



THE SEARCH FOR ALIEN LIFE

HOW IT WORKS



IS A BRAIN TRANSPLANT POSSIBLE?

YOUR HOME



ROOF INSULATION EXPLAINED

Zzzz
HOW SMART BEDS HELP YOU SLEEP

SOLAR-ELECTRIC DRONE
HOW SEA GLASS FORMS
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WHAT ARE HARD AND SOFT WATER?

BATHROOM BUGS UNDER THE MICROSCOPE

HOW INDUCTION HOBS COOK FOOD



ALL ABOARD A MODERN STEAM TRAIN



HOW TO CURE THE WINTER BLUES



INSIDE A FLAMETHROWER



DEADLY DINOSAUR DISEASES

EXPLAINED

HOW JUST ABOUT EVERYTHING IN A HOUSE WORKS

FUTURE
ISSUE 186

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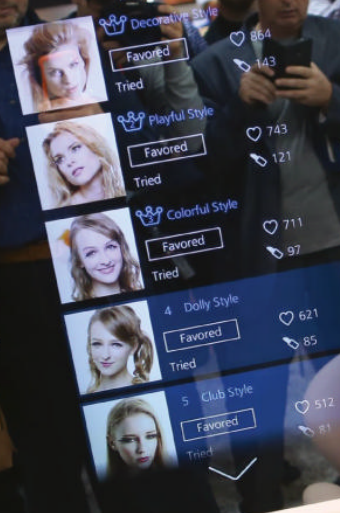
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Your home explained

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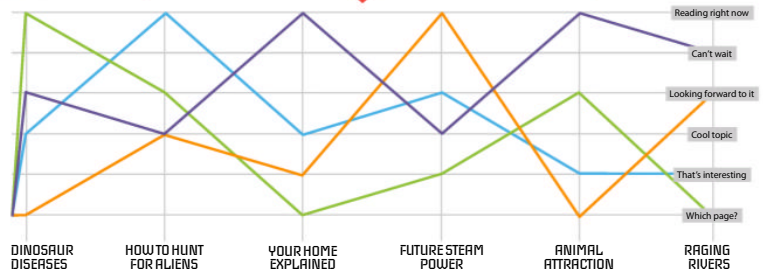


We're returning home in this issue of **How It Works** to put all the things we take for granted in our houses under the microscope. Every second we spend in the comfort and safety of a modern house, we're taking advantage of science and technology that has been decades or centuries – and sometimes millennia – in the making. That's whether you're entertaining yourself with a podcast on your tablet device, putting the kettle on for a cuppa or mopping the bathroom floor with a bucket of hot water and bleach. What could life be like in our homes 50 years from now? You can see a snapshot of advanced technologies that might be common in the home of the future, too, starting on [page 26](#). Hope you enjoy the issue!



Ben Biggs
EDITOR

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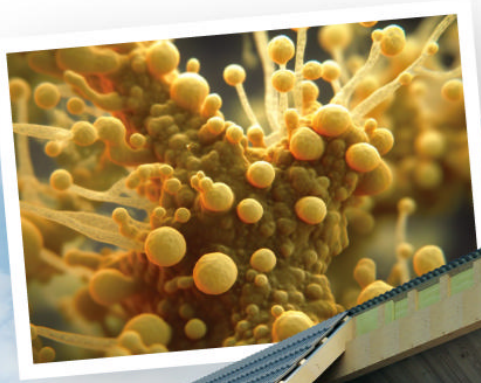
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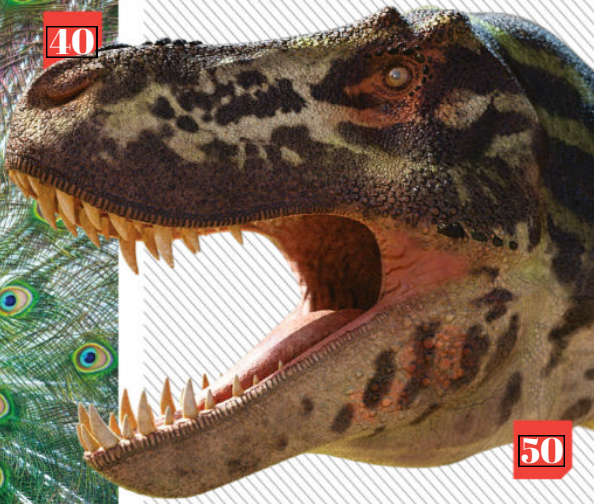
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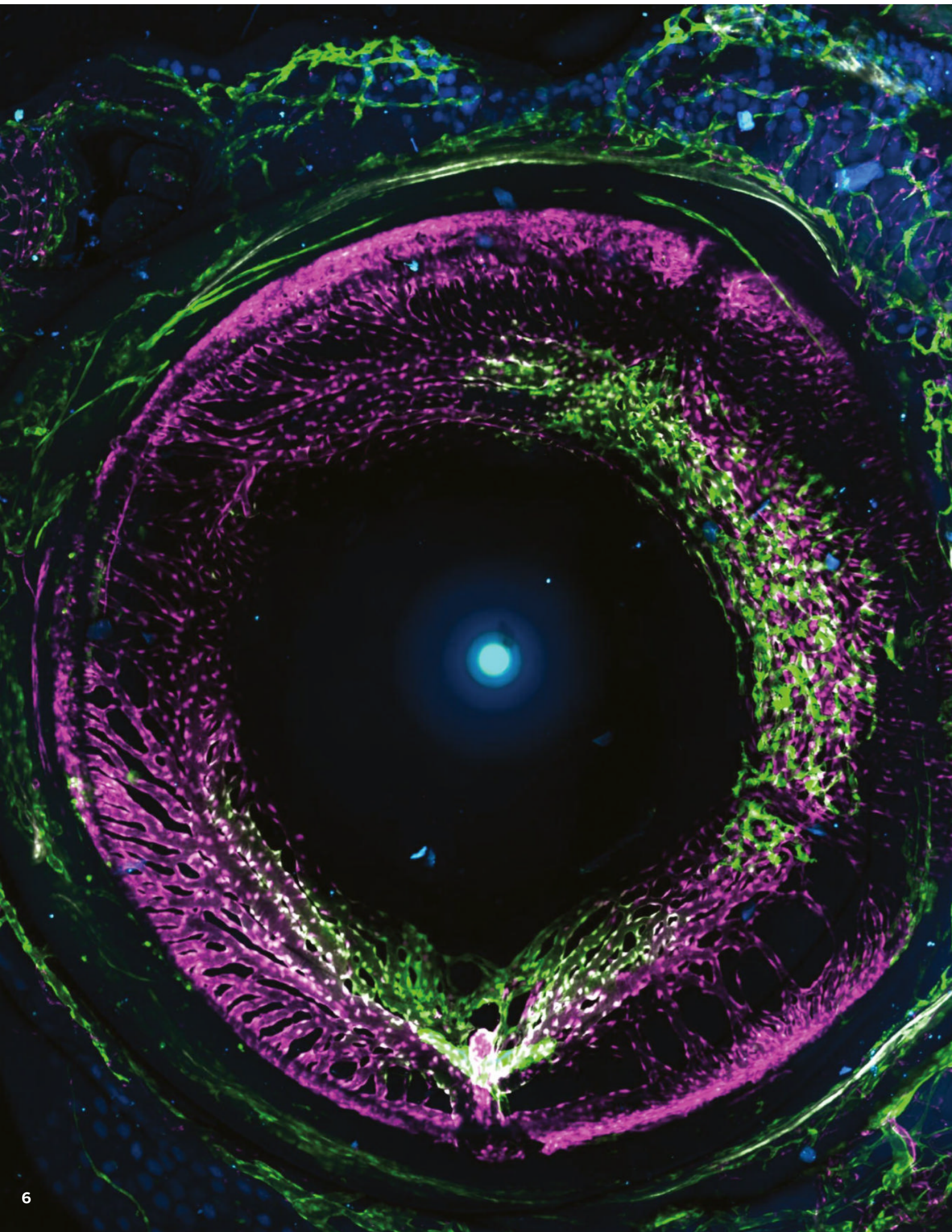
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Behind the eye

Fluorescence microscopy reveals the complex cellular network around the eye of a zebrafish. The vessels in purple are the fish's optical blood supply, whereas the green vessels show its vast lymphatic system, part of the immune response. Researchers study the development of these vessels in zebrafish to better understand human development due to our similar genetic structure.







Rainbow mountain

Taken in Zhangye National Geopark, Gansu, China, this colourful mountain range spans an area of around 197 square miles. Millions of years of tectonic uplift and compression in sedimentary sandstone and siltstone has led to the formation of a rainbow mountain range. Each layer in the rocky rainbow is packed with different minerals, such as iron and sulphur, which give them striking colours.







Interstellar heart

Around 7,500 light years from Earth in the constellation of Cassiopeia is the beautiful Heart Nebula, or IC 1805. First discovered by William Herschel in November 1787, this romantic cloud of ionised hydrogen and cosmic dust was created by the cluster of stars at its centre, called Melotte 15. The solar winds and radiation of this cluster create the nebula's love heart appearance.







Hiding in orchids

Thanks to their petal-like appearance, these deadly hunters can lay in wait on flowers in the forests of Southeast Asia to spring a trap on unsuspecting pollinators.

Known as cryptic mimicry, this type of camouflage allows the orchid mantis to trick its prey into mistaking its body for a harmless flower until it's too late to save themselves from becoming the orchid mantis' next meal.



Thawing permafrost due to climate change is releasing methane, a potent greenhouse gas



PLANET EARTH

Methane under the Arctic could trigger a climate feedback loop

WORDS SASCHA PARE

Deep beneath the permafrost that blankets a group of islands in the Arctic Ocean lurks a growing and migrating sea of methane. The thick permafrost, or ground that remains frozen for at least two years, forms a tight seal that has so far prevented millions of cubic metres of methane from wafting out, but there's no guarantee that the potent greenhouse gas won't eventually escape. "At present, the leakage from below permafrost is very low, but factors such as glacial retreat and permafrost thawing may 'lift the lid' on this in the future," said Thomas Birchall, a geologist at the University Center in Svalbard in Norway.

The base of permafrost is undulating, which creates pockets between the permafrost and the underlying geology where gas from biological and non-biological sources can accumulate and become trapped. Should this permafrost seal disintegrate, it could set off a chain reaction in which the methane's strong warming effect would thaw more permafrost and release even more gas. This vicious

feedback loop would further accelerate warming, melting and methane emissions.

Permafrost is widespread on Svalbard, a Norwegian archipelago located deep inside the Arctic Circle and just 500 miles from the North Pole. Missions that involve drilling into the frozen soil in search of fossil fuels often hit pockets of natural gas by accident, but the extent of these reserves was unknown. Birchall and his colleagues used historical data from commercial and scientific boreholes to map the permafrost throughout Svalbard and pinpoint these stores of natural gas. The researchers found deposits rich in methane are much more common than thought on the islands. Given that the archipelago has a similar geological and glacial history to the rest of the Arctic region, the same could be true of other permafrost-covered locations near the North Pole.

The permafrost seal on Svalbard isn't uniform, the study found. Coastal areas had a

thinner crust of frozen soil due to the warmth brought by ocean currents, whereas permafrost in the lowlands was thick and saturated with ice, meaning it has "extremely good sealing properties" and is able to "self-heal," scientists said. In the highlands, the permafrost was flakier and more permeable due to dry conditions.

But permafrost that's leak-proof now might not stay that way. Svalbard is one of the fastest warming places on the planet, and its 'active' layer of permafrost, the upper few metres that thaws and refreezes seasonally, grows deeper as global temperatures rise. Estimating how much methane is trapped below the permafrost is tricky because it is difficult to access and there are only a few dozen boreholes on which to draw conclusions. "With permafrost thawing in the Arctic, there is a risk that the impacts of releasing methane trapped beneath permafrost will lead to positive climatic feedback effects.

Did you know?
Permafrost covers 8.8 million square miles of the Northern Hemisphere



Pakistan faced heavy monsoon rains and severe flooding that displaced and killed many people, in addition driving an uptick in malaria

HEALTH

WHO warns that climate change could spread malaria

WORDS NICOLETTA LANESE

Climate change, and the extreme weather events it brings, could raise global malaria rates, the World Health Organization (WHO) warned on 30 November 2023. “The changing climate poses a substantial risk to progress against malaria, particularly in vulnerable regions,” said WHO director-general Tedros Adhanom Ghebreyesus. “Sustainable and resilient malaria responses are needed now more than ever, coupled with urgent actions to slow the pace of global warming and reduce its effects.”

In its latest World Malaria Report, the WHO estimated that there were 249 million cases of the mosquito-spread disease in 2022, up from about 244 million in 2021 and a similar number in 2020. That was 16 million more cases than seen in 2019, when malaria cases hit a trough just before the COVID-19 pandemic disrupted malaria prevention efforts worldwide. Most of the 5 million additional malaria cases between 2021 and 2022 happened in five countries: Pakistan, Nigeria, Uganda, Ethiopia and Papua New Guinea. Pakistan saw the largest increase at 2.6 million cases, compared to 500,000 in 2021. The uptick was tied to the destructive flooding that plunged much of Pakistan underwater, providing new breeding grounds for mosquitoes.

“With the very heavy monsoons we expected these consequences, but not up to this magnitude,” Dr Muhammad Mukhtar, director of Pakistan’s national malaria control program, said. The standing water left from the monsoons, coupled with displaced people having nowhere to hang mosquito nets, has triggered the uptick in malaria. “The places that are most affected are the places that have the least infrastructure to respond to these sorts of events,” said Ross Boyce, an assistant professor of medicine and epidemiology at the University of North Carolina. “I do think it’s going to become an increasing contributor to the global malaria burden.”

In addition to the direct effects of climate change, such as extreme flooding in places where malaria is endemic, indirect effects may also drive up malaria cases, the WHO noted. For instance, climate-related disasters could reduce people’s access to essential malaria services and cause disruptions in the supply chain of insecticide-treated nets, antimalarial medicines and vaccines.

Despite the recent surge in infection, malaria deaths fell to 608,000 in 2022 from a recent high of 631,000 in 2020, although this rate still outpaces pre-pandemic levels. Prior to the pandemic, in 2019, the death rate had been driven down to 576,000.

SPACE

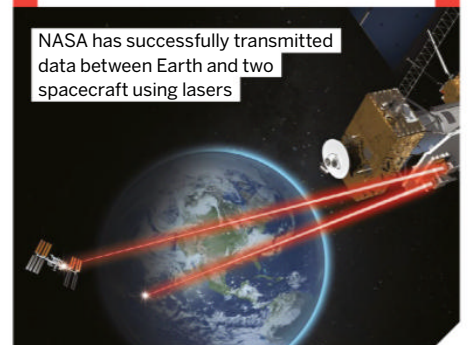
LASERS ARE A GIANT LEAP FOR MOON AND MARS COMMUNICATIONS

WORDS ANDREW JONES

NASA has completed its first laser link with an in-orbit laser relay system, marking a significant advancement in space communication technology. The successful demonstration of two-way laser communications between laser terminals in different orbits could provide faster communications between Earth and the Moon, or even beyond. The Integrated LCRD Low Earth Orbit User Modem and Amplifier Terminal (ILLUMA-T) payload was delivered to the International Space Station (ISS) on 9 November 2023. After installation onto the Japanese Experiment Module, engineers conducted tests to ensure ILLUMA-T’s functionality. ILLUMA-T was then used to communicate with NASA’s Laser Communications Relay Demonstration (LCRD) satellite, launched in 2021 and operating high up in geostationary orbit, 22,236 miles above the equator. This gap allows for a long-distance test of laser communications.

Laser communications, also known as optical communications, use infrared light rather than traditional radio waves to send and receive signals. The much shorter infrared wavelengths of lasers allow much greater amounts of information to be sent with each transmission compared with the longer wavelengths of radio. Challenges include precisely aligning the transmitters and receivers and making the components small, light and power efficient enough for use in space.

NASA has successfully transmitted data between Earth and two spacecraft using lasers



© Getty / NASA; Dave Ryan

Ancient workers used a blend of organic materials such as mosses and lichen to build the Great Wall of China



ARCHAEOLOGY

The Great Wall of China is being held together by 'biocrusts'

WORDS JENNIFER NALEWICKI

Large swaths of the Great Wall of China are held together thanks to 'biocrusts', thin layers of organic materials that have helped protect the architectural marvel from erosion. Scientists made the discovery while analysing segments of the Great Wall of China, which spans more than 13,000 miles and was built over the course of many centuries, beginning in 221 BCE, as a way to protect the country's empires from the outside world. During construction, ancient workers often used rammed earth, which included a mix of organic materials like soil and gravel that are compacted together, to build the massive wall.

While these materials may be more susceptible to erosion than other materials, such as solid stones, they often help promote the growth of biocrusts. This living stucco is made up of microorganisms that are capable of photosynthesis called cyanobacteria, mosses and lichens that help reinforce the construction, especially in arid and semi-arid parts of the country. "Ancient builders knew which materials could make the structure more stable," said Bo Xiao, a professor of soil science at China Agricultural University in Beijing. "To enhance the mechanical strength, the rammed earth of the wall was always constructed with clay, sand and other adhesives like lime by the

original builders," he said. These ingredients provide fertile ground for the organisms that build biocrusts.

To test the strength and integrity of the Great Wall, researchers collected samples at eight different sections built between 1368 and 1644 BC during the Ming Dynasty. They found that 67 per cent of the samples contained 'biocrusts', which Xiao called "ecosystem engineers." Using portable mechanical instruments, both on site and back at the laboratory, they measured the samples' mechanical strength and soil stability and compared that data to wall segments containing only bare rammed earth. They found that the biocrust samples were sometimes three times stronger than the plain rammed earth samples. Samples containing moss were particularly hearty. This is because the cyanobacteria and other life forms within the biocrust secreted substances, such as polymers, that would tightly "bind together" with the rammed earth particles, helping "strengthen their structural stability" by creating what was essentially cement, Xiao said. "These cementitious substances, biological filaments and soil aggregates within the biocrust layer finally form a cohesive network with strong mechanical strength and stability against external erosion."

HISTORY

THE WORLD'S OLDEST KNOWN FORT WAS CONSTRUCTED 8,000 YEARS AGO

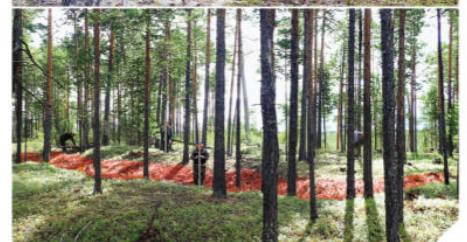
WORDS JENNIFER NALEWICKI

Archaeologists have long associated fortresses with permanent agricultural settlements. However, this cluster of fortified structures reveals that prehistoric groups were constructing protective edifices much earlier than thought. The new research rewrites our understanding of early human societies. Located along the Amnya River in western Siberia, remains of the Amnya fort include roughly 20 pit-house depressions scattered across the site, which is divided into two sections: Amnya I and Amnya II. Radiocarbon dating confirmed that the settlement was first inhabited during the Mesolithic, or Middle Stone Age. When constructed, each pit house would have been protected by earthen walls and wooden palisades, two construction elements that suggest advanced agricultural and defensive capabilities by the ancient inhabitants.

It's unknown what triggered the need for these fortified structures in the first place, but the strategic location overlooking the river would have not only been an ideal lookout point for potential threats, but also allowed hunter-gatherers to keep tabs on their fishing and hunting grounds.



The depression of a pit house (top) and outer defence line (bottom) in the Amnya I site



NASA identifies 17 planets with possible subsurface oceans

WORDS CONOR FEEHLY

As far as we know, life needs water. Astronomers and astrobiologists have naturally focused their efforts on identifying exoplanets that might harbour liquid oceans. Water in its liquid form can exist on a planet's surface, where direct heat from its host star can keep the substance from freezing, but it can also exist beneath a planet's surface, where internal sources of heat can sustain flowing subsurface oceans. In a new analysis, NASA has revealed that 17 discovered exoplanets could house subsurface oceans buried below thick sheets of ice. These worlds, much like the icy moons of Jupiter, could therefore be promising places to search for biosignatures, or chemical signs of life. While the exact composition of these worlds remains unclear, estimates of their surface temperatures from previous studies point at them being significantly colder than Earth. They're also each less dense than Earth, despite being roughly the same size as our planet.

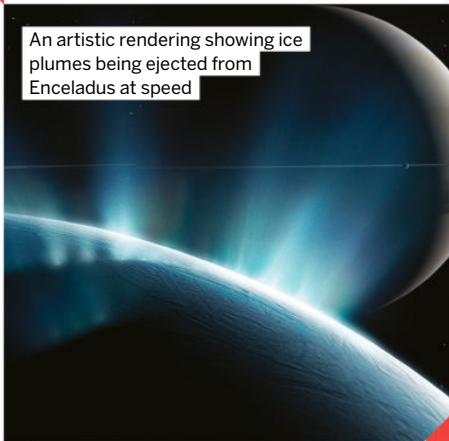
"Our analyses predict that these 17 worlds may have ice-covered surfaces but receive enough internal heating from the decay of radioactive elements and tidal forces from their host stars to maintain internal oceans," said Lynnae Quick of NASA's Goddard Space Flight Center. In other words, while their host stars may not provide conditions warm enough to keep water in liquid form on their surfaces, these planets may exhibit processes that can generate heat below their surface. The stretching and compression of rock inside a planet as it gravitationally interacts with its star, for instance, could provide significant amounts of internal heat – enough to sustain a subsurface ocean. The radioactive decay of heavy elements inside the core of a planet can provide intrinsic heat as well.

"Thanks to the amount of internal heating they experience, all planets in our study could also exhibit cryovolcanic eruptions in the form of geyser-like plumes," Quick said –

cryovolcanism meaning, in short, ice volcanoes. The study drew on what we know from the geyser activity of two of Jupiter's moons, Europa and Enceladus. Two of the exoplanets named in the research, Proxima Centauri b and LHS 1140 b, were particularly promising candidates for having oceans relatively near the surface. "Since our models predict that oceans could be found relatively close to the surfaces of Proxima Centauri b and LHS 1140 b, and their rate of geyser activity could exceed Europa's by hundreds to thousands of times, telescopes are most likely to detect geological activity on these planets," said Quick.

Follow-up observations of these worlds will likely include astronomers capturing the emission spectra of light travelling through these planets' atmospheres. Chemicals and molecules erupted into the atmosphere from cryovolcanic activity may hold clues as to whether life might exist in the cold, dark depths of these worlds.

An artist's illustration of Proxima Centauri b, one of the watery exoplanet candidates



An artistic rendering showing ice plumes being ejected from Enceladus at speed

SPACE

ICE FROM SATURN'S MOON COULD BE STUDIED FOR SIGNS OF LIFE

WORDS RAHUL RAO

When NASA's Cassini turned its instruments to Saturn's moon Enceladus, it observed plumes of ice shooting up from the moon's surface at speeds of about 900 miles per hour. These geysers seemed to be the tendrils of a vast subsurface ocean, making scientists curious if their fluid might carry organic molecules. But if scientists want to study those organic molecules, they'll need to find a careful way of collecting them without destroying them.

If one recent experiment is correct, then any possible amino acids in those geysers' fluids are expected to easily survive contact with a spacecraft. Researchers created ice particles by pushing water through a high-voltage needle; the charge fragmented the water into tiny droplets, each of which crystallised into an ice grain as it entered a vacuum. Then they shot the hardened grains through a spectrometer and imaged each grain, as well as recorded impact times. They found that amino acids within the ice grains could survive impact speeds up to 9,400 miles per hour, more than enough to survive an encounter with a probe. To determine if Enceladus' ice contains fingerprints of life, scientists want to collect ice grains and analyse their composition.

ANIMALS

We finally know how tardigrades reproduce

WORDS ELISE POORE AND TIA GHOSE

For the first time, scientists have figured out how tardigrades, some of the toughest creatures on the planet, mate. These tiny, hardy critters have few obvious differences between males and females, which made it unlikely that they found mates by sight alone. A recent study suggests that females may release a chemical cue that lures the males. The males strongly responded, moving towards the females in water environments. However, females don't seem to have the same compulsion.

Tardigrades, also known as water bears, can tolerate extreme conditions. For example, they can survive a combined exposure to the vacuum of space, cosmic radiation and ultraviolet radiation. Unlike some animals, male and female tardigrades are hard to distinguish. There are size differences, but no obvious secondary traits. As a result, it wasn't clear how most of the 1,300 tardigrade species found mates. One theory is that these microscopic animals release a chemical signal to find a mate. To test that theory, Justine Chartrain, a doctoral researcher at the University of Jyväskylä in Finland, and colleagues performed a series of experiments with the species *Macrobiotus polonicus* to see how individuals would react when exposed to members of the opposite sex.

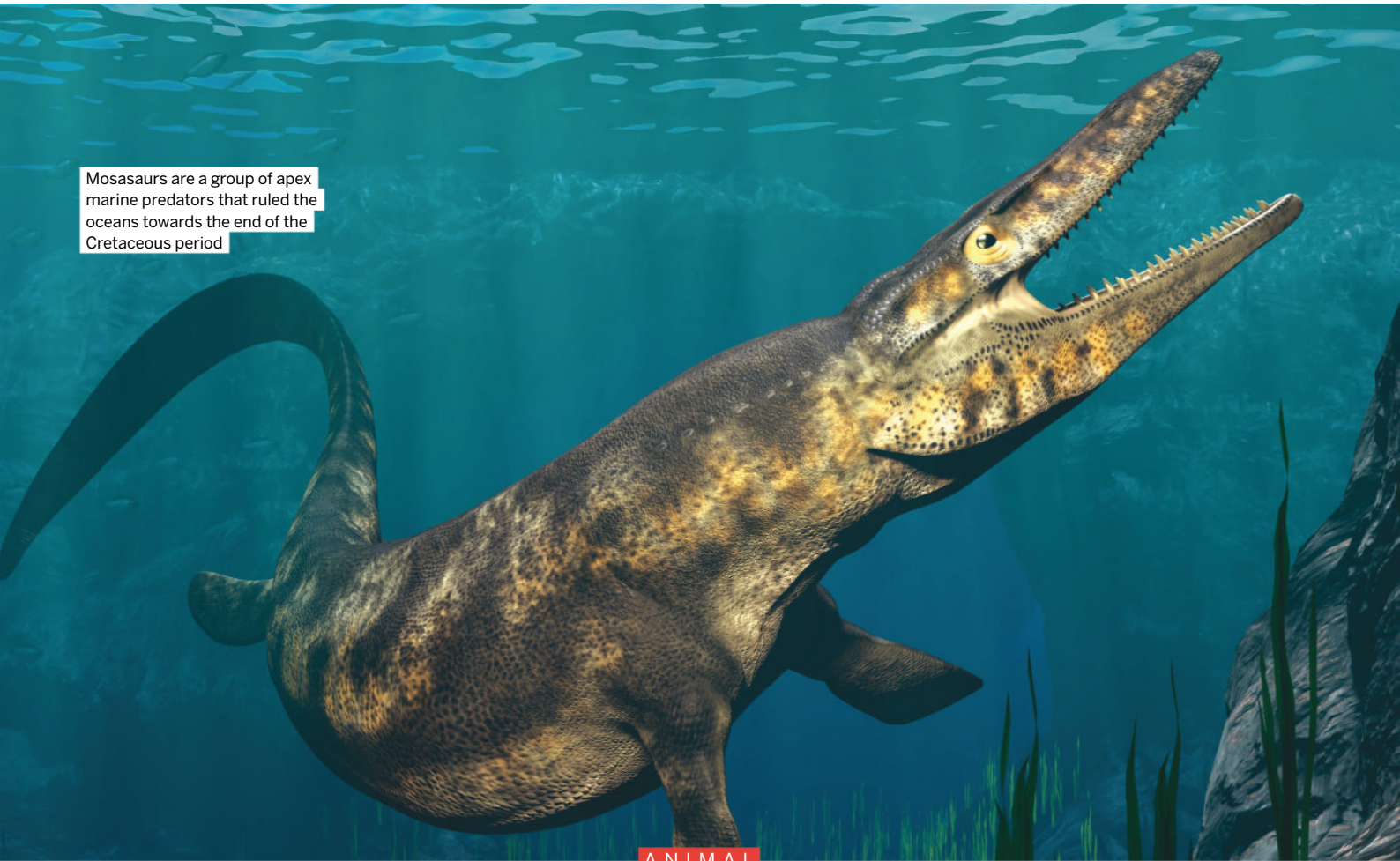
They placed a female tardigrade in one sealed 'arena' and a male in another, with another tardigrade in the middle. Then they recorded the behaviour of the middle water bear. "In the water environment, males were spending more time next to females than next to males," said Chartrain. This suggested that the males could smell the females in their chamber and were lured by it. Based on these results, the researchers wondered whether the tardigrades could follow a chemical trail that worked in a medium other than water, so they tested the chubby creatures in a jelly-like substance called agar. When one water bear was released, it was given a head start to wander across the agar before another tardigrade was released.

"We wanted to know whether tardigrades could deposit chemical cues on the agar and follow this path," Chartrain said. Neither sex followed a path created by other tardigrades, but in the agar "we saw that sometimes males followed females after randomly encountering them," Chartrain said. The females basically ignored the males, while the males often changed course to move alongside the females. The study suggests that the tardigrades can only locate opposite-sex mates in water environments and that only the males actively seek out females for mating.



Researchers have discovered the first evidence that male tardigrades can find females by scent

Mosasaurus are a group of apex marine predators that ruled the oceans towards the end of the Cretaceous period



ANIMAL

72-million-year-old 'blue dragon' unearthed in Japan

WORDS HARRY BAKER

Scientists in Japan have unearthed the near-complete remains of an ancient great white shark-sized sea monster that likely terrorised the ancient oceans it used to inhabit. The prehistoric predator, which the researchers have named 'blue dragon', has an unusual body plan that sets it apart from its extinct relatives and is unlike any living creature. The exceptional fossils, which are around 72 million years old, were discovered along the Aridagawa River in Wakayama Prefecture on Honshu island. They belong to a never-before-seen species of mosasaur, a group of air-breathing aquatic reptiles that were apex marine predators during the Cretaceous period, 145 to 66 million years ago. The "astounding" remains are the most complete mosasaur fossils ever uncovered in Japan and the northwest Pacific.

In a recent study, researchers named the new mosasaur *Megapterygius wakayamaensis*. The new genus *Megapterygius* translates to 'large-winged' after the creature's unusually

large rear flippers, and the species name *wakayamaensis* recognises the prefecture where it was found. The team nicknamed the creature the Wakayama soryu – a soryu is a blue-coloured aquatic dragon from Japanese mythology. Mosasaurs share a similar body plan and there is very little variation among species. But *M. wakayamaensis* is something of an outlier, which has surprised scientists. "I thought I knew them [mosasaurs] quite well by now," said Takuya Konishi, a vertebrate palaeontologist at the University of Cincinnati. "Immediately, [I knew] it was something I had never seen before."

Like other mosasaurs, *M. wakayamaensis* had a dolphin-like torso with four paddle-like flippers, an alligator-shaped snout and a long tail. But it also had a dorsal fin like a shark or dolphin, which is not seen in any other mosasaur species. However, what confused researchers the most was the size of the new mosasaur's rear flippers, which were even longer than their front flippers. Not only is this a first among mosasaurs, but it is also

extremely uncommon among all living and extinct aquatic species.

Almost all swimming animals have their largest flippers towards the front of their bodies, which helps them steer through the water. Having larger flippers at the rear of the body would be like driving a car by steering the rear wheels instead of the front ones, which would make it much harder to turn quickly. "We lack any modern analogue that has this kind of body morphology, from fish to penguins to sea turtles," Konishi said. "None has four large flippers they use in conjunction with a tail fin." The researchers suspect that instead of using the rear flippers to turn, *M. wakayamaensis* angled them upward or downward to quickly dive down or ascend through the water column, which may have helped make them adept hunters. The dorsal fin could have made it easier for the creature to turn, which may have counteracted the extra drag from the rear flippers. "It opens a whole can of worms that challenges our understanding of how mosasaurs swim."

A school of scalloped hammerhead sharks near Malpelo Island in Colombia

ANIMALS

Hammerhead sharks are vanishing from underwater mountains

WORDS PATRICK PESTER

Hammerhead sharks have seemingly disappeared from two underwater mountains in the southwestern Gulf of California, and fishing is likely to blame. Researchers looked at observations from divers over the last 50 years and found that scalloped hammerhead sharks (*Sphyrna lewini*) experienced a 97 per cent decline at the El Bajo seamount and a 100 per cent decline at the Las Ánimas seamount, both off the coast of Mexico, between the 1970s and 2010s.

Scalloped hammerhead sharks are a critically endangered species threatened by fishing, according to the International Union for Conservation of Nature's Red List of Threatened Species. The sharks are targeted for their large fins, which are used in shark fin soup. Researchers don't know how many of these sharks are left globally. "Scalloped hammerhead sharks, and most shark species in general, are vulnerable to extinction as they produce few offspring, have long gestation periods and are slow growing," said Kathryn Ayres, a research scientist at organisation Beneath The Waves. The El Bajo and Las Ánimas seamounts were once hotspots for

large schools of hammerhead sharks; one survey carried out in the late 1970s and 1980s recorded 225 hammerhead sharks at El Bajo, according to the study. Ayres said the sharks use seamounts as a refuge during the day, where strong currents force oxygenated water over their gills so they don't have to use energy swimming around.

