Redefining Chemical Bonds | How to Land on Europa

Science News

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The Myth of Recycling

Chemists strive to make more plastics reusable

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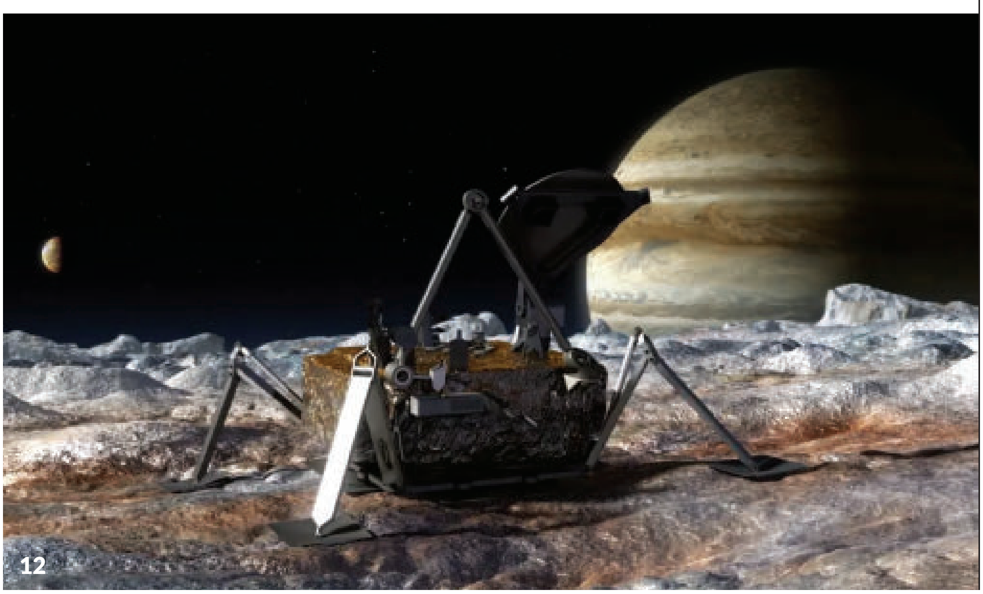
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Departments

COVER Too much of the trash that goes into the recycling bin can't be turned into new products. *Elena Feodrina/iStock/Getty Images Plus*

FROM TOP: ABDUL RAHEEM MOHAMED/EYEEM/GETTY IMAGES; STEPHANIE HIGGINS; JPL-CALTECH/NASA

When data shed light on societal challenges

In 2015, two Princeton economists published data showing that white people in their 40s and 50s in the United States were dying at much higher rates than expected — and that the death rates for that age group had been rising sharply for almost two decades. The big killers like cancer and heart disease weren't to blame. Instead, alcohol misuse, drug overdoses and suicide caused these early deaths, which the economists, Anne Case and Angus Deaton, called "deaths of despair."

I remember reading that paper and thinking it was a revelation — a dataset able to reveal something profound happening to our society that was largely hidden until this analysis. I was also moved by the phrase "deaths of despair," which casts a vision of a person being ground down by years of disappointment and struggle. People without college degrees are most affected, the study and other research shows. The reasons for their struggles are many, including the evaporation of stable manufacturing jobs and health insurance, fractured families and a lack of social supports.

This trend toward more suffering and shorter lives shows no hint of waning. In 2015, U.S. life expectancy declined for the first time in decades. Other rich countries have not experienced similar declines.

In this issue, behavioral sciences writer Bruce Bower revisits the deaths of despair hypothesis (Page 16), exploring Case and Deaton's latest research connecting despair with reports of physical pain, as well as other scientists' efforts to define despair to learn how to avoid despair-related deaths. It's a fascinating exploration of how social scientists go about testing a new construct, seeking to learn if and how despair is different than depression and other mental health diagnoses. Bower also made illuminating connections between the demoralization, grief and anger that people feel during this pandemic, as they lose friends and family, jobs and social ties.

People who feel threatened, ignored and alone are more vulnerable to conspiracy theories and misinformation. The spread of misinformation has been disastrous for our country's response to the coronavirus pandemic, with social media channels awash with misinformation about fake cures and questioning whether masks are useful (they are!). That misinformation has caused needless suffering and death. Anti-vaccine rhetoric, including false claims that the COVID-19 vaccine contains a microchip designed to track people's movements, is pushing some people to avoid vaccines, which are our best shot to end the pandemic, along with masks and social distancing. As of November, 21 percent of adults in the United States said they do not intend to get the shot, and that more information would not change their minds.

Shared facts and common truth can shed light on the challenges we face, including the pandemic and attacks on our system of government. The "deaths of despair" research is a shining example of how science can illuminate the effects of complex social and economic trends on our lives. Science can help us understand what's happening to us, and how we can build a better future. It's time to listen. *— Nancy Shute, Editor in Chief*

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Excerpt from the January 30, 1971 issue of *Science News*

50 YEARS AGO

Swamp-dweller or landlubber?

Through the years paleontologists have evolved a picture of the appearance and habits of various dinosaurs.... Giant herbivores with long necks and tails, such as the *Brontosaurus*, have almost invariably been presented as swamp-dwelling semiaquatic animals.... A young Yale University paleontologist, however, now maintains that the anatomy of the *Brontosaurus* points clearly to a life on land.

UPDATE: Debate over whether *Brontosaurus* and its fellow sauropods splashed through swamps or ambled over dry land has persisted for decades. In 1971, paleontologist Robert Bakker argued for a land-bound dinosaur, based on the resemblance of its nostrils to those of terrestrial lizards. By the late 1980s, scientists had discovered that sauropods had hollow bones. That suggested *Brontosaurus* and its kin were buoyant, though the finding did not prove the dinos swam (*SN: 4/29/89, p. 261*). Later studies of pollen and plants preserved near *Brontosaurus* fossils have shown that the dino stomped through a semiarid landscape, no floaties needed.

Big, fluffy crested rats make their own poisonous hair-care products and have unexpectedly snuggly social lives.

STEPHANIE HIGGINS

IT'S ALIVE

Rats with poison hairdos show a cuddly side

Crested rats don't just chew tree bark that's poisonous enough to kill an elephant. The rabbit-sized rodents dribble and lick the toxic drool into their long, soft rat fluff for a weaponized hairdo. Yet these dangerous rats, which scientists assumed were loners, turn out to have a close family life. They even purr.

Chewing on parts of East Africa's arrow poison trees gives the rats toxic saliva to apply to specialized zones of fur. Toxins sink into porous, easily detached hairs on a rat's flanks. Any predator foolish enough to bite a *Lophiomys imhausi* gets a hairy mouthful of bitter cardenolides, which can cause a heart attack. Human poachers use the toxin on arrows for hunting big game.

Trapping crested rats took some experimenting, says ecologist Katrina Nyawira, now at Oxford Brookes University in England. Nyawira and ecologist Sara Weinstein set traps in a weird variety of locations, from remote spots in the Kenyan savanna to behind somebody's bedroom door. They realized that the common success factor for catching rats was proximity to arrow poison trees.

The team trapped some 25 crested rats for a few days of video observation, tucking shreds of poison tree bark and roots in the cages holding the animals. Cameras caught the nocturnal rats touching up their poison hairs. Rather than luxuriate in grooming, the animals finished the poison-handling in 10 minutes or less.

Weinstein, now at the University of Utah in Salt Lake City, wondered if the animals paid some price for licking toxins: "Do they get sick and have to take a nap to sleep it off?" But the videos showed no changes in behavior after hair care. For crested rats, poison really may be just mousse. How the rats withstand the stuff is a mystery.

Weinstein hadn't planned to study crested rat home life, but one why-not whim changed that. She once reset a trap in the same place she had just caught a crested rat. Since the rats were supposedly solitary, her first catch should have emptied the territory. Yet she quickly caught a second rat. When placed next to each other, the male and female started purring: "This vocalization that we've never heard before," Weinstein says. Once in the same cage, the two groomed each other and retired to the cage's private nest box.

The researchers caught four more male-female pairs. Two pairs had youngsters, and each family snuggled together when reunited in captivity. In videos, pair members spent about half of their active time within just 15 centimeters of each other, the team reported online November 17 in the *Journal of Mammalogy*. Inside nest boxes, pairs looked even cozier bundled together in swathes of fluff "like a big scarf," Nyawira says. As Weinstein puts it: "They're super cute." *—Susan Milius*

Watch a video of crested rats at **bit.ly/SN_PoisonRats**

SCIENCE STATS

Future farming threatens thousands of species

Humankind's growing need for food is running up against thousands of other species' need for space. By 2050, humans may need to clear an additional 3.35 million square kilometers of land for agriculture. Converting these largely natural habitats, collectively about the size of India, would squeeze more than 17,000 vertebrate species from some of their lands, researchers report December 21 in *Nature Sustainability*.

David Williams, a conservation scientist at the University of Leeds in England, and colleagues calculated the amount of food needed to sustain projected human population growth for 152 countries and mapped where crops would likely be grown. By 2050, the world's 13 million square kilometers of cropland would need to increase by 26 percent. That growth is largely concentrated in sub-Saharan Africa, and South and Southeast Asia. The team then overlaid the estimates on distribution maps of nearly 20,000 species of birds, amphibians and mammals. While about 17,400 species would lose some habitat, 1,280 species would lose at least 25 percent of their ranges and 96 species would lose at least 75 percent.

Overhauling the global food system could shrink today's cropland area by 3.4 million square kilometers. Feeding the planet sustainably is "a no-brainer," Williams says. — *Jonathan Lambert*

26

percent

Projected growth of the world's cropland area by 2050

17,000+

Estimated number of vertebrate species pushed from habitats by expanding cropland

Ivory cargo recovered from a sunken 16th century Portuguese ship is answering questions about African elephants (one shown).

THE –EST

Shipwrecked ivory reveals elephant origins

In 2008, miners off the Namibian coast stumbled upon a sunken Portuguese trading ship known as the *Bom Jesus*. The ship, which went missing in 1533, bore gold and silver coins. But to scientists, the most precious cargo was a haul of more than 100 well-preserved elephant tusks — the largest archaeological cargo of African ivory ever discovered.

Genetic and chemical analyses have now traced those tusks back to many distinct herds that once roamed West Africa, researchers report in the Feb. 8 *Current Biology*.

Alida de Flamingh, a molecular biologist at the University of Illinois at Urbana–Champaign, and colleagues extracted DNA from 44 tusks and found all of that ivory came from African forest elephants (*Loxodonta cyclotis*). Comparing the DNA with that of past and present elephant populations with known origins revealed the tusks belonged to elephants from at least 17 herds.

An analysis of carbon and nitrogen in the tusks suggests the elephants lived in forests and savannas. That's surprising, the team says. Forest elephants were thought to have first ventured into grasslands in the 20th century, as poachers wiped out many savanna elephants (*L. africana*) and development destroyed forests. The finding hints that forest elephants were amenable to both habitats all along. — *Maria Temming*

TEASER

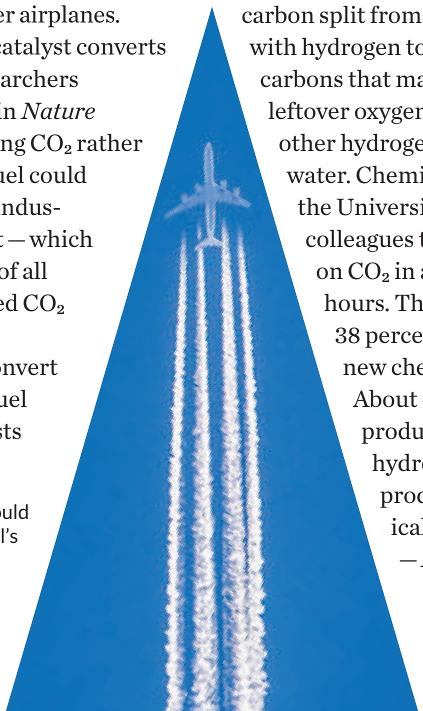
Catalyst could gas up jets with carbon dioxide

Today, airplanes pump a lot of climate-warming carbon dioxide into the atmosphere. But someday, carbon dioxide sucked from the atmosphere could be used to power airplanes.

A new iron-based catalyst converts CO_2 into jet fuel, researchers report December 22 in *Nature Communications*. Using CO_2 rather than oil to make jet fuel could reduce the air travel industry's carbon footprint — which makes up 12 percent of all transportation-related CO_2 emissions.

Past attempts to convert carbon dioxide into fuel have relied on catalysts made of relatively expensive materials, like cobalt, and required multiple chemical-processing steps. The new catalyst powder is made of inexpensive ingredients, including iron, and transforms CO_2 in a single step.

In reaction chambers filled with CO_2 and hydrogen gas, the catalyst helps carbon split from oxygen and link up with hydrogen to form the hydrocarbons that make up jet fuel. The leftover oxygen atoms join with other hydrogen atoms to form water. Chemist Tiancun Xiao of the University of Oxford and colleagues tested the catalyst on CO_2 in a chamber over 20 hours. The catalyst converted 38 percent of the CO_2 into new chemical products. About 48 percent of those products were jet fuel hydrocarbons. Other byproducts included chemicals found in plastics. — *Maria Temming*



Jet fuel made from atmospheric carbon dioxide could someday reduce air travel's carbon footprint.

FROM TOP: NICHOLAS GEORGIADIS; WILLIAM HOOK/UNSPLASH

News

BODY & BRAIN

A new vaccine takes on polio

Officials look to end outbreaks in the Middle East and Africa

BY AIMEE CUNNINGHAM

While there is intense focus on vaccines to rein in COVID-19, the work to stop other viral diseases continues. And after decades of vaccination campaigns that have spared millions of children from paralysis, the world is close to wiping out polio.

But a small number of outbreaks simmer in areas of low vaccination. Some of these outbreaks began after weakened virus in the oral polio vaccine, over time, moved around a community and regained the ability to cause disease. No other vaccines made with weakened live viruses have caused outbreaks of disease.

To stamp out vaccine-derived polio outbreaks, the World Health Organization granted emergency use for a new oral polio vaccine on November 13.

"We are very, very enthusiastically looking forward to using this new vaccine," says medical epidemiologist Chima Ohuabunwo of Morehouse School of Medicine in Atlanta, who has worked on polio eradication in Africa for more than two decades. Along with continuing to improve vaccination coverage, the new vaccine will "hopefully ... take us to the finishing line of polio eradication."

Eight years after the WHO's 1980 declaration that the world was free of smallpox, the Global Polio Eradication Initiative launched to tackle polio. The disease was a promising candidate for eradication. An effective, easily administered and cheap vaccine was available. And poliovirus, which naturally infects only humans, doesn't hang around in other animals in between outbreaks.

Most people who become infected with poliovirus don't feel sick, while some have flu-like symptoms. But about 1 in 200 become paralyzed for life. Although not a routine threat in the United States since the early 1950s, polio has continued to harm people, especially children, around the world.

This baby in Mauritania received an oral vaccination against polio in 2020.

RAPHAEL POUGET/UNICEF

In the late 1980s, wild poliovirus paralyzed over 1,000 children each day, according to the Global Polio Eradication Initiative. Since then, thanks to vaccination campaigns, cases have plummeted by more than 99 percent, and two of the three types of wild poliovirus have been eradicated. The last cases from type 2 and type 3 were reported in 1999 and 2012, respectively. Only wild poliovirus type 1 remains: In 2020, 84 cases were reported in Pakistan and 56 in Afghanistan.

