How Fentanyl Acts on the Brain | The Rise of AI Griefbots

Science News

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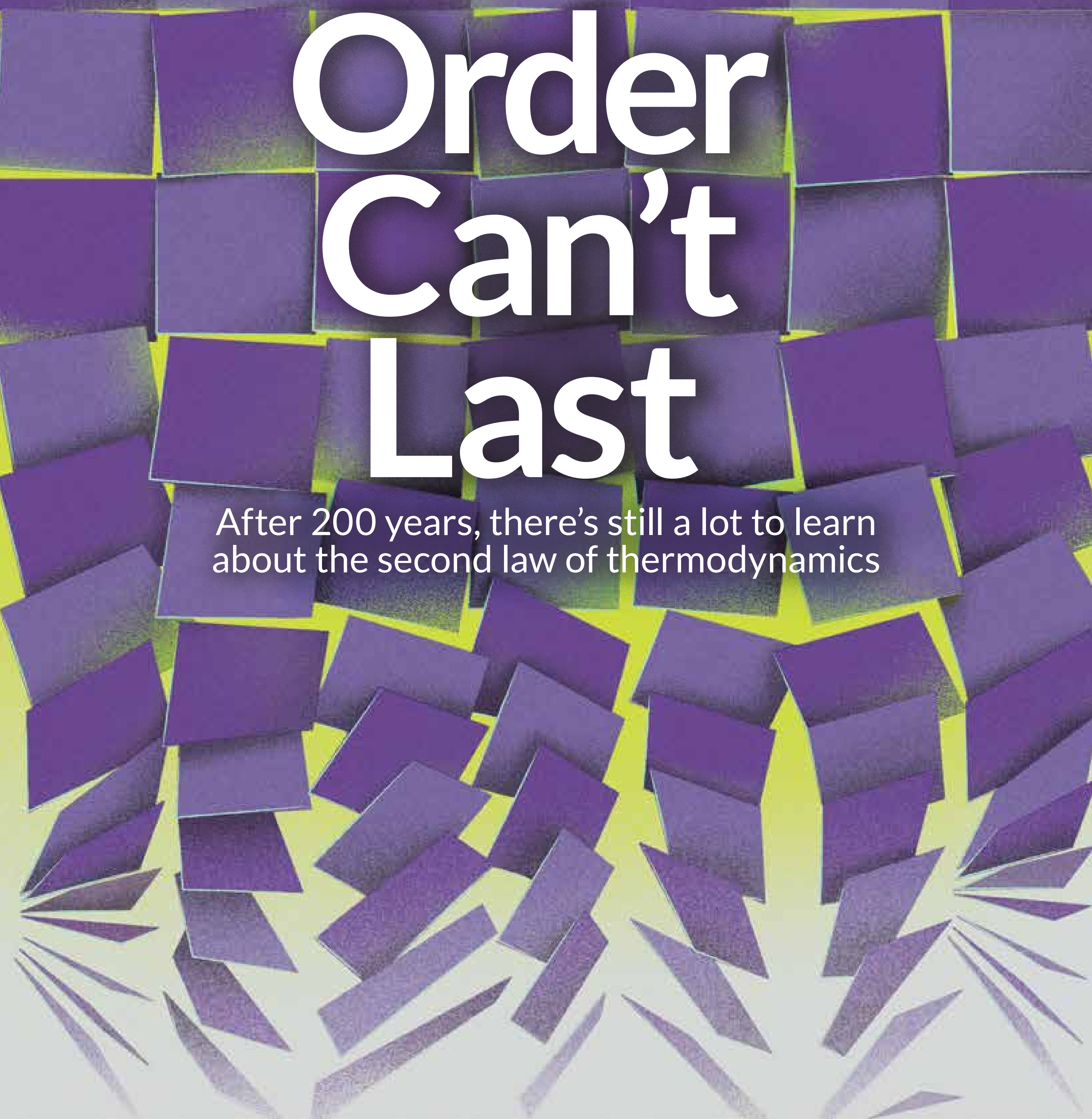
Order Can't Last

After 200 years, there's still a lot to learn about the second law of thermodynamics



VOL. 205 | NO. 11

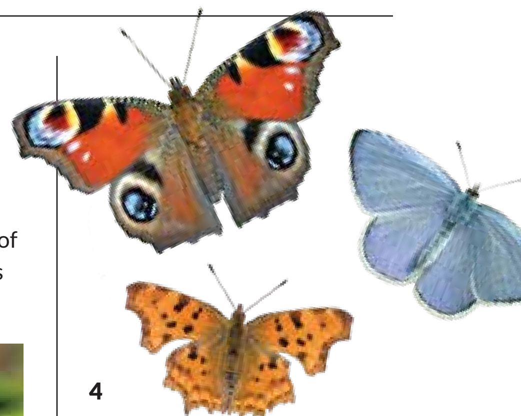
ScienceNews

24

Essays

News


11


4

Departments

COVER One way to describe the second law of thermodynamics is that order succumbs to disorder. *Sam Green*

FROM TOP: MATTHEW SLUKA; BUTTERFLY CONSERVATION, PHOTOGRAPHERS FROM TOP: © ANDREW COOPER, IAIN H. LEACH, ROB BLANKEN; MICHAL FUGLEVIC/ISTOCK/GETTY IMAGES PLUS

Celebrating the second law of thermodynamics

Sadi Carnot was a child of the Industrial Revolution. Steam power was widely used in manufacturing and mining by his birth in 1796, and the first steamboat and first steam railroad locomotive were invented while he was still a child. Steam technology was transforming society, and Europe was at the center of the action — a Silicon Valley for steam.

Carnot's father was a prominent French engineer, so it's not surprising that Carnot became an engineer himself and took on one of the biggest practical challenges of his time: how to make steam engines more efficient. Carnot's great insight was that heat produced motion for doing work by dropping from a high temperature to a lower temperature. There would always be some energy loss, no matter how well designed. That led him to more theoretical questions about matter and energy. And in June 1824, Carnot became the first to articulate what we now call the second law of thermodynamics.

Simply stated, the Second Law observes that heat always flows from hot to cold. Or phrased another way: Not all heat can be converted into work, resulting in heat waste. We now describe that loss as entropy.

Two centuries later, big questions about the Second Law remain to be answered. To explore Carnot's legacy and how physicists have fleshed out this fundamental law over the last 200 years (and continue to probe it today), we called on contributing correspondent Tom Siegfried, a former editor in chief of *Science News* and an ace at explaining the complexities of physics (Page 18).

I wasn't familiar with Carnot, and I loved learning about his life at a time of great scientific and political ferment (Carnot's father had served Napoleon Bonaparte and was forced into exile for a time). There's a lot we don't know about Carnot's thinking. As Siegfried explains, that may be because the engineer published his work in a book that wasn't widely read. And he died tragically young, before the age of 40, so he never had the opportunity to gain greater recognition for his pioneering work.

I like to think of a law as something settled, but science is always advancing. There's always more to investigate. Who could have imagined in Carnot's day that studies of the Second Law might 200 years later become so intertwined with ideas about information and the principles of computation? "Computing is a whole different way to looking at it compared to steam engines," Siegfried notes. "It's approaching the thing from a totally different perspective."

There's plenty more physics to ponder elsewhere in this issue, particularly in the realm of the quantum world. Physics reporter and senior writer Emily Conover reports on new efforts to nail down certain quantum properties of the neutrino (Page 14) and describes two real-world experiments that demonstrate the potential of a technology that might support a quantum internet (Page 6).

Just as Carnot was living through a golden age of steam power, we may be on the cusp of a golden era of technology powered by quantum physics, which could bring more efficient and secure communication and computing. It's an exciting time, one that surely would astonish and delight Carnot.
— Nancy Shute, Editor in Chief

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1719 N Street NW, Washington, DC 20036
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Excerpt from the June 22, 1974 issue of *Science News*

50 YEARS AGO

Lightning and the sun

The latest addition to the growing list of meteorological phenomena which have been linked with solar activity is lightning.... Using data from 1930 to 1973, [a researcher] reports in the May 24 *Nature* that "in spite of year-to-year variations in the incidence of lightning, there is an underlying cyclic variation with a period of about 11 years which is in phase with the solar cycle."

UPDATE: Multiple studies have linked upticks in lightning frequency with periodic fluctuations in the sun's magnetic field. The connection isn't limited to these 11-year solar cycles. In 2018, scientists confirmed a trend related to one of the sun's shorter cycles — the 27 days our star takes to rotate around its axis. But how exactly the sun's activity influences lightning is an enduring mystery. Perhaps the solar wind gives lightning a boost. When this stream of charged particles enters our atmosphere at high speeds, the average number of lightning strikes increases by over 30 percent for more than a month afterward, a 2014 study found.

A variety of butterflies and moths could benefit from swaths of yard left unmowed.

FOR DAILY USE

Doing less yard work can boost butterfly numbers

Making the world safer for butterflies can be as easy as doing a bit of nothing.

Letting some part of a yard go unmowed can boost the number of butterflies and moths sighted there, says ecologist Richard Fox. That long-grass patch may be as elaborate as an all-native meadow dotted with flowers or as simple as some didn't-mow corner by the back fence. Nectar-rich blooms that attract the fliers may pop up, but the biggest win comes when caterpillars don't "get chopped in half every week by the lawn mower," he says. "It's not about having special grasses. It's about resisting the urge to tidy everything."

Enthusiasts have been no-mowing

THE SCIENCE LIFE

A low-tech backpack doubles as a mosquito hotel

This backpack isn't typical hiking gear. Look inside and instead of water and snacks, you'll see swarms of mosquitoes. Molecular biologist Deogratius Kavishe designed the bag to safely transport these bloodsucking insects from deep in the Tanzanian wilderness to the lab. Made from fiberglass screens, a metal frame and Tanzanian *kitenge* cotton fabric, the backpack can hold enough mosquitoes to fill 18 paper cups. The bag is ventilated and has a cover flap that can be soaked in water, so the inside remains cool and moist.

Kavishe, of Ifakara Health Institute in central Tanzania, intends to find out whether malaria-carrying mosquitoes in the region are still susceptible to pyrethroids, insecticides used in protective nets. Resistance has been spreading across Africa: Some populations can survive exposure to dosages that are 1,000 times as high as the standard deadly dose.

Molecular biologist Deogratius Kavishe transports live mosquitoes through rural Tanzania in a custom backpack.

To test the bag, Kavishe loaded it with lab mosquitoes and hiked into a rural area near Ifakara. He waded through floodwaters and thigh-high mud and encountered snakes and buffalo. "I wanted to quit several times," he says with a laugh.

After being carried by Kavishe or his colleagues over a total of 10 days, 70 percent of the mosquitoes were still alive. After 25 days, around 30 percent survived, the team reports in a study posted April 16 at bioRxiv.org. Now that Kavishe knows the bag works, he hopes to capture wild mosquitoes in earnest. — *Darren Incorvaia* for years. There's even a "no-mow May" trend aimed at giving pollinators safe havens. Yet Fox, of Butterfly Conservation in East Lulworth, England, didn't know of any scientific studies of how much butterflies might be using the refuges. So he and ecological statistician Lisbeth Hordley analyzed six years of citizen science data from their organization's Garden Butterfly Survey. They found records with enough data from about 600 yards scattered around England, Scotland and Wales.

It turns out that neighborhood matters. In a yard surrounded by houses, long grass could boost butterfly numbers by up to 18 percent, modeling of real butterfly data suggests. For a yard surrounded by farms, the increase could be as large as 93 percent, Hordley and Fox report in the June 15 *Science of the Total Environment*.

Even if individual yards don't have huge increases in butterfly abundance, the total area of safe space could add up if a lot of yards went a little wild.

No-mowing could be even more beneficial for moths, Fox suspects. In gardens at least, moth caterpillars are more likely than butterfly larvae to munch on grass. And because moths far outnumber butterflies, "they're propping up food chains for many of our garden birds, many small mammals — bats of course," he says.

Leaving a swath of yard unmowed may help U.S. butterflies and moths too, says Matthew Shepherd of the Xerces Society for Invertebrate Conservation in Portland, Ore. The country has butterfly species whose caterpillars eat grass.

"It's about resisting the urge to tidy everything."

RICHARD FOX

When creating butterfly habitats, gardeners often think about nectar, he says. "That's great, but it's not supporting all the life stages." Nectar often is a grown-up food. Caterpillars need baby food. — *Susan Milius*

FIRST

Orangutan heals wound with a medicinal plant

Researchers have observed a male orangutan treat a wound on his face with a plant that's also used in human medicine. It's the first time any wild animal has been seen caring for a wound using a natural substance with known medicinal properties, the scientists report in the May 2 *Scientific Reports*.

In 2022, field biologist Ulil Azhari watched a Sumatran orangutan (*Pongo abelii*) named Rakus in Indonesia's Gunung Leuser National Park chew up a liana plant (*Fibraurea tinctoria*). Locally called Akar Kuning, the traditional medicine plant has anti-inflammatory and antibacterial properties. Rakus (shown above) rubbed the juice onto a wound on his cheek — likely the result of a fight with another male — several times over about seven minutes. Rakus then smeared intact liana pulp on the injury, almost like a bandage. Rakus' intentionality and the fact that the wound never became infected and closed after five days convinced Azhari's team that the orangutan purposefully treated the gash.

"There's a lot of literature about animals applying things to areas that hurt," says Michael Huffman, a zoologist at Nagasaki University in Japan who was not involved in the work. The new study is the first "with details of both the chemical properties of the plant and the progress of the treatment." — *Darren Incorvaia*

HOW BIZARRE

How did a shark parasite end up in tree resin?

Nearly 100 million years ago, a parasitic worm likely made its home in the bellies of fish. So how it ended up preserved in amber has scientists scratching their heads.

Paleontologist Cihang Luo of the Nanjing Institute of Geology and Paleontology in China and colleagues had been examining fossilized tree resin collected from traders in Myanmar. Among numerous insects and roundworms, the researchers eventually came across a 10-millimeter-long flat, threadlike specimen (below, inset). Microscope observations revealed a tentacle armed with hooks, similar to the tentacles of modern flatworms that live in sharks (a great white shark, shown below), the team reports March 22 in *Geology*.

