New Scientist

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COULD BABIES ONE DAY HAVE TWO GENETIC FATHERS?

FACE OF THE DENISOVANS FINALLY REVEALED

THE TINY ISLAND WHERE QUANTUM MYTHS ARE MADE

INCOMING ASTEROID COULD THREATEN EARTH'S SATELLITES

SPECIAL ISSUE

HOW TO THINK ABOUT

12 of the most mind-bending concepts in science

Quantum superposition
The anthropic principle
Animal consciousness
Quantum computing
Geoengineering
Quasiparticles
Metaphysics
Friendship
Language
Symbiosis
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Beyond the surface: Unveiling emotions with thermal imaging

Join Gilly Forrester as she shares details of her exciting new research, which shows how blood flow in our faces can reveal our inner feelings, on 18 October at Excel London. A live thermal-imaging demonstration will show changing stress states in real time. Forrester's research is increasing our understanding of the relationships between stress, resilience, self-regulation and psychological health.

newscientist.com/nslive

Tour

The science history of Scotland: The Enlightenment and beyond

Learn more about Edinburgh and Glasgow's most famous scientific thinkers and discover how their ideas underpinned our emerging understanding of the world from the 16th century onwards. This five-day tour starts on 4 September and costs £1396.

newscientist.com/tours

Podcast

The world, the universe and us

The team discusses the discovery of a Denisovan skull. Listen to sperm whales communicate and learn how they use human-like vowels. Look ahead to potential 40°C summers in the UK. Plus, hear from Rachel Clarke about her award-winning book *The Story of a Heart*.

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Scottish science Discover how Scottish thinkers shaped our world

JVPHOTO/ALAMY

Imprinted in space Does the fabric of our universe have a memory?

Video

Florian Neukart: Does space-time remember?

We normally think of space as empty, but physicist Florian Neukart has developed a framework that recasts it as being imprinted with "memories". In this view, space-time itself might even be made up of stored information. Could this bold conjecture solve some of the trickiest problems in cosmology?

youtube.com/newscientist

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Health Check

CAR T-cell therapy has shown remarkable success in treating some kinds of blood cancer, but the treatment can be costly and cumbersome. However, a new study has potentially found a simpler, cheaper way of making these cells by harnessing the technology behind mRNA covid-19 vaccines.

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Podcast

"Denisovans were the big boys of the palaeontological record"

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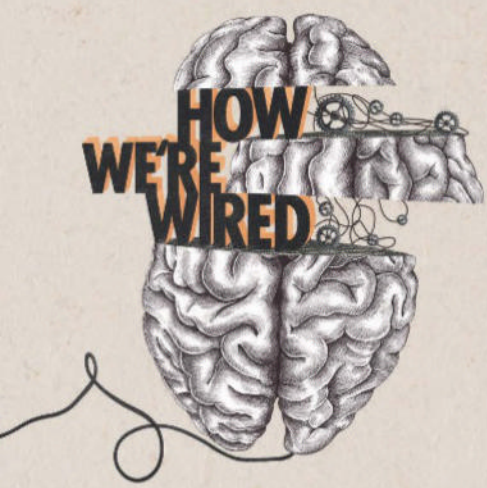

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Of mice and men

It is time to address the question of babies with two genetic fathers

"ALL hell will break loose, politically and morally, all over the world." So said James Watson, the Nobel prize-winning co-discoverer of DNA's double helix, on the possibility of human in vitro fertilisation in 1974. Four years later, Louise Brown, the first successful IVF baby, was born.

Today, more than 12 million people have been conceived via IVF, and hell seems still to be broadly contained. Few of us would bat an eye at the procedure.

But what of our attitudes to future reproductive technology? That question is raised by the birth of fertile mice with two genetic fathers (see page 8). Such feats have been attempted before, creating both motherless and fatherless mice, but this latest technique stands apart because it doesn't involve genetic modification. In principle, that makes it suitable for use in humans.

There are many technical reasons why this won't happen soon, from the low success rate to the large number of human eggs, stripped of their DNA, that would be required. Despite that, we should start thinking about the social hurdles.

"As with IVF, what was once front-page news could become run of the mill"

For some people, the thought of a child with two genetic fathers will never be acceptable, just as there are still those who decry gay couples adopting a family. Such minds will be difficult, if not impossible, to change.

But we can expect a broader group of people to have, if not strict moral objections to the idea, a general unease. The first children born in this way, if any are, will, in a way, be unlike any humans that have ever existed. While IVF children are conceived via a process our ancestors could never imagine, they still continue a genetic lineage of every person having one male progenitor and one female.

Does this matter? Quite possibly not – as with IVF, what was once front-page news could become run of the mill. But in an era when the US is curtailing reproductive and transgender rights, having an open discussion about the technology without prejudice will be the bigger challenge. It is perhaps fortunate that these questions don't have to be settled any time soon. ▮

TRIP

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News

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An extinct monstersaur had "goblin-like" teeth p19

Space

The dawn of a new era

THIS beautiful image is one of the first from the Vera C. Rubin Observatory, a powerful new telescope in Chile. The pink-and-blue ball (upper-right) is the Triffid Nebula, a star-forming region in our galaxy surrounded by thousands of young stars. In the centre is the Lagoon Nebula, an interstellar cloud of gas and dust. To create this image, astronomers combined 678 pictures taken over 7 hours.

NSF-DOE VERA C. RUBIN OBSERVATORY

Genetics

First fertile mice with two fathers

We are a step closer to two men being able to have genetic children of their own after the creation of fertile mice by putting two sperm cells in an empty egg, says **Michael Le Page**

FOR the first time, mice with two fathers have gone on to have offspring of their own – marking a significant move towards enabling two men to have children to whom they are both genetically related. However, there is still a long way to go before this could be attempted in people.

Yanchang Wei at Shanghai Jiao Tong University in China achieved the feat by putting two sperm cells together in an egg whose nucleus had been removed. The team then used a method called epigenome editing to reprogram seven sites in the sperm DNA, which was needed to allow the embryo to develop.

Of the 259 of these embryos that were transferred to female mice, just two offspring – both male – survived and grew to adulthood, making the success rate very low. Both then fathered offspring – which appeared normal in terms of size, weight and appearance – after mating with females (*PNAS*, DOI: 10.1073/pnas.2425307122).

Creating mice with two fathers has proved to be much harder than creating mice with two mothers. The birth of the first fertile mouse with two mothers, Kaguya, was reported in 2004.

Kaguya had to be genetically modified, but in 2022, Wei and his colleagues were able to create similarly fatherless mice using only epigenome editing, which doesn't alter the DNA sequence. This same method was used to make the motherless mice.

"Creating mice with two fathers has proved to be much harder than creating mice with two mothers"

The reason it is such a significant feat to create mammals with two fathers or two mothers is due to a phenomenon called imprinting, which is related to the fact that most animals have two sets of chromosomes, one inherited from the mother and one from the father.

During the formation of eggs and sperm, chemical labels are added to these chromosomes that program some genes to be active and others to be inactive. These changes are called "epigenetic" because they don't change the underlying DNA sequence, but the labels can still be passed on when cells divide, meaning their effects can last a lifetime.

Crucially, epigenetic programming in mothers is different from that in fathers, with some genes that are labelled as "on" in sperm being labelled as "off" in eggs, and vice versa.

This means that if an egg has two sets of maternal chromosomes, or two sets of paternal ones, it cannot develop normally. A gene that should be active in one chromosome of a pair may be turned off in both, or both copies of a gene may be active when only one should be, resulting in an "overdose" of that gene.

In Kaguya's case, researchers got around this by deleting part of a gene to make overall gene activity more normal. But creating mice with two fathers requires many more changes.

Earlier this year, a separate team in China got a few mice with two fathers to grow to adulthood after making 20 genetic modifications to normalise their gene activity, but these mice weren't fully healthy or fertile.

While correcting gene activity via genetic modification is useful for studying imprinting in lab animals, it would be unacceptable in people, not least because the effects of the genetic changes aren't fully understood.

For their epigenetic approach, Wei and his team used modified forms of the CRISPR proteins that are usually used for gene editing. Just like standard CRISPR proteins, these can be made to seek out specific sites on genomes. But when these sequences are found, the modified proteins add or remove epigenetic labels, rather than altering DNA.

The study is a major step forward, says Helen O'Neill at University College London. "It confirms that genomic imprinting is the main barrier to uniparental reproduction in mammals and shows it can be overcome."

Because it doesn't involve

YANCHANG WEI

These adult male mice, with two fathers, have had their own offspring

A brief history of same-sex genetic parents*

1984
Discovery of the imprinting phenomenon

2004
Creation of Kaguya, the mouse with two mothers, via genetic modification

2018
Mice with two fathers created via genetic modification, but they die soon after birth

2022
Mice with one mother and no father born via epigenome editing

2023
Mice with two fathers created by turning stem cells into eggs, but it isn't clear whether they survived to adulthood

January 2025
Mice with two fathers created via genetic modification survive to adulthood but are infertile and have health issues

June 2025
Mice with two fathers created by epigenome editing appear healthy and are fertile

*Dates are all times of the announcements of these breakthroughs

genetic modification, Wei's team's approach could, in principle, be used to allow same-sex couples to have genetic children of their own. However, the success rate would need to be much higher before the technique could be considered for use in people.

"While this research on generating offspring from same-sex parents is promising, it is unthinkable to translate it to humans due to the large number of eggs required, the high number of surrogate women needed and the low success rate," says Christophe Galichet at the Sainsbury Wellcome Centre in the UK.

There are several reasons why the success rate was so low. For starters, combining two sperm cells means a quarter of the embryos had two Y chromosomes and wouldn't have developed far. Also, the epigenome editing worked at all seven sites only in a small proportion of the embryos, and it might have had off-target effects in some cases.

The success rate and health of the animals could potentially be improved by altering more than seven sites, but this probably wouldn't translate to use in people because the sites that need altering are likely to be different from those in mice.

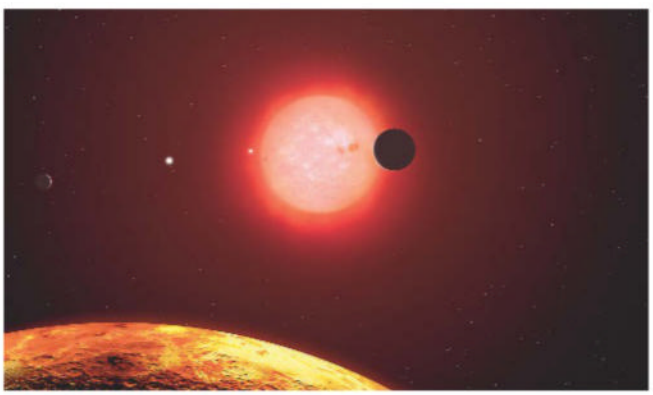
If human babies with two fathers are ever created in this way, they would technically be three-parent babies because the mitochondria in their cells, which contain a tiny amount of DNA, would come from the egg donor.

In 2023, a team in Japan announced the birth of mouse pups with two fathers using a third technique that involves turning mouse stem cells into eggs. However, it isn't clear if any pups survived to adulthood, and so far no one has managed to turn human stem cells into eggs. ▮

Space

Stellar flares hamper search for life in promising star system

Alex Wilkins



MARK GARLICK/SCIENCE PHOTO LIBRARY

Illustration of TRAPPIST-1, a star that is home to at least seven planets

THE hunt for atmospheres around planets in the TRAPPIST-1 star system, one of the most promising locations for life elsewhere in the galaxy, might be even more difficult than astronomers first thought, due to short-lived radiation blasts from the star.

TRAPPIST-1, first discovered in 2016, is a small red dwarf star about 40 light years from Earth with at least seven planets orbiting it. It is a prime target for astronomers hoping to detect extraterrestrial life because several of its planets appear to sit in a habitable zone where temperatures are just right for liquid water.

But in order to support life, those planets would have to retain atmospheres. So far, extensive observations with the James Webb Space Telescope have failed to find evidence of atmospheres on any of the planets.

Now, Julien de Wit at the Massachusetts Institute of Technology and his colleagues have detected microflares coming from the TRAPPIST-1 star every hour or so that last for several minutes. These tiny bursts of radiation appear to interfere with our ability to observe the light that passes through the planets' atmospheres – if they exist – thus thwarting the main method of detecting what chemicals might be in any atmospheres.

Using the Hubble Space Telescope, de Wit and his team looked for a specific wavelength of ultraviolet light coming from TRAPPIST-1 that is absorbed by hydrogen. If they saw less of this light than expected when a planet passed in front of the star, then it might have suggested hydrogen leaking from the planet's atmosphere.

"It's genuinely new to see these flares. It might be one of the first instances in a star that small"

They didn't find any signs of this, but they did find significant variability between different observations, suggesting that extra light was coming from somewhere at certain times.

Because the Hubble data can be broken up into 5-minute chunks, they could see the extra light was very short-lived. The researchers say the source must be microflares – bursts of radiation from the star, like the solar flares on our sun but more frequent (arXiv, doi.org/psqr).

The TRAPPIST-1 star is extremely faint, meaning that astronomers need to observe it for a long time to collect enough light.

"On top of that, there is this flaring activity, on a timescale that's relevant to the timescales of transiting planets," says de Wit. "It seems like it's really very difficult to get to say anything truly informative about the presence of [atmospheres on the exoplanets]," he says.

He and his colleagues also calculated whether these flares could affect the planets' ability to retain atmospheres. One planet, TRAPPIST-1b, on which the James Webb Space Telescope had already failed to find evidence of an atmosphere, could be losing the equivalent of 1000 times all the hydrogen in Earth's oceans roughly every million years, they found.

However, there are still a lot of unknowns and a wide range of different scenarios, says de Wit, partly because we don't know how many of these flares are actually hitting the planets.

Stars like this can have a range of activity levels, but it seems as if TRAPPIST-1 might be towards the more active side of this range, says Ekaterina Ilin at the Netherlands Institute for Radio Astronomy.

"It's not like it's an absolutely unexpected, otherworldly result; it's just kind of bad luck. It's more active than we hoped it would be," she says. "In a way, it's genuinely new to see these flares, or what we at least interpret as this, if they are what they think they are. It might be one of the first instances in a star that small." ▮

Ancient humans

Putting a face to the Denisovans

A skull from China has been identified as Denisovan – and confirms our suspicions about just how massive these ancient humans were, finds **Michael Marshall**

WE NOW know what the Denisovans, a mysterious group of ancient humans, looked like.

Using molecular evidence, Qiaomei Fu at the Institute of Vertebrate Paleontology and Paleoanthropology in Beijing, China, and her colleagues have confirmed what many researchers suspected: that a skull from China known as "dragon man" belonged to a Denisovan.

This fits with other evidence suggesting that the Denisovans were large and stocky. "I think we're looking at individuals that are all [around] 100 kilos [of] lean body mass: enormous, enormous individuals," says Bence Viola at the University of Toronto in Canada.

The Denisovans were first identified in 2010. In Denisova cave in the Altai mountains

"We're looking at around 100 kilos of lean body mass: enormous, enormous individuals"

of Siberia, Russia, researchers found a sliver of finger bone from an unidentified ancient human. Preserved DNA revealed that it wasn't a modern human (*Homo sapiens*) or a Neanderthal (*Homo neanderthalensis*), but something hitherto unknown.

Genetic evidence also revealed that Denisovans had interbred with modern humans. Today, populations in South-East Asia and Melanesia carry up to 5 per cent Denisovan DNA, which implies that Denisovans were once widespread in Asia.

After these discoveries, researchers began looking for Denisovan fossils, both in the field and in museum collections. Several have been found, notably a lower jawbone from Baishiya Karst cave on the Tibetan plateau, which

HEBEI GEO UNIVERSITY

This skull is our closest look at one of our ancient human relatives

was confirmed using proteins from the fossil and DNA from surrounding sediments. In April, a jawbone dredged from the Penghu Channel off the coast of Taiwan was confirmed to be Denisovan, based on preserved proteins.

However, there was still a frustrating disconnect. The fossils confirmed as Denisovans using molecular evidence were all small, so they weren't very informative. Meanwhile, there were many more complete fossils from Asia that were suspected to be Denisovan, but none had yielded molecular evidence.

IVPPC, CAS

The skull was confirmed as Denisovan thanks to dental plaque

Fu and her colleagues set out to obtain preserved DNA or protein from a hominin cranium found in Harbin in north-east China. First described in 2021 after having been kept secret for decades, the cranium is unusually large and bulky, with thick brow ridges and capacity for a brain of a similar size to ours.

"My impression was, this is the right kind of thing in the right place at the right time to be a Denisovan," says Viola.

Fu says it was extremely difficult to get preserved molecules from the Harbin cranium. Her team's attempts to obtain DNA from the bone proved fruitless. However, they did manage to get 95 proteins, which included three variants that are unique to Denisovans (*Science*, doi.org/psgz).

Feeling that this wasn't enough to be certain, Fu began testing dental calculus, the hard plaque that forms on teeth. This yielded mitochondrial DNA, which is inherited from the mother. It was a "tiny amount", she says, but enough to confirm that the remains were Denisovan (*Cell*, doi.org/psgx).

"That's an incredible result, and fantastic that they even tried," says Samantha Brown at the National Research Center for Human Evolution in Burgos, Spain. "I think most researchers would overlook dental calculus for genetic studies."

Now that the bulky Harbin skull has been identified as Denisovan, it confirms something long suspected: Denisovans were big.

"There were clues [to] that right from the beginning with their teeth," says Brown: the handful of molars that were found were unusually large. Known jawbones were also big. "We thought Neanderthals were the stocky ancestor, but actually it might be Denisovans that really were the big boys of the palaeontological record."

Unsolved mysteries

It isn't clear why this was the case. Neanderthals' size and build have been linked to the cold climates in Europe and western Asia where they lived. Some Denisovan sites, including Denisova cave and the Tibetan plateau, were also cold – but others were tropical. "I think we'll have to think about what this really means," says Viola.

It may be that the Denisovans changed over time. Fragments from Denisova cave reveal two groups: one from 217,000 to 106,000 years ago, and the other from 84,000 to 52,000 years ago. The Harbin cranium is at least 146,000 years old, and Fu found that its proteins and mitochondrial DNA matched the older group. But we don't have confirmed large fossils of the more recent Denisovans, so we don't know what they were like.

"There's just lots of different groups of these guys who are moving around the landscape, kind of independently, that are often separated from each other for probably tens of thousands of years," says Viola. ▮

Health

Bespoke immunotherapy could be made in the body of people with cancer

Carissa Wong

CAR T-cell therapy has the potential to revolutionise how we treat certain types of cancer by genetically engineering someone's own immune cells to attack the condition – but it is also cumbersome and expensive. Now, scientists have managed to create the bespoke therapy inside the bodies of non-human animals, which could simplify the process.

The treatment is mainly available in countries including the UK and the US for some people with various types of blood cancer, including some types of leukaemia where B-cells, a part of the immune system, grow uncontrollably.

In these cases it involves collecting a sample of immune cells called T-cells from a patient's blood and genetically engineering the genome within those cells to permanently target and kill B-cells. These engineered T-cells are then multiplied and infused back into the body. But this takes time and can cost upwards of $500,000 per patient.

To develop a more efficient approach, Carl June at the University of Pennsylvania and his colleagues turned to genetic molecules, in this case RNA, that carried instructions to make a protein that recognises B-cells. They packaged these molecules into fatty capsules, which were coated in a protein that allows them to get into T-cells, which then gain the ability to recognise and destroy B-cells. This effect is only temporary, however, as the RNA code remains in the T-cells for about a week before degrading.

