting fat from each patient's abdomen and injecting the stem cells back into the patient at the injury site. He and other scientists think that the fat stem cells remodel tissue by releasing growth factors and communicating with surrounding cells in their new location — sending and receiving signals through chemical cues. As a result, the stem cells enhance the growth of new fat tissue and boost blood supply to surrounding tissue. Over a period of several weeks, the cells he injects form a mound of fat tissue, allowing patients to fit a prosthesis or sit without pain. So far, all of the patients have benefited from the stem cell injections, he says, though his group is still working on how much to inject for each patient.

Multipurposes

Cells from fat are being tested to mend tissues found in damaged joints, hearts and muscle, and to regrow bone and heal wounds.

SOURCES: D.M. MINTEER *ET AL/CLIN. PLASTIC SURG.* 2015; A.J. LEBLANC *ET AL/STEM CELLS TRANSL. MED.* 2013



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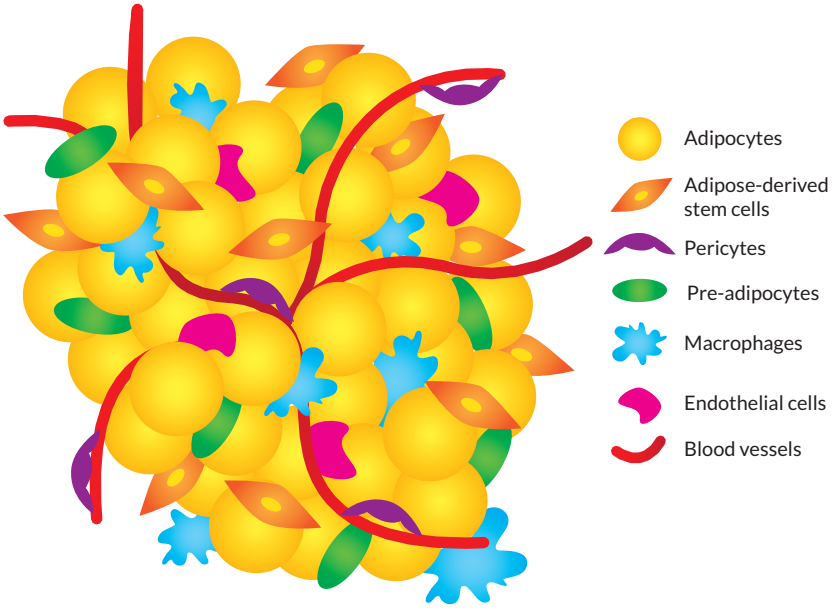


What is in fat?

Fat is an organ with a complex assembly of cells. In addition to fat cells, or adipocytes, and blood vessels, fat tissue contains stem cells, pericytes (cells that stabilize blood vessel walls), pre-adipocytes (precursors to fat cells), macrophages (immune cells) and endothelial cells, which form the inner lining of blood vessels.

Stretching limits

Other applications require manipulating cells in the lab, placing fat stem cells in a specific environment — and sometimes putting mechanical pressure on them — to direct the cells to transform into certain cell types.

Tuan's group at Pitt places fat stem cells on scaffolds that help guide the growth of the cells, developing treatments to regenerate anterior cruciate ligament tissue or to repair rotator cuff injuries and Achilles tendon ruptures. Injury to ligaments and tendons is common, especially among athletes, but tears or worn-down areas generally don't heal completely by themselves. Efforts to create substitute tissues have largely failed, Tuan says, because re-creating the structure of a tendon or ligament remains a challenge.

Tendons are the cables that connect muscle to bone, allowing arms to rotate at the shoulder, knees to bend or fists to clench. Cells in tendons, called tenocytes, line up along long fibers of collagen, creating molecular bridges that reach across and intertwine with collagen cables to help give them strength and flexibility. This structure allows tendons to be stretched up to 15 or 20 percent beyond their original length and snap back into shape.