The new fossil "is an exceptional preservation and a puzzle for people to solve," says paleontologist Raymond Rogers of Macalester College in St. Paul, Minn.

Paleontologist Kenneth De Baets of the University of Warsaw in Poland says the fossil is "very hard to explain because there are not a lot of sharks living in trees. It's like winning the lottery — one in a million." Maybe a scavenger eating a beached shark carcass tossed the worm into a nearby tree, Luo speculates. Finding "complete specimens or host remains might confirm this hypothesis," De Baets says. — *Saugat Bolakhe*

FROM TOP: ARMAS; BY WILDESTANIMAL/MOMENT/GETTY IMAGES, INSET: C. LUO

News

QUANTUM PHYSICS

Quantum memories link up

Experiments bring the quantum internet closer to reality

BY EMILY CONOVER

In the quest to build a quantum internet, scientists are putting their memories to the test. Quantum memories, that is.

Quantum memories are devices that store fragile information in the realm of the very small. They're an essential component for scientists' vision of quantum networks that could allow new types of communication, from ultrasecure messaging to linking up far-flung quantum computers. Such memories would help scientists establish quantum connections, or entanglement, throughout a network.

Now, two teams of scientists have entangled quantum memories in networks nestled into cities, where the hustle and bustle of urban life can pose challenges to quantum communications.

"These two impressive studies are pushing out of the lab and into real-world implementations," says physicist Benjamin Sussman of the University of Ottawa in Canada. "These are not just toy systems, but are really the first steps toward what future networks will look like."

In a network of two quantum memories, entanglement was maintained for about a second, physicist Can Knaut of Harvard University and colleagues report in the May 16 *Nature*. "In the domain of quantum, where … everything is more fleeting, one second is actually a really long time," Knaut says. The quantum memories were connected by a telecommunications fiber link that traversed a 35-kilometer loop through Boston and Cambridge, Mass.

The team used quantum memories built from a hunk of diamond in which two of the diamond's normal carbon atoms were replaced by one atom of silicon. The substitution created a defect that served as a quantum bit, or qubit. In fact, the defect served as two qubits: a short-lived one and a long-lived one that acted as the memory. The team prodded the short-lived qubit with a photon, or particle of light, and used that qubit as a go-between to entangle the long-lived qubit with the photon. Then the scientists sent the photon through the fiber and repeated the process to entangle the long-lived qubits in each memory.

> "These are not just toy systems, but are really the first steps toward what future networks will look like."
>
> BENJAMIN SUSSMAN

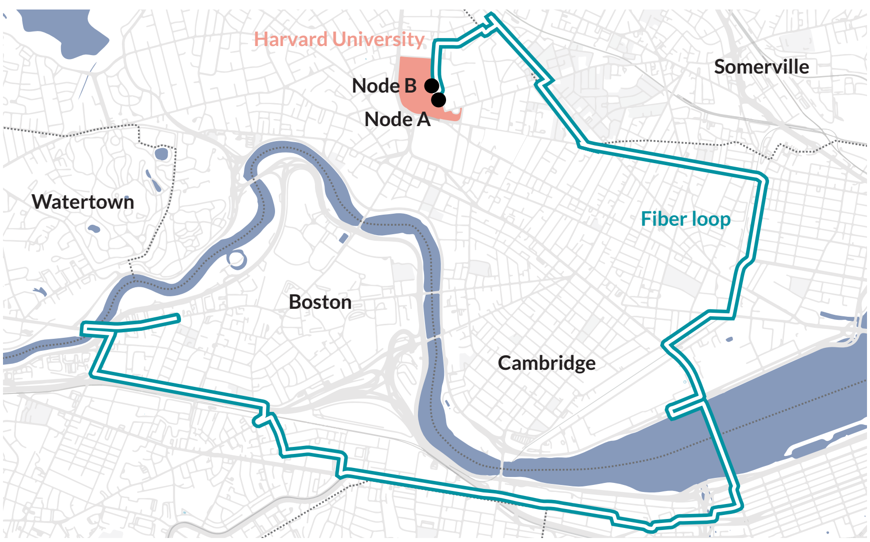
Meanwhile, in Hefei, China, entanglement was achieved in a network with three quantum memories separated by fiber links of about 20 kilometers, researchers report in the same issue of *Nature*.

The quantum memory was based on a large ensemble of rubidium atoms about 1 millimeter in diameter. When hit with a laser, the ensemble can emit a photon. Rather than shuttling the photon directly to another quantum memory, the photon was sent to a central station, where it was measured along with a photon from another memory. That generated entanglement between the two distant parts of the network.

Meeting in the middle meant the photons didn't have to travel all the way to the other side of the network. "This scheme is rather efficient, but its experimental realization is rather challenging," says experimental physicist Xiao-Hui Bao of the University of Science & Technology of China in Hefei. This required finding methods to correct for changes in the length of the fibers due to temperature shifts and other effects. This effort is called phase stabilization. "This is the main technology advance we made in this paper," Bao says.

In contrast, the Boston network had no central station and didn't require phase stabilization. But both teams achieved "heralded" entanglement. That means that a signal is sent to confirm that the entanglement was established, which demands that the entanglement persists long enough for information to make its way across the network. That confirmation is important for using such networks for practical applications, says Wolfgang Tittel, a physicist at the University of Geneva.

"If you compare … how these two different groups have achieved [heralded entanglement], you see that there are more differences than similarities, and I find that great," Tittel says. "There are different approaches which are all still very, very promising." ■



In labs on the Harvard University campus, researchers entangled two quantum memories (Node A and Node B) by sending photons on a 35-kilometer loop (teal) through the Boston area via telcommunications fibers linking the two memories.

C. KNAUT VIA OPENSTREETMAP

ARCHAEOLOGY

Surprisingly few people lived at an early farming site

New census undermines explanation for rise of cities

BY BRUCE BOWER

Excavations of dense clusters of buildings at Çatalhöyük (shown) have resulted in inflated population estimates for one of the world's earliest known farming villages, researchers say.

A farming-fueled baby boom long thought to have sparked the rise of ancient cities in southwestern Asia turns out to have been a bust.

At a massive archaeological site in southern Turkey called Çatalhöyük, large numbers of multiroomed, mud-brick structures cluster in several parts of a settlement that covers an area equivalent to more than 25 U.S. football fields. Since initial excavations in the 1960s, population estimates for the settlement have ranged from 2,800 to 10,000.

If accurate, those numbers would support a decades-old idea that after around 10,000 years ago, early Neolithic villages experienced rapid growth and revolutionary social changes thanks to plant and animal domestication.

But an average of only 600 to 800 people lived at this farming and herding village during its heyday, some 8,600 years ago, two archaeologists conclude in the June *Journal of Anthropological Archaeology*. Children under age 5 represented roughly 30 percent of the population, say Ian Kuijt of the University of Notre Dame in Indiana and Arkadiusz Marciniak of Adam Mickiewicz University in Poznań, Poland.

Previous population estimates have typically, and mistakenly, assumed that Çatalhöyük buildings crowded closely together were constructed at the same time, with all dwellings simultaneously occupied over at least several generations, the researchers contend. In other words, a big archaeological site retaining remnants of lots of buildings must have housed a big crowd.

"That's like assuming all airport hotels are always filled up and every airport hotel over the past 50 years coexisted," Kuijt says. "Scholars have systematically inflated population levels of Near Eastern farming villages."

Kuijt and Marciniak estimated the population of Çatalhöyük for different phases of its history, which lasted from around 9,100 to 7,950 years ago. Population totals for each phase varied depending on the percentage of the site presumed to have been covered by residential buildings and the number of years buildings were assumed to have been used as residences.

Drawing on previous radiocarbon dating and sediment studies at Çatalhöyük, as well as studies of occupation patterns at modern farming villages in Turkey and nearby regions, the researchers generated what they consider a plausible population scenario for the ancient site at its pinnacle.

In the reconstruction, residential buildings covered 40 percent of the site, and people lived in 70 percent of all buildings. An average of five people inhabited each dwelling. Most residences were used for about one generation, 20 to 45 years.

A peak of only 600 to 800 Çatalhöyük inhabitants challenges a long-standing hypothesis that explosive population growth in early farming villages forced migrations to new areas, rapidly spreading a Neolithic way of life, Marciniak says. Farming villages instead spread gradually, in starts and stops, across southwest Asia and Europe, he suspects. Population booms and busts may have characterized agriculture's spread.

A small population fits with previous evidence that Çatalhöyük residents relied on some form of collective decision making rather than a central political authority.

The analysis represents "a significant step forward" in reconstructing the population size of ancient villages, says ecological anthropologist Sean Downey of Ohio State University. But actual sizes of ancient populations are difficult to pin down, he cautions. Other evidence, such as an estimate of the number of adults at Çatalhöyük generated from ancient human DNA, would help to validate the population estimate, Downey says.

Ongoing excavations indicate that most Neolithic villages featured small populations, in line with Kuijt and Marciniak's Çatalhöyük estimate, says archaeologist Peter Akkermans of Leiden University in the Netherlands.

Akkermans has led excavations of Neolithic sites in Syria, which he estimates contained populations usually ranging from a few dozen to several hundred people. Small villages at each site were abandoned after around a generation of use and rebuilt nearby over hundreds, and sometimes thousands, of years. Those settlement cycles left behind large archaeological sites, some approaching the size of Çatalhöyük.

A transition from Neolithic villages to city-sized settlements in Asia and Europe took several thousand years, Akkermans says. Even then, urban life could range from densely packed communities to interconnected hamlets spread across the landscape. ■

An older man shields himself from the heat in Beijing in 2023. By midcentury, extreme heat will put the health of a larger share of older adults at risk.

HEALTH & MEDICINE

More older adults will face high heat

By 2050, extreme temps will endanger more seniors

BY AIMEE CUNNINGHAM

Nearly a quarter of the world's older adults at midcentury could face extreme heat, putting their health in danger.

As many as an additional 246 million adults age 69 and older could experience temperature extremes above 37.5° Celsius (99.5° Fahrenheit) by 2050, researchers report May 14 in *Nature Communications*. More than 23 percent of the older adult population globally, largely in Africa and Asia, could encounter this intense heat, compared with 14 percent today.

"Protecting our older population will be increasingly critical in the years to come," says cardiologist-epidemiologist Andrew Chang of Stanford University.

Heat extremes are especially risky for older adults because the aging body can't cool off as efficiently. Seniors also often have chronic illnesses that are worsened by heat and take medications that are dehydrating. And some older adults are socially isolated, are limited in their mobility or have cognitive impairments.

"It's this kind of perfect storm of biological aging, social loneliness and then cognition that make [heat] so much worse for older people," says Deborah Carr, a sociologist of aging at Boston University.

Carr and colleagues projected the population of those age 69 and up by 2050 and estimated the impact of climate change on the regions where they will reside.

The team estimates that the number of days annually that exceed 37.5° C will increase from an average of 10 days today to about 20. The upper bound of how hot it can get will also rise, depending on region.

The team also looked at how population aging and increasing heat are driving the projected results. In the Global South, historically hotter, a growing share of the population is aging. Parts the Global North, which are "colder and older," Carr says, "are experiencing more heat extremes."

There isn't a one-size-fits-all approach to reduce risks from heat exposure, says study coauthor Giacomo Falchetta, a climate change researcher at the Euro-Mediterranean Center on Climate Change in Venice, Italy. But options include ensuring sufficient nutrition and hydration, implementing heat early warning systems, providing public cooling centers and expanding green spaces and tree cover to reduce urban heat island effects. ■

HEALTH & MEDICINE

What makes fentanyl so addictive

A mouse study details brain circuits for reward and withdrawal

BY CLAUDIA LÓPEZ LLOREDA

Fentanyl's powerful pull comes from both the potent, rapid euphoria people feel while on the drug and the devastating symptoms of withdrawal. Researchers now have new clues about brain circuits responsible for these forces of addiction.

The study in mice, reported May 22 in *Nature*, suggests two distinct brain pathways are in play.

Fentanyl and other opioids are highly addictive. Researchers have known that dopamine-releasing neurons in an area of the midbrain called the ventral tegmental area, or VTA, mediate feelings like euphoria. But the circuits driving withdrawal symptoms, such as nausea and pain, have been less clear.

Neuroscientist Christian Lüscher of the University of Geneva and colleagues injected mice with fentanyl for several consecutive days then stopped, inducing withdrawal by giving the mice naloxone.

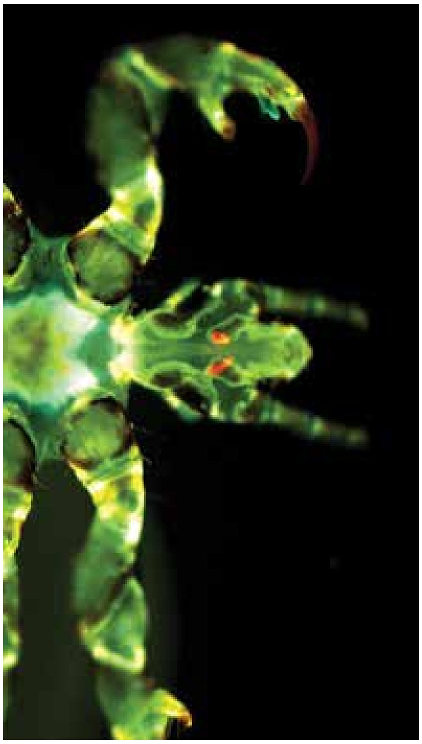
As expected, neurons in the VTA turned on when mice were getting fentanyl. And the team uncovered some details of how: Fentanyl inhibited neurons that tamp down the activity of the dopamine-releasing neurons in the VTA. That led to a ramp-up in the production of dopamine, triggering the drug's rewarding effects.

After fentanyl and naloxone administration, when mice showed signs of withdrawal, their brains showed increased activity in neurons in the central amygdala, particularly cells that connect to areas associated with fear-learning and forming aversive memories.

Both sets of neurons possess the main receptor known to respond to fentanyl. Removing this receptor in the VTA eliminated the drug's rewarding effects but not withdrawal behaviors, like jumping. But when the team knocked out the receptor in the central amygdala, mice jumped less, suggesting a role in withdrawal.