> "It is a potentially much simpler and cheaper procedure for making CAR T-cell therapy"

Putting their approach to the test, the researchers infused cancerous human B-cells and healthy human T-cells into mice that had been bred to lack an immune system. One week later, they injected the animals with five doses of the fatty capsules across roughly two weeks, with some mice receiving higher doses than others.

Three weeks later, the mice that received the highest dose had no detectable tumour cells and experienced no side effects (*Science*, DOI: 10.1126/science.ads8473). "Tumour cell levels were as close as we can detect to being eliminated," says June.

The team also injected the fatty capsules into 22 healthy monkeys. This generated CAR T-cells in the body that completely cleared all B-cells within just one day, which suggests that the approach could also treat this type of leukaemia in primates. B-cells, which make antibodies, are an important part of the immune system, yet the treatment was well tolerated in all but one of the monkeys.

"This is really impressive," says Karin Straathof at University College London. It is a potentially much simpler procedure for making CAR T-cell therapy, which could make it more affordable, she says.

But one benefit of traditional CAR T-cells is that they can offer long-term protection, says Straathof. The new approach only temporarily produces such cells. We also can't be sure of its effectiveness or safety in people without clinical trials, she says.

June says the team is testing the approach in healthy humans. "The first person was dosed in the past few weeks," he says. ▮

Neuroscience

We may know how your brain tracks sleep debt

NEURONS have been discovered in mice that help their brains track and recover from sleep debt. If a similar pathway exists in humans, it could help treatments for sleep disorders.

To find out more about how the brain tracks sleep loss, Mark Wu at Johns Hopkins University in Maryland and his colleagues mapped brain pathways that are involved in sleep in mice by injecting a tracer into 11 brain areas known to induce sleep.

The tracer, which travels from neurons receiving signals to those sending them, revealed 22 regions with connections to at least four sleep-promoting areas.

The researchers focused on 11 previously unidentified regions.

MICHAEL WHEATLEY/ALAMY

Our bodies have a way of letting us know when we need to catch up on sleep

Using a technique called chemogenetics, they gave mice specialised drugs that activate particular parts of their brains. They divided the mice into 11 groups of three to four individuals, activating a different area in each group.

A region called the thalamic nucleus reuniens seemed to be key. When neurons in this area were stimulated, the mice experienced the greatest increase in non-rapid eye movement (REM) sleep – about twice the amount as mice that weren't stimulated. However, it took several hours for the animals to fall asleep after stimulation, during which they seemed to prepare for rest, for example by fluffing up their nests. This suggests these neurons aren't an on-and-off switch for sleep, but instead induce sleepiness.

In another test, deactivating these neurons in six sleep-deprived mice made the rodents less sleepy (*Science*, DOI: 10.1126/science.adm8203).

The findings suggest this brain region drives sleepiness and triggers restorative sleep after sleep loss, says Wu. Developing therapies that target these neurons could lead to new treatments for hypersomnia, a sleep condition characterised by excessive sleepiness after rest. ▮

Grace Wade

Human evolution

Is this the secret to our big brains?

Unlike other primates, humans are exposed to high levels of placental sex hormones in utero, which may have shaped our evolutionary brain development, finds **Grace Wade**

THE human brain is one of the most complex objects in the universe – and that complexity may be due to a surge of hormones released by the placenta during pregnancy.

While numerous ideas have been proposed to explain human brain evolution, it remains one of our greatest scientific mysteries. One explanation, known as the social brain hypothesis, suggests that our large brains evolved to manage complex social relationships. It posits that navigating large group dynamics requires a certain degree of cognitive ability, pushing social species to develop bigger brains. For instance, other highly sociable animals, such as dolphins and elephants, also have relatively large brains. But the biological mechanism underlying this link has remained unclear.

Now, Alex Tsompanidis at the University of Cambridge and his colleagues say the answer may be placental sex hormones (*Evolutionary Anthropology Issues News and Reviews*, doi.org/psg4). During pregnancy, the placenta – a temporary organ that acts as an intermediary between the fetus and the mother – produces hormones crucial for fetal development. These include sex hormones such as oestrogens and androgens.

"I know that seems like a jump – thinking about human evolution and then ending up on the placenta," says Tsompanidis. "But the reason for that is because we've been looking at the fluctuations and variations in the levels of these hormones in the womb and seeing that they predict things like language development and social development."

Emerging research also shows that these hormones influence the developing brain.

PETER DAZELEY/GETTY IMAGES

The placenta produces key hormones for fetal development

For instance, a 2022 study found that administering androgens, such as testosterone, to brain organoids – simplified, miniature versions of the brain made from human stem cells – during a critical developmental period increased the number of cells in the cortex, a brain region crucial for memory, learning and thinking. Other studies in brain organoids have shown that oestrogens are important for forming and stabilising connections between neurons.

There is also some limited evidence that humans are exposed to higher levels of these hormones during pregnancy than non-human primates are. A 1983 study found that gorillas and chimpanzees have four to five times less oestrogen in their urine than humans during pregnancy. The placenta also has more activity in genes that produce aromatase – an enzyme that converts androgens into oestrogens – in humans than in macaque monkeys.

"These hormones have become very important for brain development, and if we look at it comparatively with other primates and other species, there seems to be evidence that these hormones are very high in humans [during pregnancy]," says Tsompanidis.

This influx could also help explain why humans form such large social groups. Some evolutionary biologists argue that we are able to build extensive social networks because the differences between the sexes are more subtle in humans than in other primates.

> **"The levels of hormones in the uterus predict things like language and social development"**

For example, men and women are more similar in body size than male and female Neanderthals, says Tsompanidis. This is probably due to higher oestrogen levels in utero, he says.

"If you have a lot of oestrogen, not only are you a bit less masculinised, but you're also more likely to have an interconnected brain," says Tsompanidis. "So the push to increase oestrogen, the push to make everyone social and getting along, is actually what makes the human brain larger and more connected."

Brains and brawn

"I agree that placental genes influence human brain development and likely hominin brain evolution," says David Geary at the University of Missouri. "However, I think they are underestimating the influence of male-male competition on brain and cognitive evolution."

While it is true that male humans within the same social group tend to be more cooperative and less aggressive towards one another than is seen in other primates, this may have evolved as a result of between-group conflicts, he says. After all, greater coordination and teamwork would be an advantage in a deadly confrontation, he points out.

Our knowledge of placental differences among primates is also limited. Many non-human primates, such as chimpanzees, eat the placenta after giving birth, making it difficult to study, says Tsompanidis.

Identifying which factors shaped human brain evolution is more than just an intellectual pursuit: it could also shed light on neurodiversity.

"Not all humans are social or have incredible language skills – and that is fine. That doesn't make them any less human," says Tsompanidis. Understanding how the brain evolved could provide insight on whether certain cognitive traits come with trade-offs, he says. ▮

Physics

Ice bubbles can be used to store information

James Woodford

INFORMATION could potentially be stored in ice for millennia, simply by making subtle changes to the shape and position of internal bubbles.

Mengjie Song at the Beijing Institute of Technology in China and his team were studying the formation of ice when they realised they could influence the size and shape of the bubbles that formed within it. For instance, when freezing layers of water between plastic sheets, they found that changing the freezing rate created either egg-shaped or needle-shaped bubble layers.

The researchers then assigned bubble sizes, shapes and positions to characters within Morse and binary codes. Controlling the freezing rate of the water between the plastic sheets then created ice that spelled out a message via internal bubbles.

When they converted a photo of this ice into grey scale, the areas that appeared white represented regions of ice with bubbles, while black areas were bubble-free. From this, a computer could detect the size and position of the bubbles and decode the message (*Cell Reports Physical Science*, doi.org/psbd).

Only a few sentences of information could be stored in a standard ice cube using available technology, but it is possible that information could also be stored by manipulating bubbles inside materials such as plastics, says Song.

> "I don't think it will be useful at all – unless a polar bear may want to tell us something"

He says the research has many applications, besides just the "novelty of being able to read a message encoded in an ice cube in a drink". "The advantage of this study is the capacity for long duration storage of information in a cold environment, such as in the north or south pole," says Song.

Understanding bubbles better means they could one day be made to contain ozone for food preservation or hold slow-release drugs, he says. He is particularly interested in how bubbles could help prevent ice forming on aircraft wings and learning how they will behave in lunar environments.

But Qiang Tang at the University of Sydney, Australia, is less convinced by the study's real-world potential, arguing that important information can be stored for a long time on hard discs or paper, which are easily backed up.

"It's a new way of representing a message and storing it in a new place, but from a cryptography or security perspective, I don't think it will be useful at all unless a polar bear may want to tell someone something," he says. ▮

Icy environments could become a place to hide secret messages

ANTON PETRUS/GETTY IMAGES

Technology

Dead NASA satellite suddenly reanimates

Alex Wilkins

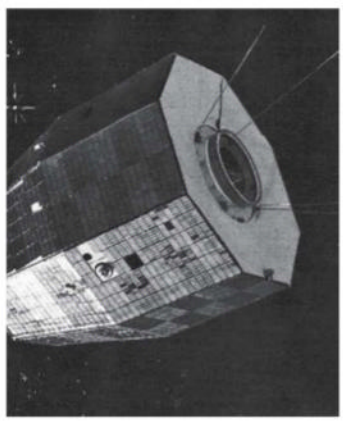
A SATELLITE that had been offline for decades unexpectedly blasted out a powerful radio pulse that briefly outshone every other object in the sky. The flash may have been caused by a freak micrometeorite impact or a random spark.

NASA's Relay 2 satellite, one of the first functioning satellites, was launched in 1964 as an experimental communications device. NASA stopped using it the following year, however, and the satellite's onboard electronics stopped working altogether by 1967, leaving the dead metal hull to orbit Earth indefinitely.

So Clancy James at Curtin University in Australia and his colleagues were perplexed when they detected a brief, powerful burst of radio waves coming from the satellite's apparent location.

James and his team were scanning the sky with the Australian Square Kilometre Array Pathfinder (ASKAP), an array of 36 radio telescopes, for signs of fast radio bursts, mysterious pulses of radiation that come from other galaxies. On 13 June last year, they saw a signal that seemed to be coming from within our galaxy. "If it's nearby, we can study it through optical telescopes really easily, so we got all excited, thinking maybe we'd discovered a new pulsar or some other object," says Clancy.

But on further inspection, the signal appeared to be so close to Earth that ASKAP couldn't focus all of its telescopes at once – like how a phone camera struggles to focus on nearby objects. This meant it must have come from within 20,000 kilometres of Earth, says Clancy. The researchers also found that the signal was very short-lived, lasting less than 30 nanoseconds. "This was an incredibly powerful radio pulse that vastly outshone everything else in the sky for a very short amount of time," says Clancy.



NASA

An illustration of NASA's Relay 1 satellite, on which Relay 2 was based

When they traced the signal to where it came from and compared it with known satellite positions in the sky, they found just one plausible explanation – the Relay 2 satellite (arXiv, doi.org/psg7). Since the satellite is no longer functional, Clancy and his team think it must have come from an external event, such as an electrostatic discharge – a build-up of electricity that causes a spark-like flash – or a micrometeorite that struck the satellite and created a cloud of charged plasma.

It would be very difficult to differentiate between those two scenarios, says Karen Aplin at the University of Bristol, UK, as the radio signal produced by both would look similar. However, it could be useful to monitor future electrostatic discharges from satellites, she says. "In a world where there is a lot of space debris and there are more small, low-cost satellites with limited protection from electrostatic discharges, this radio detection may ultimately offer a new technique to evaluate electrostatic discharges in space," she says. ▮

Entomology

Moths can travel by the light of the stars

James Woodford

DR. AJAY NARENDRA/MACQUARIE UNIVERSITY, AUSTRALIA

Bogong moths cover great distances to spend summer in cool caves

AN AUSTRALIAN moth that migrates over 1000 kilometres to escape the summer heat is the first known invertebrate to use the stars as a compass on long journeys.

Every spring, billions of bogong moths (*Agrotis infusa*) travel from various parts of southern Australia to cool caves in the Australian Alps.

It has long been a mystery how they manage to navigate so far to reach these high country caves, says Andrea Adden at the Francis Crick Institute in London.

Previous studies have shown the moths are able to use Earth's electromagnetic field, but only in combination with landmarks they can see. Adden and her colleagues wanted to find out what other cues they may be using.

"We know that daytime migratory insects use the sun, so testing the starry sky seemed an obvious thing to try," she says.

To do so, the team caught moths during their migration using light traps and took them to a lab. There, the insects were placed in a Perspex arena and an image of the night sky was projected onto a screen above them. The moths were tethered inside the arena, but could pick a flight direction based on the sky image. The researchers used a device called a Helmholtz coil to essentially cancel out Earth's magnetic field.

The tests showed that the moths use a stellar compass (*Nature*, doi.org/psgb). "When tethered moths were placed under highly realistic local starry night skies, they flew in their inherited migratory direction," says team member Eric Warrant at Lund University, Sweden.

When the team turned the starry sky by 180 degrees, moths flew in the opposite direction, and when they randomly redistributed the natural stars across the image, they were completely disoriented.

In a second experiment, the moths were fixed in place with a very thin electrode inserted in their brains. This revealed changes in their neural activity when the image was rotated.

Dung beetles use the Milky Way to stay on the same bearing over short distances, but until now no insect was known to use celestial navigation for migration. ▮

Health

More evidence rapamycin may boost lifespan

Chris Simms

THE drug rapamycin seems to have more or less the same life-extending effect as restricting calories, according to the largest study yet of longevity in different vertebrate species.

Scientists are investigating whether interventions like dietary tweaks and exercise could help us live longer while reducing the health impacts of ageing. Restricting calorie intake while ensuring essential nutrient needs are met, for example, has been shown to extend the lifespan of non-human animals by as much as 40 per cent.

"Anyone in the field who's paying attention, I think we all have known for a long time that caloric restriction usually works – and by works, I mean increases lifespan," says Matt Kaeberlein at the University of Washington in Seattle, who wasn't involved in the latest research.

Another approach garnering interest is potential anti-ageing drugs, such as rapamycin, which

"We're learning more about which people are likely to benefit from rapamycin"

was originally developed as an immunosuppressant. Earlier this year, a combination of rapamycin and the cancer drug trametinib was shown to increase lifespan in mice by 30 per cent.

Now, Zahida Sultanova at the University of East Anglia, UK, and her colleagues have looked at data from 167 studies of lifespan interventions across eight vertebrate species, including fish, mice, rats and rhesus monkeys, but not humans.

The researchers found that dietary restrictions, whether via intermittent fasting or just generally cutting calories, extended the lifespan of all eight species, for both males and females – and rapamycin seems to have roughly the same effect (*Aging Cell*, doi.org/psbk).

They also looked into the potential of the type 2 diabetes drug metformin, which has similarly been touted as a potential life-extender, but found no longevity benefit.

People shouldn't start taking rapamycin off the back of these results, though, says Sultanova. "Rapamycin, especially high doses, has side effects because it is supposed to suppress your immune system," she says, adding that studies in mice show it can disturb reproduction. Yet preliminary data from one trial recently indicated that low doses of rapamycin are relatively safe in healthy older adults.

Kaeberlein also says that people shouldn't take any medication or restrict their calorie intake in an attempt to stave off ageing, with the latter being linked to physical weakness and mental health issues. "I think we need to know more about the risk-reward ratio in humans before we can make those sorts of determinations," he says. "I believe rapamycin will have benefits for some people and we're learning more and more about who those people are likely to be."

Kaeberlein says the results fit the patterns he has seen, but adds that "you always have to be careful when you're looking across different species because the magnitude of effects that we see in shorter-lived organisms are usually larger than the magnitude we see in longer-lived organisms". ▮

Climate change

World faces huge crop shortages

No matter what farmers do, climate change will affect five of the world's six main staple crops

James Dinneen

RISING global temperatures are likely to cause deep losses to the world's most important crops – despite farmers' best efforts to adapt. A global analysis of crop yields suggests that, by the end of the century, each degree Celsius of warming will reduce the food available per person by about 121 kilocalories per day.

Under a 3°C warming scenario – roughly our current trajectory – "that works out to giving up breakfast for everyone", says Andrew Hultgren at the University of Illinois Urbana-Champaign.

Hultgren and his colleagues collected data on the yields of the world's six main staple crops, which account for more than two-thirds of global calories. "It's one of the largest datasets now available of high-resolution crop yields," he says. They also collected information on local weather patterns from 54 countries.

The researchers then used this information to project how the different crops would respond to a changing climate – and how farmers would adjust. This allowed them to estimate how different agricultural adaptations, such as changing which crop varieties are grown, boosting irrigation or using more fertiliser, would mitigate crop losses.

For all crops except rice, which grows better when nights are warmer, they found that higher temperatures would lead to steep losses (*Nature*, doi.org/psbw). For instance, global corn yields are projected to fall by about 12 or 28 per cent by the end of the century – depending on whether greenhouse gas emissions are moderate or very high, respectively – relative to what they would be without global warming.

These numbers account for how farmers would adapt to higher temperatures, as well as the impact of potentially helpful climate-change effects, such as crops being fertilised by increased levels of carbon dioxide. Without adaptation, crop losses would be about a third higher at the end of the century under a high-warming scenario.

Wolfram Schlenker at Harvard University says the conclusion tallies with previous findings focused on specific regions. "The huge contribution of their study is they didn't just focus on one country, but they compile this data from countries around the world," he says.

28%

How much global corn yields could fall by the end of the century

That global view reveals some interesting patterns. For instance, they found the largest projected crop losses don't occur in low-income countries, but in the relatively wealthy breadbaskets of the world, such as the US Midwest and Europe.

Michael Roberts at the University of Hawai'i at Mānoa says the findings are in line with results from smaller-scale studies. But he points out that huge uncertainties remain, including the extent of future climate change and how the extraordinarily complex global food system will respond. ▮

Rising temperatures could make it harder for farmers to grow most staple crops

CURT MAAS /DESIGN PICS EDITORIAL /UNIVERSAL IMAGES GROUP VIA GETTY IMAGES

Marine biology

Sea spiders use their bodies to 'farm' gas-eating bacteria

SPIDER-LIKE creatures living near methane seeps on the sea floor appear to cultivate and consume microbial species on their bodies that feed on the energy-rich gas. This expands the set of organisms known to rely on symbiotic relationships with microbes to live in these otherworldly environments.

Shana Goffredi at Occidental College in California and her colleagues collected sea spiders – marine arthropods named for their resemblance to arachnids – living near three different methane seeps in the Pacific Ocean. They found three previously unknown species from the sea spider genus *Sericosura* that appear to be abundant only near these gas seeps.

Sea spiders that don't live near seeps largely eat other invertebrates. But the researchers found the new sea spiders appear to get most of their nutrition by eating a distinctive set of bacterial species that live on their bodies. These bacteria harvest energy by metabolising methane and methanol coming from the seeps, energy that would otherwise be inaccessible to the sea spiders.

"The bacteria were confined to the spiders' exoskeletons like a microbial fur coat"

The researchers found the bacteria were confined to the spiders' exoskeletons like a "microbial fur coat", growing in what Goffredi describes as "volcano-like" clusters. The layers of bacterial growth also had markings like lawnmower tracks where the spiders may have munched on them using their hard "lips" and three tiny teeth.

To confirm the sea spiders really were eating the bacteria, the team used a radioactive labelling technique to track how the carbon in methane was consumed by the sea spiders in the lab, seeing it go first into the microbes and from there into spider tissue (*PNAS*, doi.org/g9qw6s).

