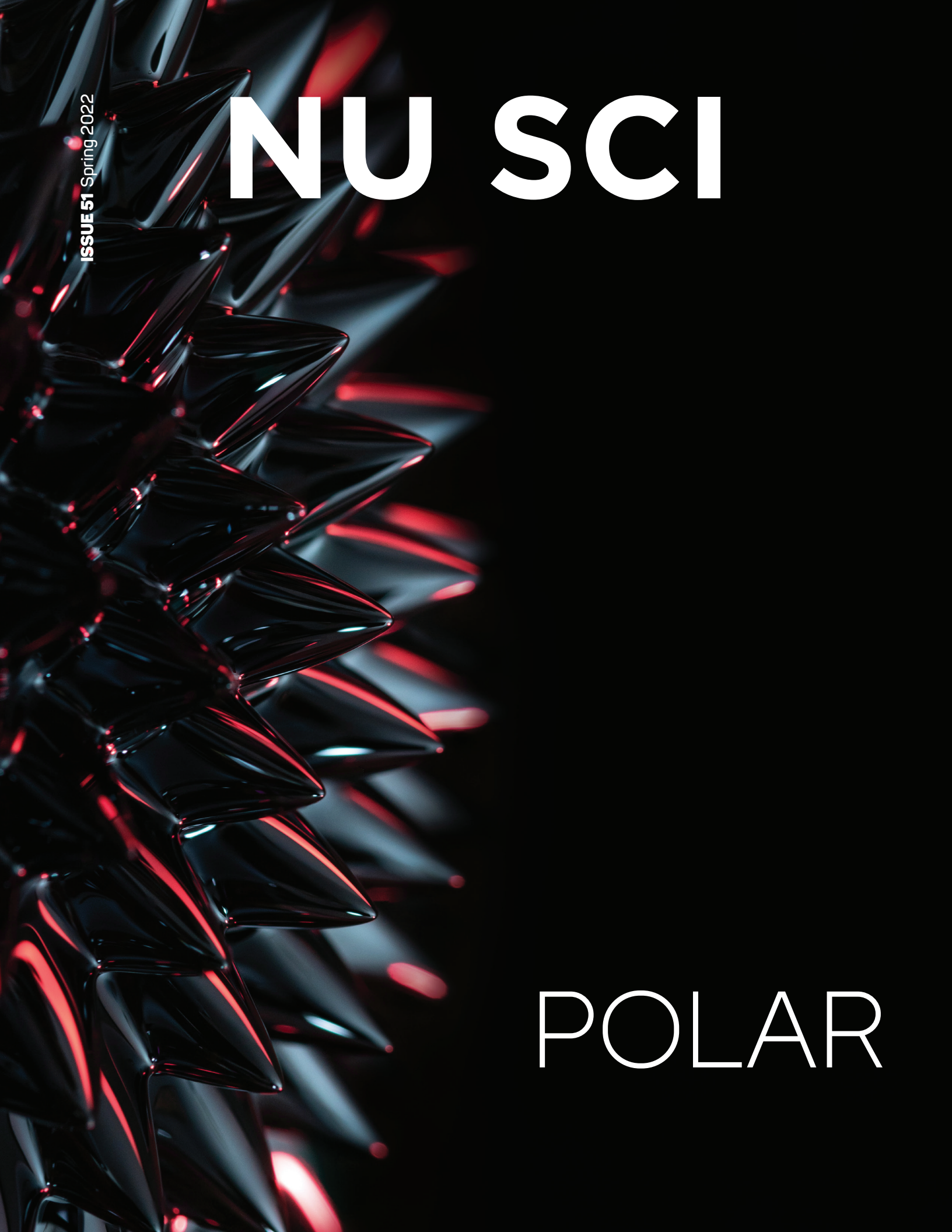

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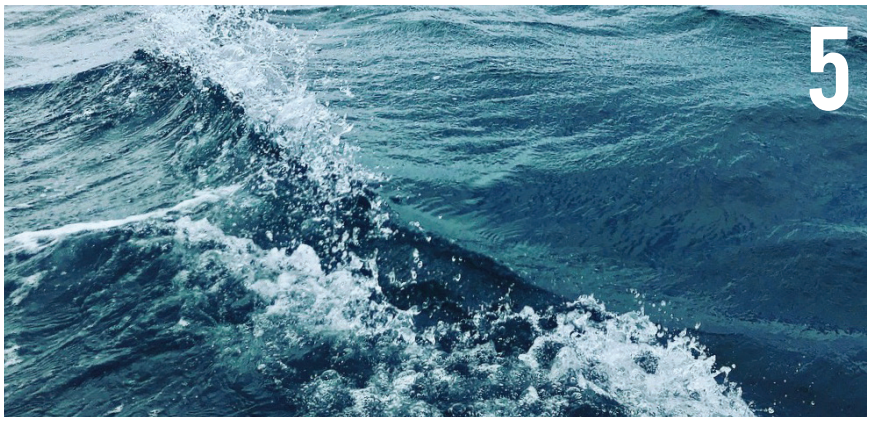

LETTER FROM THE EDITOR

From one extreme to the other, Boston's weather this semester has had its fair share of polar moments — going from sunny and warm one day to below freezing and snowing the next. Whether in jest or seriously, we can point to this shift in weather as evidence for climate change — an issue entirely polarized itself. We can take for granted the antithetical nature of poles, opposites that clash or complement, but upon further observation, we find that that's not always true.

Take the North and South Poles, for instance. Hosts to diversities of life but both nonetheless frosty and so associated with the cold. Though spatially opposite, they seem to have more in common than their middle point in the equator. What does it mean to have preconceived notions of what it means to be polar, and what does it mean to have those notions subverted?

In this 51st issue of *NU Sci*, our writers explore what it means to be polar and polarized. We take you to the distant and desolate lands of Antarctica, Mars, and Saturn to explore the different expressions of planetary poles. We visit the extremophiles of underwater volcanoes, the structures in the mantis shrimp's eyes, and the unspoken lives of drug researchers to examine the nuances of "Polar."

As always, I'd like to thank the writers, designers, and photographers who make these stories possible. And please check out our website, nuscimagazine.com, to read our Online Exclusive content from this issue.

As you go from one end to the other, take a moment to appreciate the surprising symmetries and charming asymmetries that span across this perfectly imperfect world of ours.

Binh Dang
Editor-in-Chief

STAFF

Cover Photos by Ian Hay, Mimi Perez, & Gus Mueller

THE BATTLE BETWEEN HOT AND COLD

How TRP channels are involved in temperature transduction in human skin

BY EMMA COLACO, CELL & MOLECULAR BIOLOGY, 2025

DESIGN BY JASMIN PATEL, BEHAVIORAL NEUROSCIENCE, 2025

It's a great wonder how organisms remain at a constant temperature, despite many outside influences like freezing winds or heat waves. Maintaining proper body temperature is key for most organisms. The temperature-controlling systems in mammals are extremely complex and well-designed, ensuring that they maintain homeostasis. For these animals, the environmental temperature can be sensed by external receptor cells such as thermoreceptors located on the skin. Transient receptor potential (TRP) channels, located in the plasma membrane of many animal cells, have been discovered to be extremely important in thermosensory reception.

TRP cationic channels mediate the influx and efflux of ions into cells in response to chemical or physical stimuli. There are many different human cell types in which TRP channels are present, such as keratinocytes, sensory neurons, melanocytes, and inflammatory cells. TRP channels have many functions in human cells, ranging from feeling sensations to skin homeostasis. These channels are essential to bodily functioning and, if gone wrong, can lead to chronic pain and itching.

In human skin, TRP channels can be activated by increases and drops in temperature. This temperature fluctuation can lead to the conversion of cells into heat and cold sensors. There are specific heating and cooling TRP channels that respond to their respective hot or cold stimuli.

A cold-sensitive TRP channel, TRPM8 is a non-selective cationic channel that can be activated by cold temperatures between 25 and 18 degrees Celsius. Another TRP channel called TRPA1 allows for the sensation of cold-painful temperatures that are below 18 degrees. TRPA1 is activated at lower temperatures than TRPM8 and is shown to have an outward cationic current with similar permeability for Ca^{2+} and Na^{+} ions. An experiment was performed on mice to examine the sensation of cold stimuli by both the TRPA1 and TRPM8 channels and published in the journal *Frontiers in Cellular Neuroscience*. Scientists compared TRP effects with visceral (NG) neurons (which conduct impulses from inside organs such as the heart and liver) versus somatic neurons (which conduct impulses from skin, muscles, and joints). After being stimulated with a cold sensation, the TRPA1 mice did not seem to have any difficulty sensing cold stimuli through the skin, while the TRPM8 mice had a reduced response to the same stimuli. In the paper Ion Channels and Thermosensitivity: TRP, TREK, or Both?, about 50 percent of NG neurons in culture were activated by cooling through TRPA1 channel activation. Overall, the data suggest that TRPA1 is the principal ion channel involved in cold sensation in NG neurons while TRPM8 fulfills the same role in somatic neurons. Cold activation of nerves can produce one of two sensations: moderate cold produces a sensation of pleasant coolness, while more intense cold produces a sensation of pain that triggers reflexes allowing animals to avoid tissue damage.

As for the heat-sensitive TRP channels, four TRP subtypes are activated by temperature increases, according to a study in the International Journal of Molecular Sciences. Two of them respond to warm stimuli (TRPV4 to temperatures over 27 degrees and TRPV3 to temperatures over 34 degrees), and the other two respond to hot-painful stimuli (TRPV1 to temperatures over 43 degrees and TRPV2 to temperatures over 52 degrees). It has been shown that TRP channels contribute more to the speed with which mice select a more comfortable temperature than to the value of the temperature itself. TRPV4 channels are more likely to be involved in choosing the preferred temperature from a non-painful range. Furthermore, TRPV3 channels can transmit thermal stimuli through skin keratinocytes, which then transmit this information to nerve endings.

Studying cold-sensitive and heat-sensitive TRP channels in mice allows us to expand these results to human skin and how we process extreme temperatures to maintain homeostasis. By understanding how our internal body temperature systems work, we can go outside and brave the cold knowing that our TRP channels are working to keep us warm!

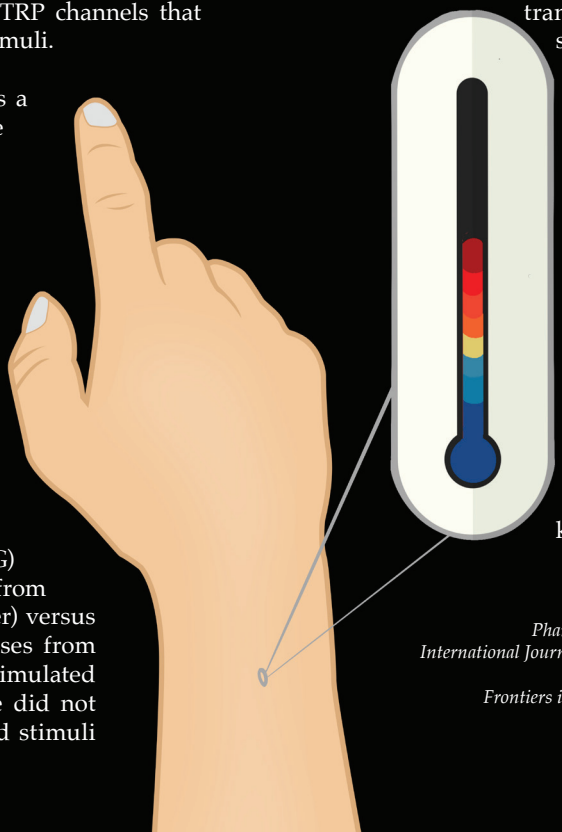

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PHOTO BY PIXABAY

CLIMATE CHANGE HURTS WARM WATERS, TOO

Coldwater fish need fuel from warm habitats

BY MIMI PEREZ, ENVIROMENTAL & SUSTAINABILITY STUDIES, 2025

We as humans must serve as protection where resources are scarce, populations are threatened, and where there lacks necessary keys to survival. Climate change is deteriorating habitats and creating unlivable conditions for aquatic ecosystems. People fight against climate change to defend and conserve these natural environments. We want to save the earth! However, this is not a "one size fits all" effort. The Redband rainbow trout species travel between habitats to survive, taking in nutrients in one place and reproducing in the other. Inhabiting bodies of water from lakes to streams, Great Basin redband trout, a population of redband rainbow trout, are found on the west coast of the United States. They need multiple habitats because higher temperature waters create food for the fish and cooler temperature waters act as safe breeding grounds. While some fish species need only one habitat with year-round temperature conditions that are suitable enough for survival, species with unique life plans like mobile fish require different conservation efforts.

Redband rainbow trout are a mobile fish species that range from California to British Columbia, populating lakes, streams, and the ocean. This excludes them from many conservation efforts. Climate adaptation planning considers habitats for refugia, or an area that allows organisms to survive through harsh environmental conditions, as the climate warms. Mobile fish take advantage of differing temperatures, so adding refugia exclusively in cooler regions to match with global warming patterns will not support this fish's life plan. Redband rainbow trout are unique as a mobile coldwater species because they utilize multiple habitats annually rather than one. For other fish that stay in one habitat, though, conservation efforts often focus on cooler habitats during summer conditions for refugia, steering away from preserving seasonally warm habitats that can be beneficial to mobile fish. So, factoring in migration into conservation efforts has become a particular challenge.

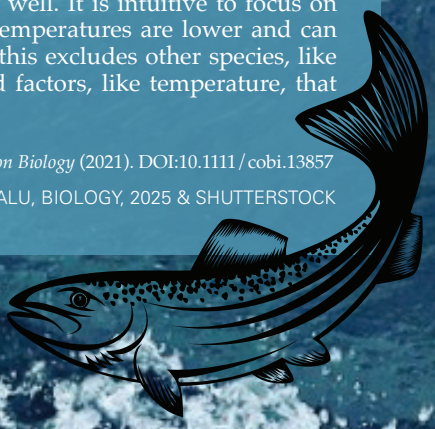
Great Basin redband trout, a population of redband rainbow trout population complete a biannual migration to and from Upper Klamath Lake, Oregon. With temperatures above 25 degrees Celsius, summer conditions are unbearable for coldwater fish. So, the trout find refuge in cooler tributaries or springs, waiting for summer to end. When it does, the lingering warm waters turn into scavenging grounds. In the fall, trout start their voyage to Upper Klamath Lake to forage. They are welcomed with an abundance of nutritious growth formed in the hot waters of summer. The lake becomes their feeding grounds, where the trout indulge on smaller fishes that have survived the warmer temperatures since they need less oxygen. The trout can benefit from the lake productivity leftover from summer. The forage rejuvenates them, and they then migrate back to cooler tributaries with fuel for their winter spawning in the cooler waters. This voyage is completed again in the spring season before summer comes. The trout must gather energy so they can make it through the summer.

Warm waters are essential for migratory fishes, but climate adaptation planning devalues the importance of warm habitats as a refuge for coldwater fish. As water temperatures rise, coldwater habitats are prioritized for adaptation planning because they are below the fish's peak temperature. What about warm water habitats? They provide trout with energy to sustain themselves. With climate change causing even warmer waters, not even the smaller fish that trout feed on would survive in such diminished oxygen. Conservation efforts that identify refugia protect populations from environmental threats. Upper Klamath Lake is overlooked as a potential refugia because it already meets stressful temperatures in the summer season; what needs to be considered is its crucial resources for mobile fish who find their energy in the warm waters. It is currently seasonally hot, but if seasonal becomes a year-round occurrence, trout will lose their incentive to migrate to the lake to feed and gather energy for spawning, depleting their population.

As climate change continues to negatively alter aquatic ecosystems, it is important to include the warm water habitats that are affected as well. It is intuitive to focus on cool water habitats where temperatures are lower and can be utilized as a refuge, but this excludes other species, like redband rainbow trout, and factors, like temperature, that complement their needs.

Conservation Biology (2021). DOI:10.1111/cobi.13857

PHOTOS BY RUTH BEKALU, BIOLOGY, 2025 & SHUTTERSTOCK



Hot and touching research wins 2021 Nobel Prize

BY ANNIKA CHANG, COMPUTER SCIENCE & BEHAVIORAL NEUROSCIENCE, 2025

On October 4, 2021, David Julius and Ardem Pataoutian won the Nobel Prize in Medicine for discovering how we can distinguish pain from spicy food and warmth from a hug. Their discovery marks a major leap in our understanding of how the human body converts sensations from the environment to electrical signals that the brain can understand. Patrik Ernfors, one of the members in the Nobel Prize Committee, remarked that their research has "unlocked one of the secrets of nature, by explaining the molecular basis for sensing temperature and mechanical force." From feeling the crisp wind against our face when we first walk outside to the wet sand between our toes on the beach, our ability to sense our ever-changing environment is one of the most quintessential facets of life and has remained a mystery to many scientists over the years. In fact, in the 17th century, René Descartes thought that humans could sense the outside environment through long threads that connected the different parts of the body to the brain. The Nobel Prize research thus represents a significant breakthrough in understanding the intricacies of the nervous system and its relation to physical stimuli.

To discover how the body feels a burning sensation from spicy food, Julius' experiment used capsaicin, a compound found in many peppers that is responsible for heat. Julius and his team at the University of California, San Francisco started by creating a cDNA library containing millions of genes that are expressed in sensory neurons associated with pain or touch. The search for the specific gene that causes cells to react to capsaicin was an arduous task, as his team meticulously expressed, or turned on, each gene in cells that were unresponsive to capsaicin and then observed which cells became responsive due to that gene expression. They ultimately identified a gene that codes for a TRPV1, a receptor on the surface of cell membranes that acts as an ion channel. Capsaicin reacts with TRPV1 to cause ion channels to open and calcium ions to flood into the cell, sending an electrical signal to the brain that produces pain. A few years following the breakthrough discovery of TRPV1, Julius and Pataoutian independently found the gene TRPM8, which works similarly to TRPV1 but reacts to menthol, a chemical compound that produces a cool and minty taste. The discovery of both receptor proteins, TRPV1 and TRPM8, explains how we feel hot, cold, and their sometimes painful effects.

As for the "touching" aspect of the research, Pataoutian and his team at the Scripps Research Institute identified how the body converts mechanical stimuli or touch to neural signals. The team identified 72 possible genes that code for receptors associated with ion channels on the cell membrane. Through manipulation of a cell line, a culture where one cell that releases an electrical signal when poked is propagated continuously, Pataoutian's team underwent the painstaking task of silencing each of the 72 identified genes to determine which was responsible for producing an electrical signal. Finally, one silenced gene caused cells to be unresponsive to any poking. The gene codes for an undiscovered ion channel that was then named "Piezo1" after the Greek word for pressure. Pataoutian also found another touch protein receptor, now called "Piezo2," and both these receptors are important for maintaining many bodily processes like blood pressure and breathing.

Julius and Pataoutian's breakthrough discovery has launched a new field of research involving the development of pain drugs that specifically target cell protein receptors similar to the ones they found. For example, another receptor called TRPC5, identified by other researchers, was found to cause pain when cold touches a damaged tooth. Developing a drug that inhibits TRPC5 could potentially be a powerful treatment technique, and this concept can be extended to a multitude of different receptors. Unfortunately, inhibiting a receptor to treat a specific part of the body is not as easy as it seems, as the same receptor could be needed elsewhere. Thus, important research on these pain-relieving drugs is still being conducted today, and some researchers are close to inhibiting specific receptors. Any new treatments created will all be thanks to the work of Julius and Pataoutian.

DESIGN BY PARKER HITT, BIOLOGY, 2024

PHOTO BY ANNA TORTEN RABINOWITZ, BIOLOGY, 2024

Nature (2014). DOI: 10.1038/nature13980
Nature (1997). DOI: 10.1038/d41586-021-01283-6
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The abominable ... mummy?