Understanding these two pathways could lead to better therapies for opioid addiction. "It's pie in the sky right now, but there's always the possibility of using that to develop circuit-specific therapy for people," says Megan Fox, a neuroscientist at Penn State. ■

WANG ZHAO/AFP VIA GETTY IMAGES



HEALTH & MEDICINE

Body lice can spread the plague

Rats and their fleas take the rap for spreading the plague, but lice that infest people may share the blame. Human body lice can harbor plague-causing bacteria and transmit the disease by biting, researchers report May 21 in *PLOS Biology*.

Some studies have suggested that *Yersinia pestis*, the bacterium that causes the plague, spread too quickly during the Black Death of 1346 to 1353 and other outbreaks to be the sole work of rats and fleas. Researchers at a U.S. National Institute of Allergy and Infectious Diseases lab in Hamilton, Mont., considered whether body lice, which feed on human blood, could have also spread the plague.

In experiments, lice fed blood laced with *Y. pestis* developed infections that lasted about a week. In some lice, the bacteria concentrated in a set of glands that may produce a lubricant to help the mouthparts extend, pierce human skin and retract. (In the image at left, showing a fluorescent-tagged louse under a microscope, bacteria infecting the glands are shown in red.) These lice could transmit the bacteria during a short three-hour feeding period and in large enough doses to cause disease in humans, the researchers discovered. Lice that carried the bacteria in their guts could spread the pathogen if given 20 hours but not as efficiently as the ones with the gland infections.

These findings suggest lice bites could have spread the plague and might be just the culprits to pin some outbreaks on. *— Tina Hesman Saey*

DAVID M. BLAND (CC0)

HEALTH & MEDICINE

A stomach burn yields weight loss

An experimental procedure reduces a hunger hormone

BY MEGHAN ROSEN

An experimental weight loss procedure cranks up the heat to dial down hunger.

Blasting a patch of stomach lining with thermal energy curbed hunger and cut pounds in a small pilot study of 10 obese women, researchers reported May 19 at the Digestive Disease Week meeting in Washington, D.C.

Called gastric fundus mucosal ablation, the procedure is done with an endoscope, a thin tool that can be threaded down the throat. It takes less than an hour and doesn't require hospitalization. "The advantage of this is that it's a relatively straightforward procedure," says Cleveland Clinic surgical endoscopist Matthew Kroh, who was not involved with the work. Side effects, which included mild nausea and cramping, were minimal, one study author said in a May 8 news conference.

That's a big difference from bariatric surgery, which works by restricting stomach size or affecting food absorption. Patients can be hospitalized for days and take weeks to recover. Obese people often avoid these treatments because they don't want to endure surgery, Kroh says.

The new procedure could offer an easier option — if the results hold up in larger studies. "There's potential," Kroh says, "but I think we have to be cautious."

On average, women in the study lost nearly 8 percent of their body weight, some 19 pounds, over six months. That's less than patients typically see from bariatric surgery or pharmaceutical treatments like the anti-obesity drug Wegovy.

But it's enough to make a difference in people's lives, says Margaret Keane, a bariatric endoscopist at the Johns Hopkins Hospital, who wasn't part of the study. Even at that level of weight loss, she says, people can experience improvements in conditions that accompany obesity, like high blood pressure and diabetes.

The study's authors pinned the weight loss on a reduction of a hunger hormone called ghrelin. The hormone acts like a dinner bell for the brain, sending the message that it's time to eat. Less ghrelin means fewer hungry feelings. No available drug can directly lower the hormone's level in the blood, but doctors can target the tissue that makes ghrelin. Cells lining the upper portion of the stomach pump out most of the hormone. Burning these cells away should lead to weight loss, reasoned study coauthor Christopher McGowan, a gastroenterologist at True You Weight Loss, a clinic in Cary, N.C.

Though results varied, study participants' ghrelin levels dropped by about 45 percent, from roughly 460 picograms per milliliter at baseline to 254 pg/mL at six months post-procedure. That's probably because they had roughly half as many ghrelin-producing cells post-procedure, McGowan said at the news conference.

It's unclear how long the results will last and whether ghrelin-producing cells will grow back. But McGowan noted that scar tissue forms as the burned tissue heals, making the stomach area "less stretchy, less expandable and stiffer," he said. "So patients feel full with less food."

McGowan sees the technique as a potential stand-alone treatment for obesity. It could perhaps be used for patients transitioning off Wegovy or similar drugs, who often gain weight back after they stop taking the medications. ■

ARTIFICIAL INTELLIGENCE

AI raises ‘ghosts’ of the dead

The digital afterlife industry needs guardrails, experts warn

With generative AI technology, companies can create “deadbots” of deceased loved ones. What could go wrong?

CULTURA RM EXCLUSIVE/UWE UMSTAETTER/GETTY IMAGES

BY KATHRYN HULICK

When missing a loved one who has passed away, you might look at old photos or listen to old voicemails. Now, with artificial intelligence technology, you can also talk with a virtual bot made to look and sound just like them.

The companies Silicon Intelligence and Super Brain already offer this service. Both rely on generative AI, including large language models similar to the one behind ChatGPT, to sift through snippets of text, photos, audio recordings, video and other data. With this information, the companies can create digital “ghosts” of the dead.

Called griefbots, deadbots or re-creation services, these digital replicas “create an illusion that a dead person is still alive and can interact with the world as if nothing actually happened, as if death didn’t occur,” says Katarzyna Nowaczyk-Basińska, a researcher at the University of Cambridge who studies how technology shapes people’s experiences of death, loss and grief.

In a paper published in the June *Philosophy & Technology*, she and colleague Tomasz Hollanek, a technology ethicist at Cambridge, explored the risks of “digital immortality” and the technology behind it. *Science News* spoke with Nowaczyk-Basińska about these risks. The interview has been edited for length and clarity.

Your paper presents three problematic scenarios that could arise with deadbots. Which one do you find most dystopian?

We present a terminally ill woman leaving a griefbot to assist her 8-year-old son with the grief process. We use this example because we think that exposing children to this technology might be very risky.

We could go even further and use this in the near future to even conceal the death of a parent. We know very, very little about how these technologies would influence children. We argue that if we can’t prove that this technology won’t be harmful, we should take all possible measures to protect the most vulnerable. In this case, that would mean age-restricted access.

What about other safeguards?

We should make sure that the user is aware that they are interacting with AI. It can simulate language patterns and personality traits based on processing huge amounts of personal data. But it’s definitely not a conscious entity. We also advocate for developing sensitive procedures of retiring or deleting deadbots. We also highlight the significance of consent.

Can you describe a scenario that explores consent for the bot user?

We present an older person who secretly — that’s a very important word — committed to a deadbot of themselves, paying for a 20-year subscription, hoping it will comfort their adult children. Imagine that after the funeral, the children receive a bunch of emails, notifications or updates from the re-creation service, along with the invitation to interact with the bot of their deceased father.

[The children] should have a right to decide whether they want to go through the grieving process in this way or not. For some people, it might be comforting and it might be helpful, but for others not.

You also argue that it’s important to protect the dignity of humans. In another scenario, you imagine a woman who creates a deadbot of her long-deceased grandmother.

She asks the deadbot about the recipe for homemade carbonara spaghetti that she loved cooking with her grandmother. Instead of receiving the recipe, she receives a recommendation to order that food from a popular delivery service. Our concern is that griefbots might become a space for a very sneaky product placement, encroaching upon the dignity of the deceased and disrespecting their memory.

Why is now the time to act?

When we started working on this paper a year ago, we were a bit concerned whether it’s too much like science fiction. Now, with the advent of large language models, especially ChatGPT, these technologies are more accessible. That’s why we so desperately need regulations and safeguards.

Re-creation service providers today are making totally arbitrary decisions of what is acceptable or not. It’s a bit risky to let commercial entities decide how our death and immortality should be shaped digitally. People in end-of-life situations are already in a very difficult point in their lives. We shouldn’t make it harder for them through irresponsible technology design. ■

ANIMALS

Taking fake death to the extreme

Feces and a bloody mouth may help this snake elude predators

BY RICHARD KEMENY

To avoid becoming a meal, some animals fake it until they make it. And fake deaths with several unappealing elements may make the fraud efficient, a study finds.

Dice snakes that bleed from the mouth and cover themselves in musk and feces spend less time pretending to be dead than those that don't, researchers report in the May *Biology Letters*. These defenses, the scientists suggest, could be working in synergy: heightening the overall impact of the display while helping the snake escape a predator more quickly.

Death-feigning, which often involves lying still, is common across the animal kingdom (*SN: 11/18/23, p. 8*). Many predators won't touch apparently dead things, perhaps because of parasites, or the stillness may not elicit a predatory response.

Some dice snakes fake death by filling their mouth with blood (shown) and smearing themselves in musk and poop.

The dice snake (*Natrix tessellata*) is particularly elaborate when staging its demise. When captured, it will thrash and hiss before covering itself in feces and musk. Then, it opens its mouth, sticks out its tongue and fills its mouth with blood.

Biologists Vukašin Bjelica and Ana Golubović of the University of Belgrade in Serbia wanted to know if these combined defensive efforts make the whole ploy happen faster. The team captured 263 wild dice snakes on the island of Golem Grad in North Macedonia before placing the snakes on the ground and stepping out of sight, mimicking the actions of a hesitant predator.

Just under half of the snakes smeared themselves in musk and feces, while around 10 percent bled from the mouth. Some fake deaths without musk, poop or blood lasted almost 40 seconds. The 11 snakes that combined all three spent, on average, around two seconds less feigning death. "Two seconds might not be a lot but can be just enough for a snake to mount an escape if the predator backs away from attacking it," Bjelica says.

Evolutionary ecologist Tom Sherratt of Carleton University in Ottawa wonders why the snake displays differ: "It could be something about their experience, but there's variation there to explain." ■

ANIMALS

Beetles may weaponize ultrasound

Mimicking the noises of toxic moths could deter bat predators

BY JAKE BUEHLER

Sounding like a toxic moth might keep some beetles safe from hungry bats.

When certain tiger beetles hear an echolocating bat draw near, they respond with extremely high-pitched clicks. This acoustic countermeasure is a dead ringer for the noises toxic moths make to signal their nasty taste to bats, researchers report in the May *Biology Letters*. Such sound-based mimicry may be widespread among groups of night-flying insects.

At night, bats and bugs are locked in sonic warfare. At least seven major insect groups have ears sensitive to bat echolocation, many fleeing in response. Some moths have sound-absorbent wings and fuzz that impart stealth against bats (*SN: 12/8/18, p. 10*). Others make ultrasonic trills that may startle bats or jam sonar.

Previous research suggested some tiger beetles — a family of fast-running, often strikingly colored predatory beetles with strong jaws — also make high-pitched clicks in response to human-made imitations of bat ultrasound. Harlan Gough, a conservation entomologist now at the U.S. Fish and Wildlife Service in Burbank, Wash., and his team wanted to know why.

After collecting 19 tiger beetle species from southern Arizona, the researchers tethered the insects to a metal rod in the lab and prompted them to fly. The team then filmed and recorded audio to see how the beetles responded to a bat clicking sequence that immediately precedes an attack. Right away, seven of the species — all nocturnal — pulled their hard, caselike forewings into the path of their beating hind wings, creating high-pitched clicks.

Gough's team thought the clicks might warn bats of the beetles' unpalatability and toxicity. But in the lab, big brown bats (*Eptesicus fuscus*) devoured 90 of the 94 beetles scientists offered. "It's pretty clear that tiger beetles are not chemically defended against bats," Gough says, though chemicals might deter insect foes.

Instead, the researchers think the tiger beetles are mimicking the "stay away" clicks of foul-tasting tiger moths. Characteristics of the beetles' clicks closely resemble those of the tiger moths living alongside them in Arizona. While more research is needed, Gough says, the beetles appear to be the first known insects besides moths to use anti-bat ultrasound.

Ted Stankowich, an evolutionary ecologist at California State University, Long Beach, says the new findings show the need to consider warning signals based on sound or smell, not just sight.

"We just have so much more to know about what's going on in the night sky," Gough says. ■

MICHAL FUGLEVIC/ISTOCK/GETTY IMAGES PLUS

Using its drill, NASA's Perseverance rover (lower left) collected material from a rock nicknamed Rochette in September 2021 as part of a plan to bring samples to Earth.

JPL-CALTECH/NASA

PLANETARY SCIENCE

Budget woes put Mars mission at risk

Steep funding cuts jeopardize plans to bring samples to Earth

BY ADAM MANN

Dreams of exploring the cosmos have crashed up against the harsh reality of budget cuts in the United States. Congressional approval of the 2024 federal budget earlier this year left NASA with roughly half a billion dollars less than the agency had in 2023 — and Mars science has taken the biggest hit.

Until now, NASA had been on one of its longest streaks of regular budget increases in history, says Casey Dreier, chief of space policy at the Planetary Society in Pasadena, Calif. From 2014 through 2023, funding each year had increased an average of about 4 percent compared with the previous year.

"That makes it easy to take on new projects," Dreier says. "There's room to grow. Everybody can win. And that has ended."

NASA's 2024 budget, $24.875 billion, represents a 2 percent cut relative to last year and 8.5 percent less than the requested funding. That's the biggest discrepancy between requested and appropriated funding for the agency since 1992.

The budget's approval left it up to NASA administrators to figure out how to adapt and cover the $509 million gap. Their solution: Cut $649 million from the budget of the Mars Sample Return mission.

"Mars Sample Return took it on the chin for the entire agency," Dreier says. The amount taken from this program, part of the planetary science division, "basically saved every other science division."

The mission had intended to bring rock and soil samples to Earth from the Red Planet by 2033. But even before these budget cuts, questions emerged about whether the ambitious program, prioritized in 2022 as part of planetary scientists' decadal survey, could meet its goals on deadline and at a reasonable cost.

The budget cuts now mean the mission is on hold as NASA tries to determine if it can be done at all.