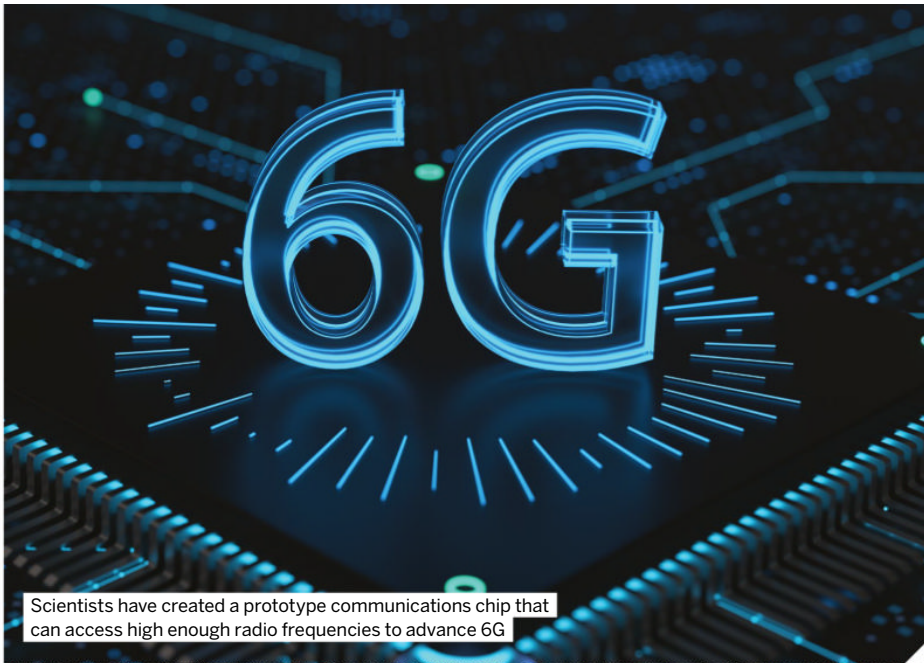
To learn more about hammerhead shark decline at the seamounts, the authors sent a questionnaire to divers between 2017 and 2020. All of the people who participated – 50 for El Bajo and 32 for Las Ánimas – were either diving guides, experienced recreational divers, researchers or photographers. However, their responses were still based on memories from up to 50 years ago. Ayres said she believes human memories are reliable enough for studies like this with such a charismatic species. "When a scuba diver encounters a large school of hundreds of hammerhead sharks, it's not something you forget, and a school of over one hundred compared to a school of less than ten is very noticeable."

The authors acknowledge that relying on people's memories is a limitation of the study, and only some of the participants had observed the seamounts in the 1970s, the team wrote. Divers reported seeing an average of 150 sharks at El Bajo and 100 sharks at Las Ánimas per dive in the 1970s, but only five sharks at El Bajo and zero sharks at Las Ánimas per dive in the 2010s.

According to the study, participants put the decline in shark numbers at the two seamounts down to overfishing, fisheries management, changes to prey abundance, habitat degradation and climate change.

Some of the study participants believed the decline was due to increasing noise from boats and bubbles from scuba divers, but Ayres thinks the decline is primarily down to fishing and called for better protection of the seamounts. "In other areas that are protected from fishing, such as the Revillagigedo Archipelago, also in Mexico, divers encounter very large schools," Ayres said. "Although they might not hang around the divers for a long time, they are still evidently present."

Did you know?
There are ten different species of hammerhead sharks



Scientists have created a prototype communications chip that can access high enough radio frequencies to advance 6G

TECHNOLOGY

Scientists create a chip that will pave the way for 6G

WORDS KEUMARS AFIFI-SABET

A first-of-its-kind chip architecture that uses both electronic and light-based components could pave the way for 6G technology. Recent research offers a blueprint for communications chips needed for advanced radar, satellite systems, advanced wireless networks and even future generations of 6G and 7G mobile technology. By integrating light-based, or photonic, components into a conventional electronic-based circuit board, researchers dramatically increased radio frequency bandwidth while demonstrating improved signal accuracy at high frequencies. They built a working prototype of the networking semiconductor chip, measuring five by five millimetres, by sourcing a silicon wafer and attaching the electronic and photonic components, in the form of 'chipelets', like LEGO bricks. Crucially, they also improved how the chips filtered information.

Wireless transceivers send out data, and microwave filters built into conventional chips block out signals in the wrong frequency range. Microwave photonic filters perform the same function for light-based signals. But it's been extremely challenging to combine photonic and electronic components and effective microwave photonic filters on one chip. But by fine-tuning precisely into specific frequencies at higher bands, which tend to be crowded, more information can flow through the chip more accurately. This is important for future wireless technologies, which will come to rely on higher frequencies. These have shorter wavelengths, and can therefore carry more energy, which equates with a higher bandwidth

for data. "Microwave photonic filters play a crucial role in modern communication and radar applications, offering the flexibility to precisely filter different frequencies, reducing electromagnetic interference and enhancing signal quality," said Ben Eggleton at the University of Sydney.

Devices that tap into 5G networks, like smartphones, transmit and receive data at varying radio frequency ranges, ranging from low band (under one gigahertz) to high band (24 to 53 GHz) in the US. Higher frequencies allow for faster speeds due to the greater energy capacity of the shorter wavelengths, but there's a higher chance of interference and obstruction. This is because shorter wavelengths struggle to pierce through larger surfaces and objects, also reducing signal range. Meanwhile, 5G data speeds average 138 megabits per second in the US, and carriers run the networks on bands ranging from 2.0 to 4.0 GHz. 6G, which is expected to become mainstream by the 2030s, will operate on a higher frequency, starting from 7.0 to 15.0 GHz. The highest 6G bands for industrial applications, however, will need to be above 100 GHz and possibly even reach 1,000 GHz, and speeds could reach a theoretical maximum of 1,000 gigabits per second. This means there's a need to build chips with a significantly higher radio frequency bandwidth and the advanced filtering to eliminate interference at these higher frequencies. This is where advancements in chip architecture come in, with photonics playing a key role in the networking semiconductor chips that will be used to power 6G devices.

SPACE

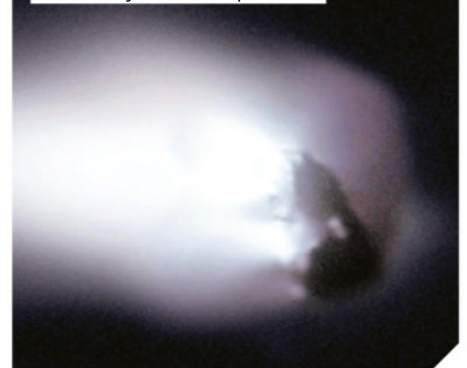
HALLEY'S COMET HAS BEGUN ITS RETURN JOURNEY TO EARTH

WORDS BRANDON SPECKTOR

After zooming away from Earth for nearly 40 years, Halley's Comet has finally turned tail and started heading back our way, setting the stage for a spectacular close up in 2061. On 9 December 2023, the famous comet was predicted to reach its farthest point from the Sun, also known as its aphelion, at a distance of about 35 astronomical units (AU), or about 35 times the distance between Earth and the Sun.

Comets are balls of ice and dust that orbit the Sun. These celestial objects are best known for their 'tails', which form when solar radiation vaporises ice particles in the comet's body, causing gas and dust to stream behind it. Astronomer Edmond Halley observed the comet for the first time in 1682 without knowing exactly what it was, dubbing it a 'hairy star.' Halley compared his observations to similar sightings reported in 1531 and 1607, and he hypothesised that all three sightings were repeat appearances of the same object. He predicted the object would appear again in 1758, and so it did. Halley, who died in 1742, never got to confirm his predictions, although future scholars named the comet in his honour. Halley's Comet makes its next close approach to the Sun on 28 July 2061.

This view of Halley Comet's nucleus was obtained by the Giotto spacecraft



WISH LIST

The latest tech for **PETS**

IFETCH FRENZY

£39 / \$39.99 GOIFETCH.COM

This brain game for dogs will keep your pooch guessing where the next ball is coming from. Simply drop the ball into the top and it will reappear randomly through one of the three holes at the base. The iFetch Frenzy is not a ball launcher and the accompanying iFetch mini balls simply roll through one of the holes. There are no electronics within iFetch Frenzy, as it relies entirely on gravity to move the balls. The three mini balls that come with the Frenzy can be stored in a handy hidden compartment. The iFetch Frenzy might be a great toy for older dogs that don't have the energy to race after far-flung balls, but still enjoy chasing them.



WICKED BALL SE

£39 / \$39.99 CHEERBLE.COM

Ideal for small pets with a lot of energy, the Wicked Ball SE is an interactive toy that's sure to become your pet's new best friend. There are three modes to choose from, which will cause the ball to either bounce on contact or continually roll around at random in a game of chase. The Wicked Ball is made from natural rubber for a gentle feel in your pet's mouth and helps reduce the noise of a bouncing ball in the

house, but is also tough enough to withstand a daily chomping.



PETKIT PURA MAX

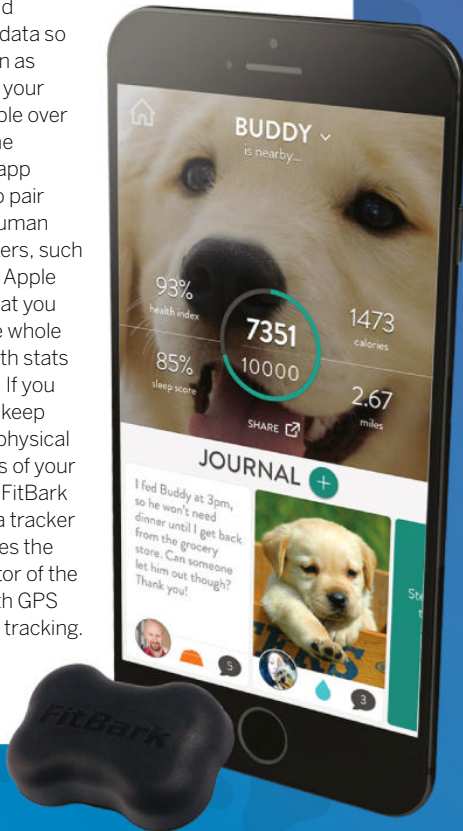
£599 / \$569 PETKIT.COM

The PURA MAX by PETKIT is an automatic self-cleaning litter box that comes with an impressive five cleaning modes and a tracking system to monitor your feline's health. PURA MAX has enough storage to allow up to 15 days without needing to scoop poop for one cat. The 76-litre volume is large enough for most cats and its low entrance means that everything from kittens to senior cats can easily hop inside. Through the companion app, this high-tech litter box not only cleans itself but also measures your cat's weight, toilet duration and frequency so that you can keep tabs on their health.

FITBARK 2

\$69.95 (APPROX. £55) FITBARK.COM

When it comes to monitoring your pet's health, there are few gadgets that can record as much detail as the FitBark 2. From sleep to separation anxiety, the FitBark 2 monitors a myriad of biological and behavioural data so you can learn as much about your pet as possible over 24 hours. The companion app allows you to pair with other human fitness trackers, such as Fitbit and Apple Watch, so that you can have the whole family's health stats in one place. If you also want to keep track of the physical whereabouts of your pooch, then FitBark also makes a tracker that combines the health monitor of the FitBark 2 with GPS and location tracking.



FURBO 360° CAT CAMERA

£209 / \$220 FURBO.COM

It's true cats will play while their owners are away, but with the Furbo you'll be able to see exactly what they're getting up to. This all-singing, all-dancing pet-monitoring system not only comes with a built-in 360-degree camera for traditional home surveillance, but is packed with interactive features such as treat release, a

controllable feather wand toy and two-way audio. The camera also comes with a meow detection system and feline tracking to follow your cat across the room. The Furbo has even been designed with a cat's favourite hobby of knocking objects over in mind and comes with industrial-strength adhesives for stability.

TORUS MAXI

£44.99 / \$49.95 TORUSPETGLOBAL.COM

With up to two litres of storage, the Torus MAXI water bowl can keep your dog hydrated throughout the day while you're on the move. A small valve in the bowl is opened as the dog is drinking for automatic refilling, while a set of strong grips and a water lock help prevent spills from messy drinkers. As well as being insulated to keep the water cool for as long as possible, there's a built-in active carbon filter to purify water for up to a month before it needs replacing. There is also a smaller, one-litre version of the Torus bowl that's perfect for smaller dogs and cats. Bowls are made with antimicrobial-protected walls and from recyclable BPA-free plastic.



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YOUR HOME EXPLAINED

DID YOU KNOW? Indoor air pollution can be two to five times higher than outdoor air pollution

WORDS AILSA HARVEY

From kitchen chemistry and bathroom bugs to the function of fittings and electronic entertainment

It's the place you begin and end each day, decorate to suit your personal taste and return to as the patch of the planet you call your own. From the second you wake up in your body-supporting bed to an evening's relaxation with entertainment on electronic displays, almost every indoor activity is a showcase of modern science. The average home in the UK has over ten internet-enabled devices, and many of these assist with daily chores like perfecting food cooking times, creating comfortable and energy-efficient temperatures and cleaning your home without you having to lift a finger.

The science and engineering of your home begins before you move in. Brick, steel, concrete, glass and other durable or technical materials are expertly crafted to keep you warm, dry and secure. Modern house building follows structural engineering principles to withstand the elements while creating light and well-ventilated living spaces. Today's integrated plumbing and electrical systems mean that buying a house doesn't just grant you a plot of land with a building on it, as had been the case for hundreds of years. Your home is part of a connected grid supplied with energy and clean water.

Cooking a meal in the kitchen relies on chemical reactions and modern technology. The bathroom is a place for you to keep clean, but it's also a sanctuary for many bacteria. Living areas are constantly evolving to provide the maximum comfort that material science can offer, while computing power makes everything so much more convenient. Turn the page to take a tour of a typical modern house and discover how everything in each room works.

Did you know?

A 'passive house' is a highly energy efficient home

KITCHEN BASICS

Explore the culinary chemistry, sophisticated physics and bacterial biology of food preparation

FUTURE TECH TAPLESS WATER

You're probably used to retrieving drinking water from your kitchen tap, but in the future, you could source most of your drinking water from the air in your home instead. One machine that achieves this is called GENNY, which produces water from thin air. The machine collects water vapour from the kitchen, condenses it and recycles it into drinking water. GENNY connects to an electrical power socket and can produce 30 litres of water in one day. To make sure the water is cleansed and safe for consumption, inside the machine is a purification system. This filters water to remove dust particles and treats it to eliminate any microorganisms or chemical contamination.

A solar-powered version of GENNY has been designed for producing drinking water in more remote locations



1 AUTOMATIC TAPS

These taps start releasing water when you place your hands underneath and stop when you remove them. Infrared sensors detect when an object comes close to the end of the spout. These are useful in the kitchen when recipes require you to get your hands messy, or to automatically shut off the tap when not in use to save water.

2 RIPENING FRUIT

Mangoes, plums, peaches, pears and bananas should be stored at room temperature to ripen, but berries and apples stay fresher in the fridge. Apples soften ten times faster at room temperature. Pineapples also ripen well in a bowl. Store them upside down so the sweetness spreads up the entire fruit.

9 MAKING COFFEE

The optimum temperature for coffee preparation is around 75 degrees Celsius, rather than the 100 degrees of boiling water. Boiling the water releases more of the bitter compounds from coffee.

7 THE FIVE-SECOND RULE

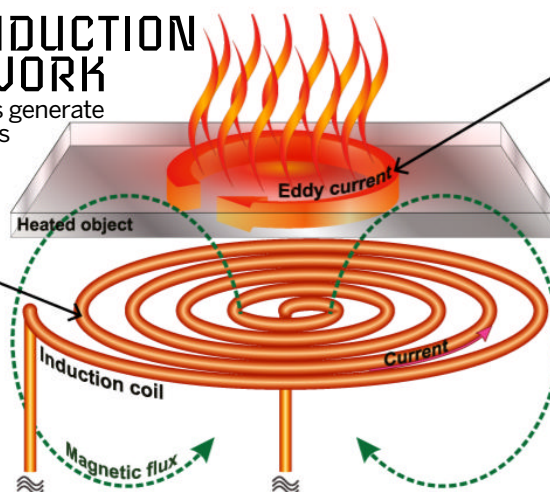
If you eat something that has had contact with the floor for less than five seconds, this doesn't necessarily make it safer to eat. A high moisture level in food increases the transfer rate of microorganisms: some bacteria can attach to food in less than one second.

10

HOW INDUCTION HOBS WORK

These cookers generate magnetic fields to cook food

INDUCTION COIL
As electricity passes through this metal coil, a magnetic field forms around it.



EDDY CURRENT
The pulsing magnetic field creates heat, which is transferred through the conductive cooktop and pan to the food.

MAGNETIC FIELD
The magnetic field forms in pulses as the alternating current keeps the electricity constantly changing direction.



DID YOU KNOW? The microwave was accidentally invented when a scientist's chocolate bar melted as he worked with a magnetron

4 RISING DOUGH

Bread dough contains a live, single-celled fungus called yeast. In the oven, the heat activates the yeast in the dough, which consumes sugars in the flour. The yeast releases carbon dioxide gas, forming air pockets in the bread and causing it to rise.

3 FRIDGE-FRESH FOOD

Bacteria in food grow quickly between 5 and 60 degrees Celsius. Fridges set at a temperature below four degrees Celsius slow bacterial growth. Molecules in food can also react with each other to break chemical bonds, leading to spoilage. Lowering the temperature reduces the energy of these molecules and causes fewer reactions. A common reaction slowed by the fridge is lipid oxidation, when fatty acids and oxygen react to spoil fatty foods.

5 FACTS

EXPLORING THE EXTERIOR

1 INSULATION

House roofs are lined with insulating materials such as cellulose fibre, foam and fibreglass. This is packed between the asphalt, metal and weather-resistant layers, with fibres trapping air and preventing heat loss.

2 CEMENT SCIENCE

Cement keeps a house's bricks firmly held together. Limestone, sand and clay are mixed with water to make cement. After binding the bricks, the water dries off and the cement hardens, strengthening the bond.

3 SMART SURVEILLANCE

Many people opt to use smart security cameras outside their homes. These cameras monitor movement, sending notifications and footage to the homeowner's phone to warn them of intruders.

4 ILLUMINATING PHYSICS

Windows are designed to let in natural light, as visible light is refracted, or bends, into the house. They can also be coated with an extremely thin low-emissivity transparent layer that reflects infrared light away from the window, preventing heat from passing through.

5 SLOW-GROWING LAWNS

Different grass species grow at different rates. Slow-growing grass, like fine fescue, can be chosen for low-maintenance gardens, since it only needs to be cut a few times in a year.

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8 CHOPPING VEGETABLES

Cutting a vegetable's cells releases enzymes and causes chemical reactions and flavour changes. A carrot chopped with a sharp knife tastes different to one cut with a blunt knife, as different compounds are released.

5 MICROWAVE COOKING

Inside a microwave oven, microwaves are reflected off the metal walls and absorbed by food. This electromagnetic wave vibrates water inside the food, generating heat energy that cooks the meal. This change converts microwaves' non-ionising radiation into heat energy to make food edible.

6 HARD AND SOFT WATER

Hard water has high calcium, magnesium and other mineral contents, while soft water usually has higher sodium levels. Hard water causes limescale, a white residue, to form on kettles.

Did you know?

Hard water reacts with soap to make scum

5



THE LAVATORY LABORATORY: HOW YOUR BATHROOM WORKS

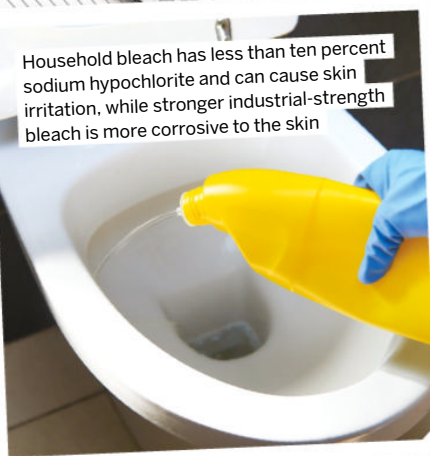
Whether you prefer a shower or bath, this room cleans you up



HOW BLEACH KILL GERMS

When it comes to cleaning the bathroom, some of the strongest disinfectants are chosen for the job, and there's good reason for this: per every 6.5 square centimetres of toilet bowl, there are around 3.2 million microbes. Bleach kills these germs with a powerful chemical reaction between water and the chemical sodium hypochlorite. This chemical oxidises molecules in the bacterial cells that it comes into contact with, killing microbes and preventing the spread of disease from toilets and other bathroom surfaces. The oxidation process involves breaking the chemical bonds within the microbes, which also damages chromophores, or colour-producing molecules, and is why bleach removes the colour from many materials.

Household bleach has less than ten percent sodium hypochlorite and can cause skin irritation, while stronger industrial-strength bleach is more corrosive to the skin

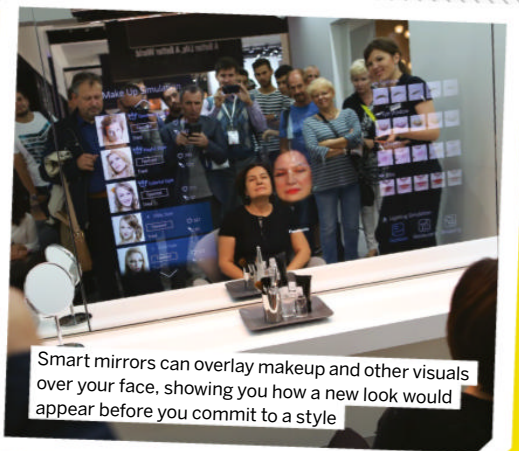


Did you know?
Thin aluminium layers in mirrors reflect 90 per cent of visible light

FUTURE TECH MIRROR, MIRROR

How much time do you spend looking in the mirror in the morning? They assist us in getting ready and show you how you will present yourself when you leave the house. But mirror assistance is getting smarter. Digitalised smart mirrors not only inform you of your appearance, but come with an electronic display behind the glass. Like a smartphone, these mirrors have different widgets that can reveal

weather conditions for the day, the time, date and news updates. More advanced mirrors in the future will be able to recognise your face in the mirror and provide an analysis of your facial features and skin. This includes mapping out your face to locate redness, dark patches, large pores, wrinkles and spots. Based on this information, the mirror will recommend types of products and provide a skincare routine tailored to the data. Instead of being a mere reflection on the wall, smart mirrors could convert your bathroom wall into your morning's personal assistant.



Smart mirrors can overlay makeup and other visuals over your face, showing you how a new look would appear before you commit to a style

DID YOU KNOW? Reducing your shower time by one minute saves around ten litres of water



CONDENSATION CONTROL

When heated, the bonds between individual water molecules can break, allowing some to escape and enter the air as a gas. This is water vapour, and it is what makes the room steamy after a long bath or shower. If water vapour doesn't have an escape route out of the bathroom, it eventually cools down and becomes a liquid once more as it condenses on cold surfaces, producing damp areas across the bathroom. Opening windows helps this steam to escape, while ventilation fans can pull the humid air inside the bathroom through a vent and outside the building. Grout, which is a mix of water, sand and cement, is used to fill and seal the gaps between bathroom tiles, preventing water damage in these small spaces due to condensation.



Grout between bathroom tiles takes between 24 and 72 hours to dry and seal

5 FACTS THINGS THAT LIVE IN YOUR BATHROOM

1 MOULD
Aspergillus is one of the most common bathroom moulds. Most people breathe these spores every day without any symptoms.



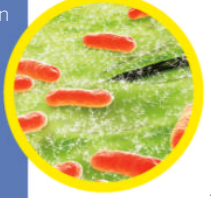
2 STAPHYLOCOCCUS
Staphylococcus aureus is a common bacteria found on bathroom toilets, floors and shower curtains. It can live harmlessly on human skin.



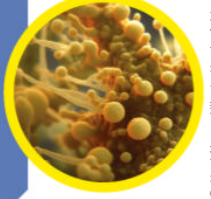
3 STREPTOCOCCUS
 This bacteria is responsible for many throat infections. It is commonly found in the bathroom on surfaces that are touched by people the most.



4 ESCHERICHIA COLI
 Everyone has harmless *E. coli* bacteria in the intestines, but some strains cause illness such as diarrhoea. Changing towels in the bathroom every few days reduces the chance of spread.

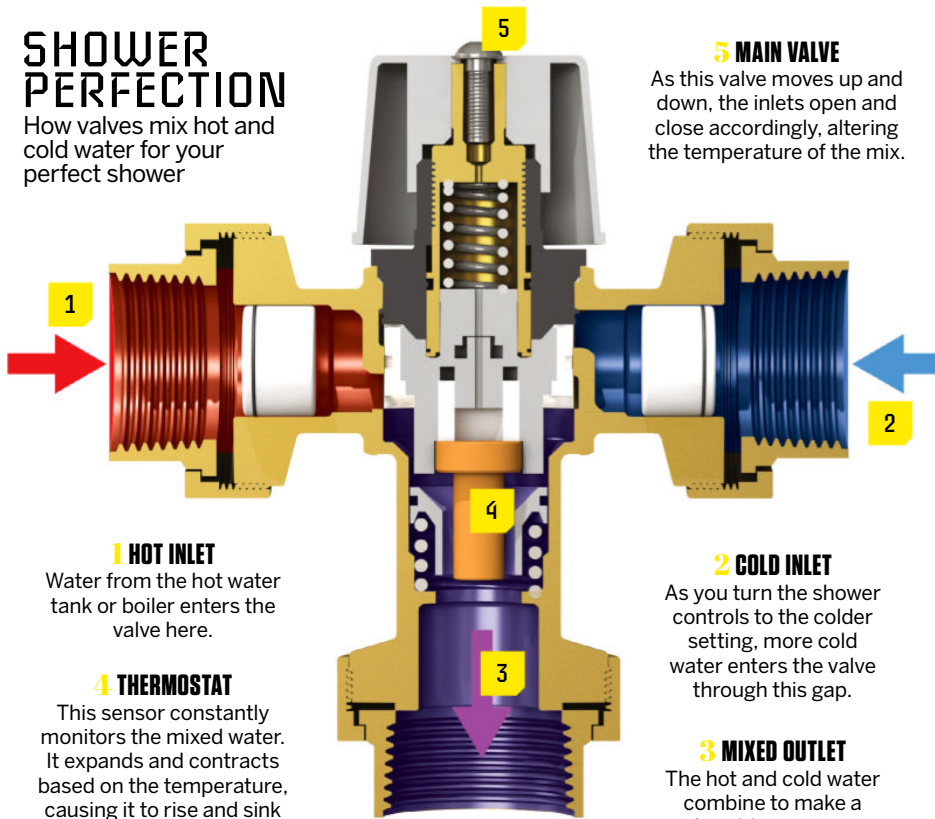


5 CANDIDA
 This is a type of yeast that can access the bathroom through airborne spores. It thrives in warm, damp environments and can lead to fungal infection in the body.



SHOWER PERFECTION

How valves mix hot and cold water for your perfect shower



THE VERY BEST REST

How home comforts are specially designed to make you cosy and restore your energy



FUTURE TECH SMART SLEEPING

Sleep is vital to physical and mental health. Smart beds could be the norm of the future, incorporating a selection of sleep-tracking sensors. While the sleeper dozes off for the night, the bed works night-long to collect biological data. This includes heart rate, body temperature, breath rate and body movement. By tracking all of these at one time, the smart bed can provide a summary of when the person was awake, asleep, restless and in deep rapid eye movement (REM) sleep. Unlike watches that just take readings, smart beds can automatically adjust their settings to the optimal firmness, elevation and temperature to improve the quality of your sleep.



Smart beds connect to your smartphone, where you can control heat and mattress position manually

“The bed works night-long to collect biological data”

TELEVISION TIMELINE

How has this box of visual delights evolved?



1928

EARLY ENTERTAINMENT

The Baird Televisor was the first television commercialised for use in the home. In the machine, a rotating disc with evenly spaced holes rotated in front of an image to scan light variations across the image.



1954

COLOUR VIEWING

The first public colour television broadcasts took place. Three filters of red, green and blue were rotated in a spinning mirror drum and revolving discs were used to swap the screen's colours.



1968

APERTURE GRILLE

The Sony Trinitron used aperture-grille technology to create higher resolution pictures. This was achieved with a vertical grille of wires that could better control electron beams on the display.

WHAT MAKES A GOOD BED?

Uncover the physics of your bed's anatomy layer by layer

1 PILLOW POSITIONING

It might be tempting to pile the pillows high, but the best position for the body when sleeping is when the neck, spine and hips all align.

2 BLANKET

Extra layers over the top of the duvet trap an insulating layer of air that keeps you warmer while sleeping.

3 DUVET

This soft fabric bag is packed with feathers, wool, cotton or synthetic material. Between these small pieces of material, air is trapped for insulation.

4 FITTED SHEET

A sheet neatly covers the mattress. This barrier between you and the mattress keeps the bed soft and clean.

DID YOU KNOW? Home security was used in Egypt in 2000 BCE, with chimes linked mechanically to the front door

Did you know?

The average US home contains more TVs than people



5 MATTRESS PROTECTOR

These polyester layers are water resistant. You can get waterproof versions to better protect mattresses against liquid and spills. Polyester retains comfort while shielding from small spills.

6 MATTRESS TOPPER

This is an extra customisable layer on the mattress. Memory-foam toppers conform to the body's shape for support and gel-infused foam toppers distribute heat away from the top of the mattress to cool the sleeper.

7 MATTRESS

The main bulk of a bed is the mattress. This supports the body comfortably and distributes the sleeper's weight evenly.

8 FOAM LAYERS

The upper layers provide comfort and usually consist of one soft foam layer and one high-density foam layer, like memory foam.

9 POCKET SPRINGS

Individual springs are wrapped in fabric pockets that allow each to move independently and support the body at different levels.

10 ANTI-SLIP

This base layer keeps the mattress layers together, while a non-slip material secures the mattress in place.

AUTONOMOUS LIVING

Not only is modern home technology providing more ways to dispense with household chores and provide home entertainment, but how these devices are controlled is making home life easier too. Smart home hubs are one example of this – devices that digitally connect all of your home's core electronics. Actions for each appliance can be controlled using a smart hub's voice activation or programmed to launch automatically, usually through a smartphone application. Daily routines can be preset for multiple actions using this software, too. For example, you can group actions for your morning routine, rolling blinds open, switching lights on, launching your coffee maker into action and adjusting your thermostat to a specific temperature just by saying a phrase like 'good morning' to the device.

Other automated functions of some modern homes include motion detecting systems with automatic warnings, smart door locks that open when you come within range of the front door and robotic vacuum cleaners and lawn mowers that map the floor and navigate autonomously to get the job done.



Smart home phone applications can control appliances from inside the home or remotely while you're away



2001

FLATSCREEN DESIGN

TVs such as the Sharp Aquos incorporated LCD technology into slim monitors. This technology has trended in homes since the turn of the millennium.



2017

ENHANCED IMAGE

The Samsung QLED Q9F was released with the latest quantum-dot technology. Nanocrystals that emit red, green and blue light combine to make 93 per cent of the colours in nature.



2021

OLED PIXELATION

The latest OLED TVs enable each pixel in the screen to emit its own individual colour. This gives more vibrant colours and deeper blacks, and therefore better contrast in images.

SURVEILLANCE FROM THE STRATOSPHERE

This lightweight solar-electric aircraft is an alternative to high-altitude satellites

WORDS AILSA HARVEY



Aircraft deployed for surveillance and communication missions usually need to be adequately fuelled before takeoff. However, PHASA-35 – a high-altitude pseudo-satellite (HAPS) made by aerospace company BAE Systems – doesn't rely on jet fuel. Instead it's solar powered and charges up its batteries during daylight while in flight, so it can fly non-stop for months at a time. What sets this pseudo-satellite apart from standard satellites and aircraft is the layer of Earth's atmosphere it operates in; PHASA-35 is designed to fly in the stratosphere, around

12.4 miles above Earth's surface, as opposed to the troposphere, where commercial aircraft fly at around six to eight miles. Satellites orbit in the outermost layers of the atmosphere, the thermosphere and exosphere, upwards of around 50 miles.

PHASA-35 is unmanned and remotely operated from the ground. Its movements can be preprogrammed, but rely on careful weather monitoring for launch. Unlike a satellite's, the payload on the HAPS can be replaced at any point, as it can be returned to

Earth in one piece at any time. It weighs just 150 kilograms, which is about the same weight as a standard motorbike. Keeping its weight low during production was essential because the stratosphere isn't an easy location to keep a vehicle aloft. The air density is lower at higher altitudes, reducing the air available to lift the aircraft. Its 'monocoque' structure means that all the components are attached to and supported by the external skin, and the lightweight materials used are a secret carbon-fibre composite.

Did you know?

PHASA stands for Persistent High Altitude Solar Aircraft

DID YOU KNOW? PHASA-35 travels at around 57 miles per hour in the stratosphere

WHAT IS IT USED FOR?

Communication enabler

Pseudo-satellites can remain in a fixed geographic position. This makes them useful for delivering mobile and internet connections, including 5G, in remote areas.

Disaster relief

PHASA-35 is controlled from the ground and can be operated to obtain aerial images of disaster zones. This gives emergency services a clear picture of the scale of events they're working with. PHASA-35's lower altitude enables it to take photos that show more detail than standard satellite's.

Environmental eye

Cameras and sensors carried as payloads on pseudo-satellites can provide aerial images for Earth observation, as well as recording environmental data about temperature, wind speed and water vapour.

Military surveillance

High-altitude pseudo-satellites give the military more control over which areas they monitor, as their positions can be controlled more easily than standard satellites. Radar, infrared and optical payloads can track the movement of enemies.

Border control

Real-time surveillance means that aircraft like PHASA-35 can alert border-control officers about unauthorised border crossings, allowing the authorities to react rapidly.