Tuan's group has discovered a trick for turning fat stem cells into tenocytes that grow in the same organized way. In 2013, the researchers outlined the method in *Biomaterials*. To replicate the structure of natural tissues, the scientists created scaffolds of biodegradable nano-sized fibers. Fat cells were then combined with bovine collagen and placed, or seeded, into the scaffold. The tiny fibers interacted with the stem cells, sending and receiving instructions that guided the stem cells' growth. Over seven days, as the stem cells differentiated into tenocytes, the scientists applied mechanical force on the ends of the scaffold — pulling the structure to keep the cells under tension just like a natural tendon would do during motion.

By tugging on fat stem cells, Tuan says, the group can create replacement tendons that are strong, stiff and resilient, like natural human tendons.

Tuan's group is also exploring 3-D printing to create artificial cartilage from fat stem cells.

Printing parts

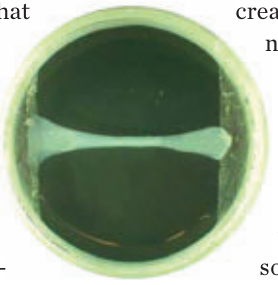
Cartilage is a flexible tissue that serves as padding between bones, allowing knees, fingers, hips and shoulders to move freely. When cartilage wears down, the result is osteoarthritis, a painful condition that affects one in four people, often those over age 65.

Once cartilage is damaged, it continues to deteriorate, forming what Tuan calls "potholes." Over time, the potholes grow, eventually reaching the bone. The standard solution is a joint replacement. In the United States, more than 1 million people get knee or hip replacements each year.

Tuan calls the process "rebuilding the road." The invasive procedure requires surgically replacing the joint with plastic and metal parts that generally last 10 to 15 years. Because an increasing number of people get new joints in their 40s or 50s, many require more than one round of surgery. "But there's a limit to the number of times you can do that," he says.

Tuan's 3-D printing method builds thin layers of fat stem cells into a custom-sized scaffold to create new cartilage in the size and shape needed. The "ink" is made of fat stem cells plus gelatin, which consists of proteins found in living tissue. The scientists chemically modify the gelatin so that the ink remains fluid during printing. Once printed, the material is irradiated with light so that enzymes in the mixture form bonds, cross-linking to create stiffer, cartilage-like material.

The procedure has been used to create cartilage implants for rabbits



Applying tension to reprogrammed human fat stem cells yields stretchable tendons that can bear weight.

FROM TOP: M. TELFER; G. YANG *ET AL*/*BIOMATERIALS* 2013

and goats. Animals that once hobbled were able to hop, trot and otherwise move about, according to a report last August in *Frontiers in Bioengineering and Biotechnology*.

"Because the engineered cartilage is a living tissue ... unlike a metal or polymer implant, it is expected to continue to grow into its natural shape and function once it is implanted into the joint," Tuan says. "No replacement is therefore necessary."

Still, it's not the ideal solution, Tuan admits. "The problem is that's not how tissues are formed," he says. "Tissues form when cells migrate to a place, make themselves at home and build their own support structure, or matrix."

His group is now devising ways to allow fat stem cells to set up their home right at the site of the pothole. The vision is to create a minimally invasive procedure, giving doctors a tool they can thread through a catheter to print the fat-derived stem cell cartilage at the site of the damage, inside the joint. Fat stem cells could then settle in and multiply directly in the joint. Additional arthroscopic instruments, also under development in Tuan's lab, will allow physicians to guide the injection and smooth out newly printed cartilage to create a perfect fit that closely resembles the real thing.

So far, each step in the new approach has been developed. The next step is to tie all the pieces together in animal studies.

Boning up on body repair

The body does a better job of healing broken bone than healing cartilage. But if the fracture is large or a significant amount of bone is lost, the bone may not heal. In such cases, surgeons can take bone from another part of the patient's body, or use bone from a cadaver, to fill in the gap. Biomedical engineer Warren Grayson of Johns Hopkins University says more than 1 million bone replacement procedures are performed each year in the United States, often after accidents or tumor removal. The surgery is invasive and carries risks of rejection, infection and lingering pain.

A better option, Grayson says, is to help patients grow bone from their own fat cells. Because the bone-growing material comes from the patient's body, the grafts are less likely to get rejected than cells from donor tissue. What's more, the bone may later grow with the patient, potentially eliminating the need for multiple surgeries in children who receive grafts but still have growing to do.

