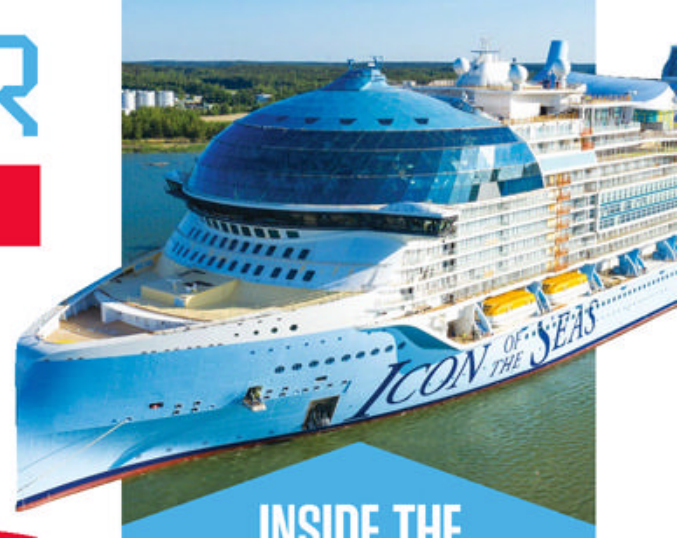
HOW EARTH GOT ITS WATER

HOW IT WORKS™



INSIDE THE WORLD'S BIGGEST CRUISE SHIP

HOW DOES SANTA DELIVER PRESENTS IN ONE NIGHT?

20 CHRISTMAS SCIENCE questions answered

...AND HOW TO MAKE FAKE SNOW

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FUTURE
ISSUE 184

WELCOME

Issue 184

"Father Christmas needs to travel around the globe at around 930 miles per second"

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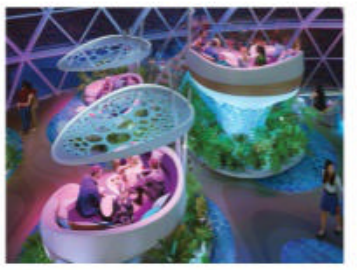

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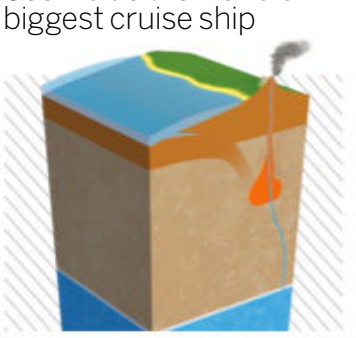

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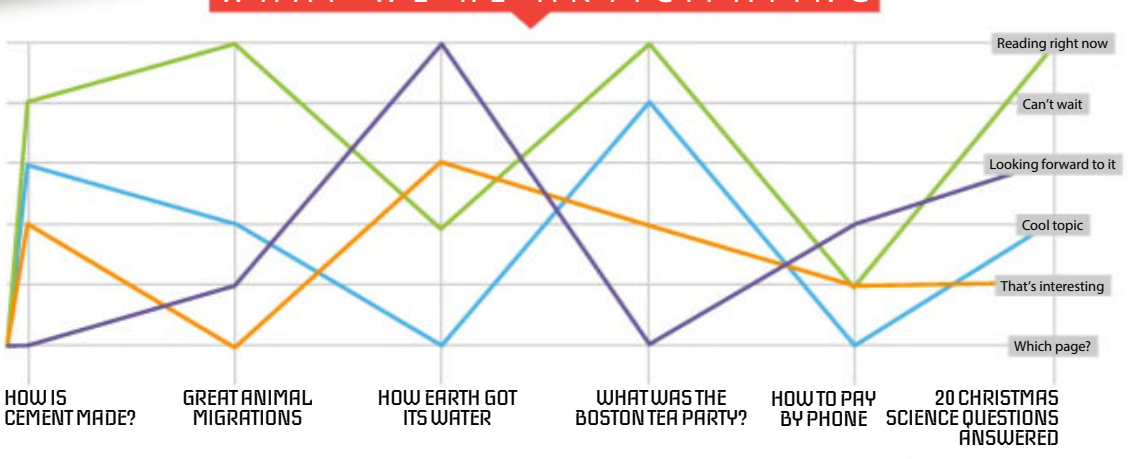
Where did all of Earth's water come from?

It shouldn't come as much of a surprise that one of the world's fastest ground vehicles is a maglev train, which uses supercooled electromagnets to travel almost friction-free along a cushion of air at nearly 400 miles per hour. It's one of several advanced technologies that Santa might employ in delivering presents to billions of children around the world in one night – a feat that has stumped scientists ever since Father Christmas began his annual rounds. In this issue of **How It Works**, we're celebrating the festive season in the way we best know how by exploring the science and technology of Christmas. Ever wondered how baubles are made, the best way to make a snowman or how Santa fits all those presents in a sack? Turn to page 26 to find out. Enjoy!

Ben Biggs
EDITOR

WHAT WE'RE ANTICIPATING



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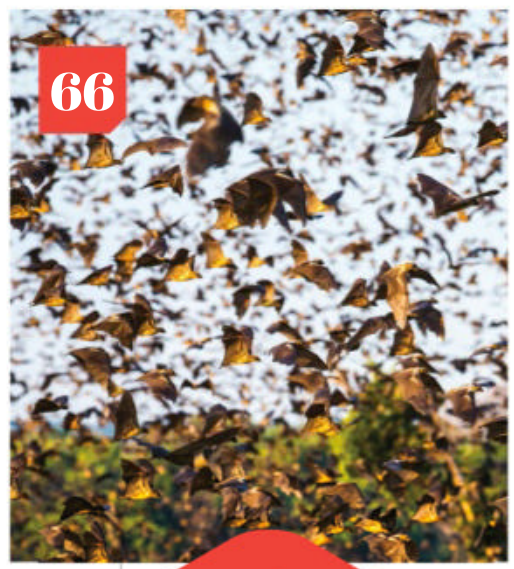

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SCIENCE AND TECHNOLOGY KITS WORTH £150
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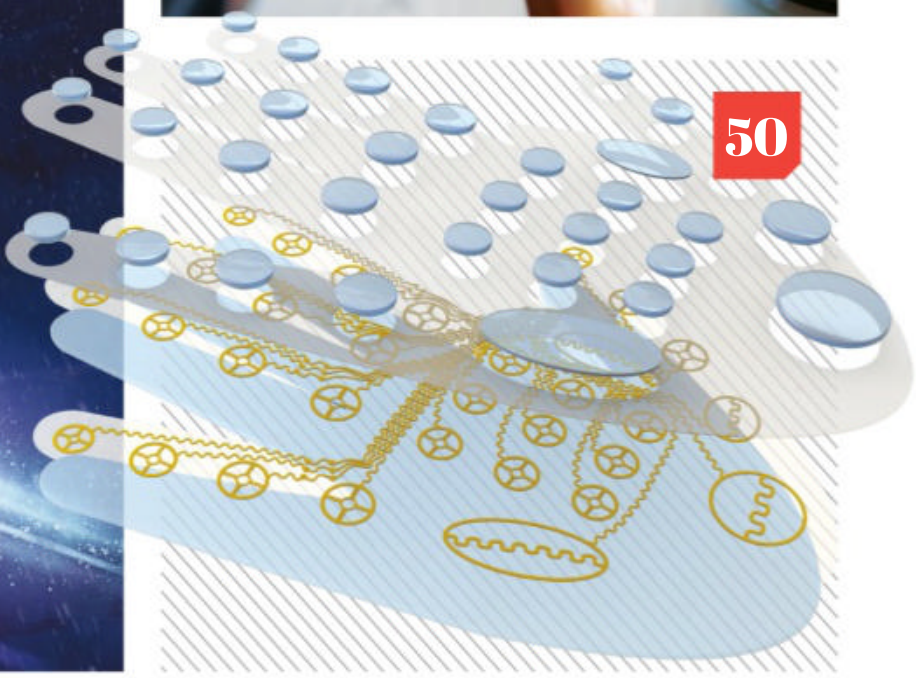
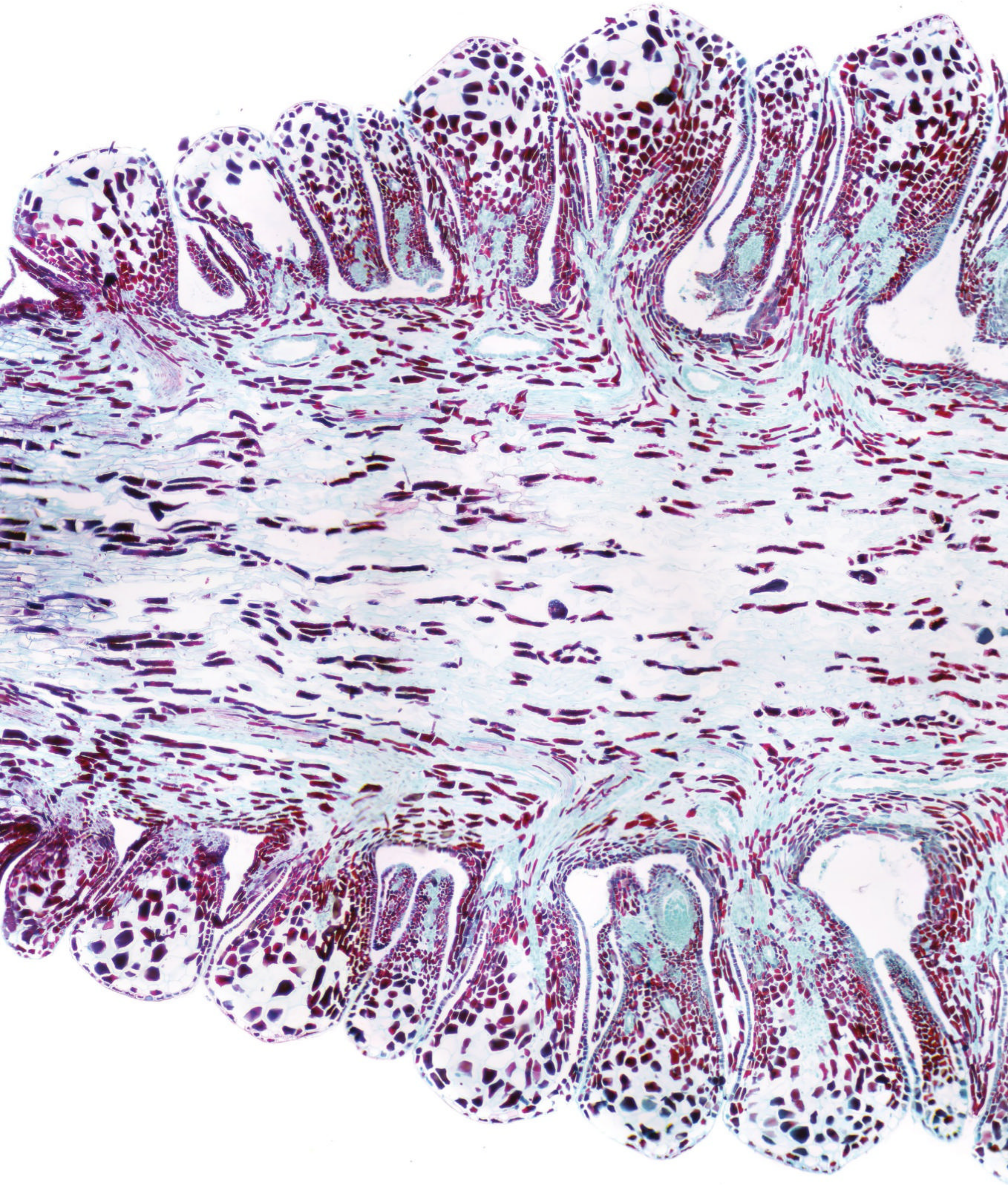




Pine cone close up

This microscopic view shows a cross-section of a female pine cone. Pine cones are either pollen-releasing males or seed-growing females. Seeds develop within the pine cone's ovules, which are the light-blue areas in this image. When the seeds are ready to emerge from the cone, they travel past the cone's woody petals, called ovuliferous scales, and fall onto the soil to germinate.

Heavenly nebula

Around 2,000 light years away is an angelic star-forming region called Sharpless 106. Found in the constellation of Cygnus, the winged shape of this nebula is caused by a newly formed star at its centre called S106 IR. The infant star is only 100,000 years old and forms cosmic winds of hydrogen gas and dust – illuminated in blue in this image – that travel at speeds of more than 124 miles per second.

Mountainside Christmas tree

Each Christmas in the Italian town of Gubbio, an enormous tree made of light is constructed on Mount Ingino. Towering over 640 metres tall, more than 550 lights are used to make the tree, and around five miles of electrical cable are needed to power the lights. Gubbio has been transforming Mount Ingino into one of the world's largest 'trees' since 1981.

Penguin party

Located in Antarctica's remote Weddell Sea is Snow Hill Island, which 4,000 emperor penguins call home. This penguin colony is one of 66 known colonies in the world. Many of the penguins in this image are juveniles, only a few months old. Having hatched around July, by December the chicks will lose their fluffy grey plumage and develop watertight black feathers, ready for life out in the freezing waters.

GLOBAL EYE

Showcasing the incredible world we live in

A caterpillar's extra legs appear to originate from primitive crustaceans

ANIMALS

Caterpillars evolved chubby little 'prolegs' from crustaceans

WORDS **RICHARD PALLARDY**

Scientists have finally figured out where caterpillars got their extra sets of legs from. Turns out these chubby little limbs originate from their crustacean ancestors over 400 million years ago. Insects have six legs, except when they don't. Caterpillars, the larvae of butterflies and moths, have additional sets of limbs known as prolegs. These prolegs pose an evolutionary mystery, and scientists have long grappled over how and why they got them. A new study suggests that these prolegs have origins in the primitive crustaceans that insects evolved from during the Ordovician period.

Prolegs are unjointed and feature sets of gripping hooks that function like spiky suction cups. Some species have as many as nine pairs. Unlike the six legs that most insects have, which extend from the thorax, or midsection, prolegs emerge from the abdomen. Their movement is mostly powered by hydraulic pressure, the movement of liquid into each limb. "Caterpillars are just eating tubes. They are maximising their eating and growth potential so they have evolved a gut-based body plan with a few legs to support the gut," said Antonia Monteiro, an evolutionary biologist at the National University of Singapore. "Prolegs help them either grab onto substrates while the other legs help them feed or move them along the substrate." After the caterpillar metamorphoses, the prolegs disappear.

Scientists have previously proposed that prolegs relate to thoracic legs, saying they are extra sets of legs that disappeared over the span of insect evolution and were reactivated when they became useful again. Another hypothesis is that they are modified endites, internally facing leg structures that were apparent in ancestral crustaceans. Scientists tested the manner in which genes direct the growth of these appendages by altering the embryonic development of squinting bush brown butterflies (*Bicyclus anynana*). In doing so, they hoped to determine which of these hypotheses, if any, was valid. By disrupting a gene that stipulates the placement of limbs and other structures while the larva is still in the embryonic stage, the researchers were able to elucidate the pathways by which prolegs develop. When the gene was partially disabled, precursors to typical legs, as well as prolegs, developed on the caterpillar's abdominal segments. When it was fully disabled, only the precursors to typical legs were present.

Because both types of limb were present when the gene was partially disabled, the researchers demonstrated that prolegs do not develop from the same types of cells as thoracic legs. They seem to be modified endites. As crustaceans evolved into insects, endites were largely lost. But in butterflies and moths, the gene for them got reactivated, providing caterpillars with prolegs. The only other place that endites appear to persist in insects is in the mouthparts – the mandibles, maxillae and labium – which are actually modified legs themselves. So structures that trace back to the crustacean ancestors of insects have been evolutionarily repurposed multiple times and for multiple functions, helping very hungry caterpillars move their ponderous bodies and sate their formidable appetites.

Did you know?

The atlas moth caterpillar can grow up to 12 centimetres

Woolly mammoths were living on the Russian mainland until around 10,000 years ago

ARCHAEOLOGY

GIRL DISCOVERS 100,000-YEAR-OLD MAMMOTH BONES IN A RIVER

WORDS **RICHARD PALLARDY**

An eight-year-old girl in Russia has discovered a set of mammoth leg bones, as well as a vertebra from a prehistoric bison, while fishing with her father along the shores of the Oka River near Novinki in western Russia. Maryam Mirsaitova noticed a series of strange objects that had been unearthed by a recent landslide. Her father sent photographs to the nearby Nizhny Novgorod Museum-reservation in the hope that researchers might identify her discoveries. As it turned out, she'd found the condyle, or knee joint, and lower tibia of a woolly mammoth (*Mammuthus primigenius*). The bones were reasonably well preserved, with spongy tissue exposed by degradation in the sediment. The size of the bones indicates that they belonged to a large adult mammoth. The researchers suggested the animal likely lived around 100,000 years ago.

Woolly mammoths were common in the frigid northern regions of Europe and Asia beginning around 700,000 years ago, and later in the northern US around 100,000 years ago. In the region where Maryam found the fossils, mammoths likely persisted until about 10,000 years ago, when the end of the ice age caused these cold-adapted megafauna to lose their habitat and food sources.

PLANET EARTH

Scientists finally discover a 'lost continent'

WORDS **SASCHA PARE**

The mystery of what happened to a lost continent that seemingly vanished 155 million years ago may have finally been solved after scientists unearthed evidence of the landmass and retraced its steps. It turns out the lost continent, known as Argoland, had a messy divorce from Western Australia. It disintegrated as tectonic forces stretched the landmass out and drove it away from the rest of the continent before scattering it across Southeast Asia.

Researchers have long known that a landmass rifted from Australia 155 million years ago thanks to clues left in the geology of a deep ocean basin known as the Argo Abyssal Plain off the country's northwest coast. But unlike India, which broke off the ancient supercontinent Gondwana 120 million years ago and still forms an intact landmass today, Argoland splintered into fragments. And until now, scientists were left scratching their heads as to where those continental fragments ended up. "We knew it had to be somewhere north of Australia, so we expected to find it in Southeast Asia," said Eldert Advokaat, a researcher in the department of Earth sciences at Utrecht University in The Netherlands.

In the new study, Advokaat and his colleagues reconstructed the breakaway continent's journey. The researchers found fragments of ancient land scattered around Indonesia and Myanmar, but when they tried to reconstruct Argoland out of these fragments, "nothing fit," he said. The team then worked backwards, gathering evidence in Southeast Asia to retrace Argoland's northward journey. Amid the scattered fragments of ancient land, they discovered the remnants of small oceans dating to roughly 200 million years ago. These oceans likely formed as tectonic forces stretched and fissured Argoland prior to the 3,100-mile-long landmass breaking off.

"That process goes on for 50 to 60 million years, and around 155 million years ago that whole collage of these ribbon continents and intervening oceans starts drifting over to Southeast Asia," Advokaat said. "We didn't lose a continent; it was just already a very extended and fragmented ensemble." To reflect this, Advokaat and his colleagues referred to Argoland as an 'Argopelago'.

Their reconstruction of the continent's history may shed light on the region's past climate, which would have cooled as oceans formed between the shreds of Argoland. As fragments of Argoland collided with landmasses in Southeast Asia, they also shaped the rich biodiversity we see today. This could help explain the uneven distribution of species along an invisible barrier that runs through Indonesia. Overall, piecing together Argoland is a springboard for new research.

Researchers may have finally solved the mystery of what happened to the lost continent Argoland

© Getty

Icicles hang from a melting iceberg on Petermann Island in Antarctica

Did you know?

Winds can reach up to 200 miles per hour in some parts of Antarctica

PLANET EARTH

The collapse of the West Antarctic ice sheet is 'unavoidable'

WORDS **SASCHA PARE**

The rate at which the West Antarctic ice sheet is melting will accelerate over the coming decades and is now an unavoidable consequence of climate change. Even if countries manage to cap greenhouse gas emissions and limit global temperature rise to 1.5 degrees Celsius above pre-industrial levels, the target adopted by world leaders in the 2015 Paris Agreement, melting will increase three times faster over the rest of the 21st century than it did during the 20th. "It looks like we've lost control of the melting of the West Antarctic ice sheet," said Kaitlin Naughten, a researcher at the British Antarctic Survey. "If we wanted to preserve it in its historical state, we would have needed action on climate change decades ago."

Enough water is locked up in the West Antarctic ice sheet to trigger up to five metres of sea level rise. Currently, the biggest contribution to sea level rise from this region appears to come from floating ice shelves in the Amundsen Sea, which are melting as a result of warmer temperatures in the Southern Ocean. Naughten and her colleagues ran simulations on a supercomputer to predict how much of this melting could still be avoided by reducing greenhouse gas emissions. Taking into account climate events and variability, such as the global effects induced by El Niño, the researchers found little change in the rate of ice loss among four different scenarios outlined in the Paris Agreement.

The three scenarios predicting the lowest rise in mean global temperature – 1.5 degrees Celsius above pre-industrial levels, two degrees Celsius above pre-industrial levels and between two and three degrees Celsius above pre-industrial levels – had nearly identical effects on the rate of melting in the Amundsen Sea. The scenario foreseeing the highest rise in mean global temperature, which is deemed unlikely to occur but would lead to 4.3 degrees Celsius above pre-industrial levels, diverged from the lower three, but only after 2045, when it projected more ice melting than the other scenarios. Until then, estimated melting was comparable for the four scenarios.

The findings are bleak, but predicting the consequences of climate change may help us prepare for them. "The bright side is that by recognising this situation in advance, the world will have more time to adapt to the sea level rise that's coming," Naughten said. Our actions to limit greenhouse gas emissions may not come in time to prevent the collapse of the West Antarctic ice sheet, but slowing the rate of sea level rise is still a vital pursuit.

SPACE

SCIENTISTS DETECT THE FASTEST EVER FAST RADIO BURSTS

WORDS **JOANNA THOMPSON**

Astronomers just found the fastest known radio pulses from outside our galaxy hiding in 30 minutes' worth of radio telescope data. Fast radio bursts (FRBs) are extremely short high-energy pulses of electromagnetic radiation that usually originate outside our galaxy. Most last one-thousandth of a second to three seconds, during which they emit as much energy as the Sun throws out in a day.

Astronomers aren't entirely sure what causes FRBs. There's evidence that at least some of the radio pulses come from magnetars, dense neutron stars with powerful magnetic fields. But astronomers had long suspected that there might be even shorter, quicker FRBs that were going undetected. By analysing 30 minutes of radio data from the Green Bank Telescope, researchers found eight ultrafast FRBs originating from a source 3 billion light years away. Each pulse lasted just ten-millionths of a second or less, the fastest bursts ever detected by far. Now that scientists have proof that these ultrafast FRBs exist, they can search for more. Unfortunately, these blips may prove difficult to find with this method. To spot the eight pulses, the researchers had to break down each second of the telescope's radio-based images into half a million frames.