Much of this progress is due to the oral polio vaccine, which has prevented more than 13 million cases since 2000, according to the WHO.

A big advantage of the oral vaccine, which is made of live but weakened poliovirus, is that it not only protects against paralysis — it also can stop wild poliovirus from spreading in a community. Poliovirus moves from person to person when someone ingests water or food contaminated with virus-containing stool. The oral vaccine prevents wild poliovirus from multiplying in the gut and being passed on. (A more expensive injected polio vaccine made with killed virus prevents paralysis but not viral spread.)

Still, the oral vaccine has a vulnerability. Weakened poliovirus in the vaccine has genetic changes that keep it from causing disease. But as vaccine virus multiplies in the gut, it can lose key genetic changes, bringing it closer to behaving like wild poliovirus. That altered vaccine virus "can be spread to others and establish community transmission," says biologist Raul Andino of the University of California, San Francisco School of Medicine. That spread can be a problem if not enough people have been immunized.

More than 80 percent of children need to be vaccinated to keep poliovirus from spreading in a community. The first known vaccine-derived polio outbreak occurred in the Dominican Republic and Haiti two decades ago. Low vaccination rates allowed altered vaccine virus, shed in the stool of the immunized, to spread and, over time, return to a form that causes paralysis. The full process of vaccine virus reverting to disease-causing virus is rare and takes many months of moving around a community.

Today, vaccine-derived outbreaks are primarily found in Afghanistan, Pakistan and countries in Africa. Most of these outbreaks — which have been responsible for more polio cases in the last few years than wild poliovirus — are linked to vaccine virus type 2. Vaccination campaigns, which had used an oral vaccine containing weakened versions of all three types of poliovirus, switched to using a formulation with just types 1 and 3 in 2016.

However, the way to stop a type 2 vaccine-derived outbreak is with an oral vaccine containing only the weakened type 2 virus. And that has sparked new outbreaks, researchers reported in *Science* last April. "It is this vicious circle," says virologist and infectious disease physician Adam Lauring of the University of Michigan Medical School in Ann Arbor. In 2020, there were 899 polio cases linked to the type 2 vaccine virus.

Hence the quest for an improved poliovirus type 2 oral vaccine. "It's a wonderful vaccine, so we didn't want to change the characteristics" that induce the body's immune response, Andino says. "The only thing we wanted to do is prevent the reversion" to a disease-causing virus.

He and colleagues altered a part of the type 2 vaccine virus's genetic instruction book, or genome, to make the virus less likely to develop a "gatekeeper" change: a first, crucial step along the road to regaining the ability to cause disease.

Poliovirus can swap bits of its genome with related viruses called enteroviruses. So the team moved a string of genetic letters the virus needs to make more copies of itself close to the "gatekeeper" modification. That way, if the vaccine virus were to ditch that modification by way of a swap, it would lose this necessary string of genetic letters too and die out.

The team also tinkered with an enzyme the virus needs to replicate. The enzyme is sloppy and can introduce a lot of genetic changes, Andino says. He and colleagues modified the enzyme to introduce fewer mistakes, "so the virus cannot evolve so quickly." The team described the vaccine in *Cell Host & Microbe* last May.

That vaccine is safe in infants and children, and produces an immune response similar to that seen with the original vaccine, researchers report in the Jan. 2 *Lancet*. The hope is that the modifications will slow the evolution of the new vaccine virus such that it can end the existing outbreaks without creating new ones.

The vaccine-derived outbreaks are a significant, yet surmountable hurdle to eradication, Ohuabunwo says, and "science is helping." But the key to ending polio is "very high vaccination coverage." Obstacles including war, migrating populations, difficult terrain and lack of vaccine acceptance have created pockets of inaccessible children, he says.

Reaching all children requires engaging community leaders, providing culturally sensitive information and learning how to meet other community needs, he says. For example, while working in Nigeria, he and colleagues made progress with nomadic populations. It meant "sometimes combining vaccinating their children with vaccinating their animals." Cattle would be immunized against anthrax and brucellosis bacterial infections. Protecting the animals also protected the nomads from these infections, he says, and motivated cooperation toward having children receive the polio vaccine: "a win-win." ■

LIFE & EVOLUTION

Acidifying oceans may turn up the glow

Scientists investigate how a lower pH affects bioluminescence

BY BETHANY BROOKSHIRE

A more acidic ocean could give some species a glow-up.

As the pH of the ocean decreases as a result of climate change, some bioluminescent organisms might get brighter, while others see their lights dim, scientists reported January 2 at a virtual meeting of the Society for Integrative and Comparative Biology.

Bioluminescence is common in parts of the ocean. The ability to light the dark has evolved independently more than 90 times. Convergent evolution has produced bioluminescent structures that vary wildly — from single chains of atoms to massive ringed complexes.

With such variability, changes in pH may have unpredictable effects on creatures' ability to glow. If greenhouse gas emissions continue as they are, average ocean pH is expected to drop from a preindustrial average of 8.2 to 7.7 by 2100. To find out how bioluminescence may be affected, sensory biologist Tom Iwanicki and colleagues at the University of Hawaii at Manoa gathered 49 studies on bioluminescence across nine phyla. The team analyzed data from the studies to see how the brightness of bioluminescent compounds vary at pH levels from 8.2 to 7.7.

As pH drops, the bioluminescent chemicals in some species, such as the sea pansy (*Renilla reniformis*), increase light production twofold. Other compounds, such as those in the sea firefly (*Vargula hilgendorfii*), have modest increases of only about 20 percent. And some species, like the firefly squid (*Watasenia scintillans*), actually appear to have a 70 percent decrease in light production.

For the sea firefly, which uses glowing trails to attract mates, a small increase could give it a sexy advantage. But for the firefly squid, which uses luminescence for communication, low pH and less light might not be a good thing.

Because the work was an analysis of previously published research, "I'm interpreting this as a first step, instead of this as the definitive result," says Karen Chan, a marine biologist at Swarthmore College in Pennsylvania who wasn't involved in the study. It "provides [a] testable hypothesis that we should ... look into."

Most of the analyzed studies took the luminescing chemicals out of organisms to test them, so finding out how the chemicals function in creatures in the ocean will be key, Iwanicki says. More than 75 percent of organisms seen in the open ocean are capable of bioluminescence, he says. "When we're wholescale changing the conditions in which they can use that [ability] ... that'll have a world of impacts." ■

These glowing specks are sea fireflies on a beach in Japan. A recent analysis suggests that these marine organisms might glow a bit brighter as the ocean becomes more acidic.

TREVOR WILLIAMS/STONE/GETTY IMAGES PLUS

EARTH & ENVIRONMENT

Active geyser isn't cause for alarm

Yellowstone gusher's restart doesn't foretell a volcanic blast

BY CAROLYN GRAMLING

A recent reawakening of the tallest geyser in the world is not a harbinger of an imminent volcanic eruption, a new study reports. And it isn't likely to portend a dangerous hydrothermal explosion either, researchers report in the Jan. 12 *Proceedings of the National Academy of Sciences*.

The reason for the sudden restart of Steamboat Geyser, found at Yellowstone National Park in Wyoming, remains a mystery, the scientists say. But the study, which examines a wealth of seismic, environmental and other data from the Yellowstone region, is helping scientists better understand what makes Steamboat, and other geysers, tick.

After over three years of dormancy, Steamboat abruptly shot a towering stream of hot water into the sky on March 15, 2018. That event kicked off a new active phase for the geyser, one of Yellowstone's most famous features — and made some park watchers wonder if the sudden eruption warned of greater dangers yet to come.

When it comes to potential threats at Yellowstone, the park's supervolcano gets most of the attention. But its deep reservoir of magma also heats groundwater that circulates underground or pools on the surface — and those boiling waters pose a far more immediate threat to park visitors. "Probably the biggest hazard in Yellowstone is people going off trail and falling in the boiling water. But there's always a risk of hydrothermal explosions," says Michael Manga, a geologist at the University of California, Berkeley.

Such explosions, which can occur when superheated water turns to steam and bursts violently out of the confining rock, are difficult to anticipate with what's known today. And they can be deadly: In December 2019, for example, a sudden hydrothermal explosion at Whakaari, or White Island, in New Zealand killed 22 people.

Yellowstone's Steamboat Geyser has erupted more than 100 times since its reawakening on March 15, 2018, including this eruption on July 18, 2019.

MARA H. REED

So after Steamboat reawakened, scientists thought it was "perfectly reasonable to consider the possibility that maybe even more violent activity might be coming along," Manga says. To assess that potential threat, he and colleagues collected a wide range of data from Steamboat — which erupted another 109 times between March 2018 and July 2020 — as well as from other geysers in the region and from the surrounding environment.

Those data included seismic records going back to 2003; GPS-determined changes in the shape of the ground that might be linked to moving magma; changes in temperature underground as well as in how much heat was emitted to the air over the geyser basin; and changes in the volume and chemistry of the water erupting out of Steamboat.

The data revealed that, just before Steamboat's 2018 reactivation, seismic activity in the region was slightly heightened, the land surface rose very slightly and heat emanating to the atmosphere from the geyser basin increased — all of which might point to some sort of magmatic movement. But no other dormant geyser in the region awoke, and temperatures underground didn't change. The team also found no other correlations between subsequent Steamboat eruptions and seismic activity, land deformation or thermal emissions.

Steamboat also seemed to show a seasonal eruption cycle, bursting forth more often during the summer than in the winter. That pattern suggests a possible relationship between eruption frequency and an increase in river flow due to melting snow, the study suggests.

But the ultimate trigger for Steamboat's reawakening is still unknown, says Michael Poland, a geophysicist at the U.S. Geological Survey in Vancouver, Wash., who is also the scientist-in-charge at the Yellowstone Volcano Observatory. The authors "did a really nice job of taking every possible variable that they could and ruling them out," Poland says. "And even though the answer is we don't see any reason why Steamboat became active, that's still valuable information."

The study also gives some insight into these mysterious, and sometimes deadly, hot-water fountains. "Most geysers don't behave in a predictable way," Poland says. "Old Faithful is very unusual" in that it erupts on a regular schedule. One of the most fundamental questions about geysers is why they erupt to certain heights, he adds — and why, for example, Steamboat can shoot water over 100 meters into the air, while Old Faithful's fountain is often roughly a third as high.

The new study gives a possible answer, by noting that the reservoir of hot water that feeds Steamboat is much deeper than those at other geysers. Water stored deeper underground is under higher pressure and can also get to higher temperatures — and that extra energy may drive those taller eruptions. ■

Chemical bond acts like a mash-up

Hydrogen bonds and covalent bonds exist on a continuum

BY EMILY CONOVER

Chemistry students the world over are familiar with covalent bonds and hydrogen bonds. A new study reveals a strange variety of bond that acts like a hybrid of the two. Its properties raise questions about how chemical bonds are defined, chemists report in the Jan. 8 *Science*.

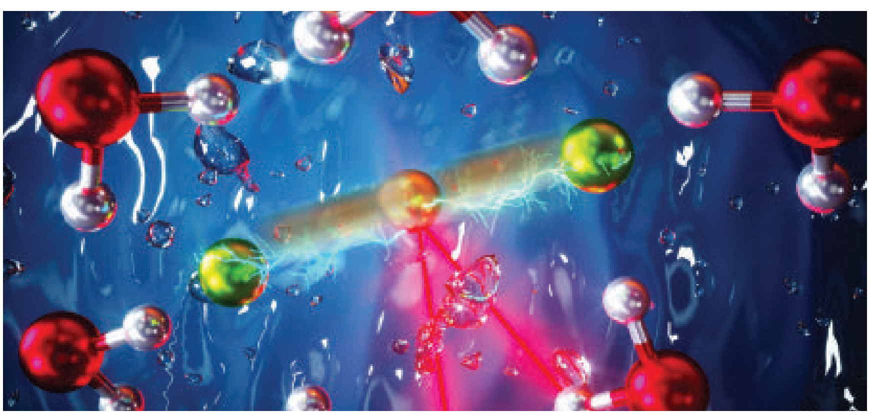
Hydrogen bonds are typically thought of as weak electrical attractions rather than true chemical bonds. Covalent bonds, on the other hand, are strong chemical bonds that hold together atoms within a molecule and result from electrons being shared among atoms. Now, researchers say that an unusually strong variety of hydrogen bond is in fact a hybrid, as it involves shared electrons, blurring the distinction between hydrogen and covalent bonds.

"Our understanding of chemical bonding, the way we teach it, is very much black and white," says chemist Andrei Tokmakoff of the University of Chicago. The new study shows that "there's actually a continuum."

Tokmakoff and colleagues characterized the hybrid bond by observing groups of atoms called bifluoride ions, consisting of a single hydrogen atom sandwiched between a pair of fluorine atoms, in water. According to conventional wisdom, the hydrogen atom is bound to one fluorine by a covalent bond and to the other fluorine by a hydrogen bond.

The researchers used infrared light to set bifluoride ions vibrating and measured the hydrogen atoms' response, revealing a series of energy levels at which the hydrogen atoms vibrated. For a typical hydrogen bond, the spacing between those energy levels would decrease as the atom climbed further up the energy ladder. In this case, the researchers found that the spacing increased. This behavior indicated that the hydrogen atom was shared between the two fluorine atoms equally, rather than being closely bound to one fluorine atom by a covalent bond and more loosely bound by a typical hydrogen bond to the other. In the newfound arrangement, "the difference between the covalent and [hydrogen] bond is erased and is no longer meaningful," says study coauthor Bogdan Dereka, a chemist also at the University of Chicago.

Computer calculations showed that this behavior is dependent on the distance between the two fluorine atoms. As the fluorine atoms move closer to each other, squeezing the hydrogen between them, the normal hydrogen bond becomes stronger, until all three atoms begin sharing electrons as in a covalent bond, forming a single link that the researchers call a hydrogen-mediated chemical bond. For fluorine atoms that are farther apart, the conventional description, with distinct covalent and hydrogen bonds, still applies.



Fluorine atoms (illustrated in green) squeeze a hydrogen atom (orange), when dissolved in water (red-and-silver molecules). Chemists used infrared laser light (red lines) to study the chemical bond that formed (turquoise lines), which acts like a hybrid between a hydrogen bond and a covalent bond.

DESIGNED BY ELLA MARU STUDIO

The hydrogen-mediated chemical bond can't be described as either a pure hydrogen bond or a pure covalent bond, the researchers conclude.

Hydrogen bonds occur in a variety of substances, most famously in water. Without hydrogen bonds, water at room temperature would be a gas instead of a liquid. While most hydrogen bonds in water are weak, strong hydrogen bonds similar to the ones found in the bifluoride ions can form in water that contains excess hydrogen ions. Two water molecules can sandwich a hydrogen ion, creating what's called a Zundel ion, in which the hydrogen ion is equally shared between the two water molecules. The new results echo the Zundel ion's behavior, says chemist Erik Nibbering of the Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy in Berlin, who coauthored a 2017 paper in *Science* on the Zundel ion. "It all fits nicely."

Strong hydrogen bonds are thought to play a role in transporting hydrogen ions, a process crucial for a variety of biological mechanisms including powering cells and for technologies such as fuel cells. So better understanding these bonds could shed light on a variety of effects.

And the new observation has implications for how scientists understand basic principles of chemistry. "It touches on our fundamental understanding of what a chemical bond is," says chemist Mischa Bonn of the Max Planck Institute for Polymer Research in Mainz, Germany, who coauthored a perspective piece on the new study, also published in *Science*.