Because the species that live on the exoskeletons are distinct from what else is in the environment, it suggests some kind of selection process, says Goffredi. "The spiders are definitely cultivating and farming a very special type of community." ▮

JD

Quantum physics

Talking big ideas on a tiny island

A hundred years after Werner Heisenberg supposedly invented quantum mechanics on Helgoland, physicists have returned for a centenary celebration. **Philip Ball** joined them

I HAVE been to more scientific conferences than I care to count, but a recent meeting held on the island of Helgoland to celebrate the centenary of quantum mechanics is one of the strangest – in a good way.

This tiny German island, barely more than a kilometre long and far out in the North Sea, has the air of a down-at-heel coastal resort: the sea less than inviting even in the summer, the little streets full of cheap gift shops and the smell of fish and chips and ice cream. Now imagine that at every turn you bump into Nobel laureate physicists, inventors of quantum information theory and experimentalists at the cutting edge of quantum technologies, fresh from discussing their work in the town hall, next to the crazy-golf course.

The reason we are here is revealed on a rock on the cliff path. It bears a bronze plaque that suggests this is where physicist Werner Heisenberg, on an excursion to seek relief from his hay fever in 1925, invented quantum mechanics. Sadly, that isn't really true – at best Heisenberg sketched out some ideas here that only subsequently did he and others develop into a full quantum theory. And the version we are more familiar with today was unveiled in early 1926 by Erwin Schrödinger, which introduced the wave function as a way of predicting the evolution of a quantum system.

All the same, if you are going to assign a centenary to quantum mechanics, this is the obvious year to choose. And regardless of how much of the story of Helgoland was due to Heisenberg's self-mythologising, the remote island is a special place to hold this party.

And what a party it is. It is hard to imagine such an eminent cast of quantum physicists being assembled again. There are four Nobel laureates here: Alain Aspect, David Wineland, Anton Zeilinger and Serge Haroche. Between them, they established the reality of the strange features of quantum mechanics, such as the way the properties of one particle can seem to be instantaneously contingent on what we measure for a second, "entangled" particle, no matter how far away it is. They also created some of the techniques for manipulating individual quantum particles that are now being used to build quantum computers.

> **"It is hard to imagine such an eminent cast of quantum physicists being assembled again"**

But here's the thing. I suspect these grand old(ish) men would agree with me that it is the younger generation that now holds the best hope for making some sense of what quantum mechanics really means, and for turning its infamously counter-intuitive nature into new technologies and a new understanding of nature. Quantum mechanics is notorious for admitting many different interpretations of what the mathematics of the theory tell us about the real world, and most of the old guard seem unlikely to shift their views.

That impasse was evident in a panel discussion on the first evening in which Aspect, Zeilinger and Gilles Brassard, a founder of quantum cryptography from the University of Montreal, Canada, pronounced with equal confidence on the fundamental meaning of quantum mechanics while being in direct contradiction with one another. To be fair to these veterans, their ideas were formed in the face of scepticism (or worse) from their peers about the value of even thinking about such "foundational" questions. They emerged from the era of "shut up and calculate" – the phrase coined by US physicist David Mermin to describe how it was deemed bad form to wonder what quantum mechanics meant, one's duty being merely to solve the Schrödinger equation. It isn't surprising that they had to cultivate thick skins.

SHUTTERSTOCK/MARKUS STAPPEN

Werner Heisenberg visited the island of Helgoland in 1925

The next generation

The younger researchers seem less dogmatic and perhaps more ready to try different interpretations, depending on how useful they are for the problem at hand.

The new generation is also less relentlessly male. For example, Vedika Khemani at Stanford University, California, told the meeting about the rich connections between ideas in condensed-matter physics and quantum information, a link that takes us from the storage of information on magnetic tape in the 1950s to the error-correction techniques essential for quantum computation today.

Harnessing quantum mechanics to build new technology is increasingly in vogue, but the theorists aren't slacking either. Flaminia Giacomini at the Federal Institute of Technology in Zurich, Switzerland, was one of several speakers who felt we might get a clearer picture of what quantum mechanics means if we can reconcile it with gravity, by seeking a marriage of the discrete and granular quantum world with the smooth and continuous world required by general relativity, usually by quantising gravity.

You might have thought this is all about exploring untestable and barely fathomable ideas in string theory, one attempt to create such

a union. But the truth, as Giacomini said, is that "we have no experimental evidence that we should quantise gravity" – we don't even have empirical reasons why gravity has to be a quantum force at all.

The exciting thing is that this, at least, is something we can hope to test in the near future, for example by seeing if we can entangle two objects solely through their gravitational interaction. The challenge here is that the objects must be big enough to produce a significant gravitational force, but small enough to show quantum behaviour: nanoparticles of, say, silica or diamond might do the trick. Several speakers expressed confidence that we will meet that challenge within a decade or so.

For me, a key revelation of the meeting is that so many strands of quantum theory are entangled. Understand more about quantum gravity from exquisitely sensitive experiments on trapped particles, and you might go into the black hole information paradox and emerge with new ideas about error correction for quantum computing or fresh insight into twisty "topological" quantum states.

Breakthroughs in any of those fields might even finally help us understand the old questions that troubled Heisenberg and his colleagues: What happens when we make a measurement on a quantum particle, and how does it turn quantum into classical? At any rate, saying that a century later we are still wrestling with those questions is the wrong way to see it. We have discovered, instead, that quantum mechanics is far richer, more useful and more astonishing than its founders could ever have guessed. ▮

For more on the weirdness of the quantum realm, turn to page 39

Space

Asteroid impact on the moon could damage Earth's satellites

Alex Wilkins

MARK GARLICK/SCIENCE PHOTO LIBRARY/GETTY IMAGES

Asteroid 2024 YR4 will miss Earth but may hit the moon

THE asteroid 2024 YR4, which was once thought to be on a collision course with Earth, may still pose a threat to the planet. There remains a chance it could smash into the moon, and the resulting explosion could shower Earth with a cloud of satellite-destroying shrapnel.

Astronomers have been tracking the building-sized asteroid since it was discovered in December 2024, when initial predictions of its path raised the possibility of a collision with Earth in 2032. Such a collision would have released enough explosive power to destroy a city, but, thankfully, follow-up observations showed that 2024 YR4 will almost certainly miss our planet.

The chance of a collision with the moon, however, has slowly been increasing, and now stands at 4.3 per cent based on the last observations taken before the asteroid flew out of view of our telescopes until 2028. And according to Paul Wiegert at the University of Western Ontario in Canada and his colleagues, such a collision could still cause significant damage to Earth's satellites.

"We were a little bit surprised at the possibility of there being a substantial amount of material at the Earth," says Wiegert. "Intuitively, the Earth is actually quite a small target when seen from the moon, and so your intuition is that not very much material would actually hit the Earth, but it turns out that the Earth's gravity can focus that material under certain conditions."

4.3%
The chance of asteroid 2024 YR4 hitting the moon in 2032

Wiegert and his team calculated that 2024 YR4 could create a kilometre-wide crater on the moon – the largest lunar impact for at least the past 5000 years, though relatively small compared with a typical crater. An impact of this size would eject a cloud of debris into space, and by simulating its potential behaviour 10,000 times, the team found that this could cause Earth's satellites to experience a level of collisions equivalent to what we would expect to see in years or even decades, but occurring in just a few days (arXiv, doi.org/g9qmps).

While these collisions might not be enough to take out entire satellites, they could cause anomalous readings due to electrical flashes, though it is hard to model exactly how damaging it will be for satellites, says Wiegert.

If we are unlucky, the effect of debris particles could be particularly bad, says Mark Burchell at the University of Kent, UK. "If they were to hit a bit of a spacecraft that was a coolant pipe, or a sensor on the spacecraft exposed to space, or an antenna, then suddenly you get a loss of that particular functionality," he says. "You can't go and fix a satellite. A minor problem is actually a serious problem."

Wiegert says the results should make the world's space agencies think about deflecting asteroids that are going to hit the moon, as well as Earth. A spokesperson from NASA's Planetary Defense Coordination Office says its job is to "identify near-Earth objects (NEOs) that could pose an impact hazard to the Earth, so planetary defense is not solely confined to near-Earth space", but that it would be "premature to speculate on potential response options" if 2024 YR4 hits the moon.

Depending on how things go, we may need to act quickly. When 2024 YR4 flies back into view of Earth's telescopes in 2028, we should be able to swiftly refine our knowledge of its exact orbital path, says Wiegert. If the odds of it hitting the moon go up, that will give us a four-year window to decide whether we need to act, he says. ▮

Climate change

Can reusable rockets help cool the planet?

James Dinneen

CHARLES BOYER/ALAMY

REUSABLE rockets that deliver sun-reflecting aerosols to the top of the stratosphere could be more effective than lower-altitude solar geoengineering.

Solar geoengineering is the controversial idea of cooling the climate by reflecting sunlight. One approach involves injecting aerosols of reflective particles into the stratosphere, using specialised cargo planes flying at an altitude of around 20 kilometres.

50 km

The altitude at which cooling aerosols may have the best effect

An issue with this is that the aerosols would absorb sunlight and heat up the stratosphere itself. Due to wind patterns, these particles would accumulate in the tropical stratosphere, causing greater warming there. That, in turn, could disrupt the jet streams and circulation patterns that affect weather around the world.

These aerosols could also accelerate the breakdown of ozone, delaying the repair of the ozone hole over Antarctica by as much as five decades.

Rockets could deliver sun-reflecting particles high into the atmosphere

Pengfei Yu at Jinan University in China and his colleagues modelled whether injecting aerosols at an altitude of 50 kilometres would change these dynamics. They found this would have more of a cooling effect, as the particles stay aloft longer, and would prevent the aerosols from heating the lower stratosphere until they travelled closer to the poles. They also found the aerosols would break down a separate chemical that eats away ozone, leading to a net delay in ozone recovery of just five years (EGUsphere, doi.org/psbh).

They estimate up to 80 reusable hydrogen-powered rockets launching every other day could inject between 3 and 8 million tonnes of aerosol each year.

"It's a little bit more efficient because you're putting it up higher in the atmosphere – but the costs are astronomical in comparison," says Douglas MacMartin at Cornell University in New York. ▮

For more about geoengineering, turn to page 35

Health

Cold sore virus reshapes the human genome

Carissa Wong

THE virus that commonly causes cold sores starts transforming our genome within an hour of infection to boost its own growth, which scientists could take advantage of to treat severe cases.

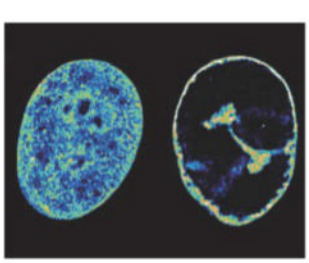
Billions of people around the world have the infection, caused by herpes simplex virus type 1 (HSV-1), although many of them don't know it. It can spread through contact with other cold sores, saliva or even unbroken skin around the mouth.

After invading host cells, the virus replicates in the nucleus, where genetic material is stored as strands of DNA. These strands wrap around proteins, with some regions forming tight coils, inactivating the genes within them, while others form wider loops, where genes are active. In these looser regions, proteins can unwind and transcribe DNA into the molecule RNA, which encodes for proteins that keep the cell running.

Prior studies had shown that the human genome becomes more tightly coiled during HSV-1 infection, which may disrupt cell function, but it was unclear why this coiling occurs.

To learn more, Alvaro Castells-Garcia at the Centre for Genomic Regulation in Barcelona, Spain, and his team imaged HSV-1 while it infected human lung cells, using a microscope that can capture structures 3500 times thinner than a strand of hair.

Human DNA inside cells before infection (left) and 8 hours after (right)



E. G. ALMELA, Á.C. GARCÍA

They found that, within 1 hour of the virus entering cells, it had stolen transcription proteins away from the human genome, something prior studies had already suggested.

But they also showed that this theft is what seems to cause the host DNA to coil up more tightly, making it shrink to 30 per cent of its pre-infection volume within 8 hours of infection.

The virus also made contact with specific regions of the host genome that encode for the transcription proteins it steals, preventing those regions from coiling up and boosting the activity of genes within them that help it grow (*Nature Communications*, doi.org/g9qtd3).

"We used to think it made contact with our genome randomly," says team member Esther González-Almela, also at the Centre for Genomic Regulation. "But the virus is able to contact our own genome in specific regions, and these regions usually harbour genes that are involved in the continuity of infection, in making viral RNA and proteins."

In another part of the study, the researchers found that using an experimental cancer drug to block one of the transcription proteins that HSV-1 steals prevented it from replicating in human lung cells in the lab. This suggests that the drug could help treat HSV-1 in people with severe cold sores or those who have a suppressed immune system and are more likely to experience complications, says González-Almela. ▮

Neuroscience

Lost memories can still influence you

Searching for forgotten memories could tell us more about how the brain works

Chris Simms

SOME memories, such as what you had for dinner last night, are easier to recall than others. However, even forgotten memories could be guiding your actions.

One way to define memory is based on what people report. Another is as a circuit of cells and connections in the brain, known as an engram.

It has been thought by many researchers that when you forget something, the engram vanishes. However, research in mice suggests forgotten memories can persist; they just can't be consciously recalled.

To see if forgotten memories are detectable in human brains, Tom Willems at the University of Bern in Switzerland and his colleagues got 40 people to quickly look at 96 pairs of images, made up of a human face and an object, such as a guitar or a stapler.

The researchers then used high-resolution functional magnetic resonance imaging to observe the participants' brain activity during tests carried out around 30 minutes later and 24 hours later. The tests asked whether they had seen two images paired up before.

"Memories don't need to be consciously retrieved in order to influence our behaviour"

The participants also stated whether they recalled that two images went together, were unsure, or were guessing.

Those who said they could remember chose the correct pairing 87 per cent of the time during both tests. Those who said they had forgotten which image went with which got about half right.

The participants who were unsure guessed correctly 57 per cent of the time after 30 minutes and 54 per cent after 24 hours. These results were slightly higher than would be expected by chance, which suggests this group may actually have remembered.

When the guessers chose the right answer, the same activation patterns were seen in the right hippocampal region of the brain as in those who remembered, which implies the engrams of forgotten memories remained and were influencing their choices (bioRxiv, doi.org/pr8d).

In the tests done 24 hours later, the engrams of memories that people correctly guessed stayed within the hippocampus, while those they could remember were distributed throughout the neocortex.

The movement of memories to the neocortex is correlated with their recall, so we don't know for sure if they are the cause or consequence of things being remembered, says Amy Milton at the University of Cambridge.

However, the findings are in line with the leading description of the workings of memory, says Nick Turk-Browne at Yale University, which says memories are made in the hippocampus. Then, during sleep, they are replayed and stored for the long term in the neocortex.

The work shows there can be a dissociation between the memory we consciously access and the related engram in the brain, says Turk-Browne.

"Essentially, what they're trying to argue is that [some] memories don't necessarily need to be consciously retrieved in order for those memories to influence behaviour," says Milton. ▮

Palaeontology

Ancient 'goblin-like' monstersaur slurped up dinosaur eggs

CULLEN TOWNSEND

The monstersaur, shown in this artist's impression, was around 1 metre long

AN EXTINCT monstersaur discovered in North America is shedding new light on life in the area around 75 million years ago.

The creature looks "like a goblin that sprang from the rocks", says Hank Woolley at the Natural History Museum of Los Angeles County. The species is a monstersaur – a member of a group of reptiles that lived during the Late Cretaceous Epoch. It was "probably 3 or 4 feet, tip to tail", according to Woolley. "I think you'd want to avoid it."

Woolley named the species *Bolg amondol*. The first part honours a *Lord of the Rings* character. The second part – derived from a fictional Elvish language – is a nod to the dermal armour on its skull, a bony trait shared by its relative, the modern-day Gila monster (*Heloderma suspectum*).

The uniquely well-preserved fossil was found 20 years ago in Utah by Joseph Sertich at the Smithsonian Tropical Research Institute, who originally assumed it to be a known prehistoric lizard.

Sertich suggested Woolley visit the fossil in a museum in 2022, which led them to the discovery that *B. amondol* is a type of extinct lizard called a monstersaur. They also found evidence it could shed its tail when injured, making it the oldest known example of this anti-predator strategy – used by some modern lizards – in monstersaurs (*Royal Society Open Science*, doi.org/pr8j).

Small mammals, frogs, snakes, insects and "basically anything that isn't a plant" would have been on *B. amondol*'s menu, according to the researchers, who reckon it would have "slurped up" dinosaur eggs. Their "kind of swampy, pretty hot and humid ecosystem" was unlike Utah's desert environment today.

Randall Nydam at Midwestern University in Illinois thinks this is a cautionary tale: "We also have to appreciate that they're gone, and they're gone because their environment changed." ▮

Meagan Mulcair

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Annalee Newitz sees a very different robot future coming p22

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Comment

Thawing attitudes

The public is tuning out the seemingly slow warming of the world, but it doesn't have to be that way, argue **Grace Liu** and **Rachit Dubey**

FOR a long time, many climate scientists and advocates held onto an optimistic belief: when the impacts of global warming became undeniable, people and governments would finally act decisively. Perhaps a devastating hurricane, heatwave or flood – or even a cascade of disasters – would make the severity of the problem impossible to ignore, spurring large-scale action. Yet, even as disasters mount, climate change remains low on voters' priority lists and policy responses are tepid.

This widespread inaction is often blamed on political or structural forces. But decades of psychological research suggest something deeper is at play: the human brain tends to overlook slow, creeping change.

While many regions are facing severe climate extremes, for most of the world, climate change appears as a slow, gradual shift in daily weather.

This subtlety is a problem. People judge the issue largely via personal experience: we are more worried on an unusually hot day, and less so when the weather feels normal. But as things gradually worsen, our sense of "normal" quietly shifts. This is known as the boiling frog effect – where subtle, incremental changes fail to trigger alarm, resulting in apathy despite worsening conditions: like a frog in a pan of slowly warming water.

In 2020, we were researching climate impacts in Princeton, New Jersey. The area doesn't face wildfires or droughts, but we realised it had lost something: winter ice skating. For decades, you could skate on Lake Carnegie every year. Now, it rarely freezes over.

ELAINE KNOX

Through conversations with long-term residents and digging into local newspaper archives, we discovered there had been a stark decline in ice skating on the lake over the past century, and a sense of loss over it. This interruption to a winter tradition suddenly made climate change in Princeton feel real. Tangible. Personal.

That led us to ask: could binary climate data – yes-or-no indicators such as "lake froze" vs "no freeze" – make people sit up and take notice better than graphs showing gradual temperature rise?

We tested this idea in a series of experiments. Participants were shown one of two graphs: one displayed a fictional town's rising winter temperatures; the other showed whether its lake froze each year. Importantly, both graphs captured the same underlying climate trend. But people's responses were very different.

People who saw the binary "froze or not" graphs consistently perceived climate change as having a greater impact than those who saw the temperature graphs. In follow-up studies with data from lakes in North America and Europe, we saw the same result. When climate impacts were presented in these kinds of black-and-white terms, people took them more seriously.

Why? We found that binary data creates an illusion of sudden shifts. When people saw a series of winters when the lake froze, followed by years when it didn't, they perceived a clear "before" and "after", even though the change was gradual.

Climate change isn't just a physical crisis. It is also a psychological problem. And unless we communicate it in ways that feel real, we risk tuning out the warning signs until it is too late.

We hope these results spur policy-makers, journalists and educators to take action. Highlight the concrete losses people can relate to: winters without ice skating, harvests damaged by drought, summers filled with wildfire smoke. Use visuals that contrast "what we had" with "what we've lost".

Let people see what's changed – not just the slope of a line. ▮

Grace Liu is at Carnegie Mellon University in Pennsylvania and Rachit Dubey is at UCLA

This changes everything

Will the real robots please stand up?