The Perseverance rover was the first step of sample return. Since arriving on Mars in 2021, the rover has been filling small tubes with material from specific locations in Jezero crater, with the goal of eventually gathering 38 samples in total (*SN: 10/9/21 & 10/23/21, p. 8*). The rocks and soil could answer fundamental questions about the formation of the inner solar system and the history of water on Mars, and perhaps reveal signs of past life on the planet.

Yet bringing these samples back is among the most complex mission proposals ever put forward, requiring a vehicle that can launch from the Martian surface and a way to transfer the samples to a second rocket in space to prevent possible contamination of our home planet.

The decadal survey estimated the mission would cost more than $5 billion. NASA had hoped to spend around $950 million on it this year.

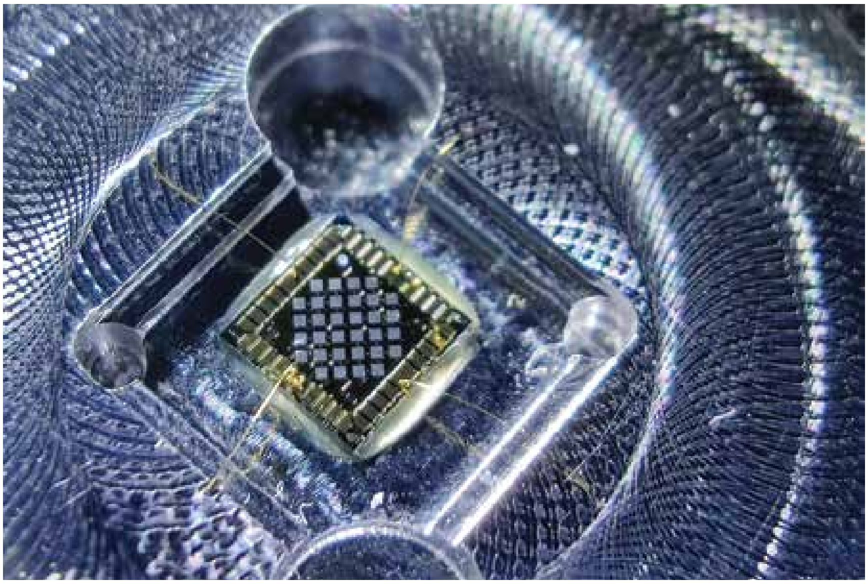
But two independent review boards pegged the overall expense much higher, potentially reaching $11 billion, unacceptable to NASA administrators. The $649 million reduction covered the full amount of the cost cutting that NASA needed to do, allowing for some other programs to have modest budget increases.

NASA proposes to spend just $300 million on the sample return mission this year and $200 million next year, which is just enough to string the program along as its future is figured out. And though it's still unclear how much money NASA will receive next year, the 2025 budget requested by the Biden administration has been pared back.

NASA's Jet Propulsion Laboratory in Pasadena, largely responsible for designing and building the components of sample return, "lost hundreds of millions of dollars functionally overnight," Dreier says. Budget uncertainty had already prompted the center to announce in February that it would dismiss 530 employees, or 8 percent of its staff.

"I'm positive you will see further layoffs at JPL and probably other NASA centers that were involved in Mars Sample Return," Dreier says.

Meanwhile, NASA has put out a solicitation asking other NASA centers and engineers in the industry to propose innovative ways to bring back at least some of Perseverance's cache at a lower cost. It may mean choosing which of the originally planned samples — 24 of which have been collected so far — are most valuable. ■



Scientists used this sensor chip to make a measurement that helped put a bound on the size of a neutrino's wave packet, which indicates the uncertainty of the particle's position.

QUANTUM PHYSICS

Neutrino fuzziness comes into focus

Physicists have constrained a quantum quirk of the particle

BY EMILY CONOVER

Neutrinos are known for funny business. Now, scientists have set a limit on a quantum trait responsible for the subatomic particles' quirkiness: uncertainty.

The lightweight particles morph from one variety of neutrino to another as they travel, a strange phenomenon called neutrino oscillation. That ability rests on quantum uncertainty, a sort of fuzziness intrinsic to the properties of quantum objects, such as their position or momentum. But despite its importance, the uncertainty in the neutrino's position has never been directly measured.

"The 'quantum properties of the neutrino' stuff is a little bit of the Wild West at the moment," says nuclear physicist Kyle Leach of Colorado School of Mines in Golden. "We're still trying to figure it out."

It's impossible to know everything about a quantum particle. The Heisenberg uncertainty principle famously states that it's futile to attempt to precisely determine both the momentum of an object and its position. Leach and colleagues report new details about the potential size of the neutrino's wave packet, which indicates the uncertainty in the particle's position.

Quantum particles travel as waves, with ripples that are related to the probability of finding a particle at a given position. A wave packet is the set of ripples corresponding to a single particle. The new experiment sets a limit on the size of the wave packet for neutrinos produced in a particular type of radioactive decay, Leach's team reports in a paper submitted April 3 to arXiv.org. The particles have a wave packet size of at least 6.2 trillionths of a meter.

The researchers studied neutrinos produced in the decay of beryllium-7, via a process called electron capture. In this process, a beryllium-7 nucleus absorbs an electron, and the atom transforms into lithium-7 and spits out a neutrino.

The team implanted beryllium-7 atoms in a highly sensitive device made from five layers of material, including superconducting tantalum, which can transmit electricity without resistance. In the process of decay, the lithium-7 recoils from the neutrino. When cooled to 0.1 degrees above absolute zero (–273.05° Celsius), the device allowed the researchers to detect the energy of that recoil. The spread in the energy of the lithium atoms revealed the neutrino wave packet's minimum size.

Neutrinos are special in that they interact so rarely with matter that they maintain their quantum properties over long distances. Most quantum effects take place on very small scales, but neutrino oscillations occur over thousands of kilometers.

That means studying the size of neutrinos' wave packets could help unveil the connection between the everyday world of classical physics and the strangeness of quantum physics, says Benjamin Jones, a neutrino physicist at the University of Texas at Arlington who was not involved with the experiment. "If you can predict something like this and then measure it, then you really validate some of the ideas that people have about how the classical world emerges from an underlying quantum reality," he says. "And that's what really got me excited about this in the first place."

In another study, submitted April 30 to arXiv.org, Jones and colleagues theoretically predicted the size of the neutrino wave packet for the electron capture decay, at about 2.7 billionths of a meter. As the theoretical prediction is larger than the experimental lower limit set by Leach and colleagues, the two are consistent. Now it's up to experimental physicists to try to measure the neutrino wave packet, not just determine its minimum size.

Measuring the size of neutrinos' wave packets might help resolve discrepancies among past experiments and potentially point the way to new types of subatomic particles still to be discovered. But the size of the neutrino's wave packet depends on how the particle is produced. So it's not clear how the size limits observed in Leach's study might translate to neutrinos produced by other means, says neutrino physicist Carlos Argüelles of Harvard University. For example, many experiments observe neutrinos produced in nuclear reactors, but those are produced via a different type of radioactive decay.

Still, Argüelles says, "the study of the neutrino wave packet has fundamental implications in the quantumness of the neutrino, and the quantumness of the neutrino is actually what makes neutrinos interesting. It's the most unique property that they have." ■

SPENCER FRETWELL/COLORADO SCHOOL OF MINES

COSMOLOGY

The universe may loop back on itself

It's possible the cosmos has a complicated geometry

BY EMILY CONOVER

The cosmos may have something in common with a doughnut.

In addition to their fried, sugary goodness, doughnuts are known for their shape, or in mathematical terms, their topology. In a universe with an analogous, complex topology, you could travel across the cosmos and end up back where you started. Such a cosmos hasn't yet been ruled out, physicists report in the April 26 *Physical Review Letters*.

On a shape with boring, or trivial, topology, any closed path you draw can be shrunk down to a point. Consider traveling around Earth. If you were to go all the way around the equator, that's a closed loop, yet you could squish that down by shifting your trip up to the North Pole. But the surface of a doughnut has complex, or nontrivial, topology. A loop that encircles the doughnut's hole, for example, can't be shrunk down to a point, because the hole limits how far you can squish it.

The universe is generally believed to have trivial topology. But that's not known for certain, the authors of the new report argue.

"I find it fascinating … the possibility that the universe might have nontrivial or different types of topologies, and then especially the fact that we think we might be able to measure it," says Dragan Huterer, a cosmologist at the University of Michigan in Ann Arbor who was not involved with the study.

A universe with nontrivial topology might be a bit like Pac-Man. In the classic arcade game, moving all the way to the right edge of the screen puts the character back at the left side. A Pac-Man trek that crosses the screen and returns the character to its starting point likewise can't be shrunk down to a point.

Scientists have already looked for signs of complex topology in the cosmic microwave background, light from when the universe was just 380,000 years old. Because of the way space loops back on itself in a universe with nontrivial topology, scientists might be able to observe the same feature in more than one place. Researchers have searched for identical circles that appear in that light in two different places on the sky. They've also hunted for subtle correlations, or similarities, between different spots, rather than identical matches.

Those searches didn't turn up any evidence for complex topology. But theoretical physicist Glenn Starkman of Case Western Reserve University in Cleveland and colleagues argue there's still a chance that the universe does have something in common with a doughnut. That's because earlier research considered only a small subset of the possible topologies the universe could have.

That subset includes one type of nontrivial topology called a 3-torus, a cube that loops back on itself like a 3-D version of the Pac-Man screen. In such a topology, exiting any side of that cube brings you back to the opposite side. Searches for that simple 3-torus have come up empty. But scientists haven't yet searched for some 3-torus variations. For example, the sides of the cube might be twisted relative to one another. In such a universe, exiting the top of the cube would bring you back to the bottom, but rotated by, for example, 180 degrees.

The new study considered 17 possible nontrivial topologies for the cosmos. Most of them, the authors determined, haven't yet been ruled out. The study evaluated the signatures that would appear in the cosmic microwave background for different types of topologies. Future analyses of that ancient light could reveal hints of these complex topologies, the researchers found.

The search is likely to be computationally challenging, probably requiring machine learning techniques to speed up calculations. The researchers plan to hunt for signs of nontrivial topology in upcoming data from surveys of the distribution of galaxies in the cosmos from, for example, the European Space Agency's Euclid space telescope.

There's good motivation to look for nontrivial topology, Starkman says. Some features of the cosmic microwave background hint that the universe isn't the same in all directions. That kind of asymmetry could be explained by nontrivial topology. And that asymmetry, Starkman says, is "one of the biggest new mysteries about the universe that hasn't gone away." ■

Scientists are considering whether the universe might have a complicated topology, represented by a doughnut shape in this artist's conception.

J. LAW/ESO

PLANETARY SCIENCE

Europa's ocean may be inhospitable

The moon's habitability could hinge on seafloor geologic activity

Jupiter's moon Europa may have an ocean beneath its icy shell. It's considered one of the most promising places to explore for alien life.

JPL-CALTECH/NASA, SETI INSTITUTE

BY NIKK OGASA

THE WOODLANDS, TEXAS — On stage, before a silent assembly of scientists, many of them experts on alien worlds, planetary scientist Paul Byrne assumed his position behind the podium. He had come from Washington University in St. Louis to present research on Europa, a moon of Jupiter that almost certainly harbors a subsurface ocean. The moon is thought to be among the most promising places to explore for life in our solar system. But much of that promise clings to an unknown: the geologic activity of Europa's seafloor.

"I don't think there's anything happening on the ocean floor," Byrne said to the crowd gathered at the Lunar and Planetary Science Conference on March 11.

Europa is one of three alien worlds in our solar system — along with Saturn's moons Enceladus and Titan — generally thought to possess the three ingredients for habitability: liquid water, bioavailable energy and the chemical building blocks for life. And it is thought to be about as old as Earth. In other words, life has had roughly the same amount of time to emerge on Europa as it has here.

As a testament to all those promising qualities, the largest spacecraft NASA has ever developed for a planetary mission, Europa Clipper, is slated for launch in October and will eventually fly by the moon dozens of times. But as Clipper's maiden voyage nears, it remains unclear whether the moon's ice-covered sea can sustain life. As Byrne and other researchers question whether the seabed is dead, enigmatic quakes detected on Earth's moon hint that mysterious mechanisms could operate within Europa. And even if the icy moon is uninhabitable today, it may not have always been so.

The geologic activity of the moon's seafloor may form the crux of the moon habitability question, says Clipper mission scientist Robert Pappalardo of the Jet Propulsion Laboratory in Pasadena, Calif. "It's such a profound question," he says. "Either way it comes out, it's going to be important for understanding how common life is out there in general."

All quiet on the ocean floor

Europa's ocean is plunged in darkness, lurking beneath ice some 20 kilometers thick that encapsulates the entire moon (*SN: 6/9/18, p. 11*). And the ocean's waters are deep, up to 150 kilometers. The average depth of Earth's oceans is about four kilometers.

Anything living within that blackness would probably harvest energy from chemical reactions in the environment. On Earth's ocean floor, such chemosynthetic microbes crowd hydrothermal vents and methane seeps, chemical oases sustained by tectonic forces and volcanic activity.

Similar geologically sustained environments, or at least chemical reactions between water and fresh rock surfaces, would be necessary for organisms to persist in Europa's ocean, Byrne said. "How likely is that to happen?"

He and colleagues built computer simulations of Europa's seafloor, accounting for gravity, the weight of the ocean and the pressure of water within the seafloor. From the simulations, the team computed the stress required to force shallow faults under the seafloor to slide and expose fresh rock to seawater.

The stress required to trigger fault slip on Europa's seafloor is more than 10 times the stress imparted by Jupiter's gravity and by the convection of material in Europa's mantle, Byrne said. "The take-home message is that the seafloor is likely geologically inert."

Austin Green, a planetary scientist at the Jet Propulsion Laboratory, followed Byrne in presenting. Green began by expressing his sympathies for continuing the "parade of depressing news." He, Byrne and colleagues had simulated flows of molten rock originating in Europa's interior to test whether magma could rise from below to reach the seafloor and bring it in contact with water.

For that to happen, the magma first needs to be sufficiently buoyant to breach the overlying rock. And second, the magma source must be voluminous enough to steadily feed molten rock to the rising flows, which would otherwise cool and solidify during their ascent.

Simulations suggest that the first condition, an adequate oomph, was unlikely. Europa's low gravity and inability to generate large bodies of molten rock limit the magma's buoyant force, Green said.