That new understanding of chemical bonding also raises questions about what qualifies as a molecule. Atoms connected by covalent bonds are considered part of a single molecule, while those connected by hydrogen bonds can remain separate entities. So bonds in limbo between the two raise the question, "when do you go from two molecules to one molecule?" Tokmakoff says. ■

LIFE & EVOLUTION

Some spiders may set traps for frogs

Leaves sewn together with silk could be a temptingly cool hollow

BY JAKE BUEHLER

On a sweltering afternoon in northeastern Madagascar, the coolness of a leaf's shade is an attractive respite for a frog. But some of these oases may hide hungry architects: huntsman spiders.

Newly reported observations show that the spiders create leafy hollows by partially attaching two leaves together using silk. One of the arachnids was spotted eating a frog inside such a pocket, suggesting that the spiders make the structures to lure and trap frogs, researchers report online December 11 in *Ecology and Evolution*.

In 2017 and 2018, biologist Thio Rosin Fulgence and colleagues were conducting an ecological survey in Madagascar when Dominic Martin, an ecologist at the University of Göttingen in Germany, spotted a huntsman spider (*Damastes* sp.) eating a type of small Madagascar reed frog, *Heterixalus andrakata*. The spider was on a small tree, near a pair of overlapping leaves that had been attached together with spider silk, forming a pocket. Upon approach, the spider backed into its leafy lair, amphibian prize in tow.

"The first time that we found this phenomenon, we were very excited," says Fulgence, of the University of Antananarivo in Madagascar. The next year, while conducting surveys in roughly the same region, Fulgence found three more spiders hiding in similar leafy retreats, though the spiders weren't spotted with prey.

Some spiders are known to prey on larger and stronger animals, such as frogs and some other vertebrates, if the opportunity arises (*SN: 3/30/19, p. 13*). But huntsman spiders may be specifically targeting frogs as prey, the researchers say. By attaching the leaves together, the spiders are creating cool, dark microenvironments that would be desirable in a dehydrating environment with plenty of predatory birds, Fulgence says.

Or the spiders could simply be hiding in the leafy retreats and ambushing prey passing by, not using the structures as traps, argues Stano Pekár, a behavioral biologist at Masaryk University in Brno, the Czech Republic.

That's true, agrees Jose Valdez, a conservation biologist at the German Centre for Integrative Biodiversity Research in Leipzig. But "what makes me think otherwise is that not only did the researchers find [the leafy retreats] multiple times, but that the spider was weaving the edges of the leaves," Valdez says. "I would think there would be much easier places for these spiders to hide in a forest."

Part of the reason for the uncertainty is that the spider spotted eating a frog was first seen outside the leaf pocket before retreating inside with the frog. "Only detailed observations and experiments" can confirm if the leaves are a frog trap, says Rodrigo Willemart, a zoologist at the University of São Paulo.

If so, such a tool could be unique among spiders, Willemart says. "I don't know of papers that have reported on traps built by spiders specifically for capturing vertebrates." ■

A huntsman spider feeds on a Madagascar reed frog inside a pocket built from leaves and spider silk.

D.A. MARTIN

LIFE & EVOLUTION

Squirrels recycle to survive winter

An Arctic animal reuses muscle nutrients while hibernating

BY CAROLYN WILKE

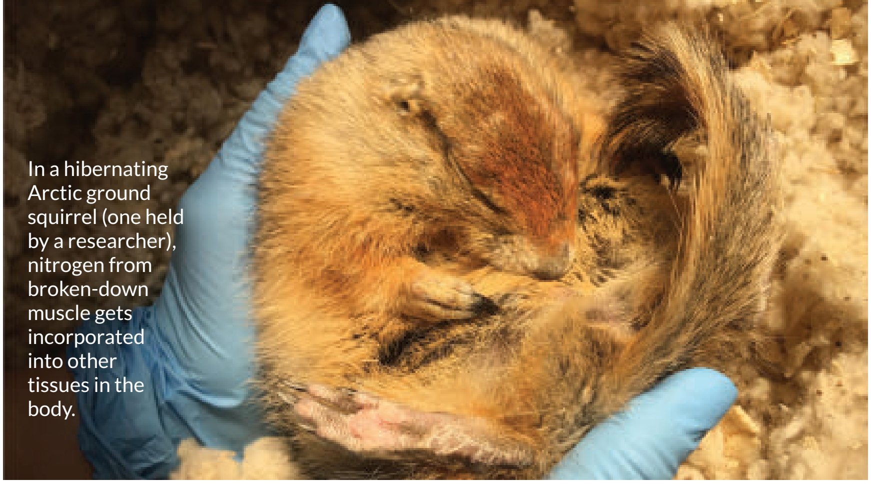
Arctic ground squirrels can survive harsh winters with below-freezing temperatures by holing up for some eight months without eating. These hibernators "live at the most extreme edge of existence, just barely hovering over death, and we don't fully understand how this works," says Sarah Rice, a biochemist at the University of Alaska Fairbanks.

By snooping on what goes on inside these squirrels, researchers now have a better idea. Nutrients recycled from muscle breakdown help the animals get by during hibernation, Rice and colleagues report December 7 in *Nature Metabolism*.

From autumn to spring, Arctic ground squirrels (*Urocitellus parryii*) hibernate in bouts of deep torpor. In a state akin to suspended animation, the squirrels breathe just once a minute, and their hearts beat five times per minute. Every two or three weeks, the squirrels revive somewhat for between about 12 and 24 hours: Their body temperatures rise, and the animals shiver and sleep, but don't eat, drink or defecate.

To monitor body chemistry, "I worked in dark, cold chambers — utterly quiet — surrounded by hibernating squirrels," Rice says. Periodically, she carefully withdrew blood from tubes inserted in their blood vessels.

During the squirrels' torpor, Rice and colleagues observed a chemical signal indicating that skeletal muscle was slowly breaking down. That process would release compounds containing nitrogen, an element important for making the proteins found in muscle. But hibernators, including these squirrels, are known to hang on to muscle mass as they hibernate. So the scientists wondered whether the squirrels build up new stores of protein during hibernation, and if so, how.



In a hibernating Arctic ground squirrel (one held by a researcher), nitrogen from broken-down muscle gets incorporated into other tissues in the body.

Tracking the flow of nitrogen in the animals' bodies provided clues. The researchers gave the critters a cocktail of chemicals labeled with isotopes, forms of elements having different masses. During those brief periods between bouts of torpor, nitrogen went into amino acids, the building blocks of proteins, that formed in the animals' muscles and also in the lungs, kidneys and other areas of the body, the researchers discovered.

By recycling nutrients from their muscles, the squirrels sustain themselves and also avoid a toxic consequence of muscle breakdown, says team member Kelly Drew, a neurochemist also at the University of Alaska Fairbanks. During hibernation, nitrogen would otherwise end up forming ammonia, which could build up to potentially deadly levels. Instead, the squirrels are able to incorporate that nitrogen into new molecules, she says.

Other studies have pointed to a role for the microbiome — the microbes living on and inside animals — in recycling nitrogen while animals hibernate, says James Staples, an environmental physiologist at Western University in London, Canada. Typically, the breakdown of proteins eventually creates urea, a nitrogen-containing chemical that gets excreted. Microbes can scavenge that urea and release its nitrogen, which can be reabsorbed back into the blood. But in the squirrels, the muscle is "being broken down and then recycled directly back into these amino acids ... the gut microbiome may not be as important as we thought."

Insights from hibernators could someday help humans, says Sandy Martin, a biochemist at the University of Colorado School of Medicine in Aurora. "Hibernators are so extraordinary" in their abilities to withstand conditions that humans are extremely sensitive to (*SN: 1/20/18, p. 16*), she says. For instance, animals like these squirrels are far more resistant to the harm that can result when organs don't receive necessary blood flow and oxygen. And harnessing hibernation-like approaches could prove advantageous in cases where a slower metabolism would be useful, from routine surgery to long voyages in space, she says. ■

CARLA FRARE, S. RICE

ATOM & COSMOS

How to safely land on Venus or Europa

Future spacecraft will face new obstacles on unfamiliar terrain

BY LISA GROSSMAN

The best way to know a world is to touch it. Scientists have observed the planets and moons in our solar system for centuries, and have flown spacecraft past the orbs for decades. But to really understand these worlds, researchers need to get their hands — or at least a spacecraft's landing pads — dirty.

Since the dawn of the space age, Mars and our moon have gotten almost all the lander love. Only a handful of spacecraft have landed on Venus, our other nearest neighboring world, and none have touched down on Europa, an icy moon of Jupiter thought to be one of the best places in the solar system to look for present-day life (*SN: 5/17/14, p. 20*).

Researchers are working to change that. In several talks at the virtual American Geophysical Union meeting held in December, planetary scientists and engineers discussed new tricks that hypothetical future spacecraft may need to land on the unfamiliar terrain of Venus or Europa. These missions are still in a design phase and are not on NASA's launch schedule, but scientists want to be prepared.

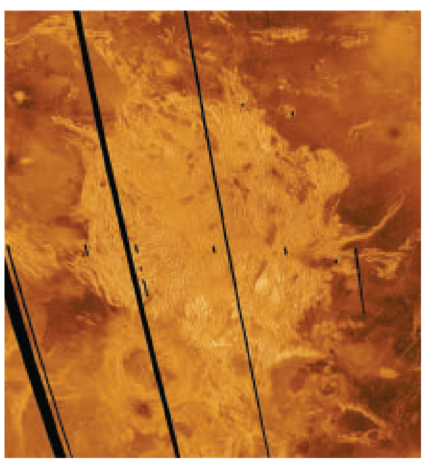
Navigating a Venusian gauntlet

Venus is a notoriously difficult world to visit (*SN: 3/13/18, p. 14*). Its searing temperatures and crushing atmospheric pressure have destroyed every spacecraft lucky enough to reach the surface within about two hours of arrival. The last landing was more than 30 years ago, despite increasing confidence among planetary scientists that Venus' surface may have once been habitable. The possibility of past, and perhaps current, life on the planet is one reason scientists are anxious to get back (*SN: 11/21/20, p. 16*).

In one of the proposed plans discussed at the meeting, scientists have a type of ridged, folded mountainous terrain called a tessera in their sights. "Safely landing in tessera terrain is absolutely necessary to satisfy our science objectives," planetary scientist Joshua Knicely of the University of Alaska Fairbanks said in a talk recorded for the meeting. "We have to do it."

Knicely is part of a study led by geologist Martha Gilmore of Wesleyan University in Middletown, Conn., to design a hypothetical mission to Venus launching in the 2030s. The mission would include three orbiters, an aerobot to float in the clouds and a lander that could drill and analyze samples of tessera rocks. This terrain is thought to have formed where edges of continents slid over and under each other long ago, bringing new rock up to the surface in what might have been some version of plate tectonics. On Earth, this sort of resurfacing may have been important in making the planet hospitable to life (*SN: 1/16/21, p. 16*).

But landing in these areas on Venus could be especially hard. The best maps of the planet — from NASA's Magellan orbiter in the 1990s — can't tell engineers how steep the slopes are in tessera terrain. These maps suggest that most of these slopes are less than 30 degrees, which the lander could handle with four telescoping legs. But some could be up to 60 degrees, leaving the spacecraft vulnerable to toppling over.



A possible landing spot for a future mission to Venus could be a rugged type of terrain known as a tessera (bright region in this false-color mosaic image) that might have formed through long-ago tectonic activity.

JPL-CALTECH/NASA

"We have a very poor understanding of what the surface is like," Gilmore said in a talk recorded for the meeting. "What's the boulder size? What's the rock size distribution? Is [the surface] fluffy?"

So the lander will need some kind of intelligent navigation system to pick out the best places to land and then steer there. But that need for steering brings up another problem: Unlike landers on Mars, a Venus lander can't use small rocket engines to slow down as it descends.

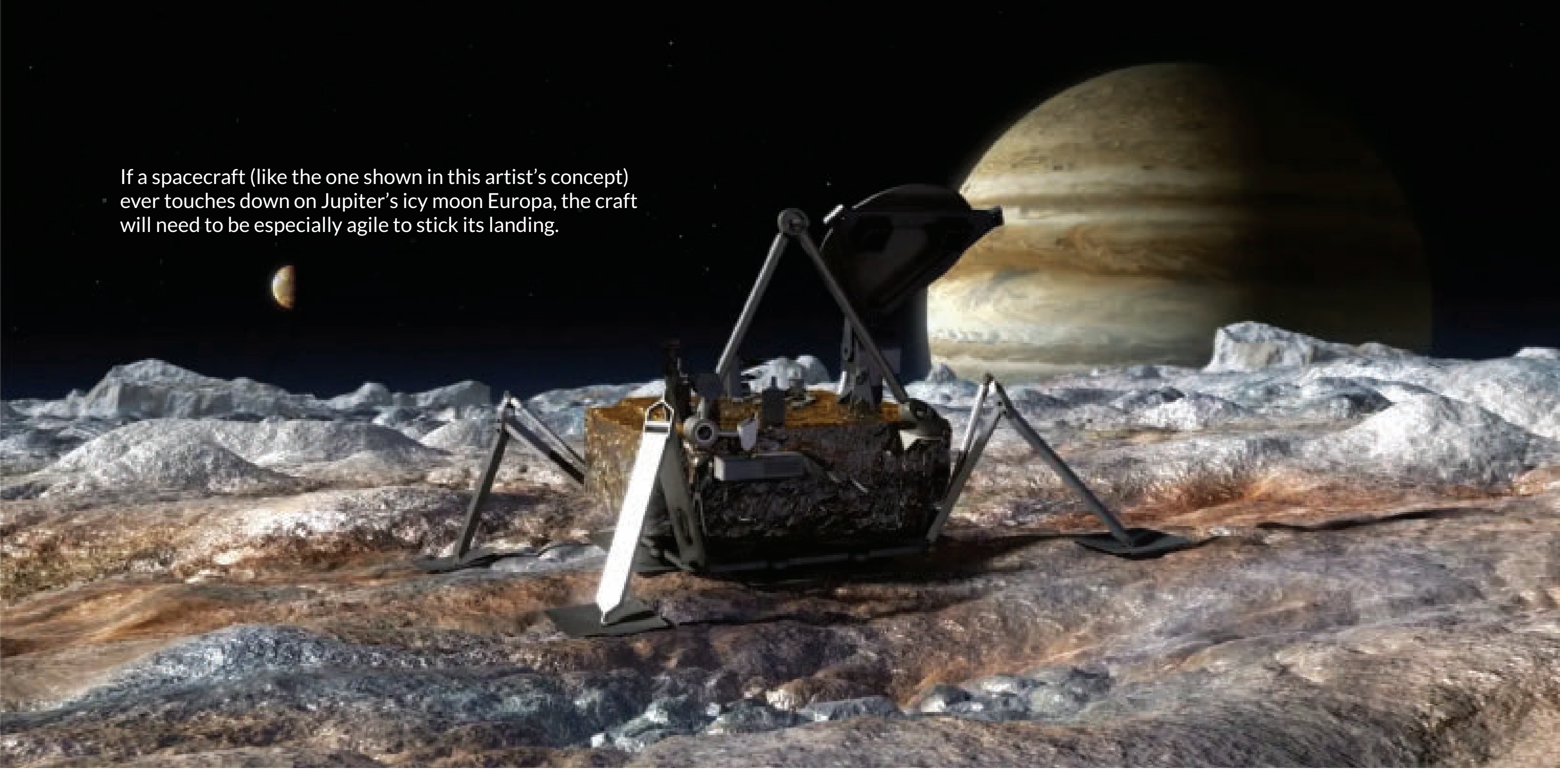
The shape of a rocket is tailored to the density of air that it will push against. That's partly why rockets that launch spacecraft from Earth have two sections: one for Earth's atmosphere and one for the near-vacuum of space. Venus' atmosphere changes density and pressure so quickly between space and the planet's surface that "dropping a kilometer would go from the rocket working perfectly, to it's going to misfire and possibly blow itself apart," Knicely says.