It is uncanny how human fears about robots mirror those about immigrants. But maybe they won't rise up Terminator-style at all, says **Annalee Newitz**

Annalee Newitz is a science journalist and author and their latest book is *Automatic Noodle*. They are the co-host of the Hugo-winning podcast *Our Opinions Are Correct*. You can follow them @annaleen and their website is techsploitation.com

Annalee's week

What I'm reading
Tochi Onyebuchi's Racebook: A personal history of the internet, *a totally engrossing essay collection about cosplay, video games and social media.*

What I'm watching
Murderbot, *obviously.*

What I'm working on
Hanging out with archaeologists at the Punic/Roman town of Tharros on Sardinia in Italy. More on that later!

This column appears monthly. Up next week: Rowan Hooper

ARE you worried that AI-powered robots are going to steal our jobs and maybe kill us all? You aren't alone. But it is time to play devil's advocate with yourself and consider whether the opposite might be true.

My new novel, *Automatic Noodle*, out later this year, is about four robots who struggle to find employment in a country where humans have made laws preventing bots from unionising, opening bank accounts, voting and owning their own businesses. Yes, it is science fiction. But it is based on real tech – and, more importantly, it explores the implications of our deeply held suspicion that robots are evil.

I have spent years writing non-fiction about real-life robots, interviewing roboticists and engineers to find out what is coming next. Recently, I visited an incredible lab at Yale University called the Faboratory, where Rebecca Kramer-Bottiglio heads up a team developing soft robots. These include bendy, squishy, pneumatic creatures with circuits made from liquid metal. One swims like a turtle and could be used for environmental monitoring in swampy areas. Another, called a tensegrity robot, looks like a bundle of plastic sticks held together with stretchy rubber. Drop it from a height and it will bounce, rolling around to check out its surroundings.

Medha Goyal, a researcher at the Faboratory, showed me minuscule balls of fluid that expand as they warm up. Eventually, thousands of these "granular actuators" could be used inside a robot, expanding and contracting to create stiffness or softness in a limb. They could also turn out to have medical applications, pushing tiny robots around inside your body to deliver medicine or diagnose a problem.

The point is, Kramer-Bottiglio and her colleagues are challenging the very idea of what a robot is. Tomorrow's bots probably won't look like giant humanoids; instead, they might be soft little guys, tumbling around using pneumatics instead of metal gears. Indeed, one of the robots in my book is an octopus-shaped soft robot, designed for search-and-rescue missions in the water. This octobot's name is Cayenne, and they are able to taste things using sensors on each arm.

When I imagine the future of robots, I see the likes of Cayenne. All they and their robot friends want is to run a noodle restaurant in San Francisco. Their robo-pals include a three-legged, wheeled bot named Sweetie; one named Hands who is nothing but a mixer with two arms attached; and Staybehind, a humanoid-ish soldier bot who would rather decorate the restaurant than fight a war. They make a ragtag family.

> "Tomorrow's bots probably won't look like giant humanoids; they might be soft little guys instead"

This family lives at a unique time in human history. In the 2060s, the government of the new nation of California has decreed that some AI-powered robots are basically people. But politicians worry that robots with the same rights as humans will multiply unchecked, rapidly taking over everything. So they deprive them of key rights "for their own good", promising that humans can vote to expand robot rights later.

Despite what their human neighbours think, Cayenne and friends don't want to take over the world. In fact, they only want to keep doing the jobs they already had. Except instead of making crap food for a distant human master, they will make something they love, with care, because they truly want to do it. They are basically immigrants in a new country, trying to survive in a nation that at best mistrusts them and at worst wants them dead.

I use this metaphor deliberately, because it is uncanny how much stereotypes about immigrants mirror human fears about robots. They will steal our jobs. They will rise up and destroy us. They will degrade the fabric of our culture. What is striking is that people who say these things about immigrants have often never spent time getting to know them. Meanwhile, people hold the same ideas about robots that *don't even exist yet*. It seems like a pattern. These are the kinds of fears we have about groups we imagine without ever doing any research about the reality of who they are. Or, in the case of robots, who they might be.

And that is why, when I think about the future of robots and society, I don't see machine overlords. I see reality obscured by scary fantasies and freedoms constrained by laws based on those fantasies. I see soft-bodied creatures and turtles and pneumatic arms, not Terminators. I see Cayenne, who lives in fear because of human hate and robophobic vigilance committees posting deepfakes online about made-up robot crimes.

Humans are masterminds at preparing for futures that are highly unlikely, while ignoring ones unfolding before our very eyes. But we don't have to be that way. We can try to make plans based on evidence and science, rather than surreal nightmares that never come true. ▮

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Feeding the future: Why agri-food is the next frontier for tech innovators

The UK's largest industry is not finance or manufacturing, but agri-food, a sector undergoing a radical, technology-driven transformation. Professor Ken Sloan, Vice-Chancellor of Harper Adams University, argues that this vital field, which touches everyone, is a hotbed for innovation, demanding a new generation of diverse talent. "We've all got something in common – we need to eat," Sloan explains, but few fully appreciate the sheer scale and technological sophistication of modern food production.

Harper Adams is at the vanguard, demonstrating how disciplines like robotics, AI, data science, animal health and wellbeing and bioengineering are "endemically part of the agri-food system". The university is pioneering automation in areas from traditional farming to vineyards, showcasing the practical application of cutting-edge research. This is not just about shiny new kit; it's about attracting the brightest minds – engineers, data scientists, and chemists – who might otherwise set their sights on aerospace or medicine, to tackle challenges in food security and sustainability.

Sloan stresses that technological advancement must go hand-in-hand with social sciences to ensure practical adoption and address ethical considerations. The university is also championing a "circularity" model, aiming to turn farm waste into energy, and fostering "Sustainable Farm Networks" to swiftly share best practice. With an outstanding graduate employability rate, Harper Adams is demonstrating that a career in agri-food offers not merely jobs, but highly skilled roles offering swift career progression, crucial for feeding the planet sustainably. The message is clear: the future of food is a high-tech, high-stakes field, brimming with opportunity.

You can find out more by visiting the Future of Food and Agriculture stand at New Scientist Live 2025. For more details go to: live.newscientist.com

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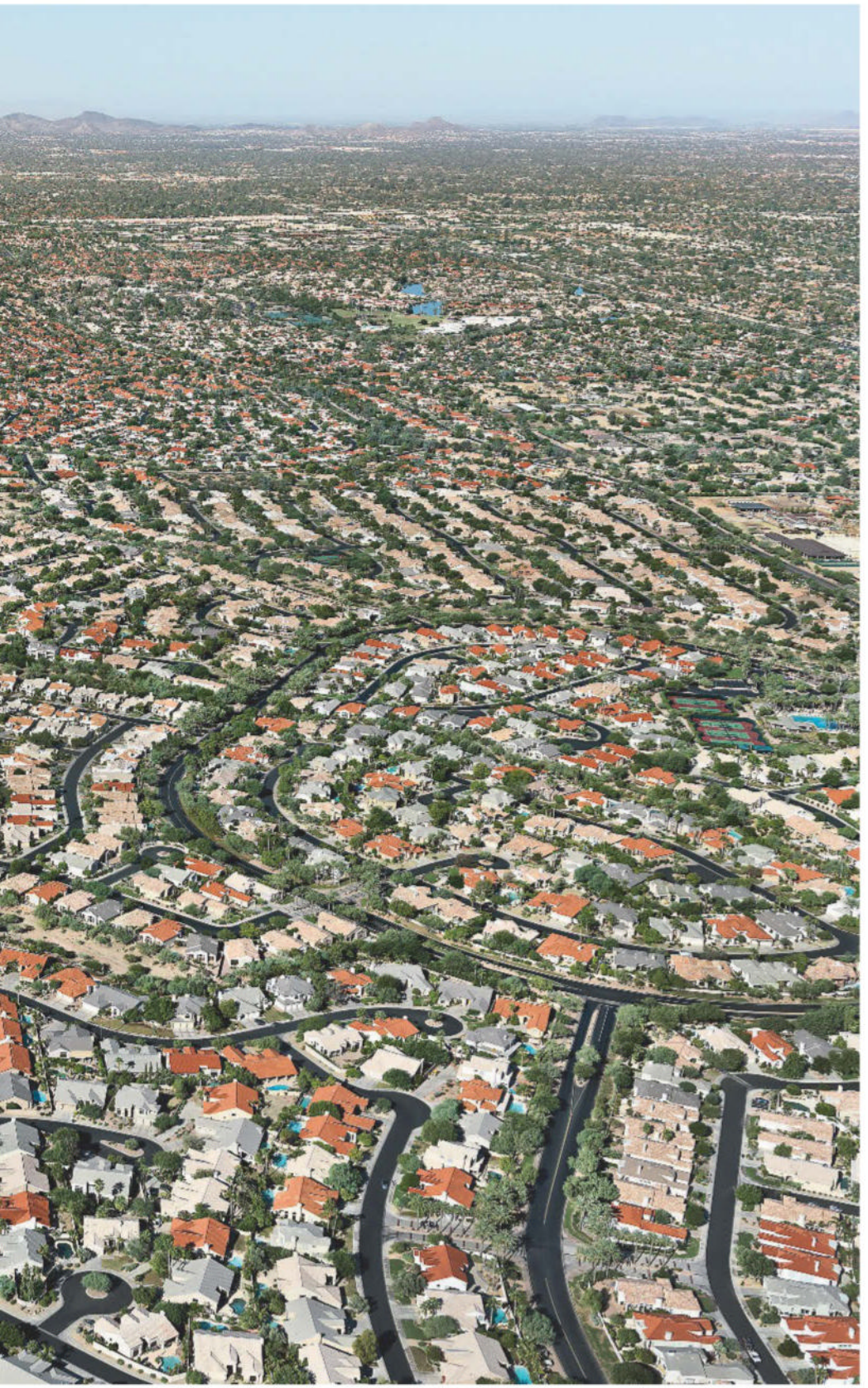
EDWARD BURTYNSKY. COURTESY HOWARD GREENBERG GALLERY, NEW YORK



A stark divide

Edward Burtynsky
ICP, New York

THERE is no geophysical logic to the sharp partition in the middle of this picture. A US federal act, the Land Ordinance of 1785, divided North America's vast western territories into rectilinear townships and sections. So when pumps pull water out of the aquifer beneath Salt River Valley, Arizona, squares of desert like this suburb of Phoenix grow green, settled and busy.

The Indigenous Pima and Maricopa peoples used to farm this land; it was turned into this comfortable conurbation in the 2000s. Valley settlements like this one depend on an increasingly complex and costly water-management system.

Photographer Edward Burtynsky was in a helicopter on his way to the already-desertified Colorado river delta in Mexico in 2011 when he spotted this place. As a student, his first assignment had been to "capture evidence of the activities of man". He likes to say that, after 40 years of pioneering effort with large-format colour, digital and drone photography, he has more or less delivered. "I was out there early," he says, "trying to figure it all out, trying to tell the story of our impact on the planet."

This shot and more of Burtynsky's photos are being exhibited in a solo exhibition, *The Great Acceleration*, at New York City's International Center of Photography until 28 September.

Simon Ings

Narrative medicine

A neurologist sensitively explores the marvels of our brains in a spellbinding debut that is being compared to the late, great Oliver Sacks, says **Elle Hunt**

Book
The Mind Electric
Pria Anand
Virago (UK); Washington Square Press (US)

DAVID DEGNER

Pria Anand sees a "vast liminal space" between wellness and illness

FROM *House* to *Grey's Anatomy*, there is good reason why the medical profession has inspired so many popular series. A patient's journey through the hospital system can mirror the time-honoured structures of narrative, with a beginning, a middle and an end, rising and falling action and often plenty of tension.

As much as we might think of medicine as a hard science – blood, bones and pharmaceuticals – it is also about storytelling, writes neurologist Pria Anand in her lyrical and frequently spellbinding first book, *The Mind Electric: Stories of the strangeness and wonder of our brains*.

When Anand was in medical school in California, she worried her predilection for narrative would disadvantage her. In fact, she discovered, "the ways people choose to tell their story" can be as revealing as any test results.

Anand is upfront about her debt, in her writing and her medical practice, to the late author and neurologist Oliver Sacks, who drew from his personal experience to diagnose his patients as well as empathise with their cases. *The Mind Electric* – she respectfully suggests – is in the vein of Sacks's best-known work, *The Man Who Mistook His Wife for a Hat*.

No one could hope to match Sacks's originality and brilliance, but Anand shares his humanity, curiosity and wide-ranging intellect. Her prose is as elegant and controlled when tackling the intricate, often perverse workings of the brain as it is when telling the stories of particular patients.

But *The Mind Electric* is more than a collection of "clinical tales". Anand's through line is the central importance of storytelling to the practice of medicine. The human desire for narrative, she notes, is ancient, universal and so hardwired that "it often survives and even surges after the most devastating of brain injuries".

How a patient describes their state of health, whether good or bad, may not be supported by a doctor's assessment or their vital signs. Anand describes a patient, a retired paediatrician, who was rendered comatose after a brain haemorrhage. She seemed to make a full recovery, except for the fact she was getting out of her hospital bed each morning to do her morning rounds on her fellow patients, mistaking Anand and other doctors for her colleagues.

"No one could match Sacks's brilliance, but Anand shares the writer's humanity and wide-ranging intellect"

Anand is perspicacious on the ways our brains can mislead us, and how they exist as both a frustration and feature of medical care. But it isn't just the patients' delusions that must be taken into account; the doctor is equally relevant, and can even be fallible.

Anand shows how shifts in her own health have affected her approach to her work – from the sleep loss of medical training to the "phantom noise" she started to hear but neglected to investigate. (It was later revealed to be caused by a malformation in the veins connecting her brain to her heart.)

The "power imbalance inherent in medical practice", Anand argues, exists not just in the arrogance of doctor-knows-best, but in the false binaries it upholds – between science and story, objective truths and subjective accounts. Through history, many confidently delivered diagnoses were rooted in "scientific" understanding that was simply wrong – consider the idea of the "wandering womb".

Though Anand and early reviewers' references to Sacks aren't misplaced, *The Mind Electric* made me think more of *A Body Made of Glass*, Caroline Crampton's history and personal account of hypochondria. Where Crampton wrote from a patient's perspective, Anand describes as a doctor that same "vast liminal expanse that stretches between wellness and illness".

The two books suggest an emerging mainstream openness to medical mysteries, not just dramas, and perhaps dawning recognition that the dichotomies we have long accepted without question – between "healthy brains and failing ones", say, and even sickness and health – may not always be clear-cut.

In *The Mind Electric*, Anand demonstrates the empathy, humility and profound interest in humanity that demarcates an exceptional doctor – and which, in a perfect world, would be consistent across the profession. ■

Elle Hunt is a writer based in Norwich, UK

Behind the scenes

Natural history museums teach us about our world, but they aren't telling us the whole story, discovers **Chris Stokel Walker**

Book

Nature's Memory
Jack Ashby
Allen Lane

MUSEUMS are strange things, Jack Ashby, assistant director of the University Museum of Zoology in Cambridge, UK, points out in his new book, *Nature's Memory: Behind the scenes at the world's natural history museums*. They are signifiers of our society and natural records of our ecosystems and habitats, yes. But they are also deeply flawed and significantly skewed.

Museums, especially the natural history ones that Ashby focuses on in his book, were once seen as a giant taxonomy of everything that ever lived – and continues to live – on our planet. From flora to fauna, mammals to insects, the goal of early cataloguers was to document and present everything in our world to help us better understand it.

That was then, and this is now. Reality bites, as Ashby deftly shows in this engaging book, which persuasively casts a critical eye over the imperfections of museums and how they aren't what we have often thought them to be. For one thing, vast volumes of our natural history aren't actually on display in these institutions, but are consigned to dimly lit storerooms.

We quickly learn how important the areas behind the velvet ropes and polished glass are: around 70,000 more species of flowering plants are believed to exist in the world than scientists have described, says Ashby, with around half of them probably already sitting in museum back catalogues waiting to be analysed.

His insights into how things work behind the scenes are some of the most arresting points in the book, as he describes how animal skeletons are stripped of their flesh for preservation and how insects are preserved and then pinned to display boards. How taxidermy models are presented and why displayed frogs are rarely real (they shrivel up badly) are two more enlightening passages, as is a section on a premium glass-maker renowned for producing the most realistic recreations of flowers.

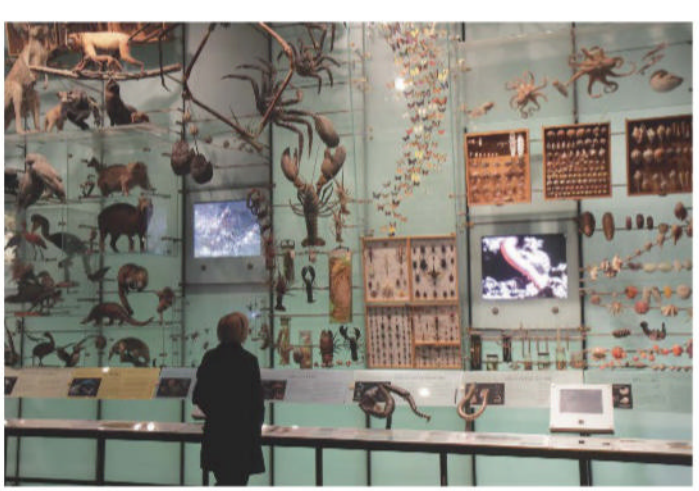
But there are even bigger issues at play than those 70,000 missing plants: the exhibits we file past on school trips as we formatively learn about our planet and its populations are biased.

Ashby points to a 2008 case study that found just 29 per cent of mammals and 34 per cent of birds in the average natural history museum are female, vastly understating their contribution to habitats. In part, that is because the male of the species is often more decorative and lends itself better to being displayed. However, it is also because the people who collect and display the items are invariably men – and white, Western men at that, says Ashby.

He is strongest in his rallying cry to change that problem of misrepresentation within museums. Ashby makes a compelling case that we have all been badly educated about our world and nature because of the squeamishness and the proclivities of past generations. Most male mammal skeletons differ from humans in one significant way: the presence of a baculum, or penis bone – not that you would know it from the displays in most museums worldwide, thanks to prudish curators who simply removed the bone from the pelvis.

This book was written before the wilful destruction of scientific institutions in the US, but in the fug of a general anti-expert malaise – and it shows. It is for this reason that it ought to be read. We must consider the consequences of what is left out of museum displays just as much as we do for what is kept in.

As Ashby puts it: "The work taking place in natural history museums has never been more important, and the role they have to play in safeguarding humanity's future is only just starting to be realised."



What's missing? Pondering the displays at the American Museum of Natural History in New York City

JEFFREY GREENBERG/UNIVERSAL IMAGES GROUP VIA GETTY IMAGES

Chris Stokel Walker is a science writer based in Newcastle, UK

New Scientist *recommends*

Bethan Ackerley
Subeditor
London

Phoebe Waller-Bridge has worked on some unusual projects since *Fleabag*, the comedy-drama that made her name and broke many a heart. **Octopus!**, a two-part documentary

PRIME

on Amazon Prime Video about (you guessed it) octopuses, may just be the oddest one yet.

That exclamation mark is an omen of the whimsy to come – this is an eccentric portrait of one of the most unusual animals to have ever lived. Rather than taking a strictly scientific approach, it is a look at octopuses through the eyes of people who adore them. They have many fans, myself included – who knew I was in a club with comedian Tracy Morgan, who credits the cephalopods for their "vulnerability"?