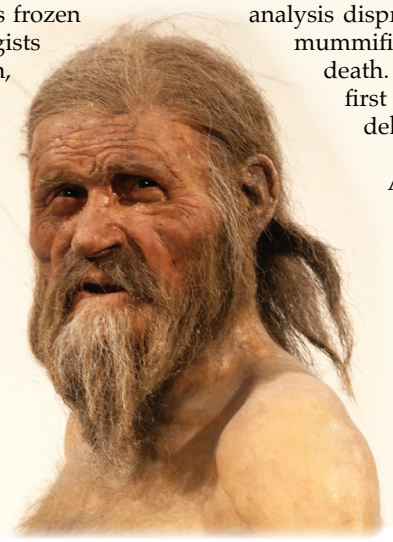
BY LILLY SCHAR, BIOLOGY & ENGLISH, 2025

DESIGN BY PARKER HITT, BIOLOGY, 2024

What do vampires, werewolves, and mummies all have in common? They are classic monsters, but only one of the three truly exists. Mummification has been used to preserve bodies for thousands of years. But mummies are more than old monsters, and science has shown that mummies offer a plethora of information to the academic community.

The German couple responsible for finding the frozen mummy in the Otztal Alps could not fathom the decades of research they kickstarted with their discovery. Iceman Otzi's discovery generated a buzz in both popular and academic culture. Why? The unique preservation of this frozen mummy allowed scientists and anthropologists to learn when Otzi lived, his cause of death, his community, and even his blood type (O). How is it possible to learn more from this mummy than any other?

The answer lies in Otzi's mummification process. Unlike many mummies predicted to have lived around the same time as Otzi, Otzi was mummified naturally in ice as opposed to intentionally by other humans. This natural mummification is not as simple as burying a person in ice, but biologists are still theorizing the precise process. Otzi's skin and muscle DNA is a useful tool in mapping how, exactly, this ancient man was preserved with any mechanical integrity. Via advancements in DNA sequencing and amplification technology, scientists analyzed DNA extracted from Otzi's skin and muscles. Their analysis revealed large quantities of bacterial DNA on Otzi's skin and an even higher concentration in his muscle. The key to understanding how Otzi was mummified lies within the characteristics of these bacteria. The skin bacteria suggest Otzi was in continual contact with plant debris and mild temperatures — an appropriate condition for the bacteria's growth. The presence of cold-adapted bacteria in Otzi's muscle suggests environmental conditions were appropriate for this bacteria to grow at another point in time. This analysis disproved initial hypotheses, claiming Otzi was mummified by rapid dehydration closely after his death. The growth of bacteria suggests Otzi was first buried in snow, then thawed, and finally dehydrated.



Analysis of Otzi was only possible due to the cooperation of his natural mummification and advancements in scientific technology. Even in 2022, we are still uncovering new information about Otzi based on what can be discerned with new technologies. Though many hypotheses about Otzi remain, we can thank the ice for preserving a rich source of history and science.

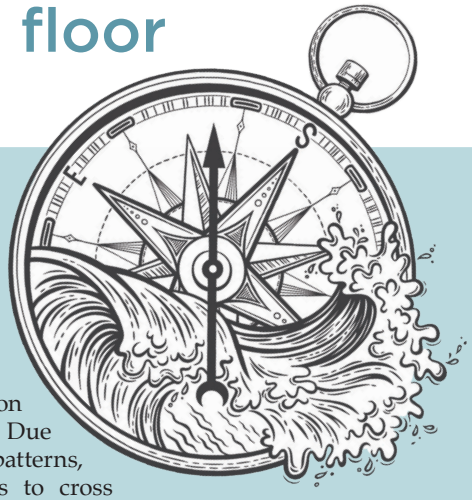
PHOTO BY CLAUDE VALETTE VIA FLICKR

American Journal of Biological Anthropology (2000). DOI: 10.1002/(SICI)1096-8644(200002)111:2<211::AID-AJPA7>3.0.CO;2-M

International travel on the ocean floor

How species move between global poles

ARTICLE AND DESIGN BY EVELYN MILAVSKY, CELL & MOLECULAR BIOLOGY, 2025



Since early expeditions to the farthest regions of the planet, scientists have been intrigued by the presence of visually similar creatures residing in both the Arctic and Antarctic. Hundreds of nearly identical worms, insects, and other small sea creatures have been discovered in both locations. These seemingly bipolar species, living at both the North and South Poles, puzzled researchers attempting to explain their similarities despite the great distance between them.

Early theories speculated that the animals had traveled across the globe thousands of years ago when global ocean temperatures were more similar to those of the polar regions. Before the early 2000s, a reliance on morphological observations, observations based on physical characteristics, prevented scientists from realizing that the bipolar species have incredibly similar DNA sequences. Separation over long periods of time typically leads to convergent evolution during which the organisms develop similar traits with different genetic sequences as a result of physical isolation. However, the lack of significant genetic differences provides evidence of continuous interaction between these animals in the modern era. In 2000, marine biologist Kate Darling identified 235 identical species between the Arctic and Antarctic, prompting marine researchers to seek new ideas about how these animals travel between poles.

It is now widely accepted that these bipolar species move via a "conveyor belt" of currents found deep in the ocean. This process, called thermohaline circulation, is caused by high-density saltwater sinking beneath lower salinity water and results in global circulation of water as salinity changes. Due to the complexity of current patterns, it takes roughly 1,000 years to cross the globe using this system. However, this continuous travel explains how the genetic similarities between bipolar species overcome the expectation of convergent evolution since it is now known that the organisms did not experience physical separation and are able to reproduce with each other to allow their DNA to interact consistently.

This research opens the door to greater questions about the evolutionary history of species that are not confined to a particular region or land mass and whether or not more global networks of interaction are hiding within the depths of our oceans.

PHOTO BY SHUTTERSTOCK

Cooler than you

How cold-water coral adapt to evolving fjord conditions

BY AUBREY BEST, BEHAVIORAL NEUROSCIENCE, 2025
DESIGN BY NIKKI SUZUKI, ECOLOGY & EVOLUTIONARY BIOLOGY, 2023

No stranger to a National Geographic photo shoot or a desktop image, landscapes of the southernmost region of South America have an undeniable beauty. But beneath the surface, a complicated ecosystem is at work.

North Patagonian Fjords hold substantial populations of cold-water coral (CWC). The scleractinian, or stony, corals predominantly exist in deep ocean regions where environmental conditions include low temperatures and low levels of aragonite saturation — a measure of ocean acidification. As the pH drops, signifying acidification, the inhabiting organisms become distressed, and at extremely acidic conditions, the skeletons of the coral can dissolve.

In the Comau Fjord of the North Patagonian region, the coral *Desmophyllum dianthus* readily thrives despite low pH levels and low aragonite saturation. Thus, researchers chose this cold-water coral species to determine if — or how — environmental conditions affect the energy demand of a species.

During the experiment conducted by Sandra R. Maier at the Alfred Wegener Institute for Polar and Marine Research, three different dietary regimes were fed to *D. dianthus* to monitor the energy demand of the species by considering the loss and uptake of carbon and nitrogen. Typical levels of carbon and nitrogen loss were determined through monitoring natural processes of respiration, ammonia excretion, and the release of particulate organic carbon. Experimental levels were then determined and compared to observe changes in energy demand.

These levels were observed under the following dietary conditions: live fjord zooplankton only, live fjord zooplankton and krill, and four-day food deprivation. The solely zooplankton diet served as a method to attain baseline levels of output and natural processes. As one might expect, the complete deprivation of food caused a significant decrease in respiration, excretion, and release of carbon and nitrogen. These factors all saw over a 50 percent decrease compared to the baseline measurements. Stress in corals often causes bleaching, when corals dispel symbiotic cells called zooxanthellae. If this continues for too long, the coral will starve and die. However, levels of reuptake, or reclaiming the zooxanthellae, dramatically increased during this period. This increase in reuptake is significant for the species, highlighting its ability to adapt to food scarcity, like during winter conditions in the fjord.

On the other hand, feedings that included the krill increased each previously discussed process; most notably, there was a 131 percent increase in excretion. The importance of krill in the diet is not only exhibited by an increase in these processes, but also by the decline in its absence. The unfed corals lost, on average, two percent of their carbon and nitrogen tissues each day, due to normal metabolism and release of particulate matter. To recover from this, each coral would need to consume at least 700 zooplankton per day or just one single krill.

The coral have proven their ability to survive in the fjord's unfavorable conditions, with the dietary advantages of krill and zooplankton. However, acidification is constantly changing, and the organism's potential response is uncertain. Global warming increases the overall levels of carbon dioxide in the atmosphere which decreases the overall pH of seawater. To resist seawater acidification, CWCs can actually modify their internal pH to maintain their skeletons but lose great amounts of energy in the process.

Coral ecosystems serve as hubs of marine life, containing networks of symbiosis, which will be exponentially disturbed by climate change and the acidification of seawater. This is where attempting to balance out the loss of energy from acidification through the different feeding regimens becomes relevant. Essentially, the extra energy expended to maintain pH depletes the energy stores of the organism, which is then replenished by consuming krill and zooplankton. Controlling feeding patterns of coral is clearly much easier in a lab, as opposed to the deep ocean, but at the very least, research like this highlights the implications of human actions, regardless of intention, such as those contributing to climate change.

PeerJ (2021). DOI: 10.7717/peerj.12609

PHOTO BY FLICKR

PHYTOPLANKTON

The chaotic backbone of the Arctic

BY KYLE KIRSHEN, CHEMISTRY, 2025
DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

It should come as no surprise that global warming is as bad as ever, and the future is not looking great. And while the entire world is feeling the effects of human actions on the environment, certain places are suffering worse than others. Specifically, the Arctic has felt consequences unlike ever before. Due to mass carbon dioxide and greenhouse gas levels, there has been a temperature rise of over 5 degrees Celsius within the last 30 years, according to a study in *Nature Climate Change*. As a result, 2010 to 2015 was recorded as the warmest five years ever for the Arctic. But besides the melting of glaciers, what exactly is global warming doing to the Arctic that cannot be seen? That answer lies below the surface.

Phytoplankton, or microalgae, are microscopic organisms that make up the foundation of most sea ecosystems. Like other plants, they contain chlorophyll and use sunlight during photosynthesis. By obtaining sunlight, phytoplankton are able to grow and mature. They also provide the necessary nutrients for shrimp, jellyfish, and snails alike. Without phytoplankton, the Arctic would likely be void of any organisms. What makes phytoplankton so impressive, though, is their super efficiency when it comes to production. They are able to use every little photon to stay alive and adapt to some of the harshest conditions on the planet.

> "Without phytoplankton, the Arctic would likely be void of any organisms."

But even though that may be true, marine scientists have always thought that phytoplankton growth is limited during the winter. With temperatures well below freezing, barely any sunlight, and almost two meters of snow and ice blanketing the waters, how is anything expected to survive? Rather, it was assumed that, when spring arrived and temperatures started to rise and ice melted, there were massive blooms of phytoplankton. New data turns this preconceived theory on its head, however. It seems that, instead of one massive bloom, phytoplankton continuously grow through the winter months with levels apparent even in the coldest parts of February. And while a gradual rise in the winter has shocked scientists the most, it also appears that blooms continue much later into the year than previously expected. Altogether, the fascinating data has perplexed the scientific community because how exactly is it possible? With little to no sunlight, it should be nearly impossible for anything to survive, much less thrive. And while more research is being conducted to explain the phenomenon, one point stands out: so much of the Arctic remains a mystery.

Yet, while phytoplankton do serve as the backbone of the Arctic, they may also be slowly killing it. Phytoplankton blooms are becoming larger and longer than ever as a result of global warming, rising sea levels, and the melting of large ice shelves. Data published in *Progress in Oceanography* shows that the net primary production of phytoplankton increased between 70 and 112 percent over a 15-year experimental study. That mass increase in the net primary production directly correlates to severe sea-ice loss of 4.2 to 5.4 percent a year. Melting ice shelves has also rapidly spread nutrients throughout the Arctic, explaining why phytoplankton blooms are now so heavily favored. And while phytoplankton allow for millions of organisms to survive, extreme blooms have phytoplankton levels which are excessive and even dangerous to the Arctic environment.

With enough open space, increased light emissions, and less ice blockage, phytoplankton blooms have become larger than ever. With excess nutrients, these blooms can produce harmful algae blooms, otherwise known as HABs. They can then produce extremely toxic compounds dangerous to all different types of sea organisms. Large blooms can also create enough surface area to completely block out light, thereby affecting or killing anything that lies beneath its massive shape. HABs have become more common within the last couple of decades and can be seen worldwide across all types of ecosystems. Additionally, there is currently no way to stop these blooms unless carbon emissions, waste, and excessive nutrients in the water are drastically decreased.

Phytoplankton, while a critical part of the natural world, are also one of the things that stand to bring it down. They can adapt to the coldest and most severe conditions and live with limited sunlight and resources. They are the central component of the Arctic and polar environments of the world. But will they help save or further hurt the declining environment? Only time will tell.

Nature Climate Change (2020). DOI: 10.1038/s41558-020-0905-y
Progress in Oceanography (2015). DOI: 10.1016/j.pocean.2015.05.002

PHOTO BY SHUTTERSTOCK

HIBERNATION:
When the past becomes the future

BY EMMA TUSUZIAN, PSYCHOLOGY, 2023

DESIGN BY PARKER HITT, BIOLOGY, 2024

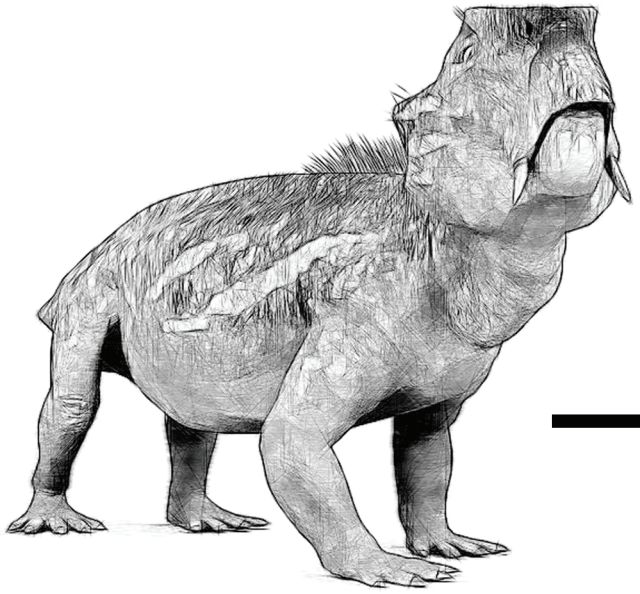
When getting out of bed means preparing for an icy plunge into a winter morning, it is tempting to retreat to a blanket of warmth and return to peaceful slumber. To a shivering early riser, the ability to hibernate is one to envy. A multitude of animal species undergo torpor, any hibernation-like state in which metabolic rate and body temperature drop in order to survive times of food scarcity, such as the winter.

Recently, scientists have found evidence for the oldest known instance of torpor. In 2020, researchers Megan Whitney of Harvard University and Christian Sidor of the University of Washington reported this instance in the extinct burrower *Lystrosaurus*, an early mammalian genus that existed in the difficult conditions of Antarctica during the Early Triassic period. It averaged about three feet long with a heavy build, splayed out posture, beaklike face, and two small tusks. According to *National Geographic*, it "somehow managed to survive the worst mass extinction the world has ever known": the Permian-Triassic extinction. By observing prolonged periods of stress in the tusks of a *Lystrosaurus*, the team concluded that polar populations adapted to their cold, dry, and often dark environment by seasonally reducing metabolic activity, or undergoing torpor. According to their paper, as the tusks of a *Lystrosaurus* grew, a tissue called dentite was "deposited during times of regular incremental growth as well as times of arrested growth reflecting metabolic stress," acting as a record of physiological activity, often in response to environmental change. Whitney and Sidor tracked two different growth patterns in the tusks: routine growth, which appeared as thin marks resembling rings of a tree trunk, and stress marks, which were thicker bands. Hibernation zones were areas between stress marks, which had reduced dentine accumulation. Despite this remarkably old evidence, it is no surprise this inhabitant of Antarctica likely slowed its activity to conserve energy needed to withstand extremes. "Animals that live at or near the poles have always had to cope with the more extreme environments present there," reported Megan Whitney to *UW News*. This finding further develops torpor as an ancient adaptation in animals, yet the question of this phenomenon reaching human physiology may seem one of science fiction.

In 1900, the *British Medical Journal* published a description of Russian peasants who were reportedly able to hibernate. Living in the nearly "chronic famine" of the Pskov government, scarcity of resources made spending one half of the year sleeping an economic measure. Families would go indoors at the first sign of snow, surrounding their stove and falling into a deep sleep they called "lotska." Once a day, they would wake up to eat a piece of hard bread and drink water. The family took turns watching the fire, all returning to regular life at the start of spring. According to a BBC article, peasants of Pskov haven't emerged since this account was revealed, but the fascination with human hibernation remains. In fact, its reality may take us to Mars.

In 2014, NASA initiated research on inducing hibernation to allow for long-term space travel. Trips to Mars are limited by the need to eat and move, so if the metabolic processes of astronauts could be drastically slowed, farther travel could become possible. According to the agency's protocol, less food would be needed, and crew members would take turns staying awake while others hibernated for two-week periods in small pods. However, there would still remain a risk of medical complications. Without natural food reserves in human bodies, astronauts would have to be fed through tubes into their stomachs. Another large challenge is the additional expenditure of energy used to combat dropping body temperatures, which could be resolved by a drug that safely drops body temperature while inducing torpor.

Remarkably, scientists at the University of Alaska Fairbanks have been able to induce this state by pharmacologically targeting adenosine receptors in the brains of rats, who do not naturally hibernate. Not only has the U.S. Food and Drug Administration begun to consider human applications of this intervention, but in 2019, the National Institutes of Health has also funded this work with an $11.8 million grant. At its core, the ability to control body temperature can have incredible impacts on energy use and its cascading influences within the body, such as metabolism. With attention on this discovery and its potential for medical interventions as well as space travel, exploring the ancient ability of the hardy *Lystrosaurus* can launch us into the future of human capacity.



Communications Biology (2020). DOI: 10.1038/s42003-020-01207-6
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PHOTO BY SHUTTERSTOCK

Seeing in the dark

Polarized light helps these animals find their way at night

ARTICLE AND DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

A solitary dung beetle rolls its round cargo across the South African grassland, looking for a suitable place to bury its prize. It quickly distances itself from other beetles at the dung pile and avoids circling back to its original location, all while moving a ball of dung much larger than itself. However, in a landscape lacking navigational landmarks, the beetle knows exactly what direction to go. The moon is its guide. Specifically, it can see directions by detecting polarized light.

While humans can only witness polarized light through sunglasses or fancy photography lenses, for many organisms, this form of vision is the norm. Fish, birds, many invertebrates (insects, spiders, and crustaceans), and some mammals all use polarized light to guide navigation. Light from the sun is initially unpolarized, and the beams are made of waves moving in many directions along a linear path. If the light is scattered off gas molecules in Earth's atmosphere — a phenomenon known as Rayleigh scattering — it becomes polarized, meaning the light now vibrates in a single plane. Even when direct sunlight is not visible, such as on cloudy days, under water, or even at night, polarized light cues can still be detected. While scientists have no way of knowing what polarized light looks like from an animal's eyes, they guess it appears as wide bands stretching across the sky. The patterns are clearest in a 90-degree angle from the position of the sun or moon at rise or set.

> "Fish, birds, many invertebrates, and some mammals all use polarized light to guide navigation."

There is still much information to discover about light polarization and how it can be used for navigation. A study in *Nature Communications* discovered the greater mouse-eared bat as the first known mammal to use polarization patterns to navigate. Bats will travel hundreds of miles in a single night looking for food, but their echolocation — the locating of objects through reflected sound waves — only reaches up to a few dozen meters. In the study, scientists showed groups of bats different polarization signals with 90 degrees of difference at sunset. They then released the bats at 1 a.m. — when no polarization is visible — and tracked the bats with small radio transmitters. The bats which had been shown a shifted version of polarization signals set off in a direction roughly 90 degrees from their counterparts. Scientists hypothesize that these bats "calibrate" an internal compass against polarization signals each sunset. This method is advantageous over other navigational cues, like referencing the direction of the sunset, because it can be detected even if the sun is obscured by clouds. It is also the perfect solution to bats' navigational challenges because polarization is very prominent at dusk and dawn, right when bats are venturing from and to their caves.