Instead of rockets, the proposed lander would use fans to push itself around, almost like a submarine, turning the disadvantage of the dense atmosphere into an advantage.

The planet's atmosphere also presents the biggest challenge of all: seeing the ground. Venus' dense atmosphere scatters light more than Earth's or Mars' atmospheres do, blurring the view of the surface until the last few kilometers of descent.

Worse, the scattered light makes it seem like illumination is coming from all directions at once, like shining a flashlight into fog. There are no shadows to help show steep slopes or reveal big boulders that the lander might crash into. That's a major issue, according to Knicely, because all of the existing navigation software assumes at least some directional lighting.

"If we can't see the ground, we can't find out where the safe stuff is," Knicely says. "And we also can't find out where the science is." While proposed



If a spacecraft (like the one shown in this artist's concept) ever touches down on Jupiter's icy moon Europa, the craft will need to be especially agile to stick its landing.

solutions to the other challenges of landing on Venus are close to doable, he says, this one remains the biggest hurdle.

Sticking the landing on Europa

Jupiter's icy moon Europa, on the other hand, has no air to blur the surface or break rockets. A hypothetical future Europa lander, also discussed at the meeting, would be able to use the "sky crane" technique. That method, in which a platform hovers above the surface using thrusters and drops a spacecraft to the ground, was used to land the Curiosity rover on Mars in 2012 and will be used for the Perseverance lander arriving on Mars next month (*SN: 7/4/20 & 7/18/20, p. 30*).

"The engineers are very excited about not having to deal with an atmosphere on the way down," engineer Jo Pitesky of NASA's Jet Propulsion Laboratory in Pasadena, Calif., said in a recorded talk for the meeting.

Still, there's a lot that scientists don't know about Europa's surface, which could have implications for any lander that touches down, planetary scientist Marissa Cameron of the Jet Propulsion Laboratory said in another talk.

The best views of the icy moon's landscape are from the Galileo orbiter in the 1990s, and the smallest features it could see were half a kilometer across. Some scientists have suggested that Europa may sport jagged ice spikes called penitentes, similar to ice features in the Andes Mountains that are named for their resemblance to hooded monks with bowed heads — though more recent work shows Europa's lack of atmosphere should keep penitentes from forming.

Another mission that's already under way, called the Europa Clipper, will take higher-resolution images when the orbiter visits the Jovian moon later this decade, which should help clarify the issue.

Dress rehearsals for a Europa landing include dropping a dummy lander named Olaf from a crane to see how it holds up.

In the meantime, researchers are running elaborate dress rehearsals for a Europa landing, from simulating ices with different chemical compositions in vacuum chambers to dropping a dummy lander named Olaf from a crane to see how it holds up.

"We have a requirement that says the terrain can have any configuration — jagged, potholes, you name it — and we have to be able to conform to that surface and be stable at it," says engineer John Gallon of the Jet Propulsion Laboratory. (The dummy lander was named for his 4-year-old daughter's favorite character in the movie *Frozen*.)

Over the last two years, Gallon and colleagues have tested different lander feet, legs and configurations in a lab by suspending the lander from the ceiling like a marionette. That suspension helps simulate Europa's gravity, which is one-seventh that of Earth's.

Without much gravity, a massive lander could easily bounce around and damage itself when trying to land. "You're not going to stick the landing like a gymnast coming off the bars," Gallon says. His team has tried sticky feet, bowl-shaped feet, springs that compress and push into the surface, and legs that lock to help the lander stay put on various terrains. The lander might crouch like a frog or stand stiff like a table, depending on what type of surface it lands on.

Although Olaf is hard at work helping scientists figure out how to build a successful Europa lander, the mission itself, like its Venusian counterpart, remains only on some planetary scientists' wish lists for now. Meanwhile, other researchers dream about voyages to entirely different worlds, including Saturn's geyser moon Enceladus.

"Some people will pick favorites," Cameron says. "I just want to land someplace we've never been to that's not Mars. I'd love that." ■

JPL-CALTECH/NASA

Watch engineers test different strategies for landing on Europa at **bit.ly/SN_EuropaLander**

EARTH & ENVIRONMENT

The pandemic's pollution insights

City shutdowns offer clues on how to improve air quality

BY CAROLYN GRAMLING

Empty New York City streets in May 2020 reflect how COVID-19 disrupted human activities. With data collected during city shutdowns, scientists are better learning how air pollution forms.

RENATA TYBURCZY/ISTOCK/GETTY IMAGES PLUS

The COVID-19 pandemic wasn't just a shock to the human immune system. It was also a shock to the Earth system, dramatically changing the air quality in cities around the globe.

As countries struggled to contain the disease, they imposed temporary shutdowns. Scientists are now sifting through data collected on the ground and by satellites to understand what this hiatus in human activities can tell us about the atmospheric cocktail that generates city pollution. Researchers shared much of this preliminary data at the virtual American Geophysical Union meeting in December.

It was already known that activities were curtailed enough to result in a dramatic drop in emissions of greenhouse gases in April (*SN: 6/20/20, p. 5*), as well as a dip in the seismic noises produced by humans (*SN: 8/29/20, p. 14*). That quiet period didn't last, though, and carbon dioxide emissions began to climb back upward. April saw a drop of about 17 percent in global monthly CO_2 emissions from fossil fuels, but by year's end, annual CO_2 emissions were only 7 percent lower than they were in 2019. Compared with the hundreds of years that the gas can linger in Earth's atmosphere, that reduction was too brief to put a dent in the planet's atmospheric CO_2 level.

Although the emissions lull didn't last, the abrupt halt in many human activities, particularly commuter traffic, created an unprecedented experiment for scientists to examine the complicated chemistry of atmospheric pollutants in cities.

That's not to say that the pandemic has a silver lining, says tropospheric chemist Jessica Gilman of the National Oceanic and Atmospheric Administration in Boulder, Colo. "Misery is no solution to our global environmental challenges."

But there's now a wealth of data on how the pandemic altered regional or local concentrations of the precursors of ozone, a primary component of smog. Those precursors include nitrogen oxides and volatile organic compounds, both produced by traffic, as well as methane, produced by the oil and gas industry.

Building a global picture of altered city pollution is no easy task, though. Researchers are finding that the pandemic's impact on levels of various pollutants was highly regional, affected by differences in wind and rain as well as by photochemical interactions with sunlight — the intensity of which also changes with the season.

That stark variety of regional effects was evident, for example, in how ozone levels changed in Denver versus in New York City. Nitrogen oxide gases produced by traffic are a powerful precursor to cities' elevated ozone levels, which can damage the lungs and trigger respiratory ailments. The United States has made strides in reducing these gases over the last few decades — but there hasn't been a corresponding drop in ozone levels, Dan Jaffe, an environmental chemist at the University of Washington Bothell, reported at the meeting in December.

The shutdowns gave researchers some insight into why, Jaffe says. From March 15 through July 23, New York City had a 21 percent decrease in nitrogen dioxide, one of several nitrogen oxide gases, compared with 2019 levels. Although the shutdowns were more stringent during the spring months, summertime reductions in nitrogen dioxide, particularly in July, are most strongly linked to the city's likelihood of exceeding ozone standards set by the U.S. Environmental Protection Agency, Jaffe said at the meeting. "In both June and July 2020, the city had far fewer projected ozone exceedance [days]" than in 2018 and 2019, he added, citing unpublished data.

That's because in the summer months, heat and sunlight react with the precursor gases in the atmosphere, like nitrogen dioxide, creating a toxic cocktail. This kind of insight can be a boon to policy makers in a non-pandemic year, suggesting that nitrogen oxide, or NO_x, regulations should focus most strongly on the summer, Jaffe says. "It's really good evidence that NO_x reductions extending into July in 2020 had an important impact."

In Denver, however, ozone didn't drop so consistently — possibly because wildfires were beginning to rage across the U.S. West by the end of the summer (*SN: 12/19/20 & 1/2/21, p. 32*). The fires produce nitrogen oxides, carbon monoxide and fine particles that can also help to increase ground-level ozone.

"There are different patterns in different cities," Jaffe says. "There are a lot of factors to sort out, and a lot of work to be done." ■

BODY & BRAIN

Severe reactions to COVID-19 vaccines appear to be rare

Out of the first 1.9 million doses of Pfizer's COVID-19 vaccine administered in the United States, there were 21 reported cases of severe allergic reactions, according to the U.S. Centers for Disease Control and Prevention.

The rate of anaphylaxis seen so far — 11.1 cases per 1 million vaccine doses — is higher than for the flu vaccine, which is 1.3 cases per 1 million doses, Nancy Messonnier, director of the CDC's National Center for Immunization and Respiratory Diseases, said in a January 6 news briefing. But this reaction to COVID-19 vaccines is "still exceedingly rare," she said. "These are safe and effective vaccines." U.S. surveillance systems for vaccine side effects are "incredibly robust," she said.

The CDC reported the 21 cases, which cover Pfizer vaccinations from December 14 to 23, online January 6 in *Morbidity and Mortality Weekly Report*. Officials don't yet know what triggered the allergic reactions.

There were no reported deaths from anaphylaxis, which can be life-threatening. Nineteen of the 21 people were treated with epinephrine and four were hospitalized. Seven of the people in the report had experienced anaphylaxis in the past. CDC officials recommend that people with a history of anaphylaxis alert the person administering a COVID-19 vaccine before getting one.
— Aimee Cunningham

GENES & CELLS

Some identical twins don't have identical DNA

Identical twins may not be carbon copies at the DNA level after all.

On average, identical twins differ by 5.2 genetic changes, researchers report January 7 in *Nature Genetics*. The finding is important because identical twins — which arise from a single fertilized egg — are often studied to determine whether particular traits, diseases or conditions result from genetics or from environmental influences. Because identical twins were thought to be genetically the same, differences in their health were considered to be the product of the twins' environment. The new finding suggests that some genetic changes might also account for health differences between twins.

Researchers in Iceland deciphered the complete genetic makeup, or genome, of 381 pairs of identical twins. Thirty-eight pairs were genetic duplicates of each other, but most had some differences that probably arose very early in development, either just before one embryo split to form two or shortly after the split. Some of the twins had many genetic differences, including 39 pairs who had more than 100 differences between the twins.

Patterns of mutations among twins suggest that embryos don't split neatly when twins form, the researchers found. Some twins may arise when a single cell or a small group of cells splits off from the embryo. The number of cells that a twin originates from may determine how genetically different they are from their twin, with more uneven splits of the embryo leading to a greater number of differences between the twins.
— Tina Hesman Saey

HUMANS & SOCIETY

Ice Age hunters' leftovers may have fueled dog domestication

Sometime between about 29,000 and 14,000 years ago, hunter-gatherers navigating northern Eurasia's frigid landscapes turned wolves into dogs by feeding them lean-meat leftovers.

That, at least, is a likely scenario that would have benefited both wolves and people, say archaeologist Maria Lahtinen of the Finnish Food Authority in Helsinki and colleagues. In harsh Ice Age winters, when game hunted by both species was largely free of fat, prey animals would have provided more protein than humans could safely consume, the researchers conclude January 7 in *Scientific Reports*. People could have fed surplus lean meat to captured wolves being raised as pets because the animals wouldn't have had the same dietary limitations, the team proposes.

The first step toward domesticating dogs may have been ancient hunter-gatherers feeding wolves surplus meat.

RICHARD NEWSTEAD/THE IMAGE BANK/GETTY IMAGES

That idea is largely based on inferences from previous research on how ancient hunter-gatherers survived in the Arctic and new calculations suggesting that, to stay healthy, Ice Age groups could not have eaten all of the lean meat that was hunted. Though far from the final word on the controversial origins of dogs, Lahtinen's group offers a novel take on how that process may have unfolded.

The group's calculations assume that, like some hunter-gatherers in the Arctic today, ancient humans acquired 45 percent of their calories from animal protein. Humans can't eat a completely carnivorous diet because the liver generates only part of our energy needs from protein. Edible plants could have been stored for the winter as a source of carbohydrates, but supplies would have waned as the annual big freeze wore on, the scientists suspect. So Ice Age hunter-gatherers probably reached a point where they focused on hunting to extract fats and grease from the bones of prey to meet energy needs, the researchers argue, leaving plenty of lean meat untouched and available as wolf food.

Competition between humans and wolves for prey would have declined as generations of pet wolves gradually evolved into dogs, the team hypothesizes. Only then, the idea goes, were more docile canines trained to help people.
— Bruce Bower

It's time to define despair and its risks

Scientists trace the roots of despair-related deaths

By Bruce Bower

Despair has contributed to deaths and mental suffering in the United States for several decades leading up to the current coronavirus pandemic. Researchers are developing ways to measure despair as distinct from any psychiatric ailment.

RAPIDEYE/ISTOCK/GETTY IMAGES PLUS

Late in 2015, a foreboding but catchy phrase from a scientific paper blew across the cultural landscape with unexpected force.

The expression "deaths of despair" was coined by Princeton University economist Anne Case and Angus Deaton — Case's colleague, husband and a Nobel laureate in economics — after they had dug into U.S. death statistics.

From 1999 to 2013, mortality had risen sharply among middle-aged, non-Hispanic white people, especially those without a college degree, Case and Deaton reported in 2015 in the *Proceedings of the National Academy of Sciences*. In contrast, during the 1900s, people's life spans had generally lengthened from roughly 50 years to nearly 80.

The shift occurred largely because white, working-class people ages 45 to 54 were drinking themselves to death with alcohol, accidentally overdosing on opioids and other drugs, and intentionally killing themselves, often by shooting or hanging.

Vanishing jobs, disintegrating families and other social stressors had unleashed a rising tide of fatal despair, Case and Deaton concluded.

This disturbing trend mirrored what had previously occurred among inner-city Black people in the 1970s and 1980s, Case and Deaton now say. As low-skilled jobs vanished and families broke apart, Black victims of crack cocaine and the AIDS epidemic represented an early wave of deaths of despair. Even today, mortality rates for Black people still exceed those of white people in the United States for a variety of reasons, with Black overdose deaths on the rise over the last few years.

"The most meaningful dividing line [for being at risk of deaths of despair] is whether or not you have a four-year college degree," Deaton says.

But despair has no clear scientific or medical definition. Psychiatric disorders plausibly related to a sense of despair, such as major depression and anxiety disorders, have been studied for decades. Despair — derived from a Latin term meaning "down from hope" — might be just another way to describe these conditions.

Or it might be its own special form of suffering. Some researchers regard despair as a distinct psychological status — one that can potentially be traced back to early childhood and may pose a risk for suicide, illegal drug use and maybe even physical pain.

For that reason, mental health clinicians need to work to distinguish despair from depression, even if despair isn't a disorder in psychiatry's diagnostic manual, says psychiatrist Ronald Pies of the State University of New York's Upstate Medical University in Syracuse. "An overreliance on what is sometimes called 'the Bible of psychiatry' is likely to be misleading or inadequate when assessing the risk of suicide and illicit drug use," he contends.