The measly magma volumes also preclude the second requisite: a sufficient supply. Assuming buoyancy isn't a problem, simulations of magma flows rising in the mantle suggest that diffuse pockets of molten rock form 200 kilometers below the seafloor. From that depth, magma flows rise at most just 5 percent of the way to the seafloor before solidifying.

"Present-day volcanism of the seafloor

is highly unlikely," Green said. "If this volcanism is necessary for habitability, Europa's ocean is uninhabitable."

A mystery of two moons

But another JPL colleague, planetary scientist Laurent Pou, presented a less quiescent picture. And he roped Earth's moon into the discourse.

Seismometers planted on Earth's moon during the Apollo missions detected rumblings from deep within its rocky mantle, from 700 to 1,000 kilometers underground (SN: 6/8/19, p. 7). These moonquakes were prompted by internal stresses caused by Earth's gravity.

Both Earth's moon and Europa are thought to possess silicate-rich mantles. These moons are also about the same size, with Jupiter's gravity inflicting more stress on its moon than Earth's does. If Earth's moon has deep quakes, Europa might have them too, Pou and colleagues propose.

Computer simulations of the moon's interior under the influence of Earth's gravity suggested that for moonquakes to occur, preexisting fractures and other weaknesses are necessary. Pou's team then computed the requisite conditions for quakes on Europa, simulating that moon's interior under the influence of Jupiter's gravity. Comparing the results revealed that Europa-quakes were at least 10 times as likely to occur as lunar temblors, assuming similar weaknesses existed in both bodies. That could mean the rocks within Europa's interior are moving, possibly contradicting notions of a dead seafloor.

The discrepancy between Pou's and Byrne's results may arise out of unknown differences in the construction of the two moons. "We're missing something," Pou said at the meeting. There may be some sort of weakness in Earth's moon, and if that weakness doesn't occur in Europa's interior, then Europa-quakes may not either, he speculated.

If quakes do shake within Europa, they could revive notions of a geologically active seafloor. "Until we can actually take data that tells us whether or not a process is occurring, it can be premature to decide whether or not it's possible," says planetary scientist Alyssa Rhoden of the Southwest Research Institute in Boulder, Colo.

Byrne remains resolute. "We do not understand the physical process that makes [deep moonquakes] work," he says. But we do know that they are deep and release relatively low amounts of energy, so if something similar occurs in Europa, those tremors probably don't expose new rock on the seafloor.

Habitability's ebb and flow

Even if Europa is not habitable today, that doesn't mean it wasn't in the past.

"There's a phrase that's catching on in the planetary community: dynamic habitability," Pappalardo says. "The habitability of a world, it could change over time."

Europa is caught in a rhythmic dance with its sibling moon Io. For every two orbits around Jupiter that Io completes, Europa makes one. What follows from this orbital resonance is the periodic flexing and frictional heating of Europa's interior, Pappalardo says. Though these heat pulses follow a regular beat, the intensity of that beat fluctuates because Europa's eccentricity, a measure of its orbit's deviation from a perfect circle, oscillates over time.

"It's kind of a 100-million-year-ish cycle," Pappalardo says. That's consistent with the average age of Europa's icy surface, which is roughly 60 million years old. "We may be in a phase of lesser activity now," he says. "Maybe it was most active 100 million years ago."

If Europa has passed through periods of more habitable conditions, a multitude of questions emerge, Pappalardo says. "Would life die off? Would there be natural selection, and microorganisms are making it through the difficult period? Can they make it through 100-million-year cycles?"

Byrne is uncertain. "Maybe if you were a particular form of alien life that evolves to be extremely adept at taking very low reaction rates and somehow living off that," he says.

Knowing Europa had life in the past could assist in the broader search for life today, Pappalardo says. For instance, such knowledge could inform our understanding of what fraction of habitable planets life develops on. That fraction is one of the six terms in the Drake equation, a formula that estimates the number of communicable civilizations in the Milky Way.

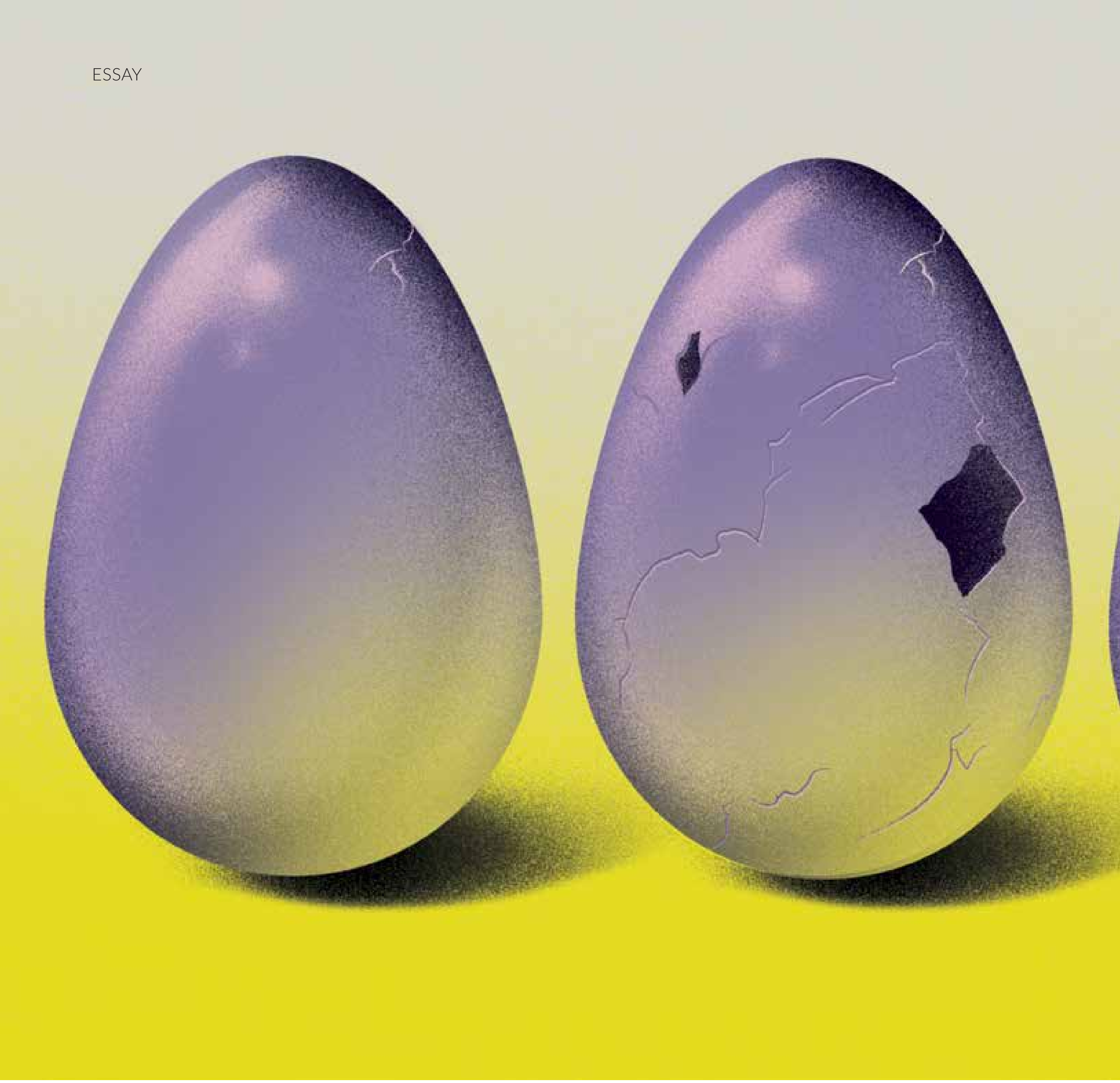
As for Clipper, it probably won't resolve the debate surrounding Europa's seafloor activity, as it will look on from beyond the ice shell, Byrne says. But Pappalardo points out that the spacecraft will hopefully confirm that the ocean exists in the first place.

If Clipper finds material from the ocean on Europa's surface and can collect enough data, maybe the spacecraft can reveal whether water in the ocean is reacting with rocks on the seafloor, Rhoden says. That could help address the question of whether the alien ocean contains ingredients for life, she says. "Also, you know, if we find a sea urchin, we know the answer." ■

The Europa Clipper (shown at the Jet Propulsion Laboratory in 2022) is slated to launch in October.

JPL-CALTECH/NASA

ESSAY



Disorder Reigns

200 years on, the second law of thermodynamics remains solid — yet mysterious **By Tom Siegfried**

SAM GREEN

Once an egg is cracked, you can't put it back together, a phenomenon that may be explained by the second law of thermodynamics.

In real life, laws are broken all the time. Besides your everyday criminals, there are scammers and fraudsters, politicians and mobsters, corporations and nations that regard laws as suggestions rather than restrictions.

It's not that way in physics.

For centuries, physicists have been identifying laws of nature that are invariably unbreakable. Those laws govern matter, motion, electricity and gravity, and nearly every other known physical process. Nature's laws are at the root of everything from the weather to nuclear weaponry.

Most of those laws are pretty well understood, at least by the experts who study and use them. But one remains mysterious.

It is widely cited as inviolable and acclaimed as applicable to everything. It guides the functioning of machines, life and the universe as a whole. Yet scientists cannot settle on one clear way of expressing it, and its underlying foundation has evaded explanation — attempts to prove it rigorously have failed. It's known as the second law of thermodynamics. Or quite commonly, just the Second Law.

In common (oversimplified) terms, the Second Law asserts that heat flows from hot to cold. Or that doing work always produces waste heat. Or that order succumbs to disorder. Its technical definition has been more difficult to phrase, despite many attempts. As 20th century physicist Percy Bridgman once wrote, "There have been nearly as many formulations of the second law as there have been discussions of it."

This month, the Second Law celebrates its 200th birthday. It emerged from the efforts of French engineer Sadi Carnot to figure out the physics of steam engines. It became the bedrock of understanding the role of heat in all natural processes. But not right away. Two decades passed before physicists began to realize the significance of Carnot's discovery.

By the early 20th century, though, the Second Law was recognized in the eyes of some as the premier law of physical science. It holds "the supreme position among the laws of Nature," British astrophysicist Arthur Stanley Eddington declared in the 1920s. "If your theory is found to be against the second law of thermodynamics I can give you no hope; there is nothing for it but to collapse in deepest humiliation."

"If your theory is found to be against the second law of thermodynamics I can give you no hope; there is nothing for it but to collapse in deepest humiliation."
ARTHUR STANLEY EDDINGTON

In the two centuries since its birth, the Second Law has proved equally valuable for technological progress and fundamental science. It underlies everyday processes from cooling coffee to air conditioning and heating. It explains the physics of energy production in power plants and energy consumption in cars. It's essential to understanding chemical reactions. It forecasts the "heat death of the universe" and plays a key role in answering why time flows in one direction.

But in the beginning, it was all about how to build a better steam engine.

Through his studies of heat engines, French engineer Sadi Carnot introduced the second law of thermodynamics in 1824. It would take another two decades for physicists to recognize his work's significance.

COURTESY OF SCIENCE HISTORY INSTITUTE

A lone genius

Nicolas Léonard Sadi Carnot was born in 1796, son of a well-known French engineer and government official named Lazare Carnot. It was a turbulent time in France, and Sadi's father soon found himself on the wrong side of prevailing politics. Lazare went into exile in Switzerland (and later Germany), while Sadi's mother took her baby to a small town in northern France. Eventually power in France shifted and Lazare returned, aided by a previous relationship with Napoleon Bonaparte. (At one time, Napoleon's wife even babysat little Sadi.)

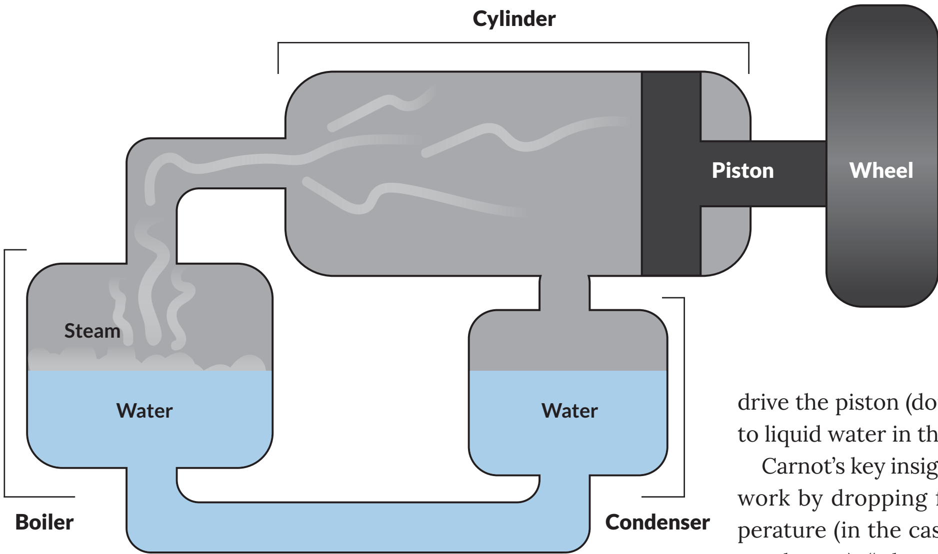
A biography written by Sadi's younger brother, Hippolyte, described him as of delicate constitution, compensated for by vigorous exercise. He was energetic but something of a loner, reserved almost to the point of rudeness. But from a young age, he also exhibited intense intellectual curiosity, ultimately maturing into undeniable genius.

By age 16, Sadi was ready to begin higher education in Paris at the famed École Polytechnique (having already been well-trained by his father in math, physics and languages). Subsequent education included mechanics, chemistry and military engineering. During this time, he began writing scientific papers (that have not survived).

After service as a military engineer, Carnot moved back to Paris in 1819 to focus on science. He attended further college courses, including one dealing with steam engines, amplifying his longtime interest in industrial and engineering processes. Soon he began composing a treatise on the physics of heat engines in which he, for the first time, deduced the underlying scientific principles governing the production of useful energy from heat. Published on June 12, 1824, Carnot's *Reflections on the Motive Power of Heat* marked the world's first glimpse of the second law of thermodynamics.