Another nocturnal creature, the dung beetle, uses polarized light from the moon to navigate. While these signals are weaker than those from the sun, they can be detected all night long, depending on the lunar phase. When the moon is full, it emits about the same amount of polarized light as the sun does during the day. However, as the lunar cycle wanes and the sky gets darker, the amount of light wanes too. In a 2019 study, researchers evaluated how the dung beetle *Escarabaeus satyrus* was affected by the strength of polarized light caused by the cycles of the moon. Scientists placed beetles and dung balls in a circle under a polarized light source and manipulated the amount of light given. They watched the beetles roll the balls to the edge of a circle, noted the angle, and repeated the experiment with different angles of light and strengths of polarization. They concluded that the beetles relied heavily on the direction of polarization and were able to detect signals equivalent to those emitted by a thin crescent moon. Due to their sensitivity at low signaling levels, scientists wonder whether light pollution from cities would hinder beetle navigation techniques.

While polarized light is not easily observed by humans, it is widespread in nature. Polarization vision is "so poorly understood," according to a 2011 review in *Current Biology*, that there is still much to uncover about the mechanisms of polarization detection, sensitivities, and ability to be applied to navigational and light-sensing machinery.

J Exp Biol (2019). DOI: 10.1242/jeb.188532
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PHOTO BY SHUTTERSTOCK

COULD A 'PLANET KILLER' ACTUALLY MAKE ITS WAY TOWARD EARTH?

BY ANOUSHKA MISTRY, BEHAVIORAL NEUROSCIENCE, 2025

An apocalypse: the end-all-be-all of Earth as we know it. Various pieces of literature and films have attempted to capture the concept, fueling a fear of the end of the world. Suitably, the collapse of society is quite frightening and not easily acceptable. For centuries, humans have tried to rationalize and control this unease through means of religion and theories about the future. But what if this type of disaster were to actually happen? What would happen to the many species that coexist on this planet? What if this large-scale disaster were preventable? Movies and television attempt to answer these questions through hypotheticals and visualizations of ominous futures.

"Don't Look Up," a movie recently released on Netflix, encapsulates a type of apocalyptic event that many deem plausible: an asteroid destroying the Earth. The movie opens with Astronomer Randall Mindy (Leonardo DiCaprio) and graduate student Kate Dibiasky (Jennifer Lawrence) locating a large asteroid in the solar system. After analyzing the comet, they come to the horrifying conclusion that it is undoubtedly headed toward Earth. It will make a direct hit, destroying Earth in the process, earning the name "planet killer." Unsettled, the two set out on a campaign to spread awareness, attempting to halt the demise of the world.

What course of action would we take if this situation were to actually play out? NASA's Planetary Defense Coordination Office is responsible for detecting near-Earth objects (NEOs), which consist of all asteroids and comets that enter within a 30 million mile radius of Earth's orbit. The most dangerous of this group are potentially hazardous objects (PHOs), which are specifically within 4.7 million miles of our planet and larger than 500 feet. Numerous small asteroids pass between Earth and the moon every month. Small pieces of asteroids under three feet in length, also known as meteoroids, go through Earth's atmosphere practically every day, although most burn up or explode while doing so. However, an asteroid that is around 98 to 164 feet could result in far-reaching damage. What's more, an object that is bigger than 500 feet would bring about global destruction, causing an "apocalypse," so to speak.

However, according to NASA, "no known asteroid poses a significant risk of impact with Earth over the next 100 years." In fact, the next asteroid that has the potential to collide with Earth has a 0.2 percent chance of impact and is not forecasted until the year 2185. NEOs are located using a variety of ground-based telescopes around the world with help from a few space-based telescopes. When a small object is found to be moving among mostly motionless stars, its orbit is predicted. This calculated value is then used to speculate when the object will be visible to telescopes again, thus allowing scientists to track the NEO.

Should a NEO be on a straight track toward the planet, a few technologies could be utilized. The most well-understood and simplest method would be a kinetic impactor: a spacecraft whose purpose is to ram into the hazardous asteroid in an attempt to (even slightly) knock it off its trajectory. It stands as the most realistic technique, and the strategy NASA would refer to first in a potential impact event. Still, maneuvering a large catastrophic-level asteroid to head in a completely different direction is a monstrous task. So monstrous, in fact, that scientists will be testing this approach's reliability and effectiveness through the Double Asteroid Redirection Test (DART) in 2022.

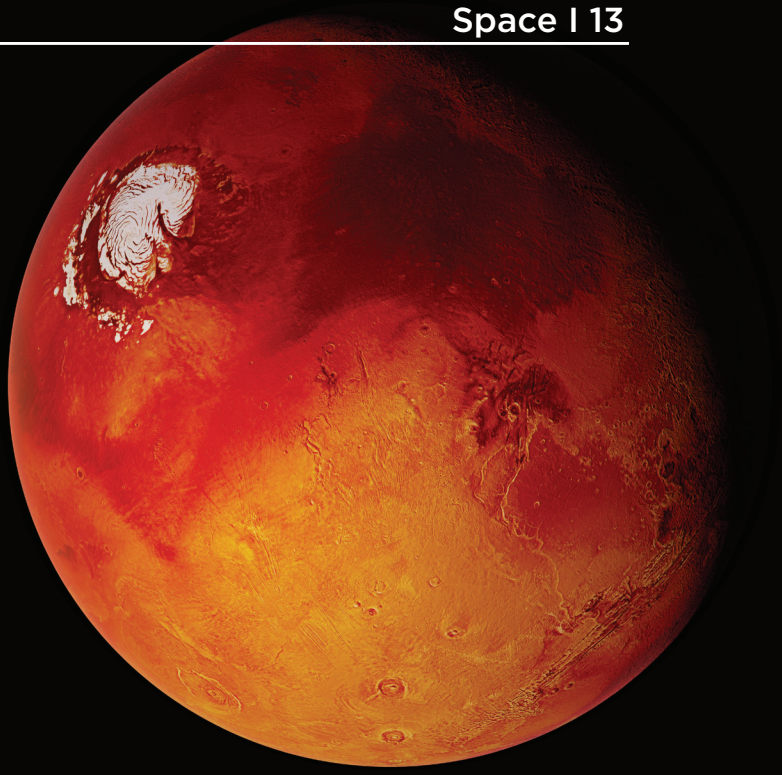
The tactic for asteroid obliteration seen in "Don't Look Up" includes the launching of missiles. Although this may seem like a logical endeavor, NASA claims "nuclear explosive devices methods are considered the last resort when it comes to NEO deflection." If the warning time of impact were too short, or the asteroid itself was very large, then nuclear devices would be the best option. However, the likelihood that an asteroid this enormous would hit Earth in the next 100 years is slim to none.

So, could humanity intercept an asteroid and put off an end of the world incident? Yes, probably. But as seen in "Don't Look Up," not everything ends pleasantly, and scientists' opinions are shoved aside and replaced with politics and personal agendas. Yet, as technologies advance and limitations are surpassed, NASA, in collaboration with many other research centers, will continue to perfect their techniques. This way, their reports will be more accurate, allowing them to act efficiently and carry on with their duties.

DESIGN BY THOMAS PAULUS, CELL & MOLECULAR BIOLOGY, 2025

DIVING UNDER MARS' ICE CAP

BY DIVYA RAVIKUMAR, BIOENGINEERING, 2025
DESIGN BY KATIE GREEN, BIOENGINEERING, 2022



Water is undeniably the source of life. Consequently, it is one main factor that scientists look for when combing the universe for habitable locations. As it turns out, they may not have to look far. Our neighboring planet, Mars, has been confirmed to have liquid water lakes deep beneath its southern polar ice cap.

Evidence for water on Mars was already being collected back in 2018 after the theory was proposed by Steve Clifford. He was inspired by the studies of saltwater bodies that exist underneath the large ice sheets in Antarctica and Greenland but applied it to Mars' south pole. Mars Express, a spacecraft for the European Space Agency, used an instrument called the Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS) to collect radar data. This allows scientists to study the interior structure of the planet, where the radar signals bounce back differently depending on the material they hit. Surprisingly, the signals MARSIS received from the south pole were a large enough magnitude that they could only be explained by a large underground body of liquid water. The lake was approximated to be about 12.5 miles long and a mile underneath the surface. Despite this astounding discovery, the results were not entirely conclusive, and scientists questioned if there was another cause for the bright reflection at the ice cap.

> "Surprisingly, the signals MARSIS received from the south pole were a large enough magnitude that they could only be explained by a large underground body of liquid water."

However, more data were gathered in 2020, and three more lakes were identified close to the first. In this study, MARSIS once again scanned the surrounding area of the previously located lake, and the resulting data were analyzed in a similar manner to the water beneath the glaciers in Antarctica. Scientists confirmed the liquid nature of the lake as well as its dimensions to be 12 by 18 miles, but its depth remains unknown. The new pools of water appear to be offshoots of the main lake, which were likely created by a past warmer climate.

Since the lakes consist of liquid water, the water must be extremely salty in order to have a low enough freezing point to not solidify in the Martian climate. Based on the theory that Mars used to imitate the current environment of Earth, the saltwater is likely remnants of a larger body of water that used to flow on the surface millions or even billions of years ago before it was pushed underground. It would have served as an ideal habitat in the past, but with our technology right now, there is no way of knowing for sure the probability of fostering life back then. When we finally have the resources, scientists hope to retrieve samples from the surface above the underground lakes to study further. For now, they're aiming to keep looking for similar systems of water at the south pole and eventually expand to include the north pole as well.

However, scientists are also expanding their search outside of the polar ice caps. It was recently uncovered in 2021 that Mars' intense canyon network, Valles Marineris, has been hiding a large water reservoir in its depths. With the help of the Trace Gas Orbiter and its neutron telescope on board, around 40 percent of the region within the valleys was found to contain hydrogen that is assumed to be from water molecules. This type of water is anticipated to exist in the form of ice, but due to the temperature, it should have evaporated unless special conditions are preventing it from doing so. The scientists working on this project established that, while this is a huge step forward, more analysis is needed to fully understand the properties and form of the water.

The water being unearthed on Mars continues to provide scientists with the motivation to keep pushing forward in their research as it is crucial to understanding and answering the questions of Mars' past and its potential for being habitable. Most importantly, we will be closer to answering the long-standing question of life existing elsewhere in the universe.

Nature Astronomy (2021). DOI: 10.1038/s41550-020-1200-6

PHOTO BY SHUTTERSTOCK

ALIEN MICROBES

THE FRONTIER OF EXTRATERRESTRIAL RESEARCH

BY MYA HEARD, HEALTH SCIENCE, 2024

DESIGN BY PARKER HITT, BIOLOGY, 2024

Extremophiles are microorganisms that survive — and thrive — in extreme conditions not considered suitable for other forms of life. This umbrella term encompasses bacteria, archaea, protozoa, and fungi with unique adaptations allowing them to inhabit extreme temperature, radiation, salinity, pH, and other physical and geochemical conditions. Extremophiles can be found in deep-sea hydrothermal vents near underwater volcanoes, the sulfur springs of Yellowstone National Park, and the cold, arid landscape of Antarctica. These microbes have intrigued NASA scientists and cultural anthropologists, who are curious about what their ability to survive in unusual terrestrial habitats means for the study of alien life.

Extremophile bacteria, archaea, protozoa, and fungi are categorized based on their adaptations to specific environmental conditions. Thermophiles, or microbes that thrive in high temperatures, have plasma membranes that contain unusual lipids that can tolerate high temperatures. Alkaliphiles, named for their adaptation to basic conditions, have cell membranes with particular mechanisms that ensure a homeostatic internal pH regardless of their environment's unstable pH. Cold-loving psychrophiles utilize antifreeze proteins to carry out cellular activities despite the low thermal energy and high viscosity of their environmental solution. Just as the conditions of extreme environments vary, so do the adaptations of extremophiles.

Extremophiles have taken center stage in the realm of astrobiology, which is defined by NASA geochemists as "the study of the origin and evolution of life in a cosmic context." Astrobiology originated during the Cold War and the Space Age when NASA was concerned about the potential need to develop defenses against extraterrestrial contaminants. Though the "grand American frontiering narratives" from the 1960s have faded, research on extremophiles in subsequent decades has sparked new speculation about the definition of habitable environments. Extremophiles are described by Massachusetts Institute of Technology cultural anthropologists "as analogs of early one-celled earthlings, ancestors of all life, and also as possible pointers to what life might look like on remote worlds, perhaps in alien oceans on Jupiter's moon Europa or on Saturn's Enceladus." The scientific conversations around extraterrestrial life have made a fascinating shift from discovering distant civilizations and cultures to the nature of microscopic organisms.

However, even the most extremophilic organisms can be limited by certain conditions. A more recent 2021 study of extremophiles and microbial habitability in Antarctic soil may have altered the research trajectory on alien microbes. Much to their surprise, geoscientists from the University of Colorado Boulder did not detect microbes in around 20 percent of 204 samples of ice-free soil. Their results suggest a combination of cold, dry, and salty conditions at the inland and high elevations of the Transantarctic Mountains is perhaps one too many extreme conditions to support microbial life, even by extremophile standards.

These scientists are also careful to note that although they were unable to detect life in their samples, this finding does not prove the soils were naturally sterile as there is always another experiment or method that may lead to different conclusions. This distinction highlights the challenge of proving a negative result – no measurement or method of data collection is perfectly sensitive, and even the best experiment may not detect the presence of microbial life.

The findings from Antarctic soil illuminate two challenges in studying potential alien life. First, extremophile microbes, once thought to be a more likely form of alien life, may not exist under some conditions. The limit to the adaptability and resiliency of extremophiles suggests thermoacidophiles and alkaliphiles may be more earthly than alien. Second, proving negative results is just as tricky as proving positive results. While confirming the existence of alien life has been a challenge, disproving alien life also remains ambiguous. Scientists are far from confirmation or denial of extraterrestrial life, and the complexities and nuances of astrobiology make their studies all the more intriguing.

PHOTO BY SHUTTERSTOCK

Social Studies of Science (2013). DOI: 10.1177\0306312713505003
Grand Challenges in Biology and Biotechnology (2016). DOI: 10.1007/978-3-319-13521-2_1
Journal of Geophysical Research: Biogeosciences (2021). DOI: 10.1029/2020JG006052

THE HEXAGON

Explaining Saturn's north pole pattern

BY CAILEY DENONCOURT, BIOENGINEERING & BIOCHEMISTRY, 2022

DESIGN BY PARKER HITT, BIOLOGY, 2024

With a radius of over nine and a half times that of Earth's and an atmosphere consisting of almost entirely hydrogen and helium, Saturn is a gas giant. But most notoriously, Saturn is known for the beautiful rings of ice and rock particles that orbit around its equator.

However, lesser known to most is its vibrant hexagon-shaped north pole. The first glimpse at this phenomenon was when the Voyager spacecraft flew by in 1980. It was not until 2012 during the Cassini mission that a motion picture was taken. With greater detail, scientists were able to observe a hurricane with an eye centered at the most northern point, which was estimated to be over 50 times wider than any storm seen on Earth. Countless smaller vortices ranging in all sizes surround the massive polar vortex. Some of these current patterns were observed getting caught up in the hexagonal jet stream while others simply spun in place. Although beautiful and magnificent to look at, scientists are still puzzled by it today: Why do they observe this hexagonal pattern on a spherical planet surrounded by elliptical rings?

As described by Andrew Ingersoll, one of the Cassini imaging team members, "the hexagon is just a current of air, and weather features out there that share similarities to [Earth] are notoriously turbulent and unstable." Despite the similarity to current patterns seen on Earth, the chaotic, unstable air flow is unfamiliar and bizarre to many scientists. Although there have been some previous investigations in understanding how the current patterns cause the hexagonal pole, a 2020 study by two scientists from Harvard University's Department of Earth and Planetary Sciences took a deeper look into the physics of this pattern using computer simulation models.

Previously, the hexagonal hurricane was believed to exist mostly along the surface, only extending about 100 kilometers down into the atmosphere. However, the two Harvard scientists suggested that the hexagon most likely pierces thousands of kilometers deep. They concluded this after the computer simulation showed deep thermal convection was the most likely explanation for the hexagonal jet stream. Thermal convection is simply the exchange of heat through the movement of liquids or gasses, so in the case of Saturn's atmosphere, this process occurs at such a rapid and large scale that giant vortices and a powerful jet stream form.

From the simulation, using the measurements taken during the Cassini mission, they discovered that at lower altitudes chaotic circular jets dominate, but as altitude increases, high-speed vortices begin to form at increasing speeds. The stable and chaotic streamlines depend on the radius and proximity to the northern pole. They interact to form the sustained central vortex and, also likely, the six hidden vortices that exist along each of the six points of the hexagon shape.

Unintuitively, there is no hexagonal shape on the south pole of Saturn. The simulation was thus also performed on the south pole, which revealed slight differences that caused an offset to disrupt the formation of the hexagon. The central polar cyclone is shifted slightly away from the southernmost point and is sandwiched between two anticyclones, which occur when winds rotate around a center of high pressure. This in turn also results in jet streams that disrupt the formation of any polygonal edges.

With this computer analysis and new understanding for this head-scratching phenomenon, there is still room for improvement. The simulation is not perfect; they were only able to recreate a nine-sided polygon but were still able to provide a scientific proof of concept for how the storm is formed and sustained. With another mission and more data, the two scientists hope to improve their calculations and almost precisely model the hexagonal top.

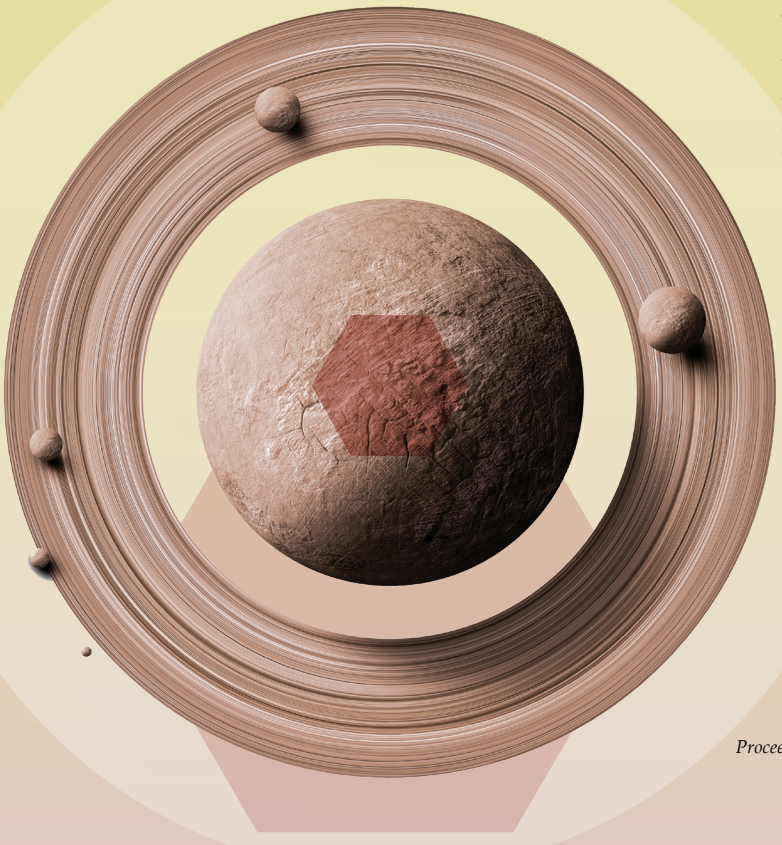


PHOTO BY SHUTTERSTOCK

Proceedings of the National Academy of Sciences (2020). DOI: 10.1073/pnas.2000317117

PICKING UP ON SOME STRANGE ENERGY

The mysterious space object baffling astronomers

BY MCKENNA FORREST, BIOLOGY & CRIMINAL JUSTICE, 2023 DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

On October 12, 2021, a team of Australian researchers, led by PhD student Ziteng Wang, reported the discovery of a possible new object in space. The mysterious source of energy has been labeled ASKAP J173608.2−321635. The catch? It doesn't fit into a category of anything scientists have ever seen before.