Since 2010, Grayson's team has been growing bone from liposuctioned fat and successfully implanting the bone in animals. Stem cells taken from fat are placed in a bioreactor, an incubator-like device that nourishes cells as they grow on a scaffold for five weeks. Added nutrients and growth factors help the cells transform into bone cells.

Already, fat stem cells have been used in a few trials to help regenerate bone in people. In 2004, German doctors successfully used stem cells collected from a 7-year-old's fat, along with other cells, to repair damage to her skull. Five years later, scientists at Cincinnati Children's Hospital Medical Center seeded a bone graft with fat stem cells to replace a teen's missing facial bones.

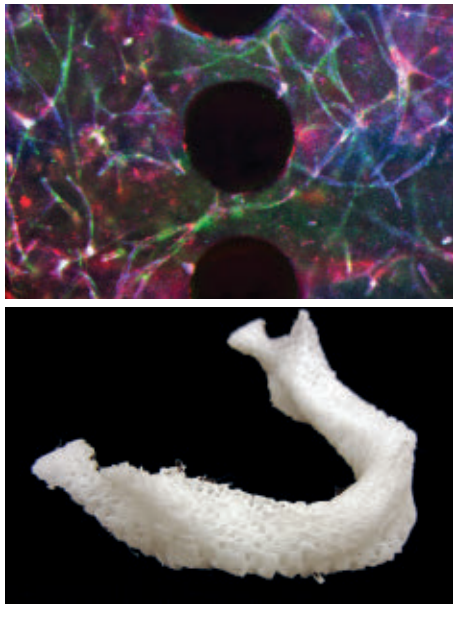
In the case of the teen, fat stem cells were injected onto a scaffold from donor bone. But such bone grafts require multiple surgeries and don't come with a ready blood supply to nourish the new bone as it grows.

Grayson's group aims to make the repair process easier on the patient. He and his team are growing fully functioning bone — with its own blood supply — from fat. Each graft can be custom-designed, using 3-D modeling and printing, to fit precisely where needed.

His team is experimenting with different formulas — and two different cell types from fat — to find the best ways to form all the cell types needed.

More recently, his group tested fat-derived stem cells against bone marrow cells in creating new bone. The fat stem cells outperformed the bone marrow stem cells. The findings, published in the September 2015 *Stem Cells*, show that in the presence of specific growth factors over a period of weeks, fat stem cells produced more calcium and bone mineral deposits per cell than did the bone marrow stem cells.

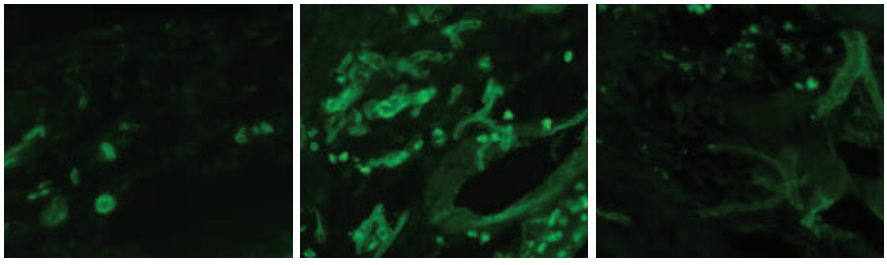
The current challenge is to produce tissue that has its own system of blood vessels to supply nutrients needed for the new bone to grow. In the *Journal of Biomedical Materials Research Part A* in 2014, Grayson's group outlined a method for printing bone grafts with internal pore structures that would allow blood vessels to grow through the graft while maintaining the structure of the scaffold. The team is now



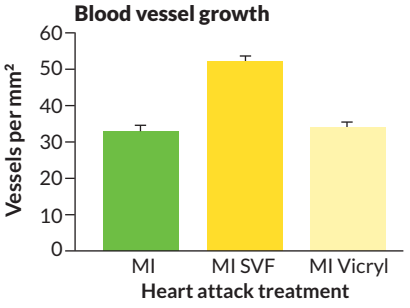
After 14 days in a scaffold with growth factors, human endothelial cells from liposuctioned fat (top) developed into a network of blood vessels and wrapped around scaffold fibers. A sample 3-D printed scaffold mimics a lower jawbone (bottom).