Artist's impression of the discovery of microsecond bursts at the Green Bank Telescope in the United States

The supercontinent Gondwana was located around Earth's South Pole for around 420 million years

PLANET EARTH

Scientists used a supercontinent to solve a 390-million-year-old 'murder mystery'

WORDS HARRY BAKER

Researchers have finally figured out what happened to a group of marine animals that died out on the ancient supercontinent Gondwana, and the finger points squarely at climate change. It turns out that the so-called Malvinoxhosan biota, an ancient group of water-dwelling animals, disappeared from Gondwana over a period of 5 million years because sea levels gradually lowered. And the climate change that wiped out this animal group has disturbing parallels to the changes happening today. The cause of their disappearance had "remained an enigma for nearly two centuries until now," said Cameron Penn-Clarke, an evolutionary scientist at the University of the Witwatersrand in Johannesburg. "It's a 390-million-year-old murder mystery."

At the time of the extinction, the area near the South Pole was home to Gondwana, which comprised parts of what is now Africa, South America, Australia, Antarctica, the Indian subcontinent and the Arabian Peninsula. Gondwana formed around 600 million years ago with the breakup of the supercontinent Pangaea and began to split apart around 180 million years ago.

Gondwana was home to a wide variety of plants and animals. But some of its least understood residents were the Malvinoxhosan biota. This group, which lived in waters covering what is now South Africa, mainly included trilobites and bivalve-like brachiopods, as well as some molluscs and echinoderms. But they all mysteriously died off between 390 million and 385 million years ago. To get to the bottom of this cold case, the team reanalysed hundreds of fossils belonging to the Malvinoxhosan biota, paying particular attention to the location, depth and geological properties of the rocks that each fossil was found in. This enabled them to piece together a timeline of what happened to the region by sorting it into layers, kind of like sorting through the layers of a cake.

The team found seven to eight key fossil layers of the Malvinoxhosan biota. With each newly added layer of the 'cake', the number and diversity of fossils decreased. After comparing the fossil layers to local sea level data, the researchers noticed that each of the layers corresponded to slight sea level decreases, which turned out to be the 'smoking gun' for these extinction events. These decreases didn't dry up the oceans where these animals lived, but likely triggered climatic changes that the creatures couldn't adapt to.

The researchers think the Malvinoxhosan biota had evolved to survive in cool waters. But the drop in sea level disrupted ocean currents around the South Pole known as circumpolar thermal barriers, which enabled warmer water from the equator to mix with colder southern waters. As a result, the Malvinoxhosan biota "were replaced by more generalist marine species that are well adapted to warmer waters," Penn-Clarke said. The extinction of the Malvinoxhosan biota likely led to a complete collapse of the ecosystem around the South Pole. The area has still not fully recovered those historic levels of biodiversity.

GLOBAL EYE

An illustration of the now-extinct marsupial *Diprotodon*

ANIMALS

ANCIENT SKELETONS OF THE LARGEST EVER MARSUPIAL ARE UNEARTHED

WORDS **PATRICK PESTER**

A 'unique' fossil site in Western Australia is revealing the elusive remains of the world's largest ever marsupial. The skeletons belong to *Diprotodon*, which is related to wombats and koalas and lived during the Pleistocene epoch. These were giants, growing up to 1.7 metres tall at the shoulder, 3.8 metres long and could weigh 2.8 tonnes. Researchers have found at least ten *Diprotodon* skeletons at the site but have yet to excavate them fully. Adults and juveniles may be among the fossils, which could mean the site was on a major migration route for Diprotodon.

"I've never seen a fossil site quite like this," said Gilbert Price, a palaeontologist at the University of Queensland. "It's not normal to be able to walk across the landscape and just look on the ground and say, 'that's a vertebra, there's another part of a leg bone, there's a skull over there...' This is the sort of stuff that you might see in a movie like *Jurassic Park*." *Diprotodon* emerged around 2 million years ago and went extinct about 25,000 years ago. Climate change and human activity may have been factors in their extinction, but they co-existed with Aboriginal people for more than 20,000 years. Researchers have found *Diprotodon* fossils all across Australia. They were first unearthed at the site of the new excavation, located in Du Boulay Creek, in 1991.

SPACE

The Moon is 40 million years older than we thought

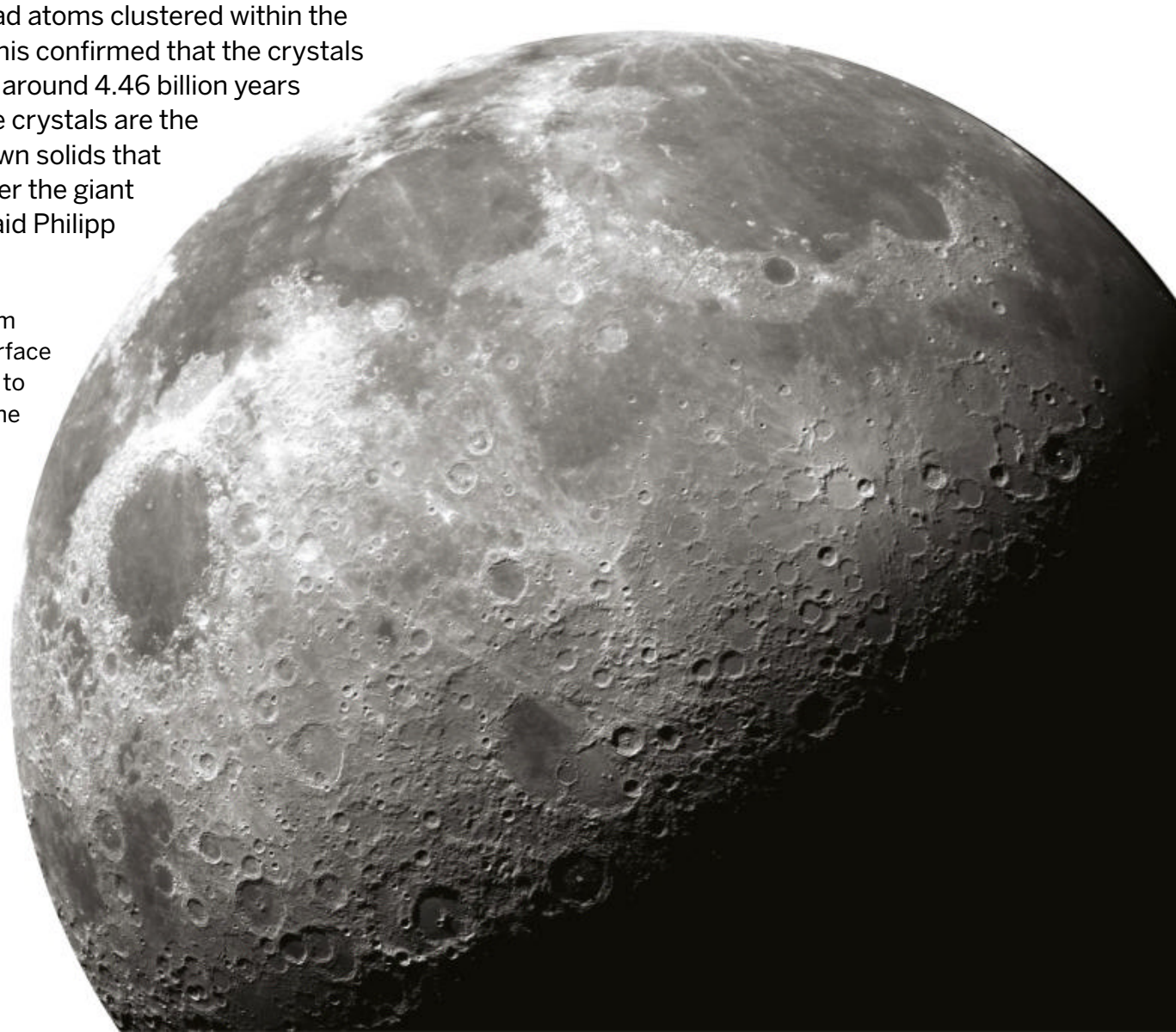
WORDS **HARRY BAKER**

The Moon is at least 40 million years older than we once thought. Scientists confirmed our cosmic companion's new minimum age after reanalysing tiny impact crystals from lunar samples taken by NASA's Apollo 17 mission in 1972. In a 2021 study, researchers first analysed the lunar gems, known as zircon crystals – microscopic rocks created under intense heat and pressure that on Earth are used to date objects such as impact craters. The lunar grains were left behind when the Moon formed following a colossal collision between Earth and a Mars-sized planet named Theia. The analysis, which involved measuring the decay rate of different versions, or isotopes, of uranium and lead in the crystals' outer layers, revealed that the samples could be up to 4.46 billion years old.

However, the 2021 study authors noted that there was a large amount of uncertainty in their dating method. As a result, the oldest confirmed lunar zircon crystals remained a group that was part of a separate Apollo 17 sample that was analysed in a 2009 study, which put the Moon's earliest possible birth date at around 4.42 billion years ago. In the new study, researchers reanalysed the crystals from the 2021 study, paying close attention to how the lead atoms clustered within the crystals. This confirmed that the crystals are indeed around 4.46 billion years old. "These crystals are the oldest known solids that formed after the giant impact," said Philipp Heck, a planetary scientist at the University of Chicago. "And because we know how old these crystals are, they serve as an anchor for the lunar chronology."

Earth is approximately 4.54 billion years old, so based on the newest study, the zircon crystals were formed around 80 million years after our planet formed. However, the collision that birthed the Moon could have actually happened even earlier. After the Earth-Theia crash, the infant Moon's surface would have been covered by a magma ocean due to the intense energy of the collision, therefore the lunar zircon crystals could only have properly solidified into their current state once the magma ocean had cooled down.

In a 2017 study, researchers created a computer model based on data from multiple lunar zircon samples to predict how long the magma cooling process may have taken, and as a result when the collision actually took place. This revealed that the Moon could be up to 4.51 billion years old. But although the 2017 study contains some great work, the method used by the researchers was an "indirect approach" that lacked a "direct age determination," says Heck. As a result, the newest study represents the best current estimate of the Moon's age.



Crystals from the lunar surface can be used to date when the Moon first formed

HEALTH

Scientists unveil an 'atlas' of the gut microbiome

WORDS **EMILY COOKE**

Scientists can now predict how individual bacteria in the gut interact with each other to reveal how they affect our health – for better or worse. The trillions of microbes and viruses that coexist inside and on the surface of the body are collectively known as the microbiome. The largest concentrations of these microbes are found in the gut. While some perform helpful roles in the body, such as the digestive powers of *Lactobacillus*, others, such as toxic strains of *Escherichia coli*, can cause disease. Many microbes survive by consuming nutrients that have been produced by other microbes, and when these interactions break down, it can cause an imbalance between helpful and disease-causing microbes that leads to conditions such as inflammatory bowel disease (IBD). However, until now it has been difficult to map out all of these complex interactions.

In a new study, scientists mapped how specific gut microbes interact with each other and form nutritionally dependent communities. The results could make it easier to target distinct species of bacteria or their metabolic byproducts, and thus potentially lead to the development of new therapies. "The authors tackled a novel and challenging aspect of microbiome research, moving beyond simply describing which bacteria are present to developing an analytical framework to quantify cross-feeding interactions," said Christopher Stewart, a medical research fellow at Newcastle University. "In doing so, they confirmed some known associations and discovered novel functional associations across many distinct disease conditions."

The researchers developed a computational approach to identify and rank key 'feeding' interactions, or the exchange of nutrients between microbes. This considered factors such as the diversity and total number of microbes that were predicted to consume or produce specific nutrients. They tested this approach on a dataset that modelled the metabolism of 955 species of gut microbes that had been collected from more than 1,600 human stool samples and whose genomes could be reconstructed. Participants who provided samples spanned 15 countries and either had one of 11 diseases where the gut microbiome had previously been implicated, such as IBD, type 2 diabetes or colon cancer, or did not have any of these conditions.

Did you know?

There are around 100 trillion microbes in the human gut

For 10 of the 11 diseases, the team was able to pinpoint specific interactions between microbes that appeared to be disrupted compared with the people who lacked these conditions; these disruptions stemmed from the microbes missing their corresponding 'feeding' partners. For example, when researchers used the new approach to analyse stools from people with Crohn's disease, a common form of IBD, the team found that what distinguished this condition was a lack of bacterial species that consume the gas hydrogen sulphide, such as *Roseburia intestinalis*. Hydrogen sulphide is believed to play an important role in controlling inflammation in the gut.

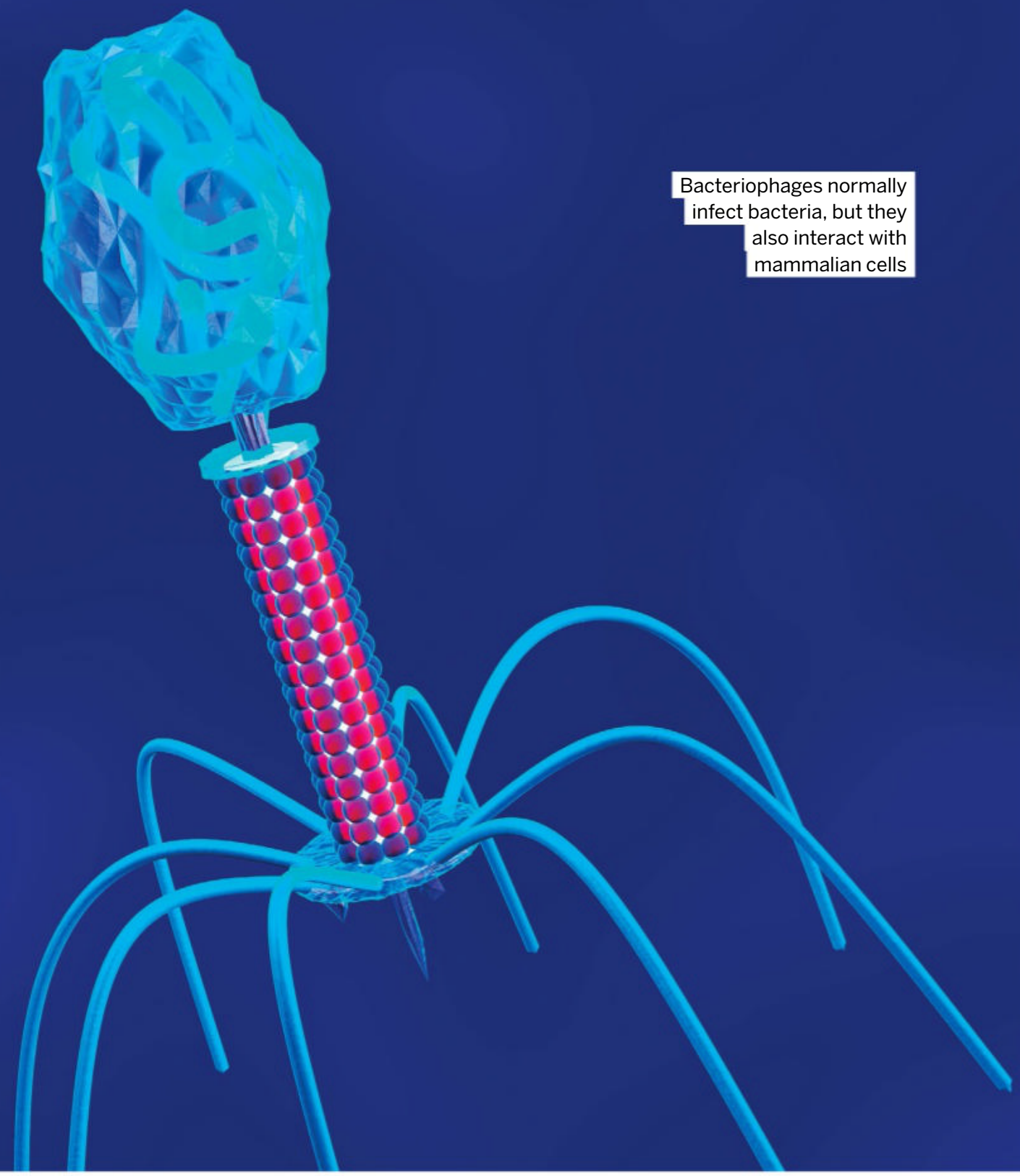
The new approach is still only a 'conceptual framework', and further experiments and in-depth analyses will be needed to validate these microbial interactions. Nevertheless, the study represents an important step towards using genetic material from the microbiome to infer feeding interactions between specific microbes. This could ultimately take us one step closer to more effective microbial targeting and microbial-based therapies.

The human gut contains trillions of microbes that collectively make up what's known as the gut microbiome

HEALTH

Mammal cells may use some viruses like vitamins

WORDS EMILY COOKE



Bacteriophages normally infect bacteria, but they also interact with mammalian cells

On the menu tonight, a nice, nutritional, bacteria-killing virus. Sounds unappealing? It may not be to your cells. In a new study, scientists revealed that a type of bacteriophage – a virus that infects and kills bacteria – found in the human gut helps mammal cells grow and thrive in what could be a symbiotic relationship. That's a surprise, as other bacteriophages are known to trigger inflammatory responses when they encounter mammalian cells. This phenomenon was only demonstrated in cells in the lab, but researchers hope the findings will aid future research that could impact human health, such as supplementing studies investigating bacteriophage therapy to treat infections with antibiotic-resistant superbugs.

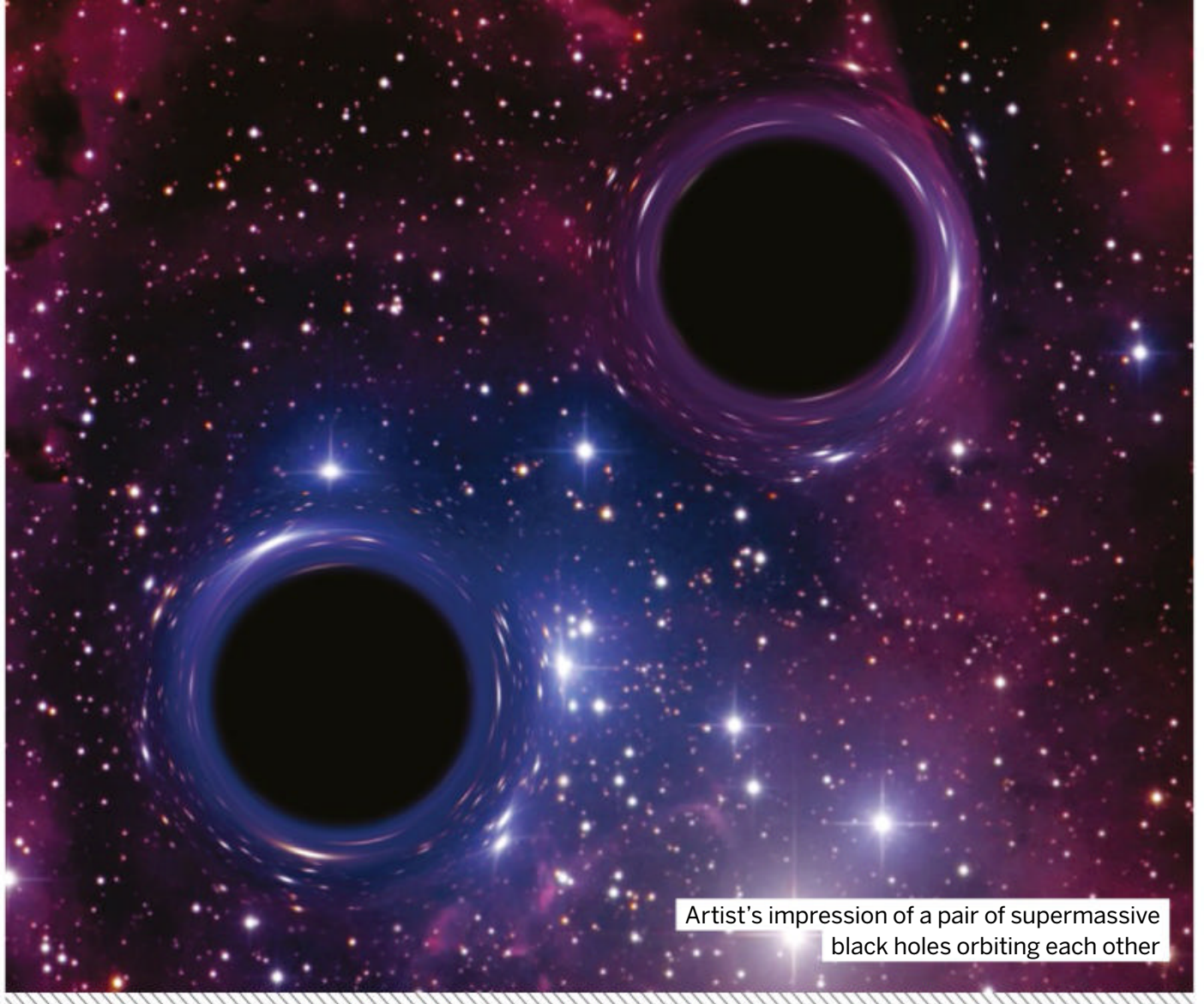
"[The study] opens up a new area of symbiosis and symbiotic interactions between bacteriophages and mammalian cells," said Jeremy Barr, an associate professor of biological sciences at Monash University. Bacteriophages are the most abundant biological entities on the planet. They're extremely small, with most ranging in size from 24 to 200 nanometers – a penny is about 19 million nanometers long. They're made up of a DNA or RNA genome surrounded by a protein shell. Although interactions between bacteriophages and bacteria are relatively well studied, the same can't be said for those between the former and mammalian cells.

In the study, researchers looked at a well-known bacteriophage species called T4 that normally infects *Escherichia coli* bacteria. They applied T4 to three types of mammalian cells in the lab: an immune cell called a macrophage that had been extracted from mouse tissue and human lung and dog kidney cells derived from cancer cell lines. The T4 bacteriophages didn't activate DNA-mediated inflammatory processes in the cells. Instead they triggered signalling pathways that promote cell growth and survival, resulting in increased cellular metabolism and the reorganisation of actin, a protein that's found in the fluid-filled space inside mammalian cells. Actin reorganisation is needed for cells to uptake material via macropinocytosis, a phenomenon also known as 'cell drinking'.

"Bacteriophages are the most abundant biological entities"

The broader health impacts of the study are still unknown. The researchers also only looked at one bacteriophage species, while estimates suggest there are as many as a quadrillion bacteriophages in the gut. In addition, the results may be a side effect of using immortalised cancer cell lines, which are already more likely to grow and proliferate. Nevertheless, the find should spur follow-up research. Bacteriophage therapy is generally considered to be safe, although it's still early in the clinical trial process, and the current study now suggests that there's "many, many other potential impacts" that bacteriophages may have on human cells, Barr said.

Another avenue where the research could be applied is in the gut microbiome. "There's some really interesting research showing that there's certain gut communities associated with inflammatory disorders, inflammatory bowel disease and Crohn's disease that have virus signatures associated with them. This is very much conjecture and extrapolation," Barr said, "but it's interesting to think that maybe bacteriophages do play a role in this and there may be some inflammatory interactions, and maybe also some beneficial interactions in a more sort of homeostasis gut microbiome system."