ASKAP J173608.2−321635 was first noticed as a radio source. It is named after the Australian Square Kilometre Array Pathfinder, the telescope used to find it, as well as the coordinates where it is located. Scientists attempted to identify the type of source through the process of elimination by performing several tests using radio imaging, pulsar searching, X-rays, and near-infrared imaging. Originally, scientists wondered if it was some type of star, specifically a pulsar, which is a highly magnetized neutron star. However, after the tests were done, it became clear that the object did not align with any of their suspected classifications. Some types of stars have varied radio waves just like the mystery source did, but the X-ray and near-infrared tests failed to detect anything, making it very unlikely for the object to be a type of star. It didn't match the criteria of a pulsar because pulsars are very regular in their production of energy, and the mysterious object had been very inconsistent, fading at some time points and completely vanishing from detection at others.

> "It became clear that the object did not align with any of their suspected classifications."

ASKAP J173608.2−321635 has been classified as highly-polarized and highly-variable. Let's break down what these classifications mean. Most common light sources are unpolarized, meaning light emits in random, multiple directions. Think of a lightbulb lighting up a room; light shines all around it. Light can become polarized if it is filtered, reflected, or scattered properly. For example, polarized sunglasses filter by absorbing one direction of light, either vertical or horizontal. By blocking one direction, they reduce glare and let the other direction reach the eye. In ASKAP J173608.2−321635, the electric and magnetic forces coming off of it seem to be filtered into one direction. At this stage, it is unclear if the polarization filter is due to magnetic fields and debris between Earth and the source or if the actual source is highly magnetized and doing it on its own.

The unknown object is also highly variable in its emission of energy. It was tracked for several months, and astronomers were baffled by the way the object sent out constant bursts of energy only to disappear after a few weeks. The brightness varies by a factor of about 100, flickering on and off in random patterns. Wang noted in an interview with the University of Sydney that the team had never seen variability on a scale quite like this before, leaving them with many questions.

Although still somewhat confused, researchers have identified other instances of space activity that have similarities to ASKAP J173608.2−321635. The new source shares similarities with a phenomenon known as "galactic center radio transients," also known as GCRTs. There have been three GCRTs identified in the 2000s, and there are others currently under suspicion and review. Much about GCRTs is still unknown, but they do have several features attributed to them, some of which correspond to ASKAP J173608.2−321635. However, the main timescale of energy emissions for the new object does not match the other identified GCRTs, so that must be kept in mind. But as of now, GCRTs are the closest identified relative of ASKAP J173608.2−321635.

Although in its early stages of research, scientists are inching toward the conclusion that ASKAP J173608.2-321635 may be the first discovery of a new type of cosmic object. In what is an eerily exciting development, this discovery is another reminder of just how extraordinarily little is known about the universe around us.

The Astrophysical Journal (2021). DOI: 10.3847/1538-4357/ac2360
Nature (2021). DOI: 10.1038/d41586-021-02836-5

PHOTO BY RAWPIXEL

Peculiar properties of a polar planet

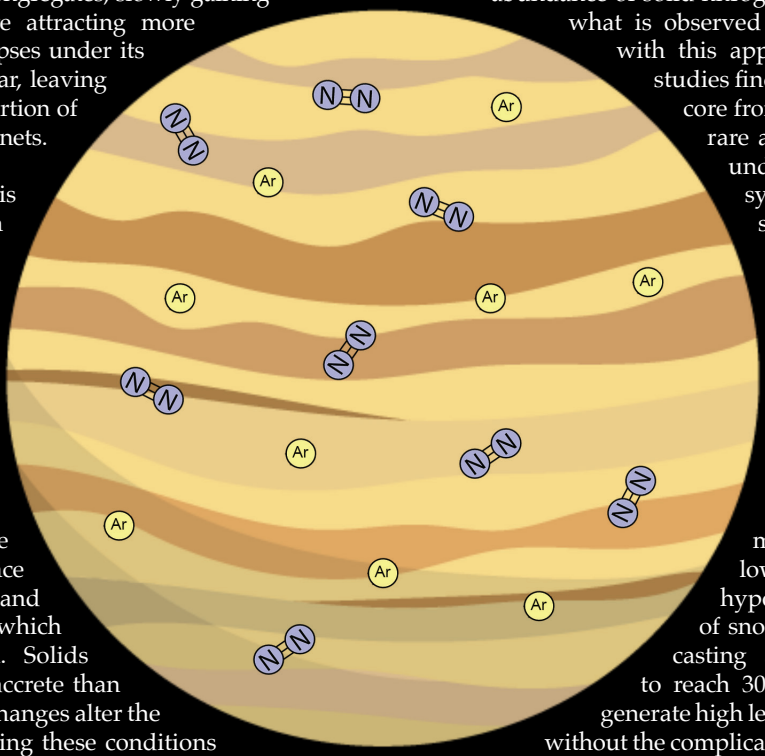
BY CARA PESCIOTTA, PHYSICS, 2022

DESIGN BY IAN PROULX, BIOENGINEERING, 2022

With 79 moons and a magnetic field 20 times stronger than that of Earth, Jupiter is a unique planet in the context of our solar system. The gas giant is the fastest spinning and most massive of our planets, not to mention home to a virulent storm called the Great Red Spot that has captivated astronomers for over 200 years. With so many peculiarities, there is one oddity without explanation – its chemical composition.

The chemical makeup of astrophysical objects helps determine characteristics from magnetic field strength to habitability. One could imagine how the properties of certain elements would contribute to the properties of an object composed of these elements. Composition can also shed light on the object's formation, where Jupiter's peculiarities began.

Solar systems originate from a collection of interstellar gas and dust. As this matter congregates, slowly gaining more mass and therefore attracting more matter, it eventually collapses under its own gravity to create a star, leaving behind a small leftover portion of interstellar gas to form planets.



Planet formation is dependent on elements in this leftover matter, called a protoplanetary disk, and the distance of these elements from the star. Planets, protoplanetary disks, and stars are believed to have similar compositions since they all form from the same region of gas and dust. As distance from the star increases, abundance of specific elements and temperature change, which affects planet formation. Solids are easier for planets to accrete than gasses, and temperature changes alter the phase of elements. Knowing these conditions allows astronomers to study a solar system's history with current observations of the system.

So, Jupiter's composition is expected to be akin to that of the sun, but observations show discrepancies that skew our idea of how the planet formed. There is an unusual abundance of nitrogen, argon, and other elements that is not consistent with the distance of Jupiter from the sun. Over 4 million miles away, Jupiter would have been around a temperature of 60 Kelvin, or negative 213 degrees Celsius, where nitrogen and argon would have been in the gas phase. The ice line, or point where an element becomes solid, for these elements is closer to 30 Kelvin. It is not likely that this abundance would occur under these conditions, so astronomers are proposing special scenarios for Jupiter's formation.

The first proposal to solve this inconsistency was entrapment of elements with low ice lines underneath water ice. Water ice has been shown to allow molecules to exist where they otherwise should not, potentially explaining how nitrogen and argon could exist in such abundance. However, this theory is unlikely because of the amount of water needed to entrap high volumes of molecules. The amount needed is far past the amount observed in the atmosphere, leading researchers to look for another solution.

A second possibility is that Jupiter formed farther from the sun than it lays now and migrated closer with time. At the proposed distance, a temperature of 25 Kelvin, the abundance of solid nitrogen and argon agrees with what is observed in Jupiter. The problem with this approach is that theoretical studies find migration of a planetary core from that far a distance to be rare and inconsistent with our understanding of the solar system's timeline, though it still remains a possibility.

Finally, a new premise from the University of California, Santa Cruz suggests that Jupiter formed in its current location, but a cloud between Jupiter and the sun shrouded Jupiter from sunlight, cooling molecules past these low ice lines. This cloud is hypothesized to be a buildup of snowballs at water's ice line, casting a cold enough shadow to reach 30 Kelvin. This too would generate high levels of nitrogen and argon without the complication of a migrating Jupiter.

In order to test these theories, UC Santa Cruz scientists are turning to Saturn. In the novel theory, effects of water dust clouds are not suspected to reach Saturn; the migration theory, however, suggests that Saturn also formed farther from the sun than its current location due to shared properties and a birthday close to Jupiter's. Therefore, if Saturn presents similar compositional anomalies, migration theory is likely. If not, this may be evidence that a dust cloud shielded only Jupiter. While the Galileo probe gathered this detailed composition data for Jupiter, a comprehensive study has not been conducted for Saturn. With a mission to Saturn to study chemical composition, scientists will further illuminate the story of planet formation and the peculiarities of Jupiter.

PHOTO BY PIXABAY

The Astrophysical Journal (2009). DOI: 10.1088/0004-637X/696/2/1348
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Astronomy & Astrophysics (2019). DOI: 10.1051/0004-6361/201935007
Astronomy & Astrophysics (2021). DOI: 10.1051/0004-6361/202141169

Ice, ice maybe

Impacts of declining sea ice on Arctic predator-prey dynamics

BY DESSY DUSICHKA, BIOLOGY & COMPUTER SCIENCE, 2025

DESIGN BY KATIE GREEN, BIOENGINEERING, 2022

If current climate trends persist, the Arctic Ocean is predicted to become seasonally ice-free by the 2030s. Sea ice follows a cyclic pattern, partially melting in the summer and re-forming with the cooler temperatures of autumn and winter. However, rising global temperatures have increased the melting rate and decreased the formation rate. During future summers, the Arctic will soon lack the dazzling ice it is known for.

Ice is invaluable to Arctic marine mammals, serving as a platform for foraging, hunting, birthing, and resting. In response to declining sea ice levels, Arctic species have adapted their behaviors and relationships to survive in changing conditions. Two such species are the polar bear and the ringed seal which are intertwined in an intricate predator-prey relationship.

Ringed seals use sea ice to build snow lairs which provide warmth and protection to young pups who lack blubber. Rising Arctic temperatures have caused land-fast ice — or ice attached to land — to virtually disappear during summer and autumn, forcing seals to use calved (broken) ice during these seasons. For polar bears, land-fast ice provides a platform for effectively hunting seals. Seals stationed on calved ice are more difficult targets, requiring a more advanced aquatic "sneak attack" performed by only 20 percent of Norwegian polar bears, according to a study in the *Journal of Animal Ecology*. Thus, while ringed seals can maintain their current habits in the wake of reduced ice, polar bears have had to adapt their spatial and feeding patterns.

To better understand this modified predator-prey dynamic, the 2017 study from Svalbard, Norway, analyzed polar bear and ringed seal behavior in the altered Arctic landscape. Bears and seals were tracked using biotelemetry devices during two distinct time periods: 2002 through 2004 (before significant ice reduction) and 2010 through 2013 (after ice reduction). The study found that after significant ice reduction, polar bears both moved greater distances in summer and spent less time near tidal glacier fronts. This means that, in the reduced-ice summers of 2010 to 2013, polar bears spent more time and energy searching for food within a narrower geographical range. These results confirmed a decrease in the spatial overlap between the polar bear and ringed seal, illustrating a less intense predator-prey relationship.

Without reliable access to ice platforms for hunting seals, polar bears shifted their hunting strategy to target different prey — namely ground-nesting birds that are abundant and easier to hunt. According to David Kimbro, assistant professor of marine and environmental sciences at Northeastern University, this is a classic example of prey-switching behavior where "due to the changes in the abundance of different prey species or access to one prey species over another, predators have to make foraging decisions." By successfully finding a new primary food source, polar bears demonstrated their adaptability amidst changing environmental conditions.

While it may seem like both seals and polar bears have adapted during this climate crisis, the two continue to face challenges that threaten their survival. Ringed seals must develop a way to survive once the ice is absent during the summer. The seals are barely clinging on to fractured portions of the frozen beauty that once was, not only fighting to survive against both their predators but also against the more daunting threat of climate change. For polar bears, ground-nesting birds may not be a sustainable long-term option. Kimbro notes that the bears' new hunting strategy is not energetically favorable, as the bears are traveling longer distances to hunt smaller prey.

At this time, it is difficult for researchers to predict long-term outcomes, but ecological theories can provide potential pathways. Ringed seals may adapt, possibly altering their breeding cycles so that pups are only born in colder seasons and thus can still be raised inside warm snow lairs. Similarly, the polar bears can adapt, and perhaps those that have mastered the aquatic "sneak attack" will be selected for. Seals would once again be placed in danger, and a new chain of ecological events would ensue.

These concerns illustrate how the Arctic is an intricate and fragile ecosystem, where ice is a crucial abiotic player whose absence poses a threat to stability. While the outlook for the Arctic can seem bleak, nature is resilient, and the species that survive will be most ecologically fit for the changing environment. Moreover, continued research is a powerful tool, strengthening our collective knowledge so that policies and conservation efforts are scientifically supported. Polar bears and ringed seals have not given up in the face of climate change, and nor should we.

Journal of Animal Ecology (2017). DOI: 10.1111/1365-2656.12685

PHOTO BY SHUTTERSTOCK

How the south polar skua brings toxic chemicals to Antarctica

BY RACHEL LINES, BEHAVIORAL NEUROSCIENCE, 2022

DESIGN BY LILY GARRETT, BIOCHEMISTRY, 2025

Across the barren landscape of Antarctica, a team of scientists spent the months of December 2013 through February 2014 collecting bird poop from seabird nesting regions. After carefully preserving these samples and sections of muscle tissue from seabird carcasses, these researchers transported their data collection to Griffith University in Australia for analysis. Why pick up bird poop? Their focus was identifying toxins carried by the south polar skua.

Many seabirds congregate in Antarctica to nest and raise their young. Penguins, albatrosses, and skua nest atop cliff tops, near the water, or inland on remote mountains. The south polar skua is a foraging seabird, diving into the water to hunt fish and stealing eggs from other seabirds. The intrigue of this species stems from one key trait – the south polar skua's impressive migration, which sends them across the globe to food sources as far north as Northern California. This behavior causes a distinct relationship between the south polar skua and the Antarctic environment. As they feed, these birds accumulate nutrients and pollutants, returning to Antarctica carrying this chemical baggage."

> "Birds accumulate nutrients and pollutants, returning to Antarctica carrying this chemical baggage."

The skua migration attracted the attention of researchers who sought to understand the role of this species as a biovector. Biovectors are species that transport chemicals from one ecosystem to another, supporting life in places that would otherwise couldn't. As a biovector, Antarctic seabirds shuttle nutrients by leaving behind bird poop or guano, eggshells, and carcasses throughout their migration. However, biovectors can also carry negative chemicals. Pollutants travel with these birds during their migration, and the predatory nature of the south polar skua positions them to be a potent pollutant biovector.

Predatory species are prone to pollution biomagnification, a phenomenon where pollutant concentration increases as species are positioned higher in the food chain. This phenomenon can be seen in messages advising pregnant women to avoid eating large, predatory fish such as bigeye tuna and swordfish. Since these fish are predators, they accumulate toxins present in their prey. For pregnant women, this build-up of mercury can damage a developing fetus.
South polar skua are predatory animals, and their vast migration results in many opportunities to encounter toxins in their food sources. When examining the samples of skua guano collected from Antarctica, researchers sought evidence for the bioaccumulation of chemicals in these predatory seabirds. Specifically, the researchers were looking for persistent organic pollutants (POPs).

POPs can originate from pesticide use or industrial processes, and they are extremely resistant to degradation. Several processes that produce POPs include the application of agricultural fungicides, waste incineration, and aircraft defoliation. These chemicals can leach from landfills or industrial equipment and affect prey in lower levels of the food chain. As predatory animals consume this prey, POPs accumulate in their bodies.

High concentrations of POPs in wildlife are alarming – these chemicals have negative health effects on both wildlife and humans. In studies of fish, birds, shellfish, and mammals, POP exposure resulted in developmental, endocrine, and reproductive effects. POPs were also found to be carcinogenic and caused thyroid and immune dysfunction. Disturbingly, some human populations have similar body concentrations of POPs as exposed wildlife in these studies, causing an increased risk of cancers and concerns for fetal development. Some human populations of concern include industrialized areas in the United States, Taiwan, South Vietnam, and Canada where POPs have been found in high concentrations in adipose tissue.

Through analysis of their samples, researchers found that bird carcasses and guano samples both contained POPs, with muscle tissue samples containing the higher concentrations of the two. Another study performed by researchers at the Institute of Biophysics in Brazil noted that in comparison to other seabirds such as penguin species, the south polar skua have much higher POP burdens. By flying to northern regions such as Japan, Europe, and North America, the south polar skua have more exposure and accumulation of POPs which they bring to Antarctica.

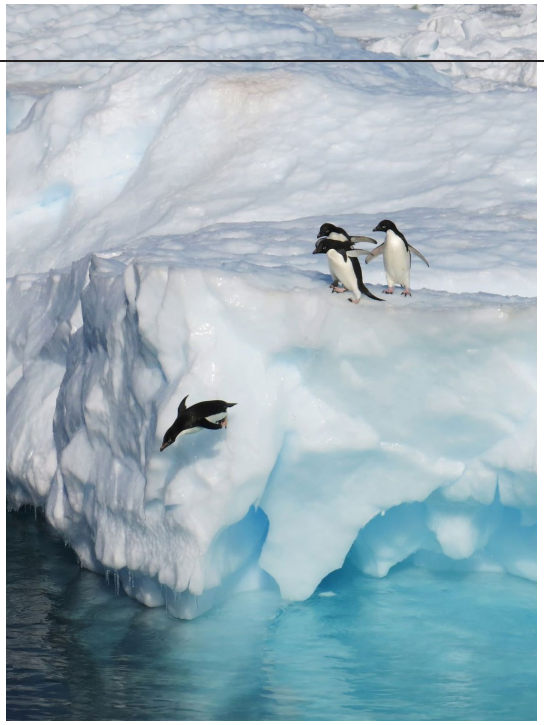
Researchers published their findings in 2021, demonstrating that POPs have a greater chemical footprint than previously described. Their presence in the Antarctic prolongs their life, as degradation of POPs is slowed in Antarctic temperatures. This research sheds light on the need to find safer alternatives to POPs and prevent the use of illegal POPs. The south polar skua's migration pattern illuminates the spread of POPs across the globe to Antarctica. By defining the role of the south polar skua as a biovector, researchers have emphasized that protecting Antarctica requires environmental action across the globe.

PHOTO BY WIKIMEDIA

Environmental Pollution (2021). DOI: 10.1016/j.envpol.2021.118358
Science of the Total Environment (2016). DOI: 10.1016/j.scitotenv.2016.07.080
Journal of Toxicology and Environmental Health (2006). DOI: 10.1080/15287390600751447

Summer campaign in the Antarctic

BY ISABELLE BRANDICOURT, ELECTRICAL ENGINEERING & MARINE BIOLOGY, 2023



While the idea of spending three months of co-op in Antarctica sounds isolating and lonely, it is, in fact, the opposite. I discovered this while on my co-op from December 2021 to March 2022 working with the French Polar Institute to improve long-term penguin observation systems. Every day is heightened by the close community of researchers and staff at the base, especially during the summer campaign. The base held 77 individuals at its busiest, compared to the current 35. The 77 inhabitants consisted of a group of 22 "winter-overers" — who prepared to spend the following year and thus Antarctic winter at the base to provide upkeep and continue the data collection of long-term projects, around 10 to 25 summer campaign scientists — who spent a shorter time at the base to conduct their research, and around 10 to 25 technicians — who maintained the functionality of the base. With all these people living here to further Antarctic research, we never lack social time. We eat every meal together, collaborate on research projects, and party together.