A solar panel on an orbiting space satellite generates double the power of a solar panel on Earth

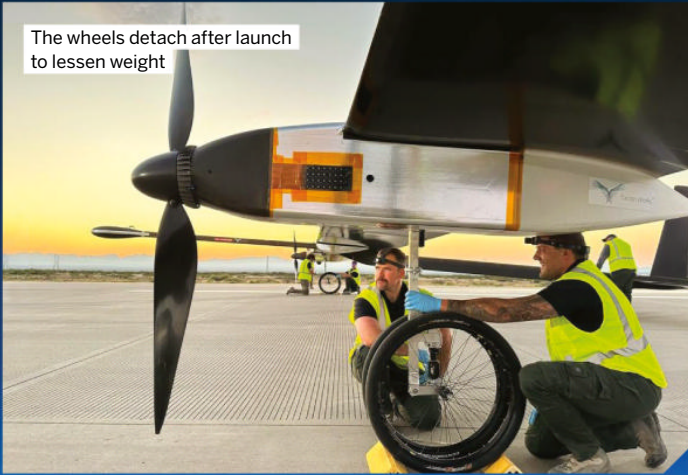
HAPS VERSUS SATELLITE

Like a drone, a HAPS can hover in one position, so each mission that pseudo-satellites like PHASA-35 are launched on can be more location-specific. Most satellites are launched into a projected orbit and generally cover one of three orbital areas: low-Earth orbit, medium-Earth orbit and

geosynchronous orbit. They are dictated by Earth's rotation. Satellites continue to orbit Earth until they are pulled closer to the planet due to gravity. Eventually, they enter the atmosphere and burn up. Operators have more control over HAPS because they can steer the aircraft to return it to the ground,

change its apparatus and send it out on a new mission.

The main difference, however, is the altitude of operation. While HAPS fly at around 12.4 miles above Earth, most satellites orbiting Earth are between 100 and 1,243 miles away.



The wheels detach after launch to lessen weight



Ground crews inspect and maintain the aircraft

PHASA IN FLIGHT

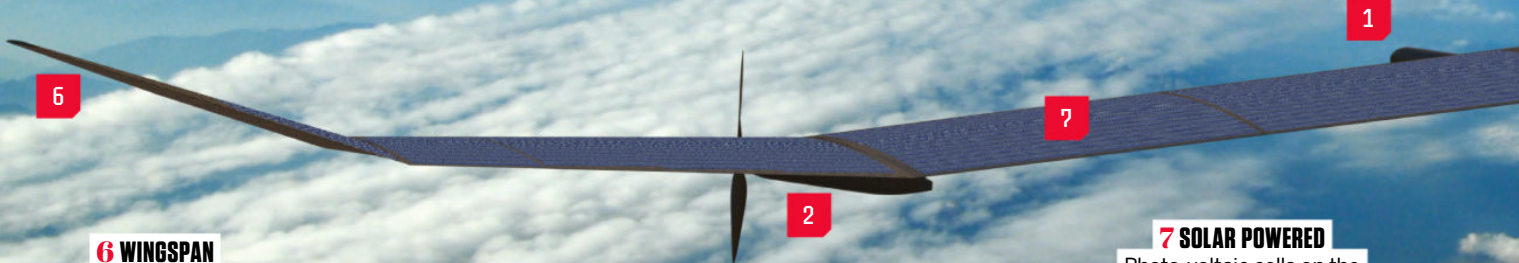
How the anatomy of this ultra-light aircraft keeps it stable in the stratosphere

2 MOTORS

Small solar-powered electric motors are attached to PHASA-35's wings. These keep the propellers turning continuously.

1 PAYLOAD POD

The payload capacity is 15 kilograms. This is stored in a nose-mounted pod.



6

6 WINGSPAN

The aircraft's 35-metre wingspan matches that of an Airbus A320.

2

7

7 SOLAR POWERED

Photo-voltaic cells on the surface absorb solar light energy, convert it to electrical energy and store it to power the aircraft during night.

1

FIRST FLIGHT: HOW THE SOLAR CRAFT FARED

To test PHASA-35's flight ability and how well its energy-storage system worked in practice, the aircraft was launched to the stratosphere on 24 June 2023. The pseudo-satellite took off from Spaceport America, New Mexico, and reached an altitude of over 20,000 metres. The mission included flight in daylight and darkness hours and successfully landed 24 hours later. New software was used for this flight, with a lidar atmospheric scanner to analyse the atmosphere above the flightpath. By following this data, PHASA-35 was steered safely through unstable regions and into the stratosphere.



The first PHASA-35 flight was in 2020, but its first flight to the stratosphere was in 2023

DID YOU KNOW? The aircraft takes off on wheels, which it leaves on the ground, then lands directly on the engine pods



The PHASA-35 takes off from a runway, just like a standard plane

“PHASA-35 is unmanned and remotely operated from the ground”

Did you know?
PHASA-35's payload is ten per cent of its total weight

4 VERTICAL TAILPLANE

This panel prevents uncontrolled side-to-side movement of the aircraft.

5 RUDDER

A rudder at the end of the vertical tailplane can be controlled remotely to move PHASA-35 left and right.

3 HORIZONTAL TAILPLANE

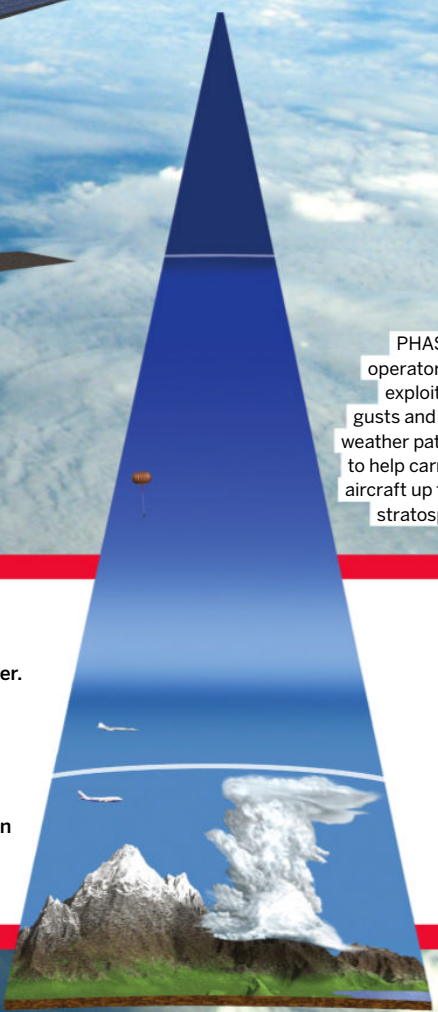
The pseudo-satellite needs this flat stabilising device due to the low air density in the stratosphere. As air flows underneath this panel, it creates lift.



PHASA-35 operators can exploit wind gusts and other weather patterns to help carry the aircraft up to the stratosphere

WEATHER ANALYSIS

Being so lightweight makes the successful launch of PHASA-35 highly dependent on the weather. It's vulnerable to strong winds and other forceful weather conditions that could throw the pseudo-satellite off track. Experts at the UK Meteorological Office worked alongside BAE Systems to deliver aviation meteorology training for those working with PHASA-35. The Met Office doesn't just provide information about the weather in Earth's lower atmosphere – the troposphere – but uses forecast tools to show the boundary between the troposphere and stratosphere. This boundary can vary in height, and it's important for the light craft to remain in the stratosphere during missions. This layer of the atmosphere is more stable than the layers below, making the launch and return to Earth the most complex parts of the mission's flight.



HOW FLAMETHROWERS WORK

These tools that hurl plumes of fire through the air were originally weapons of war

WORDS SCOTT DUTFIELD

Different forms of flamethrowers have existed for thousands of years, but the first handheld flamethrowers emerged during World War I. A creation of the German army, early handheld flamethrowers consisted of backpack-style fuel tanks with gun-like nozzles that, when ignited, released a torrent of flame towards their enemies. Used again in World War II and the Vietnam War as incendiary weapons, it wasn't until 1980 that their use was restricted under Protocol III of the Geneva Convention. Today the main role of flamethrowers lies in land management, such as eradicating invasive plant species, clearing croplands and burning land to recycle nutrients.

For a flamethrower to work, it needs to supply two of the three basic ingredients that cause the reaction that leads to fire: heat and a fuel source. The third ingredient, oxygen, comes straight from the atmosphere. To supply the heat, flamethrowers supply an initial spark when the trigger is pulled and the fuel released. Once the spark ignites the fuel, the heat generated by the fire becomes enough to sustain the reaction. As long as the trigger is held down, gasoline or diesel continues to feed the reaction with atmospheric oxygen.

With all the ingredients needed to create fire, flamethrowers need a way to prevent the flames from travelling back up the device into the tank – with explosive results – when the trigger is pulled. This is achieved by adding a tank of pressurised gas. When the trigger is pulled, the gas forces the fuel through the nozzle, creating a continuous stream of fire in one direction. When the trigger is released, a valve cuts the fuel and oxygen supply off, preventing fire from forming within the flamethrower. This pressurisation also means that flamethrowers can shoot fire over impressive distances. For example, flamethrowers used in World War I could spray fire over 40 metres.



Some countries, such as China, maintain the use of flamethrowers in their armies



An illustration of Greek fire from a Byzantine manuscript

GREEK FIRE

Flamethrowers aren't a modern invention. In the Byzantine Empire of the late 7th century, a new form of warfare was introduced by an ancient architect named Callinicus of Heliopolis. The incendiary weapon, known as Greek fire, consisted of a liquid fuel that was heated and then pressurised before being ignited and sprayed through a syphon, typically onto the hulls of invading

ships. The exact concoction of chemicals used to create the blaze is unknown, but it's been suggested that petroleum and sulphur may have been key ingredients.

As a weapon, Greek fire was a formidable foe, as water could not stop the liquid fire from burning. At the time, one of the only known ways to extinguish the fire was by covering it with sand or vinegar.

Did you know?

Orange flames burn up to 1,200 degrees Celsius



DID YOU KNOW? In 2018, Elon Musk's Boring Company sold over 20,000 flamethrowers



INSIDE A FLAMETHROWER

These ingredients and components allow the user to spout fire with the pull of a trigger

FIGHTING FIRE WITH FIRE

One of the last things you'd expect to see near wildfire is a firefighter holding a flamethrower. Nevertheless, they can be one of the best tools for stopping fire from spreading. Every year, tens of thousands of wildfires sweep through forests and grasslands around the world, destroying habitats and homes. To stop the spread, firefighters use flamethrowers to create what's known as a 'backfire'. This deliberate and controlled fire consumes some of the vegetation in a belt ahead of a spreading wildfire. By the time the wildfire reaches the belt of burnt ground or forest, there is no more fuel to feed the fire, and so the wildlife can't progress any further.



A wildfire raging through a forest in Colorado, destroying wildlife

1 FUEL TANKS

These two cylinders are filled with flammable oil-based fuel.

2 COMPRESSED GAS TANK

Compressed flammable gas, such as butane, is fed through a pressure regulator to pressurise the fuel tanks.

3 TWO TUBES

One tube delivers the fuel directly to the gun and out of the nozzle, while the other supplies pressurised gas to the ignition system.

6 SPARK PLUG

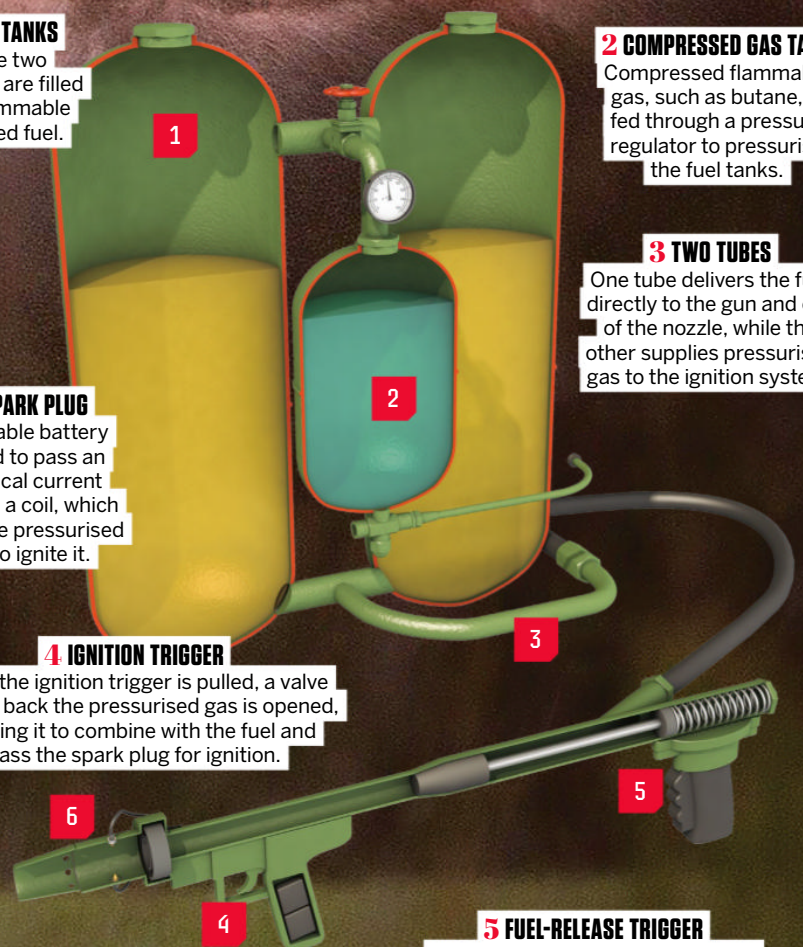
A portable battery is used to pass an electrical current through a coil, which heats the pressurised gas to ignite it.

4 IGNITION TRIGGER

When the ignition trigger is pulled, a valve holding back the pressurised gas is opened, allowing it to combine with the fuel and pass the spark plug for ignition.

5 FUEL-RELEASE TRIGGER

A spring-loaded valve is connected by a rod to the trigger. When the trigger is pulled, the valve opens and the fuel is released.



ANIMAL ATTRACTION

The weird and wonderful techniques some species use to charm potential partners

WORDS SCOTT DUTFIELD

What makes a potential partner attractive? For humans, the art of seduction can be a complex combination of biology and psychology, but for animals, luring future mates is often a lot more straightforward. The world's animals have evolved, in part, based on a principle called sexual selection, which was outlined by the father of evolution, Charles Darwin. He described how animals compete for the attention of the opposite sex through several means, including their appearance, songs and displays of affection.

Those with traits that best suit the needs of a potential partner are selected to mate with, and subsequently those traits are passed down to the next generation. These attributes typically indicate an animal's ability to survive, such as the strength to dominate other males, find food or grow beautiful feathers, which means their offspring will likely share their abilities. For the majority of the animal kingdom, the female members of wild society are the 'choosers' when it comes to finding a mate. But there are, of course, some exceptions to the rule. For example, among spotted hyenas (*Crocuta crocuta*), it's the comparatively larger females that compete for the attention of smaller males.

Did you know?
Some mantises eat their partner's head after mating

To help females choose who their next mate will be, males employ a myriad of behavioural strategies to showcase the physical characteristics that make them most appealing. Whether it's the vibrancy of their plumage or the size of their body, the appearance of a male plays an important role in seducing a female partner. One way this occurs is through what's known as ornamentation. Physical traits, such as horns and tusks or elongated tail feathers, are used as a visual cue as to

who's the best potential partner. Females then compare males and choose the better mate. Generally, scientists have found that the bigger and more elaborate the ornament – such as a rhinoceros beetle's (*Oryctes nasicornis*) horn – the more successful that male is in finding a compatible female to mate with. Some animals have even evolved to conceal physical traits, saving the viewing just for those who know what to look for. For example, some species of chameleons and jumping spiders catch the eye of females with



DID YOU KNOW? A male peacock's tail doesn't reach its peak size until around six years old





Two male greater sage-grouse performing for several females

body parts and patterns on their bodies that reflect ultraviolet light, signalling to the female that they're ready to mate.

But when you can't rely on looks to get the girl, some species use their voice in the hope of making themselves seem more attractive. From tiny cricket orchestras to the underwater booms of whales, the natural world is filled with the sounds of males calling out for a mate. Male humpback whales are particularly adept at crafting whale ballads to attract females. The call of a male whale looking for a date can reach up to 158 decibels and can travel a minimum of 20 miles away.

Calls for a mate aren't always vocal; they can also be chemical, using pheromones. These chemical compounds can signal the presence of a potential mate nearby and carry with them information about their gender and age. A

group of nematode roundworms in the genus *Caenorhabditis* exclusively use pheromones to find and select their mate, while other animals, such as lemurs and elephants, use them alongside calls to find a mate.

While some rely on the powers of physical attraction and song to find a mate, others put on alluring displays of affection, like the strange and robotic moves of peacock spiders or the entangled samba dance of seahorses. These animals have concocted strange and elaborate choreography to charm and attract. It's an exercise in advertising to a female how healthy the male is, which females will recognise, and these talents then pass to the next generation.

Birds are some of the best dancers in the animal kingdom. Males of some bird species, such as the greater sage-grouse (*Centrocercus urophasianus*), even gather together to form

PEACOCK SPOTS

The male peacock (*Pavo cristatus*) is well known for his vivid plumage and elaborate feather train that he uses to entice a mate. When he encounters a female, the feather train rises and fans, revealing a series of feathers that end in a piercing eyespot. If the female likes what she sees, then the pair will mate. However, researchers have discovered that a slight variation in the number of eyespots in their tails can affect reproduction success. In total, male peacocks have around 158 eyespots on their tails, but removing as many as 20 feather tips from the tail was enough to ruin a peacock's chances of finding a female that was willing to mate with him.



Males with eyespot numbers in the 120s and 130s are less likely to find a mate

HUMPBACK HARMONIES

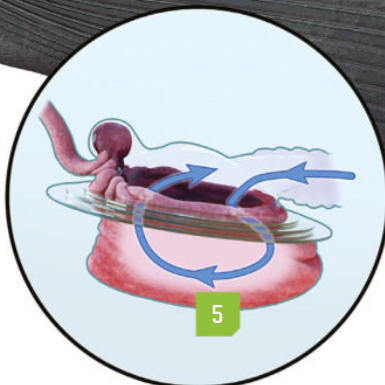
How these ocean singers produce enough noise to beckon a mate

2 NASOPHARYNX

Air is supplied to the laryngeal sac from the lungs and out through the blowhole along this nasal passage.

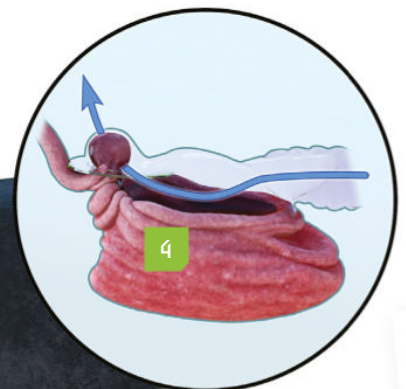
5 OPEN

When the vocal folds are open, air enters the sac, causing it to vibrate and generate low-frequency sound waves.



3 VOCAL FOLDS

These U-shaped pairs of vocal folds guard the opening to the laryngeal sac.



4 CLOSED

When the vocal folds are closed, air flows past the laryngeal sac, through the vocal tract about out from the blowhole.

1 LARYNGEAL SAC

Baleen whales produce their mating calls from this organ surrounded by muscles, which contract to control the sound's volume.

DID YOU KNOW?

White bellbirds sing the loudest birdsong at 125.4 decibels – louder than a chainsaw

WALKING ON WATER

A Clark's grebe mating ritual is a strange and sophisticated process

Did you know?

Clark's grebe mates work together to build floating nests



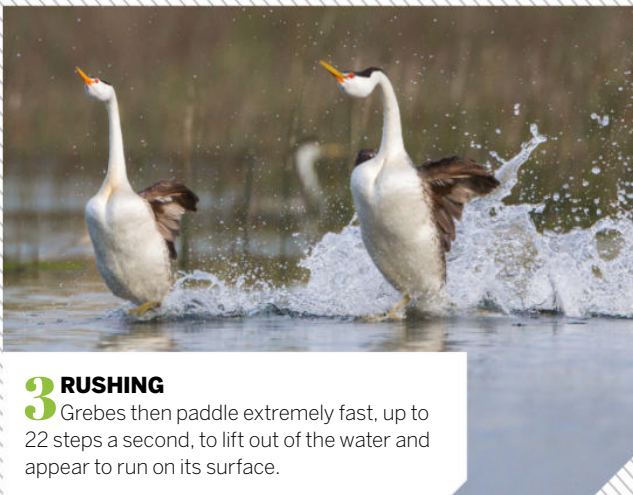
1 ADVERTISEMENT

The courtship dance starts with the uncoupled male and a female spontaneously swimming at speed around a body of water.



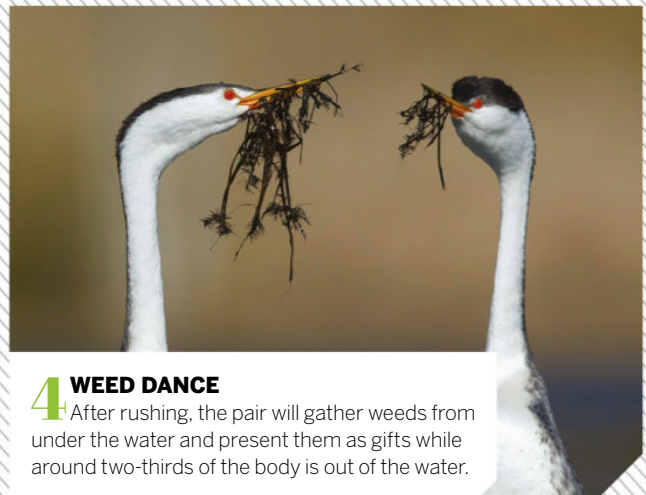
2 RATCHET POINTING

When a pair seems interested in each other, they begin to point their beaks at each other, called ratchet pointing, and splash them in the water, known as dip-shaking.



3 RUSHING

Grebes then paddle extremely fast, up to 22 steps a second, to lift out of the water and appear to run on its surface.



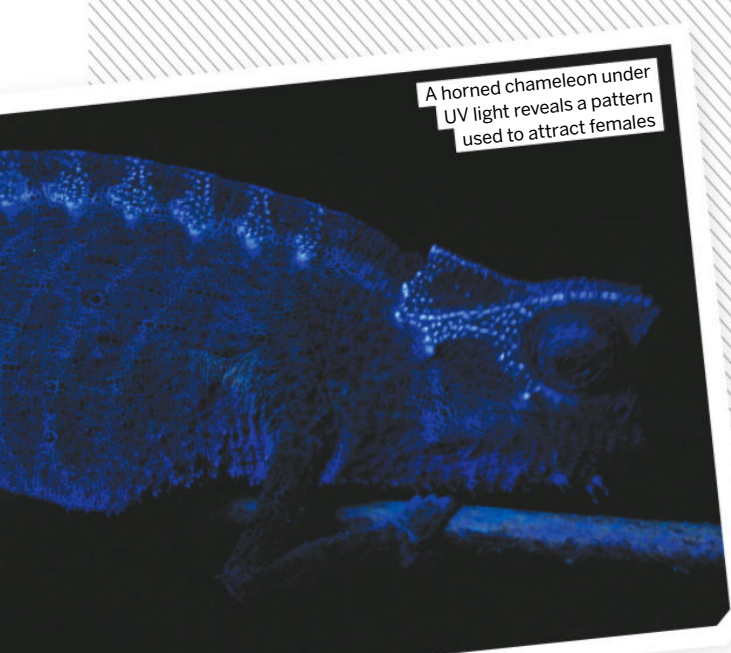
4 WEED DANCE

After rushing, the pair will gather weeds from under the water and present them as gifts while around two-thirds of the body is out of the water.



5 BOB-PREENING

A successful pairing will culminate in both birds mirroring the other's head movements, called bob-preening.



A horned chameleon under UV light reveals a pattern used to attract females

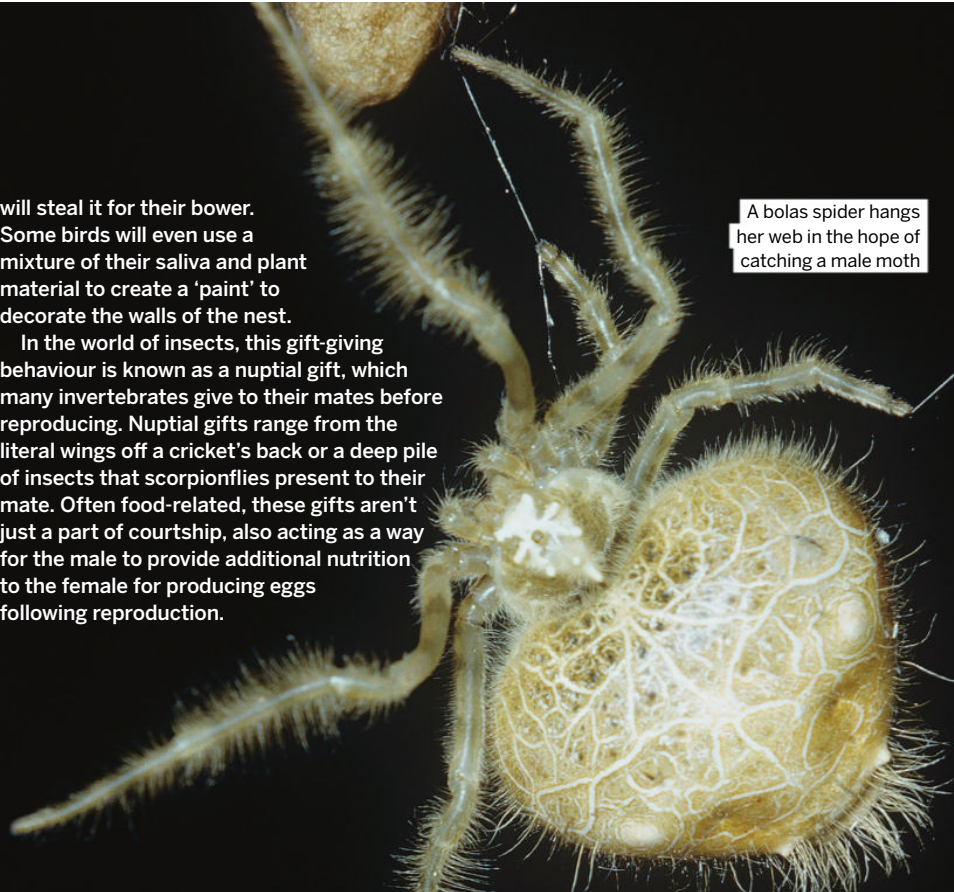
dance troops, called leks, where they put on a group performance to attract females and pair at least one of their number off. One of the most extraordinary bird mating dances is performed by both male and female North American Clark's grebes (*Aechmophorus clarkii*). The pair undergo a series of ballet-like head movements, using their legs to lift their bodies out of the water and 'run' along its surface in what's known as the rush ceremony.

Along with the myriad of dances and displays that animals perform to win over a female, some animals, such as bowerbirds, provide gifts to prove they are worthy of mating. Across Australia and New Guinea, male satin bowerbirds (*Ptilonorhynchus violaceus*) build elaborate ground nests, called bowers, for females to inspect and decide if he's done a good enough job to mate with. In an effort to seal the deal, male bowerbirds will decorate their nests with gifts, often bright-blue objects found within the natural and human world. Berries, keychains, bottle caps and more – when these birds come across anything blue, they

will steal it for their bower. Some birds will even use a mixture of their saliva and plant material to create a 'paint' to decorate the walls of the nest.

In the world of insects, this gift-giving behaviour is known as a nuptial gift, which many invertebrates give to their mates before reproducing. Nuptial gifts range from the literal wings off a cricket's back or a deep pile of insects that scorpionflies present to their mate. Often food-related, these gifts aren't just a part of courtship, also acting as a way for the male to provide additional nutrition to the female for producing eggs following reproduction.

A bolas spider hangs her web in the hope of catching a male moth



HOW HIPPOS FLIRT

Between May and June in Sub-Saharan Africa, the male hippopotamus (*Hippopotamus amphibius*) prepares to find a mate. With no flashy feathers or mighty antlers to draw the attention of female hippos, the male signals his desire to partner up by defecating and urinating at the same time. While releasing his unusual gifts of affection, he rapidly moves his tail, flinging it in the direction of the female that's caught his eye. Along with some vocalisations, the muck-slinging may win over the female, who will enter the water to mate. Hippos aren't alone in their poop appeal. Many animals, such as male wombats, similarly display their cube-shaped faeces to attract a female.

Male hippos show off their bowel movements to grab the attention of female hippos



DATING DECEPTION

Finding a partner in the wild is hard enough without the likes of bolas spiders (*Mastophora casesariata*) getting in your way. Moth-capturing experts, female bolas spiders have evolved a way to trap their prey by making them think a female moth is nearby. At night, bolas spiders produce a long string of silk with a bulbous tip that they use to swing in the direction of a passing moth and catch it midair. To entice male moths, such as the bristly cutworm moth (*Lacinipolia renigera*), female bolas will release the same cocktail of chemical pheromones into the air as a female moth. When a moth gets a whiff of the pheromones, they come flying in their direction, only to meet their sticky end.



DID YOU KNOW? Some snail species shoot 'love darts' to deliver a mucus that prepares their partner for reproduction

5 FACTS WILD GIFT- GIVERS

Did you know?

Female ring-tailed lemurs only mate for one to two days a year

1 SPONGES

In the waters around Australia, the male humpback dolphin (*Sousa teuszii*) gathers several sponges from the seafloor and offers them to a female as a gift to showcase his fitness.



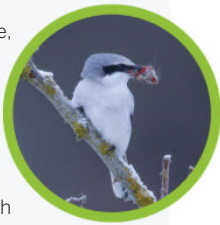
2 PEBBLES

On the frozen Antarctic tundra, small male gentoo penguins (*Pygoscelis papua*) present females with a pebble as a 'proposal' to build a nest together. If she accepts, the pair will begin to build a full nest together.



3 MICE

As a culinary gesture, the male great grey shrike (*Lanius excubitor*) offers up a mouse kebab as a gift to his future mate. Often known as the butcher bird, the male shrike impales prey, such as mice and insects, to showcase his ability to hunt and provide food.



4 SILK-WRAPPED INSECTS

For some insects, like dagger flies (*Empididae*), nuptial gifts are made of bundled-up collections of dead invertebrates in silk they spin from specialised cells on their forelegs.



5 FRUIT

Bonobo (*Pan paniscus*), one of our ape cousins, give each other apples and bananas as gifts, not just as a way of courting each other but also to encourage new social connections with strangers outside of their troop.



LEMUR ALLURE

How these primates use scent to flirt and find a mate

1 MALE RING-TAILED LEMURS

At around 20 months old, male ring-tailed lemurs reach sexual maturity and are ready to find a mate.



2 GLANDS

On the lemur's wrists and shoulders are scent glands that secrete smelly fluids.

3 RUBBING TAILS

The male lemurs rub their glands through their tails to trap potent pheromones within their hairs.



4 WAVING

While on the lookout for females, the male lemur wags his tail in the air.



5 PHEROMONES

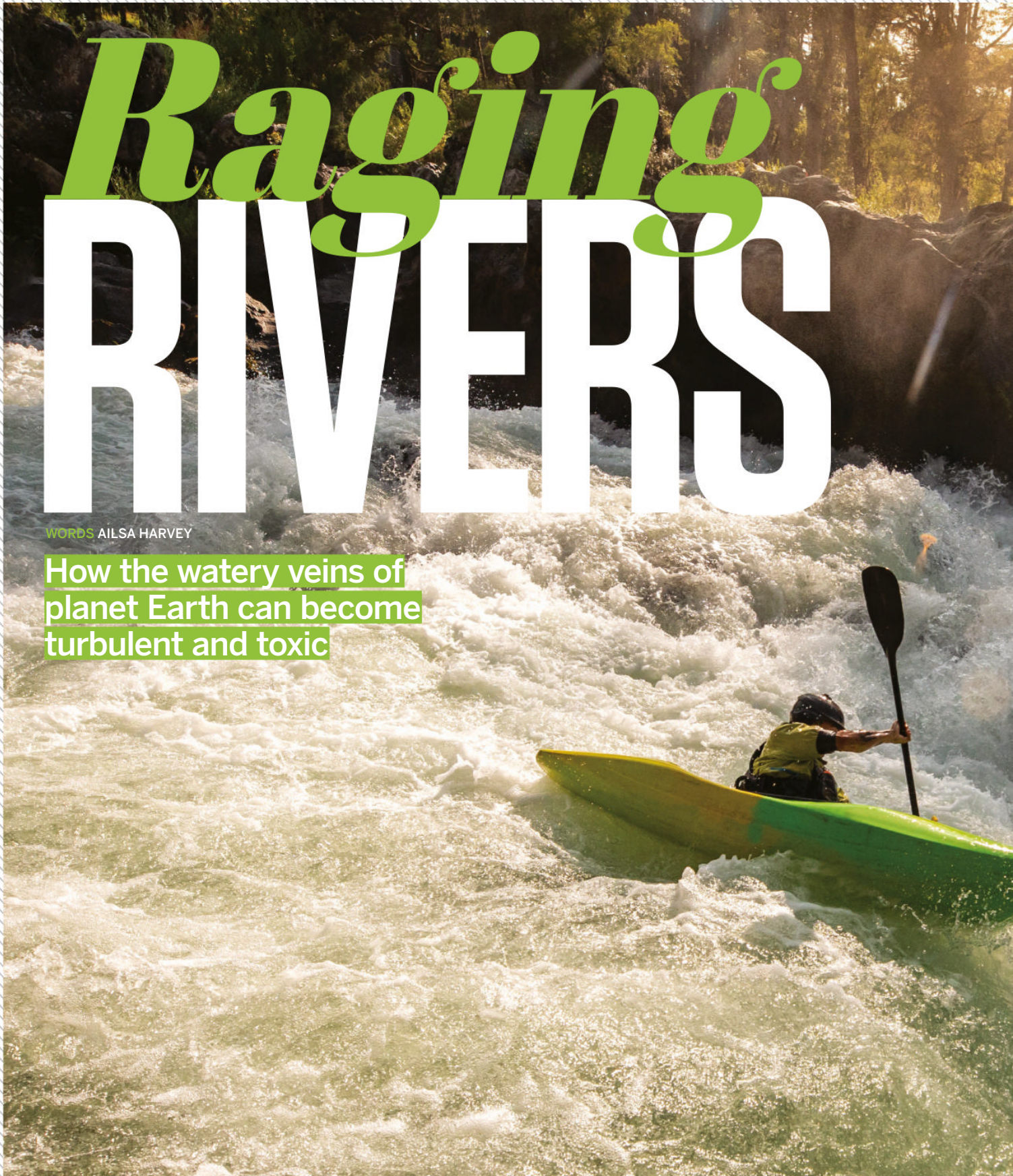
Three potent sex pheromones are released from the tail to attract the attention of a female.