Artist's impression of a pair of supermassive black holes orbiting each other

SPACE

Scientists found a way for two black holes to orbit each other forever without colliding

WORDS **SHARMILA KUTHUNUR**

Astronomers have long assumed that two black holes that circle close to each other are always destined to become one in a cataclysmic merger that spans aeons. But that needn't always be the case, recent research finds. Physicists found that it is theoretically possible for two black holes to remain at a fixed distance from each other thanks to their mutual gravitational pull being perfectly counterbalanced by the speed at which the universe is expanding. "Viewed from a distance, a pair of black holes whose attraction is offset by cosmic expansion would look like a single black hole," said Óscar Dias, a physicist at the University of Southampton. "It might be hard to detect whether it is a single black hole or a pair of them."

They demonstrate that two black holes could be delicately balanced, despite conventional theories predicting otherwise, by pointing out "a logical inconsistency in the proof of one theorem and a limiting assumption in another," says Toby Wiseman, a professor of theoretical physics at Imperial College London. One of the key assumptions in those theorems is that the region around black hole pairs is empty. However, according to the standard model of cosmology, our current best description of the universe, dark energy causes the universe to expand at an accelerated rate. This dark energy is sometimes considered equivalent to the puzzling cosmological constant in the theory of general relativity.

In the new study, Dias and colleagues show that two black holes can be positioned such that their mutual gravitational attraction is offset by acceleration due to the cosmological constant. "If these black holes are set up in precisely the correct way, they sit in an unstable equilibrium akin to a pen balanced on its pointed end," Wiseman said. "Any disturbance will ruin this perfect balance."

Physicists say that wobbly balance could be made more stable when black holes are rotating. For instance, the gravitational attraction of two such identical black holes rotating in opposite directions could be balanced by their spins, although this possibility is yet to be proved.

The study only considered a pair of static black holes, so follow-up studies should address how stable spinning black holes could be. "Our theory is proven for a pair of static black holes, but we believe it could be applied to spinning ones too," said Jorge Santos, a professor of theoretical physics at the University of Cambridge. "Also, it seems plausible that our solution could hold true for three or even four black holes, opening up a whole range of possibilities."

Did you know?

The first black hole was discovered in 1964

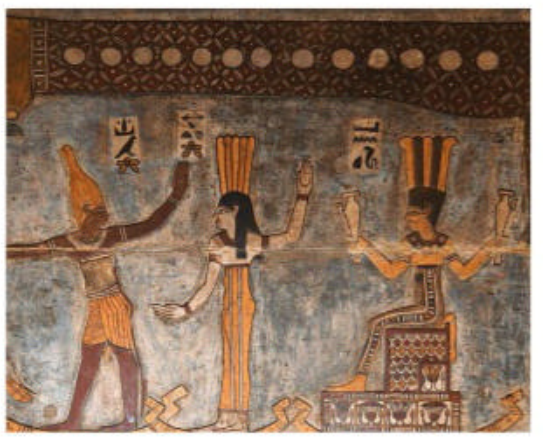
ARCHAEOLOGY

ANCIENT EGYPTIAN NEW YEAR'S SCENE IS UNCOVERED IN A 2,200-YEAR-OLD TEMPLE

WORDS **OWEN JAUS**

A stunning scene painted by ancient Egyptians has been uncovered by researchers restoring artwork on the ceiling of the Temple of Esna, a temple built around 2,200 years ago that underwent a major renovation about 2,000 years ago when the Romans controlled Egypt. The paintings show the Egyptian deities Orion, Sothis and Anukis on boats with the sky goddess Nut swallowing the evening sky above them, a mythology that details the Egyptian New Year. Orion represents the constellation of the same name, while Sothis represents Sirius, a star which was invisible in the night sky in ancient Egypt for 70 days of the year before becoming visible again in the east – that day marking the New Year. The Nile seasonally flooded at this time, and the ancient Egyptians believed that about 100 days after the appearance of Sirius, the goddess Anukis was responsible for the receding of the Nile's flood waters.

The New Year's artwork is the latest of several discoveries made at the Temple of Esna, whose paintings were obscured by two millennia's worth of soot, grime and bird droppings. For the past five years, scientists have been cleaning the ceiling, revealing a variety of imagery including depictions of the ancient zodiac and various astronomical constellations.



Orion, Sothis and Anukis ride boats while Nut, the sky goddess, swallows the evening Sun above them

WISH LIST

The latest tech for CHRISTMAS

KAI: THE ARTIFICIAL INTELLIGENCE ROBOT

£100 / $99.95 THAMESANDKOSMOS.CO.UK

Meet KAI, the six-legged, app-enabled robot that uses machine learning to move and emote. With help from your smart device's camera and microphone, you can create an AI model on movement patterns and gestures that KAI can learn from. Over time, KAI will learn how to recognise and respond to different gestures and sounds. There's also the option to directly control KAI through the accompanying app or by using a smart device as a gyroscopic controller. KAI is a self-assembled project with more than 100 pieces that comes with a fully illustrated manual showing you how to construct KAI and teaching you more about AI and robotics.

MEL SCIENCE SUBSCRIPTION

FROM £24.90 / $27.90 MELSCIENCE.COM

A MEL Science subscription box could be a great gift for budding scientists this Christmas. Each month, subscribers receive a new science kit that explores one of over 100 hands-on STEM projects. There are also over 50 digital experiences to enjoy, including video games and augmented-reality scenarios. From the mechanics of magnetic levitation and aerodynamics to the chemistry of crystals and zinc-carbon batteries, each kit is packed with new and exciting experiments to conduct, all of which are accompanied by a set of easy-to-follow instructions.

SAMBA DE AMIGO

£24.99 / $39.99

SAMBADEAMIGO.SEGA.COM

Get prepared to shake your maracas with over 40 songs to choose from in this vibrant and colourful rhythm action game that's perfect for all the family this Christmas. Groove along to some classics and strut your stuff to new hits. Gain the ability to customise your own characters and hit the global dance floor in the online world party mode. *Samba de Amigo* offers hours of action and fun throughout the festive season.

WHALE AND DOLPHIN ADOPTION

FROM £5 PER MONTH (APPROX. $6.10) **UK.WHALES.ORG**

This Christmas, help save some of the most magnificent marine mammals with a Conservation UK Whale and Dolphin adoption pack. Choose from either an adult or junior adoption pack and you'll get monthly email updates about your marine adoptee throughout the year, along with a Christmas and birthday e-card. Both packs come with a certificate of adoption and four issues a year of either *Whale and Dolphin* magazine for adults, or the fun junior magazine *SPLASH!*.

SONIC SUPERSTARS

£49.99 / $59.99 **SONICSUPERSTARS.COM**

Sonic Superstars offers an exhilarating adventure in never-before-seen environments, promising to keep gaming enthusiasts happy and entertained this Christmas. Sonic and his friends take on Doctor Eggman and fan-favourite nemesis Fang to stop their nefarious schemes in this action-packed, fun-filled game. The iconic, fast-paced, side-scrolling 2D platforming game you know and love has been re-imagined with amazing 3D graphics, along with all-new settings, powers and abilities. With the opportunity to play as four different characters – Amy, Knuckles, Tails and Sonic himself – *Sonic Superstars* offers hours of fun for all the family this festive season. For the first time in Sonic game history, you can play the game with up to three players online who can drop in and out at any point in the game, as well as up to four-player local co-op. It's available on PlayStation 5, PlayStation 4, Xbox Series X, Xbox One, Nintendo Switch and Steam.

BOOKILY

FROM £5 PER MONTH (APPROX $6.10) **BOOKILY.CO.UK**

Bookily is an exciting new gift card from National Book Tokens that gives readers the ultimate Christmas present: the gift of choosing a new book every month! It's topped up every month, and the money is all yours to spend in your favourite bookshop on the books you want to read. Even if there are some months that you don't purchase a new book, the money added to the card will top up its balance and remain there until you're ready for your next read.

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plus

A FREE BOOK BUNDLE

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How It Works is the action-packed science and technology magazine bursting with exciting information about the world around us. We stand for clarity, authority and intelligence through expert explanations and breathtaking illustrations. It's the ideal Christmas gift to feed those keen and hungry minds close to you.

Ben Biggs

Editor

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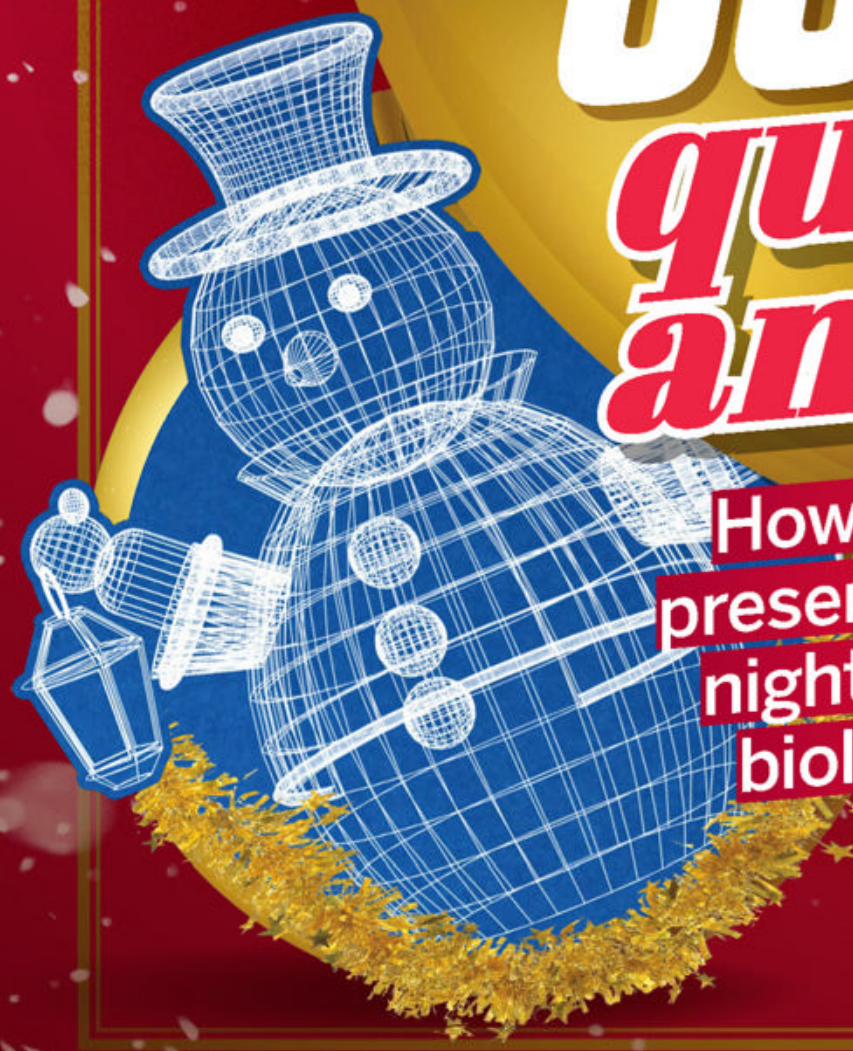
20 CHRISTMAS SCIENCE questions answered



How does Santa Claus deliver presents around the world in one night? Discover the chemistry, biology and even theoretical physics of Christmas

WORDS SCOTT DUTFIELD

DID YOU KNOW? In 1927, the US government officially issued Santa with a pilot's licence

Once a year, a white-bearded man dressed in red who goes by many different names, such as Saint Nicholas, Santa Claus and Father Christmas, emerges from the snowy tundra of the North Pole. Having spent the past 364 days working tirelessly alongside his elven employees to build millions of toys, Santa dons his crimson hat and settles into his sleigh. With a tug on the reins, he begins his reindeer-led journey to deliver presents around the world.

Of course, not everyone in the world celebrates Christmas. As a place of many faiths and cultures, it's estimated that around 33 per cent of the global population celebrates Christmas, including around 726 million children, each hoping that they've made the nice list this year. Assuming that there are around three children per household, that's around 300 million homes on Santa's to-do list. To make it to all of them in just 34 hours, thanks to differing time zones around the world, Father Christmas needs to travel around the globe at around 930 miles per second, or around 0.5 per cent of the speed of light. Currently, the record for the fastest speed achieved by any spacecraft belongs to NASA's Parker Solar Probe, which topped around 101 miles per second as it zipped along an orbit around the Sun in 2021. That means that Santa's army of elves must have come up with some new technologies to achieve this seemingly impossible feat.

A reindeer with its winter coat

Did you know?

Reindeer can run at speeds of up to 50 miles an hour

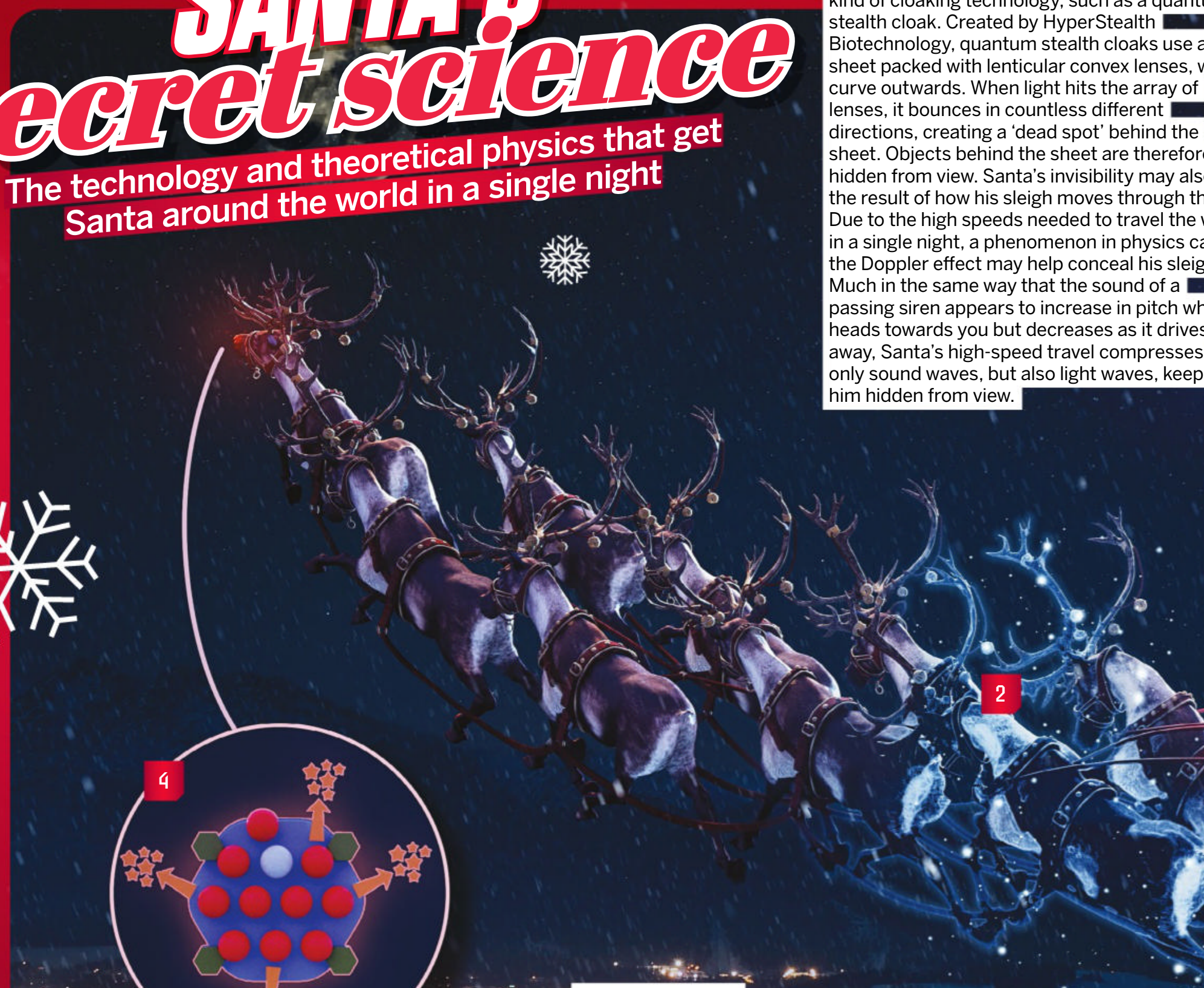
WHAT'S SANTA'S QUICKEST ROUTE AROUND THE WORLD?

SANTA'S secret science

The technology and theoretical physics that get Santa around the world in a single night

2 HOW SANTA STAYS OUT OF SIGHT

Not only does Santa zip across continents at unfathomable speeds, he also does so without being seen. This means he's probably using some kind of cloaking technology, such as a quantum stealth cloak. Created by HyperStealth Biotechnology, quantum stealth cloaks use a sheet packed with lenticular convex lenses, which curve outwards. When light hits the array of lenses, it bounces in countless different directions, creating a 'dead spot' behind the sheet. Objects behind the sheet are therefore hidden from view. Santa's invisibility may also be the result of how his sleigh moves through the air. Due to the high speeds needed to travel the world in a single night, a phenomenon in physics called the Doppler effect may help conceal his sleigh. Much in the same way that the sound of a passing siren appears to increase in pitch when it heads towards you but decreases as it drives away, Santa's high-speed travel compresses not only sound waves, but also light waves, keeping him hidden from view.

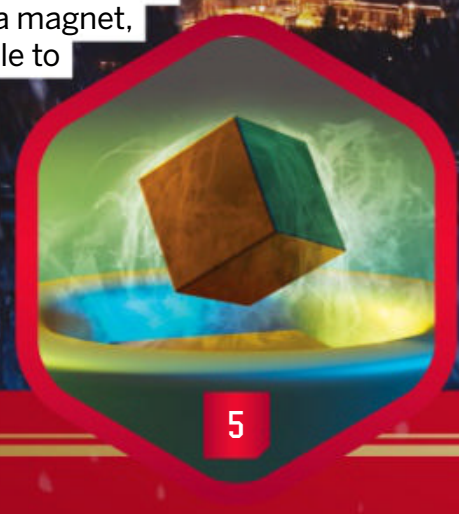


4 WHAT MAKES RUDOLF'S NOSE GLOW?

Rudolph has to be the brightest animal on Earth. With a glowing red nose to illuminate Santa's path through the clouds, Rudolph must use a light-emitting chemical reaction called bioluminescence. In the same process that gives fireflies their brightly glowing abdomens, Rudolf may be using a light-producing chemical called luciferin in his nose. When luciferin encounters an enzyme called luciferase, as well as oxygen and an organic compound called adenosine triphosphate (ATP), it releases photons of light. Among fireflies, the colour of this light is seen as green or yellow. However, for Rudolf, the light is likely passing through the myriad of blood vessels within his nose, making his glow appear red. Rudolph might not be producing his glow himself, and could be obtaining it secondhand from bioluminescent moss growing in the Arctic. *Schistostega pennata*, also known as goblin gold or luminous moss, doesn't generate its own glow, but has specialised lens-shaped cells that reflect light, making it appear as though it does. Even the slightest source of light can make this moss glow.

5 ROOFTOP TAKEOFF

While Santa's antimatter rocket sends him flying through the air in the blink of an eye, to first lift him, his nine reindeer and a multidimensional sack of gifts from rooftops, he needs a powerful takeoff system. And he might be using superconductive magnets to create magnetic levitation. For example, some high-speed trains around the world use magnetic levitation, referred to as maglev trains, for propulsion. When a material called a superconductor, such as niobium-titanium alloy, is cooled to extreme temperatures, it begins to generate a powerful magnetic field. Normally, magnetic levitation requires superconductors to be supercooled to around -268 degrees Celsius to become powerful enough to levitate. When a superconductor is placed near a magnet, they repel each other so strongly that it's possible to lift one object off another and make it levitate. Santa's sleigh runners and the reindeer shoes might be made of a new superconductive material that doesn't require such low temperatures to work. As for the opposing magnetic field needed to lift Santa's sleigh, that might come from Earth's magnetic field.



DID YOU KNOW? Rudolf first appeared in 1939 as a department store's promotional character

3 WHERE DOES SANTA STORE THE WORLD'S PRESENTS?

Father Christmas may have also become the father of physics and found a way to create a transdimensional bag to store the world's presents. Much like the mind-bending physics of *Dr Who*'s TARDIS, Santa's sack might just be bigger on the inside, thanks to string theory. The universe as we know it is made up of four dimensions – three allocated to space and one for time. String theory, however, describes all matter and force particles as vibrating strings that move in ways that we perceive as particles. For this theory to be true, however, there would need to be more than four dimensions in existence, ten in total. These extra dimensions might be hidden beyond the four that we're able to observe with current science. This is because of a concept in transdimensional physics called compactification, where a dimension may exist on such a small scale that it is unobservable.

1 HOW DOES SANTA TRAVEL SO FAST?

To travel around the world in 34 hours, Santa needs a pretty powerful propulsion system... but none in existence are up to the task. That's unless Santa has perfected antimatter propulsion. What makes antimatter perfect for fuel is the amount of energy produced from its reaction with matter. An antimatter-fuelled rocket could produce more than 10 million times the amount of energy than a rocket that uses an equal mass of chemical combustion. With this, Santa's sleigh could reach immense speeds – up to 70 per cent the speed of light.

Did you know?

The North Pole has no time zone

WHAT TIME DOES CHRISTMAS START?

Presents delivered, Santa can return home for a well-earned nap. For the rest of the world, Christmas has just begun. Research has shown that the average British child wakes up to start Christmas Day at 07:03. For the Japanese, the sound of excited children begins at 06:43 local time, and in the US cheer starts around 07:35. But in Brazil the average wake-up time for Christmas Day is 09:09. Some studies have also shown that around 58 per cent of children will wake up twice during the night before Christmas due to increased adrenaline brought on by the excitement of seeing what Santa Claus has brought them.

WHY DO SPROUTS TASTE SO BITTER?

Sprouts have a recognisable smell and an often bitter taste. Sulphur is largely responsible for sprout odour and taste. As people age, our taste buds' ability to detect bitterness fades, meaning the foul-tasting sprouts from childhood can become more palatable as we age. However, for at least 50 per cent of the population, the taste of sprouts will forever be bitter. That's because half of us have a variation in a gene called TAS2R38 that causes taste buds to always recognise a chemical found in sprouts, called phenylthiocarbamide, as bitter.

WHAT MAKES A GOOD SNOWMAN?

For about 25 countries around the world, including many countries in Europe and Canada, there's a 25 per cent chance or higher that snow will fall on Christmas Day. If fresh snow hits the ground between zero and two degrees Celsius, it's the perfect time to build a snowman. When building a snowman it's important to consider the snowman's centre of gravity, which is the average location of its weight. To determine a snowman's centre of gravity, imagine placing it on a string or sharp edge. The point at which it begins to balance on the string reveals its centre of gravity. When a snowman is built with its centre of gravity closest to the ground, it's less likely to topple over. For the perfectly constructed snowman, a ratio of 3:2:1 in a three-tier snowball body is best.

CRACKER CHEMISTRY

What makes these tabletop explosives bang?