LIFE AT THE BASE

The "polar day" refers to the 24 hours of sunlight that lasts nearly all December. Because of the lack of night, the workday hours are long and strict. In order to profit as much as possible from this, work begins at 7 a.m. every day of the week, including weekends. At noon, everyone gathers at the Sejour, or the common dining and living building at the center of the base, for lunch. In this culture, lunch is the most important meal of the day and is skipped only under serious conditions. Every table is set with an appetizer, wine, and fresh bread — baked each morning by the patisserie chef in residence. After dessert, everyone migrates from the tables to the couches and lounge area, playing games like foosball, darts, and chess; conversing; or reading books from the library — carefully cultivated since the base's opening in 1950. If the weather is good, people are quick to return to work, but if the weather is poor, the socializing can continue for nearly another hour after eating. The afternoon passes quickly, and everyone reconvenes for dinner at 7:15 p.m. A handful of the scientists continue their work after dinner in place of relaxing but can always be convinced to stick around on Saturday nights when there is a grand party with music, dancing, and the drink of the week invented by the chef (favorites include his specialty mulled wine and his crème brûlée cocktail).

There are several intriguing aspects of the base life that are essential to maintaining order. First is the "base service." In a remote location like an Antarctic base, there is no room or resources to hire a custodian. In their place, everyone is responsible for keeping their own work building clean, and two or three people are assigned to base service every day. On your base service days, you do not work at your normal job. You instead become the kitchen assistant and custodian — cleaning the common buildings, dormitory floors, and bathrooms; helping the chef prepare the day's food; dressing the tables; serving each course; clearing the tables; and cleaning dishes. Another surprising aspect is called the "manip vivre," or "life exercise," aptly named because it entails collecting the food for the week from separate large storage buildings. Each Saturday, everyone is called to the center of the base to form a long string of stationary people between the two buildings. Each item is then passed from person to person, creating an efficient line of traveling foodstuffs. Memorable moments regarding this exercise include the Horror of the Orange Juice, where we moved nearly 30 cases of orange juice into the kitchen only to realize it all expired in 2017. We then had to empty each liter bottle of putrid orange juice into the bathroom sinks. These and other details of the base life are vital in maintaining humility, community, and equality throughout the various positions and people on the base, as no person is exempt from the tasks. They create moments where the techs, scientists, and administration work together, thus dissolving any barriers between different professions.

PHOTOS BY ISABELLE BRANDICOURT, ELECTRICAL ENGINEERING & MARINE BIOLOGY, 2023

CO-OP AT THE BASE: ENGINEERING

For my role as a co-op student on the base, I have two jobs, apt for my academic combination of electrical engineering and marine biology. The first is engineering-focused and is a project called MicrObs. I have constructed four winter-proof camera structures consisting of the camera, a Jetson (similar to a Raspberry Pi), and power converters. The purpose of the cameras is to record penguins' speeds as they travel across the sea ice. There are two species of penguins in this region: the emperor penguins and the Adelie penguins. Since penguins feed at sea and fast on land, there is a marked difference between the speed of the penguins leaving the colony and the speed of those returning that correlates to how full of food they are. The departing penguins race to the sea, desperate to begin feasting on krill and fish, but those returning take their time trundling over the ice, ensuring they do not waste too much energy, so they have plenty to give to their chicks. By averaging this difference, ocean health can be observed from year to year. For example, if the walking speed difference is much greater one year, the penguins were able to find a lot to eat, and the ecosystem is doing well. If the following year, the walking speed difference is much smaller, the penguins were not able to find as much food, concluding that the health of the whole ocean ecosystem is worse. The system I set up will be in place for at least the coming five years, providing enough data to acquire long-term observations of this nature.

Another side of the engineering work requires placement and upkeep of antennas to map dispersion of penguins equipped with RFID (radio frequency identification) transponders. The base is built on an island just a couple hundred meters from the continent, with several other islands nearby. Every island and the coast of the continent is covered with Adelie penguin colonies. The colonies can be anywhere from 20 to 2,000 birds. While migration and colony switching does occur, most birds remain in the colony they were born in, increasing the individuality and therefore unique importance of each colony. Tracking the birds' movements helps us discover the dispersion radius and frequency of penguin movement into other colonies. These antennas run off of Raspberry Pis and require power

from solar panels. They often break because of the weather conditions and therefore require a fair amount of repair to ensure proper functionality.

CO-OP AT THE BASE: ECOPHYSIOLOGY IN ADELIE PENGUINS

The second job is field biology research of an Adelie penguin colony, focusing on one specific colony of about 250 birds. This colony has only two access points and at each one is a bridge with RFID readers. Each time a penguin comes in or goes out, it must go across one of the bridges and is then recorded for us to observe who is in or out of the colony. A large section of work is this system's upkeep. This colony has been under observation for at least 10 years, and having data like this for an extended period of time is incredibly valuable in the ecological and biological fields. For the RFID readers

to deliver data, each penguin who enters or exits must be pit tagged, or given a small RFID transponder. These are placed in adolescent chicks in their fat reserve area between the leg and the tail. This year, there were 255 new chicks in the colony. This meant that we had to capture each of them, take their biometric measurements, take their blood samples, and inject a transponder.

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DESIGN BY KATIE GREEN, BIOENGINEERING, 2022

EARTH UNBALANCED:

Are we changing Earth's rotation?

ARTICLE AND DESIGN BY VIANNA QUACH, PHARMACEUTICAL SCIENCE, 2025

The world is constantly in motion. From the smallest particles vibrating in a rock to planetary motion in space, few things remain unchanged. It, then, should be no surprise that Earth's poles — its rotational axis — also shift. This is actually quite normal; polar motion is categorized in multiple time scales, and the most typical ones — the annual wobbles and Chandler wobbles (which occur in approximately 433-day cycles) — periodically move the poles in a predictable circular pattern. On a larger geologic time scale, there has been a secular movement of the axis westward. However, over recent decades, this polar drift has shifted in the opposite direction — now eastward toward Greenland. For decades, observations of the Earth confirm this undisputed fact. The matter for scientists now is to answer the question: why?

Geophysics researchers attribute these polar shifts to the movement of Earth's mass between land and the ocean. These can be triggered by regular weather patterns — atmospheric winds and ocean currents — that impact the periodic pole oscillations, or by larger forces, such as excitations from tectonic plate movements or land reformation caused by the formation or melting of glaciers (known as glacial isostatic adjustment), both which have greater effects on the secular scale of polar motions. These natural forces adjust the mass underneath our feet, changing the flow rate of the mantle of Earth's inner layers and, ultimately, the inertia. However, these alone do not provide the answer to the entire movement, and a study conducted in the *Earth and Planetary Science Letters* found that this force impacts approximately a third of the drift's magnitude.

Climate change has been a large focus of many scientists in relation to polar drift. The steady warming of global temperatures has had a large impact on several natural forces, and human activity may also implicate the magnitude and rate of polar drift. In particular, researchers have found that changes in ice and sea levels contributed to eastward pole movement. Connecting these two components, melting ice sheets and mountain glaciers both decrease the terrestrial water storage while simultaneously transferring these stores to the ocean and increasing sea levels.

The effects of decreasing land water stores in mid-latitudes propagate drift. Redistribution of mass from ice to water in this region especially impacts Earth's inertia, thus becoming a location of great sensitivity to polar motion. This may be the reason that melting glaciers in certain locations across the globe, such as high mountain Asian glaciers and Southern Andes glaciers, have been reported to have a larger role in driving the amplitude and direction of polar motion, although glaciers cannot explain the entirety of depleting terrestrial water storage. Human behaviors and interactions with Earth play a role as well. The decreases in groundwater in the Middle East and India, for example, were found to have majorly impacted polar drift between 2002 to 2013, according to a study in *Geophysical Research Letters*. These storage depletions — from unsustainable consumption in human activities such as irrigation — along with climate change likely contributed to the rapid rate of terrestrial water storage depletion and consequent rise in sea levels.

Multiple studies have created climate change models that directly correlate with the eastward movement of Earth's poles. While large forces such as mantle flow and glaciation have greatly impacted these secular movements, recent studies have revealed the contributions of the rapid changes in the climate. The series of events resulting from rising global temperatures connect with the increasing rates of these secular pole movements. We can also observe this phenomenon in reverse. Through monitoring the drifting patterns of Earth's poles, scientists hope to develop a system to monitor changes in the climate over time. Climate change affects the motion of the world in various ways, from living organisms to the nonliving atmosphere. Here, we find that even the motion of Earth changes its behavior because of how we interact with it.

PHOTO BY QIMONO

Geophysical Research Letters (2021). DOI: 10.1029/2020GL092114
Earth and Planetary Science (2018). DOI: 10.1016/j.epsl.2018.08.059
Geophysical Research Letters (2013). DOI: 10.1002/grl.50552

Nanoplastics officially cover the entire Earth

Scientists investigate the source, the spread, and the consequences

ARTICLE AND DESIGN BY JASMIN PATEL, BEHAVIORAL NEUROSCIENCE, 2025

Resting in our polar ice, nanoplastics are a small force about the size of a virus silently contaminating our environment and creating potentially devastating consequences. A team of international scientists set out to measure the precise concentration of nanoplastics in polar ice cores. For the first time, there are figures on the extent to which nanoplastics have infiltrated the Earth's southern and northernmost regions.

Prior to the team's work, research showed that nanoplastics account for a large portion of plastic pollution created in the environment and displaced to remote locations. Due to a lack of technology for measuring concentrations of this minuscule plastic, it was unknown to what extent nanoplastics existed in polar regions. Thus, the scientists created a novel way to measure them using a version of mass spectrometry. They took melted ice samples, filtered them, and performed mass spectrometry. Each sample's raw mass spectra were essentially an identifiable fingerprint. Thus, by comparison, they determined which nanoplastics were present in the ice.

Samples for this experiment were 14-meter-deep cores from two locations: a firn core from central Greenland and a sea ice core from Antarctica. The study determined that nanoplastic mass concentrations were 13.2 ng/mL in Greenland and 52.3 ng/mL in Antarctic sea ice. Polyethylene (PE), used in plastic packing film, grocery and garbage bags, wires, bottles, and toys, was a major component of the pollution, making up approximately 50 percent of the samples. Both locations, however, are highly remote. This begs the question: where did these nanoplastics come from?

In Greenland, PE made up 49 percent of the sample. Multiple modes of transportation likely moved plastic to this location. Firstly, nanoplastics travel via long-range atmospheric transport or within moving air. In addition, they may come from the sea surface, where UV radiation breaks them down. Certain acts that seem harmless, like washing clothes, can cause nanoplastic pollution in waterways. Contaminated water then reaches the sea surface surrounding the poles. This is supported by the high concentrations of polyethylene terephthalate (PET), a plastic associated with the clothing industry, as well as bottle production and tire plastics. Based on previous measurements of wind trajectories, it is likely that these plastics originated in North America and Asia.

Similarly, PE contributed to more than 50 percent of the sample in Antarctica. Here, it is again likely that surface area sea water causes plastic pollutants to be incorporated into ice. In addition to PE, there were high levels of polypropylene (PP) plastics, which are used in chip bags, diapers, and food containers. Contrastingly, there was less PET and no tire plastics. In this sample, there was also a higher concentration of nanoplastics at the top and a lower concentration at the bottom. This is due to the way sea water freezes into polar ice. At the beginning of the season, surface water freezes to make columnar and granular ice. However, from July onward, ice gathers from supercooled water beneath the ice shelf, where it was protected from sea surface plastics. Thus, the concentration of nanoplastics drops deeper into the sample.

There is a mixture of ways in which nanoplastics reach polar regions. Some are transported via air, while others travel via sea water. Collectively, one thing is clear: the source of these pollutants is human-made products and habits. Whether it be overt, such as littering plastic bottles, or more hidden, such as washing highly synthetic clothes, humans are effectively starting the chain of pollution that ends with nanoplastics in our arctic poles.

The team's discovery of a method to measure nanoplastics in polar ice and the experimental determination of this concentration is highly significant in the context of our changing climate. Nanoplastics in these regions date back to the 1960s. This means that pollutants have impacted organisms that are not used to plastic in their environment for over half a century. Various studies show that nanoplastics harm organisms. For example, their toxicity to marine organisms causes impaired growth and development, larval malformation, and subcellular changes. These organisms are not the only species at risk from nanoplastics. Humans are also impacted by them, causing cell damage, inflammation, and producing reactive chemicals in the body.

This international scientist team urges further research into this subject. They believe finding the precise source of contamination is an urgent matter. It is an essential step in preserving the health of organisms that existed centuries before humans began walking — and polluting — the Earth.

Environmental Research (2022). DOI: 10.1016/j.envres.2022.112741

PHOTOS BY PIXABAY

How we can avoid polarization in conversations around climate solutions

BY MAYA KRAUSE, ENVIRONMENTAL SCIENCE, 2022

DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

In the scientific community, the consensus on human-caused global warming is almost universal — a recent study from *Environmental Research Letters* found that more than 99 percent of peer-reviewed papers agreed that humans are causing global warming and climate change. However, among Americans, the belief in anthropogenic climate change is not nearly as strong, with a recent Associated Press (AP) poll showing that only 54 percent of Americans who believe climate change is happening believe it is caused mostly or entirely by humans, with another 32 percent saying they believe it is a mix of human and natural causes. The political polarization of climate change was also stark in the AP poll, with 89 percent of Democrats and 57 percent of Republicans stating that they believe climate change is happening. A paper published in the journal *Environmental Communication* in 2019 suggests we should learn from the previous communication around climate change to help avoid polarization as scientists move toward suggesting solutions for climate change.

> "There is a risk that negative emissions technologies could become polarized in the public sphere."

In the paper, the authors argue that communication around climate solutions should avoid some key factors that polarized the discussion around climate change. Specifically, they point to negative emissions technologies as a climate solution that has garnered recent academic and political attention, and it's one that could benefit from a reframing to avoid polarization. Negative emissions technologies are methods that remove greenhouse gases from the atmosphere, such as carbon capture, planting new forests, and ocean fertilization (adding nutrients to the ocean to encourage algae growth). According to the 2018 Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5 degrees Celsius, negative emissions technologies will be necessary to reach their recommendation of limiting global warming to 1.5 degrees Celsius ; however, the research and implementation of negative emissions technologies are still very new, and public awareness of these technologies is low. The authors of the paper contend that there is a risk that negative emissions technologies could become polarized in the public sphere in the same way that climate change has become polarized, which would result in a public focused on affirming preexisting beliefs and biases as opposed to supporting solutions.

The authors of the *Environmental Communication* paper outline three main ways that communication around negative emissions technologies can avoid polarization. First, they advise avoiding ideological bundling, which is when attitudes around an unrelated issue color attitudes toward another issue. In some societies, especially the United States, the United Kingdom, Canada, and Australia, taking action on climate change is bundled in with the political left and "progressive" agendas, causing citizens' attitudes to be influenced not by evidence on the topic but by whether their political ideology is "pro" or "anti" that topic. To avoid this bundling when discussing negative emissions technologies, the authors suggest not aligning the new technologies with climate change, but rather embracing that negative emissions technologies can be beneficial in ways that speak to many different political ideologies. Second, the authors recommend choosing communication frames carefully. Typically, climate change is framed as "environment versus economy," presenting climate action as antithetical to economic prosperity, when research shows that framing various climate action scenarios as gains, rather than losses, is more likely to generate support for climate policy. The authors argue that discourse around negative emissions technologies should avoid terms such as geoengineering, which has a negative moral framing, and focus on the technologies as additions to reducing emissions, which is what climate scientists say is needed to limit climate change. Lastly, the authors argue that information about negative emissions technologies should be delivered from a variety of non-partisan, trusted messengers from different media sources to avoid aligning the technologies with any political agenda.

As climate research in the public discourse becomes less about whether climate change is occurring and moves toward the development of strategies to mitigate its effects, communication around the solutions to climate change will become increasingly important. In order to reach no more than 1.5°C of global warming, it will be critical to avoid tying the solutions such as negative emissions technologies to the already polarized issue of climate change.

Environmental Research Letters (2021). DOI: 10.1088/1748-9326/ac2966
Environmental Communication (2019). DOI: 10.1080/17524032.2019.1630463

PHOTO BY SHUTTERSTOCK

Olive oil compounds as a potential therapy for neurodegeneration

BY AMANDA BELL, DATA SCIENCE & BEHAVIORAL NEUROSCIENCE, 2023

DESIGN BY VIANNA QUACH, PHARMACEUTICAL SCIENCE, 2025

The Mediterranean diet has long been touted for its ability to decrease one's risk of suffering from health problems such as diabetes, cardiovascular disease, certain types of cancer, and neurodegenerative diseases. Although various studies support these claims, it isn't always clear how the Mediterranean diet confers these benefits. While olive oil isn't the only component in the Mediterranean diet, research suggests that it may be a crucial factor contributing to the diet's favorable reputation. More specifically, polar compounds in olive oil called phenols could potentially prevent neurodegeneration and therefore act as a potential treatment for neurodegenerative diseases.

Phenols are aromatic or ring-containing organic compounds with a hydroxyl -OH group attached to at least one of the carbons in the ring. One phenol in olive oil called hydroxytyrosol seems to be the main compound responsible for olive oil's neuroprotective potential due to its antioxidant properties and interaction with pathways that manage oxidative stress. As an antioxidant, hydroxytyrosol donates a hydrogen atom from one of its hydroxyl groups to stabilize free radicals, which are unstable molecules with an unpaired electron in their orbital. When a free radical pairs with the donated hydrogen, its unpaired electron pairs with the hydrogen's electron, ultimately becoming stable and less likely to damage other molecules. One of the pathways with which hydroxytyrosol is thought to interact is the Keap1/Nrf2/ARE pathway. This pathway regulates the expression of phase II detoxification enzymes that defend against harmful chemicals like carcinogens and free radicals.

> "Extra virgin olive oil — relative to coconut oil and butter — improved learning and memory in an early-learning and memory decline mouse model."

It is important that hydroxytyrosol plays a role in antioxidation because neurodegenerative diseases are often characterized by oxidative stress which is caused by an imbalance between oxygen-derived radicals and antioxidants in the brain. Consequently, any substance that acts as an antioxidant or increases the concentration of enzymes that assist in neutralizing free radicals could be a beneficial therapy to treat neurodegenerative diseases. Other factors to consider include how well the substance is absorbed by the body, how it interacts with other systems of the body, its ability to cross the blood-brain barrier, and its bioavailability. According to a review in *Molecules*, hydroxytyrosol is well-absorbed and able to cross the blood-brain barrier, but the chemical also undergoes processing in the small intestine and liver before entering the bloodstream, resulting in poor bioavailability. However, poor bioavailability doesn't necessarily mean that hydroxytyrosol is a poor therapeutic candidate. Instead, it means that more research should be conducted with higher concentrations of hydroxytyrosol as well as in vivo in humans to gain a better understanding of how hydroxytyrosol functions.

If olive oil contains hydroxytyrosol, how does olive oil impact neurodegeneration? Unfortunately, consuming high amounts of olive oil daily is unlikely to have a large impact in preventing neurodegeneration. One issue is that most olive oils don't have sufficient concentrations of hydroxytyrosol. The European Food and Safety Authority set a minimum daily requirement of 5 milligrams of hydroxytyrosol for beneficial effects to occur, but the median concentration of hydroxytyrosol in olive oil is 1.9 mg/kg, which isn't nearly enough for people to reach the minimum daily requirement. However, the International Olive Council is currently evaluating methods to accurately estimate the concentration of hydroxytyrosol in olive oils, which could be useful if oil producers decide to prepare hydroxytyrosol-enriched olive oils. The other issue, as previously mentioned, is hydroxytyrosol's poor bioavailability once consumed. If olive oil doesn't have high concentrations of hydroxytyrosol, it is highly unlikely that a significant amount of hydroxytyrosol would be usable anyway.