Raging RIVERS

WORDS AILSA HARVEY

How the watery veins of planet Earth can become turbulent and toxic



DID YOU KNOW? In 1981, a total of 300 people were eaten by animals after their boats capsized in the Amazon

It can be a challenge to determine the safety of a river, as not all hazards are visible. When fast-flowing water passes over land, daylight reflects off its surface and the obstacles beneath are concealed. These include rocks, pipework and concrete structures. When falling down rapids in a kayak or jumping into what looks like a deep, open river, these unexpected dangers can cause injury. Some of these obstacles don't cause blunt injury, but can trap a person in the water. The culprit is often in the form of long plants growing underwater from the sides of the banks. If a person gets tangled when submerged, they're at a high risk of drowning in the river.

Also, water pollution levels aren't always obvious. Animal waste can cause

gastrointestinal illnesses if the water is ingested, as well as waterborne diseases that include serious illnesses like cholera, typhoid and polio. Any pesticides, heavy metals or other chemicals from urban and agricultural runoff can also cause sickness and damage the skin. Changes in the nutrient levels in rivers, due to pollution, can cause harmful algae to bloom, like cyanobacteria. This algae releases deadly toxins that can kill animals in the water and the surrounding landscape, while also causing skin rashes and illness in humans.

Cholera bacteria (*Vibrio cholerae*) are found in brackish river water



Did you know?

3,500 people die from drowning in the US each year

CAN TECHNOLOGY HELP?

Small sensors can be used in rivers to keep track of the environmental conditions. These relay information about water levels, flow rate and temperature to keep environmental agencies and the general public updated. Data can be transmitted wirelessly to servers from ultrasonic sensors. These sensors send water level data that shows patterns in rising water in real time, allowing flood warnings to be made in advance.

This automatic river level sensor is installed in western France





WORLD'S DEADLIEST

There are many reasons to be wary of these well-known waterways

CONGO RIVER, AFRICA

With a depth up to 220 metres, this river in Africa is the deepest in the world. It has a navigable waterway of 9,000 miles and is useful for the transportation of goods like sugar, coffee, copper and cotton. However, the course of this river is full of rapids and waterfalls that cause many accidents. After overloading boats or travelling at night, many people have gone missing in the dark depths of the Congo River.



NILE RIVER, AFRICA

Passing through 11 different countries, the Nile is the world's longest river. Some dangerous regions it passes through are teeming with predators, such as black mambas, hippopotamuses and crocodiles, that kill 200 people annually. However, the deadliest animals that live off this river are mosquitoes. These insects infect 500 million people with diseases every year and cause hundreds of thousands of deaths.



MISSISSIPPI RIVER, US

The Mississippi River is also home to dangerous animals like the bull shark. However, a more underestimated deadly feature of this river is the change of current. Swimmers often get into difficulty in the Mississippi due to the unpredictable undercurrents that sweep people up from the lower depths, making it difficult to navigate to safety.



AMAZON RIVER, SOUTH AMERICA

As one of the most famous rivers in the world and the largest river by water volume, the Amazon River attracts many tourists and passes through many communities. It winds through dense forested areas with high biodiversity and there are a range of unique and dangerous creatures to be wary of. These include electric eels, piranhas, bull sharks and anacondas.



RIVER WHARFE, ENGLAND

The River Wharfe flows through Yorkshire in England, where the wildlife is the least of a visitor's worries. But many people who have fallen into this river's waters have been swallowed up by the river itself due to hidden undercut tunnels on the riverbed. Some of its narrow sections are deceptive – the river flows underneath the rocks at the bank, where swimmers can be sucked down and trapped underwater.



Many rivers meet their end at the sea

COURSE HAZARDS

From mountainous origins to a widening mouth, how terrain can create dangerous forces in a river

6 FLOODPLAINS

As meandering rivers erode the banks at the sides of the water, the surrounding land is easily flooded.

5 BENDS

The speed of river flow varies in meandering rivers. The insides of bends have slower movement, but the outside bend can be fast-flowing.

7 OXBOW LAKE

This stagnant body of water can accumulate pollution, such as agricultural runoff and heavy metals.



11 RIVER MOUTH

When the river's flow meets an outgoing tide, the mouth of the river can be the site of significant currents, pulling anything emerging from the river out to sea.

DID YOU KNOW? 40 per cent of rivers in England and Wales are polluted with sewage

Did you know?

300 to 400 million tonnes of industrial waste enters our waters annually



4 UNDERCUT ROCKS

When the water's flow erodes the base of rocks, a hidden hollow space can form underneath banks.

8 RAPID SNOWMELT

During periods of melting, snowy upper regions can deposit great volumes of water into the river at once.

9 COLD WATER

High mountain rivers can have cold water temperatures that bring the body into shock.

8

9

10

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10 UNSTABLE TERRAIN

In mountainous terrain, riverbeds are often rocky, with uneven and unstable slopes. These are unpredictable and dangerous underwater obstacles.

1 WATERFALLS

When a river travels over steep drops, the change in elevation causes water to fall with powerful force. Waterfalls create turbulent water at the base.

3 CONFLUENCES

Where two water flows meet, the different currents can combine to produce turbulent and whirling rivers.

2 RAPIDS

Steep gradients in terrain can cause fast-flowing white, frothy water. The bubbles in foaming 'white water' reduce its density and a person's buoyancy.



The Okavango River has many meanders

5 FACTS RIVER SAFETY TIPS

1 CHECK WATER DEPTH

Even if you are familiar with a particular point in a river, check the water depth before entering. Water levels are always changing and many people become injured jumping into unknown depths.

2 NEVER BOAT ALONE

If you are kayaking down a river, go with someone else. If you get into difficulty, there will be someone nearby to assist and call emergency services.

3 FIND EASY ACCESS ROUTES

It's safest to enter a river on an even bank that declines gently to the water's surface. This makes the entry process easier and reduces the chance of slipping into the water.

4 WEAR LIFE JACKETS

Your buoyancy changes based on the river's flow speed and other conditions. Wearing a life jacket will bring you to the surface quickly if you fall from a boat.

5 STAY ON HIGH GROUND

When near a river during heavy rainfall or a storm, try to stay on high ground as much as possible. Flooding can occur in a short time period and trap or wash away people at lower levels.



DEADLY

From prehistoric parasites to ancient airborne infections, discover the illnesses that plagued these giant creatures

DINOSAUR

WORDS JACK PARSONS

DISEASES

DID YOU KNOW? You can explore hundreds of CT scans of dinosaur bones from the University of Texas at digimorph.org

We all know the *Tyrannosaurus rex* terrorised *Triceratops* on land. Many of us can picture Pterosaurs diving down from the skies to snatch smaller prey. A few might even know the *Mosasaurus*, the leviathan that ruled the ancient oceans. But while these mighty carnivores loom large in how we imagine the age of dinosaurs, there was a far greater threat that we forget – an invisible foe that would strike without warning and killed millions more creatures in the Mesozoic era than any other: illness.

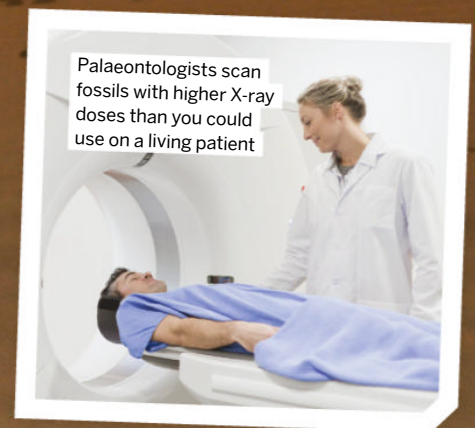
It's no surprise that dinosaurs got sick. They were living, breathing creatures just like us. But we know very little about what actual diseases made these ancient creatures ill. This is because you can identify signs of injuries like broken limbs and battle scars in the fossil record – often with little more than a magnifying glass – but diagnosing illness

is far more difficult. It's not just that bacteria and viruses are microscopic. Diseases mostly attack internal organs, which are made of fleshy soft tissue and usually rot too quickly to be preserved.

On rare occasions, some dinosaur flesh remains. The remnants of a ravenous raptor's guts were discovered in China in 2022 and the brain tissue of an *Iguanodon*-like herbivore in the UK in 2016. These were likely preserved only because the dinosaurs' bodies were submerged in bog-like water. But more often than not, paleopathologists – researchers of ancient diseases – have to make do by assessing fossilised bones for rare signs of severe illness.

However, modern technology is helping these researchers delve deeper for clues. 20 years after it was invented for use in medical diagnosis, computed tomography scans, or CT scans as they're better known, are being

used to see inside fossils. This process uses X-rays, but the results are much more detailed than the X-ray you might get at the hospital if you broke your leg. They are high-resolution 3D reconstructions that you can zoom in and out of to fully explore the structures. This can reveal lesions and

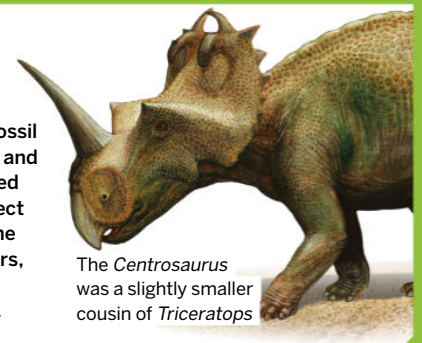


DINOSAURS BATTLED CANCER TOO

New research suggests dinosaurs could suffer from cancer. The evidence was dug up in 1989, but it just wasn't recognised until recently. A *Centrosaurus apertus* was uncovered in Alberta, Canada, with a misshapen shin bone. Experts at the time thought it was a poorly healed injury. But another team of scientists – bringing together pathologists, a surgeon and a radiologist as well as palaeontologists – reexamined the fossil in 2020 using high-resolution X-ray CT scans. They

diagnosed the deformity as osteosarcoma, an aggressive bone cancer also found in humans.

This isn't the only example of cancer in the fossil record. Tumours have also been found in *T. rex* and duck-billed *Bonapartesaurus*. But both appeared to be benign, meaning they didn't seriously affect the dinosaur's day-to-day life. Instead, this is the first example of a malignant tumour in dinosaurs, meaning that the cancer could have spread to different parts of the body and become deadly.



deformities buried in bones that are telltale signs of infections but would be unidentifiable from the outside.

As palaeontologists expand the techniques they use to analyse fossils, they're also drafting different kinds of experts to help them. Doctors and radiologists have helped by comparing CT scans of fossils with human medical records to look for similarities, while veterinary scientists have shared their knowledge of how diseases manifest in other reptiles like crocodiles, as well as birds, which evolved directly from dinosaurs. This new approach is overturning previous research. Fossils that were thought to be twisted bones or bite marks proved to be far more interesting. By diagnosing these primordial illnesses, we learn more about the dinosaurs they afflicted. We better understand their biology as we discover illnesses they share with modern-day animals. The types of diseases and how they may have spread also hint at how dinosaurs behaved with members of the same species, as well as the relationship between predators and prey.

DUCKBILL BONE DISEASE

Some 70 million years ago, a Hadrosaur lived alongside a shallow sea covering what is now New Jersey. It had a real pain in the arm, which two centuries after it was unearthed we know was due to septic arthritis – the first known case in a dinosaur. This is a common bone disease that often develops when an injury becomes infected. A CT scan revealed signs of erosion within two arm bones, with a porous texture instead of healthy, dense bone tissue. On the outside, both bones had bulges, and spurs of new bone had formed. In fact, when excavated the pioneering 19th-century palaeontologist reported that the two bones were fused, but the brittle fossil had broken apart.



The Hadrosaur was a rare find on the US' East Coast, which has few fossils



While Dolly's exact species is unknown, they were related to *Diplodocus* and *Brontosaurus*

A VERY SAURO-THROAT

Imagine how bad a tickly throat must feel if your neck is 25 metres long. There wouldn't be enough chamomile tea in the world to soothe it! A sauropod nicknamed Dolly had a serious case of the sniffles. This included a cough, trouble breathing and a fever, according to scientists. The infection

was so severe that it marked the creature's neck vertebrae, which we can still see in the fossil today. While Dolly is the first confirmed case of a dinosaur with an airborne illness, possible signs of tuberculous were found on the rib of a *Titanosaur*, another sauropod, in 2021.

ANCIENT AUTOPSY: DOLLY THE DINOSAUR

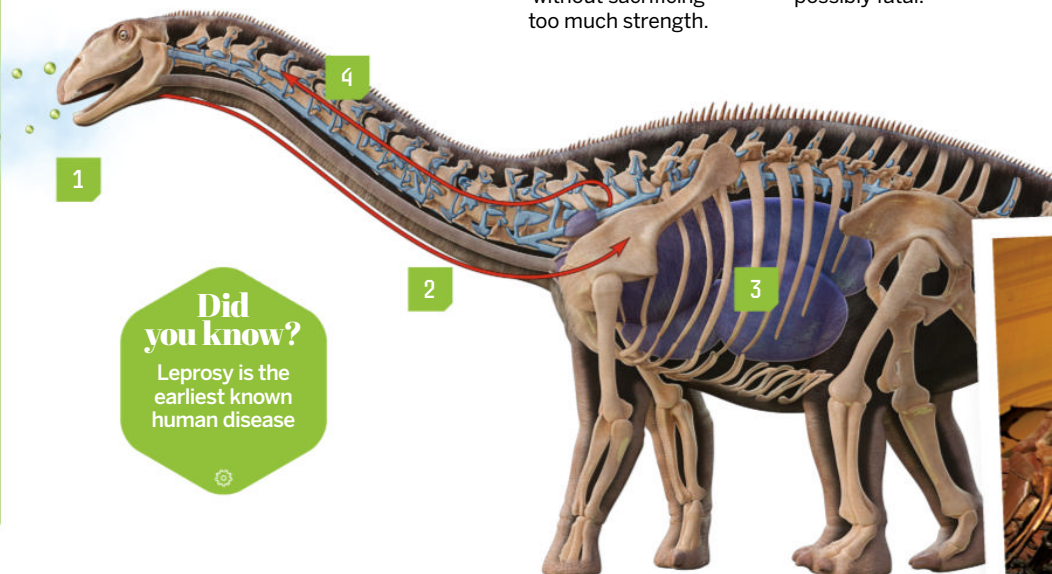
This respiratory infection would've been a real pain in the neck – and the air sac

1 LAST BREATH
Dolly inhaled an airborne disease, possibly spores from a fungus that would have thrived in the humidity of primaeval Montana.

2 DOWN WE GO
The disease was carried on Dolly's breath down their long windpipe and into the lungs, but it didn't stop there.

3 BREATHING SPACE
Like birds today, air circulated through hollow bones and inflatable organs called air sacs. These helped make Dolly's colossal frame lighter without sacrificing too much strength.

4 NO SIGNS OF RECOVERY
The disease lodged in an air sac within Dolly's thorax. Unfortunately, the infection was likely chronic and possibly fatal.



Did you know?

Leprosy is the earliest known human disease

T. REX'S TERMINAL TOOTHACHE

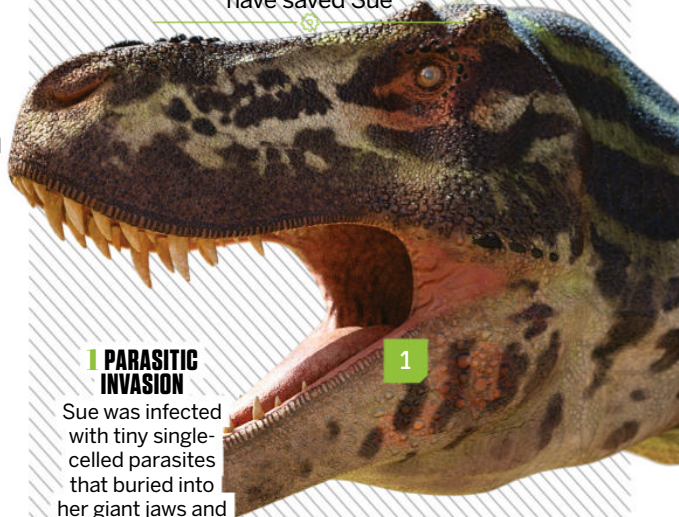
The *T. rex* was the king of the Late Cretaceous period. It boasted a mouthful of banana-sized teeth and a biting force of 3,500 kilograms – that's like the impact of three small cars. But these champion chompers were also the apex predator's weak spot. "Some of the world's most famous *T. rex* specimens have these holes in their jaws," says Dr Steve Salisbury from the University of Queensland. "Some specimens look like Swiss cheese." Working with a small team, Salisbury examined over 60 *T. rex* fossils. This included Sue, one of the best preserved skeletons, which is on display at Chicago's Field Museum.

"We now believe that these holes are caused by an infectious disease called trichomonosis," Salisbury says. This is an illness caused by microscopic parasites. Many pigeons carry it today but are immune. But hawks and falcons that eat pigeons can get very sick, developing lesions in their lower beaks. It's possible that *T. rex* caught the infection from their prey too. But the fierce theropods were also known to fight among themselves. "We don't think it's a coincidence that a significant number of adult tyrannosaur specimens show both face-biting marks and evidence of a trichomoniasis-like disease," Salisbury says. "Fighting, and specifically head-biting, would have been an ideal mechanism for spreading the disease among tyrannosaurs." However it was caught, the infection would have meant a slow, painful death. It would have made it harder and harder for the creature to eat until it starved.

A close examination suggests Sue was 28 years old when she died – very old for a *T. rex*

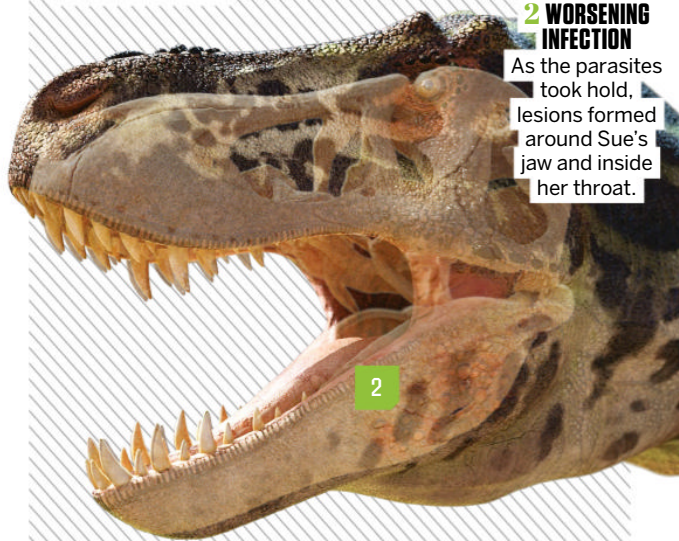
ANCIENT AUTOPSY: SUE THE *T. REX*

No trip to the dentist would have saved Sue



1 PARASITIC INVASION

Sue was infected with tiny single-celled parasites that buried into her giant jaws and fed on the tissue.



2 WORSENING INFECTION

As the parasites took hold, lesions formed around Sue's jaw and inside her throat.



3 LASTING DAMAGE

The parasites cut through the skin and ate into the jawbone, making deep holes we can see in fossils today.

5

FACTS

DIFFERENT DINO DEATHS

1 GETTING EATEN

It was a dino-eat-dino world. We know of at least 100 meat-eating dinosaurs, ranging from the crow-sized *Microraptor* to the enormous *Spinosaurus*, which at 14 metres long was three times the size of an African elephant.

2 GETTING BITTEN

You might consider yourself lucky to escape a hungry carnivore. But even a scratch could be deadly if it became infected with germs. A towering sauropod in China was discovered with signs of a pus-marked injury caused by either tooth or claw.

3 BREAKING BONES

Broken bones litter the fossil record. While many show signs of healing, meaning the creatures survived, others show signs of becoming terminally infected. But not all of these injuries were from combat. Evidence suggests theropods like the *T. rex* were prone to falling over.

4 NATURAL DISASTER

Geology suggests that volcanic eruptions were commonplace 65 to 70 million years ago, which would have been explosive and devastating. While a herd of thousands of *Centrosaurus* were struck down in a flood 77 million years ago, possibly caused by a tropical storm.

5 ASTEROID ANNIHILATION

It only took one asteroid strike 66 million years ago to wipe out the dinosaurs. The impact caused catastrophic wildfires, earthquakes, tsunamis and a dust cloud that blocked sunlight for a year.



TINY LIVING RAINMAKERS

Scientists have tracked down the culprits behind some of our rain, and they could become a force for good

WORDS IAN EVENDEN

How clouds form is one of the natural processes we thought we'd cracked. It seems so simple. First, water vapour sticks to tiny particles such as salt and dust, known as aerosols, high up in the atmosphere. Then bigger droplets form, and when these stick together, clouds are produced. The trouble is, recent research is showing that tiny organisms floating in the atmosphere – bacteria, to be exact – can act as what meteorologists refer to as 'cloud condensation nuclei'. These are the particles around which water droplets and ice crystals, another component of clouds, form. These bacteria can therefore have a profound effect on our weather.

Did you know?

British chemist Luke Howard classified clouds in 1802

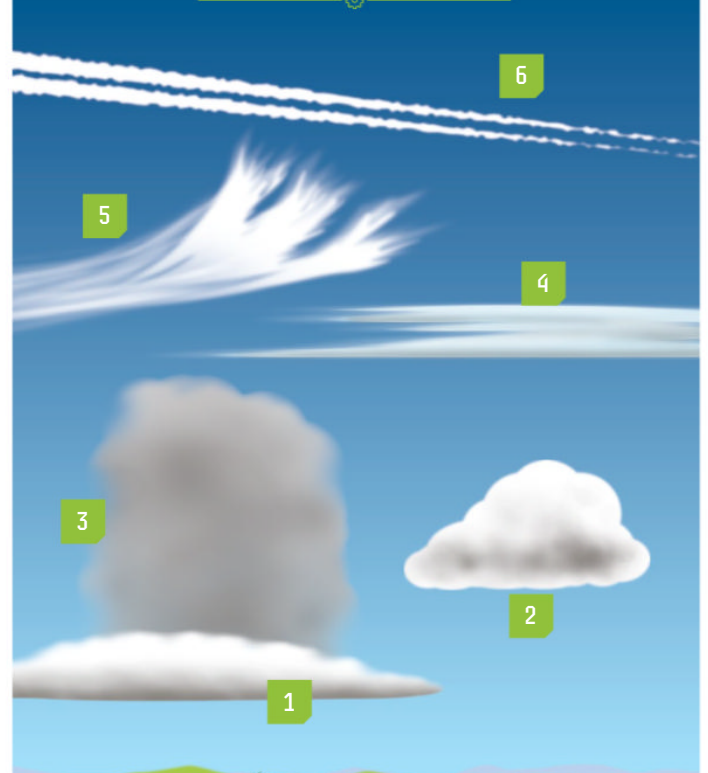


DID YOU KNOW? Clouds on Jupiter are made of ammonia gas, rather than water and ice

“Recent research is showing that tiny organisms in the atmosphere can act as cloud condensation nuclei”

A SPOTTER'S GUIDE TO CLOUDS

Learn your stratus from your nimbostratus



1 STRATUS

From the Latin for 'flattened', stratus are common, low-level grey clouds that can even appear at ground level as mist or fog. They're uniform in colour and are what you see when the weather's drizzly.

2 CUMULUS

Latin for 'heap', cumulus are the classic white, fluffy clouds that usually occur in fair weather. Due to their white colouration, cumulus clouds can cool the ground below them by reflecting solar radiation away.

3 NIMBOSTRATUS

'Nimbus' is Latin for 'rain'. Nimbostratus clouds can cover most of the sky and block out the Sun. As the name suggests, they can bring rain.

4 ALTOSTRATUS

These are thin, grey or bluish clouds that the Sun can shine through. These are mid-level clouds – 'altum' is Latin for 'height' – and can cover areas up to thousands of square miles.

5 CIRRUS

Wispy and almost hair-like, cirrus are largely made up of ice crystals and can take on the colours of a sunset for a spectacular display. Their name comes from the Latin for a tuft of hair.

6 CONTRAILS

Condensation from aircraft engines produces lines across the sky that resemble cirrus clouds. They slowly expand after the plane has passed and eventually vanish.



The clearest picture of just how many bacteria live up in the atmosphere came from hurricane research carried out by NASA in 2010. Meteorologists from the agency's Goddard Space Flight Center in Maryland flew an unmanned drone, a jet airliner and a converted Cold War-era bomber above the Atlantic Ocean during hurricane season in an attempt to learn how these devastating storms form. Analysis of the air collected from the upper troposphere – the troposphere being the part of the atmosphere from the ground up to around 11 miles – revealed that bacteria comprise 20 per cent of the particles between 0.25 and 1.0 microns in diameter.

When microbiologists at the Georgia Institute of Technology in Atlanta sequenced the genes of these airborne bacteria, the results revealed 17 different species. Some of these bacteria are 'ice nucleators' and promote the formation of ice crystals at higher temperatures than they form around other particles. This means more clouds form and there's more rain. When they are on the ground, some of the bacteria that occupy our skies are plant pathogens, which cause disease, and their ice-forming abilities



Altocumulus clouds can appear as rounded masses

Did you know?

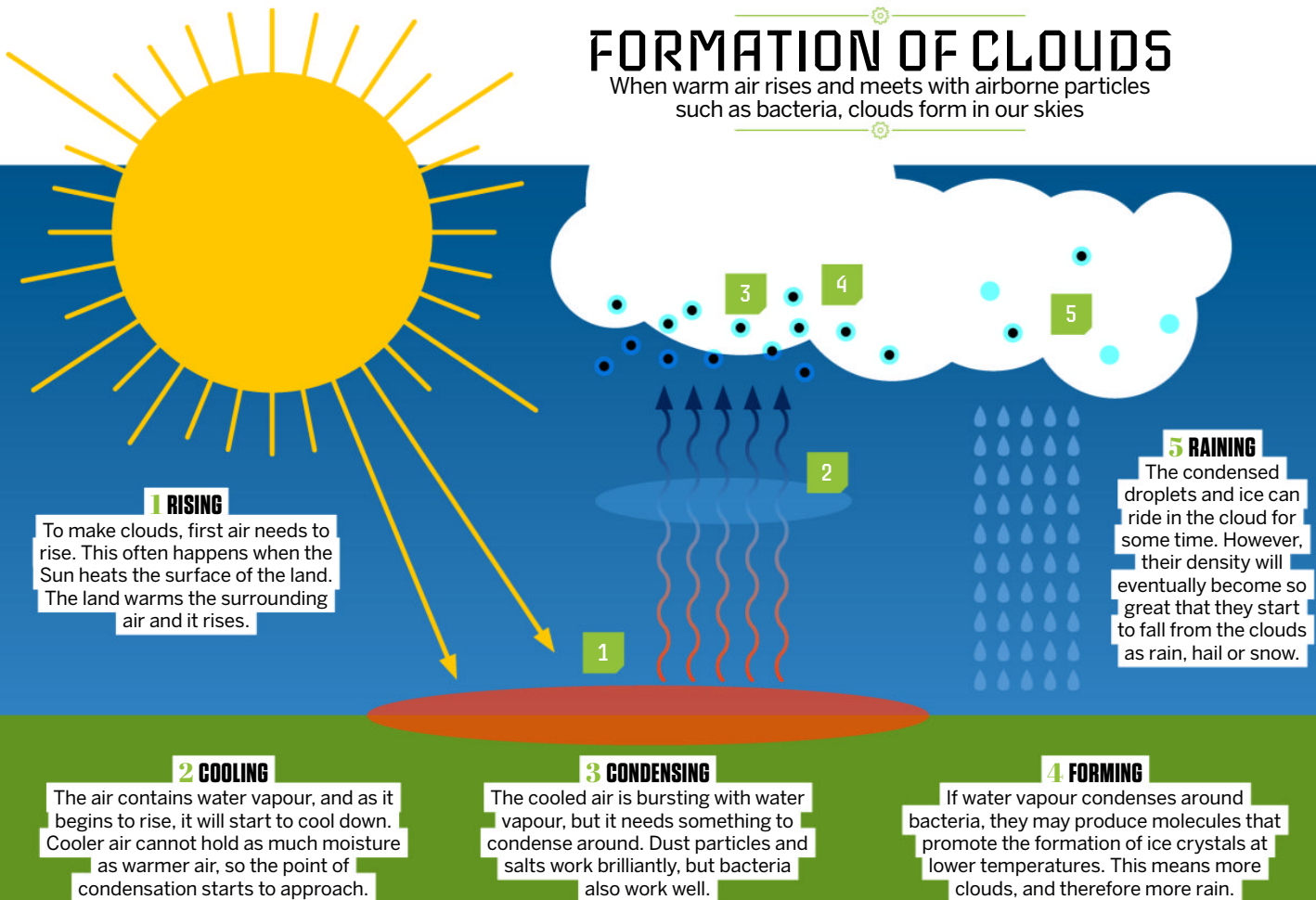
The biggest hailstone weighed 880 grams

cause frost damage to plants in colder climates. With the plant damaged, the bacteria can get hold of the nutrients they need, which allows them to multiply. "These bacteria fall off plants like dandruff. They have very little weight and get swept up by the winds," says Dr David Sands, professor of plant pathology at Montana State University, who coined the term 'bioprecipitation'. "They go off in little flying carpets, maybe 100 or 1,000 cells at a time."

Once they're in the atmosphere, the bacteria need to get down again so they can get nutrients from other plants. "The surface of the bacteria has a springy protein that's many repeats of the same amino acids," says Sands. "This structural protein binds ice, and then the fun starts. The ice bounces – it's called riming – and one nucleation event by a bacterium can cause a large number of ice crystals, as ice is the best nucleator of more ice. The bacteria are

FORMATION OF CLOUDS

When warm air rises and meets with airborne particles such as bacteria, clouds form in our skies



DID YOU KNOW? Lenticular clouds usually occur near big mountain ranges, but are occasionally seen elsewhere

just the initiators.” These new ice crystals can cause rain, and the bacteria get a ride down back down to the ground. “If you can ice-nucleate, that gives you a way to get around,” says Sands. “Out of 100 bacteria that live on a plant in a region, you’ll find that 10 or 15 of them don’t cause any trouble to the plant, and maybe half are ice nucleators.”

These rain-making bacteria may have been affecting our weather for many millennia. “If you drill down into a glacier, you can look back at history for thousands of years with ice cores,” says Sands. This research could answer some interesting questions, such as whether cycles of higher rainfall have coincided with periods when there are many more bacteria present in the atmosphere.

The idea that these bacteria can cause the formation of rain and snow is now widely accepted. Certain ski resorts use a freeze-dried preparation of ice-nucleating bacteria to make it snow. And it doesn’t end there. The bioprecipitation research has started to spark a number of intriguing ideas, such as whether planting the correct strains of crops could encourage the growth of harmless plant bacteria known to lead to cloud formation, therefore increasing rainfall.

Farmers would need encouragement to help the growth of the bacteria, but what if the microbes were harmless and produced a fungicide that would protect the plant as well? According to Sands, this could make the bacteria worthwhile to the farmer, as well as governments. Plant protection and additional rainfall are certainly an irresistible deal for dry areas, and studies are underway in Africa to find the best way to provide this using plant bacteria. It seems these microbes hovering thousands of metres above our heads could soon become a force for good.



Could planting the correct crops encourage cloud formation?



Radar can be a vital tool in examining clouds for signs of rain and hail



Q&A DR THORWALD STEIN, METEOROLOGIST

How weather forecasters use radar to probe the insides of clouds

What are you looking for when you examine clouds with radar?

I am trying to find out if there is going to be hail involved as well as rain. If there is going to be hail, there will probably be lightning, too. We can warn people about this, especially those who care about it, like Heathrow Airport.

How can you tell what’s going on up there?

We transmit radar waves into the clouds at different polarisations, either horizontal or vertical. If the drops of precipitation are spherical, you will get exactly the same signal back regardless of which type of polarised wave you’re sending. However, the large raindrops that occur in heavy rain appear flattened, so you will therefore get a lot less return in the vertical plane. We can use this information to distinguish heavy rain from hail, because hail tends to be spherical, with similar signals in both the vertical and horizontal planes.

How high are the clouds that you’re studying?

We think of clouds in terms of temperature bands rather than altitudes. If there is a strong updraft, you can get liquid rain in the below-freezing part of the cloud, and hail doesn’t melt immediately after it passes a temperature of over zero degrees Celsius. In the summer, these processes that we study take place 1.2 to 1.8 miles up.

“If there is going to be hail, there will probably be lightning, too. We can warn people about this”

HEROES OF SPACE

VALENTINA TERESHKOVA

This pioneering cosmonaut was the first woman in space and remains the only woman to fly there solo

WORDS AILSA HARVEY

When Valentina Tereshkova was 26 years old, she became the first female astronaut to go to space. After quitting school early and joining her family's factory business, her early life did not appear to be on a trajectory to the stars. However, her daring passion for parachute jumping, which she developed early into adulthood, is what brought her on track to joining the Soviet space program and made her a trailblazing space traveller.

After the space program was successful in sending the first person into space – Yuri Gagarin in April 1961 – the race was on to be the first space agency to send a woman there too. Because Tereshkova's accomplishment was achieved on the basis of record-setting and political competition, there was less urgency to send any more female cosmonauts and astronauts on a space mission after this. As a result, 19 years would pass before Svetlana Savitskaya became the second woman in space.

At her local aviation club, Tereshkova completed around 150 parachute jumps. This skill won her one of four places in the space program from 400 civilian volunteers. As part of the Vostok program, these cosmonauts needed to be able to eject themselves from the spacecraft during the return journey and parachute safely back down to Earth. What followed from her selection was 18 months of intense training, including tests to analyse her physical endurance in extremely low gravity and the pressure of solo travel in an intense environment. This included centrifugal testing, isolation tests and pilot and parachute training. During her only visit to space, Tereshkova completed 48 orbits of Earth in 71 hours. To commemorate her contribution to Soviet space travel, Tereshkova was awarded the Order of Lenin when she returned to Earth. This was the highest civilian award given by the USSR.