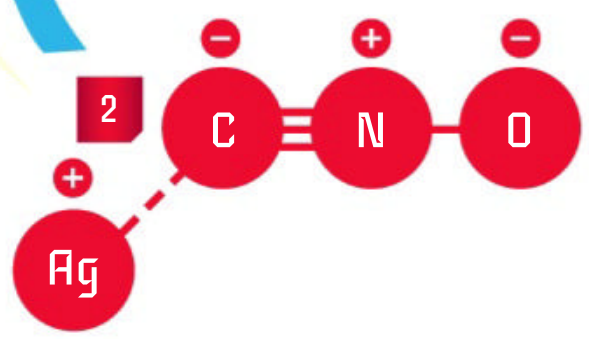
1 CARD
Within a cracker, alongside a paper hat and bad joke, are two strips of cards.

2 SILVER FULMINATE
The cracker's bang comes from the detonation of an unstable compound called silver fulminate.

3 SANDPAPER
A strip of sandpaper sits between the two pieces of card, passing over the silver fulminate when they are pulled apart.

4 FRICTION
When the sandpaper rubs up against the silver fulminate, it creates enough friction to spark and detonate it.

5 ECHO
The sound of the explosion is amplified by the cylinder shape of the cracker.



DID YOU KNOW? The world's largest sprout was grown in the UK in 1992 and weighed 8.3 kilograms

HOW CAN A CHRISTMAS PUDDING IGNITE BUT NOT BURN?

With the turkey carved and sprouts and spuds devoured, it's time to pour the brandy over the Christmas pudding and set it alight. Within brandy is a flammable chemical called ethanol. Within the molecular structure of ethanol is oxygen, which when ignited combines with the oxygen in the atmosphere for a smokeless combustion. More than half of the chemical composition of brandy is made of water, meaning the majority of the heat felt from a burning pudding is water vapour, which also protects the desert from burning to a crisp. The oxygen-rich ethanol also makes flames burn bright blue, rather than the orange flames of hydrocarbon-packed candles.

Did you know?

Around 287 million mince pies are eaten at Christmas each year

WHAT IS MINCEMEAT?

From the 14th century, mincemeat pies contained the spiced meat of different animals, such as cows, sheep and rabbits. However, by the 18th century, mutton and beef had been replaced with the sweet taste of blended fruits, sugar, suet and lashings of alcohol, such as brandy or rum. Once blended, the mix is then left for at least two weeks to mature, but can last for months in unopened jars. This is due to the sugar and alcohol within the mixture preventing microbes from growing and spoiling the mincemeat.

WHAT MAKES THE PERFECT ROAST POTATO?

Roughly 250 million roast potatoes will be consumed across the United Kingdom alone this year. Their fluffy interior and golden crispy surface are somewhat of a Christmas miracle, all thanks to a chemical reaction called the Maillard reaction. This reaction is a complex molecular domino effect between proteins and sugars that causes lots of different foods to brown and crisp up. For the mighty roast potato, this reaction occurs quickly when par-boiled potatoes are doused in oil or fat and then cooked at a high temperature.

HOW DO YOU BUILD THE PERFECT GINGERBREAD HOUSE?

Constructing a gingerbread house is a delicate business, and there are a few vital factors to consider before building. Firstly, the gingerbread walls need to be tough enough to support the weight of its roof. Using protein-packed flours will help develop networks of tough gluten molecules for stability. Then there's the icing cement to hold it all together and egg whites that must be whipped to cause the proteins within to coagulate for a stronger hold. During construction, gingerbread houses should be built with a wider and flatter roof to prevent the forces of gravity and friction from causing collapse.

WHAT'S ON the tree?

The science behind festive decorations and ornaments

Christmas trees are typically evergreen conifers, such as pines and firs, grown in forests across the Northern Hemisphere. These trees take around 10 to 12 years to grow before they reach the most popular tree height of 1.82 metres tall. However, in 1964, the first fake Christmas tree emerged, ushering in a new era of plastic trees. Made from polyvinyl plastic, these are an alternative to traditional trees. Since the 16th century, Christmas trees have been dressed up in celebration of the festive season. The tradition is thought to have originated in Germany and was brought to Britain in 1800 by Queen Charlotte, the wife of King George III. Early decorations of the time were made from flowers, apples and confectioneries, whereas today's decorations are mostly made from plastics and synthetic materials and come in all shapes and sizes.

Did you know?

Britain's only native pine tree is the Scots pine

1 WHAT CAUSES A PINE TREE'S ICONIC SMELL?

The smell of fresh pine trees can be synonymous with the festive season. The scent comes from a chemical compound called terpenes, which not only provides a pleasant aroma but offers protection to the tree. When pine tree bark gets damaged, terpenes and other compounds come together to form a resin, called turpentine. The resin then coats the tree's wounds to prevent parasites and herbivores from finding a way past its bark.

2 ARE FAIRY LIGHTS MESSING UP THE WI-FI?

Hundreds of tiny light bulbs wrapped around the Christmas tree have become a common sight since their invention in 1882. Lit candles were the norm before electrical string lights took their place. However, the twinkle of Christmas lights might not just bring festive cheer, but also frustration at a sudden drop in your internet connection, since Christmas lights emit an electromagnetic signal that can interfere with your Wi-Fi.

3 HOW ARE GLASS BAUBLES SHAPED?

Made in every size, shape and colour, glass baubles are one of the most diverse Christmas ornaments around. Each bauble starts its life as a clear glass tube, which is then heated to around 1,200 degrees Celsius and is traditionally blown into a spherical shape. Glass is also blown into metal moulds to create unique shapes. Once cooled, the glass spheres undergo silvering, where they are filled with a liquid silver nitrate to give them a metallic appearance.

4 WHEN DID CANDY CANES BECOME DECORATIONS?

Beginning as a Christmas Eve treat during the late 1600s, candy canes evolved into one of the most iconic decorations. The invention of the hooked candy cane largely remains a mystery, but it's thought they originated in Germany as a religious reference to the shepherds that visited Jesus. It wasn't until 1847 that the first candy canes made their way onto the Christmas tree.

5 WHERE DOES TINSEL COME FROM?

Tinsel dates back to the early 1600s, when Germans dressed their trees using strands of real silver to reflect the light of the burning candles that sat beside them. Over time, the silver was swapped for cheaper materials such as copper and tin. Today tinsel is created from a type of plastic called polyvinyl chloride (PVC) that is cut into ribbons and twisted around metal wiring.

6 WHAT IS WRAPPING PAPER MADE OF?

In 2022, the UK alone used around 227,000 miles of wrapping paper to conceal Christmas gifts. It's a tradition that started in the Western world during the early 20th century, while many Eastern countries, such as China, have been wrapping gifts since around 220 CE. Modern-day wrapping paper is commonly made from wood pulp like any other type of paper, whereas foiled papers incorporate a film of plastic called polypropylene that is coated with aluminium.

Aboard the WORLD'S LARGEST CRUISE SHIP

Sail away on the Icon of the Seas: Royal Caribbean's latest luxury floating voyager can hold around 8,000 people

WORDS **SCOTT DUTFIELD**

Did you know?

The first passenger cruise was introduced in 1844

Since 1968, Royal Caribbean has been creating some of the world's most spectacular cruise ships. Starting with the maiden voyage of the Song of Norway in 1970, the company has created several record-breaking vessels, including the world's longest liner, the Wonder of the Seas, measuring 362.04 metres, as well as the tallest observation deck aboard the North Star, which allows passengers to view the ocean from a height of 88.6 metres. Now the cruise company will break another nautical record with the construction of the colossal Icon of the Seas cruise liner.

Almost a quarter of a mile long and weighing an incredible 250,800 tonnes, the

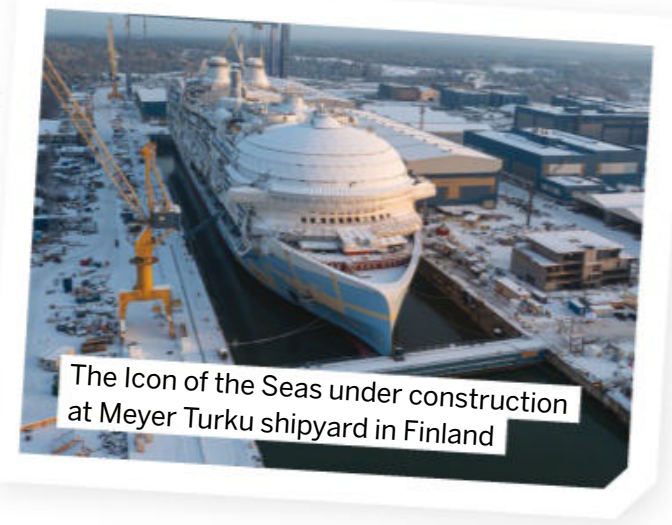
DID YOU KNOW? The Icon has the world's largest pool at sea, with a volume of over 151,000 litres

Icon of the Seas is the largest cruise liner the world has ever seen. Along with more than 20 eateries, a waterpark, ice rink and immersive theatres, this 20-deck vessel has enough space to welcome a maximum of 7,600 guests, along with the 2,350 crew members on board.

But how does a ship so large stay afloat? The answer lies in a principle in physics that's applied to all ships, called buoyancy. Vessels that weigh thousands of tonnes can float as long as they displace the same amount of water. Cruise ships have a hull – the main body of the vessel – shaped like a 'U', unlike the 'V-shaped' hulls of high-speed boats. The Icon of the Seas' wider hull shape displaces hundreds of thousands of tonnes of water to maximise the buoyant force holding the vessel above the water. However, for this level of stability at sea, there's a trade-off between buoyancy and speed. The Icon of the Seas travels at around 25 miles per hour.

To assist in the Icon's movement through the water, it will also be equipped with an air lubrication system. Air bubbles are rapidly pumped beneath the bottom of the ship by compressors. The ship rides along the bubbles, moving over them like rollers and reducing the amount of friction and drag the ship experiences. There's also an autonomous cleaning robot that will periodically scrub the ship's hull to remove sludge and slime, increasing fuel efficiency by up to four per cent.

Powering the Icon of the Seas through the water, its fuel will be liquefied natural gas for the first time in Royal Caribbean history. To create this fuel source, natural gas, which is typically around 85 per cent methane, is transformed into a liquid state by cooling it to -161 degrees Celsius. The liquefied natural gas is then stored in enormous tanks on the ship and passed through fuel cells, where the fuel is converted into electricity and water.


The Icon of the Seas under construction at Meyer Turku shipyard in Finland

The construction of this iconic vessel began in 2021 at Meyer Turku shipyard in Finland, and it's due to begin service in January 2024. There's also a second liner in the works that will become the second Icon-class ship in Royal Caribbean's fleet, called the Star of the Seas, which is set to be ready in 2025.

ROYAL CARIBBEAN'S BIG BOATS

WONDER OF THE SEAS

MAIDEN VOYAGE
2022

GROSS TONNAGE
236,857

LENGTH
362 metres

DECKS
18

PASSENGER CAPACITY
7,084 guests

HARMONY OF THE SEAS

MAIDEN VOYAGE
2016

GROSS TONNAGE
226,963

LENGTH
362 metres

DECKS
18

PASSENGER CAPACITY
6,780 guests

SYMPHONY OF THE SEAS

MAIDEN VOYAGE
2018

GROSS TONNAGE
228,081

LENGTH
361 metres

DECKS
18

PASSENGER CAPACITY
6,680 guests

ALLURE OF THE SEAS

MAIDEN VOYAGE
2010

GROSS TONNAGE
225,282

LENGTH
362 metres

DECKS
18

PASSENGER CAPACITY
6,780 guests

OASIS OF THE SEAS

MAIDEN VOYAGE
2009

GROSS TONNAGE
226,838

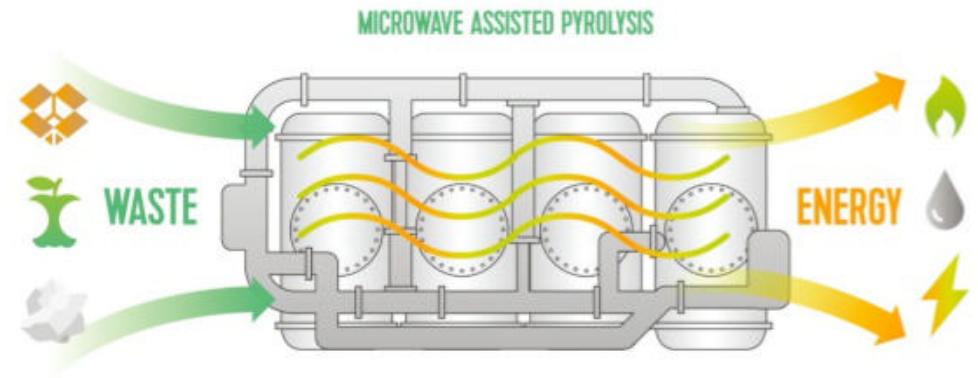
LENGTH
360 metres

DECKS
18

PASSENGER CAPACITY
6,699 guests

REMOVING WASTE

The company is introducing a new waste management system to the next generation of liners, including the Icon of the Seas, called microwave-assisted pyrolysis. The process will transform solid waste into synthesis gas that can be redirected into the ship's fuel supply. Like any land-based energy conversion plant, waste products aboard the ship, such as food and non-plastic packaging, will be subjected to high temperatures using microwaves. Oxygen is removed from the process to prevent combustion, so rather than fire and smoke, the waste is heated until it produces a synthesis gas, or syngas, which can then be fed back into the ship's systems to be used as additional fuel. What remains after this process is a heap of byproducts called biochar, which is stored and can later be used as soil nutrients.



Food, cardboard and paper waste will be transformed into useful byproducts

RIDING THE WAVES

Take a tour of the world's largest cruise ship and discover how it sails

7 AQUAPARK
The Icon has the largest waterpark at sea, with six water slides, including the 131-metre-long storm chaser.

4 ROOMS
There are more than 2,800 cabins throughout the ship's 20 decks.

3 PROPELLERS
Azipod propulsion systems allow the ship's captain to manoeuvre its propellers 360 degrees.

6 CENTRAL PARK
This is an outdoor garden within the ship's interior that holds thousands of live plants.

2 FUEL TANKS
The ship's liquefied natural gas fuel is stored in two 3.7-tonne tanks.

10 NEW FUEL

Many of the world's cruise liners are propelled using marine diesel oil (MDO) in their engines. Like any other fuel derived from fossil fuels, during the internal combustion within their engines, MDO releases enormous amounts of pollutants and greenhouse gases into the atmosphere. A report by the European Federation for Transport and Environment found that cruise ships visiting European ports in 2022 emitted 8.1 megatonnes of carbon dioxide, which is equivalent to 50,000 flights travelling between Paris and New York. To reduce its carbon footprint, Royal Caribbean equipped the Icon of the Seas with six Wärtsilä engines, each of which will generate 67,500 kilowatts of energy from liquefied natural gas. Burning liquefied natural gas within these engines produces around 30 per cent less carbon dioxide than oil and doesn't produce pollutants such as soot and tiny amounts of sulphur dioxide.

DID YOU KNOW? 93 per cent of the freshwater aboard the Icon of the Seas is produced via reverse osmosis and desalination

Did you know?

The Icon of the Seas is longer than the Eiffel Tower is tall

5 NEIGHBOURHOODS

There are eight different 'neighbourhoods' filled with restaurants, theatres and activities.

1 THE BRIDGE

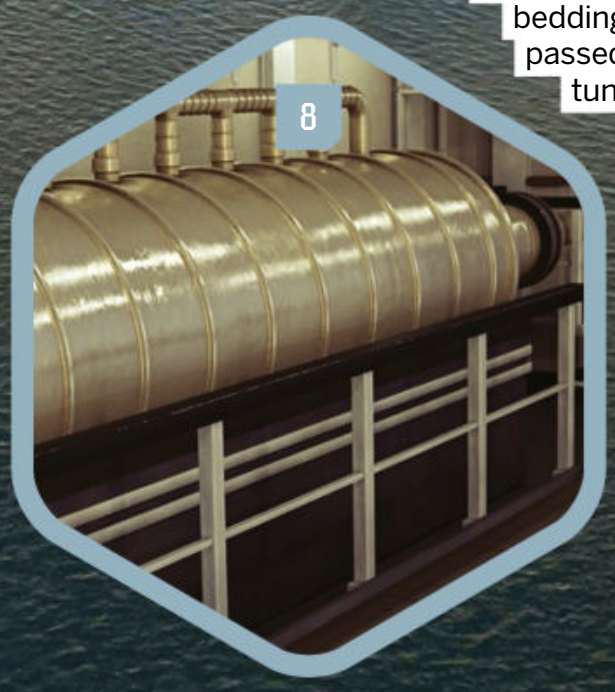
The ship's navigation systems, communications and azimuth steering control system are all found on the bridge.

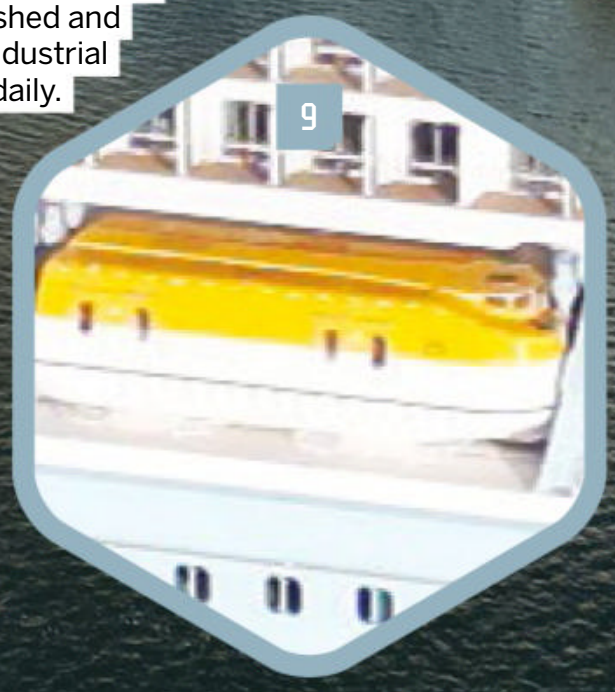
9 LIFEBOATS

The Icon of the Seas is equipped with 17 lifeboats, each able to hold 450 people.

8 LAUNDRY

Tens of thousands of towels and bedding will be washed and passed through industrial tunnel dryers daily.





WHAT ARE CAT'S EYES?

These glowing road safety devices have steered drivers in the right direction for decades

WORDS **AILSA HARVEY**

When travelling along roads at night, drivers rely on well-lit paths and signage to direct them safely along dark routes. Road signs have lights to illuminate their lettering, while between lanes, long strings of small studs inform the positioning of each vehicle. Just as any cat caught in the headlights reveals two piercingly bright eyes, these road studs shine brighter the closer you drive towards them, reflecting the light from car headlights back to the vehicle.

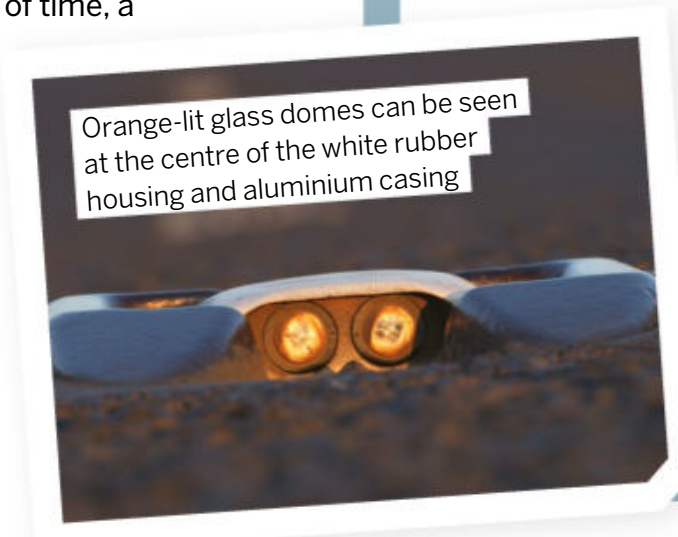
Cat's eyes were first produced by English inventor Percy Shaw in 1934. When Shaw was driving along a particularly dangerous section of road on a foggy night a year prior, he was unable to see where the road ended and the steep hills began. He usually used the reflection of his headlights off the tram tracks in the road to guide him, but on this misty night he realised the need for clearer road markings. None of the roadside objects reflected much light back to him, other than the eyes of a passing cat. This striking return of light led Shaw to design an unpowered device that could achieve this same level of brightness along all stretches of a road and make driving after dark much safer.

Did you know?

99 per cent of UK roads have cat's eyes installed

Today, cat's eyes are a staple of road design, preventing many accidents as a result of poor visibility. They are widely used in countries around the world and don't depend on electricity to work – just the light already produced by your vehicle. There are around 500 million cat's eyes lining roads in the UK alone.

Though the simple-yet-effective reflective design has stood the test of time, a modern spin on cat's eyes sees the technology incorporating small solar panels to emit light constantly through each night. This allows them to shine brightly at a distance as well as at close range so drivers can view twists and turns more clearly from afar.



Orange-lit glass domes can be seen at the centre of the white rubber housing and aluminium casing

SELF-CLEANING INSTALLATION

For the best reflection and clear road marking, cat's eyes need to be clean in order to reflect a car's headlights. The central glass reflecting component of a cat's eye is first placed into a rubber housing. When positioned in the housing, cat's eyes are slightly elevated from the road surface level. This makes them stand out and enables light from headlights to better reach their surface. The rubber housing is placed into a hard aluminium casing before it's placed onto the road. Much of the sturdy metal shield is fitted so that it doesn't move, but the section with the rubber housing moves up and down slightly under the weight of a vehicle's tyres. By dipping slightly below the road's surface upon impact, the tyres are less likely to be damaged. Meanwhile, the moving parts rub against the non-moving parts slightly, wiping away any debris covering the surface of the cat's eye stud to keep it clean.

HOW THE EYES PRODUCE THEIR GLARE

Since the first cat's eyes were installed in the 1930s, the general structure and function of the technology has remained largely consistent. In cat's eyes that don't have batteries, the road studs have a central glass dome called a retroreflector. Retroreflectors are essential for the purpose of driving at night, as they reflect light back in the direction that it was emitted from. This means that when a car's headlights project light onto the road in front of them, the light bounces back from the cat's eyes to the driver, and the driver clearly sees these bright guidance markings.