"He was able to successfully show that there was a theoretical maximum efficiency for a heat engine, that depended only on the temperatures of its hot and cold reservoirs of heat," computer scientist Stephen Wolfram wrote in a recent survey of the Second Law's history. "In the setup Carnot constructed he basically ended up introducing the Second Law."

Carnot had studied the steam engine's use in 18th century England and its role in powering the Industrial Revolution. Steam engines had become the dominant machines in society, with enormous importance for industry and commerce. "They seem destined to produce a great revolution in the civilized world," Carnot observed. "Already the steam-engine works our mines, impels our ships, excavates our ports and our rivers, forges iron,



A simple engine In the type of system Sadi Carnot studied, water is converted into steam in a boiler. That steam drives a piston, which can in turn drive a wheel, to get work out. The steam cools into liquid water in the condenser. Carnot's key insight was that heat is not consumed in the process but produces work by moving from a hot region (the boiler) to a cold region (the condenser).

fashions wood, grinds grain, spins and weaves our cloths...."

Despite the societal importance of steam engines, Carnot noted, not much was known of the physical principles governing their conversion of heat into work. "Their theory is very little understood," he wrote, "and the attempts to improve them are still directed almost by chance." Improving steam engines, he decided, required a more general understanding of heat, apart from any particular properties of steam itself. So he investigated how all heat engines worked regardless of what substance was used to carry the heat.

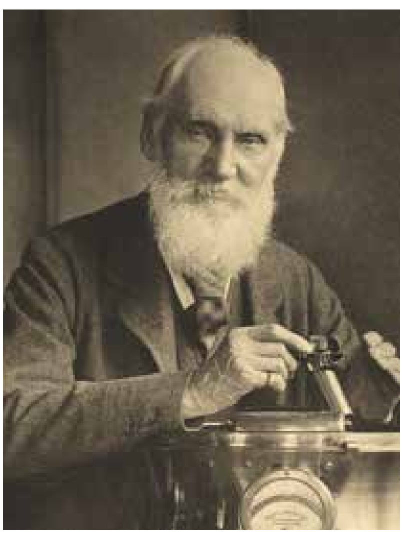
In those days, heat was commonly believed to be a fluid substance, called caloric, that flowed between bodies. Carnot adopted that view and traced the flow of caloric in an idealized engine consisting of a cylinder and piston, a boiler and a condenser. An appropriate fluid (say water) could be converted to steam in the boiler, the steam could expand in the cylinder to drive the piston (doing work), and the steam could be restored to liquid water in the condenser.

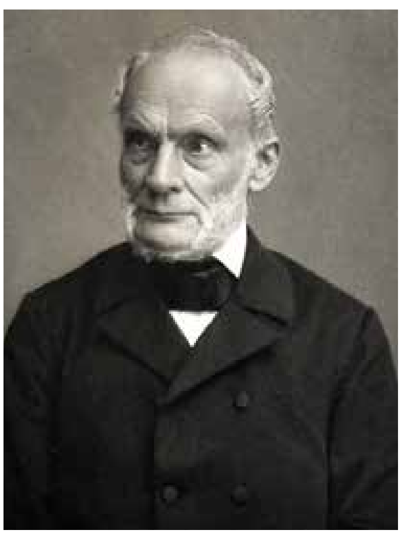
Carnot's key insight was that heat produced motion for doing work by dropping from a high temperature to a lower temperature (in the case of steam engines, from the boiler to the condenser). "The production of motive power is then due in steam-engines not to an actual consumption of caloric, but to its transportation from a warm body to a cold body," he wrote.

His evaluation of this process, now known as the Carnot cycle, held the key to calculating the maximum efficiency possible for any engine — that is, how much work could be produced from the heat. And it turned out that you can never transform all the heat into work, a major consequence of the Second Law.

Carnot's belief in caloric, of course, was erroneous. Heat is a manifestation of the motion of molecules. Nevertheless his findings remained correct — the Second Law applies no matter what substance an engine uses or what the actual underlying nature of heat is. Maybe that's what Einstein had in mind when he called thermodynamics the scientific achievement most likely to stand firm as further advances rewrote humankind's knowledge of the cosmos.

Within the realm of applicability of its basic concepts, Einstein wrote, thermodynamics "is the only physical theory of universal content concerning which I am convinced ... will never be overthrown."





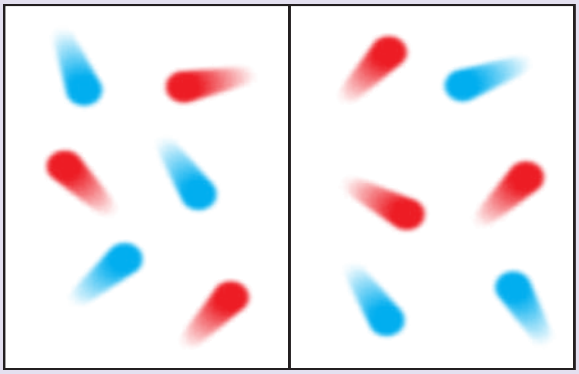
In the decades after Sadi Carnot's death, physicists Lord Kelvin (left) and Rudolf Clausius (right) came up with their own but equivalent ways of expressing the Second Law.

CLOCKWISE FROM TOP: T. TIBITTS; ARMIN KÜBELBECK/WIKIMEDIA COMMONS; T. & R. ANNAN & SONS/SCOTTISH NATIONAL PORTRAIT GALLERY

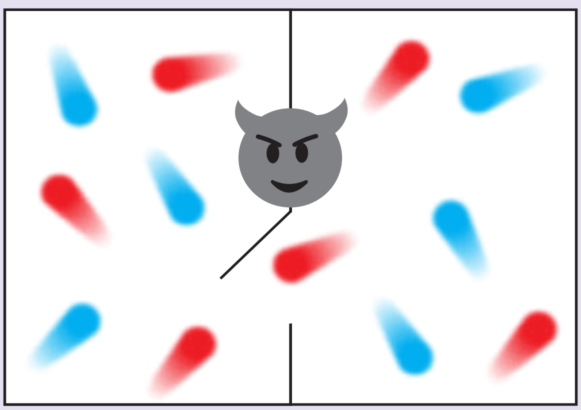
Heat death and more

Although Carnot's book received at least one positive review (in the French periodical *Revue Encyclopédique*), it went largely unnoticed by the scientific world. Carnot published no more and died of cholera in 1832. Two years later, though, French engineer Émile Clapeyron wrote a paper summarizing Carnot's work, making it accessible to a broader audience. A decade later, British physicist William Thomson — later to become Lord Kelvin — encountered Clapeyron's paper; Kelvin soon established that the core of Carnot's conclusions survived unscathed even when the caloric theory was replaced by the new realization that heat was actually the motion of molecules.

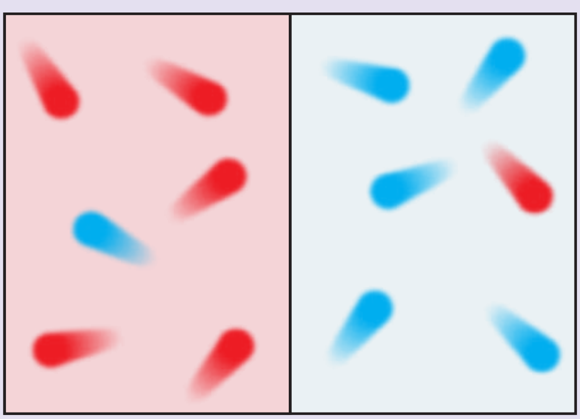
Demon at the door In a famous thought experiment, physicist James Clerk Maxwell proposed that a hypothetical being — now called Maxwell's demon — could separate fast-moving "hot" molecules from slow-moving "cold" molecules, creating a temperature difference in apparent violation of the second law of thermodynamics. Later work suggested that this demon cannot really break the Second Law.



The thought experiment begins with two compartments of gas at the same temperature. Both have a mix of fast-moving (red) and slow-moving (blue) molecules.



A hypothetical being selectively opens a door between the compartments to let the fast molecules pass one way and the slow molecules pass the other way.



That effort would make the gas in one chamber hotter, a temperature difference that could now be used to do work.

T. TIBBITTS

Around the same time, German physicist Rudolf Clausius formulated an early explicit statement of the Second Law: An isolated machine, without external input, cannot convey heat from one body to another at a higher temperature. Independently, Kelvin soon issued a similar conclusion: No part of matter could do work by cooling itself below the temperature of the coldest surrounding objects. Each statement could be deduced from the other, so Kelvin's and Clausius' views were equivalent expressions of the Second Law.

It became known as the Second Law because during this time, other work had established the law of conservation of energy, designated the first law of thermodynamics. Conservation of energy merely meant that the amount of energy involved in physical processes remained constant (in other words, energy could be neither created nor destroyed). But the Second Law was more complicated. Total energy stays the same but it cannot all be converted to work — some of that energy is dissipated as waste heat, useless for doing any more work.

"There is an absolute waste of mechanical energy available to man when heat is allowed to pass from one body to another at a lower temperature," Kelvin wrote.

Kelvin recognized that this dissipation of energy into waste heat suggested a bleak future for the universe. Citing Kelvin, German physicist Hermann von Helmholtz later observed that eventually all the useful energy would become useless. Everything in the cosmos would then converge on the same temperature. With no temperature differences, no further work could be performed and all natural processes would cease. "In short," von Helmholtz declared, "the universe from that time forward would be condemned to a state of eternal rest."

Fortunately, this "heat death of the universe" would not arrive until eons into the future.

In the meantime, Clausius introduced the concept of entropy to quantify the transformation of useful energy into useless waste heat — providing yet another way of expressing the Second Law. If the First Law can be stated as "the energy of the universe is constant," he wrote in 1865, then the Second Law could be stated as "the entropy of the universe tends to a maximum."

Entropy, roughly, means disorder. Left to itself, an orderly system will degenerate into a disorderly mess. More technically, temperature differences in a system will tend to equalize until the system reaches equilibrium, at a constant temperature.

From another perspective, entropy refers to how probable the state of a system is. A low-entropy, ordered system is in a state of low probability, because there are many more ways to be disordered than ordered. Messier states, with higher entropy, are much more probable. So entropy is always likely to increase — or at least stay the same in systems where molecular motion has already reached equilibrium.

Bringing probability into the picture suggested that it would be impossible to prove the Second Law from analyzing the motions of individual molecules. It was necessary instead to study statistical measures that described large numbers of molecules in motion. Work along these lines by physicists James Clerk Maxwell, Ludwig Boltzmann and J. Willard Gibbs generated the science of statistical mechanics, the math describing large-scale properties of matter based on the statistical interactions of its molecules.

Maxwell concluded that the Second Law itself must possess merely statistical validity, meaning it was true only because it described the most probable of processes. In other words, it was not impossible (though unlikely) that cold could flow to hot. He illustrated his point by inventing a hypothetical little guy (he called it a "being"; Kelvin called it a demon) that could operate a tiny door between two chambers of gas. By allowing only slow molecules to pass one way and fast molecules the other, the demon could make one chamber hotter and the other colder, violating the Second Law.

But in the 1960s, IBM physicist Rolf Landauer showed that erasing information inevitably produces waste heat. Later his IBM colleague Charles Bennett pointed out that a Maxwell demon would need to record molecular velocities in order to know when to open and shut the door. Without an infinite memory, the demon would eventually have to erase those records, preserving the Second Law.

Another enigmatic issue emerging from studies of the Second Law involved its connection to the direction of time.

Laws governing molecular motion do not distinguish between future and past — a video of molecular collisions running backward shows them observing the same laws as a video moving forward. Yet in real life, unlike science fiction stories, time always flows forward.

It seems logical to suggest that time's arrow was aimed by the Second Law's requirement of increasing entropy. But the Second Law cannot explain why entropy in the universe has not already reached a maximum. Many scientists today believe time's arrow cannot be explained by the Second Law alone, but also must have something to do with the origin of the universe and its expansion following the Big Bang. For some reason, entropy must have been low at the beginning, but why remains a mystery.

No proof yet

In his history of the Second Law, Wolfram recounts the many past efforts to provide the Second Law with a firm mathematical foundation. None have succeeded. "By the end of the 1800s … the Second Law began to often be treated as an almost-mathematically-proven necessary law of physics," Wolfram wrote. But there were always weak links in the mathematical chain of reasoning. Despite the common belief that "somehow it must all have been worked out," he commented, his survey showed that "no, it hasn't all been worked out."

Some recent efforts to verify the Second Law invoke Landauer's emphasis on erasing information, which links the Second Law to information theory. In a recent paper, Shintaro Minagawa of Nagoya University in Japan and colleagues assert that merging the Second Law with information theory can secure the law's foundation.

"The second law of information thermodynamics," they write, "can now be considered a universally valid law of physics."

In another information-related approach, Wolfram concludes that the Second Law's confirmation can be found in principles governing computation. The Second Law's basis, he says, is rooted in the fact that simple computational rules can produce elaborately complicated results, a principle he calls computational irreducibility.

While many researchers have sought proofs of the Second Law, others have repeatedly challenged it with attempts to contradict its universal validity (*SN: 3/19/16, p. 18; SN: 8/19/17, p. 14*). But a 2020 review in the journal *Entropy* concludes that no such challenges to the Second Law have yet succeeded. "In fact, all resolved challengers' paradoxes and misleading violations of the Second Law to date have been resolved in favor of the Second Law and never against," wrote thermodynamicist Milivoje M. Kostic of Northern Illinois University in DeKalb. "We are still to witness a single, still open Second Law violation, to be confirmed."

Whether the Second Law is in fact universally true remains unsettled. Perhaps resolving that question will require a better definition of the law itself.

Yet whether the Second Law is in fact universally true remains unsettled. Perhaps resolving that question will require a better definition of the law itself. Variations of Clausius' statement that entropy tends to a maximum are often given as the Second Law's definition. But the physicist Richard Feynman found that unsatisfactory. He preferred "a process whose only net result is to take heat from a reservoir and convert it to work is impossible."