Tereshkova held a short career as a cosmonaut before taking to politics. Before the collapse of the Soviet Union, she was appointed an official head of state, and in 1966 joined the



Above: Tereshkova posing next to the Vostok 6 capsule in 2015

Right: Tereshkova was selected for the space program when she was 24 years old

Right inset: Tereshkova took part in numerous physical tests before her spaceflight

5 THINGS TO KNOW ABOUT VALENTINA TERESHKOVA

1 DINNER STOP
After her spaceflight, Tereshkova landed by parachute in Kazakhstan and went for dinner with the local villagers instead of going for medical tests.

2 PROTECTED
After Yuri Gagarin died in an aviation accident, Tereshkova was ordered to cease her career as a test pilot because the Soviet space program didn't want to lose another space icon.

3 WORDS OF WISDOM
In one of her famous quotes, Tereshkova said: "If women can be railroad workers in Russia, why can't they fly in space?"

4 SEAGULL
During her spaceflight, Tereshkova's call sign was 'Chaika', which is the Russian word for 'seagull'.

5 LUNAR DEDICATION
On the far side of the Moon is a small lunar impact crater named after the cosmonaut: Tereshkova crater.

VOSTOK 6 WAS THE LAUNCH OF FEMALE SPACE TRAVEL

On 16 June 1963, Tereshkova boarded the Vostok 6 spacecraft as part of a dual flight. Two days prior, Valery Bykovsky took off in Vostok 5. Vostok 5 was originally meant to be Tereshkova's spacecraft, with two women taking part in the mission. Valentina Ponomaryova was the second cosmonaut scheduled to fly in Vostok 6, but plans were changed, and she was replaced with a male cosmonaut to compare the effects of space travel on male and female bodies. Tereshkova and Bykovsky took different flight paths. The two spacecraft came within 2.8 miles of each other, which enabled the cosmonauts to communicate for a short time.



Tereshkova pictured aboard Vostok 6

The BIG idea

Did you know?
Russian astronauts are called cosmonauts

DID YOU KNOW? The images Tereshkova captured of Earth were used to identify aerosol layers in Earth's atmosphere



World Peace Council. She continues to work in politics, and her latest election into Russian parliament was in 2021. Her time in the space program and interest in flight to other worlds became a large part of Tereshkova's identity. In 1977 she completed a doctorate in aeronautical engineering and has more recently shown a desire to return to space. On multiple occasions she has publicly expressed her dream to travel to Mars. In 2013, she stated: "I want to find out whether there was life there or not. And if there was, then why did it die out? What sort of catastrophe happened? I am ready."

Today, women aren't limited to merely dreaming of going to space. Despite the significant gap in female space travel since Tereshkova's mission, she inspired an increase in young girls studying STEM. Over 70 women have since followed her in travelling to the stars.



A LIFE'S WORK

From textile factory to space

1937

Tereshkova was born in Russia on 6 March.



1939

Her father was killed in the Russo-Finnish Winter War when Tereshkova was two.



1947

Tereshkova didn't start school until she was ten years old.



1959

With an interest in parachute jumping, Tereshkova made her first jump aged 22.



1960

She graduated from Light Industry Technical School.



1962

She was one of five to be selected to join the female cosmonaut corps.



1963

Tereshkova completed her spaceflight mission, which took almost three days.



1963

On 3 November, Tereshkova married fellow cosmonaut Andriyan Nikolayev.



1964

The couple had a baby girl together in June, called Elena.



1976

Tereshkova became a colonel in the Soviet Air Forces.



1982

Tereshkova and Nikolayev divorced, and she remarried surgeon Yuli Shaposhnikov.

BIZARRE INVENTIONS

From passenger jets to the internet, humanity has changed the world with many ingenious technologies. But some creations have been a little unusual...

WORDS ALEX DALE

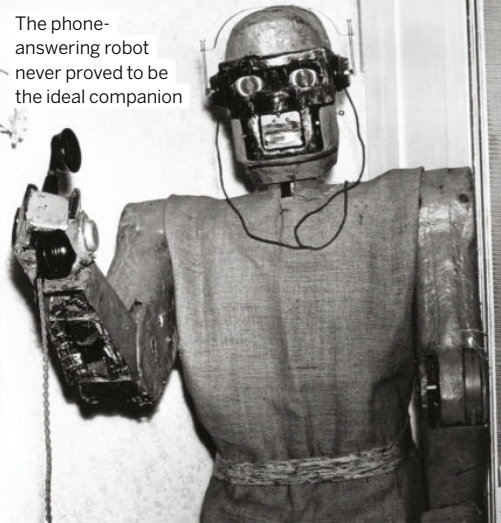
HOME HELP

A TELEPHONE-ANSWERING ROBOT

Robot butlers who would perform our household chores with a beep and a smile were a common fantasy in the 1950s and 1960s, but back then the technology seemed pretty far off. But a Viennese inventor named Claus Scholz attempted to prematurely kick-start the household robotics movement in 1964 with the MM7 – a towering humanoid who would answer your telephone calls for you.

Unfortunately, the MM7's functions were restricted to simply picking up the phone and putting it down again – the robot was unable to speak to the person on the other end, or take a message for you. Considering that answering machine devices had already been commercially available for over a decade, this rendered MM7 as little more than a very expensive coat stand. That is a role MM7 could have performed ably alongside one of his sister robots, whose purpose was to gingerly put guests' hats onto a hook. Another invention poured wine at a glacial pace. Scholz's robots are preserved for posterity in an ITN news clip.

The phone-answering robot never proved to be the ideal companion



Aimed at bringing the great outdoors to inner-city children, the baby cage was suspended from windows



CHILDCARE

BABY CAGE

Although we tend to think of cramped living conditions as being a relatively recent phenomenon, a lack of garden space or natural sunlight has plagued the inhabitants of inner-city tower blocks for well over a century. In 1922, one enterprising mother, Emma Read of Spokane, Washington, devised an ingenious way to reclaim the space around her apartment window for her baby – a portable wire-mesh cage designed to be suspended from the outside of an open window.

The original patent for the baby cage even included plans for a

curtain that could be pulled to prevent draughts from creeping in while the baby slept. Although it's not documented how popular these cages became, First Lady Eleanor Roosevelt was reported to have owned one. The invention made its way over to England in the late 1930s, when members of the Chelsea Baby Club in London distributed the devices to their members. However, air raids during World War II put a stop to the baby cage's usage before either common sense or tragedy had a chance to intervene.

DID YOU KNOW? Over 19,000 UK patent applications were filed in 2022



Requiring motion to stay upright, the monowheel lacked stability when cornering

TRANSPORT

MONOWHEEL

As strange as it might seem given its comical appearance, the monowheel was once tipped as the future of motorised transport. It resembles a unicycle in that it has one wheel, except the driver sits inside that single wheel. The driver anchors a solid-framed inner loop and either motors or pedals are used to turn the outer loop, propelling the unorthodox vehicle forward. As long as the driver is applying a force using the pedals or motor, the vehicle will stay in motion.

Supporters of the monowheel – most famously English inventor Dr J. A. Purves, whose 1932 Dynasphere prototype was

capable of speeds of up to 30 miles per hour – considered it the endgame of motorised transport. But a lack of wheels brings with it a lack of balance, and this resulted in several intrinsic problems. Its reliance on forward motion to remain upright meant that the vehicle would become unstable as soon as the wheel slowed down – in braking or cornering, for instance. There were also visibility issues for the driver.

Today, monowheels are still being built, though largely by hobbyists, and they make for an exciting spectacle. Lightweight designs are making them more practical.

Did you know?

'Patent' comes from the Latin for 'to lay open'

EMERGENCY SERVICES

TAMPER-PROOF FIRE ALARM

Some inventions solve one problem, only to create another. In the late 1930s, false fire alarms initiated by pranksters were such a problem that a deterrent was needed. Enter the Fire Box, as documented in the February 1938 issue of *Modern Mechanix*. To sound the alarm, the user had to pass their hand through a compartment

that resembled a stock, which then handcuffed them in place until the fire service arrived and freed them with a key. While this certainly would have made errant youths think twice before setting off a false alarm, it also had the unfortunate side effect of locking someone into place in the event of an actual inferno.

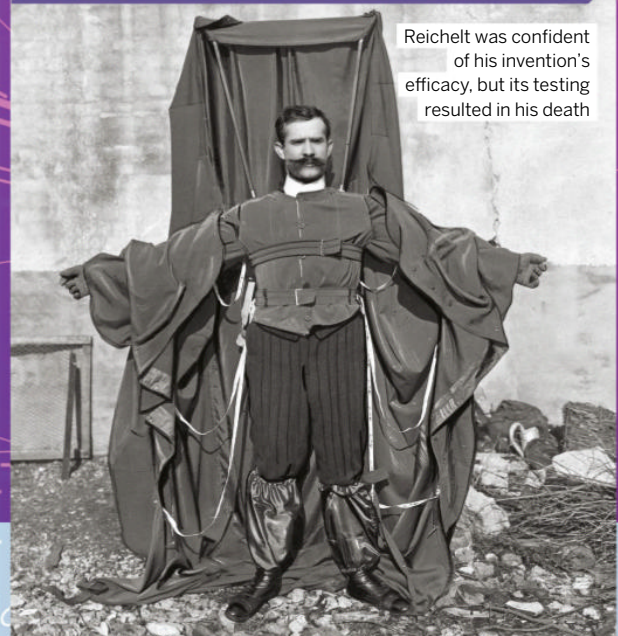
AIR SAFETY

PARACHUTE SUIT

Aircraft were still in their infancy in 1912, and no proper contingency plan had been put in place to account for how a pilot might survive if they were forced to evacuate their craft mid-flight. While a patent for a packed parachute had already been filed, Franz Reichelt believed he had devised a more elegant solution. His parachute suit was only a little bulkier than civilian clothes and required minimal effort to open out – the faller need

only make a cross shape with their limbs.

Initial tests using dummies met with mixed results, which Reichelt blamed on the lack of high test platforms. Reichelt gained permission to perform a test drop from the first floor of the Eiffel Tower in front of a throng of press and curious onlookers. He was so confident that he decided to demonstrate the suit himself – without a safety net. Alas, his faith in his invention was misplaced, and he plummeted to his death.



Reichelt was confident of his invention's efficacy, but its testing resulted in his death

ARE BRAIN TRANSPLANTS POSSIBLE?

This controversial surgery has complicated technicalities to consider before our body's most sophisticated organ can be switched out

WORDS AILSA HARVEY

Before the first successful heart transplant in 1967, the idea of removing this life-sustaining organ from a body and replacing it with someone else's was thought impossible. Now, around 3,500 heart transplants are carried out each year. Can the same happen for those with healthy brains but a body that's failing them?

Unlike the heart – the function of which scientists have a great understanding of – the brain is considered the most complex thing in the universe. It contains trillions of cellular connections, efficiently controlling the way you think, feel, remember, move and the way you perceive the world. The brain, which is connected to the spinal cord to make up the

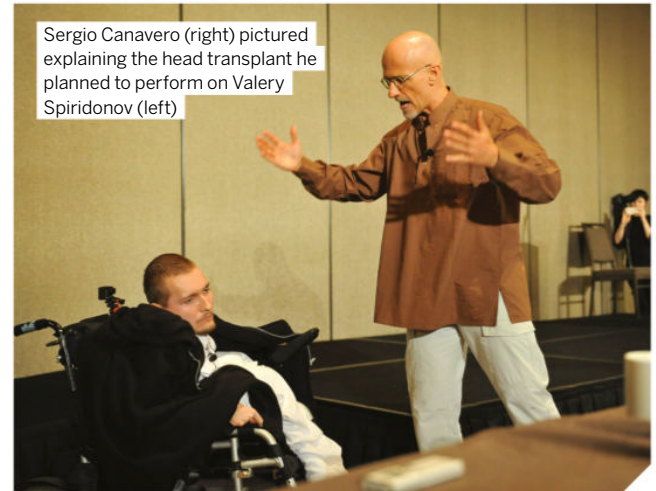
central nervous system, would need to be cut away from the spinal cord for a transplant. The greatest challenge following this irreversible act is to precisely reconnect the blood vessels, nerves and other tissues quickly enough that vital brain tissue doesn't die, and do it with such precision that the individual wakes up from the procedure with their mental and physical abilities uncompromised.

For now, the technical and ethical challenges that come with relocating a brain keep the reality of such a transplant in the distant future for most. But this hasn't stopped all neurosurgeons. In 2017, Italian neurosurgeon Sergio Canavero claimed that

he could successfully carry out a head transplant. Instead of isolating just the brain, the surgeon planned to cut off the head of a Russian man called Valery Spiridonov. Spiridonov volunteered to be the first person to receive this transplant, as he suffered from a severe muscle-wasting condition that destroyed nerves in the spinal cord. This left him wheelchair-bound and willing to undergo the reconnection of his head onto a new body and spinal cord. The date was scheduled in 2017 – but it didn't take place. The case

highlighted the ethical concerns of using vulnerable patients in high-risk experimental procedures. Neurosurgeons like Canavero continue to work on brain transplant research, while others focus more on the future technologies that are emerging to improve patients' quality of life with robotics. This involves

brain-machine interfaces that replace the brain's communication with the central nervous system to keep the most complex biological systems intact.



Sergio Canavero (right) pictured explaining the head transplant he planned to perform on Valery Spiridonov (left)

Did you know?

There are 100 billion neurons in a mature human brain

DANIEL HOLSGROVE

A consultant neurosurgeon from Salford Royal Hospital explains the complications of a brain transplant procedure



What elements of brain transplants are possible?

I think lots of the technical aspects are already done in other types of surgery, for example reconnecting blood vessels. You could reconnect a blood vessel from donor and recipient. There are ways of doing that, and that's done in lots of surgeries already.

What would be the most difficult part?

The biggest challenge is in relation to the

spinal cord, and connecting the donor and recipients' brain and spinal cord, depending on where exactly you choose to make the division. Although it's been proposed there are certain technologies that could help, there's no proven way of reconnecting a spinal cord in a way to maintain or restore function in a way that would be useful.

Wouldn't transplanting a whole head onto another body be a lot easier than a brain transplant?

Just transplanting the brain means you've

also had to cut all the nerves that go from the brain to around the head and neck, so that makes it more complicated. If you were to transplant a whole head, then you have the issues with the blood vessels, spinal cord, trachea and oesophagus. However, the nerves connecting the brain to the eyes, for example, would be left intact. The nerves that go directly from the brain to the cranial nerves and directly to the areas around the face and neck would be left intact. That would be more straightforward in that regard.

DID YOU KNOW? A full-head transplant has only ever been carried out on a cadaver

ORGAN ACCESS

How parts of the brain and head fare when detached

4 FRONTAL LOBE

Partial brain transplants risk a frontal lobe injury, which in some cases can alter a person's personality and make them more argumentative, act and speak more impulsively.

5 CEREBELLUM

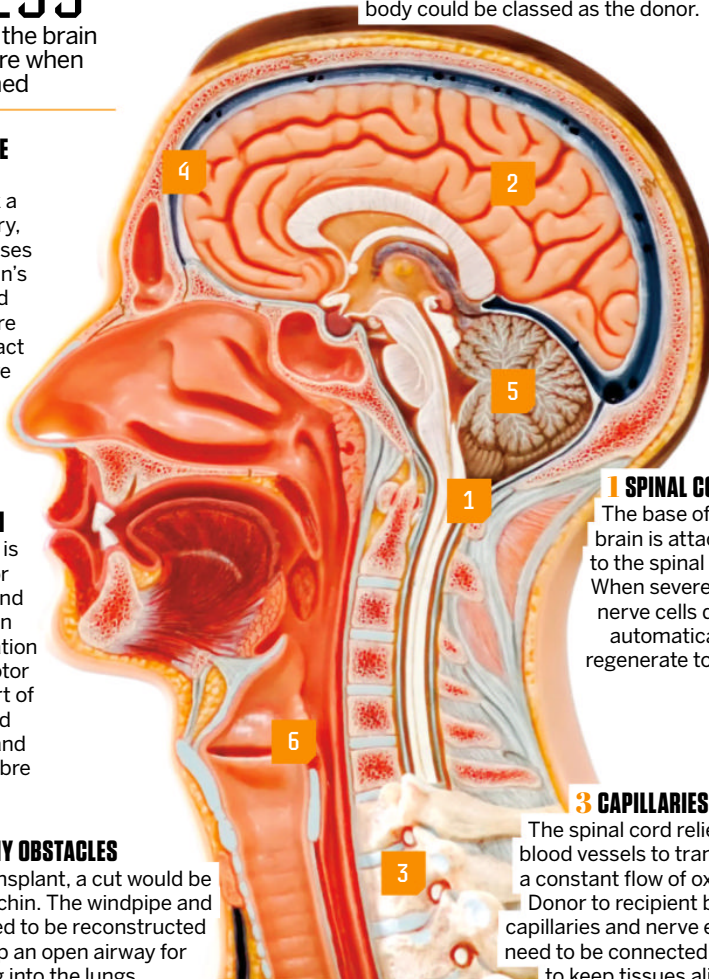
This brain area is responsible for motor control and coordination. In brain transplantation for regaining motor function, this part of the brain would need accurate and intricate nerve fibre connections.

6 MANY OBSTACLES

In a full-head transplant, a cut would be made below the chin. The windpipe and oesophagus need to be reconstructed exactly to keep an open airway for breathing into the lungs.

2 DONOR OR RECIPIENT?

In a brain transplant, the brain being transplanted would carry a person's thoughts. In reverse to standard organ donation, the organ's new body could be classed as the donor.



1 SPINAL CORD

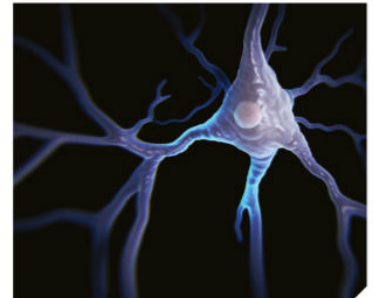
The base of the brain is attached to the spinal cord. When severed, its nerve cells don't automatically regenerate to heal.

3 CAPILLARIES

The spinal cord relies on blood vessels to transport a constant flow of oxygen. Donor to recipient blood capillaries and nerve endings need to be connected quickly to keep tissues alive.

PARTIAL TRANSPLANTATION

The core goal of a brain transplant is to keep a person's mind the same, but provide a new body with renewed functionality. As each section of the brain has its own roles, are partial brain transplants possible? A large part of what shapes your personality are your memories, so if a brain transplant became feasible, you would want to keep hold of as many of these as possible. For this outcome, a partial brain transplant is ruled out. The hippocampus, a complex brain structure near the centre of the brain, is regarded as the memory centre of the brain. However, in reality memories are formed and stored in multiple areas. Trying to transplant part of the brain risks cutting off neural connections between memories and destroying them.



Pyramidal neurons process external signals and motor control

What could happen if it went wrong?

I think there are huge psychological aspects to it. Without that spinal cord connection, there would be a risk of brain injury through ischemia – lack of blood flow and oxygenation – during transplantation, so you could easily harm the brain. You are taking a healthy brain to connect it to a healthy body where the body has failed. But you risk causing an injury to the brain, and there's a risk that you could have someone sort of locked in, which is when they may maintain brain function but are unable to communicate or have a functioning body.

What happens when you remove a brain from a body?

If you cut off the blood supply to parts of the

brain, the neurons will start dying after about three minutes, but you can extend that period of time through various techniques. You can give medication, like a very deep form of anaesthesia, to reduce the brain's metabolic activity so that the activity within the separate cells is reduced. Often, this makes that three minutes extend to seven minutes, for example, before you start seeing changes in the brain's electrical activity to suggest that the brain is becoming impacted by the reduced blood flow to it. Other procedures can intentionally lower the brain's temperature that can extend it further

into the region of 20 to 30 minutes, potentially. However, we're not at the stages where you could put a brain in an ice box and transport it across the country.

Will the advances in technology improve the likelihood of brain transplants becoming commonplace in the future?

I think technological advancements such as exoskeletons that can be controlled by someone's thoughts, using wearable or implanted sensors or stimulators to help send the messages to the nerves to get people moving is likely to make transplantation irrelevant before it's even begun.

“There are huge psychological aspects to it”

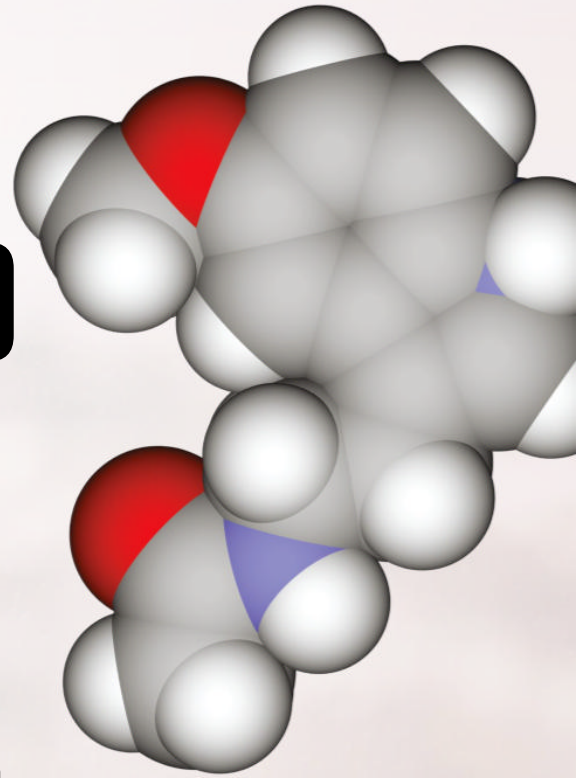
HOW SEASONS CAN CHANGE YOUR MOOD

The science behind seasonal affective disorder and how the brain responds to daylight

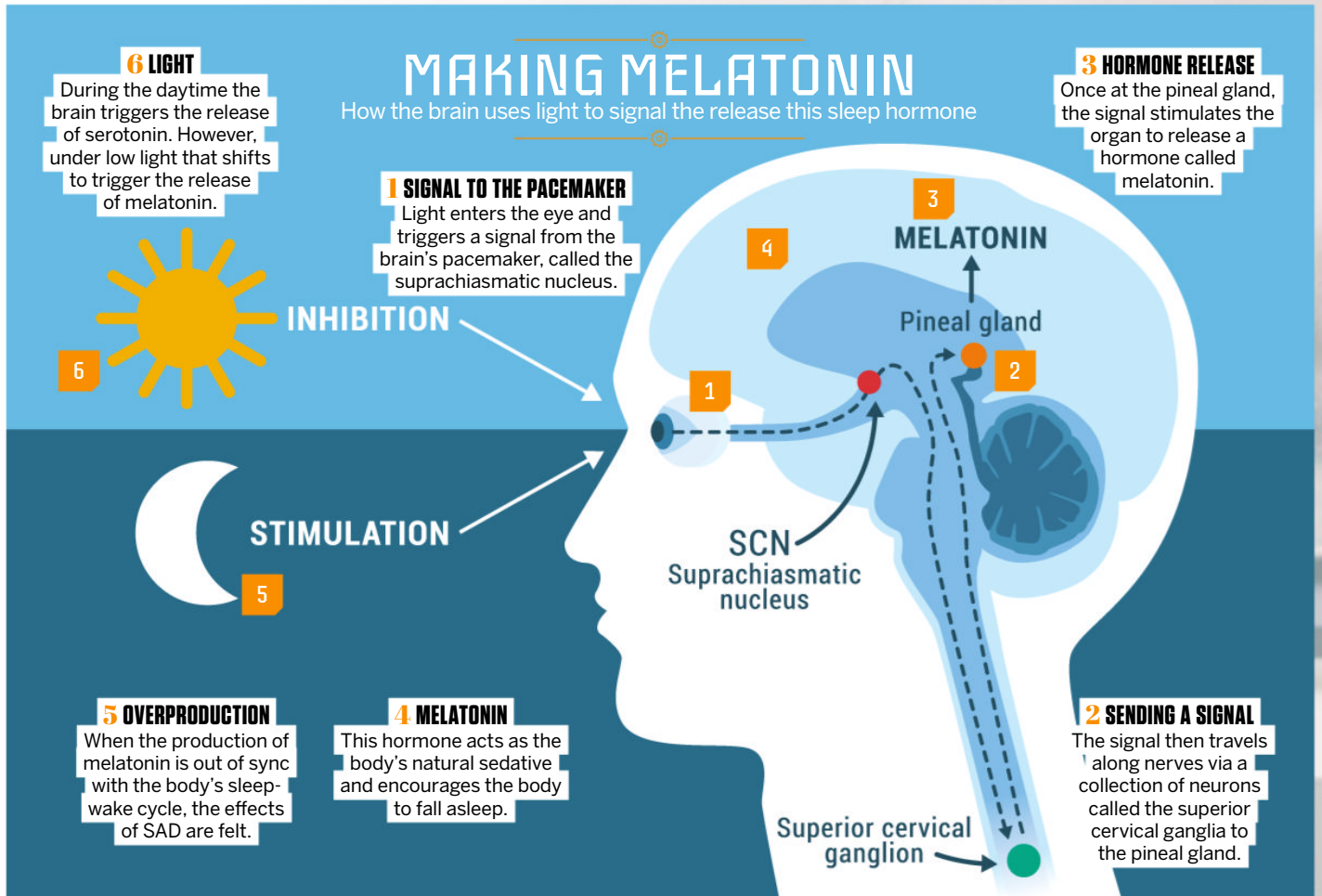
WORDS SCOTT DUTFIELD

Often known as winter depression, seasonal affective disorder (SAD) is a form of depression brought about by the changing pattern of the seasons. Typically starting in autumn and lasting throughout winter, many people who suffer from SAD experience symptoms such as feeling lethargic, despair and a general loss of interest in everyday activities. Why some people experience SAD and others don't remains largely a mystery. However, there

are many theories, including the seasons throwing your body clock out of sync. Known as circadian rhythm, the body generally follows a sleep-wake cycle across 24 hours that's attuned to the body's exposure to natural sunlight. Increasing light levels at dawn fire up the brain's production of the feel-good hormone serotonin, while decreased light levels at dusk slow serotonin production, and in its place starts the production of the sleepy hormone melatonin.



An illustration of a molecule of melatonin, the hormone that contributes to SAD



DID YOU KNOW? The UK's shortest day lasts 7 hours, 49 minutes and 42 seconds

LIGHT THERAPY

Since the 1980s, one of the most widely used treatments to tackle SAD is light therapy. Using a device called a light box, sufferers of SAD sit in front of artificial light, typically in the morning, to stimulate the production of serotonin and reduce the production of melatonin. Unlike other lamps, like those used for tanning, these light boxes come with filters to remove harmful ultraviolet light that can damage the skin and eyes. Some studies have shown that between 30 and 45 minutes of regular exposure to a light box at around 10,000 lux, which is around the intensity of light the Sun provides in the morning, is effective in treating SAD. Sufferers may experience some side effects, such as headaches or skin irritation during use, so it's advised to always seek medical advice before using a light box.



Using a light box can help trick your body into thinking it's daytime

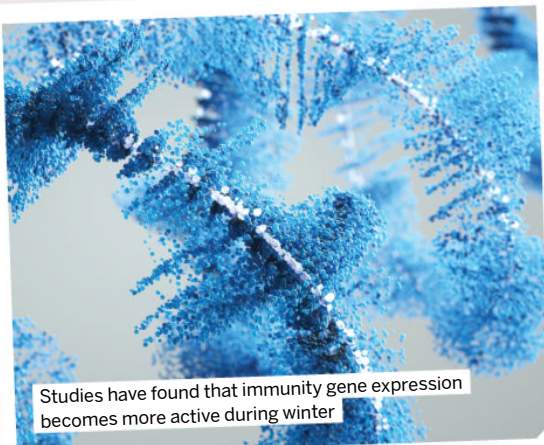
During winter, when light levels during the daytime are lowest, serotonin production is also at its lowest, while melatonin continues to be released. For some, this can leave them longing for summer and feeling symptoms of SAD. However, SAD isn't strictly associated with the darker winter months. During the bright warm weather of summer and spring, excessive daylight can lead to the reduction of melatonin production to the point where normal sleep is impacted, which can also lead to symptoms of SAD.

Studies of families and twins have found that there may be a hereditary explanation for the expression of SAD. From the differences in genes involved in the transport of serotonin to those keeping circadian rhythm in check, scientists have suggested that SAD may be caused by changes in our DNA. One study by the University of South Wales found that people with blue eyes were less likely to experience SAD compared to those with brown eyes. While the scientists say more research is needed to explain their findings, it's possible that blue eyes are more sensitive to light and have a different threshold to brown eyes for the release of melatonin during the daytime.

“Decreased light levels at dusk slow serotonin production”

Did you know?

0.5 to 3.0 per cent of people experience SAD



Studies have found that immunity gene expression becomes more active during winter

SEASONAL GENES

SAD isn't the only way the seasons can alter the way our bodies work. In 2015, a team of international scientists discovered that the seasons could change human genes, especially those involved with immunity and inflammation. Having taken samples of blood and tissue from 16,000 people from around the globe, the researchers found that during December to February for those living north of the equator and June to August for those south of the equator, genes associated with the body's immune system were more active compared to other seasons. However, among those that live in warm climates near the equator, which experience little seasonal change, the same genes were more active during rainy seasons.



HOW SEA GLASS IS MADE

This ocean process turns household trash into sea treasures

WORDS SCOTT DUTFIELD

All glass starts its journey as silicon-rich sand. Through a series of chemical processes and heating in a furnace, sand is transformed into molten glass and is shaped into a variety of different bottles, ornaments and glassware. Once that glassware is no longer in use and is discarded, it finds its way to a recycling centre to find new life or is disposed of through a landfill, where it can creep into waterways and eventually the ocean.

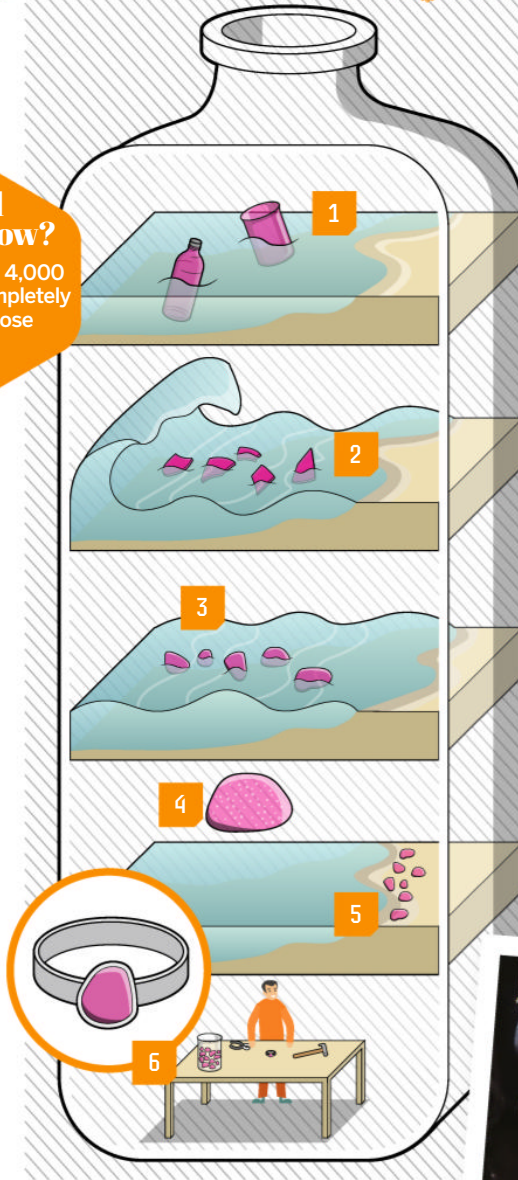
When it passes into the ocean, collisions with rocks and other hard objects break up the glass into small pieces before decades or even hundreds of years of water erosion create small, smooth glass pebbles that wash up on the beach. Because glass is made up predominantly of silicon dioxide – the same compound that quartz is made of – it shares this mineral's hardy qualities. However, it's still susceptible to the chemical erosion of salt water. The frosty texture of sea glass is not only caused by years of physical abrasions, but the hydroxide that is leached out of the glass by the water's high salt levels, forming a crystalline texture on its surface.

Since the increase of single-use plastic during the 1970s, glass has taken a backseat as the preferred material for packaging, meaning that less glass is finding its way into the ocean and fewer sea glass pieces find their way to shore.

SHAPING JUNK GEMSTONES

From waste glass to sought-after stones

Did you know?
Glass takes 4,000 years to completely decompose



1 WASTE

Sea glass starts its journey as discarded glassware that's been tossed in the ocean.

2 BROKEN APART

Under the power of the ocean, glass tumbles through water, collides with rocks and is broken apart.

3 DRAGGED

The angular pieces of glass are dragged along the seafloor along with the tides, rounding off their sharp edges in the process.

4 FROSTING

Over time, the salinity of the ocean water and the abrasion the glass experiences cause the surface to frost over.

5 WASHED UP

Sea glass eventually washes up on the shoreline.

6 ARTWORKS

Jewellers and artists often collect sea glass to incorporate it into their work.