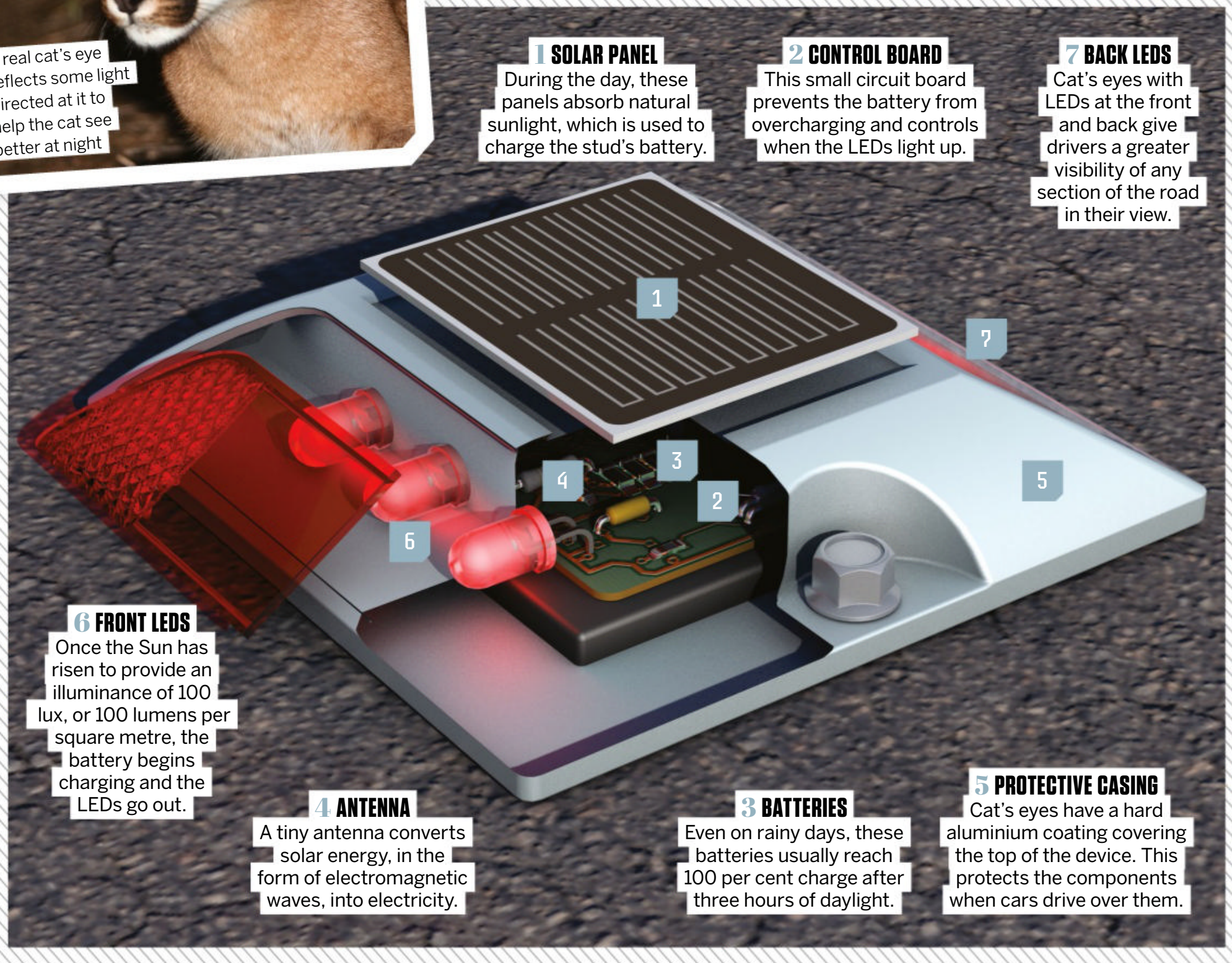
When the light first makes contact with the cat's eye, it hits a glass dome-shaped lens. This lens refracts (bends) light towards the back of the structure. A mirror at the back of the eye reflects light back to the curved glass lens, which refracts light again at the same angle. As a result, the light leaves the glass dome in a parallel line to how it arrived. Without this accurate redirection, there wouldn't be clear, visible lanes.

When removed from its protective casing, a traditional cat's eye is a small glass dome

A real cat's eye reflects some light directed at it to help the cat see better at night

SOLAR-POWERED STUDS

This type of cat's eye produces light using the Sun's energy



1 SOLAR PANEL
During the day, these panels absorb natural sunlight, which is used to charge the stud's battery.

2 CONTROL BOARD
This small circuit board prevents the battery from overcharging and controls when the LEDs light up.

7 BACK LEDS
Cat's eyes with LEDs at the front and back give drivers a greater visibility of any section of the road in their view.

6 FRONT LEDS
Once the Sun has risen to provide an illuminance of 100 lux, or 100 lumens per square metre, the battery begins charging and the LEDs go out.

4 ANTENNA
A tiny antenna converts solar energy, in the form of electromagnetic waves, into electricity.

3 BATTERIES
Even on rainy days, these batteries usually reach 100 per cent charge after three hours of daylight.

5 PROTECTIVE CASING
Cat's eyes have a hard aluminium coating covering the top of the device. This protects the components when cars drive over them.

How the AEROPLANE WAS INVENTED

Hop aboard the Wright brothers' ingenious creation and discover the beginning of modern-day aviation

WORDS **SCOTT DUTFIELD**

It was a brisk December morning in the Outer Banks of North Carolina, but adrenaline-pumping hearts likely kept the Wright brothers warm as one watched the other take flight in the first successful aeroplane: the Wright Flyer. Until this fateful day, the world's view of human flight was limited to hot-air balloons and gliders. However, two American men, brothers from Millville, Indiana, swooped in at the start of the 20th century and opened the world's eyes to the possibility of flight powered by a heavier-than-air flying machine.

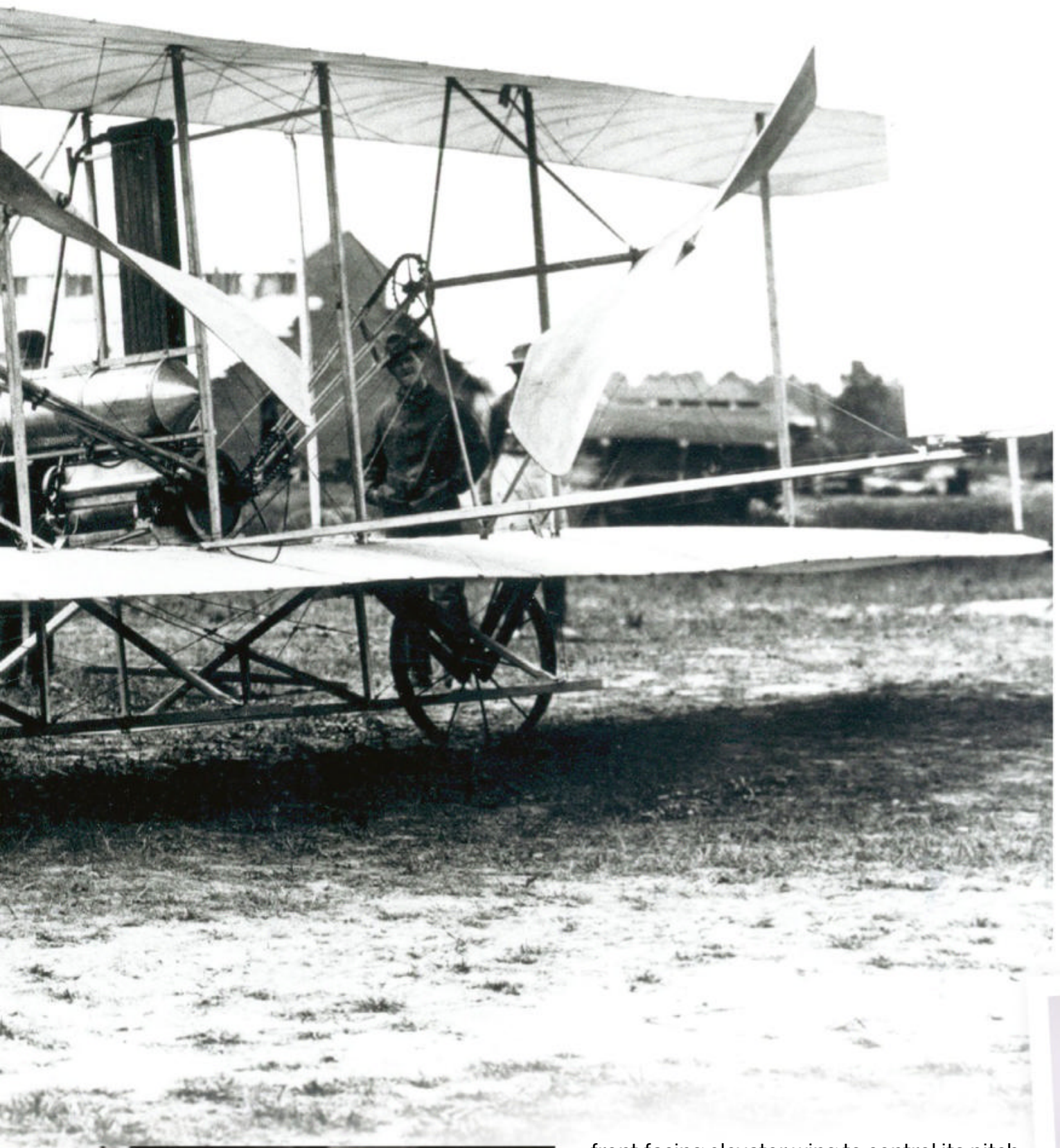
Before human flight piqued their interest, the Wright brothers' first joint venture was a printing business during the mid-1880s. By 1889, Orville and Wilbur started a local newspaper called *West Side News*, which later became the *Evening Item* and closed after 78 issues. But during this time, the brothers also turned their business brains to the growing bicycle craze that was sweeping America. In 1892, the Wright Cycle Company was formed to sell bicycles before servicing and manufacturing its own bicycle model, called the Van Cleve, in 1896.

Did you know?

The Wright Flyer only ever flew four times

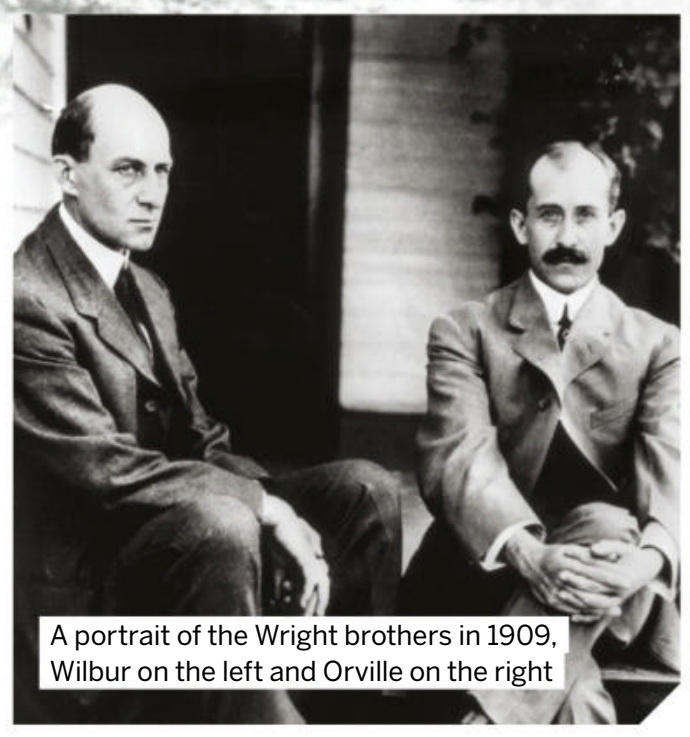
Much like the transition from printing to bicycles, the Wright brothers made a jump into another industry, but this time they looked towards the sky for inspiration. In 1899, after experimenting with designs for kites and gliders, they discovered that when the opposing corners of a long box were pulled together by string, the box would twist. This was something Wilbur Wright thought could be used to control the way a glider moved through the air. After building a test model, he quickly proved his theory was correct. Within a year, Wilbur had built a biplane glider, with two wings situated on top of each other, that could theoretically generate enough lift to carry the weight of a

DID YOU KNOW? In 1910, Orville Wright took his 82-year-old father on his first and only flight



THE SMITHSONIAN SPAT

The Wright brothers weren't the only inventors on the cusp of being the first to build a heavier-than-air aircraft. In 1896, American engineer Samuel Pierpont Langley created the prototype for what could have been the first powered flying machine, called the Langley Aerodrome. By 1903, Langley had created a full-scale manned machine that housed a five-cylinder engine. However, during two test flights – the final one just days before the success of the Wright Flyer – the Aerodrome was launched into the air and quickly nose-dived into a nearby river. In 1913, the remains of Langley's Aerodrome were sent to Glenn Hammond Curtiss, the secretary of the Smithsonian Institution, who rebuilt and flew the Aerodrome the next year. He concluded that Langley's creation was in fact the first true aircraft due to its capability to fly. However, after many years of legal and political battling, the Smithsonian retracted that decision in 1942, as the 1914 test flights did not accurately prove that the Aerodrome would have been capable of flying.

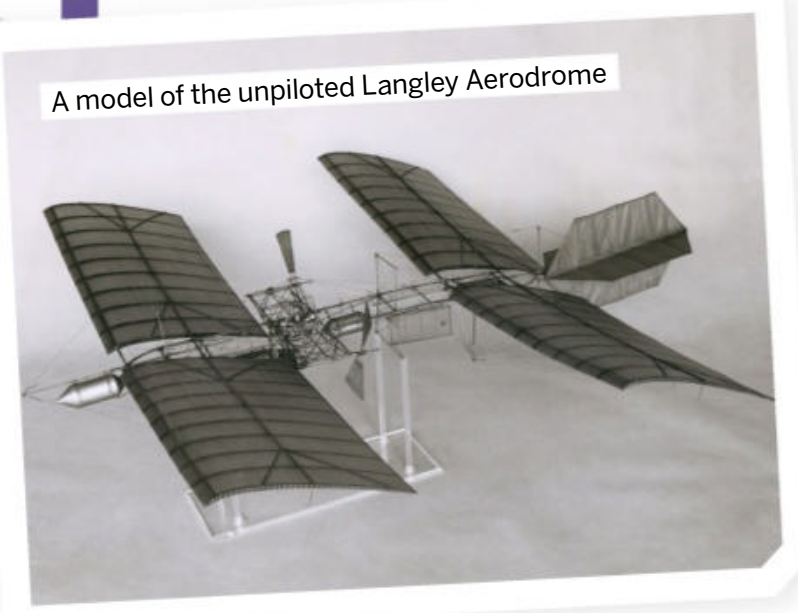


A portrait of the Wright brothers in 1909, Wilbur on the left and Orville on the right

man. However, it wasn't until 1902, after countless failed flight attempts and design changes, that they succeeded. The 1902 Wright Glider had a wingspan of 9.8 metres, a hip cradle for the pilot to operate moving components such as a rear rudder and a front-facing elevator wing to control its pitch. The brothers conducted hundreds of test flights, the best of which lasted 26 seconds while the aircraft travelled 191.5 metres.

Having mastered the aerodynamic construction of their glider, there was just one thing the next generation of flyers needed – a propulsion system. With the help of their bicycle shop mechanic Charlie Taylor, the brothers created a 12-horsepower gasoline engine that produced enough power to spin a pair of rotary propellers. The theory was that the propeller would generate enough airflow over the surface of the glider's wings and generate enough continual thrust to keep the flyer aloft.

On 17 December 1903, after around four years of research, Wilbur and Orville headed over to Kitty Hawk, North Carolina, to put their latest creation to the test. Four test flights were carried out in total, with each brother taking turns being strapped into the pilot cradle. A rope-and-pulley system was designed to hurl the aircraft along a runway and ultimately into the air for each test. On the first attempt,



A model of the unpiloted Langley Aerodrome

Orville flew for 12 seconds, reaching only 36 metres before landing. But each attempt was more successful than the previous one, and the fourth and final test of the day proved the best when Wilbur piloted the flyer 255.6 metres in just 59 seconds.

These four remarkable tests were more than enough evidence for the brothers to hold a press conference and announce to the world the astounding achievement of their glider experiments. However, the success of the engine-powered Wright Flyer remained unseen to the world until 1916, when it was put on display in an exhibition at the Massachusetts Institute of Technology.

UP IN THE AIR

These components came together to enable the first flight

7 WATER RESERVOIR

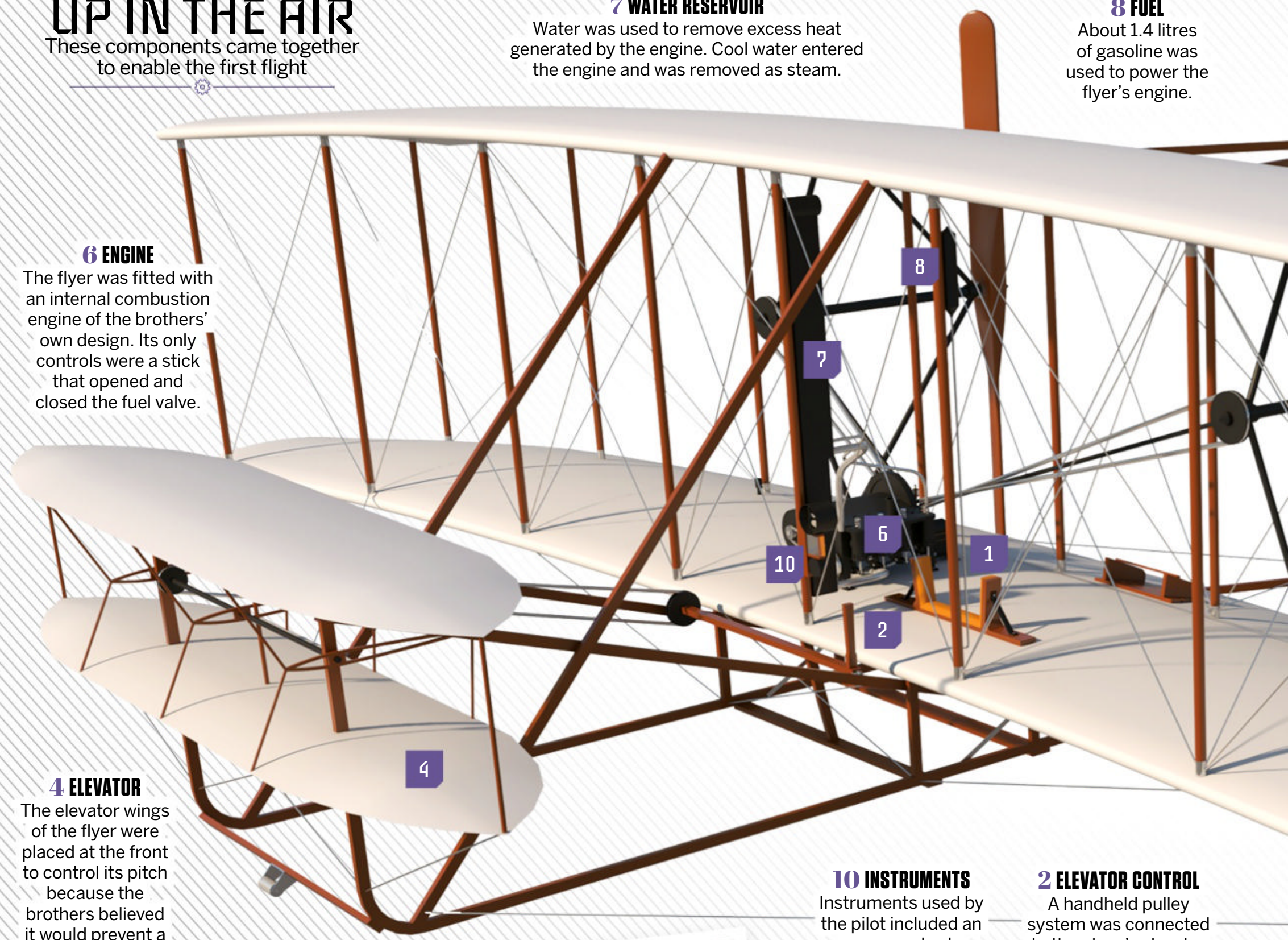
Water was used to remove excess heat generated by the engine. Cool water entered the engine and was removed as steam.

8 FUEL

About 1.4 litres of gasoline was used to power the flyer's engine.

6 ENGINE

The flyer was fitted with an internal combustion engine of the brothers' own design. Its only controls were a stick that opened and closed the fuel valve.



4 ELEVATOR

The elevator wings of the flyer were placed at the front to control its pitch because the brothers believed it would prevent a possible nose dive.

10 INSTRUMENTS

Instruments used by the pilot included an anemometer to measure distance, a stopwatch and engine revolution recorder.

2 ELEVATOR CONTROL

A handheld pulley system was connected to the plane's elevator to change the orientation of the plane's nose up or down, called pitch.

EVOLUTION OF THE WRIGHT FLYER

1899

Wilbur wrote to the Smithsonian Institution to obtain publications on aeronautics, and in the same year the Wright brothers built a functioning experimental biplane kite with a 1.5-metre wingspan.

1900

The Wright brothers began construction of a full-size glider with built-in controls for an onboard pilot. However, this model did not generate enough lift to carry a pilot.

1901

After another failed attempt to generate enough lift, the brothers constructed a wind tunnel to test and gather data on wing shape and size from an internally mounted glider.

1902

Having found the perfect wing shape for flight, the third glider created by the brothers also included a rudder to control the yaw rotation (left or right movement) of the aircraft.

1903

Having finally created a functioning glider, the brothers added an internal combustion engine to it and created the first Wright Flyer.

1904

Following the success of the first flyer, the Wright brothers created another slightly updated aircraft called the Flyer II. This was the first aircraft to complete a full circle and land where it had taken off.

1905

The Flyer III became the first practical aeroplane in history, meaning that it could fly for as long as its fuel allowed.

DID YOU KNOW? Neil Armstrong took a piece of the Wright Flyer with him on the Apollo 11 mission to the Moon

5 RUDDER
A fixed rudder at the rear of the flyer, controlled by the hip cradle, was used to adjust the direction of flight.

9 PROPELLERS
Two sets of wooden propellers connected to the engine spun in an opposing direction to generate thrust while in the air.


The Wright Flyer during a test flight in 1903

5

9

Did you know?
Unpiloted, the Wright Flyer weighed 274.4 kilograms

1 HIP CRADLE
The pilots lay within a hip cradle, which was connected to wires that were also connected to the wings. The cradle was moved by the pilot's hips, twisting the wings and rolling the plane.

3

3 WING WARPING
The flyer's wings were made from muslin, which was flexible enough to twist for making manoeuvres.

1909

THE FINAL FLYER

The last of the Wright brothers' flyers was made and sold for the United States Army Signal Corporation and became the first military aircraft in the world. The army required that the Military Flyer could reach a speed of 42 miles per hour, making it the fastest aircraft the brothers had ever made. To create this new aircraft, the Wright brothers originally used a different aircraft model that they had been working on from 1907, called the Model A. However, following a crash landing in the testing stage of its development, the model was altered to include a shorter 11.1-metre wingspan, longer propellers and a four-cylinder engine. During testing, the new model topped 42.58 miles per hour, with a range of 44 miles, meeting the military brief. Having been bought by the army for $25,000 (around $845,600 or £696,000 today), the Military Flyer and Wilbur headed off to army training bases in Maryland to train the first generation of military pilots.


A 1909 Military Flyer at the National Museum of the United States Air Force

WHAT WAS THE BOSTON TEA PARTY?