BOTH: J. TEMPLE *ET AL*/*JOURNAL OF BIOMEDICAL MATERIALS RESEARCH* 2014

Repairing heart damage Rats treated with a patch seeded with endothelial cells from fat tissue two weeks after a heart attack (MI SVF) show more new blood vessels (green) in the damaged area of the heart, compared with untreated rats (MI) and rats treated with an unseeded patch (MI Vicryl). Four weeks after treatment, the MI SVF rats had better heart function and less tissue damage. Total vessel density (vessels per square millimeter) was determined through staining methods. SOURCE: A.J. LEBLANC *ET AL/STEM CELLS TRANSLATIONAL MEDICINE* 2013



MI MI SVF MI Vicryl



investigating ways to help spur such growth by seeding the structure with endothelial cells or blood-vessel forming cells from fat.

Heart-healthy fat cells

Endothelial cells and other cells in fat are the lifeblood of efforts to develop a patch that can be applied to damaged heart tissue following a heart attack. Stuart Williams, a cardiologist at the University of Louisville in Kentucky, is creating a cell-infused patch seeded with a mixture of smooth muscle cells, endothelial cells and blood cells, all obtained from fat tissue.

"This fat tissue contains a huge number of blood vessel–forming cells," Williams says.

The idea for the patch, outlined in 2013 in *Stem Cells Translational Medicine*, is to harvest fat from a patient, pull out the vessel-forming cells and seed the cells onto a biomaterial that can be immediately implanted. The whole process, from start to finish, will take about an hour.

The fat-cell patch works particularly well to promote healing in very small blood vessels, Williams says, a feature that may be especially beneficial for women, who often have more problems with their small blood vessels and fewer problems with the large ones.

"The interesting thing is, there's really no stemness to these cells at this point," Williams says. "They don't have to differentiate. All they have to do is reconnect with each other to form these new blood vessels."

The patches could be created in the operating room during surgical bypass, he says.

Such patches might also be applied to other areas of the body, such as legs, hands or feet, where patients have limited blood flow, Williams says. In wounds that aren't healing well, cells could be injected directly into the area to promote blood flow and healing.

While Williams has shown his technology works in animals, he hasn't yet tested it on people. Getting the federal go-ahead to pursue studies in humans remains a challenge for the heart patch and many other new applications of fat cells.

Current guidelines issued by the U.S. Food and Drug Administration allow trials for treatments in which cells are harvested and injected back into the same patient in a single surgery. But the FDA, and regulatory agencies worldwide, are wrangling with questions on how to test and assess new types of therapies in which cells are grown on scaffolds or manipulated in the lab.

Questions remain, for example, on how to best handle cells in the lab to ensure safety and purity of a product, and how to package and transport products once they are made. Fat stem cells, for example, may change or dedifferentiate when growing in a lab dish, sitting on a warehouse shelf or even following injection into the body, Tuan says.

Later this year, the FDA plans to hold a public hearing to solicit comments from scientists, manufacturers and others on how to proceed. Meanwhile, scientists in the field agree that the potential for fat to do good is here.

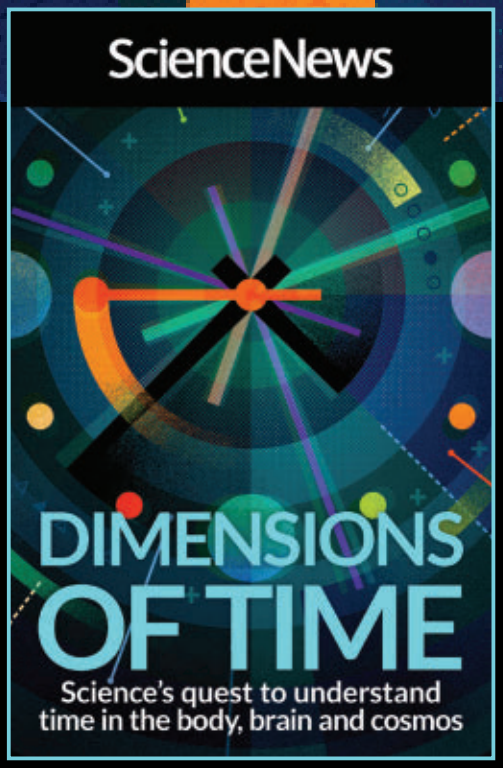
"Fat may actually be a natural storehouse of regenerative cells," Williams says. "When applied correctly, these cells may someday help repair bodies on an as-needed basis." ■