There are many octopuses featured here that I instantly fell in love with, from *femme fatale* Samantha, who kills her mate during an erotic encounter, to Inky, who broke out of a New Zealand aquarium and made it to the ocean. This is a fitting tribute to our tentacled friends.

Mind games

This exhilarating, experimental thriller is packed with puzzles and narrative threads, finds **Jacob Aron**, who had an awful lot of fun piecing it all together

Book
Basilisk
Matt Wixey
Titan Books (out 1 July)

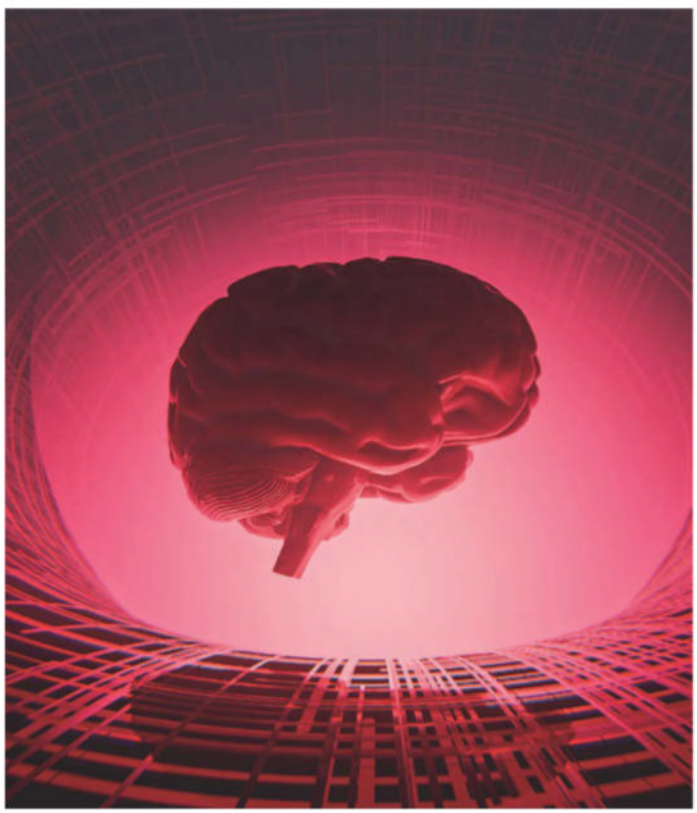
I AM hacking your brain. Simply by reading this, you have allowed me to hijack your thoughts, each word leaping from my mind to yours. I can even conjure mental images against your will – quick, don't think about a pink elephant! Whatever you do, don't imagine it!

Thankfully, there are limits to what I can do to you with words and ideas alone. But what if there weren't? What if there were a phrase so powerful that I could use it to turn your own mind against you, to the point of death? That is the subject of *Basilisk* by Matt Wixey, an experimental thriller that feels like it was specifically designed for my brain and, I suspect, that of many *New Scientist* readers.

The book has a multi-layered structure similar to *House of Leaves* by Mark Z. Danielewski. On one level, we follow Alex Webster, an "ethical hacker" who works at a computer security company, attempting to hack clients' networks and helping them to shore up their defences (a profession shared by first-time author Wixey).

But it isn't that simple. Webster tells her story in two intermingled strands. In the first, we learn how she and a colleague, Jay Morton, stumbled across a puzzle that ultimately led to his death. In the second, she describes the process of coming to terms with his death, and its consequences.

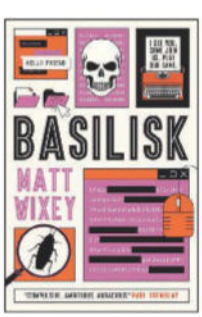
But we aren't done yet. Webster's writing includes footnotes written by both herself and a detective investigating Morton's death, and is further interspersed by "The Helmsman Texts" – missives released by a mysterious character called the Helmsman, as Webster and Morton solve his puzzles.



SUMAID PAL SINGH BAKSHI/UNSPLASH

Could an idea cause physical harm through exposure, asks this novel

"This book feels like it was specifically designed for my brain, and those of *New Scientist* readers"



Matt Wixey's *Basilisk* follows "ethical hacker" Alex Webster

If that all sounds exhausting, *Basilisk* probably isn't for you. Personally, I found it exhilarating, working to hold all these narrative threads in my head as I pieced together the actual story.

The Helmsman Texts themselves take a number of forms, from bureaucratic emails and scientific reports to Socractic dialogues. They encompass topics that are well-explored here at *New Scientist*, from psychology to artificial intelligence (I enjoyed noting the accurate references to scientific papers). The Helmsman describes an attempt to develop a "basilisk" – an idea capable of causing physical harm through exposure alone, named after the mythical creature that could kill you with a single glance.

As far as we know, basilisks aren't real, but the concept is an increasingly fascinating one. Science fiction author David Langford created the idea in his short story *BLIT*, in which basilisks take the form of images capable of "crashing" the human mind, in a way that is similar to malformed computer code.

Perhaps the most famous example is Roko's Basilisk, a fairly stupid suggestion that a future, all-powerful AI would punish anyone in the present who failed to bring about its existence (a more detailed explanation is no more sensible, I'm afraid), which has reportedly caused people mental distress, or at least driven them to post about it online. The most recent series of the sci-fi anthology show *Black Mirror* also featured a basilisk, a reference to Roko's.

Basilisks are just one form of a wider concept known as cognitohazards, ranging from the knowledge of how to build a nuclear weapon to, under some definitions, organised religion.

While reading *Basilisk*, often staying up late into the night with the urge to read just one more chapter, I wondered whether the book itself qualified as a cognitohazard. I certainly couldn't stop thinking about it, long after I had actually finished it. And now that you have read this review, perhaps you are also at risk.

Go on. Start the book. Don't you want to know what happens? ▮

Editor's pick

No need to rename autism in women and girls

Letters, 3 May and 24 May

From Penny Jackson, Derby, UK

A few readers suggest that female autism should be given a different name. This is a misunderstanding of the problem. Autism isn't a different condition in women, and diagnostic criteria are the same. The issue is how a behavioural difference manifests given the difference in behavioural expectations of men/boys and women/girls. This is also a generalisation – there are autistic women who are closer to the male stereotype and vice versa.

It is possible that what we call autism is more than one condition, and some of them could be linked to chromosomes, but research into this is far too early to tell.

Don't change the words, change adverse attitudes

7 June, p 21

From Inés Antón Méndez, Madrid, Spain

To describe individuals with conditions such as ADHD, James Brown and Alex Conner want us to use new terms – "neurodivergent" instead of "neurodiverse", for example. They think that "vague or inaccurate language reinforces stereotypes".

I beg to differ. History shows it is naive to think changing the term for something is going to achieve a change in attitude towards it. While there is a close connection between language on one side and cognition and emotion on the other, this doesn't necessarily mean it is possible to change the latter by manipulating the former.

Neurodiverse may appear less "proper" when considering the original meanings of diverse and divergent, but, if speakers have opted to use neurodiverse to refer to individuals, there is nothing wrong with it. By all means, try to change damaging attitudes, but let's do it in a more efficient way. Changes in attitudes always drive change in language, but imposing new terminology often just results in the new terms inheriting the connotations of the old ones.

Can we look around corners in old photos?

7 June, p 14

From Harry Lagoussis, Athens, Greece

You report that an algorithm can allow a camera to see around corners by decoding information reflected in a surface such as a wall. I wonder if this could be used on existing photos or videos, as long as the wall in question is still available to be mapped. If so, the privacy issues are clear and, should the tech mature, quite dystopian.

On research bias and corporate influence

7 June, p 36

From Paul Goddard, Bristol, UK

In your recent interview, Tracey Woodruff says that corporations are new disease vectors. What a wonderful analogy... companies acting like parasites spreading disease. Yes, they really do and they try to blame the customer. Hence the water companies, to provide another example, take huge bonuses and dividends while polluting waterways with sewage and failing to collect enough fresh water, all the time blaming us for using too much and, presumably, also producing too much effluent.

From Eric Kvaalen, Les Essarts-le-Roi, France

Woodruff talks about the danger of bias in supposedly scientific studies. Bias always exists, even in this interview. For instance, it implies chemical firms didn't care that perfluoroalkyl substances (PFAS) can harm people, rather than considering the possibility that executives didn't know some of these chemicals don't simply go to the ocean and get diluted to negligible concentrations – they stay on the surface, get into the air and then come back down in rain.

Why quantum theory can't kill off free will

7 June, p 8

From Dave Holtum, Bathampton, Somerset, UK

Quantum laws may well be at odds with the idea of free will, but the behaviour of complex systems can't always be predicted by the actions of their parts. The capacity for free will arises from complex interactions of brain cells that can't be divined from quantum theory.

Time to levy parking charges on all roads

24 May, p 22

From Ronald Watts, Charlestown, New South Wales, Australia

Calls for higher fees for car parking to cut urban vehicle use raise a question: what is the total value of parking real estate provided free to drivers? Streets in many places are full of cars parked at taxpayer expense. It is seen as a right. If I wish to take over a park or hall for exclusive use, I must pay. So should the street-parking public.

Will de-extinction put an end to conservation work?

31 May, p 9

From John Fewster, London, UK

Presenting a gene-editing project as the "de-extinction" of the dire wolf confuses the true status of such a creation. Sadly, the threat of extinctions may eventually be made more acceptable by the offer of technology to "regenerate lost species"... for a price. Marketing such projects could be interpreted as offering profitable tech fixes as an alternative to conservation.

Keep your butts away from Mars for a billion years

17 May, p 26

From Martin Welbank, Cambridge, UK

A book you review, *Out of This World and Into the Next*, suggests the sun's eventual wrathful death makes it wise to get our butts to Mars. We should be able to persist on Earth for the next billion years or so before solar changes get too bad. For perspective, a billion years ago, we were little more than sea-dwelling sponges. To imagine what we may evolve into a billion years from now is as meaningless as those sponges trying to imagine us. By the time the sun makes things difficult for life here, we probably won't even have butts.

Parenting tips from the 1960s

24 May, p 26

From Alison Ross, Lyttelton, New Zealand

Here is an addition to Melinda Wenner Moyer's parenting advice that you highlight in your review of her book, *Hello, Cruel World!* I was at the bookshop of Otago University in New Zealand in the 60s when a small child accidentally demolished a stand of books. As the distraught mother attempted to salvage things, a fellow shopper, a professor of psychiatry, boomed out: "Reassure the child!"

For the record

- **A diagram for BrainTwister #73 (17 May, p 45) got a little mangled. The correct version is online at bit.ly/43QiDMS.**
- **In Almost the Last Word (7 June, p 46), Miles Drake asked about hot air blowers and Adrian Moore about flowers.**

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HOW TO *THINK* ABOUT...

IF YOU want to grasp modern physics, you need to have a handle on a stack of concepts, from quantum fields to gravity; particles to energy and much more. The same is true when talking about plant biology or consciousness: understanding of these fields hinges on being versed in, say, photosynthesis or the nuances of subjective experience. All of this can make understanding the latest discoveries and most fascinating insights a little mystifying.

Sometimes it helps to pause and take stock of the concepts on which science is built. And over the next 11 pages, that is exactly what we will do. This time, we cover ideas that have a reputation as mind-bogglers – like quantum superposition and quasiparticles – as well as others – like friendship and symbiosis – which may well have depths you didn't realise existed. Join us as we explore how to think about some of the most crucial concepts in science, and prepare to expand your mind.

Language

The anthropic principle

Mindset

Quasiparticles

Symbiosis

Geoengineering

Friendship

Geometry

Animal consciousness

Quantum superposition

Metaphysics

Quantum computing

JOOS MIND/GETTY IMAGES

How to think about…
Language

MY SON is a wizard. He walks into the kitchen, looks at me and utters the magic words: "Can I have a cheese and tomato sandwich, please?" A few minutes later, just such a snack appears in front of him.

Other young animals can communicate their desire for food through grunts, tweets and growls. But only humans have the grammar and vocabulary that allows us to communicate in precise terms.

In fact, with studies of animals increasingly showing that they share many characteristics once thought to be the preserve of humans – from culture to emotions and even morality – language may seem like the one thing that truly sets us apart. "I think language makes us feel special as a species," says Brian Lerch at the University of North Carolina at Chapel Hill.

Given all that, one of the key things researchers want to know about language is how it evolved, and why it only did so in our human lineage.

Psychologist Shimon Edelman at Cornell University in New York state thinks language's magical power has a fairly straightforward evolutionary explanation. With his colleague Oren Kolodny, now at the Hebrew University of Jerusalem, he argues that it may have emerged 1.7 million years ago, when ancient humans began making stone hand-axes that are beyond the ability of non-human animals to produce.

The idea is that novice tool-makers would have required guidance from an expert to make their own hand-axes, so tool-making sites became classrooms. Proto-language might have emerged as a way for teachers to communicate to students – which could explain why both language and tool-making seem to require the brain to arrange and order thoughts into structured sequences.

But about a decade ago, a key experiment challenged that view. In 2014, Shelby Putt at Illinois State University and her colleagues tasked 24 volunteers with learning to make hand-axes from an expert who either talked them through the process or merely made the tools in the volunteers' presence while occasionally pointing to direct their attention. Surprisingly, both methods were effective, suggesting verbal language isn't necessary for complex tool-making.

This doesn't mean Putt sees language and tool-making as completely unconnected. She thinks complex tool-making really ›

did require humans to arrange and order their thoughts to stay on task. This, she argues, led to the expansion of the brain regions involved in working memory, which we use to briefly hold and manipulate ideas.

But Putt suspects it was only at some later date that humans used this ability to structure and order their thoughts to develop language – presumably because it helped them communicate better and boosted their chances of survival.

These scenarios all assume that language is fundamentally a tool for communicating with others. But that might not be the case. A third way to think about the evolution of language focuses almost exclusively on the way it can help individuals "talk" to themselves and organise their thoughts to undertake complex tasks.

According to some, including the linguist Noam Chomsky, this is what drove the evolution of language, meaning it had nothing at all to do with tool-making. Instead, these researchers think language emerged as recently as 70,000 years ago, perhaps simply because of a random genetic mutation that prompted brain rewiring.

Truth be told, there is still little consensus about quite how language arose. But if Chomsky and his ilk are right, though it didn't involve magic, it might at least have involved a little luck. **Colin Barras**

How to think about…
The anthropic principle

WHEN we look out into the universe, we know it can support life – if it couldn't, we wouldn't exist. This has been stated in different ways over the years, but the essential thrust makes up the core of a philosophical argument known as the anthropic principle. It sounds obvious, even tautological, but it isn't as simple as that.

To understand it, start with what scientists call the fine-tuning problem, the fact our universe seems perfectly balanced on the knife's edge of habitability. Many fundamental constants, from the mass of a neutron to the strength of gravity, must have very specific values for life to be possible. "Some of these constants, if you make them too large, you just destabilise every atom," says Luke Barnes at Western Sydney University in Australia.

The anthropic principle began as an attempt to explain why the universe is in this seemingly improbable state, and it boils down to: the universe has to be this way, or else we wouldn't be here to see it.

There are two main formulations of the principle, both set out in a 1986 book by cosmologist-mathematicians John Barrow and Frank Tipler. The weak principle states that because life exists, the universe's fundamental constants are – at least here and now – in the range that allows life to develop. The strong principle adds the powerful statement that the fundamental constants must have values in that range because they are consistent with life existing. The "must" is important, as it can be taken as implying that the universe exists in order to support life.

If the weak principle is "I heard a tree fall in the forest, and therefore I must be in a place where trees can grow", the strong principle says "A tree has fallen nearby, and therefore this planet was destined to have forests all along."

For scientists today, the weak anthropic principle is a reminder of possible biases in observations of the cosmos, particularly if it isn't the same everywhere. "If we live in a universe that is different from place to place, then we will naturally find ourselves in a place that has some specific conditions conducive to life," says Sean Carroll at Johns Hopkins University in Maryland.

As for the strong version of the principle, there are physicists who consider it useful too, Barnes among them. He works on developing different flavours of multiverse models and sees the strong principle as a handy guide. It implies that, within a multiverse, there is a 100 per cent chance of at least one universe forming that is conducive to life. So, for any given multiverse model, the closer that chance is to 100 per cent, the more plausible it is. If the probability is, say, around 50 per cent, Barnes sees that as a good omen for the model's veracity. "But if it's one-in-a-squillion, then that's a problem," he says.

In truth, however, most physicists write off the strong principle as simply too strong. It suggests the universe is deterministic; that life was always certain to emerge, according to Elliott Sober at the University of Wisconsin–Madison. "But that probability could have been tiny and life could have still arisen, and the observations would be the same."

Where does that leave us? The strong principle does, on the surface, provide an answer to the fine-tuning problem – but that answer is widely considered unreasonable. On the other hand, while the weak principle doesn't provide a reason why the constants of our universe are so finely tuned, it is a useful tool for researchers. As principles go, this one is rather slippery. Leah Crane

THE ANTHROPIC PRINCIPLE

ADOBE STOCK

How to think about…
Mindset

FOR some of us, the phrase "mindset" might bring to mind the unscientific platitudes you find in certain kinds of self-help books. A growing body of research, though, is showing that our mindset can powerfully shape our lives, thanks to its impact on our perception, motivation and behaviour.

"We think of mindset as a belief about how the world works – which includes either you or your environment – that, in turn, shapes your interpretations of the world and your responses to events, as well as your goals," says David Yeager at the University of Texas at Austin.

It was Carol Dweck at Stanford University in California who first popularised this concept. She was initially interested in people's beliefs about intelligence and how these affected their academic achievement.

In psychological questionnaires, some people will strongly endorse statements like "Your intelligence is something very basic about you that you can't change very much." These people are said to have a "fixed mindset". Others are more likely to endorse statements like "No matter how much intelligence you have, you can always change it quite a bit." They are said to have a "growth mindset".

Dweck's research found that people in the latter group tended to be more likely to persevere after failure and were more willing to take on challenges outside their comfort zone – two behaviours that encourage intellectual development.

Crucially, Dweck and her colleagues found that mindsets are malleable; teaching people about their brain's natural plasticity, for example, seems to promote a growth mindset. Despite some failed replications, the effect appears to be robust, though this depends on the context.

"The intervention tends to work better in schools that have a supportive culture and when the teachers endorse more of a growth mindset," says Yeager, who led some of these studies.

Inspired by Dweck's research, psychologists have now uncovered many other mindsets that might affect our health and prosperity. Alia Crum, also at Stanford University, has pioneered research on "stress mindsets", showing that people who believe that stress is enhancing and energising tend to cope better with life's challenges than those who believe stress is inherently debilitating.

Crum compares our mindsets to "lenses" that filter our view of the world – and recent research suggests those optics can have long-term consequences for our health. A study of first responders, for instance, found that those with the mindset that stress is enhancing had a lower risk of cardiovascular disease, regardless of the total amount of stress they experienced in their lives.

Combining a growth mindset and a stress-is-enhancing mindset may amplify the benefits of both. In a series of studies published in 2022, Yeager found that teaching a "synergistic mindset" that incorporated the two improved students' mental health and academic progress better than either alone. "These two mindsets go hand in hand," says Yeager. "You're daisy-chaining your beliefs."

That said, mindset research has at times been misinterpreted. The scientists behind it would never propose that a positive mindset can work miracles – as Dweck highlights in her book on the subject. "Do people with [the growth] mindset believe that anyone with proper motivation and education can become Einstein or Beethoven?" she wrote in *Mindset: The new psychology of success*. "No, but they believe that a person's true potential is unknown (and unknowable)."