Despite evidence that olive oil currently doesn't have enough hydroxytyrosol for people, studies have analyzed the neuroprotective effects of olive oil in mice. One study published in the *Journal of Alzheimer's Disease* found that extra virgin olive oil — relative to coconut oil and butter — improved learning and memory in an early-learning and memory decline mouse model known as SAMP8. While it is unknown whether studies like this will translate to humans, there is still potential for hydroxytyrosol to be a therapy for neurodegenerative diseases and for producers to create hydroxytyrosol-enriched olive oil or other hydroxytyrosol-enriched products.

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AN INVESTIGATION INTO "ACQUIRED SOCIOPATHY":

The underpinnings of behavior inhibition and aggression

BY TENZING BRIGGS, ENGLISH, 2022
DESIGN BY JASMIN PATEL, BEHAVIORAL NEUROSCIENCE, 2025

When it comes to the complexity of human behavior, no behavior is more intricate than the social nets we weave. In complex social networks, empathy is an important key to social behavior, but because it is felt emotionally complicates the matter. When it comes to the brain and personality, many people might be aware of the idea of "nature versus nurture" — that each person's emotional and psychological makeup is affected by genetics and life experiences. Emotions are complicated, however, because they are subjective and thus hard to measure. As an emotion, one might easily dismiss the neurological basis of empathy and, in attempting to understand individuals who cannot feel empathy, assume the difference is simply perspective. But one thing points to a deep neurological difference: the incredible discovery of what psychologists and neuroscientists call "acquired sociopathy."

"Acquired sociopathy" is the phenomenon where, after an individual has sustained severe brain damage, an individual's personality changes drastically. The person may gain sociopathic traits such as increased aggression and the inability to understand others' emotions. This points to something fascinating in the development of sociopathy. While genetics may predispose someone to sociopathy, lived experiences often catalyze the condition. Negative psychological experiences, such as trauma or neglect, during periods of early development can reduce an individual's care for others, but acquired sociopathy points clearly to a neurological element underpinning a lack of empathy. Moreover, studies on acquired sociopathy reveal some of the cognitive processes included in empathy.

A study in *Brain: A Journal of Neurology* examined one such individual known as J.S. In November 1997, J.S. was admitted to a hospital after he was found unconscious. Doctors discovered brain trauma indicative of stroke caused by a general convulsion. After hospitalization, he was reported as "gravely disturbed" and had several "unpredictable episodes of aggression," yet relatives described him as "a quiet, rather withdrawn person who was never aggressive." In particular, J.S. had brain trauma primarily in the orbitofrontal cortex. This portion of the brain has been associated with acquired sociopathy since the late 1980s when the first individual with acquired sociopathy was studied and the term introduced.

Since that first case, experts have developed many hypotheses on why sociopathy might be associated with atypical social behavior, the most widely accepted being the idea of a "somatic marker system" by Antonio Damasio. In this hypothesis, the mind "tags" certain social situations and has an "autonomic nervous system response" unique to each social situation. An autonomic response is something that someone experiences unconsciously, such as heart rate, hunger, respiratory rate, or arousal. According to this hypothesis, the body and mind physically respond to social situations in a way that directs attention to possible negative outcomes of social interaction, guiding people toward positive outcomes and acting as a warning system. This hypothesized autonomic response would be analogous to a physical experience of emotion, like empathy or other especially social emotions like anxiety or humiliation. In line with this, studies of patients with trauma to the frontal cortex have shown these patients do not have an autonomic response when passively viewing pictures of disaster, mutilation, or nudity. Interestingly, patients did have autonomic responses in active viewing — viewing when asked to pay special attention to a picture or scene. This might indicate that acquired sociopathy does not mean the inability to recognize the emotions of others but instead means a lack of emotional response occurs unless the individual's attention is externally directed to the emotions of others.

In the case of J.S., his scores on tests, which were designed to measure an individual's recognition of others' emotions, were incredibly low for the average person with sociopathy. This was true in both passive and active viewing, showing perhaps that the trauma to his frontal cortex contributed especially to a lack of recognition of emotions. The wealth of research leaves unclear whether this cognitive or emotional process is the only one involved in sociopathy. As any neurologist will tell you, the brain in its adaptability can achieve a great many things, and each person's brain varies greatly. With trends in neurotypical or non-neurotypical psychology there is often a spectrum — something well accepted not only for conditions such as sociopathy, but also others such as autism, attention deficit disorder, and depression. In other words, multiple factors contribute to how these conditions present. Research into acquired sociopathy, as one manifestation of the disorder, reveals some of the ways in which it develops and functions, both psychologically and neurologically.

Brain (2000). DOI: 10.1093/brain/123.6.1122
PHOTOS BY FREEPIK

WORDLE

The five-letter phenomenon

BY RAISA BHUIYAN, COMPUTER SCIENCE & MATH, 2025

Every night, precisely at midnight, thousands of people visit a website and wrack their brain, going through every five-letter word they know to find the correct solution in six tries or less. Once they solve the word — or fail to do so — they wait for 24 hours to do it all over again. But, what is it about Wordle that is so appealing, inspiring *The New York Times* to purchase the quick game for a price of seven figures? According to psychologists and neuroscientists, there are three main aspects to Wordle's popularity: the dopamine rush from winning, the challenge the game poses, and the social aspect.

The feeling of reward from solving that complicated question or winning that challenging round is caused by dopamine, a chemical neurotransmitter that your brain releases when it expects a reward. According to psychologist Lee Chambers, Wordle "activates both the language and logic parts of our brain." Although the difficulty posed by puzzles may feel frustrating, all that frustration is outweighed by the dopamine rush caused by figuring out the correct word in six or fewer tries. But what if we don't figure it out in time? According to Jonny Thomson, professor of philosophy at the University of Oxford, seeing the target word even after failure provides a sense of satisfaction.

In addition to the rush of joy from success, people find Wordle addictive because of the challenge of six limited attempts. This feeling is amplified when we cannot solve the daily Wordle in the given amount of guesses. Our brains can't stand losing, and we resolve that feeling of anger by trying again tomorrow. We just *have* to try again to get the dopamine rush.

The final and perhaps most unique aspect of Wordle's popularity is the social aspect. After solving the target word, we can post our stats online so that our friends can see our success (or failure). Guessing the same word allows us to bond over our shared success or collectively complain about the difficulty. Most importantly, this game unleashes our competitive nature. Who doesn't want to compare their Wordle stats with their friends to see who did better? Being able to share results and compete with each other creates a sense of unity.

Of course, other factors make Wordle so addictive, such as the free and easily accessible website and the short time span of playing once a day. As shown by *The New York Times'* purchase, it doesn't look like Wordle is going anywhere for a while, so sit back and good luck on today's challenge!

DESIGN BY KATIE GREEN, BIOENGINEERING, 2022

A formula for stability

The math behind treating bipolar disorder

ARTICLE AND DESIGN BY EVELYN MILAVSKY, CELL & MOLECULAR BIOLOGY, 2025

Studies about bipolar disorder have consistently found that patients tend to display either predominantly manic or predominantly depressive characteristics. This means their respective treatment options must be appropriately modified to fit the individual.

In response, Dina Popovic from the University of Barcelona and researchers from other European universities developed a pharmacological scale for measuring medications used in the treatment of bipolar disorder. This scale, called polarity index, is a relative measure of the antimanic and antidepressant efficacy of pharmaceuticals.

The polarity index can be calculated by first finding values referred to as numbers needed to treat (NNTs). NNTs are found by determining how many medication doses prevent a depressive episode, then determining how many doses prevent a manic episode. The NNT for depressive episodes is then divided by the NNT for manic episodes to find the polarity index value. To obtain these values, Popovic organized double-blind, randomized trials on medications she researched and placed participants on either a placebo or actual treatment plan for at least 24 weeks while assessing the drug's ability to stabilize their mood. The average dose across all participants who received a certain drug was then used to find the NNT values of that medication. Using these calculations, medications that receive a polarity index value of one are said to be equally effective in preventing the onset of manic and depressive episodes, whereas values greater than one are more effective at preventing mania, and values less than one are more effective at preventing depression.

Popovic's results revealed that many drugs commonly associated with bipolar disorder treatment are much more effective at managing manic episodes than depressive episodes, uncovering a bias within the realm of bipolar disorder research. The spectrum of polarity is not given equal attention, with mania commonly seen as "more severe or problematic." A quantitative tool like the polarity index can limit biases to curate more appropriate treatment plans for individuals regardless of their predominant polarity.

For patients with bipolar disorder, a comprehensive measurement system for approved medications means the possibility of longer maintenance treatment phases between relapsing into manic or depressive stages. Correct usage of the polarity index provides a sustainable approach to long-term bipolar disorder treatment that seeks continual prevention rather than cycling through episodes, giving insight into the lasting maintenance that remains as the final frontier of bipolar disorder treatment.

European Neuropsychopharmacology (2012). DOI: 10.1016/j.euroneuro.2011.09.008

PHOTO BY SHUTTERSHOCK

Do opposites really attract?

Predicting romantic interest before meeting

BY LAUREN VOSO, BEHAVIORAL NEUROSCIENCE, 2023

DESIGN BY SOPHIE PATE, BEHAVIORAL NEUROSCIENCE, 2024

The neat-freak and the slob, the good girl and the bad boy, the introvert and the extrovert. All are recurring tropes in our media (and maybe everyday life too) that seem to embody the phrase "opposites attract." The saying is used to justify every seemingly insignificant or extremely vast difference within romantic couples. But are we really more attracted to those we perceive as opposite to us?

A group of researchers led by Sally Olderbak at Ulm University in Germany aimed to put this question to the test by setting up a study, published in the European Journal of Personality, to test what factors predict romantic interest at initial acquaintance. Heterosexual young adult participants completed personality questionnaires before watching videos of people of the opposite-sex (targets) talking about themselves. The researchers then asked participants to rate the target's traits and their romantic interest in the target. Olderbak and her team compared the participants' personalities to their perception of each target's personality to find if there was any correlation between these factors and their rated romantic interest. The study focused on the Big Five personality factors considered in psychology: conscientiousness, extraversion, agreeableness, openness to experience, and emotional stability.

Specifically, the researchers were looking at several hypotheses based on contradicting theories in personality psychology. The dissimilarity theory, which is closest to the concept of opposites attract, states that finding a partner with dissimilar traits will lead to more diverse ideas and approaches to problems, thus leading to a survival advantage. According to the theory, people may still have greater attraction to those with similar demographics, but within those demographics, they will be more attracted to others with different personality traits. This also correlates with research on attachment styles, which are ways that we relate to others in a relationship emotionally and behaviorally. Studies have found that complementary attachment styles, such as avoidant and anxious, are associated with higher success in couples. On the other hand, the researchers also wanted to test another hypothesis, which was that having similar personality traits will predict attraction. This theory states that individuals envision a romantic partner with similar attitudes and beliefs to themselves. Both hypotheses have been supported in past literature, leading to a need for more research studies like this one.

However, neither hypothesis was supported by the findings of the study. So, opposites don't seem to attract, but similarities don't seem to either. In fact, the only factor that the researchers found to predict romantic interest, across the binary genders, was perception of physical attractiveness. More specifically, subjects were most romantically interested in those they viewed as more physically attractive than themselves.

It is interesting to consider whether or not this effect would be found in different age groups. The study only focused on college-aged participants, an age for which the brain is known to focus on sex and sexual attraction. A follow-up study targeting different age groups would show us how predictors of romantic interest and priorities for romance change as we get older.

The study also aimed to explore sex-related differences and found that females tended to share more agreement in their perception of traits. In other words, the female participants generally saw similar levels of personality traits when rating the same male targets in their videos. Male participants had more variance in their responses when viewing the same female's video. The authors were unsure of the cause of this finding. It could have been that the female targets' videos were harder to distill personality traits from or the female participants could have been better at identifying personality traits from the videos. This sex-related difference could be explored further and may have interesting considerations for relationship dynamics if there truly is a female advantage in recognizing personality traits.

Overall, this study focusing on predictors of romantic interest at first acquaintance has surprising implications for psychological research on relationships, as it was found that neither perceived similarity or dissimilarity in personality traits had an effect on romantic interest. The finding that perceived physical attractiveness is the only predictor of romantic interest shows that physical attraction, at least in the college-aged population, might be more important than initially thought. So, opposites might not actually attract, but looks certainly do.

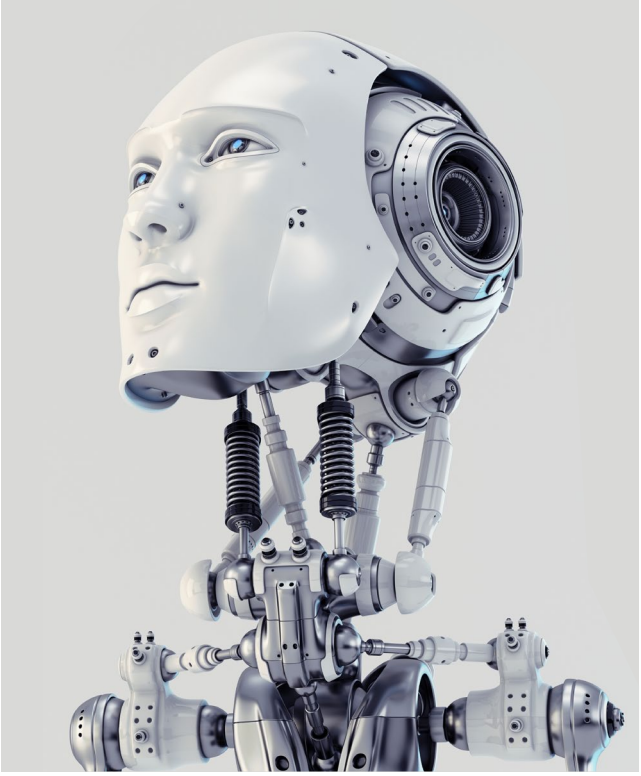
PHOTO BY UNSPLASH

European Journal of Personality (2017). DOI: 10.1002/per.2087

BELIEVE:

‘The Polar Express’ and the polarizing uncanny valley phenomenon

BY HIBA HUSSAIN, BIOLOGY, 2024



Dressed in cozy pajamas and armed with steaming cups of hot chocolate, millions of families flock to their televisions to watch “The Polar Express,” a film that has arguably become a holiday classic. While “The Polar Express” encourages the audience to believe in Christmas magic and draws upon childhood innocence, it is equally known for eliciting eerie feelings due to hyperrealistic computer animations. NPR’s Aliva Noë described the characters as having an expressive face with “zombie-like” eyes due to the limitations of the motion capture technology utilized. This strange feeling is known as the uncanny valley effect and has been studied by scientists and engineers for the past few decades.

In 1970, Professor Masahiro Mori, a robotics professor at the Tokyo Institute of Technology, mathematically described human appreciation for human-like robots as a function of human likeness that increases until a certain point where the feeling of appreciation suddenly turns into one of eeriness or repulsion. This area of the graph is analogous to a valley sloping downward, and was termed the uncanny valley. The uncanny valley phenomenon now extends to various different fields, from animation to medicine, and may serve as a prediction of failure in human-technology relationships as more futuristic technologies are integrated into our daily lives.

A recent study at the University of Cambridge provides strong evidence for the neurological origin of the uncanny valley phenomenon. In this study, 21 individuals were asked to rate the likability and human likeness of various groups (humans without physical impairments, humans with physical impairments, humanoid robots, synthetic humans, and android robots) in certain social situations. In keeping with the uncanny valley effect, the participants consistently ranked human or human-like groups higher and were monitored under fMRI to analyze the physiology behind this behavior. The University of Cambridge team found that the medial prefrontal cortex, a structure responsible for higher-order decision making, experienced greater activation during the ranking task. Surprisingly, two parts within the structure built upon one another to generate this response. One region translated human likeness into a “human is here” signal and elicited a strong response when presented with human groups. The other region, called the ventral medial prefrontal cortex, processed the “human is here” signal and turned it into a likability rating; this rating experienced decreases around the boundary between human and non-human groups and is a hallmark of the uncanny valley effect. This study provides a good launching-off point for understanding the neurobiology behind the uncanny valley effect and why the response exists in the first place.

While the University of Cambridge study provides a basis for the physiology behind the uncanny valley effect, several theories for why we feel this repulsion have been proposed by psychologists. For instance, the evolutionary aesthetics theory explains the uncanny valley effect as a product of human preferences for physical attributes indicating health, fertility and overall fitness. Perhaps our strange feeling toward semi-realistic beings can be attributed to low aesthetic value. On another note, the mortality salience hypothesis, another concept in line with evolutionary psychology, suggests that humans are reminded of death upon observing human replicas without human liveliness. As a result, humans experience a feeling of uncanniness as a coping mechanism. While these theories are plausible, further studies must be conducted to confirm the link between human reactions to the hyperrealistic and the psychological factors behind them.

With recent developments in robotic technology, robots are nearing human resemblance and intelligence. Futurists have predicted artificial intelligence surpassing human intelligence in the next few decades. Animation technologies are getting more realistic with each film, and the line between animation and lifelike figures is likely to become blurred to the extent that we recognize them as one and the same. It is only a matter of time before we are able to overcome the uncanny valley.

PHOTO BY SHUTTERSTOCK
DESIGN BY KATIE GREEN, BIOENGINEERING, 2022

Journal of Neuroscience (2019). DOI: 10.1523/JNEUROSCI.2956-18.2019
IEEE Robotics & Automation Magazine (2012). DOI: 10.1109/MRA.2012.2192811

Using natural language processing to analyze religious texts

BY DINA ZEMLYANKER, DATA SCIENCE & BIOCHEMISTRY, 2024

DESIGN BY LILLIE HOFFART. ENVIRONMENTAL SCIENCE, 2022

Religion has sparked many a war over differences in beliefs and interpretations. And yet, the different religious texts on which these belief systems are built are quite similar. However, the textual data that exists in religious texts is difficult to analyze because of the multitude of different languages used. Additionally, texts often don't follow typical or set syntax. Most of all, analysis is complicated by the sheer amount of different texts. Comparing all religious texts is a virtually impossible task for any human and a complex task for computers. Specifically, this becomes an intriguing natural language processing problem.

> "Texts not often associated with each other, like the New Testament and Tao Te Ching ... have significant topic overlap."

Natural language processing (NLP) is a subset of artificial intelligence focused on processing and understanding textual information through machine learning. A few different NLP techniques are used, which include term frequency analysis, (tracking the number of times certain words appear), sentiment analysis (classifying text into positive or negative depending on its connotations), and topic extraction (determining the main topic discussed in the text). In a study by researcher Daniel McDonald at Utah Valley University, various religious texts were analyzed and compared, including the Bible, Qu'ran, and Torah. In this study, the primary NLP technique was topic extraction.

First, the text was divided into sentence chunks, and words were tagged based on their content and part of speech. McDonald's research focused on just the verbs and nouns used. After this initial round of processing, a second pass through the text combined similar content tags to make more encompassing topic tags. Topics were then sorted based on the frequency of the terms in each topic, with only the most relevant kept. Topics with the greatest term frequency were considered the most relevant. Additionally, the topics were divided based on whether they were noun or verb topics. Some examples of noun topics were animals, family relationships, and Earth, so these consisted of words like "sheep," "brother," and "world." Some examples of verb topics were to amuse, to appear, and conjecture, so words like "dazzle," "arose," and "knoweth." The analysis determined how much overlap existed between different texts in both noun and verb topics.

With noun topic overlap, the books most similar were the Torah and Old Testament, with the Book of Mormon and Old Testament following close behind; the former had 80 percent similarity while the latter had 78 percent overlap. The Tao Te Ching, a book about the fundamentals of Taoism, and the Torah were most different in noun topic similarity, with an overlap percentage of only 27 percent. Verb overlap scores produced similar results, with the Torah and Old Testament still as the most similar. The verb overlap scores between the Tao Te Ching and Torah were still low, but the Greater Holy Assembly and the Rig Veda, an ancient Indian collection of Vedic hymns, beat them out for the lowest score.