What's more, recognizing and measuring despair, or something like it, as a state of mind separate from depressive disorders might shed light on the uptick in mental distress reported by people of all backgrounds during the coronavirus pandemic, Pies says. Developing a despair scale may also help identify those individuals at risk of succumbing to despair-related fatalities. Long-term trends in national mortality data suggest that such deaths will continue to climb, even long after the viral calamity ends.

Downhearted minds

Case and Deaton's emphasis on escalating 21st century deaths of despair — further detailed in their 2020 book, *Deaths of Despair and the Future of Capitalism* — hit a nerve, especially among researchers studying groups of children as they grow into adults. These developmental scientists are in a prime position to uncover the roots of deadly despair and identify how some individuals nurture hope during difficult times while others experience a toxic brew of mental pain.

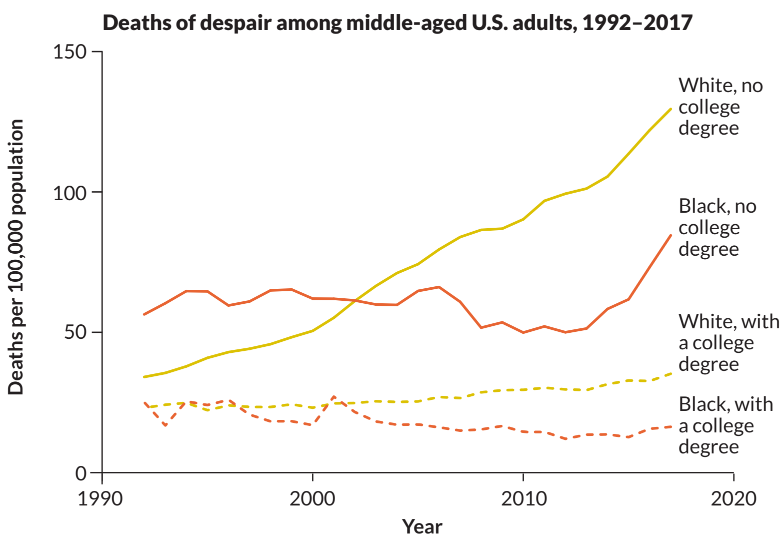
First, though, despair must be defined in a measurable way. In a study in the June 2020 *JAMA Network Open*, researchers described a preliminary assessment of a tool that can be used to estimate an individual's level of despair. To develop the tool, psychologist William Copeland of the University of Vermont Larner College of Medicine in Burlington and colleagues focused on youngsters living in mostly rural parts of western North Carolina, a section of Appalachia that has been devastated by opioid overdoses and other deaths of despair. Known as the Great Smoky Mountains Study, the research was launched in 1992 and has assessed mental health in 1,266 individuals as many as 12 times, from ages 9 to 13 up to age 30.

Inspired by Case and Deaton's findings, Copeland's team reexamined the North Carolina data from a new perspective, identifying seven indicators of despair.

Two of the indicators — feeling hopeless and having low self-esteem — are among the symptoms of persistent depressive disorder, a psychiatric condition consisting of a depressed mood that lasts for at least two years in adults. Another indicator — feeling unloved — is a symptom of major depression, a mental disorder that includes bouts of overwhelming sadness and social isolation lasting at least two weeks. A fourth indicator — frequent worrying — contributes to what mental health clinicians call generalized anxiety disorder. The remaining three indicators — loneliness, helplessness and feeling sorry for oneself — are not symptoms of any psychiatric disorder.

Combining those seven indicators into a despair scale let the researchers compare levels of despair among youngsters. Between 1 and 5 percent of participants up to age 21 in the study

Heightened risk In an analysis of national data from 1992 to 2017, U.S. adults ages 45 to 54 without a college degree experienced an overall increased risk of alcohol-, drug- and suicide-related deaths, whether Black (orange lines) or white (yellow lines). For reasons that are not yet clear, Black college graduates (orange dotted line) had the lowest rates of deaths of despair in this statistical comparison.
SOURCE: A. CASE AND A. DEATON/*DEATHS OF DESPAIR AND THE FUTURE OF CAPITALISM* 2020



T. TIBBITTS

experienced at least one symptom on the scale in the three months before being interviewed, Copeland's group reported. Among 25- to 30-year-olds, about 20 percent reported one despair item, and 7.6 percent cited at least two in the previous three months. Few participants suffered from more than five of the seven despair indicators. A minority of individuals who cited single despair items related to depression met criteria for a depressive disorder in psychiatry's diagnostic manual.

Young adults' despair scores were generally higher among people who didn't get a college degree and among Black people in general.

Overall, 25- to 30-year-olds became increasingly likely to think about or attempt suicide and to abuse illicit drugs, including opioids, as they scored higher on the despair scale. These trends were especially strong among participants who had elevated despair scores that traced back to childhood.

In contrast to Case and Deaton's national findings indicating that alcoholism contributes to deaths of despair, despair scores among participants in Copeland's study displayed no link with alcohol abuse. Alcoholism is more widespread than suicide and opioid abuse, suggesting that excessive alcohol drinking stems from a wider range of stressful situations and personal problems than the other two behaviors do, Copeland says. As a result, any influence of despair on alcohol abuse may be difficult to pick up statistically.

And though lower education levels were associated with higher despair scores, Copeland's team failed to find an elevated tendency of less-educated participants to become suicidal or abuse drugs. That finding deserves closer scrutiny in a nationally representative sample of young adults, not just rural North Carolinians, Deaton says. Further research also needs to expand the current despair scale to include other potential indicators of despair, such as sadness, recklessness and declining immune function, Copeland adds.

Despair as measured by the new scale represents a downhearted state of mind, not a mental disorder, Copeland suspects. High despair scores predicted illicit drug abuse and suicidal thoughts and behaviors regardless of whether 25- to 30-year-olds qualified as depressed. Despair was not usually accompanied by depression, though depressed participants typically reported experiencing indicators of despair, such as being lonely.

Scores on this instrument highlight growing concerns that a sense of despair contributes to self-destructive but not necessarily lethal behavior among people on the cusp of adulthood. "We're seeing a large effect of despair on [some] young adults," Copeland says. "It makes their lives miserable."

Big hurts

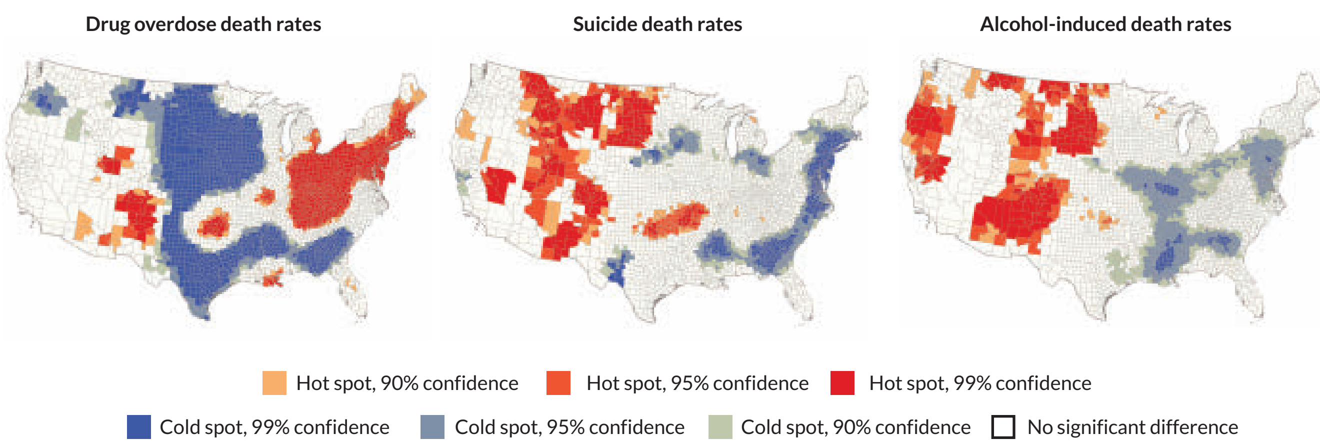
As for older adults, despair doesn't just fuel deaths among less-educated Americans, it may also sucker-punch these people into a world of physical pain, a recent study from Case, Deaton and psychologist Arthur Stone of the University of Southern California in Los Angeles suggests.

By their own accounts, today's Americans in their 40s and 50s with no college degree have already experienced more pain throughout life than today's elderly Americans have over longer periods of time, the team reported in the Oct. 6 *Proceedings of the National Academy of Sciences*. These findings are from two nationally representative surveys of U.S. white and Black non-Hispanics.

U.S. hot spots

Deaths of despair vary by geography and cause, based on a review of mortality data for U.S. counties recorded from 2013 through 2017 versus what would be expected based on 2000 rates. Increases in deaths (hot spots) from drug overdoses appeared in the Northeast, Appalachia and the Rust Belt. Parts of Western states displayed especially high rate increases in suicide and alcohol-related deaths. Rural areas experienced sharp rate increases only in suicide fatalities.

Changes in U.S. despair-related deaths, 2013–2017 compared with 2000 expectations



M.S. SHIELS *ET AL*/*JAMA NETWORK OPEN* 2020

In samples of adults without college degrees, participants increasingly reported lower-back pain from 1997 to 2018, the researchers found. Weight gain over that time statistically accounts for only about one-quarter of the reported rise in lower-back pain among those lacking college degrees, the researchers say, and so can't fully explain the pain.

In other wealthy countries, the prevalence of physical pain reported by adults without a college degree increased by 4 percent between those born in 1950 and those born in 1990. In the United States, the increase was 21 percent, an analysis of data on self-reported physical pain from several national and international surveys shows. Deaths of despair have also increased to a much greater extent in the United States than in other Western nations, the researchers say.

Like deaths of despair, reports of increasing pain by less-educated adults reflect a snowballing erosion of working-class life and rising levels of despair among those born after 1950, Case, Deaton and Stone speculate. In their new book, Case and Deaton present evidence for that argument based on trends in unemployment, loss of health insurance, out-of-wedlock births and other factors.

"The mind-body connection is incredibly important," Case says. "Feeling excluded and socially isolated can trigger physical pain."

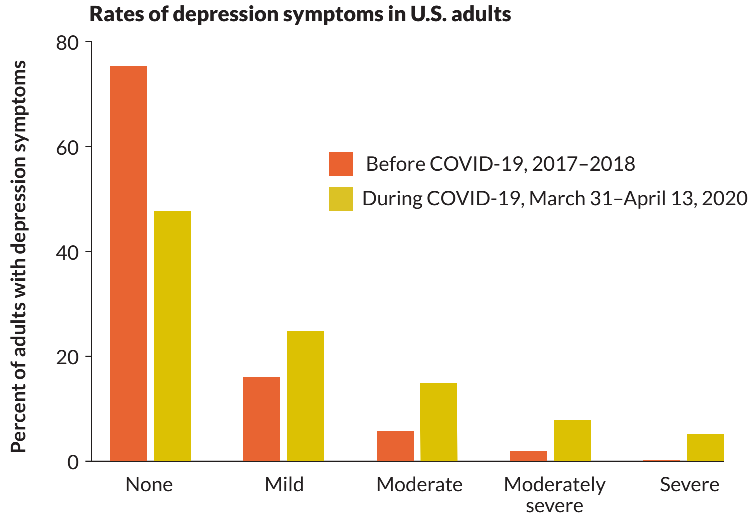
Viral distress

Despair also deserves close scrutiny as an unfortunate consequence of the coronavirus pandemic, Pies says.

No one doubts that emotional suffering has accompanied COVID-19. A survey published in August by the U.S. Centers for Disease Control and Prevention found that U.S. adults reported substantially more symptoms of anxiety disorder and depressive disorder last June than in a longer period the year before, April through June 2019.

Reported symptoms of stress and trauma disorders, as well as thoughts about suicide, also rose in 2020 when compared with data from 2018. About 13 percent of 5,470 survey participants said that COVID-19 caused them to start or increase drug and alcohol use.

Another national survey run from March 31 through April 13 found that 27.8 percent of the U.S. adult population reported depression symptoms, compared with 8.5 percent of U.S. adults surveyed in 2017 and 2018. These survey results appeared in the September *JAMA Network Open*.



Pandemic impact
As the coronavirus flared in 2020, mild to severe depression symptoms rose among U.S. adults (yellow bars), relative to rates of depression symptoms before the pandemic (orange bars).
SOURCE: C.K. ETTMAN *ET AL*/ *JAMA NETWORK OPEN* 2020

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But increased psychiatric symptoms during the pandemic don't necessarily mean that more people are suffering from psychiatric disorders, Pies says. Self-reported anxiety and depression symptoms may not be long-lasting enough or impair daily functioning enough to be classed as mental disorders. And Copeland's findings on despair suggest that it may be too simplistic to assume that the pandemic has led to a widespread outbreak of depression and other mental disorders, Pies says.

Instead, many emotional reactions to the pandemic detected in surveys may reflect understandable demoralization and grief at painful losses of jobs, social contacts and loved ones felled by the virus, Pies wrote August 24 in *Psychiatric Times*. Demoralization, he says, involves experiencing a loss of meaning and purpose in life, accompanied by frustration, anger and a feeling that one is fighting a losing battle. That definition partly overlaps with Copeland's despair scale, Pies says. The extent to which demoralization and despair intersect is uncertain.

How despair, depression and the pandemic may overlap is still fuzzy. But what is clear is that deaths of despair can't be blamed on mental disorders and can lead to real costs to society, Case and Deaton contend. And that won't end with a vaccine. "Deaths of despair are a long-term phenomenon that will be with us after the COVID-19 crisis is over," Case says. ■

Explore more

- Anne Case, Angus Deaton and Arthur A. Stone. "Decoding the mystery of American pain reveals a warning for the future." *Proceedings of the National Academy of Sciences*. October 6, 2020.

Recycling

Chemists tackle the world's mountains of plastic

By Maria Temming

It feels good to recycle. There's a certain sense of accomplishment that comes from dutifully sorting soda bottles, plastic bags and yogurt cups from the rest of the garbage. The more plastic you put in that blue bin, the more you're keeping out of landfills and the oceans, right?

Wrong. No matter how meticulous you are in cleaning and separating your plastics, most end up in the trash heap anyway.

Take flexible food packages. Those films contain several layers of different plastics. Because each plastic has to be recycled separately, those films are not recyclable. Grocery bags and shrink wrap are too flimsy, prone to getting tangled up with other materials on a conveyor belt. The

Reimagined

polypropylene in yogurt cups and other items doesn't usually get recycled either; recycling a hodgepodge of polypropylene produces a dark, smelly plastic that few manufacturers will use.

Only two kinds of plastic are commonly recycled in the United States: the kind in plastic soda bottles, polyethylene terephthalate, or PET; and the plastic found in milk jugs and detergent containers — high-density polyethylene, or HDPE. Together, those plastics make up only about a quarter of the world's plastic trash, researchers reported in 2017 in *Science Advances*. And when those plastics are recycled, they aren't good for much.

ABDUL RAHEEM MOHAMED/EYEEM/GETTY IMAGES

A lot of plastic goes to landfills because the material is too difficult to recycle into useful new products. Chemists are trying to change that.