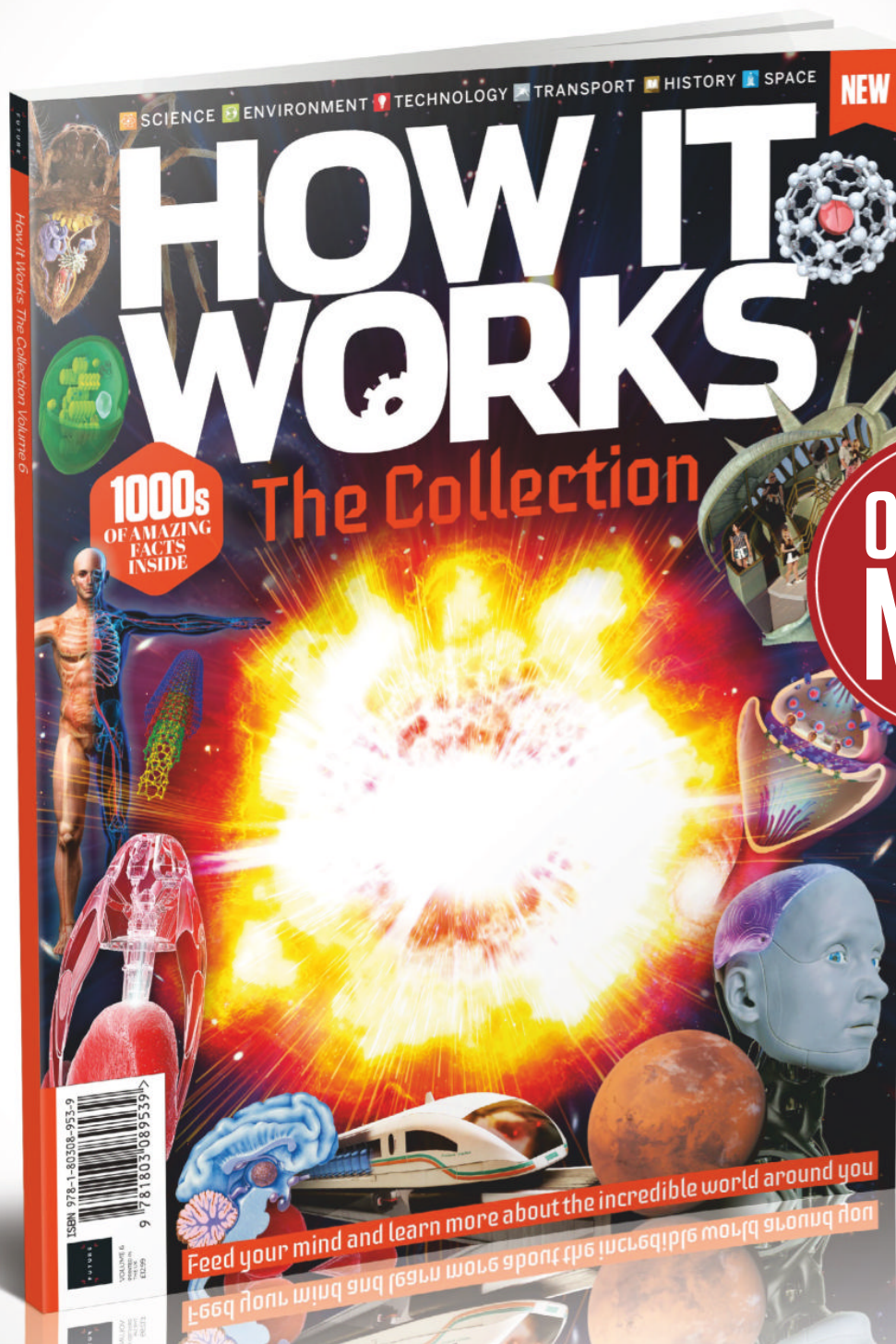
BEAUTIFUL BEACH DEBRIS

The beaches at Fort Bragg in California were once used as a dumping site for locals to discard their rubbish, including heaps of glass waste. By 1967, the beach was overflowing with rubbish and the locals sought new dumping grounds, leaving the trash to the mercy of the elements. Over time, the heaps of rubbish began to dwindle as people rifled through the piles to repurpose metal waste and biodegradable materials rotted

away. Eventually, all that remained were glass and ceramics, which were claimed by the ocean. As decades passed, continual bombardment by ocean waves smoothed the glass and rounded its edges, transforming the once-sandy beach into a floor of frosted sea glass. The Fort Bragg Glass Beach is now under the protection of MacKerricher State Park, and removing any of the glass is prohibited.

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SPACE

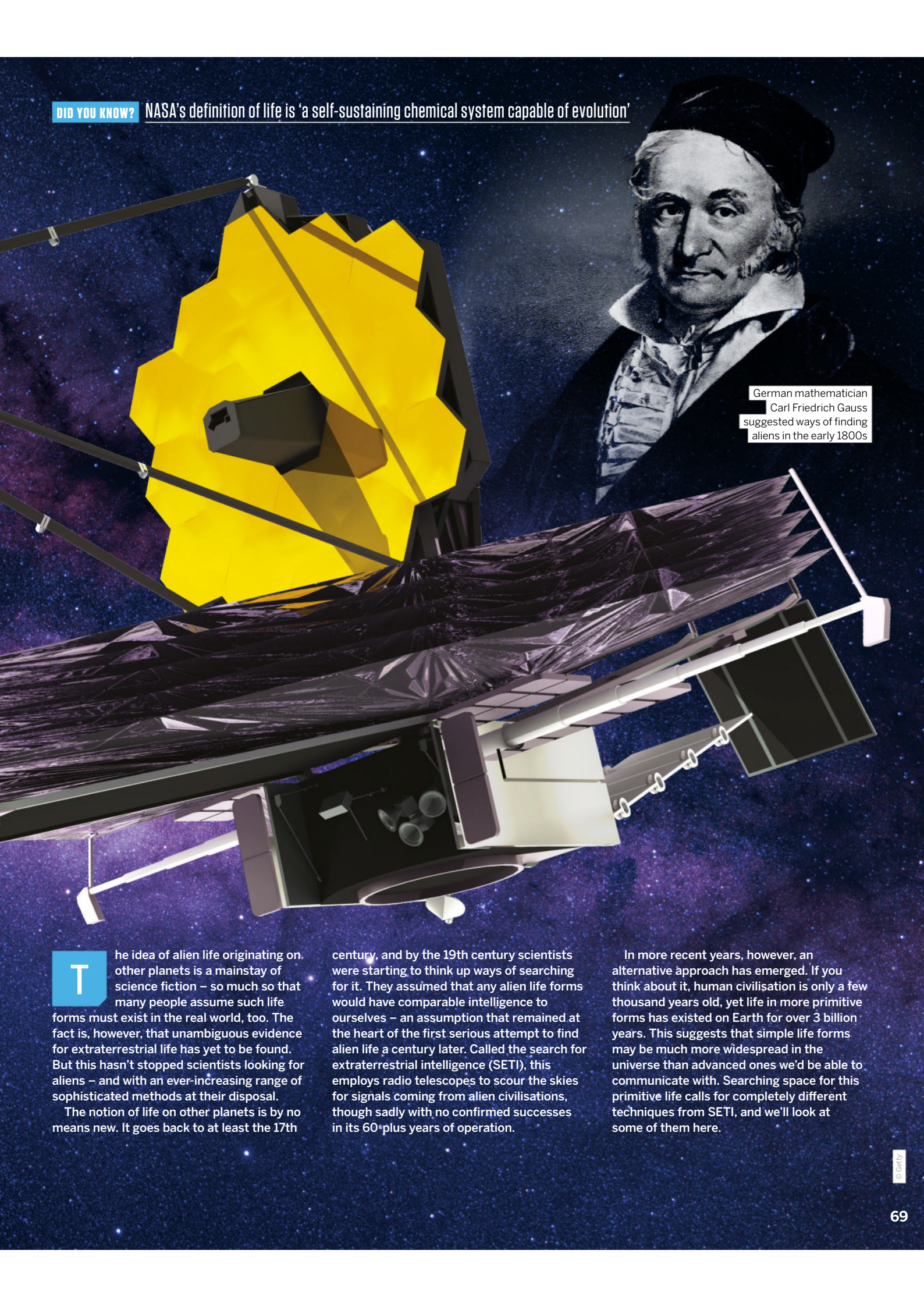
HOW TO FIND ALIEN

Scientists have a variety of ways
to search for life in the cosmos

LIFE

WORDS ANDREW MAY

DID YOU KNOW? NASA's definition of life is 'a self-sustaining chemical system capable of evolution'



German mathematician
Carl Friedrich Gauss
suggested ways of finding
aliens in the early 1800s

The idea of alien life originating on other planets is a mainstay of science fiction – so much so that many people assume such life forms must exist in the real world, too. The fact is, however, that unambiguous evidence for extraterrestrial life has yet to be found. But this hasn't stopped scientists looking for aliens – and with an ever-increasing range of sophisticated methods at their disposal.

The notion of life on other planets is by no means new. It goes back to at least the 17th

century, and by the 19th century scientists were starting to think up ways of searching for it. They assumed that any alien life forms would have comparable intelligence to ourselves – an assumption that remained at the heart of the first serious attempt to find alien life a century later. Called the search for extraterrestrial intelligence (SETI), this employs radio telescopes to scour the skies for signals coming from alien civilisations, though sadly with no confirmed successes in its 60-plus years of operation.

In more recent years, however, an alternative approach has emerged. If you think about it, human civilisation is only a few thousand years old, yet life in more primitive forms has existed on Earth for over 3 billion years. This suggests that simple life forms may be much more widespread in the universe than advanced ones we'd be able to communicate with. Searching space for this primitive life calls for completely different techniques from SETI, and we'll look at some of them here.

WEBB'S SEARCH FOR LIFE

NASA's space telescope can help the search in several ways

LOOKING FOR LIFE IN THE GALAXY

While it's possible to conceive of life forms that are very different from those on Earth, astrobiologists – the scientists who search for life on other planets – generally focus on Earth-like biology because they know exactly what signs to look for. Comparing our planet with other locations in the Solar System that don't have life, we know that key requirements include the presence of liquid water, an atmosphere, plenty of carbon-based chemicals and a strong magnetic field to protect the planet from harmful radiation.

Thanks to initiatives such as NASA's Kepler space telescope and Transiting Exoplanet Survey Satellite (TESS), we now know of thousands of exoplanets beyond our own Solar System. But not all of these planets are suitable habitats for Earth-like life. In order to qualify, a planet needs to have a rocky composition like our own, as opposed to a gas giant like Jupiter. It should also lie within the 'habitable zone', sometimes known as the 'Goldilocks zone', around its host star at a distance where water can exist in liquid form. If a planet is too close to the central star, it

will be so hot that any water will boil, while a planet that's too far away will be so cold that water will only exist in frozen form as ice. To date, at least two dozen potentially habitable planets have been discovered, in the sense that they orbit within their star's habitable zone and have similar dimensions and compositions to our own planet. Most of these planets belong to different star systems, but one nearby star called TRAPPIST-1 has no less than four potentially habitable planets orbiting around it.

Unfortunately, simply being a rocky world located at the right distance from a star doesn't mean a planet is necessarily inhabited. Think of our Moon, for example, that is airless and devoid of both liquid water and life. The same may be true of some of the exoplanets that at first sight appear to be habitable. While planet-hunting telescopes like Kepler and TESS can't tell us whether an exoplanet has an atmosphere or not, there are other instruments that can. An important resource in this context is NASA's James Webb Space Telescope. This has already

shown, for example, that two of TRAPPIST-1's closest planets are devoid of atmospheres. But these were too close to the parent star to be habitable anyway, and scientists are still awaiting Webb's results for the more interesting planets lying inside TRAPPIST-1's Goldilocks zone.

Once an atmosphere is detected around a rocky, Earth-like planet within a star's habitable zone, it becomes a prime target in the search for extraterrestrial life. A key concept that enters the picture at this point is that of a 'biosignature' – a telltale chemical that, in the case of our own atmosphere, is primarily produced by living processes. Key biosignatures include things like oxygen, ozone and dimethyl sulphide, and one of Webb's main tasks will be to look for such chemicals from other worlds.

ORGANIC MOLECULES

While they don't necessarily indicate the presence of life, these are the basic chemical building blocks from which life is made. Early in 2023, Webb detected the most distant organic molecules to date – seen as an orange ring in this image – in a galaxy over 12 billion light years away.

STELLAR FLARES

Webb has also been observing flares on the central star of the TRAPPIST-1 system. While the flares themselves don't tell us anything about the habitability of the planets, they can interfere with measurements of planetary atmospheres, so obtaining a good understanding of them is important.

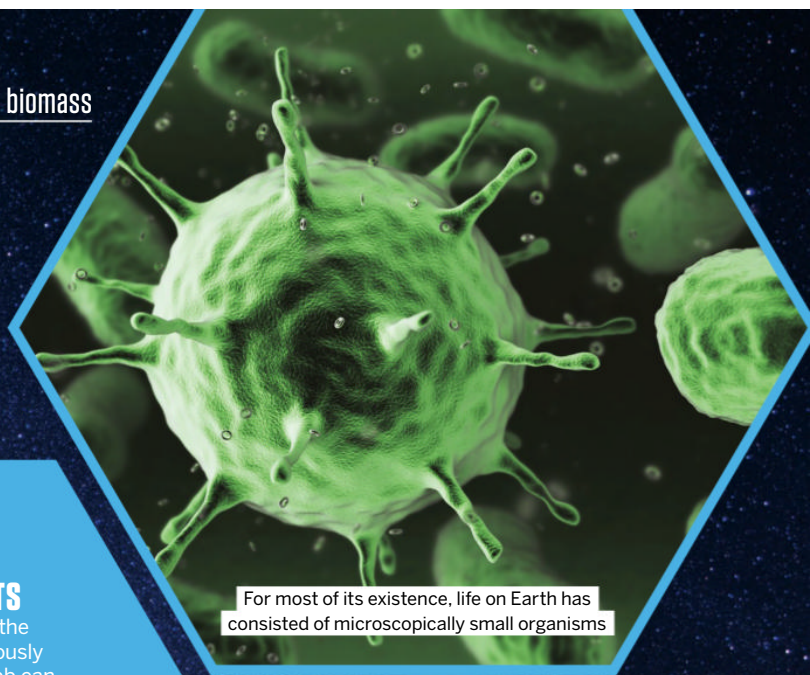
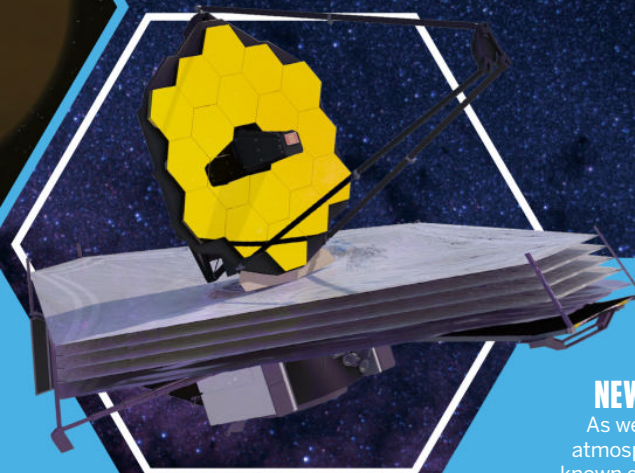
EXOPLANET ATMOSPHERES

Drawing on Webb data, an international team produced a detailed analysis of the atmosphere of exoplanet WASP-39 b in 2022. As a gas giant it's not a prime contender in the search for life, but the thick atmosphere of carbon monoxide and sulphur dioxide was an excellent testbed for the scientists.

DIMETHYL SULPHIDE

On Earth this molecule is primarily produced by microscopic organisms called phytoplankton that inhabit both freshwater and saltwater environments. This makes it an important biosignature, and in 2023, Webb discovered it in the atmosphere of an exoplanet called K2-18 b, 120 light years away.

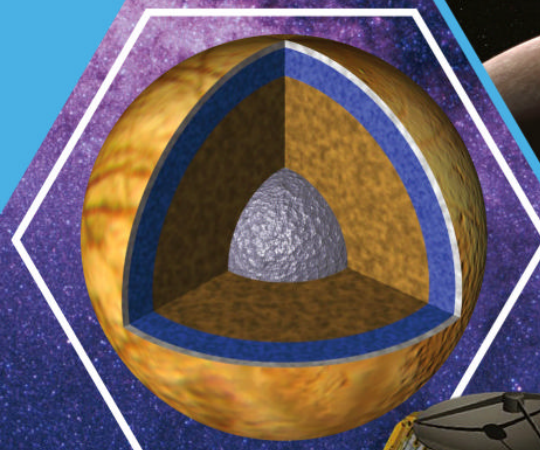
DID YOU KNOW? Humans make up one ten-thousandth of Earth's total biomass



For most of its existence, life on Earth has consisted of microscopically small organisms

NEW EXOPLANETS

As well as analysing the atmospheres of previously known exoplanets, Webb can also locate new planets of its own. In January 2023 it discovered LHS 475 b, a rocky exoplanet that's very similar in size to Earth.



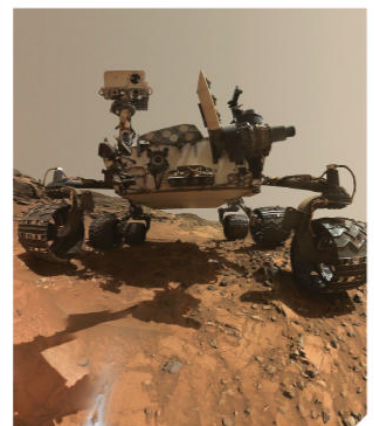
Seen in blue here, the subsurface ocean on Jupiter's moon Europa may harbour life

Did you know?
The TRAPPIST-1 system has seven known planets in all

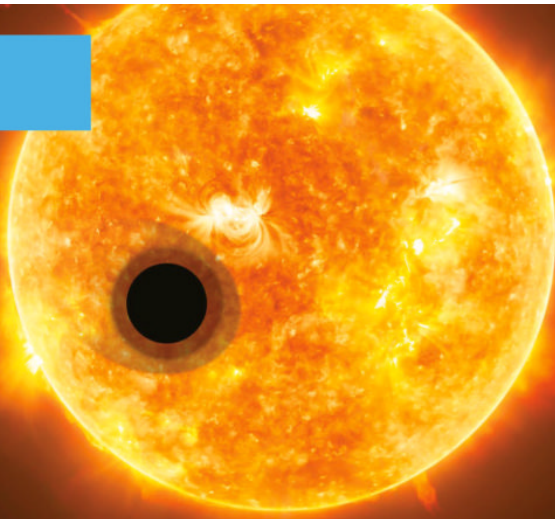
TESS aims to find promising exoplanets that Webb can study in detail

LIFE IN THE SOLAR SYSTEM

We know there's life in at least part of the Solar System, here on Earth, so what about the other planets and moons? Mars is probably too cold and dry for any kind of life today, but it was much more Earth-like 3.5 billion years ago. NASA's Perseverance rover is currently searching for evidence of primitive life from that era. At the opposite extreme, Venus looks much too hot to support life, although there is some evidence – not accepted by everyone – of a biosignature molecule called phosphine in its clouds. More promising locations for life are the subsurface oceans of liquid water believed to exist on some of Jupiter's moons, which the European Space Agency's JUpiter Icy Moons Explorer (JUICE) is on its way to investigate.



NASA hopes its Perseverance rover will discover if Mars had life in the past



A transit occurs when an exoplanet passes in front of its host star

PROBING EXOPLANET ATMOSPHERES

Webb uses a method called transit spectroscopy to work out what molecules are present in an exoplanet's atmosphere. A transit occurs when a planet moves across the face of its parent star as seen from the perspective of the telescope observing it. One effect of this is to produce a small decrease in the apparent brightness of the star, and this gives us one of the most useful methods of discovering exoplanets in the first place. All the planets found by the TESS and Kepler spacecraft, for example, were detected by observing the small dips in brightness occurring during a transit.

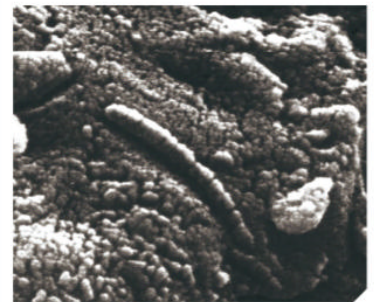
There is another side effect of transits that a powerful telescope like Webb can exploit. If the exoplanet happens to have an atmosphere, then some of the star's light will pass through this during a transit. But the light doesn't pass through unhindered,

because the gas molecules in the atmosphere will absorb a fraction of it. When this happens, it's possible to determine exactly which gases are involved because a particular molecule only absorbs light at certain well-defined wavelengths. As a result, when astronomers look at the spectrum of light – a technique known as spectroscopy – they see characteristic dips at the wavelengths where light has been absorbed. The pattern of these dips then allows them to work out which gases are present in the planet's atmosphere.

Spectroscopy is a well-established astronomical technique when applied to the composition of stars. But it becomes much harder in the case of exoplanets due to the tiny amount of light involved. Fortunately, Webb is sensitive enough that it should be able to measure the spectra of even relatively small planets like Earth.

A FAMOUS FALSE ALARM

Scientists are normally very cautious when talking about extraterrestrial life, but there was an occasion in August 1996 when a NASA team claimed with some confidence that they had found evidence for primitive life on early Mars. This came in the form of a meteorite that was ejected from Mars around 15 million years ago before eventually ending up in Antarctica. Seen under a microscope, the meteorite revealed what looked like tiny fossils of bacteria-like organisms – an interpretation that was supported by the presence of organic molecules and other signs of biological activity. As time has gone on, however, it's looked increasingly likely that these features all have simpler, non-biological explanations.



These tiny structures on meteorite ALH84001 were once thought to be fossilised Martian microbes

Did you know?

Joseph Fraunhofer invented spectroscopy in 1814



THE SEARCH BEGINS

1896

Inventor Nikola Tesla suggested that, assuming Mars had intelligent life, we could communicate with it via radio.

1947

Following reports of supposed 'flying saucers', the idea of extraterrestrial life sparked the public's imagination for the first time.

1960

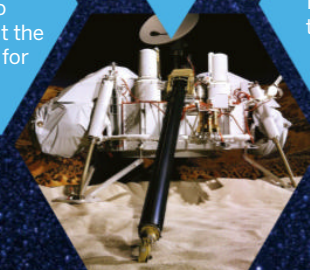
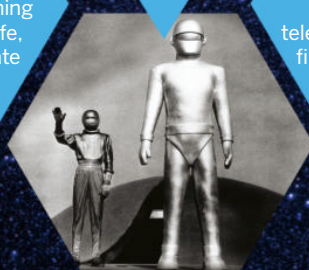
Astronomer Frank Drake used a large radio telescope to carry out the first serious search for extraterrestrial intelligence.

1976

NASA's two Viking landers carried special instruments designed to search for life on Mars, but their results were inconclusive.

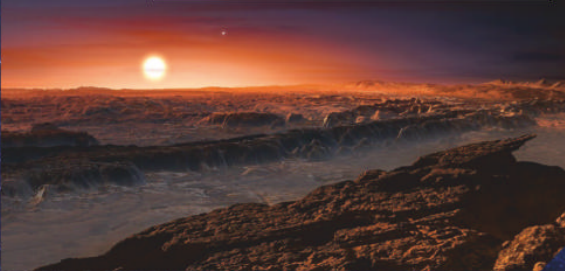
1995

Didier Queloz and Michel Mayor found 51 Pegasi b, the first exoplanet orbiting a normal star beyond the Sun.

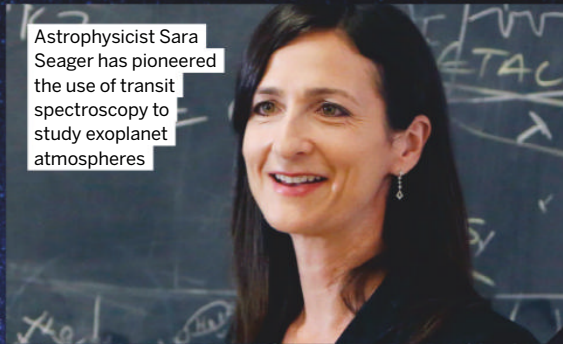


DID YOU KNOW? Two possible locations for life in the Solar System, Europa and Enceladus, are both smaller than the Moon

A speculative view of what our nearest potentially habitable exoplanet, Proxima b, might look like



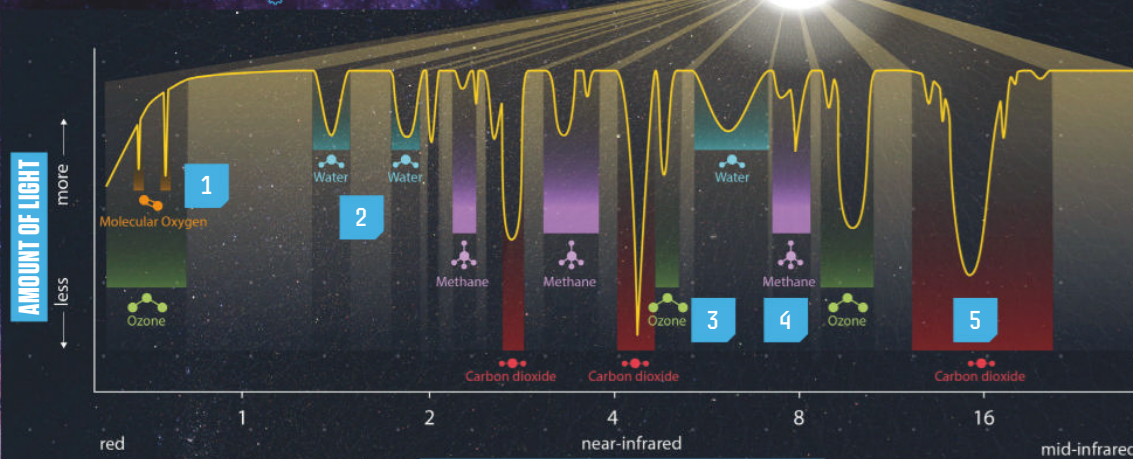
Astrophysicist Sara Seager has pioneered the use of transit spectroscopy to study exoplanet atmospheres



5 FACTS PLACES TO FIND LIFE

SIGNS OF LIFE?

These are the spectral signatures that Webb would detect coming from an Earth-like planet



1 MOLECULAR OXYGEN

Oxygen is important to animals like ourselves because it's what we breathe. It may also indicate the presence of plants or bacteria, which produce most of the Earth's oxygen.

2 WATER

Liquid water is one of the most crucial requirements for Earth-like life, so its presence will be an important indicator to look out for.

3 OZONE

This is a form of oxygen that, on Earth, is produced by environmental modification of biologically produced oxygen, so it's an indirect indicator of life.

4 METHANE

Methane can be produced by both living and non-living processes, so its presence doesn't necessarily indicate life, but may hint at it when seen in combination with other biosignatures.

5 CARBON DIOXIDE

Although CO₂ is prominent in Earth's spectrum, it isn't a good biosignature, as both Venus and Mars also have CO₂ in their atmospheres.

2005

The Cassini spacecraft observed plumes of water ejected from Saturn's moon Enceladus.

2007

The first detailed study of an exoplanet's atmosphere was made using observations by the Hubble Space Telescope.

2014

NASA's Kepler telescope found the first Earth-like exoplanet orbiting inside its star's habitable zone.

2020

NASA launched its Perseverance mission, with the specific aim of searching for evidence of past life on Mars.

2021

Avi Loeb published a book suggesting the interstellar object 'Oumuamua was an artificial structure created by aliens.

1 MARS

It's unlikely to harbour life today, but Mars was so Earth-like a few billion years ago that finding fossil evidence of ancient microorganisms is a strong possibility.

2 EUROPA

Many scientists consider this moon of Jupiter – or more specifically, its vast subsurface ocean – to be the most promising location for extraterrestrial life somewhere in the Solar System.

3 THE TRAPPIST-1 SYSTEM

Most of the potentially habitable planets found to date orbit red dwarf stars. Of these, TRAPPIST-1 has four such planets, making it a stronger bet than most.

4 PROXIMA CENTAURI B

Another potentially habitable planet orbiting a red dwarf, it would be exciting if this one is inhabited as it's only four light years away, making it our closest exoplanet.

5 KEPLER-452 B

Although it's 1,800 light years away, this promisingly habitable exoplanet – sometimes referred to as 'Earth 2.0' – orbits a star similar to our Sun, rather than a red dwarf.

SEARCHING FOR EXTRATERRESTRIAL INTELLIGENCE

If aliens use lasers, this advanced new tool might be able to catch them in the act

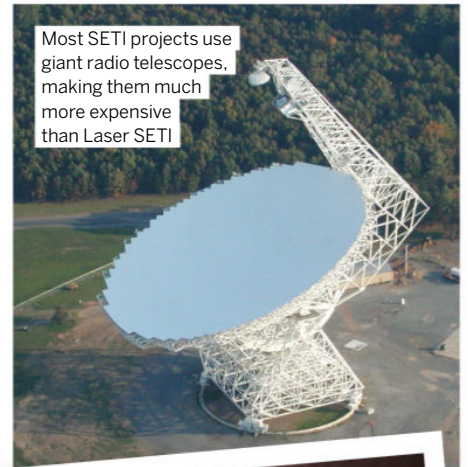
WORDS ANDREW MAY

Astronomers have been looking for evidence of alien civilisations for over 60 years now. Known collectively as the Search for Extraterrestrial Intelligence (SETI), much of the work to date has involved some fairly restrictive assumptions. In particular, it tended to focus on the detection of radio signals, assuming the aliens are blasting these out at high power either as a deliberate attempt to announce their presence, or for other reasons of their own. A second assumption behind traditional SETI is that the alien signals are continuous and long-lasting, so that when we come to point our telescope in the right direction, the signal will be right there waiting for us to pick it up. But what if these assumptions aren't valid? That's where a new technique called Laser SETI comes in.

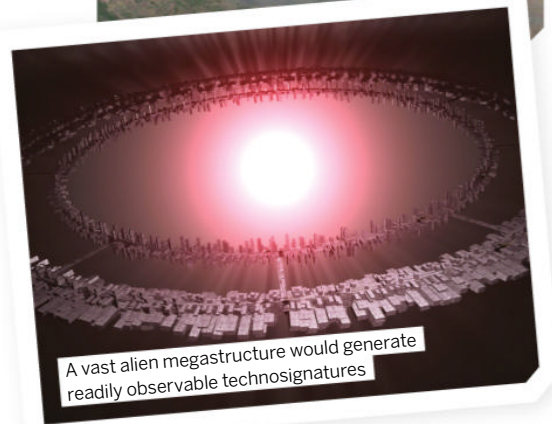
Many scientists believe that advanced civilisations are more likely to use lasers than radio for ultra-long-distance communications, for example between different planetary

colonies or interstellar spacecraft. One reason is that a laser signal has potentially much higher bandwidth than radio, allowing it to carry almost a million times as much information. Secondly, the fact that laser beams are more tightly focused than radio broadcasts means that energy isn't wasted by sending it in the wrong direction. The ability of lasers to project narrow beams of energy opens up other uses too, such as propelling light-sail-driven spacecraft to the enormous speeds needed for interstellar travel. The idea of setting up a SETI study to specifically look for extraterrestrial lasers used in this way was originally proposed back in 2015.

Aside from using optical instruments instead of radio telescopes, Laser SETI differs from traditional SETI in other ways, too. Whether the alien lasers are being used for communication or for powering spaceships, they're likely to operate in short bursts rather than



Most SETI projects use giant radio telescopes, making them much more expensive than Laser SETI



A vast alien megastructure would generate readily observable technosignatures

continuously. On top of that, the fact they're confined to narrow beams means we'll only ever have a chance of seeing them if they happen to be pointing exactly in our direction. Astronomers can't just scan small parts of the sky every now and then as they do with radio-based SETI. To have any chance of success, they have to look at the whole sky all of the time in the hope of catching the brief flash of an alien laser beam.

Fortunately, this isn't as impossible as it sounds, because Laser SETI has several practical advantages over its radio counterpart. Most importantly, it can be done

TECHNOSIGNATURES

Early efforts to search for aliens focused on looking for messages, but more recently scientists have realised this is just one way a distant technological civilisation might reveal its existence. There are other potential traces that astronomers might discover that could only be explained as having a technological origin, collectively known as 'technosignatures'. To be powerful and recognisable enough for us to detect it, an alien message would likely have to be

beamed at us in a deliberate effort to communicate. But that's not true of other technosignatures, which may be inadvertent byproducts of an alien civilisation. For example, industrial pollution could be detectable in an exoplanet's atmosphere, as could the effect of city lights. If a civilisation is more advanced than ours, we might see technosignatures from spaceship propulsion systems or artificially constructed megastructures built around stars.



Nighttime city lights on Earth would produce a distinctive technosignature detectable to alien observers

DID YOU KNOW? Laser SETI's funding comes entirely from public donations, including an online crowdfunding campaign

THE LASER SETI HARDWARE

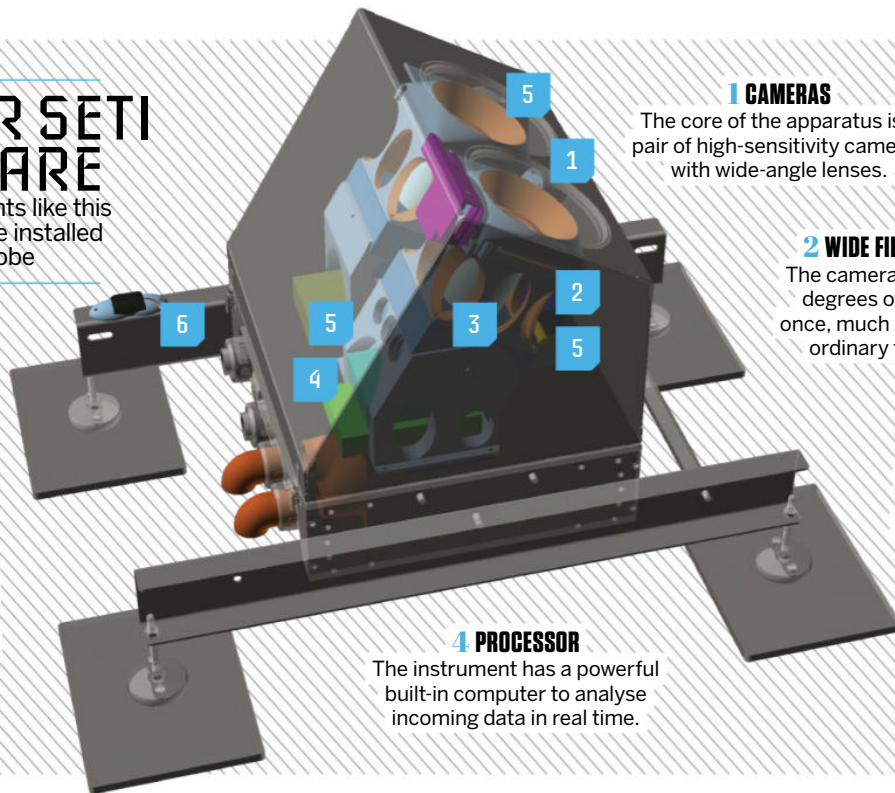
Numerous instruments like this one will ultimately be installed around the globe

6 3D PRINTING

To ensure the design is easily reproducible, much of the structure is made from 3D-printed components.