Explore more

- D.M. Minteer, K.G. Marra and J.P. Rubin. "Adipose stem cells: biology, safety, regulation, and regenerative potential." *Clinics in Plastic Surgery*. April 2015.
- Yunfan He and Feng Lu. "Development of synthetic and natural materials for tissue engineering applications using adipose stem cells." *Stem Cells International*. 2016.

LEBLANC *ET AL/ STEM CELLS TRANSL MED.* 2013

DISCOVER the mysteries OF TIME



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MorphoSource is a free database of 3-D images of fossils (*Homo naledi* shown).

SCREENTIME

Free virtual fossils for everyone

At MorphoSource.org, playing with fossils is not only allowed, it's encouraged. The online database is home to oodles of digital 3-D scans of bones from both extinct and modern-day creatures. Anyone with an Internet connection is free to peruse the images, manipulate and rotate specimens and even download instructions to 3-D print them.

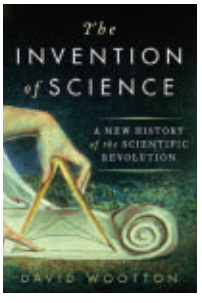
So far, scientists have contributed images representing over 200 genera. Among the newest uploads are fossils of the recently discovered *Homo naledi*, the controversial species that may be at the base of the human genus (*SN: 10/3/15, p. 6*). MorphoSource's collection is primate-heavy, but users will also find scans of other mammals, reptiles, fish and even insects.

The website, funded by Duke University and the National Science Foundation, offers several ways to search for specimens, such as by taxonomy. But those unfamiliar with animals' Latin names may find the database difficult to navigate. Still, MorphoSource is a great resource for anyone who's always wanted to get their hands on some fossils. — *Erin Wayman*

BOOKSHELF

The Rarest Bird in the World
Vernon R.L. Head
A bird-watcher recounts an expedition to see the elusive Nechisar nightjar, a bird identified in the 1990s based on a few feathers. *Pegasus Books, $26.95*

Strange Glow
Timothy J. Jorgensen
In this history of radiation, a biologist examines the risks posed by cellphones, nuclear power plants and other sources of radiation. *Princeton Univ., $35*



The Invention of Science
David Wootton
HARPER, $35

BOOKSHELF

The rise of science reconsidered

When Columbus discovered America, European culture hadn't yet grasped the concept of discovery. Various languages had verbs that could be translated as *discover*, but only in the sense of discovering things like a worm under a rock. Scholars operated within a worldview that all knowledge had been articulated by the ancients, such as Ptolemy, the astronomer who compiled the mathematical details of the Earth-centered universe. As it happened, Ptolemy was also the greatest of ancient geographers. So when Columbus showed that Ptolemy's grasp on geography was flawed, it opened the way for Copernicus to challenge Ptolemy on his picture of the cosmos as well. Deep thinkers who were paying attention then realized that nature possessed secrets for humankind to "discover."

"The existence of the idea of discovery is a necessary precondition for science," writes historian David Wootton. "The discovery of America in 1492 created a new enterprise that intellectuals could engage in: the discovery of new knowledge."

Appreciating the concept of discovery was not enough to instigate the invention of science. The arrival of the printing press in the mid-15th century was also especially essential. It standardized and magnified the ability of scholars to disseminate knowledge, enabling the growth of communities, cooperation and competition. Late medieval artists' development of geometrical principles underlying perspective in paintings also provided important mathematical insights. Other key concepts (like discovery) required labeling and clarifying, among them the idea of "evidence."