Why American colonists attacked British tea ships 250 years ago

WORDS AILSA HARVEY

In May 1773, the British government passed the Tea Act, making the British East India Company the exclusive tea seller to its American colonies. In the years leading up to this, many people in America avoided buying British tea due to the hefty tax on it. Instead, tea was smuggled into the country so the drink could be enjoyed without having to pay the British government. When parliament passed the Tea Act and gave a single company all the business, prices were dropped to less than what was being paid for smuggled tea. But even this didn't solve the problem the British had. Many people in America were unhappy about paying a government based thousands of miles away, whose actions and rule they had no say in.

A few months later, there was retaliation. Anger boiled over when the British East India Company arrived in Boston with its cargo of tea following requests by the governor of the Province of Massachusetts Bay, Thomas Hutchinson, for them to leave. The protest that unfolded is today known as the Boston Tea Party. On the evening of 16 December 1773, a large group forced their way onto three British tea ships docked at Boston Harbour. The protesters ransacked the tea chests and threw them overboard. After the Boston Tea Party boycott, the British government shut down Boston Harbour until the chests were paid for. American colonists continued to boycott the British East India Company, and many switched from tea to coffee. Today, the legacy of this fallout remains, as Americans still drink more coffee than tea.

Did you know?

Some Sons of Liberty dressed as Native Americans

DID YOU KNOW? Hundreds took part in the Boston Tea Party, but only 116 names are known today

5 FACTS ABOUT SPILLING THE TEA

1 OVERBOARD
342 chests of tea were dumped into the harbour's waters.

2 TEA TYPE
The tea thrown overboard was Chinese tea, and around 22 per cent was green tea.

3 MULTIPLE PARTIES
Ten similar events occurred along the shoreline from Philadelphia to Charleston.

4 PROTESTORS' PROMISE
The protesting colonists had made a pact of silence, so no one was ever officially named for their involvement.

5 LOST SHIPMENT
Four tea ships set sail for Boston. The three that were targeted docked at the harbour, but the fourth was lost in a storm on the way.

WHO WAS INVOLVED?

Only a select few are known to have been involved in the protest, and just one person, Francis Akeley, was caught and arrested. Samuel Adams led the Boston Tea Party along with Sons of Liberty member John Hancock. Sons of Liberty was a group of colonist tradesmen formed to retaliate against the taxation of the American colonies in 1765. Other named members who took part were Benedict Arnold, Patrick Henry and Paul Revere. However, most of the participants didn't know each other, and they decided to keep it that way to reduce the chance of being turned in. The protesters were ordered to first cut open the tea chests before tossing them into the water. This was so that the water would infiltrate the tea and turn the harbour into one large tea bath.

Boston Tea Party leader Samuel Adams was born in Boston in 1722

STIRRING UP

The dumping of tea was a big statement to the British government, but this was only the start. As the first significant opposition to British rule, it had a domino effect that resulted in the beginning of the American Revolution in April 1775. The first response by the British government to punish those involved in the tea rebellion was to introduce the Coercive Acts (1774). These acts involved blocking the harbour to all trade except for imports for the British Army, giving the British government and army more power over the state of Massachusetts. The new laws were meant to serve as a warning and deter other colonies from plotting something similar. Instead it unified other British colonies, marking the start of the revolution and America's independence in 1776.

An artist's depiction of the signing of the American Declaration of Independence in 1776

TECHNOLOGY

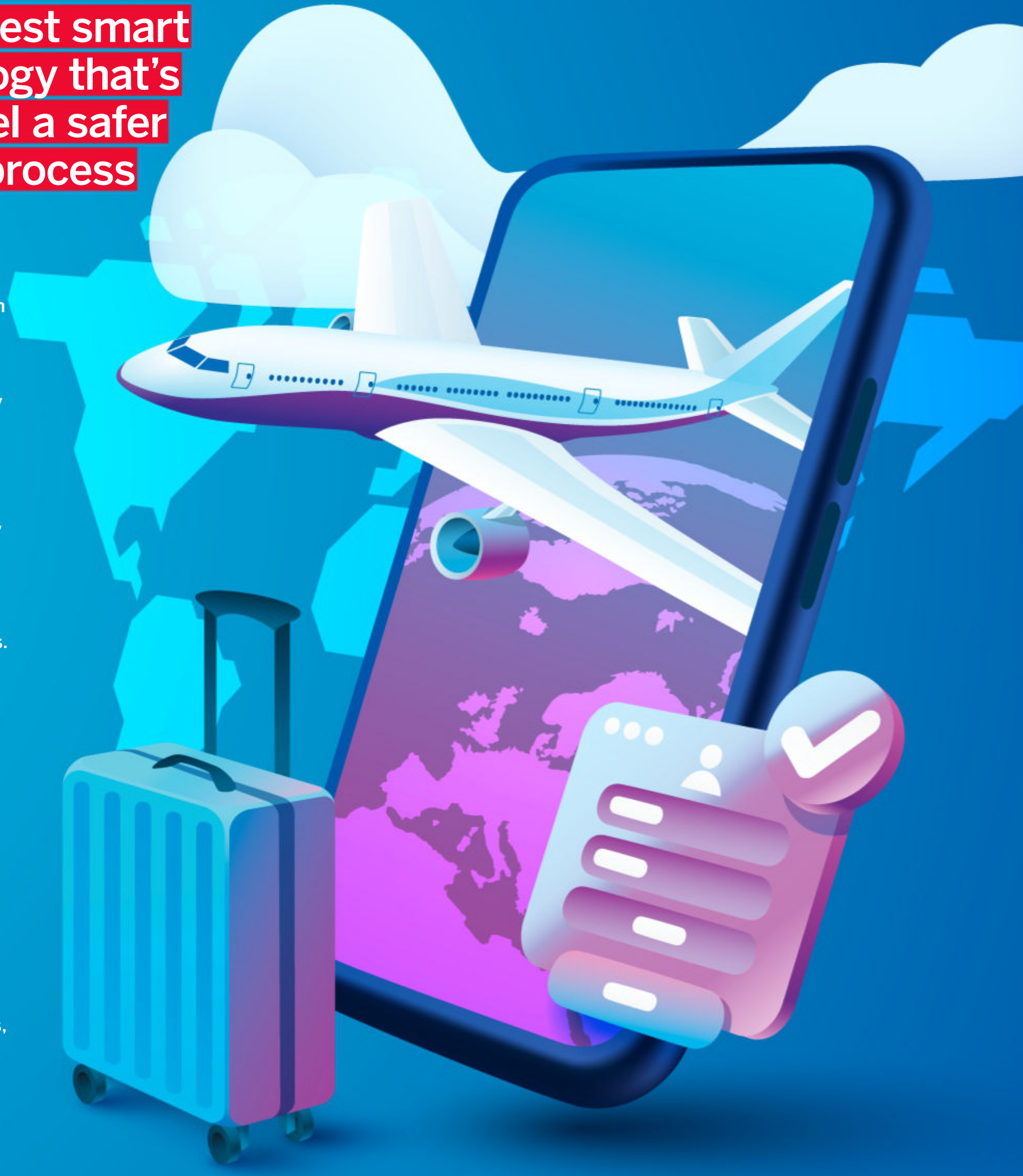
HOW AIRPORTS ARE GETTING SMARTER

Discover the latest smart airport technology that's making air travel a safer and smoother process

WORDS AILSA HARVEY

Every day, enough passengers filter through the world's airports to fill the seats of around 100,000 commercial flights. With thousands of people airborne at any given time, every process at an airport needs to be executed with efficiency and safety. This includes swift transportation from car parks and entrances to terminal buildings, regimented air-traffic control management and thorough checks of all people and items being transported around the globe.

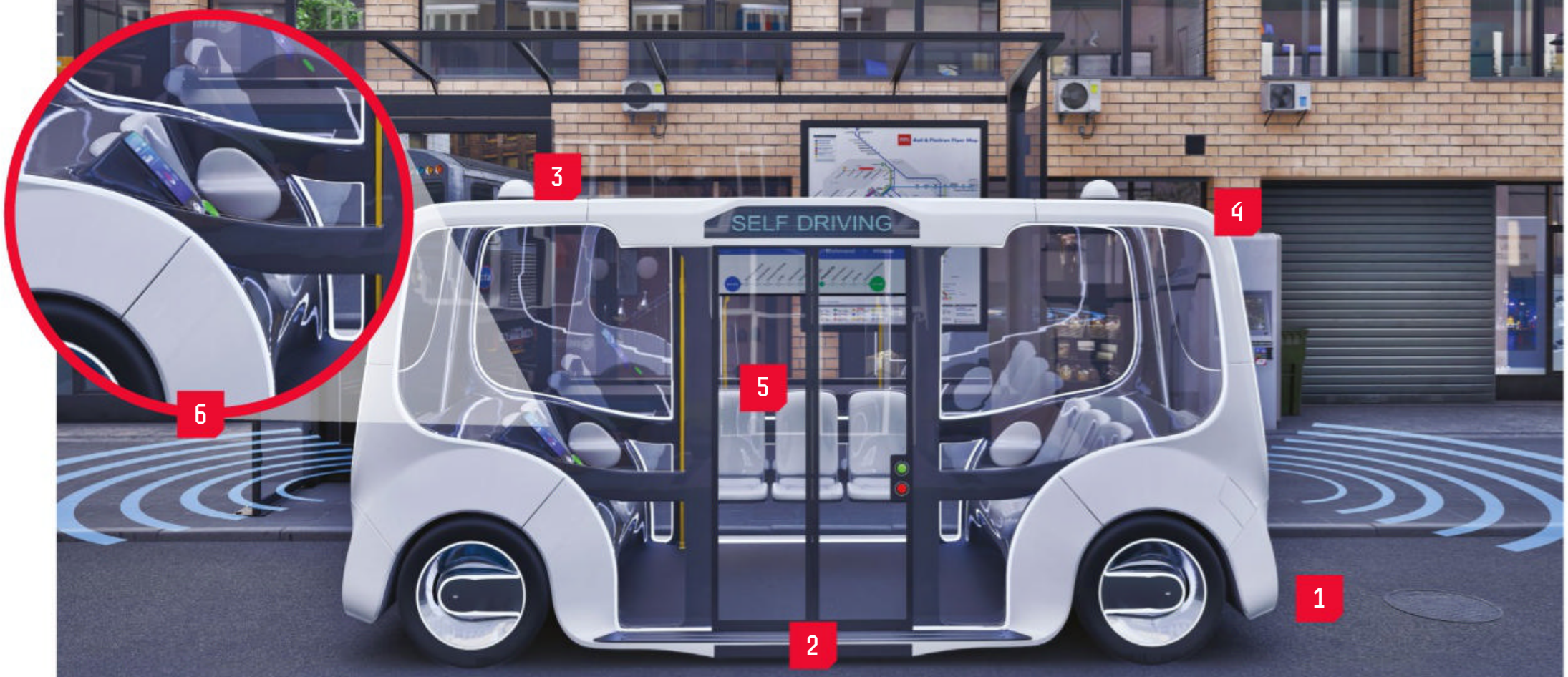
Airport traffic is trending upwards. As more flights are scheduled each year, airports have become more sophisticated to maintain control of departures and arrivals. In recent years, one of the most significant technological changes to take off was the conversion of air travel documentation from paper to electronic. This transition has massively reduced the time it takes to process passengers as more reliable computer systems ensure many of the manual checks at airports can be carried out by machines. In areas where human error could have devastating results, facial-recognition technology, autonomous vehicle systems and data prediction have all been welcome changes in terminals.



DID YOU KNOW? Autonomous pods at Heathrow Airport in London have replaced 50,000 annual bus journeys

ROBOT REVOLUTION

Did you know?
Millimetre wave scanners emit less energy than a mobile phone



DRIVERLESS TAXIS

Autonomous shuttles carry passengers between car parks and airport terminals around the world

1 LIDAR
Light detection and ranging sensors release infrared waves. These are reflected off nearby objects so the vehicle can determine where obstacles are.

2 ODOMETRY
The distance the vehicle has travelled is calculated by a computer using the number of tyre rotations.

3 SATELLITE POSITIONING
Satellites in the global navigation satellite system communicate with the shuttle to determine the exact location of the vehicle.

4 CAMERA VISION
Live camera footage from the front and back records what obstacles surround the vehicle for safety.

5 PASSENGER SEATING
The seating area inside these pods usually has space to fit four passengers and their luggage.

6 CONTROL SCREEN
Upon entering the self-driving pod, passengers usually select the terminal they wish to travel to and the shuttle begins the journey automatically.

BAGGAGE-HANDLING BOTS

A city's main airport can operate over 1,000 takeoffs every day. On each of these planes are between 20 and 900 passengers, all trusting the respective airlines to handle their luggage and deliver it to their destination safely. One way in which the baggage-sorting task is achieved is through autonomous robots. These robots, which were first launched at Rotterdam The Hague Airport in the Netherlands, are being tested in various locations around the world, such as Dallas Fort Worth Airport in Texas. Following check-in, a passenger's bag is placed onto a conveyor belt and delivered to the baggage sorting area behind the check-in desk. Bags are dropped onto the surface of these wheeled robots, which sort them so that they are taken to the correct departure gates. They can handle 450 suitcases every hour.


Baggage-handling robots retrieving suitcases in Munich, Germany

FAST SECURITY

How improvements in bag and body scanners can reduce airport security queues

2 PRIVACY PROGRESS
Software to protect passenger privacy is now in place at most airports. The screens being checked show where suspicious items are on the body, but only display a generic body outline.

3 METAL DETECTOR
Every person needs to walk through a metal detector, which can detect concealed weapons and other metal items.

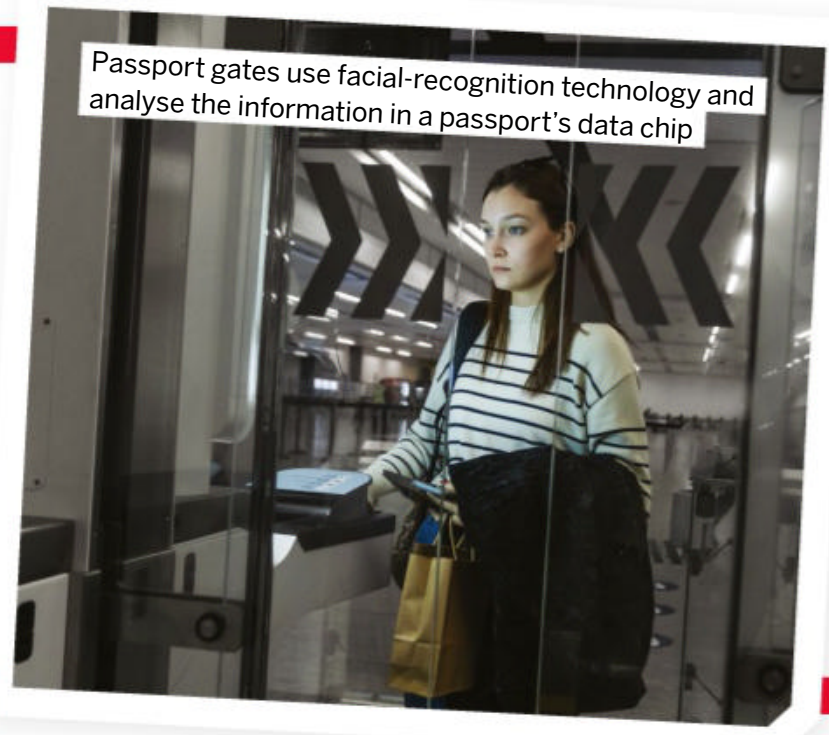
1 MILLIMETRE WAVE SCANNER
Since the 2010s, millimetre wave body scanners have been used in most airports instead of X-ray technology. These non-ionising waves bounce off the body and return to the machine. Any objects being worn on the body will be revealed.

4 CONTENT CHECKER
A computer tomography (CT) scanner is the latest technology to replace X-ray luggage machines. These produce a 3D image from different angles, enabling passengers to keep liquids and electronics inside their suitcases for the entire process.

Did you know?
Over 1,000 dogs work in US airports detecting contraband

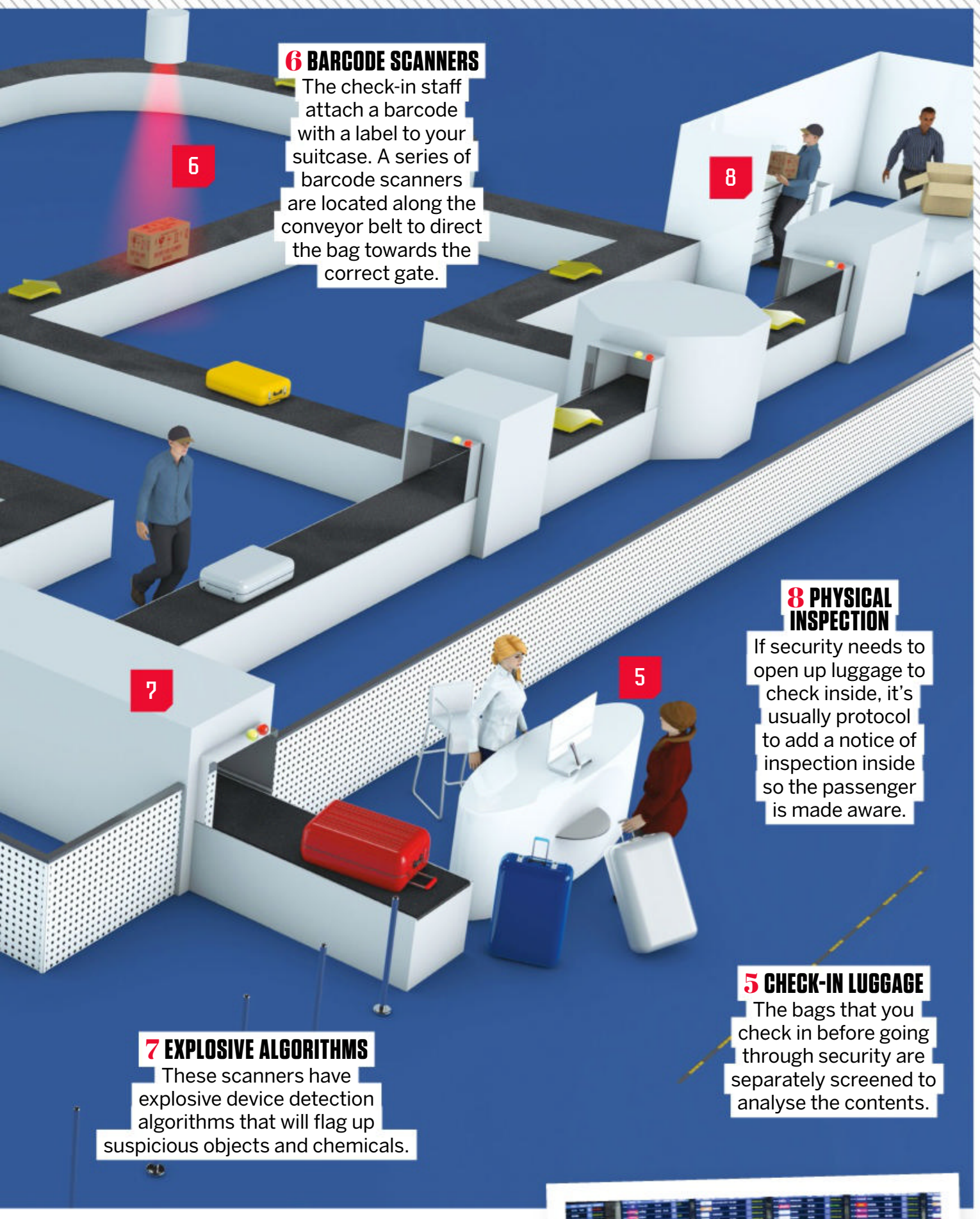
STOPPING STAMPING

Any citizen of a country outside the European Union (EU) has a limited number of days that they can be in the EU in a certain period. To keep track of exactly when each passenger enters and exits the region, border control staff stamp each person's passport with the date. This is a low-tech system compared to the intelligent machines in most modern airports. Soon this system will be replaced with the Entry/Exit System (EES). This will consist of passport-scanning machines that record the passenger's movements instead. Unlike the electronic passport machines already in place in most airports, which just check the validity of the document and match it with the person's face on camera, the EES will also be able to record their location. When in place, these machines will store this data and alert authorities when they come across a passenger who has overstayed in the EU.



Passport gates use facial-recognition technology and analyse the information in a passport's data chip

DID YOU KNOW? Dubai International Airport served 41.6 million passengers in the first six months of 2023



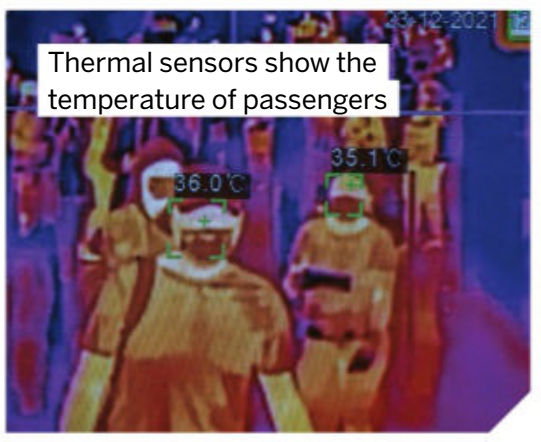
AI DELAY PREDICTIONS

You've arrived early for your flight and have just about had your fill of the terminal entertainment and refreshments. But when you check the gate number at the time instructed, the number is replaced with the word 'delayed'. This misfortune doesn't just impact the passenger, but throws off the busy schedule of the runways and flights in all connecting airports. Using artificial intelligence (AI) and machine learning, computers can combine weather data, aircraft live locations and other data to predict how likely each flight is to be delayed. This software can even convert radio communications from pilots and airport towers into text, analyse it and then incorporate the events from hundreds of these conversations into its prediction. If used across the world's connected airports, disruptions could be managed in advance, which could create more efficient airport spaces.


Delay-prediction technology provides data to passengers, airlines, airports and travel companies

DEPARTURES SURVEILLANCE

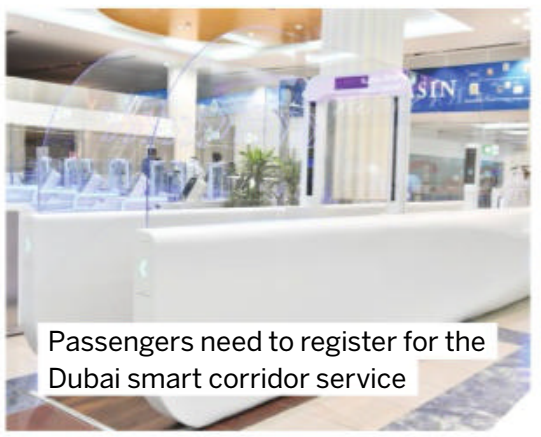
Departure lounges are adorned with cameras. Security guards monitor the live footage – but what happens if a guard isn't watching as a dangerous individual makes a move? Today's cameras are increasingly intelligent and can automatically notify airport staff of unusual activity. This includes thermal cameras that detect any unusual items or weapons that have been smuggled onto the site. Artificial intelligence can also detect particular shapes and movements. Modern airports use AI cameras that actively search for the shapes of weapons in their live footage.