5 LOW-COST COMPONENTS

In order to keep costs down, the camera, lenses and computer are all readily available off-the-shelf items.



1 CAMERAS

The core of the apparatus is a pair of high-sensitivity cameras with wide-angle lenses.

2 WIDE FIELD OF VIEW

The cameras can see 70 degrees of the sky at once, much more than an ordinary telescope.

3 TRANSMISSION GRATING

This purpose-built device splits light into its component colours, much like a prism.

4 PROCESSOR

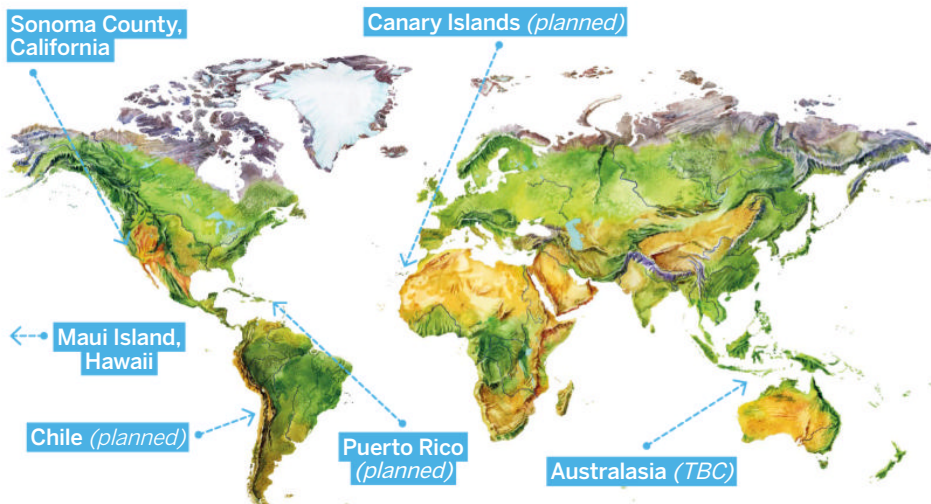
The instrument has a powerful built-in computer to analyse incoming data in real time.

with much smaller instruments – essentially just modified cameras – rather than the giant dishes needed by radio telescopes. This makes Laser SETI a relatively cheap venture, with a complete camera costing around \$100,000 (£80,000) and needing only a handful of people to set it up and run it. Another advantage of concentrating the search on laser signals is that there are essentially no known astronomical processes that produce these naturally. Unless there are bizarre natural

phenomena we don't yet suspect, any flash of laser light that's seen coming from deep space must originate from an alien civilisation.

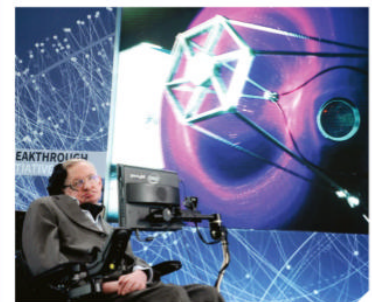
Operated by the SETI Institute, there are currently two laser SETI installations – one in California and one in Hawaii. Both are busily scanning the skies above them 24 hours a day, but that's only the start. To genuinely cover the entire sky all the time, several more observatories will have to be built at other sites around the world.

LASER SETI SITES AROUND THE WORLD



BREAKTHROUGH STARSHOT

The idea of an advanced civilisation using super-powerful lasers to push spacecraft between stars may sound like science fiction, but it's almost within our capabilities today. A test project was proposed in 2016 under the name Breakthrough Starshot. This would see dozens of centimetre-sized spacecraft, each with its own much larger mirror-like sail, being pushed on their way by an array of giant lasers on Earth's surface. This could accelerate the probes to 20 per cent the speed of light in just a few minutes, allowing them to reach a neighbouring star in just a few years.



Stephen Hawking was among Starshot's high-profile supporters



SEEING STARS IN A NEW LIGHT

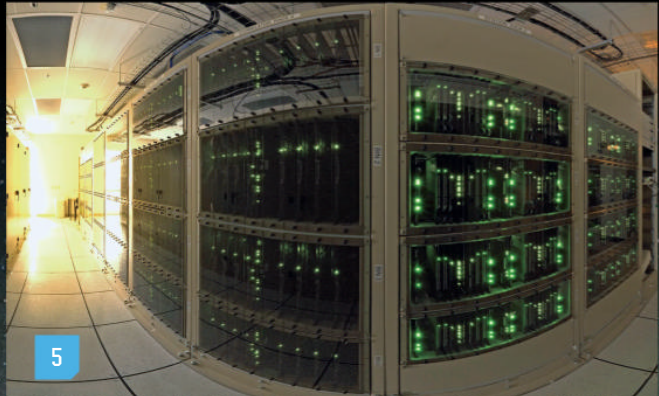
A telescope perched on a mountain in Chile allows us to watch stars and planets form in the most distant parts of the universe

WORDS DR ALASTAIR GUNN

There are many ways to view the universe. We can study the optical light we see with our eyes, infrared that we can feel as heat or ultraviolet, which gives us a suntan. All these form part of the electromagnetic spectrum and are characterised by the 'wavelength' of their radiation. But a telescope built in Chile's Atacama Desert, the Atacama Large Millimeter/submillimeter Array (ALMA), is designed to observe the sky at millimetre wavelengths, which lie between infrared and radio waves. This makes ALMA unique, capable of probing the universe in ways that were previously not possible.

Millimetre radiation generally comes from cold objects that are invisible in optical light. ALMA has revealed the complex chemistry of the giant molecular clouds that infest our galaxy. It has picked out the dust and gas created by exploding stars in the very earliest phases of the universe and has caught stars and planets in the act of formation. Millimetre wavelengths are many thousands of times longer than those of optical light. The resolution of a telescope is determined by how many wavelengths fit across its diameter, so ALMA would have to be many hundreds of miles wide to achieve the same detail as an optical telescope. To overcome this, it uses an array of separate antennae whose signals are cleverly combined to mimic what would be seen using one giant dish. In all, there are 54 12-metre dishes and 12 seven-metre dishes, spread over an area 9.9 miles across.

ALMA cost between \$1.4 and \$1.5 billion to build, making it the most expensive ground-based telescope in operation. It's located 5,000 metres above sea level in one of the driest locations on Earth, helping make its views clearer. This puts it above 40 per cent of the planet's atmosphere, which could otherwise distort the telescope's images, and 95 per cent of the water vapour that absorbs the all-important radiation.



5

5 CORRELATOR

A supercomputer in the central building with the processing power of 150,000 PCs, called a 'correlator', combines the signals from each antenna in such a way as to create a virtual telescope up to 9.9 miles in diameter.

6 ANALYSIS

Finally, the output of the correlator is processed by astronomers to produce an image of the object under study to provide information on its size, location, motion, temperature and composition.

6



An ALMA scientist hard at work

EXTREME ASTRONOMY

Working at the ALMA telescope in Chile, 5,000 metres above sea level, is not easy – it's located in one of the most inhospitable places on Earth. The air is so thin it makes breathing difficult, and many astronomers work with oxygen tanks on their backs. Any visitors to the site must sleep for at least one night in a nearby town to get used to the low oxygen levels, as well as undergoing a medical check-up.

DID YOU KNOW? The prevailing theory is that planets form when clouds of gas and dust collapse

1 ANTENNAE

The ALMA antennae gather incoming radiation from the sky and concentrate it to a focus below the bowl's surface. To operate at millimetre wavelengths, the antenna surfaces are smooth to an accuracy less than the thickness of a single sheet of paper.

HOW ALMA SEARCHES THE SKIES

Combining images from several antennae gives a clearer view of space

2 RECEIVERS

Radiation is directed through a series of mirrors and waveguides to a number of state-of-the-art receivers, operating at frequencies from 30 to 900GHz, each cooled to within a few degrees of absolute zero to prevent unwanted 'noise'.

3 BACK END

Each antenna's 'back end' amplifies the extremely weak signals being received, converts them to lower frequencies that are easier to analyse and then digitises them, converting them to a format that can be analysed by computers.

4 OPTICAL FIBRES

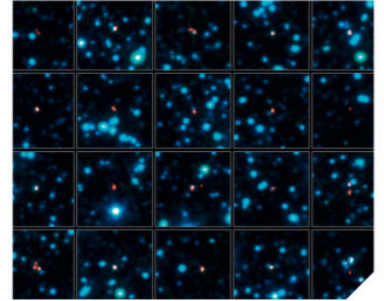
The signals from each antenna are transmitted to the central building along optical fibres. To line up the signals from each antenna precisely, the length of these fibres – some of which are up to 9.3 miles – are continuously measured by laser.

Did you know?

The telescope was patented in 1608 by spectacle maker Hans Lippershey

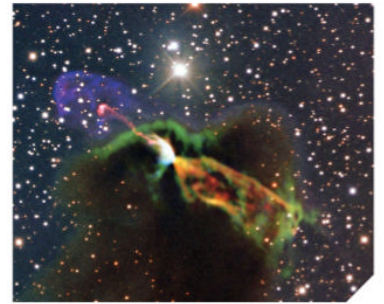
“ALMA is located 5,000 metres above sea level in one of the driest locations on Earth”

KEY TARGETS FOR ALMA



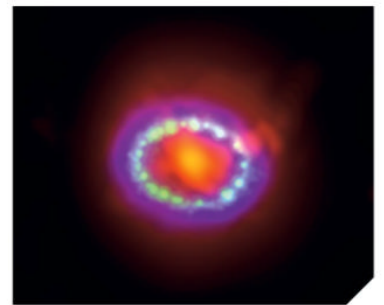
THE EARLIEST GALAXIES

Most of the light from the very first stars and galaxies, formed a few hundred million years after the Big Bang, has been stretched out to millimetre and submillimetre wavelengths. ALMA detects the glow of warm dust from these, providing insights into how they formed.



STAR FORMATION

Unlike visible light, ALMA's wavelengths are not impeded by gas and dust. It can peer into dense, dusty regions where stars and planets are forming. Astronomers have already caught planets in the act of formation, growing and warming from debris in new solar systems.



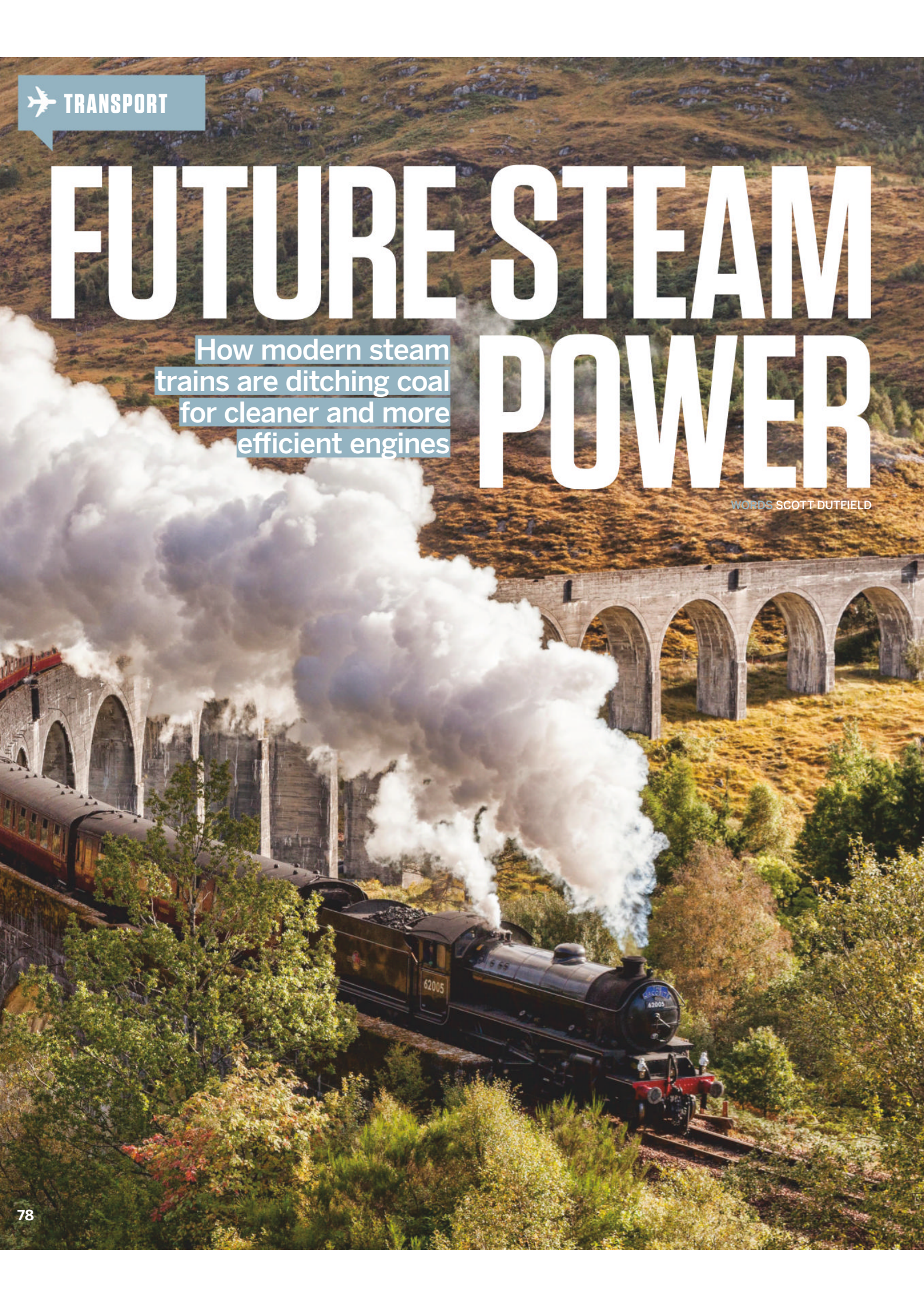
SPACE DUST

Complex organic compounds, including amino acids and sugar, have been detected in space. ALMA has provided crucial insights into the universe's complicated chemistry and helps map the distribution of molecules and dust grains throughout the Milky Way.

FUTURE STEAM POWER

How modern steam
trains are ditching coal
for cleaner and more
efficient engines

WORDS SCOTT DUTFIELD



DID YOU KNOW? The last passenger steam train in Britain ran between Liverpool and Carlisle in 1968

Encapsulated in billowing clouds, steam trains have been trudging around the world's railway systems for around 200 years. To propel them along their tracks, steam locomotives have used the energy released by combusting fuel, such as coal, to heat a boiler of water. As the water heats and generates steam, the pressure inside the boiler increases. Attached to the boiler is a piston mechanism that feeds on high-pressure steam, causing it to move back and forth and ultimately driving the adjoining train wheel. The steam then finds its way out of the train through a chimney in billowing white-grey clouds of exhaust.

Using an external combustion engine, traditional steam trains ran the risk of rogue embers igniting other fuel on the train or damaging the tracks below. To mitigate this risk, the first fireless locomotives were introduced to the world in 1882. Like other steam engines, superheated water was the source of their propulsion, but the water was loaded into the locomotives, preheated and pressurised. This meant that the locomotives could only run for as long as the water stayed hot, or until the water ran out.

Did you know?
America's first steam train lost a race with a horse

During their heyday, steam locomotives were adapted to carry tonnes of freight and move passengers up mountainsides. However, by the 1930s coal-fuelled steam trains were in decline, with diesel and electric-powered trains leading the charge as the modern way to travel. Steam trains haven't disappeared completely, though, remaining in use around the world for both recreational and practical purposes. While the mechanics of steam locomotives remain similar today as they did during the early 1900s, there have been some upgrades to the way they consume fuel. For example, some locomotives have adopted a Gas Producer Combustion System (GPCS) to enhance fuel efficiency. This system reduces the amount of airflow into the firebox and redirects some of the steam from the engine to increase the efficiency of the coal's combustion.

In place of the coal piles of traditional steam trains, many modern locomotives are adopting different types of fuel, such as oil or biofuels. German train manufacturer Dampflokomotiv- und Maschinenfabrik (DLM) has developed steam-powered locomotives that have replaced coal with a 'light oil firing system' to reduce greenhouse gas emissions and provide the

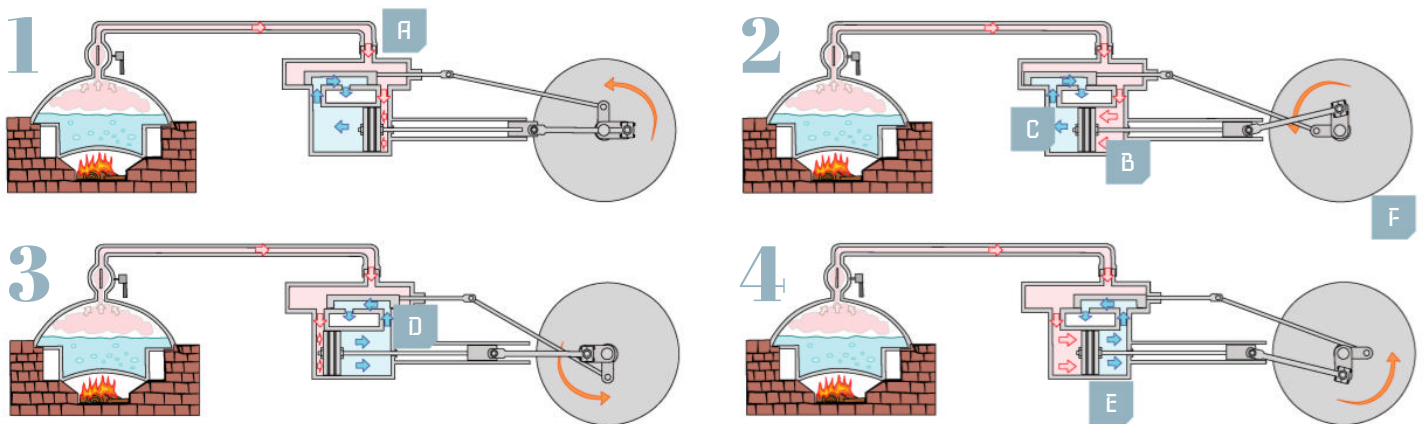
driver with better control of the train. DLM recently completed the conversion of a traditional 99 787 steam locomotive from coal to this light oil firing system.

Researchers are also finding new and interesting ways to keep people's passion for the steam locomotive alive, without the environmental cost of burning coal. At the University of Minnesota's Natural Resource Research Institute (NRRI), scientists have transformed a plant-based material into a carbon-neutral biocoal, known as torrefied biomass. The process of torrefaction requires plant matter, such as wood, to be heated up to around 300 degrees Celsius in the absence of oxygen. The resulting blocks of biocoals release far less carbon dioxide than traditional coal but still burn at a 96 per cent thermal efficiency.

“Many modern locomotives are adopting different types of fuel”

GAINING TRACTION

The physics that move steam trains along the tracks



A STEAM IN
Superheated steam from the boiler enters the steam engine's cylinder behind the piston.

B MOVING THE PISTON
As more high-pressure superheated steam enters the cylinder, the piston is driven forward.

C REMOVING STEAM
Steam from the previous stroke is forced out of the valve and exhausted out of the train's cylinder.

D CHANGING DIRECTION
An arm moves as the wheel turns to open and close the exhaust valve, ensuring that spent steam is removed and superheated gas continually moves the piston.

E TURNING THE WHEEL
To complete a full turn of the train's wheel, the piston is forced backwards by the steam and again exhausts the steam from the previous stroke.

F CONNECTING ROD
The piston is directly connected to a connecting rod that turns the wheel as it is pumped back and forth.

An oil-fired steam locomotive driving up the Brienz Rothorn mountain in Switzerland



THE SCIENCE OF STEAM

How modern steam trains turn boiling water into propulsion

HEILMANN'S STEAM-ELECTRIC LOCOMOTIVE

With an ambition to combine steam propulsion with electrical power, French train pioneer Jean-Jacques Heilmann patented the first locomotive that used a steam engine to generate electricity in 1890. The original Heilmann locomotive, a 16.3-metre-long train, was driven by a two-cylinder steam engine that turned a 400-kilowatt generator for electrical propulsion. A completed locomotive was showcased in 1893 on a test run in Paris. The following year, in a test run carrying 250 guests on the railway network in Compiègne, it reached a top speed of around 67 miles per hour. However, due to the complexity and expense of building trains that used steam and electricity, Heilmann's locomotives weren't further developed or constructed.



An illustration of one of Heilmann's experimental steam-electric locomotives

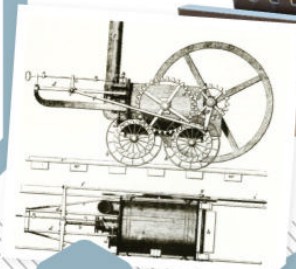


1 FUEL

A light crude oil reservoir feeds fuel into the firebox to be combusted.

2 FIREBOX

Oil is funnelled into the firebox and ignited to generate enough heat to boil the surrounding water-filled boiler.



1804

The first-ever steam locomotive, built by British inventor Richard Trevithick, ran along a track in Wales.

1814

Engineer George Stephenson built the 'travelling engine' – the first practical steam locomotive to ferry coal.

1825

American inventor John Stevens built the first steam locomotive with a multi-tube boiler engine.



1829

Robert Stephenson showcased his steam locomotive called 'the Rocket', which could reach speeds in excess of 30 miles per hour.

STEAM TRAIN EVOLUTION

DID YOU KNOW? The world's largest steam locomotive is 40.5 metres long and weighs over 544 tonnes

3 HEATING WATER

Hot air, produced by the combustion of oil, flows through pipes surrounded by water.

4 CREATING STEAM

Water housed in a tank is heated to more than 205 degrees Celsius to generate steam.

5 SUPERHEATED STEAM

Steam passes through a series of pipes close to the firebox, reaching around 420 degrees Celsius.

Did you know?

The fastest steam train reached 126 miles per hour

8 CHIMNEY STEAM

The steam exhaust and excess heat are vented and released into the atmosphere via the chimney.

6 ENTER THE ENGINE

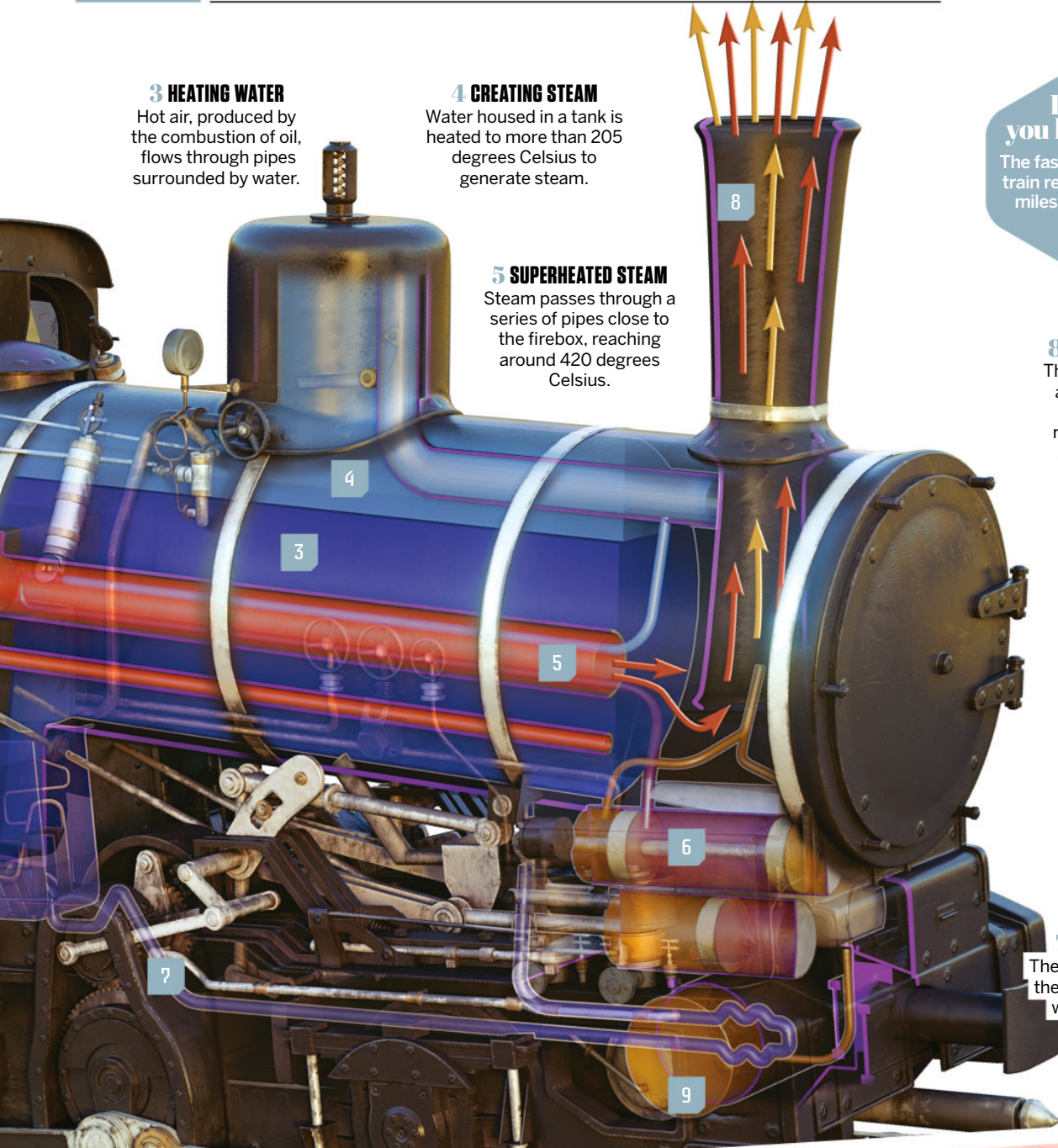
The superheated steam enters the train's piston engine to drive the crankshaft.

9 STEAM BRAKES

Steam produced in the boiler is also used in the train's braking system.

7 TURNING THE WHEELS

The driving rod connected to the engine drives the train's wheels along the track.



1829

The first American passenger locomotive, called 'Tom Thumb', was constructed by Peter Cooper.



1831

The John Bull passenger steam train was the first locomotive fitted with headlights and a 'cowcatcher' to deflect obstacles on the track.



1923

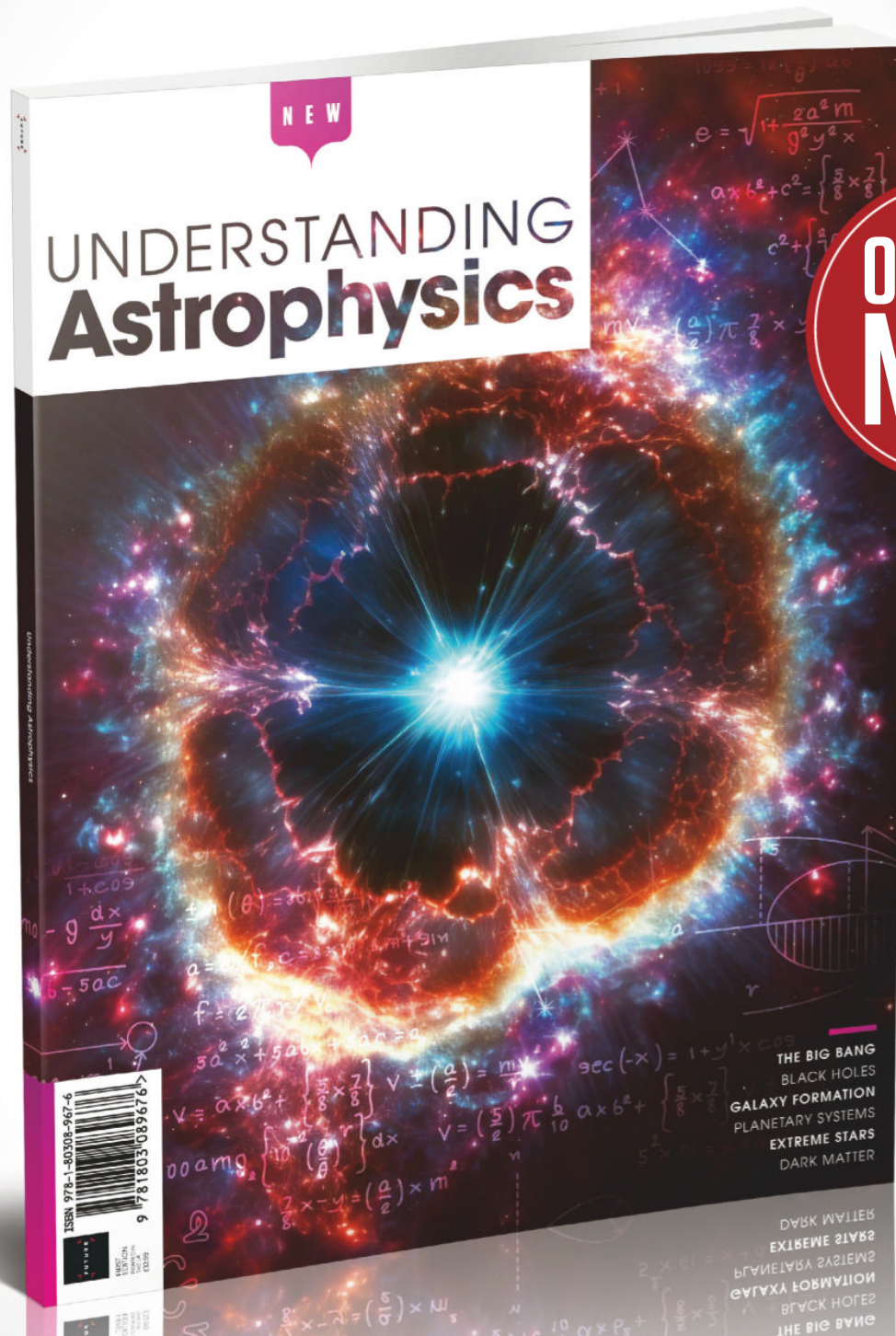
The Flying Scotsman was the first steam locomotive to reach 100 miles per hour.

An example of torrefied biomass, used as an alternative to coal



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IF MY GLASS IS FILLED WITH ICE AND WATER, WILL IT OVERFLOW ONCE THE ICE HAS MELTED?

The mass of the ice cube is roughly the same as that of the water it pushes aside while floating in the glass. When the cube melts, the surrounding liquid can move into the space it filled. If the glass contains only ice and water, it will not overflow because the amount of extra water will be equal to that previously displaced by the cubes.



WHY DO ALBINO ANIMALS HAVE RED EYES?

Eye colour is determined primarily by the brown pigment melanin. Dark eyes have lots of melanin in the iris. Blue eyes only have melanin in a layer on the back surface. Albinos don't even have melanin on the back surface, so the iris is translucent. The red is the haemoglobin in the capillaries at the back of the eye. Albino animals find bright light uncomfortable as their irises can't block as much light as non-albino ones.



HOW IS GLASS ABLE TO BLOCK INFRARED LIGHT?

Infrared light is a form of electromagnetic wave consisting of longer wavelengths than that of visible light. How any light interacts with materials depends on the arrangement of atoms – specifically the arrangement of the electrons – in the material, and the wavelength of the incoming light. Various wavelengths of light have different amounts of energy, and electrons in all materials are selective about which energy will make them absorb light or allow it to pass through. Visible light will not be absorbed by the electrons in glass, so it shines through. Certain wavelengths of infrared light can also pass through glass, but many are blocked as their energy is absorbed.

WHY DO SONGS GET STUCK IN OUR HEADS?

It's a universal truth that most of us can remember, word for word, a certain song, or songs, from our early childhood. It's an extreme example of this question – just what is it that makes a song memorable? It's probably a combination of several factors, including the song itself, which relies on an indefinable gift of talented composers throughout history to construct tunes, lyrics and arrangements that listeners will respond to. However, there are other factors: the context in which we first hear the song, how many times we hear it, any repetition in the song, peer pressure and so on.



Why does ice cream that's melted and refrozen often have ice crystals?

Ice cream is usually made from milk – which contains water, lipids, proteins and lactose – flavourings and sugar. Separate ice crystals are always present in ice cream, but they are so small and numerous that our tongues can't detect them. Ice cream gets its smooth texture in the manufacturing process by being stirred slowly while cooling. Larger ice crystals will form upon refreezing melted ice cream due to the preference of water droplets to join together, and thus form bigger droplets. Mixing while refreezing would help keep the droplets as small as possible, but you should never return thawed ice cream to the freezer anyway, as this is a health risk.

BRAINDUMP

HOW DO DEER KNOW WHEN IT'S RUTTING SEASON?

Rutting season has evolved to ensure that young deer are born in spring when there is more new grass available for lactating mothers. This means the timing of the rut is different depending on the gestation period of each species, but the trigger is the same: shortening daylight hours in autumn. Special cells in the eye that aren't used for vision, called retinal light-sensitive ganglion cells, measure the length of daylight hours. This is relayed to the suprachiasmatic nucleus located in the brain, and when the autumn days get short enough, it prompts the release of the appropriate hormones in males so they start competing for mating rights.



What is a cramp?