And modern science's birth required a trigger, a good candidate being the supernova observed by Tycho Brahe in 1572. Suddenly, the heavens became changeable, contradicting the Aristotelian dogma of eternal changeless perfection in the sky. Tycho's exploding star did not cause the scientific revolution, Wootton avers, but it did announce the revolution's beginning.

In *The Invention of Science*, Wootton incorporates these insights into an idiosyncratic but deeply thoughtful account of the rise of science, disagreeing frequently with mainstream science historians and philosophers. He especially scorns the relativists who contend that different scientific views are all mere social constructions such that no one is better than any other. Wootton agrees that approaches to science may be socially influenced in their construction, but nevertheless the real world constrains the success of any given approach.

Wootton's book offers a fresh approach to the history of science with details not usually encountered in the standard accounts. It might not be the last or even best word in understanding modern science's origins or practice, but it certainly has identified aspects that, if ignored, would leave an inadequate picture, lacking important perspective.
— *Tom Siegfried*

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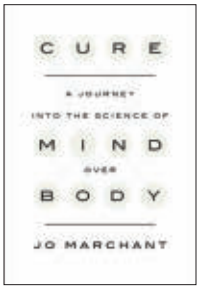

Cure
Jo Marchant
CROWN, $26

BOOKSHELF

Putting the mind's healing powers to the test

In a wide-ranging and compelling new book, science journalist Jo Marchant explores whether the mind can heal the body. The question is polarizing: Conventional doctors dismiss the power of the mind as New Age hooey, while alternative medicine advocates are quick to claim miracle cures for whatever ails you. The murky middle ground between these poles is where Marchant lingers.

Inflammation, blood sugar and breathing rate can all influence mood, and it seems mood may influence those processes right back, Marchant argues. Those blurred boundaries cloud Descartes' old distinction between mind and body, integrating the two so tightly that "it is impossible to consider one without the other," she writes.

With lively, clear prose, Marchant surveys the evidence for the mind-body connection. One of the most compelling arguments comes from the placebo effect. A surge of the chemical messenger dopamine floods the brains of people with Parkinson's disease after they receive a placebo, mimicking the effects of a drug, for instance. Placebos can help even when people know they're taking a fake. After forking over money for inert capsules from an online vendor, Marchant found that the pills eased her headache in 20 minutes. That experience was admittedly nonscientific, but Marchant draws from plenty of studies to make the case that something interesting — and potentially powerful — lurks in placebos (*SN: 2/22/14, p. 12*).

Throughout *Cure*, Marchant uses deeply reported stories of patients and researchers to raise questions about the status quo of health care. These stories reveal that simple changes that soothe people's psychological states may lead to better outcomes. Terminal cancer patients who talked with palliative care specialists focused on quality of remaining life, rather than medical care, had less depression and better experiences than patients who didn't get such care, a small study found. These patients also lived nearly three months longer. "We are humans, not machines, after all," Marchant writes. "When we're receiving medical care, our mental state matters."

Other research makes the case that the mind is a strong ally in the quest for health: Studies of hypnotherapy for people suffering from irritable bowel syndrome, virtual reality snow worlds for burn victims and comforting talk for women undergoing breast biopsies all make clear that the mind can have a powerful effect on the body. And as Marchant argues, that's a realization that matters. — *Laura Sanders*

"I think it is important for socioeconomically challenged students to participate in science fairs because they give students opportunities beyond what can be offered in the classroom during the traditional school day...."

"Students have to prepare something that is authentically theirs, work on a presentation and defend their work in front of judges. Preparing for this type of activity can take lots of work outside of the classroom and this is a place where I see socioeconomically challenged students struggle.... This program has allowed me to help with that struggle so that my students can enter competitive projects in the science fair."

SCOTT BOLEN
2015 SOCIETY ADVOCATE

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Funding is provided by the Alcoa Foundation, the Jack Kent Cooke Foundation, and the Society to support 30 advocates for the 2016–2017 program year. Each advocate receives a $3,000 grant and has an opportunity to meet their fellow grant recipients and receive ongoing training from the Society.