Cultivating a growth mindset can also be taken as justifying uncritical encouragement, in which every effort is uniformly praised. Yet having this mindset often means setting high standards. "It sometimes involves being tough, but also supporting someone so that way they can grow to meet those standards," says Yeager. "It can be uncomfortable."

So, contrary to the self-help gurus, a positive attitude can't conjure instant riches. But it can help us to put in the necessary efforts to reach our goals – and to cope with the tears along the way. **David Robson**

How to think about…
Quasiparticles

WHEN we think of particles, we tend to think of them as real objects – tiny, point-like entities with definite properties such as position or speed. But particles are really just energetic spikes in the underlying fields that permeate the universe, which themselves can't be observed directly. All of which can get a bit confusing.

And yet deeper bafflement awaits when you consider the existence of quasiparticles, which emerge from the complex interactions between the "fundamental" particles in solids, liquids and plasmas. They boast near-magical properties that promise exotic new materials and technologies, while forcing us to confront some of our deeply held beliefs about particles in general.

"They very much muddy the waters when it comes to the question of what is a particle," says Douglas Natelson at Rice University in Houston, Texas. A quasiparticle is "some kind of excitation in a material that has many of the properties you think of as being particle-like", he says. They can have a reasonably well-defined position and velocity. They can have charge. They can carry energy. Why, then, are they only quasiparticles and not real particles?

It comes down to them existing only inside matter. Natelson compares it to spectators doing "the wave" in a stadium. "We can look at the wave and say 'Oh, look! There's a wave, it's about so big and it's travelling at a certain speed.' But the wave is actually this collective thing made up of the behaviour of all of the fans in the stadium."

To coax quasiparticles into existence, physicists take an object, such as a piece of metal, and subject it to extreme temperatures or pressures or magnetic fields. Then they observe the collective behaviour of the particles within.

One of the first of these odd phenomena was discovered in the 1940s. It was a "hole": the absence of a negatively charged electron where one should exist. These holes hop around inside solids like positively charged particles, and by treating them as independent entities, researchers were able to create the semiconductors that power our electronics.

"Basically, all of modern electronics is based on electrons and holes," says Leon Balents at the University of California, Santa Barbara. "We make use of these quasiparticles all the time."

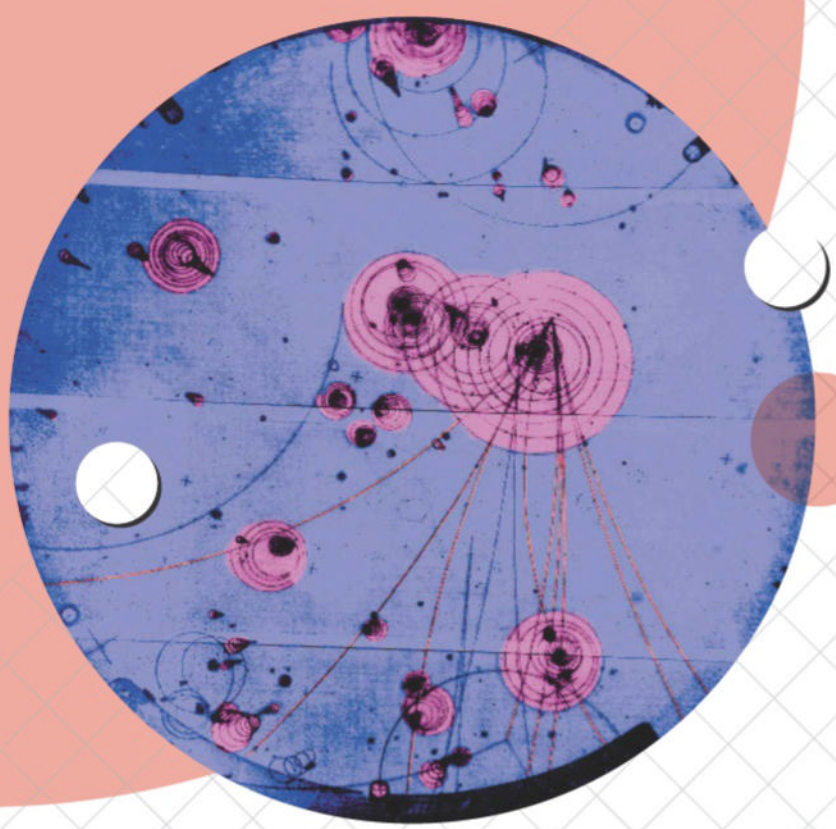
In the intervening decades, we have discovered a whole zoo of quasiparticles. There are magnons, emerging from waves in spin, the quantum property that is the basis of magnetism. There are Cooper pairs, which emerge at low temperatures and carry electrical charge with no resistance in superconductors. And the list continues to grow as physicists predict and observe even weirder species with strange-sounding names, including pi-tons, fractons and even wrinklons.

One of the most exciting, says Balents, are non-Abelian anyons. Unlike other particles we know of, these quasiparticles can, in effect, remember how they have been manipulated – a property that makes them a tantalising proposition for use in quantum computers.

"The jury's still out on whether they'll actually be useful," says Balents. Nevertheless, Microsoft and other major corporations are investing heavily in quasiparticle research.

The other reason quasiparticles are so fascinating takes us back to the question of what a particle is. If quasiparticles have particle-like properties, then we have to consider that the "fundamental" particles from whose interactions they arise – your electrons, photons and quarks – may themselves emerge from something deeper.

"Are the things that we think of as fundamental particles really fundamental, or are they somehow quasiparticles of some underlying fundamental theory?" says Natelson. "Is it elephants all the way down?" Daniel Cossins



SCIENCE HISTORY IMAGES/ALAMY

How to think about…
Symbiosis

"SYMBIOSIS IS THE REASON WE ARE HERE, AND IT STILL SUSTAINS US NOW"

FOR the first 2 billion years of life on Earth, our planet was dominated by single-celled bacteria and their cousins, archaea. It was Slimeball Earth, and it would have stayed that way were it not for the single most important merger and acquisition in the history of our planet.

One of those archaeal cells engulfed a bacterial cell and, somehow, the bacterium survived. Both cells reproduced together and, in time, the engulfed bacterium became the mitochondrion, a tiny structure that acted as a powerhouse of that early cell.

Nick Lane at University College London has shown that mitochondria allowed these cells to express 200,000 times more genes, enabling them to grow and produce endless forms. The new combo became the complex eukaryotic cell, which ultimately gave rise to almost every living thing you can see without a microscope, including us.

Symbiosis is the reason we are here, then. And it still sustains us now. Over 80 per cent of land plant species form symbiotic relationships with mycorrhizal fungi, where the fungus provides nutrients and the plant supplies food to the fungus. Without this relationship, we wouldn't have oxygen to breathe. The soil itself was formed by symbiosis between fungi, bacteria and plants, which didn't even have roots when they first moved onto land from the oceans, roughly 500 million years ago.

When most of us hear the word "symbiosis", we probably think of life forms "living together", which is literally what the Greek root of the word means. It is a clownfish nestling in an anemone. Or a coral reef and the spectacular array of life it supports. Or lichens, which are an intimate association of organisms from two or even three separate kingdoms of life. In other words, symbiosis has positive vibes and we assume it means some harmonious, mutually beneficial arrangement.

It is better, however, to think of symbiotic relationships as spanning a continuum, from parasitism at one end to mutualism at the other, says Katie Field at the University of Sheffield, UK. And don't think that even mutualism is selfless: partners usually only give to receive something later.

To see how this continuum works, just look at the diversity of ways in which orchids demonstrate it. Orchid seeds are minute, containing almost no resources, so to germinate, these plants must always parasitise mycorrhizal fungi in the soil, from whom they steal sugars and nutrients. Later, when they have grown leaves, some species begin to pay the fungi back, and it starts being a mutualistic relationship.

Then there are cases when older orchids supply food to young orchids. And there are other species of orchid that never develop green leaves and remain parasitic their entire lives. "You have this whole cycle of different phases of symbiotic function," says Field.

There is yet another important and practical way to think about symbiosis: as a key to unlocking our future. Legumes such as pulses, beans and lentils use symbiotic bacteria to make their own fertiliser from the nitrogen in the air. Recent work indicates that the plants' method for doing this was adapted from pre-existing cellular machinery.

This means it should be possible to engineer other crops – especially cereals such as wheat and corn, which contribute half of all the calories people eat – to produce their own fertiliser, says Giles Oldroyd at the Crop Science Centre at the University of Cambridge. Pull that off and we could vastly cut the amount of fertiliser we pour onto fields.

Oldroyd, who is running trials of crops modified to boost their symbiotic powers, says his mission is to get rid of chemical fertilisers. "I'm super optimistic we're going to get there," he says. **Rowan Hooper**

GEOENGINEERING

How to think about…
Geoengineering

WE KNOW the only safe and long-term solution to climate change is cutting our greenhouse gas emissions. But in the face of still-rising emissions and escalating climate impacts, some are considering an option that – until recently – would never have escaped a researcher's lips without a good deal of trepidation.

"Geoengineering" is a catch-all term used to describe human interventions in climate systems, generally with the intention of preserving ecosystems or cooling the planet. But defining what counts as geoengineering is tricky. At its most broad, it can capture anything from planting trees to propping up ice sheets with giant underwater curtains.

Some geoengineering ideas are more contentious than others. Large-scale reforestation, when done right, is widely accepted as a positive climate action. But more extreme ideas, such as modifying the way sunlight behaves in Earth's atmosphere, cause more concern.

It is "different levels of risk and return", says Janice Lachance at the non-profit American Geophysical Union (AGU), which recently drew up an "ethical framework" for scientists working in this space. "Planting trees in a park… will probably be very quick, very noncontroversial," she says. "However, it quickly changes when you start thinking about new technologies, new ways of doing things."

Take the idea of reflecting more sunlight back into space to cool the planet, known as solar radiation management (SRM). ›

This could potentially be done in three basic ways (see diagram, below), and most modelling studies suggest the technique could provide some cooling effect within a few years of first deployment, although it might also cause substantial disruption to rainfall cycles and cloud formation.

SRM has long been a taboo research topic, but as temperatures continue to rise and climate impacts become increasingly severe, it is attracting more attention from scientists, governments and philanthropists.

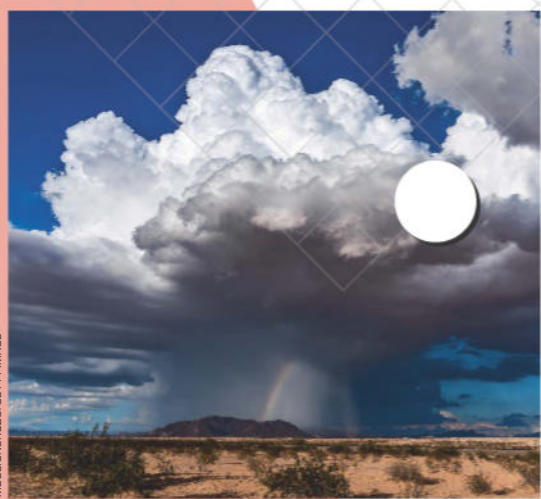
Some activists say we should stay well away from even researching this kind of intervention, warning it risks distracting people from the need to rapidly cut emissions. But Andy Parker at The Degrees Initiative, a nongovernmental organisation focused on SRM, warns emissions cuts are no longer enough for humanity to cope with the impacts of climate change.

He says we "need to consider how we manage risks from greenhouse gases we've already emitted". Plus, without international research and discussion on geoengineering, there is an increasing risk that a "rogue actor", such as a country suffering acute climate impacts, could decide to unilaterally start geoengineering.

Against this backdrop, a growing number of scientists now support research into geoengineering strategies. "There's a recognition among some scientists that we are not doing well in meeting the goals of the Paris Agreement," says Lachance. That is what prompted the AGU to compile its ethical framework to steer research on climate interventions.

It isn't just how research is conducted that has people worried – who conducts it is also a pressing concern. Planetary-scale geoengineering ideas often put lower-income countries, particularly those around the equator, on the frontline of unintended consequences, such as disruption to monsoon patterns. But most of the research into geoengineering techniques happens in higher-income nations, with less skin in the game.

As part of The Degrees Initiative, Parker is working with researchers across lower-income countries in the southern hemisphere to build research capacity in SRM, with the hope that it will ensure any future decision on deployment is influenced by those who have the most at stake. "We've got no position on whether SRM is ever used or not," he says. "But we do think that developing countries need an informed voice to do their own research." Madeleine Cuff



MDESIGNER125/GETTY IMAGE

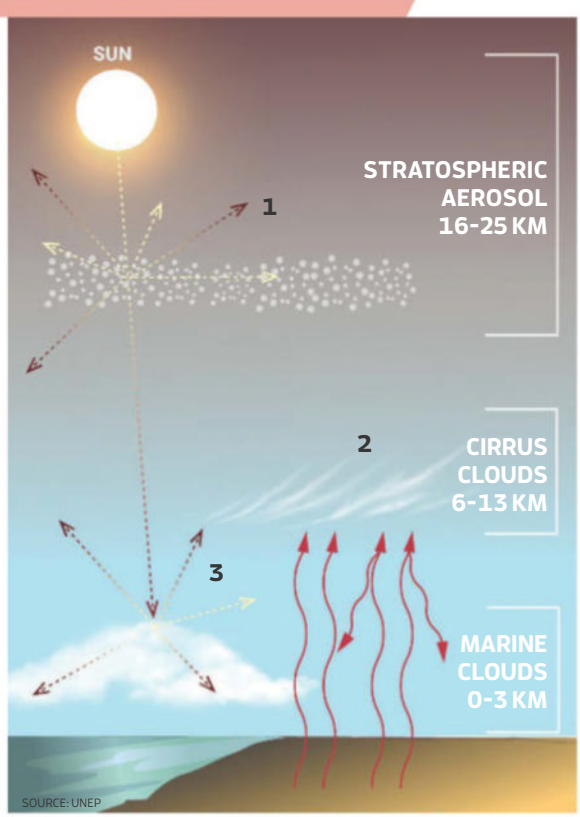
TAMING THE SUN'S POWER

There are three basic solar geoengineering methods for cooling the planet

1. Stratospheric aerosol injection
This would involve releasing tiny particles of liquid called aerosols from planes high in the atmosphere, where they would reflect away sunlight

2. Cirrus cloud thinning
Aerosols such as nitric acid could thin cirrus clouds, therefore allowing more heat to escape back into space. However, injecting too much aerosol could thicken the clouds and have the opposite effect

3. Marine cloud brightening
Tiny droplets of sea water are sprayed into clouds, brightening them and increasing the sunlight they reflect. This idea was tested in a small field trial in 2024 designed to protect the Great Barrier Reef in Australia



How to think about…
Friendship

MEANINGFUL friendships might feel like they should come naturally. We enjoy people's company or we don't; we find the same things funny or we don't. But the unwritten rules of different kinds of friendship can be surprisingly tricky to navigate. Over the past decade, though, careful research has begun to unravel not only how significant such relationships are for our well-being but also how to ensure the right ones thrive.

Jeffrey Hall, director of the Relationships and Technology Lab at the University of Kansas, is one researcher investigating how to foster friendship. He says to think of our friendships as lying on a continuum – from mere acquaintances and friends of friends to our besties who are always there for us.

"A minimum standard is that two people like each other, and that there is a frequency of communication that allows for the flourishing in that relationship," he says. "We expect a sense of trust and reliability, the expectation we can confide our secrets, and that they are people who we genuinely enjoy spending time with and will prioritise over others."

Time investment plays a big role in Hall's definitions. In a series of surveys, he asked people who had recently moved to a different city to chart the development of their new social lives. He found that people needed to spend between 57 and 164 hours with someone before they could be considered a "friend", and roughly 200 hours together to become a "good" or "best" friend.

The type of time spent together is vital, too. "It's involving the person in the day-to-day affairs of your life – eating, drinking, playing, hanging out – because you want to have them there, and sharing those things makes them better," says Hall, who is the co-author of a new book, *The Social Biome*, exploring these themes. Being forced into each other's company through work or study, in contrast, didn't aid friendship formation.

We are considerably more likely to spend time with people who are similar to us, of course. Over the past decade, anthropologist Robin Dunbar at the University of Oxford has identified seven "pillars of friendship" that seem to undergird the most meaningful connections. They are: having the same language or dialect, growing up in the same location, having the same educational and career experiences, having the same hobbies and interests, having the same world view, having the same sense of humour and having the same music taste.

We will share just one or two of these pillars with the 150 or so people that we loosely define as friends rather than acquaintances, but six or seven with our five or so closest allies, he writes in his book *Friends: Understanding the power of our most important relationships*.

Surprisingly, similarities between friends even stretch to their neural activity. In 2018, Carolyn Parkinson at the University of California, Los Angeles, asked university students to watch a series of videos while they lay in an fMRI scanner. She found that she could predict who was friends with whom based on the similarity of their brains' reactions to the clips they were watching. The closer they were to each other, the more likely it was that the same regions would respond at the same time.

Parkinson's work chimes with the theory that having a "shared reality" – a common way of viewing the world – is the basis of any strong relationship. "These are people who are paying attention to the same things as us, having similar emotional reactions to what they're seeing, and so on," she says. "Such people can be easier to predict and understand when we're interacting with them – making conversations flow more easily, feel less taxing, and minimising misunderstandings."

Can we experience that connection remotely? Hall thinks so. "Phone calls and video chats with the people that we love are probably as valuable as face-to-face communication," he says. "And creating routine opportunities to communicate through the phone or video chat sustains and nourishes relationships." **DR**

"SIMILARITIES BETWEEN FRIENDS EVEN STRETCH TO THEIR NEURAL ACTIVITY"

FRIENDSHIP

SHUTTERSTOCK/SHCHUS

GEOMETRY

How to think about…
Geometry

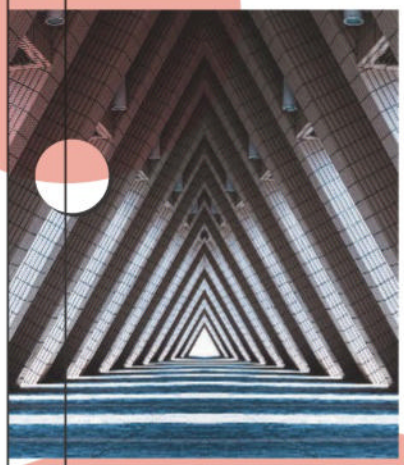
CAN you imagine the imprint a four-dimensional hexagon might leave as it passes through your three-dimensional kitchen table? Probably not, but some people can.

One such person was mathematician Alicia Boole Stott, daughter of logician George Boole. Early in the 20th century, she made models of the shapes four-dimensional objects would create when passing through three-dimensional objects. Decades later, when mathematicians could check such things using computer programs, they found Boole Stott had possessed an uncanny gift for finding these shapes.

For most of us, geometry conjures up thoughts of pencils, rulers, triangles and circles. It means those complicated questions you got asked at school involving parallel lines and angles. But as Boole Stott's story shows, researchers have been taking geometry way beyond this for some time.

Geometry can stray far from the comprehensible world of two- and three-dimensional shapes – and in so doing, it can be extremely illuminating. ›

How to think about…
Animal consciousness



SHUTTERSTOCK/HANOHKI

ARE dogs conscious, with thoughts and feelings of their own? What about pigeons? Honeybees? Earthworms? Jellyfish? How you answer will probably reflect the human tendency to ascribe consciousness to familiar and so-called "higher" animals, while doubting that it extends to "simpler" ones, such as invertebrates.

In fact, we can never be certain if another being is conscious. "The subjective nature of experience means you can't be totally sure – you can't even be 100 per cent sure about other humans," says Jonathan Birch at the London School of Economics, author of *The Edge of Sentience*.