Although this compares texts in only one way and doesn't fully cover religious text complexities, it still shows how similar they are and, interestingly, how texts not often associated with each other, like the New Testament and Tao Te Ching, which together surpassed 50 percent similarity, have significant topic overlap. In the future, even more NLP processes should be applied, such as sentiment analysis, to determine similarity further and aid our understanding of why texts are perceived the way they are.

PHOTO BY SHUTTERSTOCK

SCIENTISTS ON SUBSTANCES:
CAN RESEARCHERS BE OPEN ABOUT DRUG USE?

BY LILY WEBER, BIOLOGY & ENGLISH, 2023

DESIGN BY IAN PROULX, BIOENGINEERING, 2022

Drugs are highly stigmatized in society. Furthermore, there exists a particular stigma regarding drug use for those in the scientific community. Many companies, hospitals, and research facilities include drug testing in their hiring process. In fact, according to the American Addiction Centers, healthcare and hospital-related jobs were the second most common positions to require drug testing before employment. These fields have arguably valid reasons to drug test their employees. Workers in these fields can have both direct impacts on people's wellbeing, such as in patient care, or indirect effects if involved with research.

Where things become murkier is in the realm of academic drug researchers. As highlighted by a 2020 article in *Contemporary Drug Problems*, while some drug researchers may have anecdotal drug experiences, this is rarely reflected in published work. While such exclusions may seem obvious at first, this contradicts the highly valued research principles of transparency and reflexivity. Furthermore, the authors posit that such disclosures could go a long way toward reducing stigma and improving understanding of drug use and users alike. In spite of these potential benefits, those who consider discussing their drug use in professional settings risk not only legal consequences but also ostracization by their peers, thereby limiting their ability to contribute to research in the future.

Despite the potential drawbacks presented by self-disclosure, academics have engaged in it both historically and in modern times. Two such examples are Timothy Leary (1920–1996), a former lecturer at Harvard University, and Carl Hart, a psychology professor and scientist at Columbia University. Both represent examples of individuals who were not only researching drugs but who also openly partook in them themselves.

Timothy Leary attended University of California, Berkeley where he earned a PhD in psychology. He established the Harvard Psilocybin Project, which focused on the effects of hallucinogenic mushrooms. Leary was able to administer the compound to subjects and study their reactions. Furthermore, Leary employed rather unorthodox methods including conducting such experiments while under the influence of psilocybin himself.

By 1962, many faculty members became disenchanted with Leary's research, citing both safety concerns and unscientific methods as their concerns. Despite Leary's attempts to mitigate these concerns, he was fired in 1963 for administering psilocybin to an undergraduate student. Accordingly, his project came to an abrupt halt and he was effectively banned from the world of academia.

Leary went on to become an icon of the counterculture and psychedelic movement. In his case, it was clear that the world of academia and drug use could not coexist. Both his fascination with and partaking in drug use seemed to preclude him from the academic world. This raises the question, however, as to whether this is always the case.

An interesting counterexample lies in the more modern example of Carl Hart. Hart published a book in 2021 titled "Drug Use for Grownups: Chasing Liberty in the Land of Fear." In it, he discusses his professional ambitions and his research on the behavioral and neuropharmacological effects of psychoactive drugs. Hart endeavored to open up a frank conversation about drug use and what drug users actually look like, a portrait which may be more nuanced than people think. Hart is a respected, tenured neuroscientist at one of the most prestigious universities in the country. Hart opens his book by proclaiming that he is "now entering [his] fifth year as a regular heroin user," a bold statement given the highly publicized destructive nature of the substance.

It's a daring and even shocking pronouncement, one that may be difficult for the public to square with their idea of a typical scientist. It's also a situation that clashes heavily with society's preconceived notions of a typical drug user. Hart exists as a direct counter to what many see as a rule — namely, that drugs are inherently dangerous and will ruin your life. This may be a difficult pill to swallow for those who hold fast to current stigmas surrounding drugs. It has now been over a year since Hart's book was published, and he remains employed at Columbia and is the principal investigator of the Neuropsychopharmacological Lab.

One of the main pleas he drives home in his book is that society reexamines its perceptions surrounding drugs and those who use them. Hart also questions why drug users are so ardently villfied and whether drug use should be viewed as a personal liberty. Regardless of one's own philosophies on drugs, such dialogues may be the key to reducing stigma and bringing healing to those affected by addiction.

Contemporary Drug Problems (2020). DOI: 10.1177/0091450920953635

PHOTOS BY PIXABAY

How artificial intelligence is revitalizing the world of finance

BY VINITHA VIVEK, BUSINESS ADMINISTRATION, 2025
DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

> **"Ignoring technological change in a financial system based upon technology is like a mouse starving to death because someone moved their cheese."**
> — Chris Skinner.

The word "fintech" — the cutting-edge fusion of finance and technology — has gained more popularity in the last few years than ever before. Artificial intelligence is transforming the field of finance as we know it through advancements in risk assessment, fraud detection and management, algorithmic trading, robo-advisory, and more.

In the risk assessment sector, new algorithms are being developed to assess whether someone is eligible for a loan. These algorithms are deeply rooted in machine learning, so the technology learns over time. Traditional analysts are more prone to error and bias than AI and machine learning, which employ clear-cut and logical thinking matched with consistent stamina to analyze copious amounts of data. Plus, the obvious factor: these technologies can go through cases considerably faster than humans. These same machine learning algorithms can be used to assess the eligibility of someone for a credit card and even postulate personalized interest rates. This customized judgment is more advanced and comprehensive than traditional credit scoring. This is because it is done through evaluating thousands of pieces of relevant data from a person which allows AI to make a more well-informed decision.

Algorithmic trading is the process in which instantaneous decisions are made to carry out trades based upon detectable patterns. High-speed and devoid of emotional skews, AI has dominated the trading field. In fact, 80 percent of all United States trade operations are facilitated by AI algorithms today. Furthermore, these new systems are growing stronger through utilizing natural language processing mechanisms, a branch of AI dealing with teaching computers to comprehend and analyze human-written text. Accordingly, these algorithms are now starting to sift through alternative data sources like useful information in news articles and other online sites to make rational trading decisions.

E-criminals who attempted and succeeded in credit card fraud a few years ago would have virtually no success today. AI can recognize and report transactions made in locations a client usually isn't at and withhold abnormal amounts of money that are out of the client's specific spending zone. Plus, because these machine learning algorithms are constantly learning, if a client tells the service that it has incorrectly detected fraud for a normal transaction they made, it will take that information into account and make even more accurate decisions when examining future transactions. The powerful, recurring idea here is that machine learning can never move backward — it will only get smarter and smarter.

Robo-advisory, a group of automatic investment advisory services, has grown relevant in forecasting the investment and wealth management market. Employing sophisticated algorithms to formulate investment decisions, robo-advisor services weigh a client's personal preferences like risk appetite and financial goals against unpredictable forces like market volatility. Moreover, these services do not require financial knowledge to use, encouraging the self-management of finances.

As Skinner implied, fintech is here — and it is here to stay. In addition to these AI innovations, there are plenty more already in use and others in the making. In fact, financial institutions are in the process of developing quantum algorithms. Quantum computers essentially carry out calculations based on the probability of an object's state in advance, giving them the ability to work with significantly more data compared to traditional computers. They process and analyze substantial and unstructured financial data at unthinkable speeds, performing a task in as little as three minutes that would take a supercomputer thousands of years. Quantum computers will especially be of use in areas where algorithms are driven by live data streams and involve extensive random noise like real-time equity pricing.

There is no doubt that new advancements in financial technology are going to keep coming — the question is, are businesses and consumers ready to keep up?

PHOTO BY SHUTTERSTOCK

Polar plunge: No pain, no gain

BY ANYA GHAI, BIOLOGY, 2023

DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

In the dead of winter, the Atlantic Ocean can reach a frigid 37 degrees Fahrenheit. Diving into this water would immediately activate the cold receptors beneath your skin, causing you to experience a "cold shock." This reaction has the potential to be lethal. First, it triggers an involuntary gasp of air, followed by hyperventilation. This is incredibly dangerous if your head is underwater, as it creates a risk of drowning. Your blood vessels constrict in response to the cold shock, elevating heart rate and blood pressure to levels that can cause heart failure, strokes, or arrhythmia in vulnerable individuals. Within minutes, you may begin to feel dizziness, ringing in your ears, cramping of your hands and feet, and numbness in your extremities. In extreme cases, your nerves could freeze up entirely, inducing muscle weakness and the inability to move. Needless to say, paralysis is the last thing you want to happen while swimming in the ocean.

Despite the risks, thousands of individuals gather each year to submerge themselves in icy waters for charity in an event appropriately titled the "Polar Plunge." Katie Beatty, a cousin of mine and Cape Cod resident, is a polar plunge enthusiast and posts monthly ice-cold dives on her Instagram, @katie_capecod. "My inspiration is for sure Wim Hof," she said. "He's so badass!"

> "There is increasing evidence that repeatedly experiencing short-term physiological stress could improve health and wellness in the long run."

If you are unfamiliar, Wim Hof, also known as the "Ice Man," is a Dutch athlete known for his superhuman ability to withstand freezing temperatures. His achievements include: running the fastest barefoot half marathon on ice, swimming a distance of 188 meters beneath ice while holding his breath, and climbing Mount Everest wearing only shorts and boots. He attributes his success to the "Wim Hof Method," which involves gradually exposing his body to low temperatures by taking cold showers. Although his method is scientifically controversial, a study of the athlete in 2011 found that Wim Hof could voluntarily activate his autonomic nervous system to produce a controlled stress response. This finding has caused the public interest in cold-water therapy to skyrocket in recent years.

Researchers are also taking interest in this growing trend. There is increasing evidence that repeatedly experiencing short-term physiological stress could improve health and wellness in the long run. Incidences of infectious diseases in the upper respiratory tract are 40 percent lower in cold-water swimmers compared to a control group, according to a 2020 review on cold-water swimming. This is primarily due to the increased concentration of white blood cells that occurs during exposure to acute stress. Cold-water swimmers generally have lower stress and inflammatory response than an unhabituated control group. This phenomenon is termed "cross adaptation," meaning that adapting to one stressor helps partially adapt to others. Additionally, the more cold shocks one experiences, the less severe they get.

"I've done at least ten cold plunges. I have noticed I can stay in longer, or maybe do a second dunk in winter," Beatty said.

Experts say adaptation is reached after about six cold shocks: you become more in control of your breathing, panic less, and your heart rate rises less. Furthermore, the immune cells responsible for inflammation, cytokines, can induce depression-like symptoms by inhibiting serotonin production. By reducing the cytokine response, cold-water exposure may be able to biologically mitigate symptoms of depression as well. This was described in a case report of a woman at the University of Portsmouth who was diagnosed with severe depression and anxiety at 17. At 24, when she decided she wanted to be medication-free, researchers suggested a novel treatment plan: weekly cold-water swimming. After one month, the patient reduced her medication; after four months, she no longer needed drug treatment. Even a single 20-minute immersion in cold seawater has been shown to improve the mood of young, healthy participants immediately after the swim.

Although the scientific community is still skeptical of cold-water therapy, anecdotal evidence tells a different story. According to Wim Hof's website, over 500 people have "successfully completed" his academy for mastering the Wim Hof Method. Undoubtedly, people who participate in cold-water activities swear by its benefits.

When I asked my cousin whether she would recommend her hobby to others, she eagerly answered: "Yes! I hope more will start the more I do it! I hope you will do it with me someday!"

Cold water may not be enjoyable for everyone, but you never know until you try. A cold shower is a pretty brave start.

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PHOTO BY SHUTTERSTOCK

BREAKING RECORDS AT RECORD PACE:

How biomechanics have influenced the Olympics

BY ELI PAUL, MATHEMATICS & DATA SCIENCE, 2024

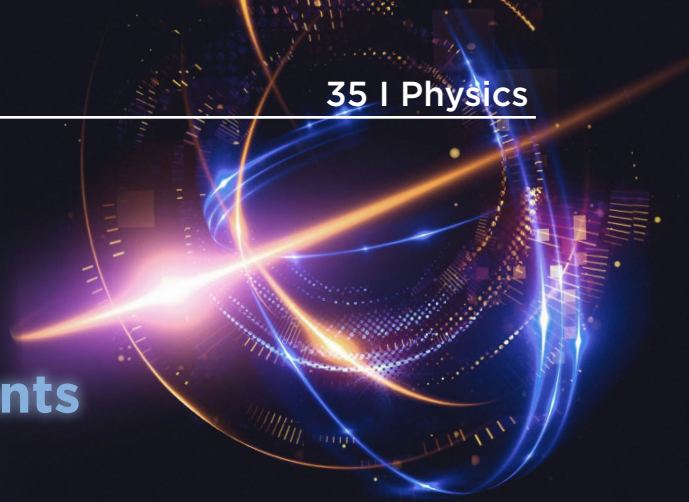
The world record for the 100 meter dash is 9.58 seconds. A record set by Usain Bolt after beating his own preceding record at the previous Olympic Games. With such impressive records already, it has become onerous to imagine how Olympic records can continue to get broken, yet every round of Olympic events brings a new list of records longer than the previous one. In fact, the 2021 Summer Olympics saw the highest number of records broken, another record in and of itself, compared to any other year. The explanation behind the continuous improvement boils down to advancements in biomechanics. Whether it be developments in equipment or athletic techniques, the evolution of biomechanics has encouraged the shattering of records in recent years. As the 2022 Winter Olympic Games arrest the world for the month of February, biomechanics is shaping the way athletes compete in winter sports.

One of the most technically complex winter sports is cross-country skiing, which sees athletes traverse diverse terrains, requiring multiple different techniques for maximum performance. Cross-country skiing has been a staple of the Winter Olympics since its first iteration in 1924, but recent biomechanical advancements have significantly impacted the sport in just the last decade. Cross-country skiers must quickly accelerate and reach a high speed to maximize distance traveled for energy expended. This requires athletes to use their entire body to generate substantial force and propel themselves forward. These phenomena have resulted in the development of new techniques like the "kangaroo" double-poling form, which attempts to produce stronger forces from the legs and the poles. Compared to classical skiing techniques, this form involves athletes standing more upright, like a kangaroo, when they extend their legs to lurch forward, so that their center of mass becomes higher. A 2018 article published by Barbara Pelligini and others in Frontiers in Physiology noted, in elite skiers, that "the process may be so dynamic that the heels and, indeed, sometimes the entire foot are lifted off the ground," resembling the hop of a kangaroo. A higher center of mass allows the force of gravity to have a larger effect on the poles as the body position of the athlete lowers in preparation for another leg push. Since more energy is transferred to the poles, the subsequent pull from the arms contrives a greater propulsion force. Since this technique relies on forces generated by the athlete's arms and legs, the training regimen has also adapted to focus more on strength training, as ergometers have shown that faster athletes are stronger, possessing more lean mass. As maximally efficient techniques are continuously refined, acceleration and pace continue improving while records become increasingly fragile.

Developments in motion analysis over the last decade have shown significant impacts on enabling the peak movement of athletes. One of the most notable developments comes from the cutting-edge blades widely used in speed skating. The design of a skate with a hinge was patented in 1894, but it wasn't until 1980 when a prototype of the now popular clap skate was created. The clap skate was designed with a hinge at the rear, which would allow the heel to detach from the blade, so the entire blade remains in contact with the ice as the skater pushes forward. It was theorized that the extended contact time would allow for longer strides and thus increase the amount of power per push. In the mid-1990s, a group of 100 skaters were given either clap skates or "normal" skates and their progression through an entire season was measured. Skaters using clap skates saw performances improve by an average of over 6 percent compared to 2 percent for normal skaters, and subsequently, skaters using clap skates went on to win the Dutch National Championship. The clap skates became instantaneously widespread, and numerous records were shattered soon after. Records are made to be broken, and biomechanical developments will inevitably lead to distinguished performances during this year's Winter Olympics.

Frontiers in Physiology (2018). DOI: 10.3389/fphys.2018.00976

DESIGN BY KATIE GREEN, BIOENGINEERING, 2022



Quantum spin liquids and ices:

Challenging universal constants

BY ANNABELLE MATHERS, CIVIL ENGINEERING, 2022
DESIGN BY KATIE GREEN, BIOENGINEERING, 2022

The world of physics is as much dependent on rules and laws as it is on phenomena that break them. At times, the physical properties and behaviors of particles are characterized as precise and accurate; other times, they are anomalous. Even when particles behave as expected, the answer to why they behave like they do eludes even the brightest minds. The fine-structure constant, or the standard strength of electromagnetic interactions involving charged particles, has been one of those inexplicable but reliable behaviors. Enter quantum physics. In true quantum fashion, the exploration of a new state of matter, quantum spin ices, has completely thrown traditional explanations of how particles interact into unprecedented turmoil. Not only have investigations into quantum spin ices reenvisioned the fine-structure constant, thereby reenvisioning interactive forces throughout the universe, but they have hinted at a curious and unexpected ability — the ability to deliberately manipulate such particle forces.

Typically, the fine-structure constant is a ratio of the interaction between energetic photons and the repulsion of elementary charged particles (e.g., electrons) calculated to be approximately 1/137. This quantification of interparticle forces, a value which repeatedly and mysteriously appears in the results of mathematical calculations of particle behavior, has been thought to dictate how atoms, elements, and materials universally behave. Thus, when Physical Review Letters published the 2021 discovery that the interparticle force ratio increases to approximately 1/10 when observed in quantum spin ices, the paradigm of particle interactions and the potential makeup of the universe suddenly shifted. Quantum spin ices are part of a larger class of models and materials known as quantum spin liquids, which are mostly theoretical states of matter that have unusual particle and quasiparticle interactions based on magnetic polarization.

It is crucial to note that this international collaboration of scientists derived these results from an experiment using rare-earth magnetic materials to mimic and approximate the theoretical behavior of quantum spin ices, which have yet to be truly synthesized. Before spin ices can be understood, quantum spin liquid must be discussed. In a December 2021 publication of *Science*, scientists detailed the first synthesis of a nearly accurate representation of quantum spin liquid, hailed as a new state of matter. Scientists excited a lattice of rubidium atoms, manipulating their motion and spin with lasers, until the atoms were entangled (inclined to affect one another) and thus displayed quantum behaviors. Spin refers to the quantum form of angular and magnetic momentum of electrons, which can spin up or down. Generally, the quantum behaviors displayed by spin liquids prevent electron spins from aligning in and maintaining usual north-south poles. Electron spins in typical magnets assume a regular pattern or order to create a stable magnetic field, but electrons in the quantum-liquid state remain disordered and energetically unequilibrated with spins constantly fluctuating up and down. This instability is caused by the presence of a third spin, which along with the repulsive nature of the electron spins, prevents a balanced distribution of spins and creates a frustrated triangular lattice structure where some spins point in different directions.

This energetic disorder generally continues in spin ices even at temperatures near absolute zero. Rare-earth metals known as pyrochlores have been used as theoretical representations of spin ices. Atoms in pyrochlores are organized into a tetrahedral lattice such that spins are located at the corners of the pyramidal formations. Initially, each pyramid of spins consists of two spins pointing inward and two pointing outward. Soon, the proximity of spins to one another — inside and between each pyramid — causes a chain reaction of repulsive instability where the entangled spins constantly flip. This frustrated behavior allows spinons (quasiparticles characterized by electrons' spin behavior) to emerge and interact with one another and other particles (e.g., electrons, photons). In this experiment, quasiparticles are concentrated collections of behavioral phenomena that occur in spaces within the crystalline lattice. These entities are only treated as particle-like for the purposes of analysis. Quasiparticles, such as spinons, arise from the interactions between actual particles and interact with them. It is within these particles and quasiparticle interactions that scientists encountered a fine-structure constant of unprecedented strength that could be further manipulated by altering the metals' properties.