Applications for the 2016–2017 program will be accepted March 1–April 13. Help connect underserved students to science fairs by becoming a Society Advocate. For more info or to apply visit:

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ADVOCATES

JANUARY 23, 2016

Stress sequel

*Men and women react differently under pressure, **Susan Gaidos** reported in "He stress, she stress" (*SN: 1/23/16, p. 18*). Scientists are studying the genetic and cellular underpinnings of stress responses to try to understand why some stress-related disorders, including depression, anxiety and post-traumatic stress disorder, are more common in women than men.*

Several online readers drew attention to a chart accompanying the story that showed higher prevalence of alcohol and drug abuse in men compared with women. Stress-related disorders that disproportionately affect men also need explaining, they agreed.

"We respond differently (on average) to stress," wrote **Owen Okie**, "but responses can be hidden behind coping mechanisms — addiction or gambling, or violence, or so on."

The prevalence of alcohol and drug abuse in men is yet another example of how the sexes respond differently to stress, **Gaidos** says. This particular disparity could be a story in itself. "In 2008, Yale University researchers found that men are more likely to abuse alcohol than women under stressful conditions, and that women are more likely than men to respond with depression or anxiety," she says. "Researchers continue to explore how the higher rate of alcohol abuse and drug abuse is related to stress in men."

Tat therapy

*The tattoos on the wrist, legs, back and ribs of Ötzi the Iceman predate the body art on a mummified man from South America, **Bruce Bower** reported in "Iceman has the world's oldest tattoos" (*SN: 1/23/16, p. 5*).*

"The really cool part is, they may have been done to help with a medical condition," wrote Twitter user **@firejohn78**. It's possible, says **Bower**. Scientists who study Ötzi, discovered in the Italian Alps in 1991, say that most of his tattoos are located on or next to parts of his body that probably caused him pain. Though the therapeutic importance of the tattoos is unknown, many appear at points considered to be crucial in acupuncture treatment today. That connection is intriguing because acupuncture was thought to have originated in Asia — a couple thousand years after Ötzi's death.

Cosmic outlook

Origins: The Scientific Story of Creation *takes a chronological approach, according to our recent review of the book (*SN: 1/23/16, p. 27*). "The universe's 'let there be light' moment arrived an estimated 380,000 years after the Big Bang," wrote **Sid Perkins**. "That's when the light-blocking fog of charged subatomic particles generated in the universe's first few moments finally cooled enough for neutral hydrogen and helium atoms to form, thus rendering the universe transparent to photons long trapped in limbo."*

Rob Walty wondered how this description fit with other explanations he has heard that make it sound like the universe went dark in these moments. "Can you clarify these apparent contradictions?" **Walty** asked.

Though they might appear so, the two explanations are not contradictory, says managing editor **Tom Siegfried**. Instead, they take two different points of view on the universe. Until 380,000 years after the Big Bang, the universe was akin to a big ball of radiant plasma. Imagine, for example, that the whole universe resembled the sun. It would have been incredibly bright, so bright in fact that anybody within the universe wouldn't be able to see anybody else because light emitted from one object would instantly be engulfed in the firestorm. At 380,000 years after the Big Bang, though, the temperature cooled enough for the plasma to form ordinary atoms. In one sense, the universe, the firestorm, went dark. But now light could freely travel, making anybody visible to anybody else.

Clarification

In "Secrets of the ice giants" (*SN: 2/20/16, p. 24*), the affiliation provided for planetary scientist Leigh Fletcher was not up to date. Though he was previously at the University of Oxford, he is now at the University of Leicester.

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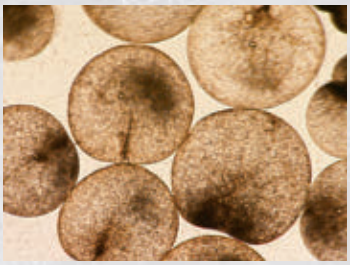
Plankton bloom in the Arabian Sea

Masses of plankton add swirls of green to the blue waters of the Arabian Sea in this February 3 snapshot from NASA's Aqua satellite (Iran and Pakistan at top of the image; India, to the right). Most of the vibrant color probably comes from algae living in the single-celled bodies of the dinoflagellate *Noctiluca scintillans*.