Nevertheless, we can gather evidence. But first, we must decide what we mean by consciousness. Here, says Birch, it is useful to follow the thinking of philosopher Herbert Feigl and split consciousness into three layers.

The most basic is sentience, the raw sensation of the present moment, including sensations from the outside world and more interior feelings like pain, pleasure, excitement and boredom. On top of that is sapience, the ability to reflect on our experiences – to think, for example: "This pain is the worst pain I've ever had." The final layer, selfhood, is a sense of ourselves as beings with

GEOMETRY

Perhaps the best example is general relativity, Albert Einstein's theory of gravity, which joins the three dimensions of space with time, creating a four-dimensional stage on which everything in the universe plays out.

But geometry can also make use of dimensions that aren't physically real. Think of meteorology, for instance, where a point in the atmosphere can have many "dimensions" – latitude, longitude, temperature, pressure, wind speed and so on.

Researchers map these dimensions as shapes that extend into higher dimensions to help understand the workings of the atmosphere. "From things like this, you can apply mathematical models and actually work out what happens to [those properties] in many dimensions," says mathematician Snezana Lawrence at Middlesex University in London.

For theoretical physicists, extra dimensions seem to be a necessary part of any full description of the universe, with some proposing that our reality is a "projection" from a higher dimension, for instance. This may sound outlandish, but if physicists make certain simplifying assumptions related to this idea, it suddenly makes it possible to carry out calculations to do with fundamental particles and black holes that are otherwise impossible.

Some physicists are banking on even stranger geometrical ideas being a route to a "theory of everything", a single framework that explains the cosmos and everything in it. One of these is the "amplituhedron", a mathematical object developed by Jaroslav Trnka at the University of California, Davis, and Nima Arkani-Hamed at the Institute for Advanced Study, New Jersey. Think of this as an abstract, multi-dimensional crystal, the properties of which provide an alternative way of describing the fundamentals of particle physics.

Or there is "causal dynamical triangulation", developed by Renate Loll at Radboud University in the Netherlands. This stitches together an ensemble of geometrical shapes to create a description of space-time that seems to have some of the properties of both quantum theory and general relativity – two ideas that are normally incompatible. It is, she says, not just an abstract geometrical notion, but a testable reflection of the universe's real properties that could be mirrored in our observations of the cosmic microwave background radiation that fills the whole of space.

Neither of these ideas yet amount to a theory of everything. But some suspect that to have any hope of finding one, we need a fresh vision for physics – and there is an increasing sense that this might be written in the language of geometry. Whether that is true or not, geometry is definitely more than hexagons – even four-dimensional ones. Michael Brooks

"NON-WESTERN CULTURES HAVE ALWAYS THOUGHT OF ANIMALS AS SENTIENT BEINGS"

a past, a future and a life of our own.

Studies of animal consciousness tend to focus on sentience. "A lot of that research has been on pain, though people are moving towards looking at positive emotions like joy as well," says Kristin Andrews at York University in Toronto. For instance, fish that are in pain may swim to a part of their tank that has a painkiller dissolved in the water.

A second type of evidence of sentience comes from social behaviour. "Animals are socially learning so much of their knowledge and skills," says Andrews. Even insects do it. Fruit flies, for example, learn whom to mate with by watching other fruit flies mate.

The extent to which some animals are aware of their cultural context is revealed in some extraordinary findings, including the recent discovery that mice seemingly give "first aid" to unconscious companions. Researchers have also looked for episodic memory, which is the ability to relive past experiences – suggesting selfhood – and found it in various mammals, includingrats and chimpanzees, as well as in birds like scrub jays.

Although evidence of widespread sentience is growing, we still don't understand the neurobiological requirements of consciousness. There are some studies in mammals pointing to the brain regions that are involved, says Andrews, "but we can't generalise to other species that have very different neural structures". For instance, insects don't have anything like a human brain, and yet there is good evidence they can feel pain – and are therefore sentient.

Nevertheless, last year, Andrews, Birch and their colleagues released the New York Declaration on Animal Consciousness, which states there is "a realistic possibility of conscious experience" even in many invertebrates. Andrews goes further, arguing that we should start by assuming all animals are conscious.

This upends the current assumptions held by most biologists, but it might not be such a stretch for the rest of us. The idea that animals are unfeeling automata is "an aberration of Western science", says Birch. "Non-Western cultures, and indeed a lot of people in the West, outside of the academy, have always thought of animals as sentient beings." **Michael Marshall**

ANIMAL CONSCIOUSNESS

I-HWA CHENG/AFP VIA GETTY IMAGES

How to think about…
Quantum superposition

THERE is always a "look of indignation" on students' faces when they first learn about quantum superposition, says physicist Marcelo Gleiser. He has taught quantum mechanics, the theory governing the microcosmic world of atoms and particles, for decades, and his students' consternation inevitably emerges right on cue: when he reaches the part about quantum objects apparently being in several places at once.

The trouble is that words like "apparently" crop up an awful lot around this topic. Indeed, in the century or so since the idea of superposition emerged, its true meaning has remained contested. The only thing physicists agree on is that it takes us to the heart of what it means for something to be "real".

QUANTUM SUPERPOSITION

A good place to start is the Schrödinger equation. Developed by Erwin Schrödinger in the 1920s, it is a foundation stone of quantum theory that tells us the probability of finding a particle in a given state when we measure it. The point is that quantum mechanics is concerned with predicting the outcome of a situation – it says nothing concrete about what a particle was doing before it was measured.

However, the Schrödinger equation works by describing all the possible places a particle could be before it is measured using a piece of maths known ›

as the wave function. This gives us one mathematical definition of a superposition: it is a sum of different possible quantum states.

We certainly know particles can exist in a superposition. In the double-slit experiment, for example, a single photon, a particle of light, is fired towards a grating with two narrow gaps in front of a screen. If a detector is watching, the photon will "pick" one slit and hit a specific spot on the screen. But if there is no detector, an "interference pattern" will appear on the screen, suggesting the particle behaved like a wave and went through both slits at once, interacting with itself.

What we don't know for sure is what "being in superposition" means. Broadly, there are two views. One says the wave function is a useful mathematical tool and no more. That is the view of Gleiser, who is based at Dartmouth College, New Hampshire. "Nothing in the formalism of quantum mechanics tells us that the wave function needs to be part of physical reality," he says. "The belief in mathematics as truth is becoming a bit like a cult."

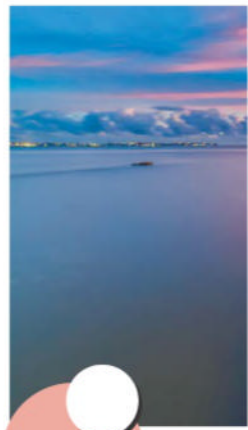
Gleiser supports an interpretation of quantum mechanics called quantum Bayesianism, which says the theory doesn't describe reality per se, but rather what we know about it. Ultimately, what changes when we measure a quantum state is our information about it, not reality itself.

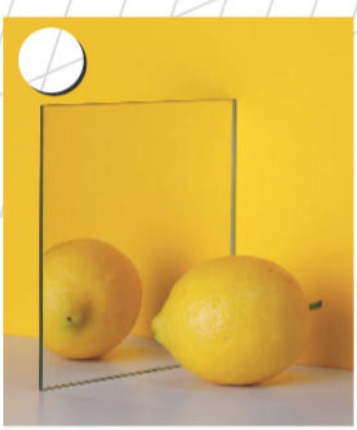
But there is a camp that flatly refutes this view. Simon Saunders, a philosopher at the University of Oxford, believes the wave function is real. For him, a particle in a superposition is physically in more than one place simultaneously. "It is an extended object," he says. "It is delocalised." According to this perspective, we must accept that the world of particles doesn't bear any resemblance to reality as we experience it. The electrons orbiting an atom, for instance, exist as a cloud of probability before we measure them.

Critics of this position often ask what happens to those other possibilities when a measurement snaps a particle into one place. Saunders is happy to embrace the radical answer that they all manifest themselves in their own branch of an infinite multiverse.

A resolution to this question isn't going to come any time soon. In the meantime, researchers have gone far beyond placing single particles into superposition – it has been achieved for large molecules and even a 16-microgram crystal. If this tells us anything, it is that reality is far stranger than it seems. Miriam Frankel

QUANTUM SUPERPOSITION





SHUTTERSTOCK/RADOMIR REZNY

How to think about... Metaphysics

METAPHYSICS has something of an iffy reputation. "I think a lot of people think it's a complete waste of time," says philosopher Stephen Mumford at the University of Durham, UK, author of *Metaphysics: A very short introduction*. "They think it's all just arguing over pointless questions, like, classically, how many angels could dance on the head of a pin?"

It's easy to see why. Classical metaphysics – the term comes from the Greek "meta", meaning beyond – does ponder some bizarre-sounding questions. What is a table? What form of existence do colours have? In addition, it does so through reasoning alone, with tools such as "reductio ad absurdum" – a mode of argumentation that seeks to prove a claim by deriving an absurdity from its denial. It is a far cry from the empirical knowledge scientists pursue through observation and experiment.

But the idea that metaphysics is all just abstract theorising is a misconception, says Mumford: "Metaphysics is about the fundamental structure of reality beyond the appearances. It's about that part of reality that can't be known empirically."

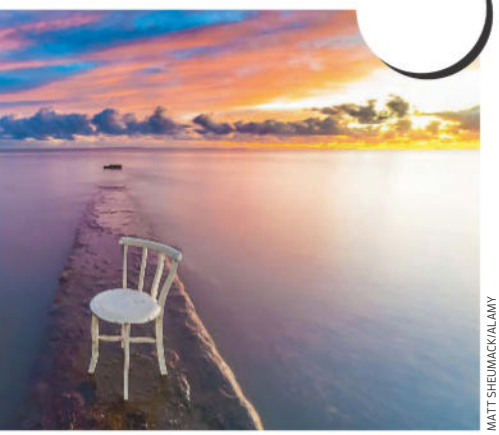
Indeed, as modern science has expanded its reach into territories that were once seen as the purview of metaphysics, such as the nature of consciousness or the meaning of quantum mechanics, it has become clear that one can't succeed without the other.

To see why, the first thing to understand is that everyone has metaphysical beliefs, says Vanessa Seifert, a philosopher of science at the University of Bristol, UK. You probably believe objects exist when we aren't looking at them, for instance, even though there is no hard and fast empirical evidence for this.

There is also such a thing as "naturalised metaphysics", which is distinct from classical metaphysics in that it is informed by science, says Seifert. "You look at what science tells us about the world, and you investigate how literally you can take that."

This brand of metaphysics provides a vital service for science because it examines the assumptions underlying our attempts to understand the world. "In many cases, metaphysical beliefs are the fundamental bedrock upon which empirical knowledge is built," says Mumford. Take causation – the idea that effects have causes – which we all believe despite the fact that causal connections aren't observable. "Basically, the whole of science is premised on this metaphysical notion of causation," he says.

These days, scientists routinely grapple with all manner of other concepts that are



MATT SHEUMACK/ALAMY

deeply infused with the metaphysical, from chemical elements, space and time to the concept of species and the laws of nature.

We have a choice, says Mumford. We can either scrutinise our metaphysical beliefs for their coherence or ignore them. "But in the latter case, we're just assuming them unreflectively," he says.

One of the most striking cases in which science and metaphysics collide is quantum mechanics, which describes the world of atoms and particles. It is a hugely successful scientific theory, yet when grappling with its meaning, physicists must confront metaphysical questions, like how we should interpret superposition (see page 39), the apparent ability of a quantum system to exist in multiple states simultaneously.

Here, all we have are competing interpretations of what is actually going on that won't submit to experimental testing, and it is becoming clear that progress will be impossible without confronting our hidden assumptions. To do so, some researchers have recently begun to revive a tradition known as "experimental metaphysics", in which they test the coherence of the metaphysical beliefs underlying the various interpretations of quantum theory.

"In the end, you can't do physics without metaphysics," says Eric Cavalcanti at Griffith University in Brisbane, Australia, one of the foremost proponents of this approach. "You have to deal with both at the same time." **DC**

How to think about…
Quantum computers

OVER the past decade, quantum computing has grown into a billion-dollar industry. Everyone seems to be investing in it, from tech giants, such as IBM and Google, to the US military.

But Ignacio Cirac at the Max Planck Institute of Quantum Optics in Germany, a pioneer of the technology, has a more sober assessment. "A quantum computer is something that at the moment does not exist," he says. That is because building one that actually works – and is practical to use – is incredibly difficult.

Rather than the "bits" of conventional machines, these computers use quantum bits, or qubits, to encode information. These can be made in several ways, from tiny superconducting circuits to extremely cold atoms, but all of them are complex to build. The upside is that their quantum properties can be used to do certain kinds of computation more quickly than standard computers.

Such speed-ups are attractive for a range of problems that normal computers struggle with, from simulating exotic physics systems to efficiently scheduling passenger flights. Five years ago, it seemed quantum computers would ameliorate these and many other computational challenges.

Today, the situation is a lot more nuanced. Progress in building ever bigger quantum computers has, admittedly, been stunning, with several companies developing machines with more than 1000 qubits. But this has also revealed impossible-to-ignore difficulties.

One major problem is that, as these computers get larger, they tend to make more errors, and finding ways to prevent or fix these has proven to be harder than expected. Last year, Google's researchers made the most notable dent in this problem so far, but even so, fully fledged, useful quantum computers aren't here yet – as Cirac points out.

Because of this, the list of realistic applications for these machines may be shorter than we once hoped. Weigh the cost of building one against the smaller-than-imagined savings it could deliver, and, for many use cases, it may not make economic sense. "The biggest misconception is that a quantum computer can accelerate any problem," says Cirac.

So, which problems might still benefit from quantum computation? Quantum computers could break the cryptography systems we currently use for secure communication, and this makes the technology interesting to governments and other institutions whose security could be imperiled by it, says Scott Aaronson at the University of Texas at Austin.

Another place where quantum computers should still be useful is in modelling materials and chemical reactions. This is because quantum computers, themselves a system of quantum objects, are perfectly suited to simulate other quantum systems, such as electrons, atoms and molecules.

"These will be simplified models; they won't represent real materials. But if you design the system appropriately, they'll have enough properties of the real materials that you can learn something about their physics," says Daniel Gottesman at the University of Maryland.

Quantum chemistry simulations may sound more niche than scheduling flights, but some of the possible outcomes – such as finding a room-temperature superconductor – would be transformative.

The extent to which all this can truly be realised is significantly dependent on quantum algorithms, the instructions that tell quantum computers how to run – and help correct those pesky errors. This is a challenging new field that Vedran Dunjko at Leiden University in the Netherlands says is forcing researchers like him to confront fundamental questions about what information and computing are.

"This provides an amazing motivation to study the hardness of problems and the power of computing devices," says Dunjko. "For me, this would be reason enough to dedicate a significant fraction of my life to these questions." ∎

Karmela Padavic-Callaghan

"YOU CAN'T DO PHYSICS WITHOUT METAPHYSICS"

Mathematics of life

It all adds up

This handy maths trick can help you count moving objects, from vanishing spoons to a herd of cows, says **Katie Steckles**

Katie Steckles is a mathematician, lecturer, YouTuber and author based in Manchester, UK. She is also adviser for *New Scientist*'s puzzle column, BrainTwister. Follow her @stecks

WHETHER it's enemy tanks in battle, animals in the wild or cutlery in a busy canteen, it is difficult to count objects that are moving around. Luckily, there is a technique that can estimate how many there are of something without requiring you to count every single one.

The capture-recapture method involves getting a sample – waiting for some animals to wander by, for instance, then collecting some – marking the individuals distinctively, then releasing them back into the population. After some time has passed, you repeat the process to pick another group of animals and count how many of them are already marked.

If you captured, say, 50 animals initially and marked them all, then on your recapture step you found half the animals you saw were marked, this tells you something about the whole population. Since half the sample is marked, this implies that half of the whole population is marked – so there must be about 100 individuals. This can give a reasonably accurate estimate of a population, without having to find and count every single member of it.

During the second world war, allied statisticians wanted to determine how many tanks the German army was producing. Captured tanks couldn't be re-released, but, as tank components are marked with serial numbers, another approach allowed them to make an estimate. They logged the serial numbers of all captured or destroyed tanks, working on the assumption they were numbered sequentially and randomly distributed. If the largest serial number in your data is L and the number of captured tanks is n, one estimate for the total number of tanks is given by $L+L/n$.

SHUTTERSTOCK/CONNECT IMAGES - CURATED

So, if we had four numbers, the largest of which was 80, we could assume the whole range extends about another 80/4 = 20, so there would be about 100 tanks overall. This is known as the German tank problem in statistics.

One of my favourite population estimation stories was told to me by a teacher friend, who tasked her students with estimating the number of forks in the school canteen – impossible to count as, at any given time, a number will be in use and others will be in the wash.

Her class "captured" a set of forks and marked each one with a drop of nail polish, then released them back into the population. A week later, they recaptured another sample population and used it to make an estimate of the total number of forks.

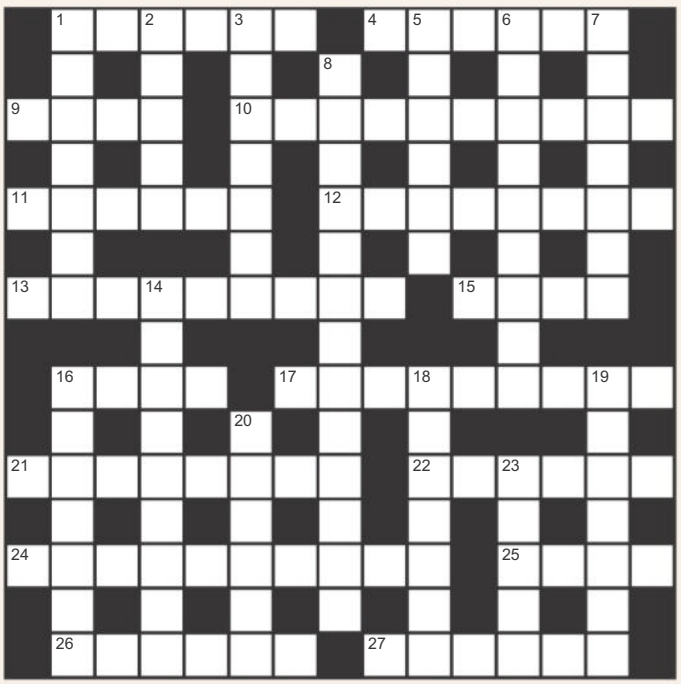
Researchers performed a similar experiment 20 years ago. A worrying number of teaspoons were going missing in their lab, so they marked a set of spoons before releasing them, studying their movements and publishing the results. It turns out science is effective: the publication of the paper did result in five teaspoons being sheepishly returned by spoon stealers in the building. ▮

Mathematics of life appears every four weeks

Next week
Debunking gardening myths

These articles are posted each week at newscientist.com/maker

Quick crossword #186 *Set by Richard Smyth*



Scribble zone

Answers and the next cryptic crossword next week

ACROSS

1 Medium-grained metamorphic rock (6)
4 Work (6)
9 2^2 (4)
10 Study of immune systems (10)
11 Subatomic particle (6)
12 Not outside (8)
13 Stony meteorite (9)
15 Utilised (4)
16 Alkali (4)
17 Blockage (9)
21 Barbiturate brand (8)
22 Omnivore with a striped face (6)
24 Skin-fold dermatitis (10)
25 Mumbai-based steel-making multinational (4)
26 Decrease (6)
27 Plant reproductive organ (6)

DOWN

1 Organ of digestion (7)
2 G. H. ___, English mathematician (5)
3 B. F. ___, US behaviourist (7)
5 Not limitless (6)
6 Sudden petroleum shortage, as in 1973 or 1979 (3,6)
7 Striped (like a tiger) (7)
8 Supportive liquid that surrounds a fetus (8,5)
14 Epistaxis (9)
16 Sydney ___, South African biologist and Nobel laureate (7)
18 Experimental clothing? (3,4)
19 ___ window, concept in political science (7)
20 Still (6)
23 Item of information (5)

Our crosswords are now solvable online
newscientist.com/crosswords

Quick quiz #308
set by Corryn Wetzel

1 Which planet in our solar system has the shortest day?

2 Flamingos get their pink colour from which natural pigments?

3 What gland produces the hormone melatonin?

4 Which English mathematician is considered to be the first person to write a computer algorithm?

5 Over how many kilometres does the Large Hadron Collider's ring of superconducting magnets stretch?

Answers on page 47

BrainTwister
set by Christopher Dearlove
#79 Hamming it up

Consider five-digit binary numbers: strings of five bits that are either 1 or 0. The "Hamming distance" between two numbers is given by how many of their corresponding bits are different. So the distance between 01011 and 11001 is 2, because the first and fourth bits differ.