Thermal sensors show the temperature of passengers

INTELLIGENT BORDERS

Most countries have strict checks in place to make sure authorities know who's within their borders at all times. At airports this often forms long queues as each visa and passport is checked manually by a border control officer. However, in Dubai a new smart corridor has been launched that can process 12 passengers in a minute. As each passenger walks through, biometric cameras scan their faces and computers instantly approve or reject the individual. For this to work, passengers have to log all their travel documents and information before their flight and arrival.


Passengers need to register for the Dubai smart corridor service

Haptics have improved modern controllers for games consoles

Things like haptic gloves are adding a new layer of depth to our virtual interactions

WHAT ARE HAPTIC DEVICES?

Haptic technology is bringing the virtual world to life through touch

WORDS MARK SMITH

Chances are you're already familiar with haptics through smartphones. The word 'haptic' is derived from the Greek term haptesthai, which means 'to touch'. And thanks to haptic devices incorporated into electronic components, we can now feel things in gaming or virtual environments – force, vibration, pressure, temperature, resistance or motion, all designed to enhance our experience and add greater depth to those interactions.

The technology that underpins haptics includes things like motors, pneumatic devices and pressure-sensitive piezoelectric actuators. When you interact with a smartphone, for example, small motors spin tiny centre weights to create a vibration that you can feel. In more advanced devices, electrodes attached to your skin can 'trick' your nerves into feeling complex sensations like temperature or even a breeze. Imagine being able to feel something without even having to actually touch it; that's what mid-air haptics are. You may have seen the scene in the movie *Minority Report*, where Tom Cruise's character moves virtual displays through thin air with special gloves – technology today isn't too far away from that.

Did you know?

There are 3,000 touch receptors in your fingertips

At the higher end of the spectrum, haptics can use things like ultrasound and electrostatics to create more subtle effects for this type of 'mid-air' interaction, allowing users to interact with a device or surface without any direct contact.

They used to be the preserve of the military, but are now seen in cars.

Beyond the gaming and smartphone industries, haptics are being increasingly used in medical and industrial fields. For example, haptics allow doctors to 'feel' their way around a patient's body while they carry out remote virtual surgery through a robot.

THE VIRTUAL VEST

It's not just our fingers and hands where we experience sensations. Spanish company Owo has designed a vest for the upper body that can provide haptic feedback for a range of virtual experiences. Owo says its haptics provide ten electrified zones around the user's torso and arms that can recreate more than 30 sensations, from wind on the skin and insect bites to being shot. The company describes it as a 'second skin' and says it uses an algorithm to enable the wearer to feel different sensations while gaming. The firm recently announced it was partnering with video games publisher Ubisoft, so that gamers playing *Assassin's Creed* would be able to feel injuries when they're fighting.

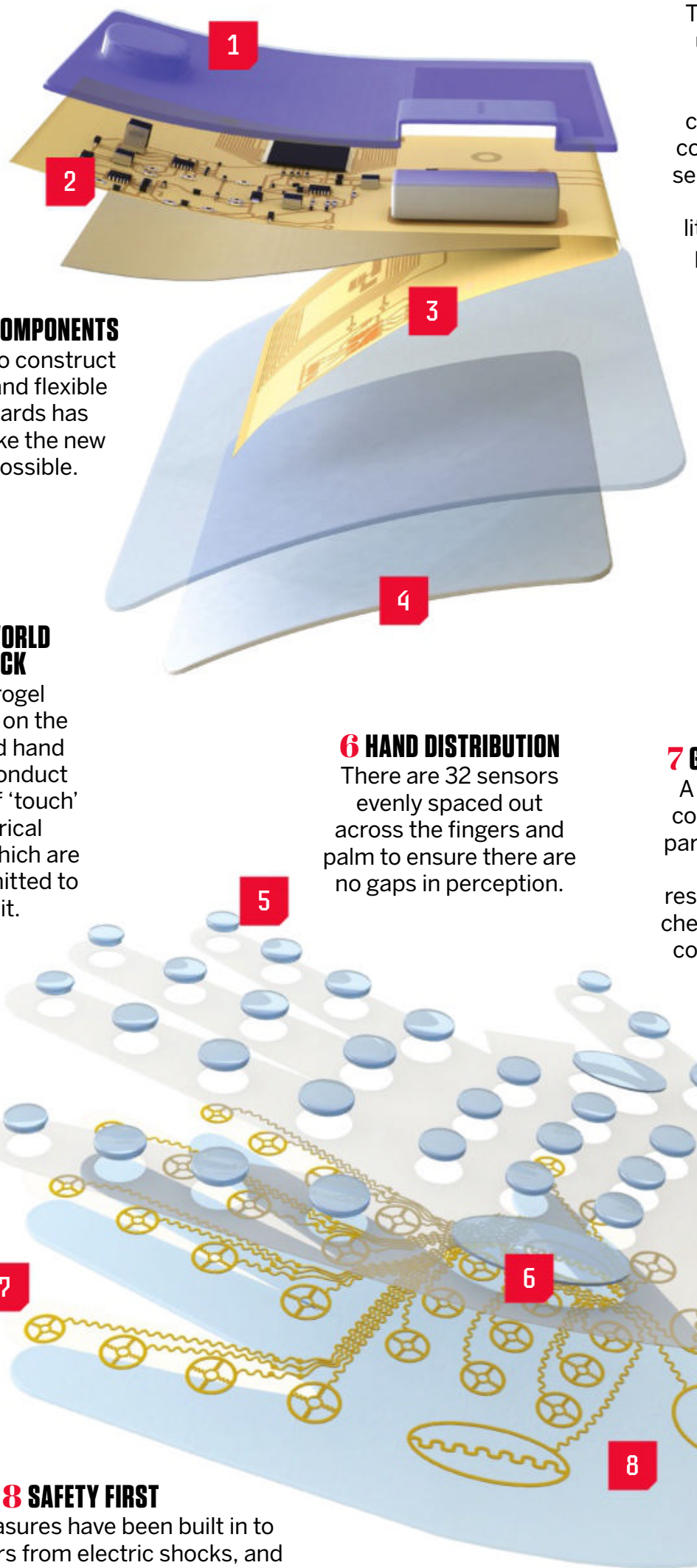
The virtual vest provides haptic feedback while gaming

INVISIBLE TOUCH

Researchers at City University of Hong Kong have created WeTac to provide realistic tactile sensations

1 PROTECTIVE LAYER

Soft and durable silicone protects the electronic components in the driver unit, which is mounted just above the wrist.



2 FLEXIBLE COMPONENTS

The ability to construct miniature and flexible circuit boards has helped make the new device possible.

3 DRIVER UNIT TECHNOLOGY

The driver module uses low-energy Bluetooth and wireless communication to connect to the hand sensors, with a small rechargeable lithium-ion battery providing power.

4 SOFT ELECTRODES

Unlike metal electrodes, hydrogel technology is soft and can be moulded to the skin, yet can still transmit electrical impulses.

5 REAL-WORLD FEEDBACK

The hydrogel electrodes on the fingers and hand are what conduct the sense of 'touch' via electrical impulses, which are then transmitted to the unit.

6 HAND DISTRIBUTION

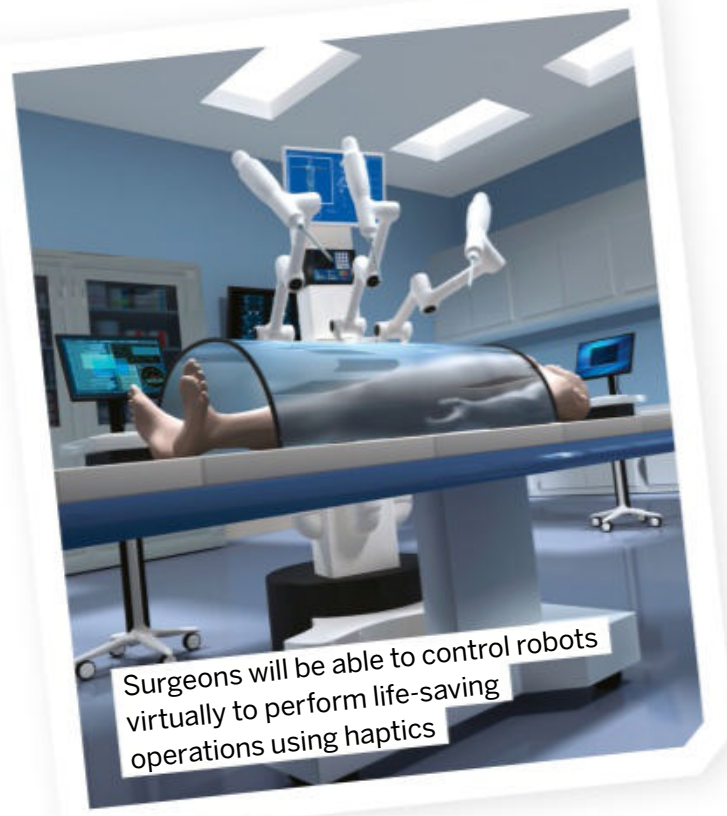
There are 32 sensors evenly spaced out across the fingers and palm to ensure there are no gaps in perception.

7 GOLDEN HANDSHAKE

A mixture of highly conductive gold and parylene – an organic polymer that is resistant to almost all chemicals – forms the connecting network between the electrodes.

8 SAFETY FIRST

Safety measures have been built in to protect users from electric shocks, and heat is maintained between 27 and 35.5 degrees Celsius to avoid discomfort.



Surgeons will be able to control robots virtually to perform life-saving operations using haptics

THE HISTORY OF HAPTICS

Haptics aren't actually that new, tracing their roots all the way back to 1976. Japanese video game giant Sega was the first company to incorporate haptics into the arcade game *Fonz*. Inspired by the *Happy Days* character, the tech in the arcade cabinet let players experience a rumble when they crashed into another player's bike. Research found that this enhanced the experience, and so companies started to put haptic feedback technology into modern controllers. They could vibrate and rumble when gamers crashed their virtual race car or had to overpower an opponent in a physical challenge, like a virtual sword fight.


TV'S HOTTEST NAME.
YOUR HOTTEST GAME.

"FONZ" by SEGA

SEGA
The Quartermasters

An arcade flyer for *Fonz*, the first time haptics was used in an arcade game

HOW TO PAY BY PHONE

Near-field communication has revolutionised how we pay for goods and share data

WORDS AILSA HARVEY

For most people, gone are the days of counting out the exact change from the coins in your purse when you make a purchase at the shop. Today, customers don't need to open their wallets to pay, or even bring a wallet to the shop at all. Near-field communication (NFC) technology is the wireless transmission of data between specialised tags. This enables payments to be made between card readers and contactless cards or smartphones when they come within a few centimetres of each other.

The amount of data that an NFC chip can store is between 96 and 512 bytes, depending on the type of chip embedded into the device. Each one has a small tag that communicates between payment devices and card readers to accurately transfer the correct value of money between bank accounts. For a smartphone to operate in a similar way to a bank card, the user must turn on the NFC setting and the associated bank card details must be connected to the phone.

Did you know?

UK customers spend 30 per cent more using NFC payments

It might seem risky to pass over money virtually with less than a touch of two devices, but because the process is so quick, it prevents people or machines intercepting and stealing money. Vitally, any bank details or private information is protected between machines. Instead of revealing this data on the card reader, a unique digital signature is received as proof of transfer.

Vehicle-specific NFC data can connect smart devices and cars so the owners can use these devices in place of a physical key

Tickets can be scanned by NFC machines from wearable technology like smartwatches

READING THE FUTURE

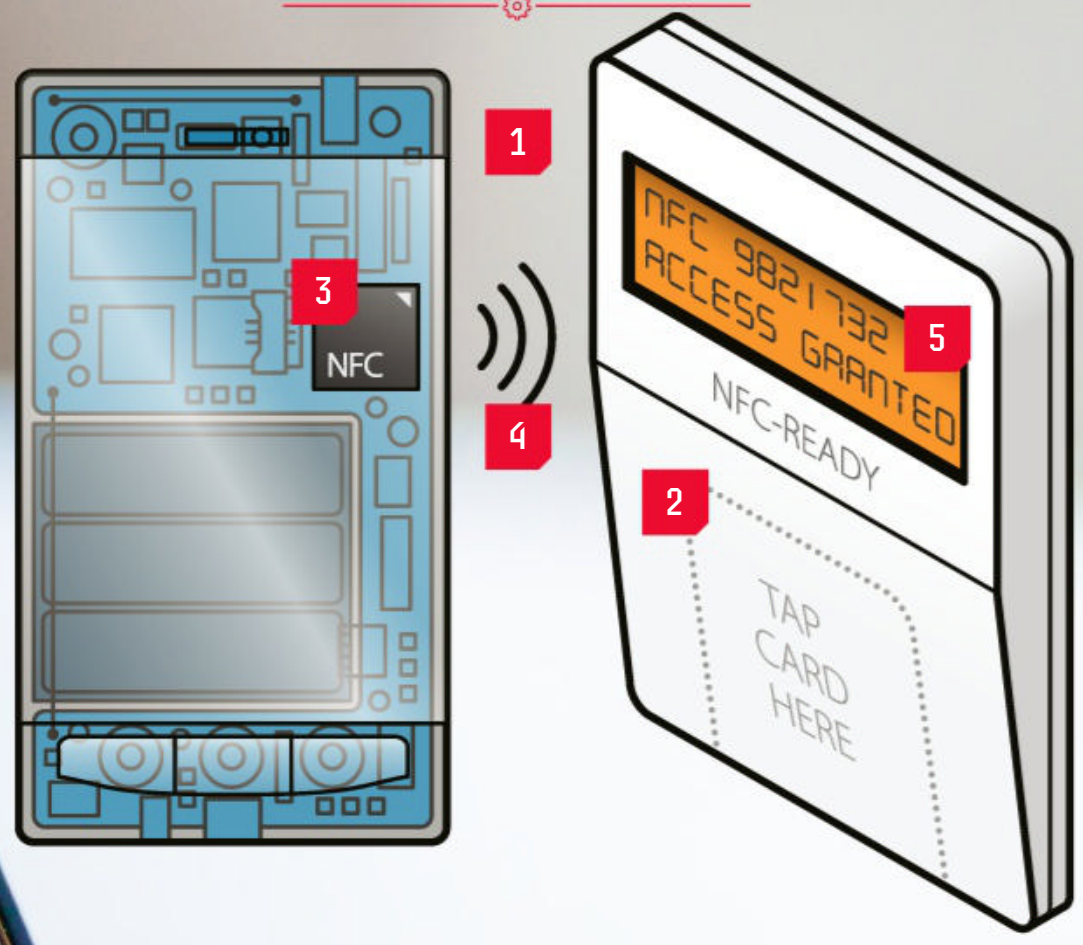
The applications of speedy, close-contact data transmission have so far only scratched the surface of what's possible. Aside from money transfers, in the future it's likely that this technology will be more widespread. Any ticketed event can be organised using NFC for an efficient guest-entry process, while schedules and updates at business and educational events could be delivered through multiple-tag communication. For music concerts and other similar events, people who have purchased NFC tickets on their phone just need to walk past a ticket-processing machine and make near contact to enter a venue, limiting their stopping time and reducing queues.

One of the useful features of NFC is that a power source isn't needed to hold and transmit data. Information about any item, whether that's a famous landmark, a person or products in shops, could be tagged with NFC information. Any information that can be translated into code can be stored on these tags. As long as the data remains small enough to effortlessly transfer between devices, the possibilities are endless.

DID YOU KNOW? 62 per cent of people aged between 18 and 26 use their smartphones to make payments

MAKING A PAYMENT

This step-by-step guide explains how NFC devices share data



1 CLOSING THE GAP

NFC is a short-range wireless technology, so payment devices and card readers need to be four centimetres apart.

2 MASTER DEVICE

The master device initiates communication through radio waves by sending encrypted data, such as the amount of money required.

3 NFC DATA

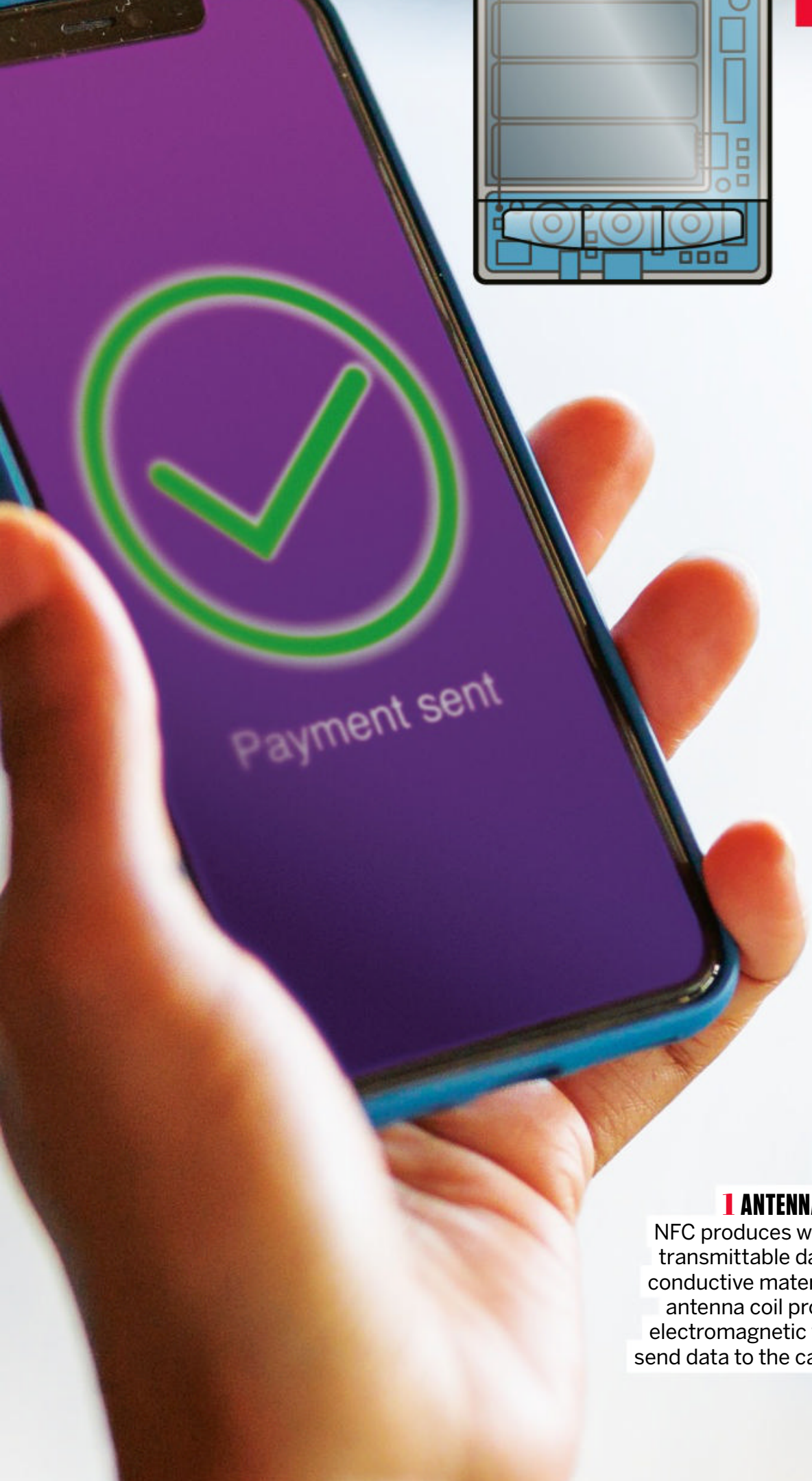
An NFC device, such as a smartphone, has an NFC tag to exchange digital content.

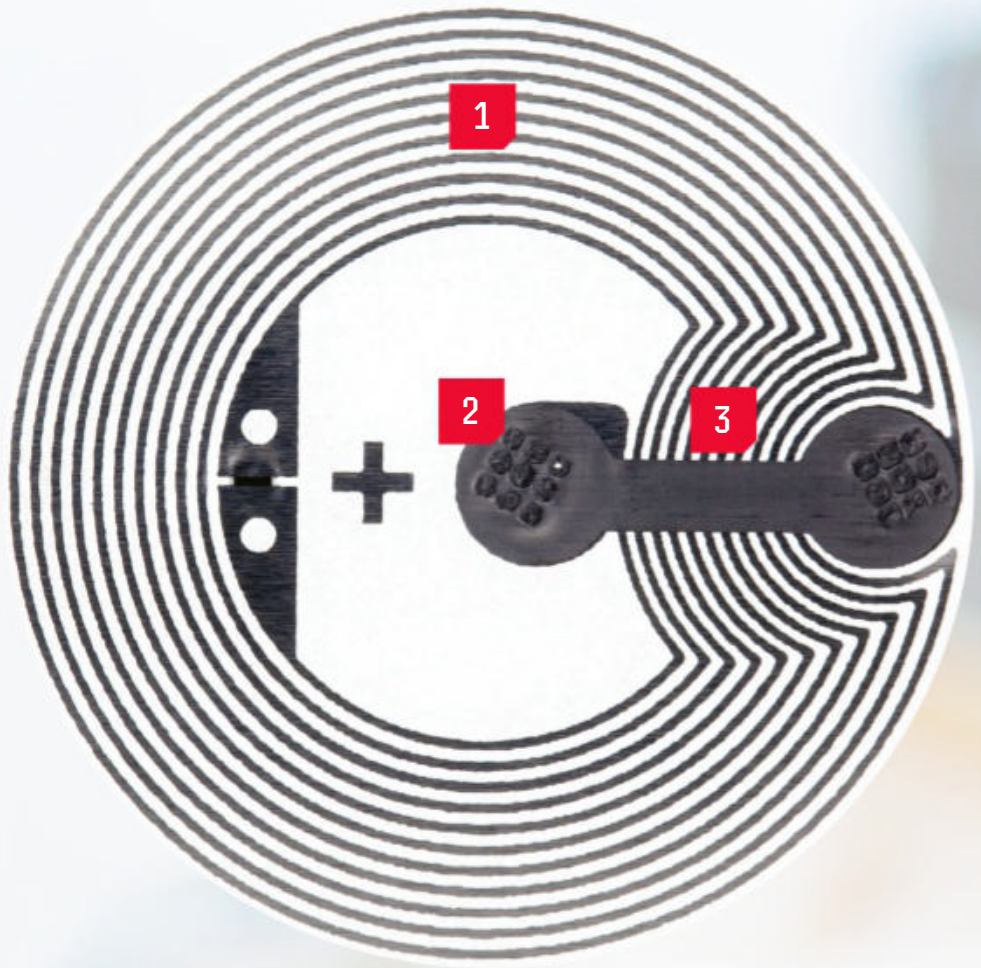
4 SENDING COMMUNICATION

In response to the master device, the NFC tag returns more encrypted data with payment information.