Not only does investigating the unusual properties of these materials advance quantum computer and superconductor development, but theorization around stronger, transformable interparticle forces inspires experts to consider a universe created from fewer or different elements. Ultimately, these experiments re-envision once-stubborn parameters for known physics and demonstrate the often surprising nature of quantum phenomena.

Physical Review Letters (2021). DOI: 10.1103/PhysRevLett.127.117205
Nature Physics (2018). DOI: 10.1038/s41567-018-0116-x
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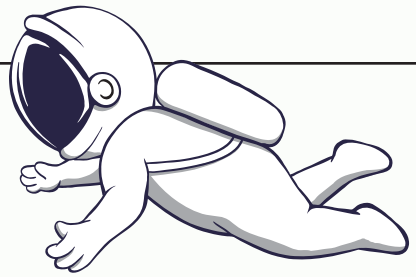

Creation and destruction

Investigating the disappearance of antimatter

BY ABIGAIL POTTER, PHYSICS & PHILOSOPHY, 2023

DESIGN BY PARKER HITT, BIOLOGY, 2024

In 1980, astronomer Carl Sagan stated, "We're made of star stuff." Around 13.8 billion years ago, the Big Bang occurred and created the "star stuff" that forms the universe we know today. However, that explosion created more than just matter; it created antimatter too. Always produced as a pair, antimatter and matter are very similar. However, some of their characteristics are flipped, such as electric charge. All particles of matter have an antimatter equivalent. For example, the antiparticle to a negatively charged electron is a positively charged positron. Same mass, different charge. Neutrally charged particles, such as neutrons or photons, are their own antiparticles.

If the two forms of matter are always produced as a pair, it seems the universe should have the same amount of matter and antimatter. Yet, this is impossible. When matter and antimatter meet, they destroy each other and release energy in the form of light or heat. If there were equal amounts of matter and antimatter in the universe, constant bursts of energy would be released. Masses of matter, such as our sun or the earth, would never be able to form as they would constantly be in contact with antimatter and quickly destroyed. The observable universe is made up of almost entirely matter. Ergo, antimatter is disappearing.

So where did all the antimatter go? Many scientists have conducted experiments to investigate antimatter's disappearance. One theory was that antimatter reacts differently to gravity than matter does. If true, this theory violates Albert Einstein's weak equivalence principle which states that free-falling particles have the same laws of motion as particles observed from a position moving at an unchanging speed. While conducting a somewhat unrelated experiment to determine the charge-to-mass ratios of protons and antiprotons, the RIKEN-led Baryon Antibaryon Symmetry Experiment (BASE) collaboration at CERN determined that, under the strict initial boundary conditions set by the experiment, matter and antimatter respond identically to gravity.

Over the course of 18 months, these experts studied antiprotons and negatively charged hydrogen atoms. The negatively charged hydrogen atoms served as a substitute for protons. The team used CERN's Penning trap, a device commonly used for storing charged particles such as antimatter. The trap consists of a magnetic field with electric trapping plates. This creates a magnetic field that is orthogonal to an oscillating electric field. The particles are excited by the oscillating electric field to a harmonic frequency and the combination of the fields causes them to move in a cyclical trajectory. The antiprotons and negatively charged hydrogen are placed one by one into the trap. The trap applies identical conditions to the particles so that their cyclotron frequencies, or the frequency at which a charged particle moves perpendicular to a magnetic field, can be measured. The cyclotron frequency is based on a circular path and depends on the strength of the trap's magnetic field and the charge-to-mass ratio of the particle. With this method, scientists determined the particles' precise charge-to-mass ratios. Their results matched the existing Standard Model of relativistic quantum field theory, which describes three of the fundamental interactions between particles (electromagnetic, strong, and weak). Interestingly, the Standard Model omits gravitational interactions between particles.

The team then investigated the gravity-based weak equivalence principle. By accounting for the fact that the experiment was conducted on Earth and that the measurement was made in Earth's gravitational field, the scientists determined how matter and antimatter respond to gravity. The gravitational accelerations of the particles were 97 percent identical.

Other research groups currently planning to conduct similar experiments hope to produce results with the same 3 percent inaccuracy. Should there be a greater error, perhaps that is the answer as to why antimatter is so scarce. Regardless, the answer to this question is not simply knowledge for knowledge's sake. Inspired by the Starship Enterprise from "Star Trek," NASA is already exploring the possibility of creating antimatter spaceships to reach Mars and other star systems. From nuclear weapons to space exploration, the discovery and development of antimatter can lead to new breakthroughs in the energy we use.

Nature (2022). DOI: 10.1038/s41586-021-04203-w
Comprehensive Analytical Chemistry (2015). DOI: 10.1016/B978-0-444-63340-8.00002-9

PHOTOS BY SHUTTERSTOCK

On the counterintuitive quantum phenomena

BY PATRICK DONNELLY, ELECTRICAL & COMPUTER ENGINEERING, 2026

DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

Quantum mechanics is weird. For nigh on a century, the mysteries of quanta and quantum interactions have eluded the brightest minds of several generations. One of the progenitors of the field, Richard Feynman, once famously quipped, "I think I can safely say that nobody understands quantum mechanics."

First, a quick primer: quantum mechanics is the science concerning the existence of and interactions between quanta, the elementary units of a field. A field is an abstract model used to categorize fundamental phenomena (e.g., electromagnetism), whose perturbations both comprise and mediate the aforementioned quanta.

Quantum physics' oddity stems from the fact that quanta play by very different rules than we are used to. Whereas macroscopic interactions are well-understood, intuitive, and, given enough information, deterministic, quantum interactions are none of these. Despite Albert Einstein's declaration that "God does not play dice with the universe," quantum phenomena are probabilistic in nature, not deterministic.

"Quantum physics' oddity stems from the fact that quanta play by very different rules than we are used to."

The most well-known of these probabilistic phenomena is superposition. Superposition is the notion that an unobserved system exists in multiple states until directly observed, at which point the resulting waveform collapses into certainty. The waveform, in this case, is a mathematical description of these probabilities. British polymath Thomas Young proved this as early as 1801 with his revolutionary double-slit experiment, which not only experimentally shows superposition and its consequences, but supports the quantum mechanical notion that all quanta exhibit wave-like properties. Furthermore, it is from this principle that several apparent impossibilities arise.

In their 2008 textbook, "Quantum Paradoxes: Quantum Theory for the Perplexed," the authors describe the many paradoxes that have plagued quantum mechanics from its conception. They categorize scientific paradoxes into three groups, "errors," "gaps," and "contradictions," evaluating each through the lens of quantum physics.

The simplest paradox, the error, is admittedly a misnomer, for the error is not a paradox at all but a lapse in deductive reasoning. Most often, errors arise from a misunderstanding or misrepresentation of a problem. If you have ever made a mistake in math class and gotten an impossible answer, you have discovered an error.

The second category, gaps, arises not from inaccuracies in deduction, but from inaccuracies in our models. To use the authors' example, Wheeler's paradox of black hole entropy illuminated the incompleteness of thermodynamics, necessitating revisions to the theory. Thermodynamics, the study of heat transfer, could not explain black holes, which appeared to spontaneously reverse entropy (condensing heat rather than dispersing it) until Jacob Beckenstein and, later, Stephen Hawking reformulated the model to rectify this knowledge gap.

The last category, contradictions, arise from a fundamental incompatibility between reality and a given model and are generally indicative of scientific revolution. To once more borrow from "Quantum Paradoxes," Neils Bohr noted the fundamental incompatibility of the electron's nuclear orbit, experimentally proven in 1911 by Ernest Rutherford, with the classical model of physics, necessitating the exploration of what is today known as quantum mechanics.

This finally leads to the *quantum pigeonhole paradox*. The pigeonhole principle states that if you try to fit N pigeons into fewer than N holes, at least one hole must have at least two pigeons. Proposed in Aharonov et al. (2016) and corroborated by Chen et al. (2019), theoretical and experimental demonstrations have concluded that quanta may violate the pigeonhole principle under weak measurement (think identifying someone by footsteps rather than sight). To demonstrate this the 2019 study used electrons. More specifically, they sent three electrons through two polarization channels, one perpendicular to the other, and weakly measured their polarization. The scientists noticed that, after passing through the channels, none of the three electrons had the same polarization. This implies that none of the three electrons passed through the same of the two channels. This phenomenon fails under strong observation.

This notion, suffice it to say, does not so much violate any established law of quantum mechanics as it does flaunt the principles of mathematical induction and set theory. Thus, it would be fair to say this conclusion poses a major challenge toward our current models of, well, everything. Though, as is the nature of science, whether these observations prove to be truly revolutionary has yet to be seen, but as it stands, the quantum pigeonhole paradox is but another facet of physics that cannot yet be explained.

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PHOTO BY SHUTTERSTOCK

Opinion:

& The search for the magnetic monopole & physicists' obsession with symmetry

BY NOAH HAGGERTY, APPLIED PHYSICS, 2024

DESIGN BY KATIE GREEN, BIOENGINEERING, 2022

At the end of the 19th century, James Clerk Maxwell condensed centuries of work in the study of electricity and magnetism into four eloquent and simple equations. Maxwell's equations describe electric and magnetic fields as a yin and yang, ebbing and flowing through space. A change in one field creates a swirl in the other, and if they oscillate in sync with one another, they dance together, shooting off into space as electromagnetic radiation: light.

But there was a blemish in the equations: electricity and magnetism weren't perfectly balanced. Where one equation describes electric charge, the magnetic counterpart just shows zero.

The most fundamental unit of electric field is electric charge, which can exist at one point that creates a monopole in the electric field. However, the most fundamental unit of magnetic field mimics two charges, a negative and a positive, perfectly canceling out to create a dipole shape and a total magnetic charge of zero, just as Maxwell's equations describe.

When Maxwell published his four equations, physicists had questions. Why weren't the equations symmetric? What explained the added complexity to the equations? These questions are motivated by the philosophical principle of Occam's razor: When two hypotheses make the same prediction, the one with the fewest assumptions, the simplest explanation, is the stronger theory. In physics, simpler math means fewer assumptions are made about the fundamental nature of the Universe.

This search for simplicity is behind theories of everything, looking to unify all four of the most fundamental forces into one, and the concept of supersymmetry in particle physics, which asserts that each particle has a symmetric counterpart.

Maxwell's theory didn't prohibit magnetic monopoles from existing; he just didn't include them in his equations because no one had ever observed magnetic charge. In the extension of Maxwell's electrodynamics to quantum theory, physicists introduced mathematical gauges, or hidden underlying mathematical machinery that helped simplify the math of theories without holding any physical significance.

These gauges polarized physicists because they tended to imply magnetic monopoles didn't exist — in part simply because Maxwell's equations, from which their theories were derived, didn't include them. Some physicists accepted the conclusions of these gauges, which were supported by experimental results. Others worked to include magnetic monopoles into more complex quantum gauges, leaving the possibility for their existence open. By the 1970s, it seemed quantum mechanics had killed the idea of magnetic charge.

Then, as physicists began developing the math for theories to unify the four fundamental forces, the gauges used in the math seemed to imply — and rely on — magnetic monopoles existing. For many of these theories, this prediction from the pure math spelled trouble: The types of monopoles it predicted were over a quadrillion times heavier than protons and just as plentiful. This, of course, would have collapsed the Universe billions of years ago, so physicists added a mechanism that would cause these monopoles to be extremely rare and almost undetectable.

All these theories — from the original conception of magnetic monopoles to the attempts to unify the fundamental forces — which were inspired by Occam's razor, now seemed to violate it. By trying to find the simplest possible math to describe the Universe, they required counterintuitive, massive, exotic particles to exist and complementary theories to explain why we can't find them.

The goal of physics is to explain "how" the universe works, not "why" it is what it is. Occam's razor is not infallible, but physicists use it for guidance because it implies testability: a theory is only relevant to science if experimentalists can test it against real-world observations, and simpler theories tend to be easier to test. Scientists can almost always add complexity to theories to explain why certain predictions can't be observed.

A universe with symmetric electric and magnetic charges and completely interchangeable fields sounds elegant and beautiful, but it is not the universe we live in. Evidence does not favor the explanations that our universe's forces must combine into one force, that all particles have perfectly symmetric counterparts, or that electricity and magnetism are equal.

This fact is uncomfortable because the question "why does the universe have complexity?" really boils down to "why are we here?" — but our complex existence ultimately requires a fundamentally complex universe.

Playing with these abstract theories can provide insight into what's next for the field of physics, but we shouldn't stray too far down the symmetry path without experimental support. At some point, we have to embrace the asymmetry and complexity that brought us here.

Contemporary Physics (2012). DOI: 10.1080/00107514.2012.685693

PHOTO BY SHUTTERSTOCK

THE LITTLEST EYES MAKE THE BIGGEST IMPACT

BY EVAN DOGUS, BUSINESS ADMINISTRATION & MARINE SCIENCE, 2025

DESIGN BY SOPHIE PATE, BEHAVIORAL NEUROSCIENCE, 2024

Light tends to come with life, and with darkness, death. This theme extends throughout the animal kingdom, but what if there was a way to see light in the darkness? Just ask the mantis shrimp, a 340-million-year-old carnivorous marine crustacean with an amazing gift. This little critter has perhaps the best vision in the history of life on this planet. The mantis shrimp's eyes contain 12 photoreceptors, compared to 3 in human eyes. The main properties of light are color, intensity, and polarization. Mantis shrimp can perceive each property in-depth and are able to detect the slightest change in their environment.

Light is a very complex phenomenon. It travels through space as a transverse wave, meaning it is S-shaped and vibrates vertically, horizontally, or at any angle in between. Generally, light waves are evenly distributed across all angles, which scatter once they reflect off of an object. A particular kind of light is polarized light, which has its wave oscillation limited to one plane that moves along the same angle in space, allowing it to reflect off of a large surface in the same direction. An example of this is a laser pointer. Mantis shrimp use this reflective property to their advantage. By using the mid-band of their 12 photoreceptors, they can filter polarized light and can view the angle at which the light is reflected (sometimes up to about 10 to 20 degrees), thus allowing them to pinpoint an object or animal in space. This helps them hunt, avoid predators, and even potentially mate. This adaptation allows them to sense properties of light invisible to other animals.

Light can exhibit a phenomenon called circular polarization. This is when the light beam moves in the shape of a helix, meaning that the wave could rotate clockwise or counterclockwise. Mantis shrimp can physically reflect circularly polarized light off of their eyes, as a hidden method of communication, allowing them to signal others without alerting predators of their presence. Cuttlefish, squid, and octopus, which all prey on the mantis shrimp, are able to detect the same polarized light, but are oblivious to circularly polarized light. This provides the mantis shrimp with a safe method of signaling for mates and navigating through murky water.

The incredible adaptation that mantis shrimp possess has inspired the next generation of cameras that can closely imitate their impressive visual apparatus. The new camera was developed last year and can be manufactured in bulk for prices as cheap as 10 dollars per unit. Researchers from the University of Illinois at Urbana-Champaign believe it could help self-driving cars and military drones detect hidden objects and hazards. In a real-world test with the camera, the research team drove around in a car mounted with the shrimp-inspired camera and a standard camera. Images derived from the new camera displayed a much higher contrast of images taken in low-visibility conditions, such as rain and shadows, in comparison to the standard one. The details detected in the background of the images were unlike any sample ever taken before. Previously, most high-tech cameras were only able to distinguish the visible spectrum from infrared and ultraviolet light, which brought out some hidden details, but not nearly as much as the new innovation.

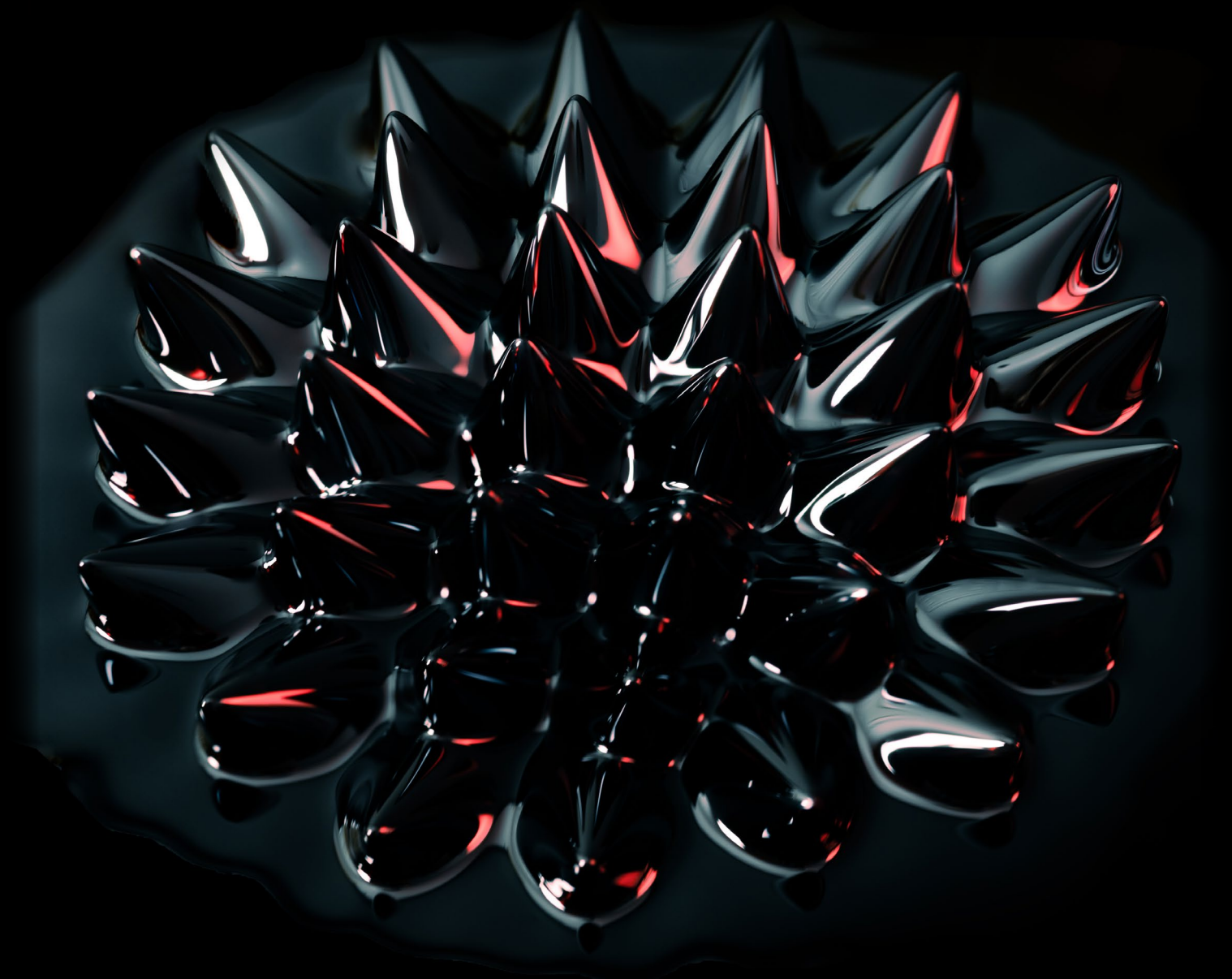
> "Human technology has drastically improved over the last 100 years, however, the mantis shrimp beat us to this amazing innovation by 340 million years."

This camera has roughly 500,000 sensors that view a wide variety of light and dark spots within the desired range, allowing it to detect polarized light wavelengths and interpret that information. The nanosensors inside of the device are meant to imitate the photoreceptors of the shrimp, converting the polarized light into pixels that the car can recognize. This camera is revolutionizing the self-driving technology of the future. In addition, these cameras can aid in healthcare by allowing doctors to differentiate cancerous cells from benign tumor cells and to see more clearly during surgeries.

Human technology has drastically improved over the last 100 years, however, the mantis shrimp beat us to this amazing innovation by 340 million years. Who would have thought that such a tiny animal could potentially have such a large impact on human civilization?

PHOTO BY ADAM SEBIRE VIA FLICKR

Current Biology (2012). DOI: 10.1016/j.cub.2012.01.010



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