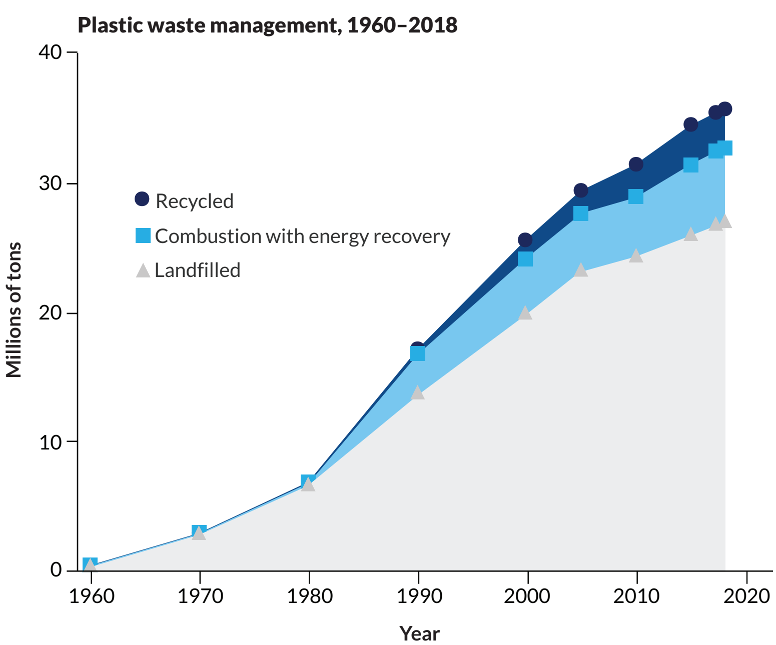
Melting plastic down to recycle changes its consistency, so PET from bottles has to be mixed with brand-new plastic to make a sturdy final product. Recycling a mix of multicolored HDPE pieces creates a dark plastic good only for making products like park benches and waste bins, in which properties like color don't matter much.

The difficulties of recycling plastic into anything manufacturers want to use is a big reason why the world is littered with so much plastic waste, says Eric Beckman, a chemical engineer at the University of Pittsburgh. In 2018 alone, the United States landfilled 27 million tons of plastic and recycled a mere 3 million, according to the U.S. Environmental Protection Agency. Low recycling rates aren't just a problem in the United States. Of the 6.3 billion tons of plastic that have been discarded around the world, only about 9 percent has gotten recycled. Another 12 percent has been burned, and almost 80 percent has piled up on land or in waterways.

With plastic collecting everywhere from the top of Mount Everest to the bottom of the Mariana Trench, there's an urgent need to reduce the amount of plastic that gets thrown away (*SN: 1/16/21, p. 5*). Some people propose replacing plastics with biodegradable materials, but those replacements are generally not as strong or cheap to make as plastics (*SN: 6/22/19, p. 18*). Since, realistically, plastic is not going away any time soon, chemists who understand the ins and outs of all this pesky plastic are working to make it easier to recycle and turn into higher-quality material that's useful for more things.

"There's not going to be a single technology that's going to be the answer," says Ed Daniels, senior project manager at the REMADE Institute in West Henrietta, N.Y., which funds research into new recycling techniques. Some projects are on the brink of breaking into industry; others are still just promising lab experiments. But all are focused on designing a future where any plastic that ends up in the recycling bin can have a second and third life in a new product.

Good news/bad news The amount of plastic recycled in the United States has increased over the last few decades — but those levels still pale in comparison with the amount of plastic that goes into landfills. SOURCE: EPA



E. OTWELL

Picking plastics apart

One of the biggest bottlenecks in plastic recycling is that every material has to get processed separately. "Most plastics are like oil and water," says chemist Geoffrey Coates of Cornell University. They just don't mix. Take, for example, a polyethylene detergent jug and its polypropylene cap. "If you melt those down, and I make a bottle out of that, and I squeeze it, it would basically crack down the side," Coates says. "It's crazy brittle. Totally worthless."

That's why the first destination for plastic recyclables is a material recovery facility, where people and machines do the sorting. Separated plastics can then be washed, shredded, melted and remolded. The system works well for simple items like soda bottles and milk jugs. But not for items like deodorant containers — where the bottle, crank and cap could all be made of different kinds of plastic. Food packaging films that contain several layers of different plastic are particularly tricky to take apart. Every year, 100 million tons of these multilayer films are produced worldwide. When thrown away, those plastics go to landfills, says chemical engineer George Huber of the University of Wisconsin–Madison.

To tackle that problem, Huber and colleagues devised a strategy for dealing with complex mixtures of plastics. The process uses a series of liquid solvents to dissolve individual plastic components off a product. The trick is choosing the right solvents to dissolve only one kind of plastic at a time, Huber says.

The team tested the technique on a packaging film that contained polyethylene and PET, as well as a plastic oxygen barrier made of ethylene vinyl alcohol, or EVOH, that keeps food fresh.

Stirring the film into a toluene solvent first dissolved the polyethylene layer. Dunking the remaining EVOH-PET film in a solvent called DMSO stripped off the EVOH. The researchers then plucked out the remaining PET film and recovered the other two plastics from their separate solvents by mixing in “antisolvent” chemicals. Those chemicals caused the plastic molecules that were dispersed in the liquids to bunch together into solid clumps that could be fished out.

This process recovered practically all of the plastic from the original film, the researchers reported last November in *Science Advances*. When tested on a jumble of polyethylene, PET and EVOH beads, the solvent washes recovered more than 95 percent of each material — hinting that these solvents could be used to strip plastic components off bulkier items than packaging films. So in theory, recovery facilities could use this technique to disassemble multiplastic deodorant containers and other products of various shapes and sizes.

Huber and colleagues next plan to look for solvents to dissolve more kinds of plastic, such as the polystyrene in Styrofoam. But it will take a lot more work to make this strategy efficient at sorting all the intricate plastic combinations in real-world recyclables.

Making plastics mix

There may also be chemical shortcuts that allow multilayer films and other mixtures of plastics to be recycled as they are. Additives called compatibilizers help different melted-down plastics blend, so that unsorted materials can be treated as one. But there is no universal compatibilizer that allows every kind of plastic to be mixed together. And existing compatibilizers are not widely used because they are not very potent — and adding a lot of compatibilizer to a plastic blend gets expensive.

To boost viability, Coates and colleagues created a highly potent compatibilizer for polyethylene and polypropylene. Together, those two plastics make up more than half of the world’s plastic. The new compatibilizer molecule contains two segments of polyethylene, interspersed with two segments of polypropylene. Those alternating segments latch onto plastic molecules of the same kind in a mixture, bringing polyethylene and polypropylene together. It’s as if polyethylene were made of Legos, and polypropylene were made of Duplos, and the researchers made a special building block with connectors that fit both types of blocks.

At the Waste Management Material Recovery Facility in Elkridge, Md., workers sort trash moving past them on conveyor belts.

SAUL LOEB/AFP VIA GETTY IMAGES

False advertising

Many plastic products are labeled with a number inside a triangle that symbolizes recycling. Yet, only plastics with 1 (polyethylene terephthalate) or 2 (high-density polyethylene) are widely recycled in the United States. The rest typically go to the landfill. SOURCE: ELLEN MACARTHUR FOUNDATION 2017

1 **PET**
Water and soft drink bottles, salad domes, cookie trays, salad dressing and peanut butter containers

2 **HDPE**
Milk and juice bottles, freezer bags, shampoo and detergent bottles

3 **PVC**
Cosmetic containers, commercial cling wrap

4 **LDPE**
Squeeze bottles, cling wrap, trash bags

5 **PP**
Microwave dishes, ice cream tubs, yogurt containers, detergent bottle caps

6 **PS**
CD cases, plastic disposable cups, plastic cutlery, video cases

6 **EPS**
Foam polystyrene hot drink cups, food takeaway trays, protective packaging for fragile items

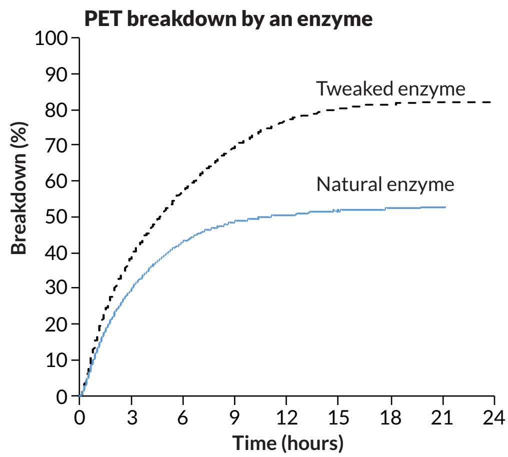
7 **Other**
Water cooler bottles, flexible films, multimaterial packaging

Having two polyethylene and two polypropylene connectors for each compatibilizer molecule, rather than one, made this compatibilizer stronger than previous versions, Coates and colleagues reported in 2017 in *Science*. The first test of the new compatibilizer involved welding together strips of polyethylene and polypropylene. Ordinarily, the two materials easily peel apart. But with a layer of compatibilizer between them, the plastic strips broke, rather than the compatibilizer seal, when pulled apart.

In a second test, the researchers mixed the compatibilizer into a melted blend of polyethylene and polypropylene. It took only 1 percent compatibilizer to create a tough new plastic.

"These are crazy potent additives," Coates says. Other compatibilizers had to be added at concentrations up to 10 percent to hold these two plastics together. The new compatibilizer is now the basis for Coates' start-up, Intermix Performance Materials, based in Ithaca, N.Y.

Microbial help An enzyme naturally produced by microbes broke down about 50 percent of polyethylene terephthalate, or PET (blue line). A tweaked version of the enzyme broke down more than 80 percent of the plastic (black dotted line). Increasing the amount of the enzyme from 1 milligram per gram of PET to 3 milligrams made it even more efficient — breaking down about 90 percent of PET. SOURCE: V. TOURNIER *ET AL*/*NATURE* 2020



Good as new

Even if every piece of plastic trash could easily be recycled, that still wouldn't solve the world's plastic problem. There are a couple major issues with how recycling currently works that severely limit the usability of recycled materials.

For one thing, recycled plastics inherit all the dyes, flame retardants and other additives that gave each original plastic piece its distinctive look and feel. "The plastic that you actually recover at the end of all this is really a very complex mixture," says chemist Susannah Scott of the University of California, Santa Barbara. Few manufacturers can use plastic with a random mishmash of properties to make something new.

Plus, recycling breaks some of the chemical bonds in plastic molecules, affecting the strength and consistency of the material. Melting down and remolding plastic is sort of like reheating pizza in the microwave — you get out basically what you put in, just not as good. That limits the number of times plastic can be recycled before it has to be landfilled.

The solution to both problems could lie in a new kind of recycling process, called chemical recycling, which promises to make pure new plastic an infinite number of times. Chemical recycling involves taking plastics apart on the molecular level.

The molecules that make up plastics are called polymers, which are made of smaller monomers. Using heat and chemicals, it is possible to disassemble polymers into monomers, separate those building blocks from dyes and other contaminants, and piece the monomers back together into good-as-new plastic.

"Chemical recycling has really started to emerge as a force, I would say, within the last three or four years," says University of Pittsburgh's Beckman. But most chemical recycling techniques are too expensive or energy intensive for commercial use. "It's not ready for prime time," he says.

Different plastics require different chemical recycling processes, and some break down more easily than others. "The one that's farthest along is PET," Beckman says. "That polymer happens to be easy to take apart." Several companies are developing methods to chemically recycle PET, including the French company Carbios.

Carbios is testing enzymes produced by microorganisms to break down PET. Researchers at the company described their work on one such enzyme last April in *Nature*. Microbes normally use the enzyme, called leaf-branch compost cutinase, to decompose the waxy coating on plant leaves. But the cutinase is also good at breaking PET down into its monomers: ethylene glycol and terephthalic acid.

"The enzyme is like a molecular scissor," says Alain Marty, chief scientific officer at Carbios. But because it evolved to decompose plant matter, not plastic, it's not perfect. To make the enzyme better at snipping apart PET, "we redesigned what we call the active site of the enzyme," Marty says. This

E. OTWELL

involved swapping out some of the amino acids along that PET docking site for others.

When the researchers tested their mutant enzyme on colored plastic flakes from PET bottles, applying 3 milligrams of the enzyme per gram of PET, about 90 percent of the plastic broke down in about 10 hours. The original enzyme had maxed out at about 50 percent. Using the terephthalic acid monomers produced in that process, the researchers made new plastic bottles that were just as strong as the originals.

Carbios is now building a plant near Lyon, France, to start chemically recycling PET later this year.

Milder conditions

But other plastics, like polyethylene and polypropylene, are much harder to break down via chemical recycling. Taking apart polyethylene molecules, for instance, requires temperatures over 400° Celsius. At such high heat, the chemistry is chaotic. Plastic molecules break down randomly, generating a complex mixture of compounds that can be burned as fuel but not used to make new materials.

Scott, the UC Santa Barbara chemist, proposes partially breaking down these sturdy plastics in a more controlled way, under milder conditions, to make other kinds of useful molecules. She and colleagues recently came up with a way to transform polyethylene into alkylaromatic compounds, which can be used as biodegradable ingredients in shampoos, detergents and other products. The process involves placing polyethylene inside a reaction chamber set to 280° C, with a catalyst powder containing platinum nanoparticles.

Polyethylene is a long molecule, in which hydrogen atoms are connected to a carbon backbone that can be thousands of carbon atoms long. The platinum is good at breaking carbon-hydrogen bonds, Scott says. "When you do that, you generate hydrogen in the reactor, and the platinum catalyst can use the hydrogen to break the carbon-carbon bonds [in the molecule backbone]. So it actually chops the chain into smaller pieces."

Since this reaction takes place at a relatively mild 280° C, it happens in an orderly fashion, snapping long polyethylene molecules into shorter chains that are each about 30 carbons long. Those fragments then arrange themselves into the six-sided ring structures characteristic of alkylaromatic compounds.

After 24 hours in the reaction chamber, "most of the products are liquids, and most of the liquids are alkylaromatics," Scott says. In experiments, about 69 percent of the plastic in a low-density polyethylene bag was converted into liquid. About 55 percent of a high-density polyethylene bottle cap was transformed. The process produces hydrocarbon gases too, which could be used to generate heat to run the reaction at a recycling plant, Scott says.

For now, this is just a lab demo, and like many new recycling strategies, it's still a long way off from commercialization. And no single upgrade to the recycling pipeline will rid the world of its growing mountains of plastic trash. "We're going to need a suite of technologies to meet this challenge," says Daniels, of the REMADE Institute. But each new technology — whether it's focused on making plastics easier to recycle, or transforming them into more useful materials — could help. ■

Built to last

The plastics produced today were never designed to be used more than once. That's why recycling plastics — particularly into material that is as good as new — is so difficult. But researchers are going back to the drawing board to ask themselves, "What does the next generation of materials look like? How do you design a material specifically so that it never has to go into a landfill?" says Eric Beckman, a chemical engineer at the University of Pittsburgh. "Chemists are looking at whether you can design a polymer that falls apart on command."

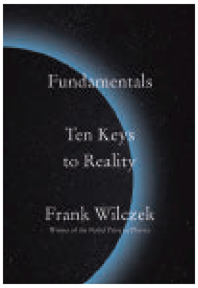
The development of a class of next-gen polymers, called PDKs, for poly(diketoenamine)s, was reported in *Nature Chemistry* in 2019. "PDKs have the ability to break their bonds under relatively mild conditions — certainly with much lower energy intensity than any of the plastics that are currently used today," says study coauthor Brett Helms, a chemist at the Lawrence Berkeley National Laboratory in California. Simply dunking the plastic in an acid solution with a pH of 1 or 2 is enough to break the bonds between its monomer building blocks.