A cramp is an involuntary contraction or shortening of muscle, and it's often painful. There are two main kinds of cramps: skeletal muscle and smooth muscle cramps. The former includes leg spasms, which you might call a dead leg, charley horse or corker. Smooth muscle cramps, meanwhile, include menstrual or stomach cramps. Skeletal muscle cramps have many different causes. You can bring them on by straining or overworking a muscle, or failing to stay hydrated when exercising, especially in hot weather. Health conditions like atherosclerosis (hardening arteries) in your legs can be the culprit because the muscles aren't getting enough blood, plus deficiencies in some vitamins and minerals, like potassium, can also trigger this kind of cramp.

WHY IS BROWN BREAD 'BETTER' THAN WHITE?

Some brown breads are merely white breads with added sugars and colourings, and therefore are no better for you at all. The key word to look for is 'whole grain', which means the bread, or flour, contains the germ and bran portion of the grain. Bran provides the fibre, as well as magnesium, vitamin E and essential fatty acids. Fibre improves digestion, lowers cholesterol and, as whole grains take longer to digest than processed ones, helps maintain blood sugar levels, making you feel fuller for longer. Ideally, half the grains you eat every day should be of the whole variety.



WHY DO WE SHIVER WHEN WE'RE COLD?

Although shivering is a universal sign of feeling chilly, it's an evolved response to keep us alive. If the temperature of our internal organs falls below 37 degrees Celsius, we could die of hypothermia. When the brain detects that we are cold enough, it stimulates muscles to jiggle. In moderately low temperatures this creates enough heat to keep our organs from slowing.

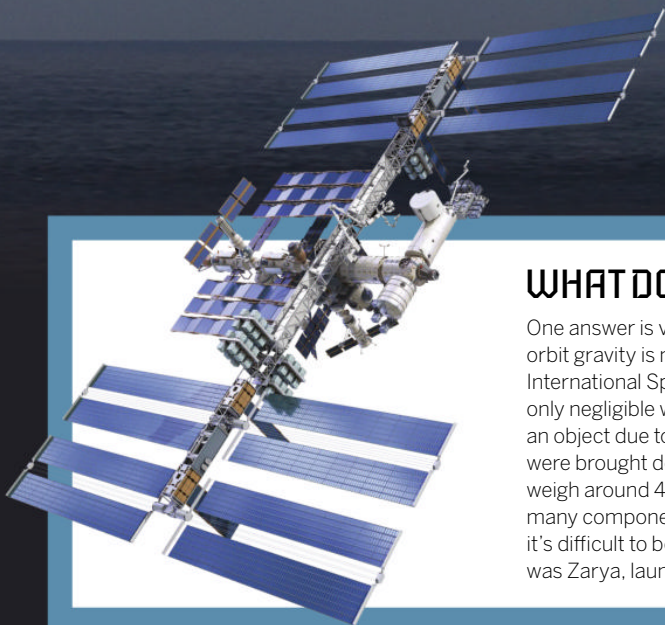


IF I WAS DRIVING AT 60 MILES PER HOUR THE SAME WAY AS A 60-MILE-PER-HOUR WIND, WOULD I FEEL AIR FRICTION IF I STUCK MY ARM OUTSIDE?

Even if the wind was moving at exactly the same speed as you, wind exhibits constant slight changes in speed and direction, giving rise to unpredictable gusts and turbulence. While it may feel calmer than usual, in reality you'd still feel some air resistance from this turbulence.

Can you get sonic booms underwater?

The low density of air makes it relatively easy to go fast enough to cause the pressure changes around a supersonic aircraft that produce a sonic boom. These conditions are far less likely underwater because liquid is denser than air. The speed of sound in water is around 1,500 metres per second. To break the sound barrier, an underwater object would have to go much quicker than a jet and need far greater thrust to force its way through water. In the 1990s, American military researchers briefly fired a submerged projectile at 1,550 metres per second by surrounding the bullet with gas using a method called supercavitation. No boom was reported, however.



WHAT DOES THE ISS WEIGH?

One answer is virtually nothing, as in low-Earth orbit gravity is nearly zero, meaning the International Space Station (ISS) has mass but only negligible weight, defined as the force on an object due to gravity. However, if the ISS were brought down to Earth now, it would weigh around 420 tonnes – although with so many components bolted on over the years, it's difficult to be exact. The first ISS module was Zarya, launched via the Russian Proton

rocket on 20 November 1998. This unit was responsible for propulsion, orientation control, communications and electrical power. It weighed around 19,300 kilograms. Since then 15 more modules and other components have been ferried by various American and Russian missions and installed through over 1,000 hours of extravehicular activities, as well as operations by the ISS' European Robotic Arm (ERA).



WHY DOES MY NOSE TEND TO GET SUNBURNT MORE THAN OTHER PARTS OF MY FACE?

If you're going to get sunburnt, your nose is probably going to be a victim. But is it really because your nose is that much closer to the Sun? No. Your nose might burn faster because of the angle at which you're positioned at the time, or because you're getting a glare off something. But it's more likely you've failed to protect your nose. Sunglasses shield your eyes and the skin around them. A hat keeps the sunlight off your forehead, but not necessarily all of your face, depending on its size. And when putting sunscreen on, your nose often gets neglected.

CAN ANYTHING WITHSTAND THE IMMENSE HEAT OF THE SUN?

The Sun is surrounded by a layer of plasma, in some places reaching up to 3 million degrees Celsius. There are no known materials that can exist as solids,

liquids or gases at such extreme temperatures. Protons, neutrons and electrons can withstand this heat as they are virtually indestructible, but they can only

exist as plasma. If you could somehow get past the corona to the surface of the Sun, where it is 'only' 5,500 degrees Celsius, some liquids could exist.



HOW COME ALL OF THE PLANETS IN OUR SOLAR SYSTEM ARE ON A SINGLE PLANE?

It all has to do with the way the planets, and the Sun, formed. When the Sun was in its early stages about 4.57 billion years ago, the cloud of gas and dust surrounding it began to collapse in on itself. With no other force to counteract that of already-moving matter, the cloud compressed and started to spin faster and faster. This rotation caused the cloud to flatten out into a disc called a solar nebula. Scientists believe that the planets formed in this disc through accretion, a process by which the grains of dust and clouds of gas slowly

clumped together, which then collided with one another to form baby planets.

Just keep in mind that being in the same orbital plane doesn't mean that everything is nice and neat. Each planet has a different-shaped orbit – some are incredibly ovoid, in fact – and there are big variations in the distances between the orbits and speeds of each. The inner planets, for example, orbit the Sun much faster than the outer ones, and they're relatively bunched together in comparison, too.



Will we ever have floating cars?

Believe it or not, there have been flying cars already. The first that actually worked was the Fulton FA-2 Airphibian in 1946, and was not so much a flying car as a driving plane, with detachable wing and tail sections. It failed to find commercial backing, as have all flying car prototypes, for a variety of reasons, not least the massive infrastructure changes they would require. Most modern transport systems are based on exclusivity – cars go on roads, trains on tracks, planes in tightly controlled air corridors. The idea of one

type of vehicle crossing into another's space would require whole new systems of planning, signalling and policing. This is not to say governments have not been developing technologies that could be used in flying cars. The most impressive was the VZ-9 Avrocar, whose distinctive saucer shape suggests that similar top-secret technology may have been behind the 1947 Roswell alien sightings. However, without truly massive investment, the flying car will remain the stuff of science fiction for the time being.

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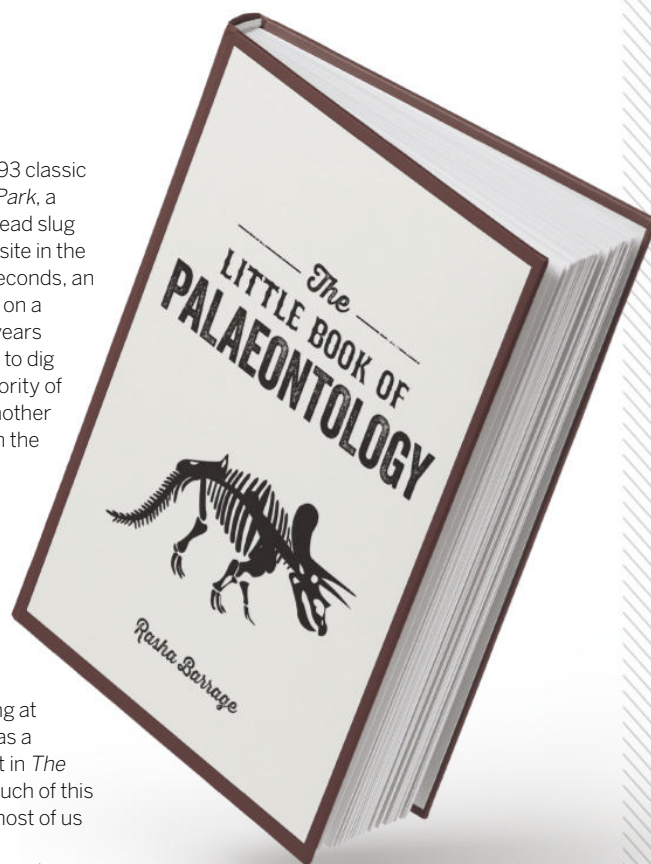
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In an early scene of the 1993 classic dinosaur movie *Jurassic Park*, a palaeontologist shoots a lead slug into the ground at a fossil site in the South Dakota badlands. After a few seconds, an image of a dinosaur skeleton appears on a monitor as he declares: "A few more years development and we won't even have to dig anymore." At the time, and to the majority of us without a PhD, this sounded like another wild yet fun crumb of science fiction in the *Jurassic Park* universe. But 30 years later, microcomputed tomography scanning has advanced to the point where we can look inside rocks and fossils to make highly detailed three-dimensional images of the fossilised bones and structures within. And because none of the *How It Works* team are close friends with dinosaur professionals or moonlighting at dig sites around the world, this fact was a surprise to us when we encountered it in *The Little Book of Palaeontology* – as is much of this pithy introduction to a vocation that most of us have little to no experience of.

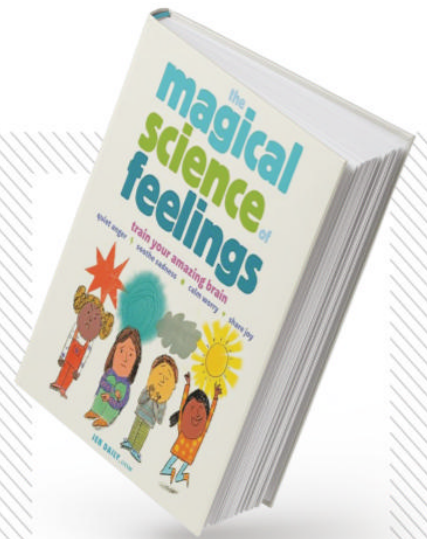
Author Rasha Barrage isn't a palaeontologist. In fact, she studied law and was a practising lawyer for many years, which in some ways has made her very well suited to writing this entry-level guide – diligent research and plain language being key to convincing a jury. She engages the reader in a series of bite-sized explanations of the different vertebrates, invertebrates and plants that could be found in the age of the dinosaurs. In a loose chronology, she moves onto palaeoanthropology – the study of humans and their origins through the fossil record – before wrapping it all up with a timeline and conclusion.

Some of the most interesting passages of this book concern the history of palaeontology and our appreciation of fossils: as little as 200 years ago, we had scant understanding of what the



strange and fantastic specimens were that people were pulling out of rocks. They were often believed to be the bones of large crocodiles and mythical creatures, or even the remains of the animals that didn't make it onto Noah's Ark. *The Little Book of Palaeontology* is peppered with as many of these kinds of historical anecdotes as it is dinosaur stats and facts. It's a quick, interesting and accessible book that's sure to put anyone on the path to finding a more in-depth read on palaeontology.

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RELEASE 27 JUNE

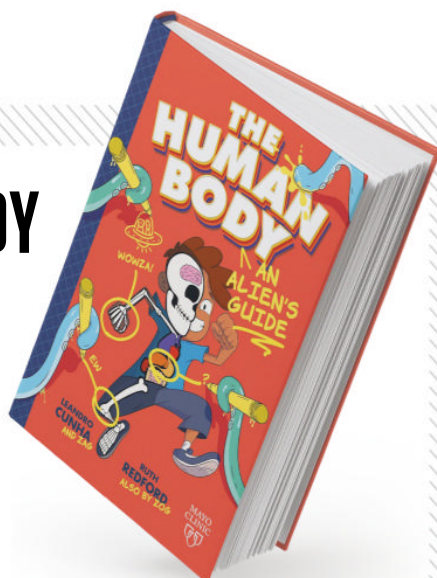
By turning our emotions into science that children can grasp, this book makes for a great tool to help them understand why they feel the way they feel. With the help of four fun characters, children will learn all about the parts of the brain that help it process our emotions. There are also a heap of activities, called 'emotion potions', to do at home, such as how to make sadness goo or an anger volcano as a way to conceptualise feelings interactively. From explaining simple happiness to the more complex emotions of feeling overwhelmed or worried, this book can give children a way to explore their own emotions and learn how to control them.

THE HUMAN BODY

AN ALIEN'S GUIDE TO OUR
ORGANS AND THEIR
FUNCTIONS

AUTHOR RUTH REDFORD
PUBLISHER MAYO CLINIC PRESS
PRICE £7.99 / \$9.99
RELEASE OUT NOW

This playful graphic novel follows two aliens journeying through the human body as one attempts to educate the other about its many systems and parts. Zipping through the body and exploring its skeletal, cardiovascular and nervous systems, the pair uncover human biology, which to them seems incredibly strange. For a fun, light-hearted and humorous children's book with an educational twist, this alien's guide packs a punch when it comes to turning interesting science into



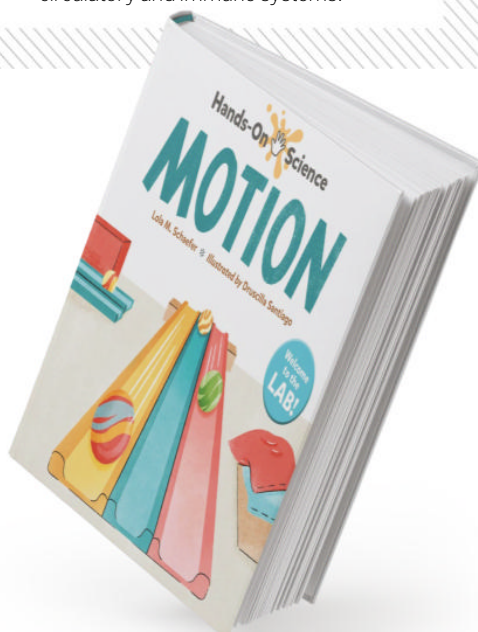
an engaging narrative. There are heaps of snappy facts and stats to discover throughout, such as the fact that 200 muscles are required to take a single step. The charming graphics throughout not only move the story along but are brilliantly used to illustrate different systems in the body, like the blood capillaries and immune cells of the circulatory and immune systems.

HANDS-ON SCIENCE: MOTION

WELCOME TO THE PHYSICS LAB

AUTHOR LOLA M. SCHAEFER
ILLUSTRATOR DRUSCILLA SANTIAGO
PUBLISHER CHARLESBRIDGE
PRICE £15.99 / \$16.99
RELEASE 27 FEBRUARY

This cleverly produced, hands-on picture book is the perfect choice for children who prefer to learn through activities and experiments, without requiring any extra materials or apparatus. That's right, *Hands-On Science: Motion* is all the material you will need. Each page comes with clear instructions for the reader so that when they turn the page, they can see what their imaginary action has done. The realistic imagery will make young children between the ages of four and eight feel like they really have poked, tilted and shaken the illustrated materials off the page. The subtle movements that the reader needs to make with or on the book are explained succinctly so that children will be able to carry out each virtual activity without being confused. Just by slightly tilting the book towards their toes and turning the page, they will learn how two bean bags on different surfaces are impacted by



friction and gravity. As you turn the 'physics lab door' page at the end of *Hands-On Science: Motion*, an outdoor scene shows some of the physical forces you have just experimented with taking place in daily life.

This book is a mess-free introduction to simple physics that will help young readers better understand every action that occurs around them. And if this interactive read has put you in the mood for a practical experiment, there are instructions at the end for a real-life simple physics experiment with materials you may already have in the home.

SEA SMILES

INSIDE THE
MYSTERIOUS
MOUTHS OF
THE OCEAN

AUTHOR AND ILLUSTRATOR
BONNIE KELSO
PUBLISHER GNOME
ROAD PUBLISHING
PRICE £14.99 / \$18.99
RELEASE 13 FEBRUARY

When a child loses a tooth, they can become insecure. Why do we lose our teeth as children? And how do human teeth compare to those of the animal kingdom? In *Sea Smiles*, Bonnie Kelso combines comedic cartoons and fascinating facts to answer these questions and make any young reader proud to show off their teeth. Hearing about an animal that can go through 20,000 teeth in its lifetime will help make a single loose tooth feel much less overwhelming. Throughout the book, the main character meets an array of animals from the sea, who each teach her about the different ways their fangs, tusks and not-so-pearly whites help them survive. From penguins with fleshy spines that coat their tongues to the giant tusk that grows from the skull of the narwhal, this book provides a peek into the dentistry of usually hidden mouths.



BRAIN GYM

Give your brain a puzzle workout

Sudoku

Complete the grid so that each row, column and 3x3 box contains the numbers 1 to 9

EASY

		8	5	9	2		4	7
2	1	4	3	7	6			
9			1		6	3	2	
				9	7		6	
1			3			5	4	
8	7		4	5				
	6				2	7		
		3	9	6	5		8	
4	8	1					6	

MEDIUM

1	9	7	8		4			
3		8	6			7	9	5
6	2		9		7		4	
	7		5	1	6		2	
							6	7
	6	4					8	
				3	8			
2			9					
7			8					4

HARD

	9	4		3				7
		2						5
		3	5	1		6	2	4
2			9					
3		5		7			1	9
	6							
		7					4	
					2			
		9	4	5				



Word search

Find the following words

DINOSAUR
STAR
SETI
ALIEN

STEAM
DRONE
SEASON
BRAIN

GLASS
FLAME
SPACE
RIVER

D	R	A	I	N	E	A	S	I	V	O	R	U	W	S
P	Y	L	X	E	C	K	M	O	G	L	A	F	H	E
N	R	I	D	I	N	O	S	A	U	R	P	E	I	A
D	I	N	A	R	S	I	E	N	A	M	E	C	Q	S
P	L	A	G	T	O	A	R	B	A	C	O	A	L	O
G	U	E	R	K	R	N	T	I	K	I	U	P	N	N
E	C	A	P	B	S	W	E	P	C	A	O	S	B	F
N	U	J	S	D	S	R	I	V	E	R	U	L	B	N
E	T	P	T	E	A	D	R	O	N	S	S	A	L	G
I	Y	V	A	S	T	Q	A	H	M	A	I	L	C	B
L	F	W	R	O	S	H	E	A	M	T	O	F	I	N
A	N	K	A	S	E	T	L	F	E	L	M	A	S	T
S	E	A	S	O	M	Y	Z	S	A	P	O	T	H	D
D	I	F	L	A	M	E	N	O	S	A	U	R	E	X
E	R	B	O	T	S	T	E	A	M	K	U	L	V	S

What is it?

Hint:
Little insect,
big jump

A



Spot the difference

See if you can find all six changes between the images below



QUICKFIRE QUESTIONS

Q1 What did Benjamin Franklin discover with his famous kite experiment?

- Oxygen
- Air resistance
- Electricity
- Kite surfing

Q2 How many litres of water can an oyster filter daily?

- 5
- 50
- 500
- 5,000

Q3 How fast can the world's fastest elevator ascend?

- 5 metres per second
- 11 metres per second
- 18 metres per second
- 21 metres per second

Q4 What are bats mostly immune to?

- Radiation
- Snake venom
- Viruses
- Acid

Q5 How hot can it get on the Moon's surface?

- 20 degrees Celsius
- 20 degrees Celsius
- 50 degrees Celsius
- 120 degrees Celsius

Q6 What organs do starfish have on the tips of their arms?

- Brain
- Liver
- Eyes
- Taste buds

Answers

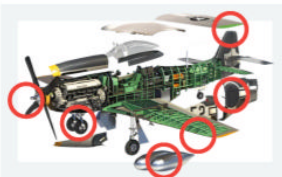
Find the solutions to last issue's puzzle pages

- Q1** PHOTON
- Q2** MELON
- Q3** RADIO
- Q4** 80 PER CENT
- Q5** GOLD
- Q6** MERCURY



What is it?
LED LIGHT

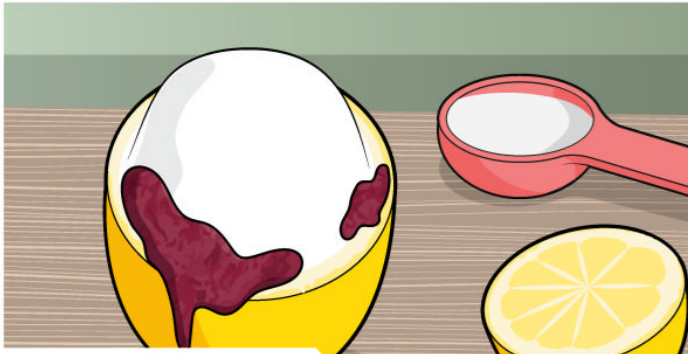
Spot the difference



KIT LIST

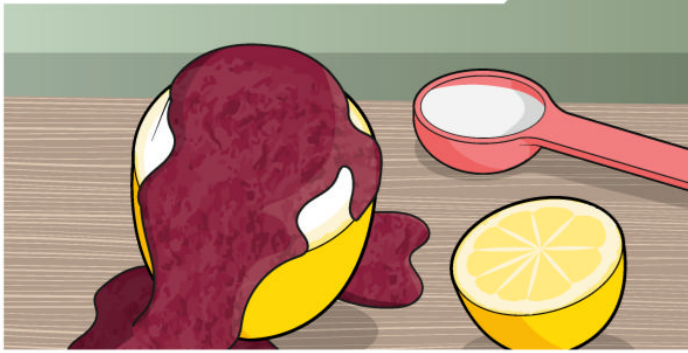
- Large tray
- Lemons
- Baking soda
- Cutting knife
- Butter knife
- Spoon
- Measuring cup
- Food colouring

DON'T DO IT ALONE!
 If you're under 16, make sure you have an adult with you

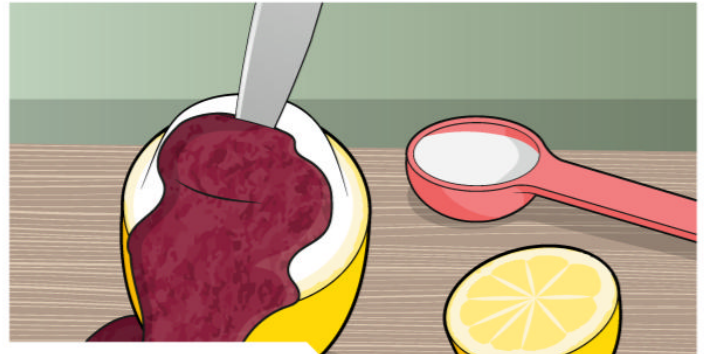


7 INITIAL REACTION
 How quickly does the lemon start to foam? Watch the initial eruption beneath the pile of powder.

9 OVERFLOWING BUBBLES
 The volume inside the lemon should increase when mixed, causing the foam to spill out like lava. Keep mixing and adding baking soda until the reaction stops.



10 EXPLOSION OF COLOUR
 Depending on how many lemons and other citrus fruits you are able to use, experiment with new colours and compare the chemical reactions of different citrus fruits.



8 MIX THE CONTENTS
 Use a butter knife to mix in the baking powder and increase its contact with the fruit.

SUMMARY

The sour taste that lemons are famous for is produced by their high citric acid content. This acidic compound has a high concentration of hydrogen ions, which our taste buds interpret as a sour taste. The hydrogen ions are positively charged, making the electric charge unbalanced. Because of this, the acid easily releases its hydrogen ions. By contrast, baking soda is a base – an alkaline compound that has a high concentration of negatively charged hydroxide ions. When the lemon (acid) and the baking soda (base) come into contact with each other, an acid-base chemical reaction takes place as the base neutralises the charge of the acid. During this reaction, carbon dioxide gas is released as a byproduct. The gas produces bubbles in the liquid as it escapes, increasing the volume of the lemon and creating the overflowing dyed foam that pours out in a dramatic eruption.

Had a go? Let us know!

If you've tried out any of our experiments – or conducted some of your own – let us know! Share your photos or videos with us on social media.

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Dogs don't understand that their reflection is themselves

DOG IDENTITY

Dear HIW,

Do dogs know they are dogs if they only interact with human owners?

Chris Holligan

The mirror test is one way of testing whether an individual recognises itself in the mirror and knows what they look like. A mark is put on the animal before they are placed in front of a mirror. If they look at or touch the mark on their own body, they know the reflection is them. Dogs fail this test, but their sense of smell is better than their sight, and they are able to identify other dogs' scents and their own.

PLANE PAIN

Dear HIW,

I would like to know why my ears hurt when I take off and land when travelling in a plane. What can I do to stop this from happening? Also, why are only certain people affected?

Karen Wharton

This ear pain is caused when the air pressure inside and outside the ear don't match. A narrow passage inside the ear, called the eustachian tube, controls the internal air pressure. But when a plane quickly changes altitude during ascent and descent, the external pressure changes too quickly for the ear to adjust, and the eardrum is pulled due to the imbalance. This is what causes the earache. Any condition that blocks the eustachian tube or prevents it from working properly makes a person more likely to suffer from this pain during flights.

f X i
WE ASKED YOU

This month on social media, we asked you:
If you could achieve a world first, which record would you claim?

@AESTHETICALLY_RJ
TO DISCOVER A NEW SPECIES OR DISCOVER A PREVIOUSLY THOUGHT EXTINCT SPECIES
JAMES LENTON
FIRST TO MAKE A SUCCESSFUL TELEPORTATION MACHINE

@????FATEMEH????
FIRST HUMAN TO LAND ON THE MOON, OR ON MARS, IN THE FUTURE
STEVEN P
DISCOVERING A UNIVERSAL CANCER CURE

@FATEMEH?FOR?
FIRST PERSON TO EXPLORE PYRAMIDS
CARRA MARTIN
THE FIRST TO VISIT A NEW PLANET

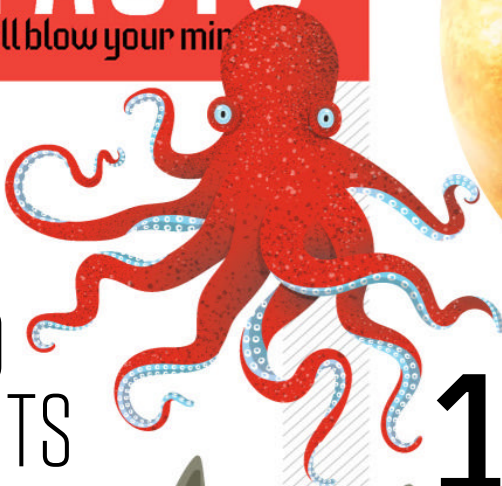
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© International Animal Rescue / Getty

FAST FACTS

Amazing trivia that will blow your mind

OCTOPUSES
HAVE NINE
BRAINS AND
THREE HEARTS

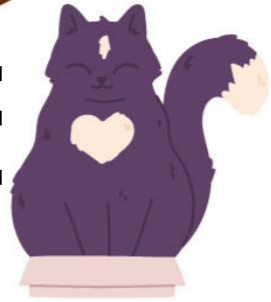


243 DAYS

A single day on Venus is nearly as long as an Earth year

1233 CE

In the 13th century, Pope Gregory IX decreed that cats were agents of the devil



Sphenopalatine ganglioneuralgia is the scientific term for brain freeze



25%

A basking shark's liver is one-quarter of its body weight

1957

Sputnik 1, the first satellite, launched over 60 years ago

1 IN 100

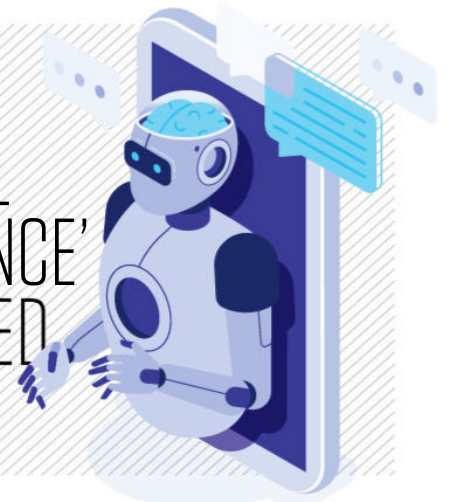
Just one per cent of the population has the AB negative blood type

227 TRILLION LITRES

A gas cloud 6,500 light years away contains a massive amount of alcohol



THE TERM 'ARTIFICIAL INTELLIGENCE' WAS COINED IN 1956



0.3 MILLIMETRES

The world's smallest computer is the same size as a grain of sand

IF I HAD SOMEWHERE TO LIVE...

I COULD GO ANYWHERE IN LIFE



When Abi's mum died, life got tough. She didn't get on with her dad and the arguments became violent. Abi felt her only choice was to leave home. With just the clothes on her back, and no idea where to go, she ended up sleeping on the streets in the freezing cold.

Right now, you could give a homeless young person like Abi somewhere to start their future

Abi's life changed when she was given a room at Centrepoint. A safe place to sleep and recover. A place to develop the skills and confidence she needed to rebuild her life – and leave homelessness behind for good. Now, Abi believes she can go anywhere.

Thousands of homeless young people like Abi are desperately trying to find their place in the world – but first they need a place to start again. **You could help right now by sponsoring a room at Centrepoint for just 40p a day.**

We know this support changes lives. 88% of the young people we help move on positively in life. So please, help someone like Abi today. **Thank you.**

Text **PLACE** to **78866** to donate **£3**

Call free on **0800 472 5798**

Visit **centrepoint.org.uk/place**

Or **complete and return the form below**



SPONSOR A ROOM. HELP A HOMELESS YOUNG PERSON FIND THEIR PLACE.

YES, I WANT TO SPONSOR A ROOM FOR £12 A MONTH

Please collect my payment on the 1st/15th of every month (please circle preferred date).

Instruction to your Bank or Building Society to pay by Direct Debit

To the Manager:
Name and full address of your
Bank or Building Society: _____
Originators Identification No.

Postcode _____

Name(s) of Account Holder(s) _____

Bank Sort Code: - - Account Number:

Instructions to your Bank or Building Society: Please pay Centrepoint Direct Debits from the account detailed in this instruction, subject to the safeguards assured by the Direct Debit Guarantee. I understand that this instruction may remain with Centrepoint and, if so, details will be passed electronically to my Bank/Building Society.

Signature(s) _____ Date _____

Banks and Building Societies may not accept Direct Debit Instructions for some types of account.

Increase your donation by 25p for every £1 you donate with Gift Aid *giftaid it*

By ticking this box I confirm I am a UK taxpayer and want Centrepoint to Gift Aid all donations I've made in the last four years and any donations I make in the future until I notify you otherwise. I understand that if I pay less Income Tax and/or Capital Gains Tax in any tax year than the amount of Gift Aid claimed on all my donations it is my responsibility to pay any difference.

Your name and address are needed to identify you as a current UK taxpayer.

Your donation will go towards funding Centrepoint's vital work with young people all year round providing accommodation and support. We sometimes use models and change the names of the young people we work with to protect their identity; however all stories are true and as told by the young person.

Full Name: _____

Address: _____

Postcode: _____ Telephone: _____

Email: _____

Thank you for donating to Centrepoint today.

We'd love to show the impact of your support and share how young people continue to need your help, through newsletters, fundraising appeals and information about events. Please let us know how best to stay in touch with you by adding your details above, and ticking the relevant boxes:

Please contact me by email **Please contact me by phone**

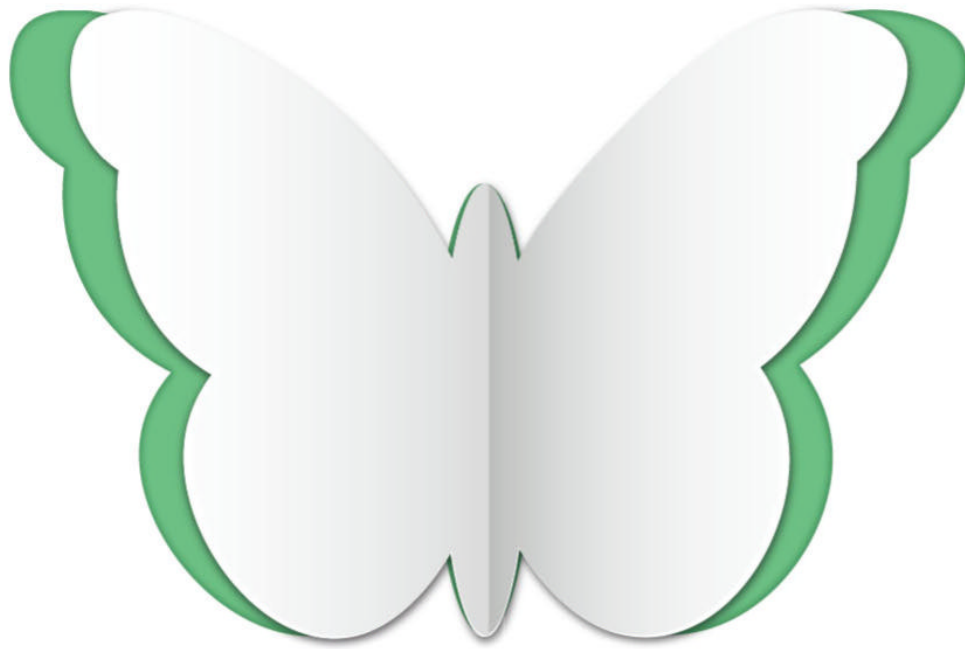
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Source: FAO and UNEP, The State of World's Forests, 2020



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