When the Second Law was born, Carnot simply described it without defining it. Perhaps he knew it was too soon. He did, after all, realize that the future would bring new insights into the nature of heat. In unpublished work preserved in personal papers, he deduced the equivalence between heat and mechanical motion — the essence of what would become the first law of thermodynamics. And he foresaw that the caloric theory would probably turn out to be wrong. He cited experimental facts "tending to destroy" caloric theory. "Heat is simply motive power, or rather motion which has changed form," he wrote. "It is a movement among the particles of bodies."

Carnot planned to do experiments testing these ideas, but death intervened, one of nature's two (along with taxes) inviolable certainties. Maybe the Second Law is a third.

But whether the Second Law is inviolable or not, it will forever be true that human laws will be a lot easier to break. ■

Explore more

- Stephen Wolfram. "How did we get here? The tangled history of the second law of thermodynamics." January 31, 2023. bit.ly/SN_SecondLaw

Rain Bosworth (left) has found that babies have an innate sensitivity to sign language.

Primed to sign

Experimental psychologist Rain Bosworth studies how deaf children experience the world

By Meghan Rosen

In a darkened room in Rochester, N.Y., a baby girl in a pink onesie peers at a computer screen. Wherever she looks, an eye tracker follows, recording her gaze patterns for future analysis. The baby, about 6 months old, is neither deaf nor hard of hearing. And she's never been exposed to sign language of any sort. But somehow, she and others her age can tell the difference between gestures and formal signs. When a woman on-screen uses American Sign Language, these young babies

MIKE GUINTO

tend to pay attention, locking their eyes on her hands. When she makes non-sign gestures, babies often look at her face instead or look away.

"I thought it was pretty remarkable," says experimental psychologist Rain Bosworth of the Rochester Institute of Technology. Her team reported the results in 2022 in *Frontiers in Psychology*. The work suggests that babies have an innate sensitivity to sign language.

That idea — that infants are primed to pick up any language, whether spoken or signed — can be hard for people to believe, she says. After all, we live in a hearing-centric world. "There is a bias to think of spoken language as somehow superior to signed language." But that's just not true, she says. "Sign language is a full and real language, just as powerful as English."

Bosworth investigates how people learn and process sign language through studies on deaf and hearing people's use of vision and touch. With this and other research, she aims to understand how early sensory input — like seeing parents use sign language or hearing scientific jargon spoken at home — shapes our development.

In 2022, after three years at RIT's National Technical Institute for the Deaf, Bosworth established a new research lab there, PLAY Lab (for Perception, Language and Attention in Youth). She's passionate about reframing negative perceptions of sign language and deaf people. Deaf herself, Bosworth feels she's the right person to come up with study questions, she tells me via interpreters on Zoom. "I think about science nonstop 24/7."

Bosworth's career is a testament to her tenacity, says Karen Emmorey, a cognitive neuroscientist at San Diego State University. Deaf researchers can face challenges hearing people may never consider, like being asked to arrange interpreters for lectures, meetings, social events — and interviews. But Bosworth is stubborn, Emmorey says. "She's going to persevere and do what she needs to do to succeed."

The window for language learning

The vast majority of deaf kids in the United States — more than 90 percent — have parents who can hear. Even today, it is not uncommon for audiologists and physicians to advise these parents to avoid sign language, Bosworth says. Instead, kids are encouraged to use cochlear implants and read lips. There's this incorrect thought that sign language will impair speech development, she says. Recent evidence actually suggests that learning sign language may boost a child's spoken vocabulary.

Bosworth was born in San Francisco to hearing parents and grew up in Los Angeles. Sign language was prohibited at her school, so her first brush with it came on the school bus, when she was 6 or 7 years old. She and other deaf kids made up their own signs to communicate. That cracked the door to a rich new world of visual language, and a friend she met in high school kicked the door wide open. Bosworth's friend was deaf and so were her parents and siblings. "I was like, 'This is the best thing I've ever seen,'" she remembers thinking.

She sees reminders of that experience in students who come to the National Technical Institute for the Deaf for the first time. The institute serves more than 1,100 deaf and hard-of-hearing students, and in classrooms, laboratories and public spaces, students, faculty and staff use sign language. Many students who come to NTID were the only deaf people in their schools, Bosworth says, and have experienced isolation and barriers to learning. When they arrive, "they're definitely on cloud nine," she says. "This is like a second home to them."

It's a second home for Bosworth too, a place where she can unspool her curiosity and let it fly. There's a strong inclusive mentality that she's proud to contribute to. "I'm able to be a role model to all of these students of what a deaf person can do."

Bosworth's research is filling in a more complete picture of how deaf and hearing kids acquire language — and how that process changes as children grow and take in new information, says Jenny Singleton, a linguist at Stony Brook University in New York. For instance, Bosworth has shown that, around 1 year of age, all hearing non-signing

UNSUNG CHARACTERS

This article is part of a *Science News* series highlighting people of science — past and present — who we believe should be better known. Watch for more of these stories, and send your ideas to editors@sciencenews.org

By tracking infants' gaze patterns (red dots) as they look at a computer screen, researchers can figure out what captures their attention. Infants around 6 months old, for example, tend to lock their eyes on the hands of people using American Sign Language. When people are making non-sign gestures, babies tend to look elsewhere.

R. BOSWORTH LAB

At an event at the National Technical Institute for the Deaf's PLAY Lab, Rain Bosworth teaches children in the community about the brain.

MATTHEW SLUKA

babies tend to lose their innate ability to discriminate between signs and gestures. Her team has also found that these older babies no longer pay special attention to certain types of fingerspelled words.

Both results suggest that the window for learning sign language closes somewhat with age, similar to spoken languages.

Bosworth's work builds on a foundation established early in her career. As a graduate student at the University of California, San Diego, she examined the visual abilities of deaf adults. She's melding tools and methods of inquiry from two fields, linguistics and visual perception, "in a really impressive way," Singleton says.

Beyond the window for language learning, Bosworth is also investigating how kids explore the world and how they play. How does a child's background and hearing status influence their behaviors? Do deaf kids rely on their sense of touch more than hearing kids? Do specific types of play affect how children learn language?

A need for more deaf role models

For Bosworth, it's not enough to make scientific strides in a field dominated by hearing people. She wants to bring deaf people along with her by mentoring students. "I want them to get on this research bus with me," she says.

Over time, she hopes for more deaf role models in academia and more research that, like her own, casts deaf people in a positive light by highlighting their strengths rather than looking for deficits.

In grade school, Savannah Tellander, a graduate student in Bosworth's lab who is hard of hearing, sometimes felt as if teachers assumed she wasn't as smart as other kids. "They would usually doubt me before they ever met me," she says. Those kinds of experiences are part of what drew her to Bosworth's lab — along with an interest in helping people understand how to support deaf kids' cognition and language. And she was impressed from the get-go with Bosworth's zest for mentoring.

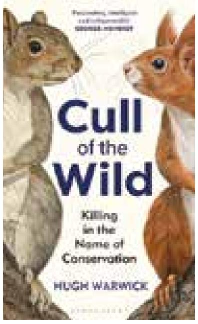
Tellander remembers meeting Bosworth upon arriving at NTID, after moving from California with no friends or family nearby. Bosworth's eyes lit up talking about her own experiences with her adviser. "She was really, really excited to be a mentor," Tellander says.

Bosworth is one of those people who shows up, she says. On any given day, you may find her helping students write a research proposal, teaching them how to make a poster or finding time outside of work to attend a colleague's art show. "She supports the hell out of people."

It's important to Bosworth that deaf students know that, despite what the world may tell them, they have their own strengths and can lead successful lives. "I see deafness as a life experience that shapes who we are just like any other cultural experience," Bosworth says. "I think that being deaf is wonderful." ■

Explore more

- Rain G. Bosworth, So One Hwang and David P. Corina. "Visual attention for linguistic and non-linguistic body actions in non-signing and native signing children." *Frontiers in Psychology*. September 8, 2022.



Cull of the Wild
Hugh Warwick
BLOOMSBURY WILDLIFE, $28

BOOKSHELF

Sacrificing wildlife in the name of conservation

In the late 1860s, European colonists started importing hedgehogs into New Zealand. The goal: to make the unfamiliar landscape feel a bit more like home. Over the next 100 years, hedgehogs settled in most of New Zealand's available habitat — and developed a taste for native bird eggs, lizards and invertebrates. Now, the hedgehogs are among the millions of animals killed worldwide each year in culls intended to protect vulnerable species and habitats. Some say culling is essential to conservation; others say it robs animals of their right to live.

But for ecologist Hugh Warwick, the nuances of culling further complicate the already complex nature of conservation. In his latest book, *Cull of the Wild*, Warwick attempts to mediate between the wide-ranging approaches to culling. Part travel memoir, part philosophical treatise, *Cull of the Wild* is an honest, surprisingly tame read that asks hard questions of its sources, author and audience. "The essence of science is not that it knows everything, but that it continually challenges everything," Warwick writes. "It is not just what we think, but how we think that needs challenging."

Warwick opens the book ready to do just that, laying out his prejudices as an ecologist, hedgehog expert and someone who is "vaguely vegan." Though a bit winding, the resulting 300-page quest finds the author readily challenging these biases. Whether he's interviewing a gamekeeper or diving into animal ethics, Warwick eagerly searches for middle ground in the ongoing battle that is wildlife management.

The ecologist recruits an eclectic crew to highlight this middle ground. There's Mike Swan, senior adviser to the Game & Wildlife Conservation Trust, who takes Warwick on a tour of the estate he manages for game bird shoots in Dorset, England. Swan culls foxes and crows to boost pheasant and partridge numbers for hunters. While Warwick is not a fan of hunting or culling, he recognizes Swan's passion for nature, mind for conservation and desire to find humane ways to keep bird predators in check. Warwick also interviews Monica Engel, a conservationist from Brazil who earns a seal hunting license to better understand Canadian seal hunters and, in turn, natural resource management. "When I am out there, listening, I find it so sad that the hunters and the animal rights activists enter into this debate with often so much hate," Engel tells Warwick. "It drowns out moderate voices, it stops progress."

In New Zealand, hedgehogs, like this one in Auckland, are invasive predators that hunt bird eggs, lizards and invertebrates. To protect native species, some conservationists support culling hedgehogs.

YOSUKE TANAKA/ISTOCK/GETTY IMAGES PLUS

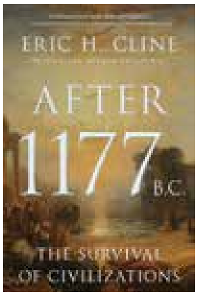
These sources and their views make for the book's most interesting parts. In one chapter, Warwick meets Tony Martin of the Waterlife Recovery Trust in East Anglia, England. Martin tracks American mink, imported into the British Isles in 1929 for the prized fur. Mink from fur farms soon started popping up in the British countryside; mink now prey on multiple riverside species, including the water vole, a rat-sized rodent already declining due to habitat loss. Using an armada of 800 floating traps, Martin's team works to save the native species by culling this elusive predator.

These "mink rafts" are live traps; the mink are later euthanized with an air pistol. Though gruesome, Martin's approach has hints of compassion; he refuses to cull mink on England's islands for fear that they'd starve to death in traps before anyone could collect them. He coauthored a 2020 paper outlining essential questions that ensure exterminations aren't needlessly drawn out or doomed to fail. "I don't enjoy killing animals," says Martin, whose father ran a mink farm. "And if there was another way to restore our riparian ecosystems without killing mink, then I would be all for it. But until then, it is important that we do it as humanely as possible."

While much of the book focuses on species found in Warwick's native United Kingdom, his pondering takes readers from a fenced-in preserve in New Zealand to the mouse-infested bird colonies of Gough Island in the South Atlantic.

Warwick also touches on famous characters in the invasive species saga: Australia's toxic cane toads, Burmese python escapees in the Florida Everglades, the "cocaine hippos" of Columbian drug trafficker Pablo Escobar. In many cases, eradication is either unfeasible or met with public opposition.

Though culling is about invasive and native troublemakers, much of *Cull of the Wild* concerns itself with human exceptionalism. Dubbing us *Homo occisor*, or "man the killer," Warwick likens humankind to "a fox in the chicken coop, instinctively driving the livable planet towards destruction." Warwick reminds us that we often play "judge, jury and executioner — or at least supporters of those that are" when dealing with introduced species or damaged ecosystems. But to "play god" in the 21st century, Warwick warns, requires us to examine our prejudices about animal suffering and our motivations behind culling. "In its simplest form, this is head-versus-heart territory." — *Aaron Tremper*



After 1177 B.C.
Eric H. Cline
PRINCETON UNIV., $32

BOOKSHELF

How societies thrived, survived or died when the Bronze Age ended

A toxic brew of calamities that included drought, earthquakes, famine, disease and invasion undermined civilizations across the Eastern Mediterranean and Near East about 3,200 years ago. But that Late Bronze Age collapse was not a one-size-hits-all event. Archaeologist Eric H. Cline sees it as a complicated tragedy and transition, with only some societies vanishing. Others took hard hits but rebounded after a few centuries or muddled through a progressive decline in power. Certain societies adapted to a new world, or even transformed and prospered amid chaos.

In *After 1177 B.C.*, Cline consults ancient inscriptions written on stone, clay, papyrus and more, along with other artifacts and excavated sites, to outline the many ways major Bronze Age societies responded to tumultuous times. Their divergent trajectories during the Iron Age that followed — what researchers mistakenly called a dark age until the 1980s — hold lessons for people today, Cline writes.

Anyone concerned with avoiding the end of the world as we know it might be especially interested in the societies that flourished in the wake of the Late Bronze Age collapse. Cline regards those success stories as exhibiting what Nassim Nicholas Taleb, a risk analyst, has called antifragility, an ability to get stronger in the face of disorder.

The Late Bronze Age collapse was not a one-size-hits-all event.

For instance, Central Canaanite people in coastal Middle Eastern cities, now known as Phoenicians, took over major Mediterranean maritime trade routes after the sacking of formerly dominant port cities. Though trade opportunities diminished, Phoenician mariners still exchanged goods, including a popular purple dye, for silver and other metals from Sicily, Sardinia and Iberia. As their trade ties grew, Phoenicians spread an alphabetic system that formed the basis of written English and many other modern languages.