"Materials don't usually encounter a pH that's that low, so it's not like if you put PDKs in vinegar, the polymer is going to start breaking down," Helms says. But it could make for easy recycling. The PDK monomers can then be used to make pristine new plastic, again and again.

Widespread plastics like polyethylene terephthalate, or PET, and polyethylene are so cheap to make that any breakout polymer would have a tough time entering the market, Beckman says. So for now, inherently recyclable plastic is just an academic curiosity. But maybe, decades from now, plastics made to be recyclable from the get-go will help solve the world's plastic waste problem. — *Maria Temming*

Explore more

■ Roland Geyer, Jenna Jambeck and Kara Lavender Law. "Production, use, and fate of all plastics ever made." *Science Advances*. July 19, 2017.



Fundamentals
Frank Wilczek
PENGUIN PRESS, $26

BOOKSHELF

Building reality from a few ingredients

As the story is usually told, science began when some deep thinkers in ancient Greece decided to reject the popular mythological explanations for various natural phenomena. Those early philosophers sought logical explanations for things like thunderstorms, rather than attributing them to Zeus throwing temper tantrums in the form of thunderbolts.

But early Greek scientific philosophy was not merely about replacing myth with logic. For the Greeks, explaining reality did not mean just devising a logical reason for each natural phenomenon in isolation — it was also about seeking a deep, coherent explanation for everything. And that meant identifying fundamental principles that explained a diversity of phenomena, encompassing the totality of physical reality. That's the essence of science.

Science today is vastly more advanced, accurate and complex than it was in ancient times. Nevertheless, all of today's sophisticated knowledge of physical reality is also rooted in a few fundamental principles, which physics Nobel laureate Frank Wilczek attempts to identify and explain in his latest book, *Fundamentals: Ten Keys to Reality*.

Wilczek's fundamentals are framed as the "fundamental lessons we can learn from the study of the physical world," as expressed by "the central messages of modern physics." Each chapter assesses one of the "broad principles" he regards as fundamental. He explains their role in modern physical understanding and relates them to "how we humans fit into the big picture."

He divides his account into two main parts: "What there is" and "Beginnings and ends." He describes the fundamentals he identifies from the perspective of two themes: "abundance" and "born again." (He does not mean "born again" in a religious sense, but rather as an expression of the need to realize that the view of the world based on ordinary human experience does not conform to the underlying reality that modern science reveals. As adults, we must be "born again," without preconceptions formed in childhood, to appreciate the actual fundamentals of reality.)

What there is, Wilczek avers, includes plenty of space and plenty of time. Space, for instance, is vast no matter which way we look — compared with the universe, people are tiny; compared with the atom, people are huge. Similarly, the universe has existed for a very long time and has an even longer future ahead of it. Additional ingredients of this vast cosmos ultimately consist of a handful of subatomic particles, or more precisely, quantum fields responsible for those particles. And their behavior is governed by a small set of physical laws, as codified in the equations of general relativity and physicists' "standard model" of particles and forces. Those ingredients, though limited in type, exist in abundant quantities. And the supply of energy in the cosmos needed to cook those ingredients into complex things is immense: A single star (the sun) emits thousands of times more than the total annual energy consumption of the Earth's entire population.

Wilczek describes how all those ingredients came to be in the form we see today in his "Beginnings and ends" chapters. A key part of the story is the emergence of complexity despite the simplicity of the fundamentals — the very few ingredients governed by very few laws. It turns out that tiny differences in the distribution of the ingredients lead to a diversity of structure and composition found on all scales throughout the cosmos. Gas clouds in space that differ only slightly, for example, "can yield systems of stars and planets that differ drastically."

> "The world is simple and complex, logical and weird, lawful and chaotic."
> FRANK WILCZEK

Another key idea is Wilczek's final fundamental, the physicist Niels Bohr's principle of complementarity. Understanding the world requires the mind-expanding realization that one thing viewed "from different perspectives, can seem to have very different or even contradictory properties." And that is why "the world is simple and complex, logical and weird, lawful and chaotic."

Fundamentals is an engaging account of the history of humankind's understanding of reality, told by one of the key contributors to recent parts of that story. Wilczek's grasp on the physics he relates is comprehensive and authoritative; he conveys technicalities with a rare combination of accuracy and accessibility. He is a little sketchy on some of his history, though. He gives an incorrect date for the Geiger-Marsden experiment leading to the discovery of the atomic nucleus, for example. Also, Einstein did not base his original proposal of photons on Max Planck's work, and Wolfgang Pauli did not say the neutrino could not be observed in the letter wherein he originally proposed it.

Such quibbles aside, Wilczek provides an exceptionally clear guide to the state of physical knowledge in the early 21st century, much in the spirit of the sort of explanation that the ancient Greeks desired. Of course, as Wilczek emphasizes, the story is not nearly over. Perhaps a century or more from now, someone else will have to take up the task again.

"We *do* understand many aspects of the physical world very deeply," Wilczek writes. Yet "our understanding of the physical world is still growing and changing. It is a living thing." *— Tom Siegfried*

Editor's Note: Frank Wilczek is a member of the Honorary Board of Society for Science, which publishes Science News.

80TH ANNIVERSARY

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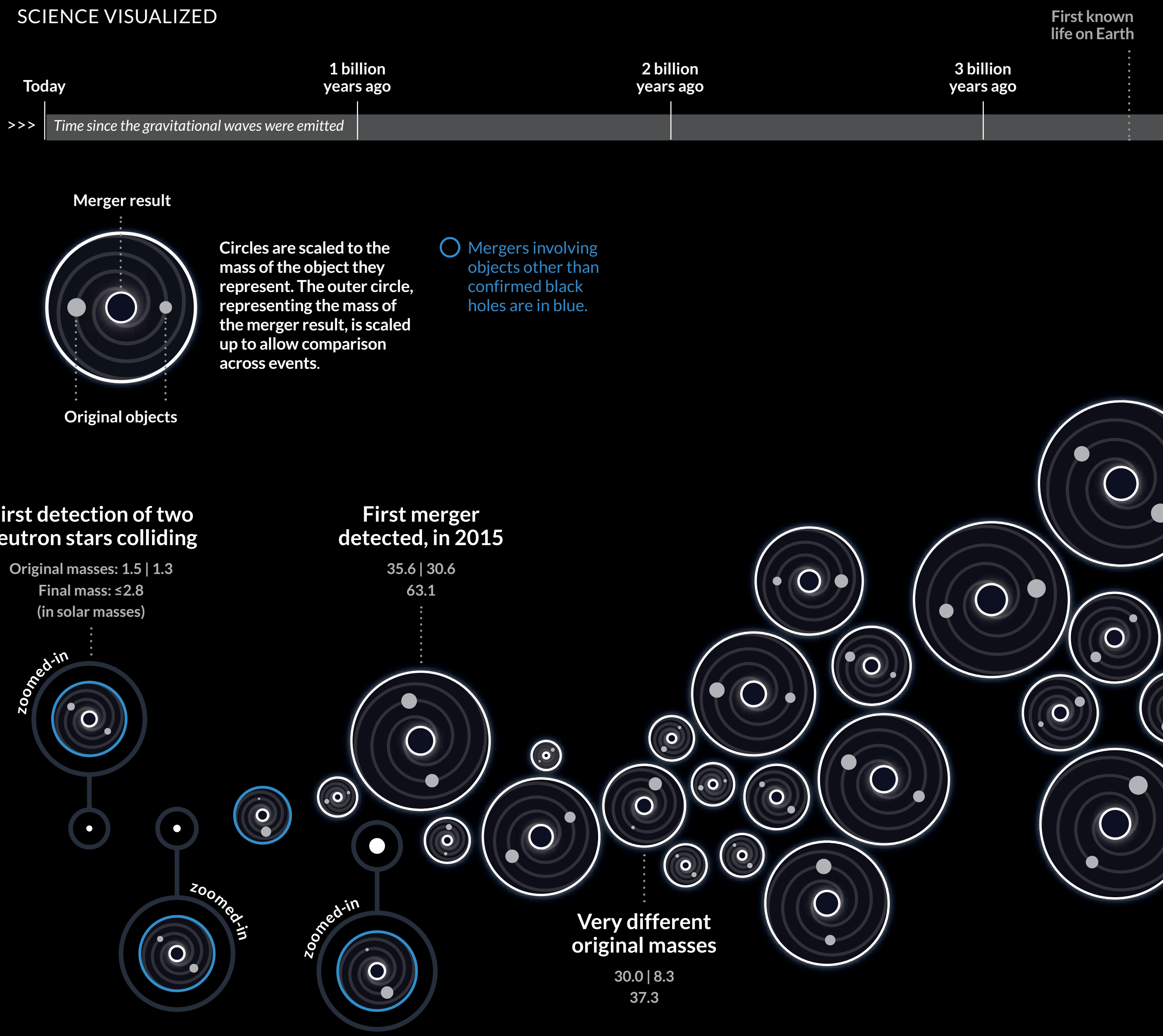
TOP 300 SCHOLARS

Society for Science is proud to announce this year's Top 300 scholars in the Regeneron Science Talent Search, the oldest and most prestigious science and math competition for high school seniors in the United States. The scholars were selected from 1,760 entrants and come from 193 American and international high schools in 37 states, Puerto Rico, Taiwan and Singapore. Each scholar receives a $2,000 award with an additional $2,000 going to their respective school.

Laalitya Acharya • Vardhan Agrawal • Shray Alag • Ibrahim Al-Akash • Mir Zayid Alam • Foyez Alauddin • Ashley Alcantara • Christopher Alexander • Isabella An • Yash Anand • Sraavya (Aashi) Anne • Parth Asawa • Perisa Ashar • Elena Bai • Akhilesh Balasingam • Manav Bansal • Alexandra Bardas • Clara Barschdorff • Hannah Barsouk • Hirak Basu • Michael Batavia • Alexander Bell • Anika Bhadriraju • Sid Bharthulwar • Niharika Bhattacharjee • Tymber Boldt • Malik Bradford III • Alex Breslav • Charles Brown • Jonathan Bruce • Tyler Burden • Callie Burns • Nicole Camilliere • Olivia Canter • Katrina Case • Anya Chabria • Benjamin Chan • Maya Chari • Alexander Chasteen • Alan Chen • Alvin Chen • Anthony Chen • Eddie Chen • Eric Chen • Linda Chen • Quanlin Chen • Sarah Chen • Dev Chheda • Derek Chien • Erica Choe • Kenneth Choi • Yunseo Choi • Sam Christian • Elizabeth Chun • Joseph Clary • Patryk Dabek • Raiya Dhalwala • Saisha Dhar • Mia Dittrich • Kosei Dohi • Melissa Du • Owen Dugan • Karin Ebey • Maya El-Sharif • Daniel Feng • Rachel Field • Tali Finger • Alexandra Fitzgerald • Halley Friedman • Tara Fusillo • Jessie Gan • Noah Getz • Animesh Ghose • Aryan Ghotra • Gopal Goel • Hannah Goldenberg • Bailey Goldstein • Michael Gomez • Shayna Gordon • Amy Guan • Anshul Guha • Sanjana Gurram • Ali Hafez • Priva Halpert • Emily Hashem • Ryan Helmer • Ava Herzog • Anthony Hill • Sammy Hillenmeyer • Zen Ho Sang • Erin Horack • Wenjun Hou • Hayden Housen • Alicia Hsu • David Hu • William Hu • Lixin Huang • Jared Ilan • Vedanth Iyer • Rincon Jagarlamudi • Eshani Jha • Kylan Jin • Elisha Johnston • Eli Jones • Danielle Kacaj • Yash Kadadi • Vasu Kaker • Raquel Kanner • Sohum Kapadia • Sarah Karam • Saaim Khan • Ishan Khare • Beom Joon Kim • Eric Kim • Isabel Kim • Jaeah Kim • Song Kim • Thomas King • Khushi Kohli • Jordyn Krinsky • Siddharth Krishnakumar • Aravind Krishnan • Navya Lam • Hope Lane • Victor LaVaglia • Jessica Lee • Katelyn Lee • Julia Levine • Aidan Li • Danny Li • David Li • Marvin Li • Sabrina Li • Sean Li • Victor Li • Yangyang Li • Anne Liang • James Licato • Julie Lin • Zipeng Lin • Addison Liu • Catherine Liu • Daphne Liu • Friedrich Liu • Kelly Liu • Stanley Liu • Noah Loewy • Michael Lu • Lana Lubecke • Emily Ma • Srinath Mahankali • Michael Maloney • Andrei Mandelshtam • Linlee Mangialardi • Neha Mani • Aerin Mann • Sriya Mantena • Tarun Kumar Martheswaran • Lucia Martin • Arjun Mazumdar • Michaela McCormack • Tanya Mehta • Viraj Mehta • Beatrice Mihalache • Brian Minnick • Roshni Mishra • Rebecca Monge • Taylor Moniz • Nina Nair • Sathvik Nallamalli • Rithika Narayan • Charit Narayanan • Aryan Naveen • Om Nerurkar • Divya Nori • Nnamdi Obi • Ethan Ocasio • Michael Odzer • Lara Ozkan • Celeste Paerels • Jian Park • Allison Pascual • Sayalee Patankar • Alexander Patti • Aalok Patwa • Michael Pavelchek • Nicholas Pietraszek • Alexandra Popescu • Jayanth Pratap • Sofia Pronina • Ritvik Pulya • Jeffrey Qian • Timothy Qian • Melanie Quan • Maiya Raghu • Vishaal Ram • Shreya Ramachandran • Giselle Rasquinha • Rhea Rasquinha • Sean Reichbach • Elaina Render • Sarah Rojas • Leela Roye • Tyler Ruvolo • Meagan Ryan • Saksham Saksena • Julia Salatti • Sreenidhi Sankararaman • Laboni Santra • Anushka Sanyal • Julia Savino • Sam Savitt • Lori Saxena • Lila Schweinfurth • Krupa Sekhar • Ganesh Selvakumar • Jack Sendek • Alay Shah • Saloni Shah • Vyom Shah • Raiyaan Shaik • Andy Shar • Siddharth Sharma • Sasha Shefter • Jerry Shen • Justin Shen • Fareed Sheriff • William Shi • Eleanor Sigrest • Emma Silverman • Sam Singer • Priya Soneji • Edgar Sosa • Isabella Souza • Christian Spadini • Nitin Sreekumar • Saraswati Sridhar • Alliyah Steele • Suvin Sundararajan • Nitya Sunkad • Aditya Tadimeti • Claire Tang • Dasia Taylor • Emily Tianshi • Marie-Hélène Tomé • Christopher Tong • Arya Tschand • Katherine Tung • Zoya Unni • Amulya Vatsavai • Parisa Vaziri • Vetri Vel • Bala Vinaithirthan • Adway Wadekar • Emma Wang • Eric Wang • Jason Wang • Jeffrey Wang • Mia Wang • Jerry Wei • Ethan Weisberg • Scott Weitman • Maya Weitzen • Kevin Wen • Kate Weseley-Jones • Bella Wiebelt-Smith • Devin Willis • Joseph Winterlich • Andrew Woen • Michael Wong • Charles Wu • Jiefei Wu • Helen Xiao • Zheheng Xiao • Angelina Xu • Justin Xu • Sidra Xu • Noam Yakar • Emily Yang • Emma Yang • Jason Yang • Kaien Yang • Lixin Yang • Vivian Yee • Julius Yoh • Lucy Zha • Alex Zhang • Jason Zhang • Jessica Zhang • Michael Zhang • Sarah Zhang • Aaron Zhao • Andrew Zhen • Alec Zhou • Alexander Zhou • Amy Zhou • Beining Zhou • Jeremy Zhou • Alec Zhu • Honglin Zhu



A complete collection of cosmic smashups

Since 2015, scientists have observed the ripples in spacetime, called gravitational waves, produced when cosmic beasts such as black holes merge. But what started as a trickle of detections by the gravitational wave observatories LIGO and Virgo has turned into a torrent.