N. scintillans started appearing in the Arabian Sea in large numbers in the early 2000s, blooming in the winter months. It seems that the plankton, which love low-oxygen waters, have made a happy home in the increasingly oxygen-poor Arabian Sea, says marine ecologist Joaquim Goes of Columbia University.

That's bad news for local ecosystems. *N. scintillans* feasts on the sugar its internal algae make from sunlight, but the dinoflagellate also eats anything smaller than itself, Goes says. "It becomes very difficult for other organisms to survive." Few species chow down on *N. scintillans*, and evidence suggests that the plankton is "short-circuiting" marine food webs, Goes says.



Some *N. scintillans* house green algae (dark patches) in their bodies, which measure 0.2 to 2 millimeters across.

N. scintillans and its algae may also be warming their surroundings by changing how incoming sunlight is absorbed at the sea's surface. Such warming waters could be contributing to the recent uptick in Arabian Sea cyclones, Goes says. "What we see now is a complete change of that ocean." —*Sarah Schwartz*

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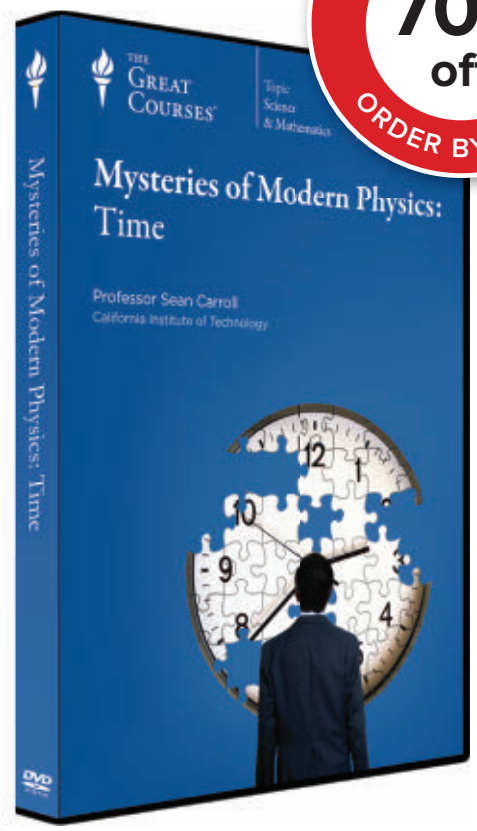

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But the clock is ticking...

The Most Affordable Precious Metal— GOVERNMENT GUARANTEED

Silver is by far the most affordable of all precious metals — and each full Troy ounce American Eagle Silver Dollar is government-guaranteed for its 99.9% purity, authenticity, and legal tender status.

A Coin Flip You Can't Afford to Lose

Why are we releasing the most popular Silver Dollar in America for a remarkably affordable price? We're doing it to introduce you to what hundreds of thousands of smart collectors and satisfied customers have known since 1984—GovMint.com is *the best source for coins worldwide*.

Timing is Everything

Our advice? Keep this to yourself. The more people who know about this offer, the worse for you. Demand for Silver Eagles in recent years has shattered records. Experts predict that the 30th anniversary 2016 Silver Eagles may break them once again.

30-Day Money-Back Guarantee

You must be 100% satisfied with your 2016 American Eagle Silver Dollars or return them within 30 days of receipt for a prompt refund *(less s/h)*. Don't miss out on this exciting new release. Call immediately to secure these American Eagle Silver Dollars NOW!

2016 American Eagle Silver Dollar BU
Shocking Low Price $17.95 ea. ***(plus s/h)***
LIMIT 10.

Additional 2016 Silver Eagle BU Dollars may be purchased for $18.95 each. Limited to 50 total coins per household.

FREE SHIPPING on 9 or More!

Limited time only. Product total over $150 before taxes (if any). Standard domestic shipping only. Not valid on previous purchases.

For fastest service, call today toll-free

1-800-969-0686

Offer Code ESB273-03
Please mention this code when you call.

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