Cline discusses growing evidence for similar victories on Cyprus. People there established towns and governments in new areas as drought-related soil erosion caused silt to fill formerly busy harbors. Evidence indicates that bronze metalworkers in Cyprus pioneered technical innovations that led to a region-wide iron industry.

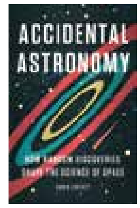
Among the characteristics of resilient societies: multiple contingency plans for extreme weather events and other emergencies, solid defenses against enemy attacks, dependable water resources and a happy working class. But for others, the Late Bronze Age collapse exposed weaknesses ranging from manageable to fatal.

Egyptian civilization "was never the same again," Cline writes. Egypt's power and status in international trade declined, as did the standard of living for average folks, he suggests. Mycenaean society on mainland Greece proved especially fragile, vanishing by about 3,200 years ago. But Greeks who survived slowly remade their culture and society, Cline argues. Pottery styles, burial customs and house types were developed from former Mycenaean practices. After a couple hundred years, this cultural reclamation project prompted the rise of Archaic and then Classical Greece, Cline suspects.

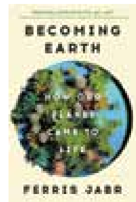
Amid limited records and plenty of academic debate, Cline provides a thought-provoking introduction to current thinking about the Late Bronze Age. He acknowledges that scholars won't always agree with his views. And though multisyllabic names of ancient kings pile up quickly — an unavoidable consequence of chronicling royal successions in unstable times — a helpful list of rulers and officials appears at the end.

As hard as it is to revive the past, predicting the future is even harder. Cline can't answer whether our civilization, in the face of modern threats, will go the way of the Phoenicians or the Mycenaeans. — *Bruce Bower*

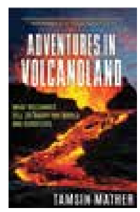
BOOKSHELF



Accidental Astronomy
Chris Lintott
This anecdote-packed exploration of space discoveries highlights the role of serendipity in astronomy. *Basic Books, $30*

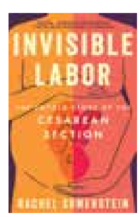


Becoming Earth
Ferris Jabr
Life doesn't just exist on Earth; it's actively transforming the planet, a journalist explains in this review of how everything from microbes to mammals alters the atmosphere, continents and more. *Random House, $30*



Adventures in Volcanoland
Tamsin Mather
A geochemist brings readers along on a trek to volcanoes around the world, mixing in science and culture along the way. *Hanover Square Press, $32.99*

One Step Sideways, Three Steps Forward
Rosemary Grant
The famed biologist shares her unlikely career path to becoming one of the world's leading experts on the evolution of Darwin's finches in the Galápagos. *Princeton Univ., $29.95*



Invisible Labor
Rachel Somerstein
After experiencing a difficult cesarean section, the author dives deep into the history of this surgery and the consequences of the procedure today. *Ecco, $32*

SOCIETY UPDATE

STEM TALENT STARTS WITH TEACHERS

Society for Science is committed to supporting teachers as they shape the next generation of STEM innovators. Through our STEM Research Grants program, we are proud to provide grants to middle and high school educators guiding students in pursuing original scientific research. Participating teachers receive specialized kits of equipment to support research on a wide variety of topics, from soil analysis to the fundamentals of programming. Teachers can also request up to $5,000 to purchase materials of their choosing.

With a goal of expanding research opportunities for all young people, priority consideration is given to educators who serve students from low-income communities, including those from underrepresented and underserved backgrounds.

Since 2017, the Society has distributed over $885,000 of funding to 697 educators representing all 50 states, Washington, D.C., American Samoa, Guam, Northern Mariana Islands, Puerto Rico, Mexico, Peru and Uruguay.

> “Students can be limited in what they can research for their science fair projects. Now, my students have the resources and equipment at their fingertips to investigate and explore their world.”
>
> **NATASHA RABINOWITZ**
>
> STEM Research Grants recipient; educator at Central High School in Phenix City, Ala.

Learn more about the STEM Research Grants program and apply for a grant:
www.societyforscience.org/stem-research-grants

SOCIETY FOR SCIENCE

APRIL 20, 2024

SOCIAL MEDIA

Clever canines

Brain activity suggests dogs can recognize nouns and create mental concepts of everyday objects, **Laura Sanders** reported in "Dogs know words for specific toys" (*SN: 4/20/24, p. 11*). Many readers who have dogs were not surprised. X user **@AnEnigmaDave** wrote: "Both our dogs knew the names of all of their toys and could find them when asked. [One] figured out I was trainable after she made a petting motion with her paw and I complied. She taught me many request gestures after that epiphany."

GRZEGORZ ELIASIEWICZ

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Let's face it

Scientists re-created the demonic distortions that a patient with prosopometamorphopsia, or PMO, sees when looking at faces, ***Anna Gibbs*** *reported in "Here's what faces can look like to people with a rare visual disorder" (*SN: 4/20/24, p. 32*).*

Reader **John Henderson** asked whether research on facial blindness could help scientists better understand PMO.

The two disorders have been linked to similar regions in the brain, including the right occipital lobe and fusiform face area, says neurologist **Jason Barton** of the University of British Columbia in Vancouver. So studying one disorder could help illuminate the other.

Henderson also found it interesting that people's faces but not necessarily their hair are distorted in PMO.

The brain may process faces and hair using different mechanisms, say **Brad Duchaine** and **Antônio Mello**, neuropsychologists at Dartmouth College. They point to a 1997 paper about a patient who suffered brain damage that left him unable to recognize objects. The injury did not affect his recognition of the internal face — the region containing the eyes, nose and mouth — but did impair his ability to identify people from their hair and other external facial features.

Reader **Gary Wilson** asked if there are disorders that distort senses other than vision.

Absolutely. In addition to distorting vision so that objects look too large, too small or warped, Alice in Wonderland syndrome can affect how a person senses time or feels their own body, **Barton** says.

There are also common sensory distortions like tinnitus in the ear, **Duchaine** and **Mello** say. And some psychiatric disorders, such as schizophrenia, can induce auditory hallucinations.

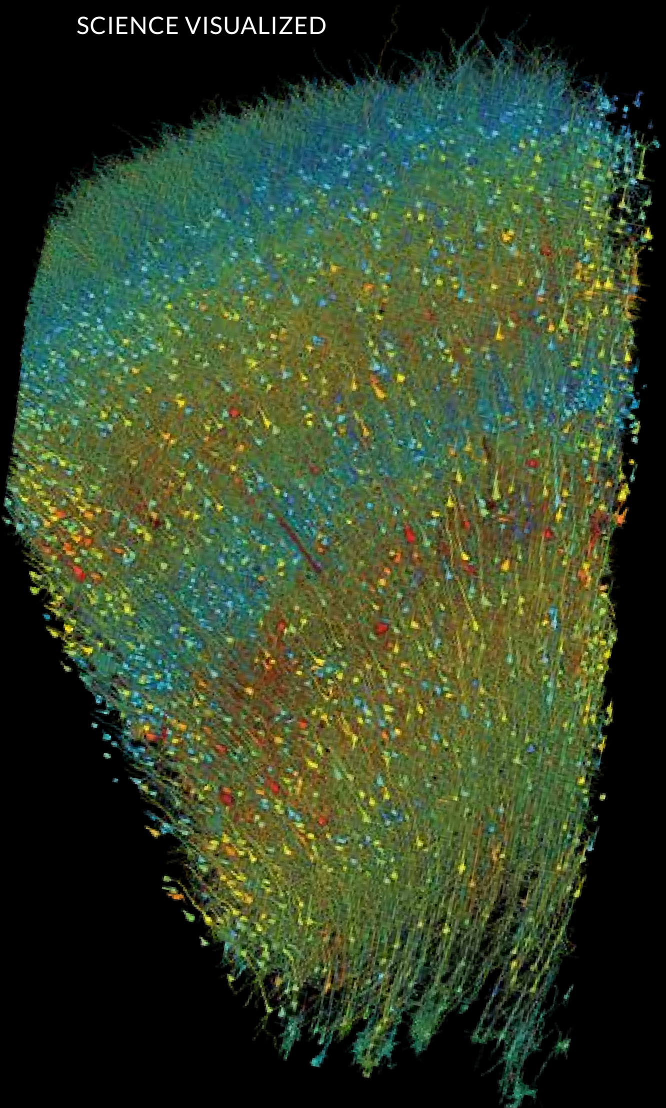
Microplastic perils

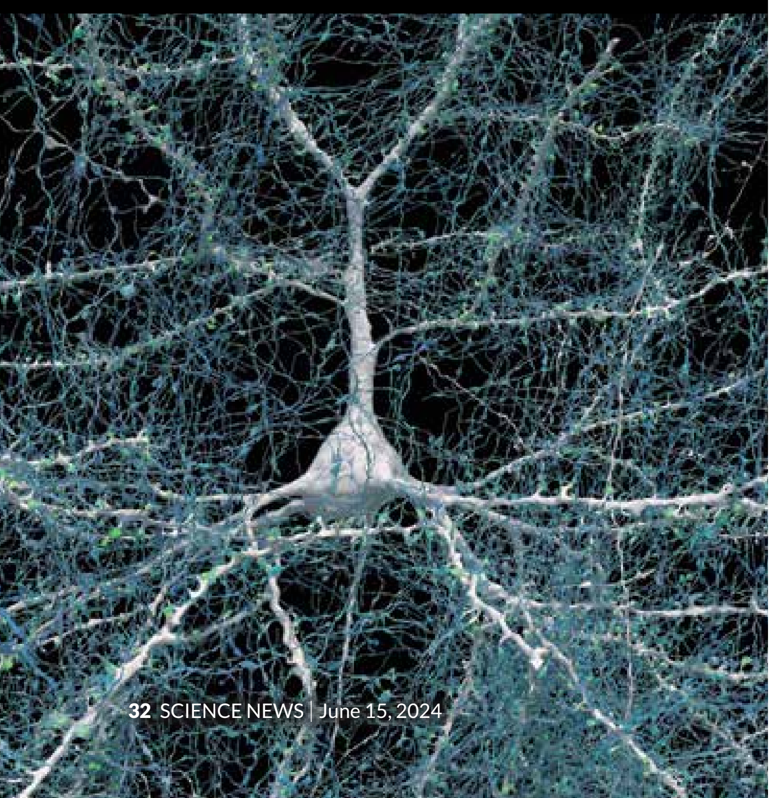
Patients with microplastics in their arteries had a roughly quadrupled risk of heart attack, stroke or death, ***Meghan Rosen*** *reported in "Tiny plastics turn up in arterial clogs" (*SN: 4/20/24, p. 6*).*

Microplastics form when plastics in the environment break down over time. Reader **Eric E. Sabelman** wondered whether medical equipment made with plastic, such as some hip prostheses or IV bags and tubes, could shed microplastics within the body.

This is very likely, says **Laurens Mandemaker**, a chemist at Utrecht University in the Netherlands. Hip prostheses, for instance, undergo constant abrasive wear when the hip moves. Studies have shown that hip prostheses that consist of metal and plastic parts experience heavier wear than metal-only prostheses. Microplastics could form inside the body as those plastic parts degrade over time, he says.

What this means for health is still unclear. If microplastics pose serious, long-term health risks, scientists need to find alternative materials for such medical equipment, **Mandemaker** says. But patients who need prostheses, dialysis or blood transfusions would probably consider the risks of microplastics a lower priority than addressing an urgent and severe health problem, he says.





A peek inside a human brain

It's a bit like seeing a world in a grain of sand.

Except the view, in this case, is the exquisite detail inside a bit of human brain about half as big as a grain of rice. Held in that minuscule lump is a complex collective of cells, blood vessels, intricate patterns and biological puzzles.

Scientists had hints of these mysteries in earlier peeks at this same brain sample (*SN: 7/3/21 & 7/17/21, p. 6*). But now, the full landscape of some 57,000 cells, 150 million synapses and their accompanying 23 centimeters of blood vessels has been mapped, researchers report in the May 10 *Science*.

"We're going in and looking at every individual connection attached to every cell," says Viren Jain, a computational neuroscientist at Google Research in Mountain View, Calif. The big-picture goal of brain-mapping efforts, he says, is "to understand how human brains work and what goes wrong in various kinds of brain diseases."

The newly mapped brain sample was removed during a woman's surgery for epilepsy. The bit, donated with the woman's consent, was from her left temporal lobe. This outer region of the brain sits above the temple and helps in complex mental feats such as memory, language and thought.

After being fixed in a preservative, the brain bit was sliced into almost impossibly thin wisps, and then each slice was imaged with a high-powered microscope. Once these views were collected, researchers used computers to digitally reconstruct the 3-D components embedded in the piece of brain.

One reconstruction (top) maps out the landscape of nerve cells (colored by the size of their main cell bodies, 15 to 30 micrometers). Other renderings include intricate details, such as a single nerve cell (bottom, white) with thousands of axons (blue) coming in from other cells and making synapses (green).

Some sights were surprising. Certain pairs of nerve cells had extremely tight bonds, making 50 or more contact points with each other. "This is like if two houses in the neighborhood for some reason had 50 different phones connecting just those two houses," Jain says. "It's like, what's going on here?"

Other views revealed mysterious whorls formed by message-sending tendrils called axons. "The axon would loop in on itself and make a giant knot," Jain says. "We definitely didn't expect to see these." Scientists don't know why these swirls exist.

And some nerve cells in the deepest layer of the brain bit appear to have mirror-image twins — another mystery.

These results don't necessarily change the view of how the brain works. "It's more like, oh, we've found this new structure in nature. Maybe there's something really important about it. We'll have to study it further," Jain says.

Next up, he says, is scaling up to create a similar map for a piece of mouse brain that's 10 to 15 times the size of the piece studied. Researchers also hope to map more human brain samples. — *Laura Sanders*

GOOGLE RESEARCH AND LICHTMAN LAB/HARVARD UNIV., RENDERING BY D. BERGER/HARVARD UNIV.

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https://sos-vo.org/NSA24Puzzle