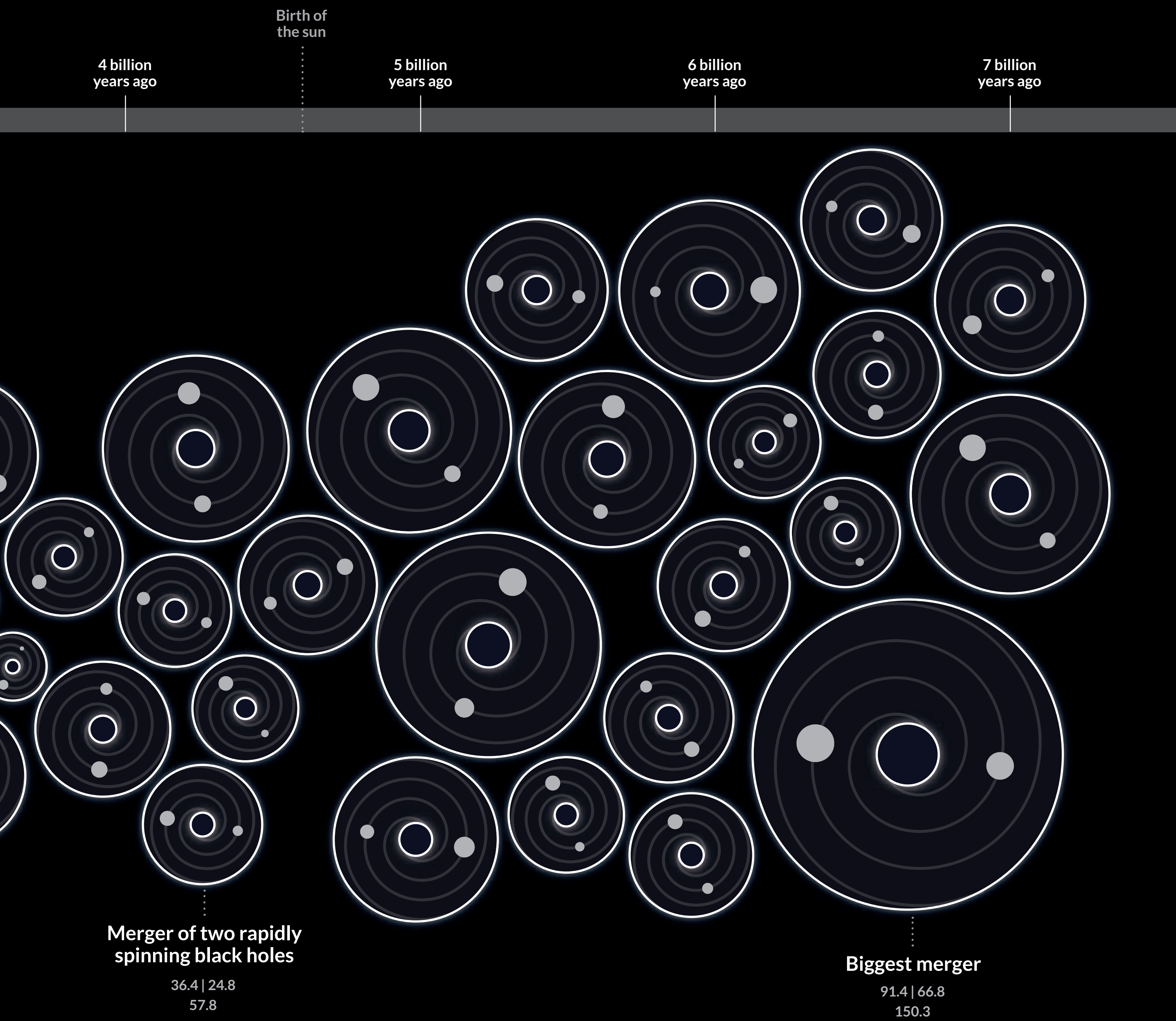
Each of the large circles above represents one of the 50 detected mergers. Most resulted from two black holes spiraling inward before colliding. A few arose from either collisions of dense stellar corpses called neutron stars or celestial bodies that couldn't be confidently identified.

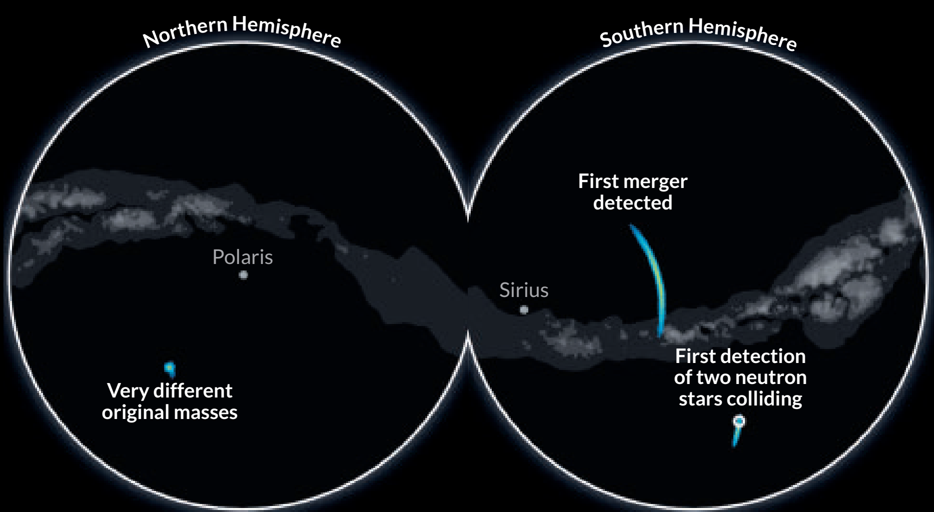
Because neutron stars are less massive than black holes, their mergers are harder for LIGO and Virgo to see. So those found so far tend to be closer to Earth, which also means they happened in the more recent past.

Some of the collisions left behind surprisingly large black holes, including the biggest known merger, which created the first definitive example of a class of medium-sized black holes (*SN: 9/26/20, p. 7*). Other smashups involved objects with very different masses or black holes spinning rapidly, systems that could help reveal how pairs of black holes form. Future detections will further illuminate the furtive movements of these mysterious objects. *— Emily Conover, with graphics by Nadieh Bremer*

SOURCE: LIGO AND VIRGO

Explore an interactive version of this graphic at **bit.ly/SN_GravitationalWaves**





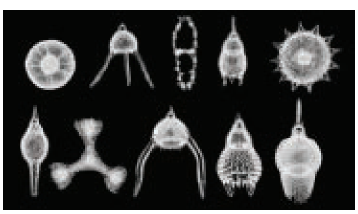
Location on the sky

Colored areas on this map indicate regions of the sky where these three labeled mergers probably occurred. To locate the sources of gravitational waves, researchers compare the timing of the waves' arrival at detectors around the world. For the neutron star collision, a more precise location (white circle) was determined by also observing light from the smashup.

NOVEMBER 21, 2020 & DECEMBER 5, 2020

Stay tuned

In 1970, researchers thought Earth's magnetic pole reversals might be to blame for long-ago extinctions of single-celled organisms called Radiolaria (10 living species shown below). But no strong evidence of a direct link has turned up, **Jonathan Lambert** reported (*SN: 11/21/20, p. 4*) in an update to the article "Effects of Earth's magnetic field" (*SN: 11/21/70, p. 392*). Reader **Doug Pruner** joked: "Radiolarian extinctions? Of course. The reversals caused interference with their radios."



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Lying low

During Africa's dry season, when mosquitoes are scarce, malaria parasites in human blood turn their genes on and off to keep numbers low so infection doesn't set off alarm bells for the immune system, ***Erin Garcia de Jesus*** *reported in "Malaria hides in the dry season"* (SN: 11/21/20, p. 8).

"How on Earth does the malaria parasite know it is the dry season from within the moist human body?" reader **Elizabeth McDowell** asked. "The human body must maintain moisture levels year-round.... What signals the parasite to alter gene activity?"

The mechanism remains unclear, **Garcia de Jesus** says, "but the researchers are searching for answers." One hypothesis is that mosquito bites play a role. "Perhaps some protein in mosquito saliva tells the parasites, 'Hello, I'm here to take you to your next victim,' and the parasites adjust gene activity to ramp up their numbers," she says.

E.T. phone home?

New methods are ramping up the search for alien intelligence, ***Maria Temming*** *reported in "Sixty years into the search for E.T."* (SN: 11/21/20, p. 18).

Many readers were intrigued. The story "challenged my memory on the search for messages from aliens with [Temming's] statement: 'So far, SETI scientists haven't picked up a single alien signal,' " reader **David Cosson** wrote. "My recollection was that NASA launched the two Voyager spacecraft in 1977 each carrying a golden record that included 90 minutes of world music, including Bach, Mozart and Chuck Berry's 'Johnny B. Goode.' I thought I recalled a press report ... that NASA had received a reply from aliens who had played the record. The message was: 'Send more Chuck Berry.' Perhaps my memory is faulty, but I recall the reporter as somebody named Steve Martin," **Cosson** joked.

Reader **Bob Johnson** remains puzzled by some researchers' efforts to detect radio frequency signals. "It is highly unlikely other civilizations are, like us, going through the first 100 years of communication evolution," **Johnson** wrote. "We should be hunting for signals in the ultraviolet, X-ray and gamma-ray frequencies. Even though older technologies work, they are displaced by new methods. Looking for [radio frequency] signals from E.T. is analogous to listening for ... modem tones as an indication of intelligent life."

Watery skies

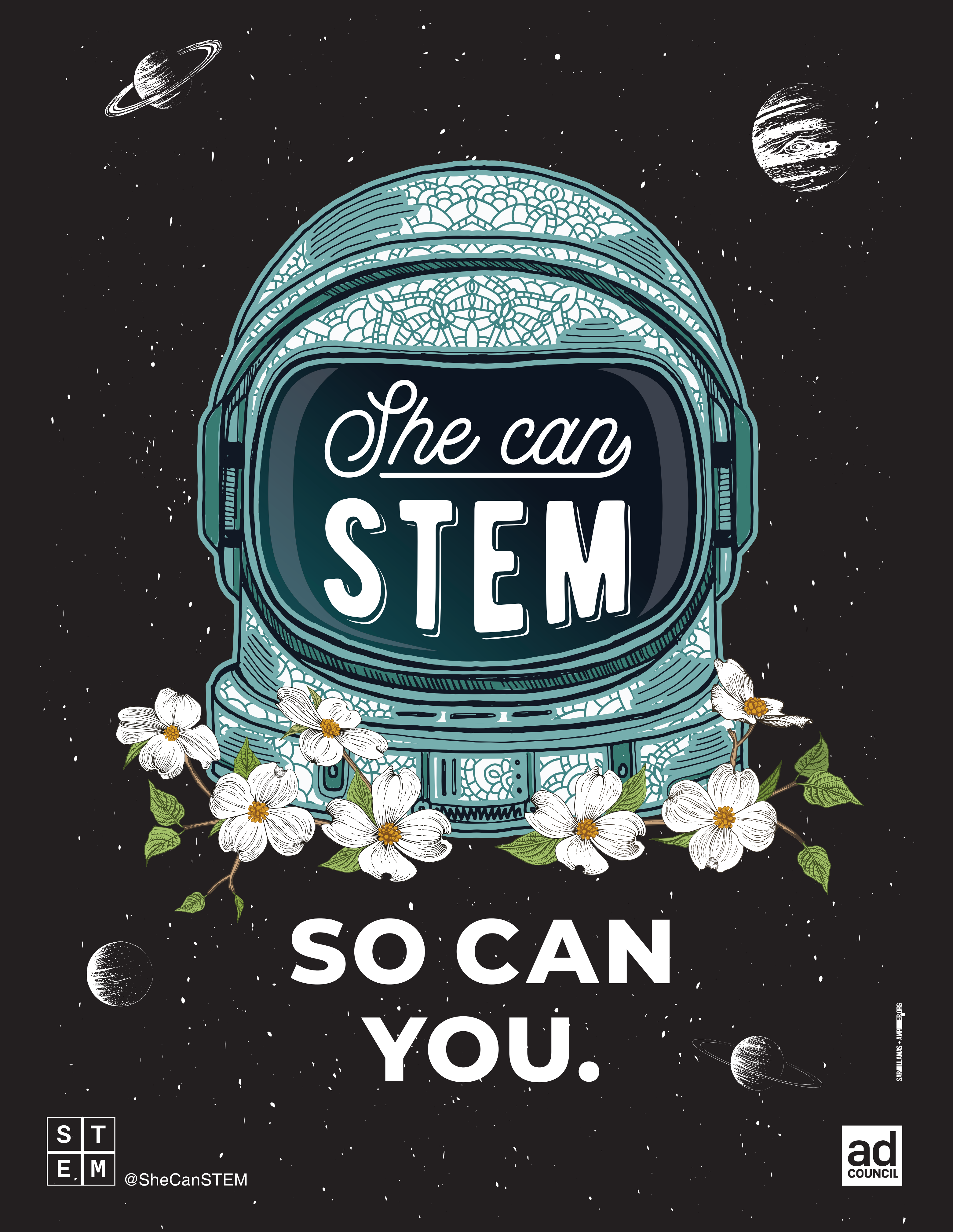
Water high up in Mars' atmosphere splits apart within a few hours, leaving hydrogen atoms to float away, ***Lisa Grossman*** *reported in "Scientists rethink how the Red Planet loses water"* (SN: 12/5/20, p. 14).

Reader **Lorenza Zamarron** wondered what happens to oxygen. "Where does the oxygen go? If the oxygen is heavier, does it fall back down to Mars? Is it destroyed?"

At least some oxygen breaks free of Mars' gravity in a process called photochemical escape, says **Shane Stone**, a planetary chemist at the University of Arizona in Tucson. "Additionally, some oxygen would inevitably be transported down toward and around the planet," **Stone** says. "Many scientists believed that atmospheric chemistry would, over very long time periods, balance the escape of hydrogen and oxygen to match the 2:1 ratio that these elements are found in water. However, some of us are rethinking this concept in light of this discovery of water transport directly to the upper atmosphere," **Stone** says. That oxygen is slow to escape could partly explain why the Red Planet is red. "Oxygen in the atmosphere reacts with minerals on the surface to produce iron oxide (rust), which is responsible for the reddish-orange color that is so indelibly Martian," **Stone** says. "In other words, Mars is oxidized."

Correction

In "#BlackInSTEM leaders make change happen" (*SN: 12/19/20 & 1/2/21, p. 26*), the name of a BlackAFinSTEM group member was incomplete. Her name is Anna Gifty Opoku-Agyeman.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Solve the problem below.

A cylinder with a radius of two centimeters and height of eight centimeters is full of water. A second cylinder with a radius of four centimeters and height of eight centimeters is empty. If all the water is poured from the first cylinder into the second cylinder, what will be the depth of the water in the second cylinder?

Visit rose-hulman.edu/RoseChallenge to submit your answer. If your answer is correct, you'll be entered for a chance to win a Rose-Hulman swag item!