What is the distance between 01011 and 01100?

What is the smallest number (considered as a binary number) that starts 01 and has a distance of 3 from 00000?

What is the smallest number starting 10 that has a distance of 3 or more from 00000 and from the previous answer? And what about the smallest number starting 11 that has a distance of 3 or more from 00000 and from each of the two previous answers?

How can you add a sixth bit (either a 1 or a 0) after 00000 and after the three previous answers so that the distance between any two of these four numbers is 4?

Solution next week

Flavour gap

Why do low and non-alcoholic beers taste so much closer to the "real thing" than non-alcoholic wines do?

Ron Dippold
San Diego, California, US
Basically, it comes down to time invested. Just think about how terrible early vegetarian meat and dairy substitutes were – it is the same thing here. Brewers have been working on non-alcoholic beer seriously since the 1920s (the Prohibition era in the US, when alcohol was illegal). This is a far earlier start than for non-alcoholic wine, and it shows.

As a brewer, I can tell you it is quite hard to make a non-alcoholic drink (defined as anything less than 0.5 per cent alcohol) that tastes like an alcoholic drink. Beside the grains, the primary factor for all the flavours is the yeast. Depending on the temperature, ingredients and yeast used, you can produce hundreds of different alcohols and other compounds. But if you want to make a non-alcoholic drink, you have three main options.

First, you can make an alcoholic drink with yeast, then remove most of the alcohol from the beer after it has been brewed. This was the most commonly used method for brewing alcohol-free beer until about 10 years ago. Indeed, the byproduct of distilling beer to whiskey is low-alcohol beer, and the byproduct of distilling wine to brandy is low-alcohol wine. Unfortunately, it is very hard to remove the alcohol without severely affecting the flavour, so you could definitely tell which was a "near beer" before 2010.

"While beer brewers have been working on this problem for a long time, the idea of non-alcoholic wine as a market is fairly new"

Second, you can make a non-alcoholic drink and then try to recreate the other flavours. This is the only way to get a truly zero-alcohol drink, but this is hard to achieve because the other flavours aren't fully understood. This approach can work for "mocktails" (non-alcoholic cocktails) because they tend to have strong flavours. But it usually doesn't work well for beer or wine, which have a more pure flavour. With non-alcoholic beer, you get something like barley soda. With wine, you get weird grape juice. But there is another option.

The third option is to use yeast that is allowed to ferment, but in a controlled way, so it produces the usual flavours with only a fraction of the alcohol. Beer-makers have really made this work in the past decade, so you get a low-alcohol beer that still tastes like beer. It is, in my opinion, the optimal solution so far. The entire process is the same as for a "real" beer, but you just get less than 0.5 per cent alcohol.

While brewers have been working on this problem for a long time, and – as mentioned – the strong flavours in cocktails let you make passable mocktails without too much effort, the idea of non-alcoholic wine as a market is fairly new, so it is still catching up. As far as I know, removing the alcohol from wine still gets you terrible "wine", and there isn't yet an option to use low-alcohol yeast. But some companies are doing fairly well with the second method: taking a version of grape juice and adding tannins, salinity and minerals to get close to the taste of real wine. Some of them get pretty close, and I would say they are better than bad wine, but they aren't quite as far along as beers are. Just give them time.

Jussi Tolvi
London, UK
The quick answer is the difference in alcohol content: full-strength wines are up to 15 per cent alcohol by volume (ABV), whereas most beers are under 5 per cent. Removing more alcohol also removes more of what we perceive as the flavour of wine or beer. You can produce a decent beer with fermentation restricted to 0.5 per cent alcohol, but alcohol-free wines are almost all de-alcoholised from full-strength wine. That de-alcoholisation process, unfortunately, also removes flavour compounds.

PHOTOS BY RA KEARTON/GETTY IMAGES

This week's new questions

Effortless ride **When driving over hills, which is more fuel-efficient: accelerating downhill for uphill momentum or maintaining a steady speed?**
***Raffi Katz**, Watford, Hertfordshire, UK*

To the left **Why is our heart not in the centre of our body?**
***David Lockyer**, Bedhampton, Hampshire, UK*

Is it more fuel-efficient to stay at one speed or build momentum by accelerating downhill?

Under pressure

Does car tyre pressure affect the radius of the wheel, or the speedometer or milometer (odometer) readings? (Continued)

Sam Edge
Ringwood, Hampshire, UK
Modern road-vehicle tyres are made of extremely tough synthetic rubber and have steel wire and mesh reinforcement embedded within them, so they are far less elastic than, say, the tyres on my childhood tricycle. The composite structure makes them much harder wearing and safer, but also makes them extremely difficult to recycle.

Nonetheless, the radius of the tyre does increase with increased inflation pressure. Therefore, a speedometer that uses the rotation rate of some element of the transmission will be affected by the radius of the driving wheels. However, speedometers are generally calibrated conservatively, so it is unlikely that an over-inflated tyre, whether by mistake or because

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Tom Gauld
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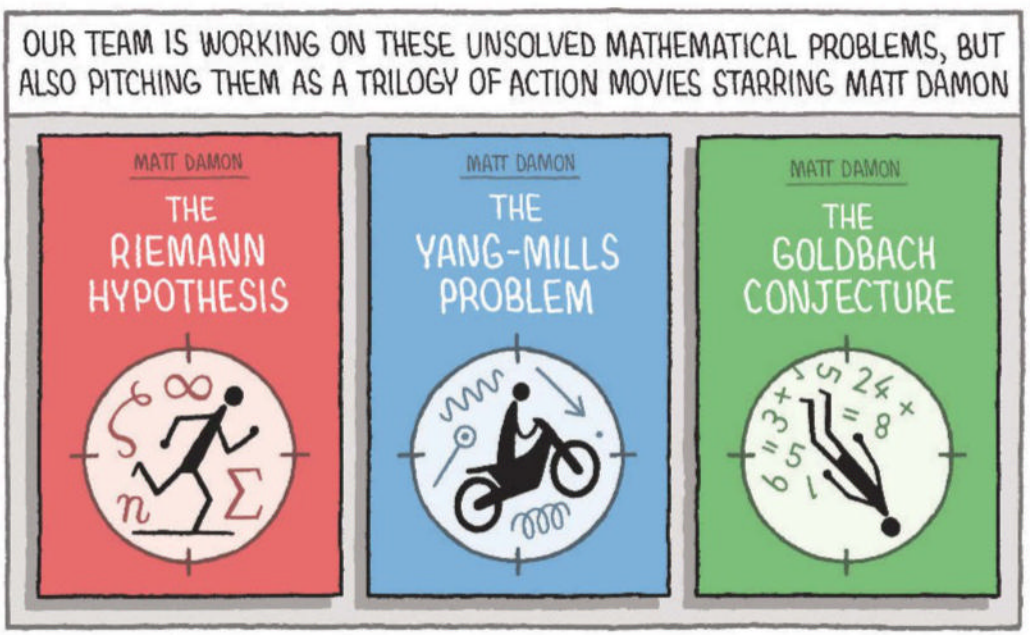

of frictional or climatic heating, is going to cause a low enough speedometer reading that one gets an inadvertent speeding infraction.

The effect can also be harnessed for diagnostics. My partner's car measures and remembers the relative rotation rates of each wheel. Should one of them start rotating faster compared with the others, indicating its radius has decreased, probably due to loss of pressure, it flags a dashboard warning. After reinflating the tyres to the recommended front and rear pressures, she pushes a button on the dashboard to tell the system to recalibrate.

Some cars now have electronic barometers in each wheel that can measure and report the pressures directly. Military wheeled vehicles, especially amphibious ones, often have both pressure sensors and compressors on each wheel. This allows the pressure to be monitored and modified on the go to minimise drag in water and optimise traction on different types of terrain.

"It is unlikely that an over-inflated tyre is going to cause a low enough speedometer reading that one gets a speeding infraction"

Danny Colyer
Bristol, UK

For many years, my morning cycle commute was 5.37 miles (8.64 kilometres), according to a computer calibrated over a measured mile, and using a magnet attached to my 20-inch front wheel at a tyre pressure of 80 pounds per square inch (psi).

If the tyre were at 100 psi, then the computer would consistently show a ride distance of 5.36 miles. If the computer showed a ride distance of 5.39 miles, then I would know that my tyres needed pumping up. This doesn't necessarily show that the tyre diameter varied with changes in air pressure (although it seems likely). Instead, it shows a variation in the deformation of the tyre while it is rolling.

As car tyres are less pliable than those of bikes (but also run at lower pressures and carry greater weight) and car odometers are less precise, I wouldn't like to extrapolate these observations to car tyres.

Andrew Shead
Tulsa, Oklahoma, US

Yes, tyre pressure does affect the wheel radius, fuel efficiency and odometer readings of the vehicle. I can tell when I need to reinflate my tyres because my average speed is reduced by the higher rolling resistance of soft tyres, and the odometer reads an extra tenth of a mile.

That's because the slightly smaller wheel radius increases the number of revolutions of the wheel that are needed to complete the entire journey, and the odometer sensor is activated by a magnet attached to the spokes. In an automobile, the reduced rolling resistance of higher tyre inflation pressures does make a significant difference to fuel consumption. ▮

Answers

Quick quiz #308 *Answers*

1 Jupiter

2 Carotenoids

3 Pineal gland

4 Ada Lovelace

5 27 kilometres

Cryptic crossword #164 *Answers*

ACROSS 1 Aliquot, **5** Sebum, **8** Goldeneye, **9** Sou, **10** Ninth, **12** Liftman, **13** Miscalculated, **15** Bobsled, **17** Delta, **19** Use, **20** Statement, **22** Elder, **23** Hosiery

DOWN 1 Argon, **2** Ill, **3** Urethra, **4** The Black Death, **5** Shelf, **6** Base metal, **7** Mourned, **11** Nosebleed, **13** Mob rule, **14** Ladders, **16** Laser, **18** Aptly, **21** Eve

#78 One on top *Solution*

If the expression is grouped, 1 = (1/6 + 1/6 + 1/6) + (1/6 + 1/6) + 1/6, then this becomes 1 = 1/2 + 1/3 + 1/6.

We can group the 12 twelfths into groups of 6, 3, 2 and 1, giving 1 = 1/2 + 1/4 + 1/6 + 1/12.

There are five other sets of four different unit fractions totalling 1: 1/2 + 1/3 + 1/9 + 1/18, starting from 18 eighteenths; 1/2 + 1/4 + 1/5 + 1/20, from twentieths; 1/2 + 1/3 + 1/8 + 1/24 from twenty-fourths; 1/2 + 1/3 + 1/10 + 1/15 from thirtieths; and 1/2 + 1/3 + 1/7 + 1/42 from forty-twoths.

Problematic coupling

In a long-ago time (May), Feedback asked for examples of "no shit, Sherlock" – scientific studies spending an inordinate amount of time and effort to demonstrate something obvious. Reader Roger Erdem obliged, with evidence that injuries are more likely if you don't rest long enough and that fiddly tasks take longer to perform.

However, Roger isn't done, and continues to send examples of self-evident findings. While we wait for someone else to pick up the baton, here are two more. First, in June the journal *Demography* published a paper with the gloriously gossipy title "Sleeping with the enemy: Partners' heterogamy by political preferences and union dissolution. Evidence from the United Kingdom". Phys.org neatly summed this up: "Couples with opposing political views face higher risk of separation, study finds".

Feedback is staggered that differences over politics could lead to strife in relationships. Whatever happened to judging prospective partners based solely on their looks and fashion sense?

Speaking of problematic coupling behaviours, Roger's other obvious result is from 2016, when the journal *PLoS One* published a paper titled, "Coy males and seductive females in the sexually cannibalistic colonial spider, *Cyrtophora citricola*". It's about the relationship dynamics in a group-living spider species, whose females are prone to eat males after sex. The researchers found that the males were selective about their mates, favouring younger and well-fed females.

Or, as the headline on phys.org put it: "Male orb-weaving spiders cannibalized by females may be choosy about mating".

With no apologies whatsoever, Feedback is going to be pedantic about this, because it isn't quite as obvious as it seems. According to the researchers, males of solitary species might not be choosy at all. Such males might encounter females so rarely that they choose to risk postcoital decapitation regardless of their mate's quality. Hence the focus on a social species, in which natural selection has favoured males that choose carefully before sacrificing their lives for sex.

Clearly, there is a great deal of "no shit, Sherlock" out there. Can anyone else find any other examples? Let's not always see the same hands.

Twisteddoodles *for New Scientist*

Got a story for Feedback?
Send it to feedback@newscientist.com
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Consideration of items sent in the post will be delayed

Fiction, disproved

As a long-time science fiction reader, Feedback appreciates the peculiar experience of reading an older story that can no longer be true. That is, a story that turns on a premise that used to be plausible, but which, given current knowledge, is either mildly daft or entirely impossible.

Sometimes this is just "predictions" that have now been surpassed by the passage of time. *Blade Runner* was released in 1982 and set in 2019. We are now six years beyond that date, and Feedback notes the continued absence of flying cars. However, we will concede the film was basically right about the awfulness of tech billionaires. And depending on whether you followed *Star Trek* or *The Terminator*, the late 1990s were supposed to be marked by either eugenically created superhumans or a nuclear war.

However, we want to highlight another phenomenon: that of a new scientific result seemingly obviating the entire premise of a story. For instance, *The War of the Worlds* has long been condemned to implausibility by the apparent lack of Martian animal life.

Something similar appears to have just happened to the *Revelation Space* books by Alastair Reynolds. Feedback would like to say right now that we still really like these books, and also that anyone who hasn't read them should stop reading now, because the next paragraph spoils one of Reynolds's biggest reveals.

The story turns on the fact that our galaxy is going to collide with the Andromeda galaxy in a few billion years. As a result, humanity comes under threat from a machine species called the Inhibitors, who aim to limit intelligent life in the galaxy until the crisis has passed.

Except that *Nature Astronomy* published a paper on 2 June with a blunt title: "No certainty of a Milky Way–Andromeda collision". The researchers simulated the movements of all the galaxies in our local cluster and found that "uncertainties in the present positions, motions and masses of all galaxies leave room for drastically different outcomes". As a result, they say, "the fate of our galaxy is still completely open".

We encourage readers to tell us about other examples of recent discoveries that have undermined formerly plausible sci-fi premises.

More Gs

Over at newsletter London Centric, readers may read about "The real 5G conspiracy: How Londoners are being lied to about their phone signal". This describes the common experience of "high levels of mobile phone coverage (as shown by the signal bars on your phone screen) but no functioning data download capacity". Apparently, Londoners' phones are telling them "they are connected to modern 5G mobile data networks", but, in reality, they are "unknowingly stuck running their work and social lives over 4G".

The journalists were tipped off to this by the creator of an app called SignalTracker. The article describes this man wandering around London "carrying five different mobile phones" to test the various networks.

So far, so late-period capitalism. However, reader Brian Darvell wishes to highlight the name of this cellphone detective: Martin Sims.

Discovery Tours
NewScientist

A journey through North America's wonders

Yellowstone wolf and wildlife winter safari: US

24 January 2026
7 days

Experience the magic of Yellowstone National Park in winter without the crowds, where steaming geysers meet snowy landscapes and the wildlife roams freely. Accompanied by an expert guide who will delve into the fascinating science behind the region's dramatic geology and powerful geothermal features, from bubbling hot springs to erupting geysers.

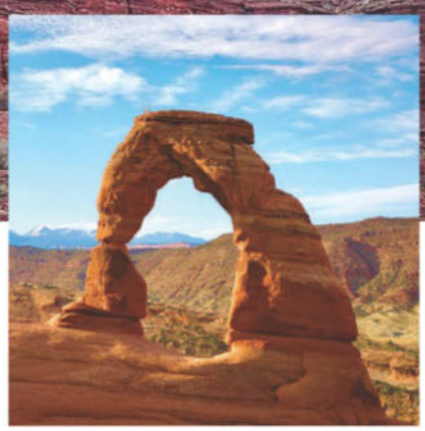
- Search for grey wolves in their natural winter habitats while learning about wolf reintroduction efforts, pack behaviours and tracking techniques
- Explore the Upper Geyser Basin, home to Old Faithful and other iconic features
- Spot bison, elk, foxes and coyotes as they navigate the snow-covered landscape
- Travel by sleigh over the National Elk Refuge in Jackson Hole for close-up views of the vast winter herds beneath the jagged spires of the Teton mountain range

The great monarch butterfly migration: Mexico

15 February 2026
6 days

Witness one of the world's most astounding wildlife events, the monarch butterfly migration, which occurs each year in the forested Central Highlands of Mexico and features the most delicate of creatures. This all-encompassing itinerary offers extensive time among the butterflies, as well as a chance to enjoy authentic cultural encounters.

- Observe the monarch butterfly migration along with three separate visits to two monarch sanctuaries
- Discover the remote fir forests of Mexico's Central Highlands, where millions of monarchs roost and breed each winter
- Explore traditional Mexican mountain villages and visit a market, witnessing the benefits of butterfly ecotourism for local people



Colorado geology exploration through Moab, Arches and Canyonlands national parks: US

1 May 2026
5 days

Discover how the power of deep time has sculpted some of the most awe-inspiring landscapes on Earth. Explore towering sandstone arches, dramatic canyons and monolithic rock formations shaped over hundreds of millions of years. From well-known landmarks to secluded gems, this adventure offers an unparalleled look at the region's natural splendour.

- Visit Arches and Canyonlands national parks, Dead Horse Point State Park and the Colorado National Monument
- Witness the desert sky ablaze with colour at sunrise and sunset, casting deep shadows and golden hues over the rock formations
- As night falls, experience some of the darkest skies in the country – perfect for stargazing and connecting with the vast cosmos

Find out more at
newscientist.com/tours

locommotion?

Every mechanical watch has a balance wheel, but not all balance wheels are created equal. The **C12 Loco's** 'free sprung' balance wheel (and hairspring) isn't merely a part of the watch. It's the star. Placed below the time-telling dial, on the artfully coloured and stepped platine, its mesmeric oscillations are driven by a new in-house movement – Calibre CW-003, whose hand-wound, hand-finished architecture delivers a six-day power reserve and chronometric accuracy. And because we want to tell the story of how we got here – and because we're a little *loco* ourselves – we've made a feature-length documentary about it. Just make sure you're sitting down when the price is revealed.

Scan the QR code for the full (com)motion picture.

Do your research

Christopher Ward

christopherward.com