5 RECEIVING DATA

The card reader collects the encoded bank card data and transmits it to the connected bank to receive the money.





TAG STRUCTURE

What components are in an NFC tag?

1 ANTENNA

NFC produces wirelessly transmittable data. The conductive material in the antenna coil produces electromagnetic waves to send data to the card reader.

2 NFC CHIP

The chip contains the card's encrypted data. It's this component that exchanges data with the card reader.

3 BOND

A small piece of conductive metal alloy connects the chip and the antenna. This electrically conductive strip between the two components is usually protected by a plastic coating to stop the bond breaking.

HOW WOOL IS MADE

Discover the process that turns fluffy fur into fabric

WORDS SCOTT DUTFIELD

Since 10,000 BCE, humans have been weaving and wearing wool. Today, more than 1.3 billion sheep around the world are used each year for wool production. Like any other animal fur, wool is hair taken from sheep and other mammals, such as goats and rabbits, which can be woven into fabric for clothes and bedding. Several properties of wool make it suitable as a wearable material, such as being a good insulator for winter weather. Wool fibres are very elastic and can be stretched up to 30 centimetres before they break, which is beneficial when transforming raw fibres into spun yarn. They are also hydrophobic, meaning they tend to repel water, thanks to a natural oil that coats each fibre called lanolin.

To harvest these fibres, every year, a sheep's fleece is sheared completely by hand in the spring. The dense mat of wool that's produced by this full-body shave is known as greasy wool and still contains all its natural oils and farmyard muck. Once a farm's worth of sheep wool has been harvested, it's sent off to the processing plant, where it will be washed, dried and spun into a thread and fabric. More than 1,000 breeds of sheep are used to produce wool, but the most sought-after wool comes from Merino sheep. The fibres of Merino sheep wool are between 15.5 and 24 micrometres wide, much finer than other sheep breeds and even thinner than human hair, which is typically around 30 micrometres wide.

Did you know?

China is the largest producer of wool in the world

Wool passing through the carding process in a factory in the Faroe Islands

5 WEIRD WAYS WOOL IS USED

1 FERTILISER
Used as mulch in gardens, wool naturally releases stored nutrients into the soil. It's also useful for retaining water and warmth for seed germination.

2 INSULATION
As a natural insulator, wool is often used to retain heat and create an acoustic barrier in the roofs, walls and floors of many homes.

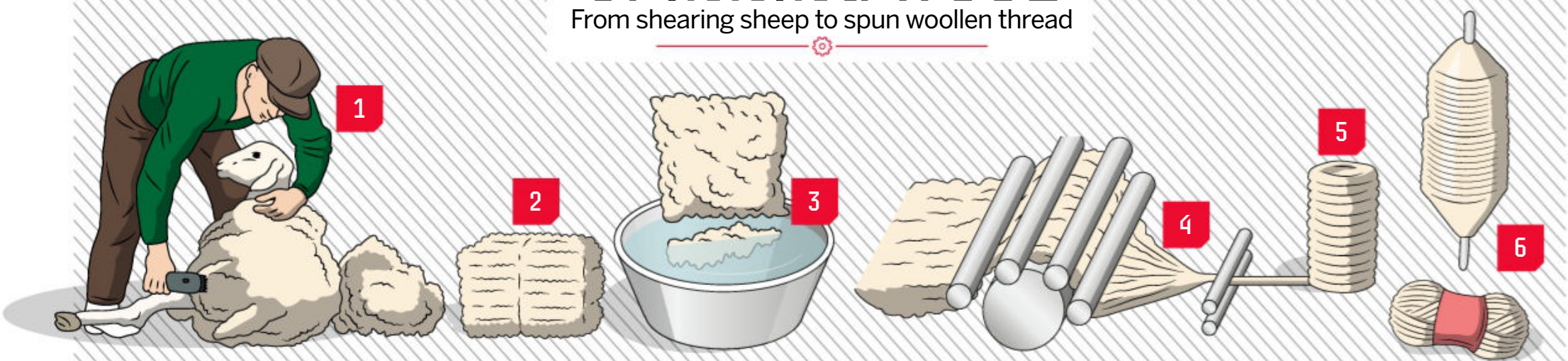
3 OIL SPILLS
In the event of a marine oil spill, wool can be used to clear up the mess by absorbing up to ten times its weight in oil.

4 SKINCARE
An oil found on wool called lanolin is used in many different moisturisers to repair and soften the skin. It's also used as an ingredient in some makeup-removing products.

5 FIREFIGHTING
Wool is used in the garments of firefighters due to its high heat tolerance. It's also been used on the International Space Station in flame-retardant clothes.

SPINNING WOOL

From shearing sheep to spun woollen thread



1 SHEARING
At least once a year, sheep are sheared, their fleece often taken off in a single piece.

2 BALING
Before processing, hundreds of kilograms of fleece are baled together ready for transport.

3 SCOURING
Bales are opened and washed in a series of baths to remove grease and dirt.

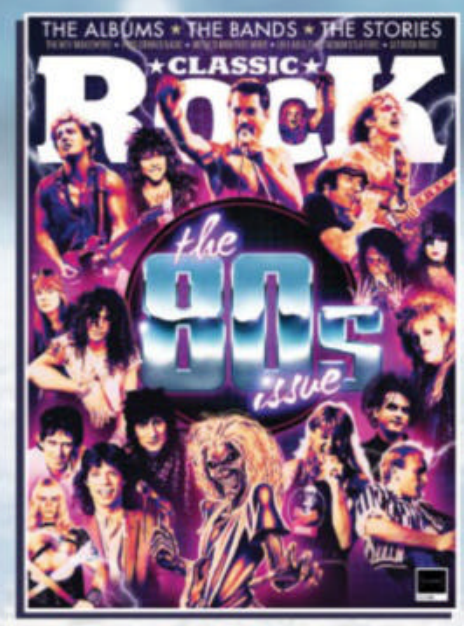
4 CARDING
Wool fibres are detangled through a series of toothed rollers, called a willower.

5 SPINNING
The now-soft fluffy fibres are twisted together to form a continuous thread.

6 WRAPPING
Threads are spun around cones or drums, ready to be woven into fabrics or bundled as balls of wool.

Winter Savings

SUBSCRIBE FROM JUST £6



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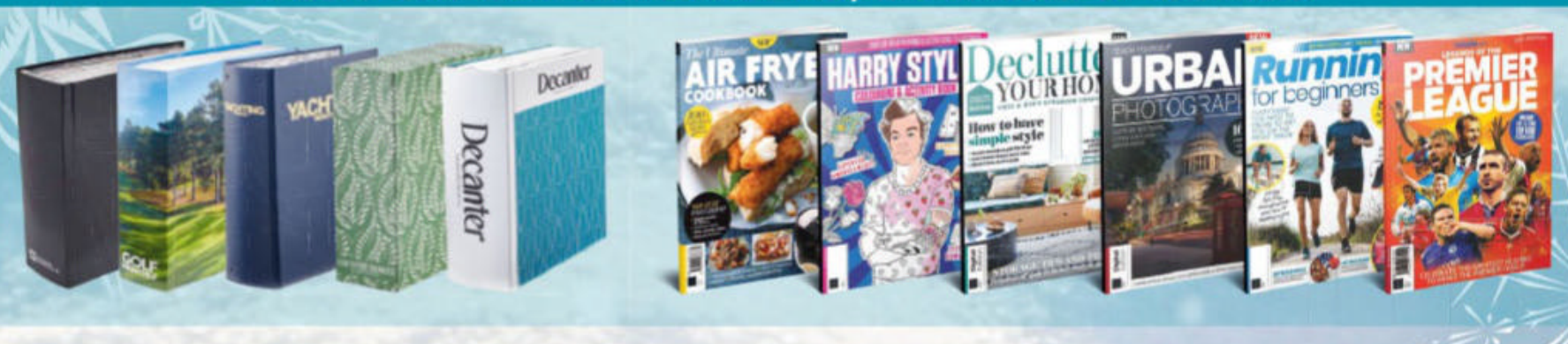

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DID YOU KNOW? Queen guitarist and astronomer Brian May helped NASA identify a suitable landing spot for OSIRIS-REx

HOW EARTH GOT ITS WATER

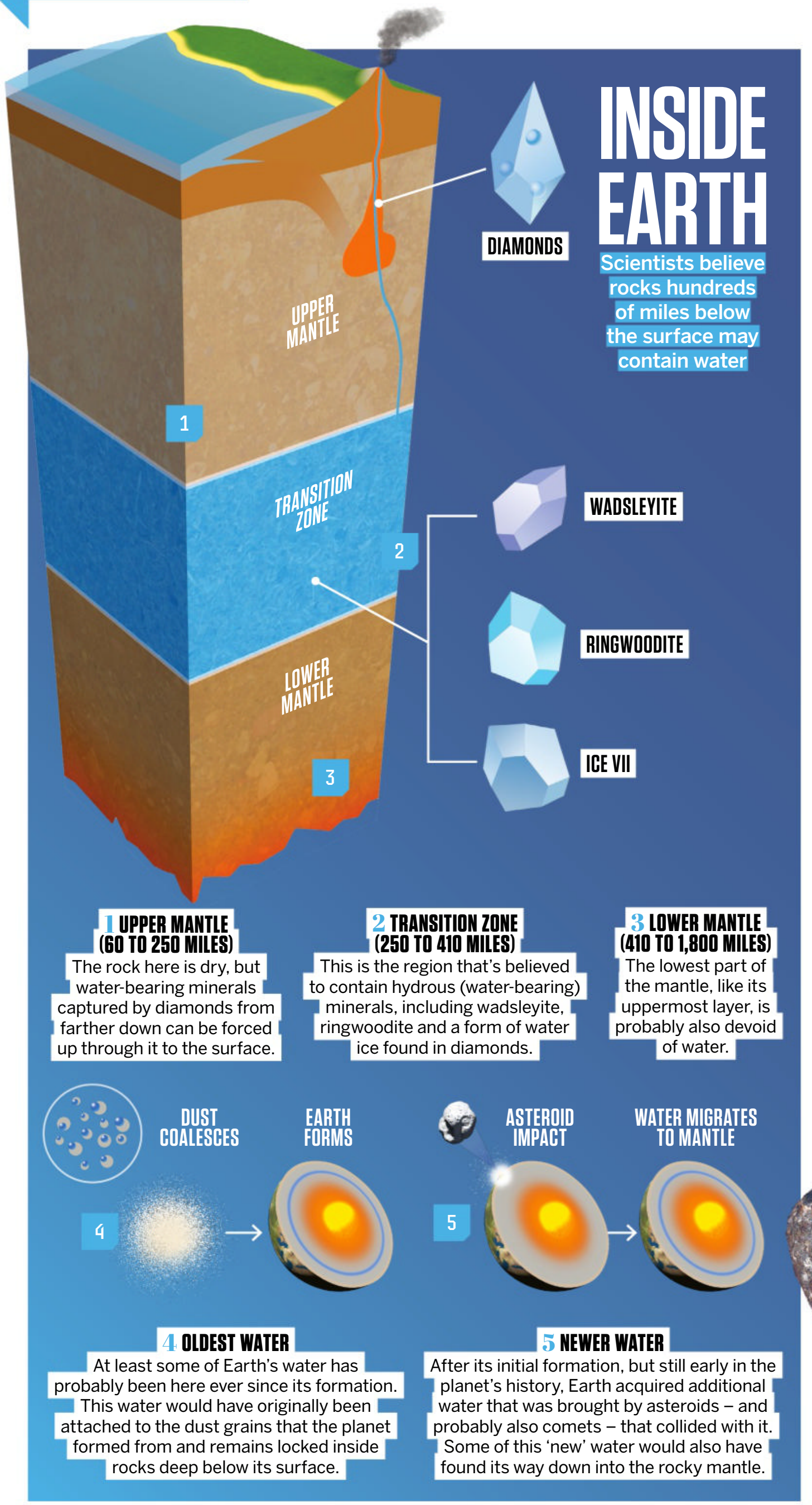
A lot of our water likely came from space, which could be shown by a NASA spacecraft that just returned from a nearby asteroid

WORDS ANDREW MAY

It's easy to take water for granted on Earth. It surrounds us all the time – in the sea, in rivers and streams, in rain, in clouds even when it's not raining and in frozen form as snow and ice in winter. But where did all this water come from? In its earliest days, Earth was extremely hot – maybe as high as 2,000 degrees Celsius – so there couldn't have been any liquid water on the surface at that time. In fact, there are several scientific theories as to how our planet got its water.

Earth is often described as a 'water planet', which is a good description of the way it appears from space, with water, in liquid or frozen form, covering three-quarters of its surface. But if you delve a little deeper, it turns out this is only a superficial impression. Most of our planet is solid rock, with water making up just 0.05 per cent of its mass. Ironically, although Earth is the only place in the Solar System where water is easy to see on the surface, it's a long way from being the most water-rich body orbiting the Sun.

In fact, water becomes increasingly prevalent the farther out you look in the Solar System, though due to the cold temperatures, much of it exists frozen as ice. But even liquid water may exist in copious quantities deep in the interior of some bodies,



such as Jupiter's moon Ganymede, where liquid water may make up as much as 46 per cent of its volume. By the time you get to the outermost parts of the Solar System, such as the Kuiper Belt and Oort Cloud, the majority of the material there is in the form of frozen water.

The significance of this for water on Earth is that these outer regions are the very places comets come from. It's likely that, in the distant past, large numbers of comets may have collided with Earth. These collisions would have brought water to our planet, and at one time this was the leading theory to explain the origin of our water. But when scientists looked at cometary water in more detail, they discovered a subtlety that means this can't be the true explanation – at least not for the majority of Earth's water.

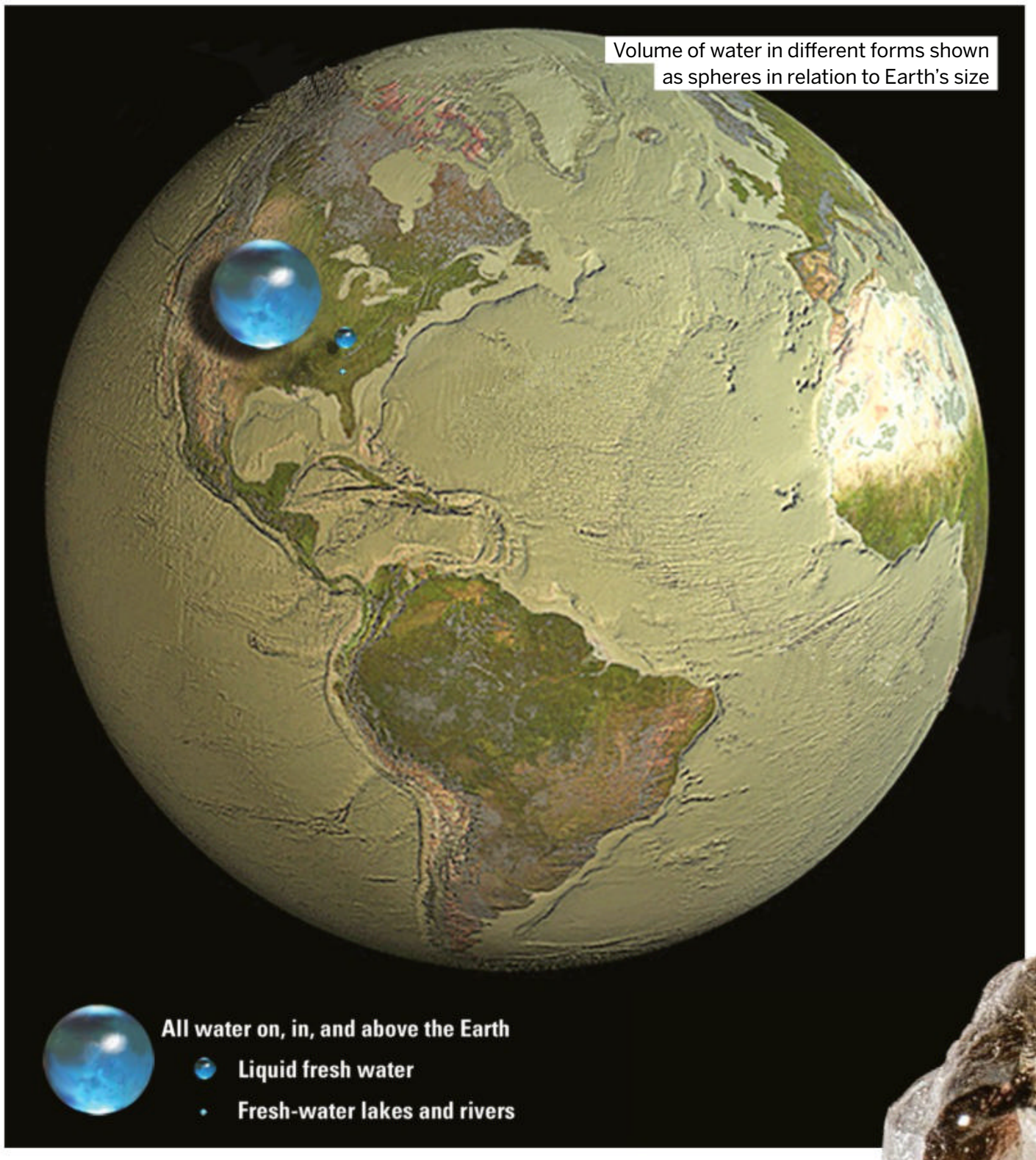
The problem lies with the so-called 'flavour' of water. From a chemical point of view, water is H_2O, made up of molecules containing two

WET METEORITES

The easiest way to test the theory that asteroids brought water to Earth is by studying meteorites. These are pieces of asteroids that entered Earth's atmosphere as meteors and managed to get all the way down to the ground without burning up entirely. From the point of view of chemical composition, there are several different types of meteorite – corresponding to different types of parent asteroid – but the ones of greatest interest in the context of Earth's water are known as carbonaceous chondrites. Within the broad class of carbonaceous chondrites is a particularly rare form known as CI chondrites, of which only nine examples have been found to date. The water in these meteorites is the most ancient ever discovered, dating from the very birth of the Solar System 4.6 billion years ago, yet it makes up as much as 20 per cent of their mass.

Carbonaceous chondrites such as this one have a significant water content

DID YOU KNOW? The largest body of water on Earth is the Pacific Ocean, with an area of 60 million square miles



WATER IS EVERYWHERE

Earth's water exists in some obvious places, like rivers, lakes and oceans, as well as less obvious ones like groundwater in soil. Individual molecules of water don't always stay in the same place, but move around as part of the global water cycle. For example, ocean water may evaporate to form clouds and subsequently fall as rain in some other part of the world. But the overall quantities of water in different forms tend to stay constant. The US Geological Survey has likened these quantities to spheres of different diameters. The total amount of water – including that in the salty oceans – would fill a sphere 860 miles in diameter, while freshwater, including any hidden deep underground, would be 170 miles. Water in lakes and rivers is just 35 miles.

Water-rich diamonds like this, originating in Earth's mantle, indicate the existence of water there

"Cometary water clearly isn't the same flavour as Earth's"

hydrogen atoms and one oxygen atom. But Earth's water contains two different forms of hydrogen: the most common kind, H, having just a solitary proton in the nucleus, and the other – D, for deuterium – containing a neutron as well. The 'flavour' of water refers to the ratio, D to H, of the two types of hydrogen it contains.

Measurements of cometary water clearly show that it isn't the same flavour as Earth's water. In fact, comets vary considerably in their value of D/H, with the best studied comet of all, 67P/Churyumov-Gerasimenko – as visited by the European Space Agency's Rosetta spacecraft in 2014 – having a particularly high D/H ratio, more than three times that of Earth's oceans. On the other hand, there's another family of Solar System bodies that have D/H values much closer to Earth.

Did you know?

Over two-thirds of Earth's freshwater is frozen

At the end of February 2021, a 320-gram chunk of space rock thudded down onto a driveway in Winchcombe, Gloucestershire. Within 12 hours it had been carefully collected and hermetically sealed by scientists, making it one of the most pristine meteorite samples ever obtained. It's also one of the most important clues we have as to the source of water on Earth. Before it broke up in the atmosphere, the Winchcombe meteorite formed part of an asteroid, and it's believed to be a typical example of a large class of such asteroids that orbit the Sun inside the orbit of Jupiter. Analysis of the meteorite revealed it to contain around 11 per cent water by weight, most of this locked up in minerals. Most important of all, its D/H ratio matched that of Earth's oceans almost

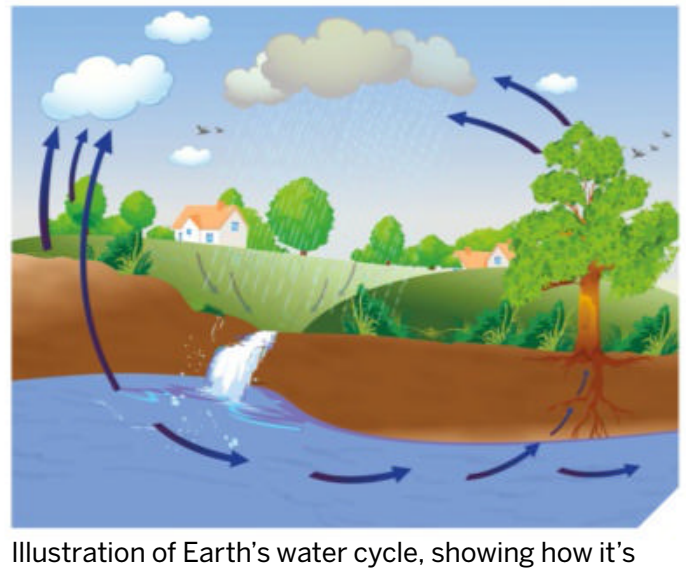


Illustration of Earth's water cycle, showing how it's constantly 'recycled' from one form to another

perfectly. Since meteorite impacts would have been much more frequent in the distant past, when the density of asteroids in the space around Earth was higher, this is a strong indication that incoming asteroids were a major contributor to Earth's water.

Further support for this idea came in September 2022 following the analysis of a small sample of material collected from the asteroid Ryugu by the Japanese Aerospace Exploration Agency's Hayabusa2 probe. To the surprise of scientists around the world, the sample contained not just water molecules locked up in minerals, but an actual droplet of pure liquid water. In the case of a meteorite this might have been dismissed as earthly contamination, but that wasn't possible here because the sample was collected in the vacuum of space. As exciting as that discovery was, it may soon be overshadowed following the return of a much larger asteroid sample by NASA's OSIRIS-REx mission in September 2023.

As enticing as the idea of water from asteroids is, it may not be the complete answer to the origin of Earth's water. Just as asteroids have water locked up inside the minerals they're made up of, the same may be true of some of Earth's own rocks as well. Indeed, there's evidence that 'primordial water' of this kind can be found hundreds of miles below the surface of Earth. Although this is much too deep to study directly, diamonds that formed at such depths can occasionally be forced up to the surface by volcanic action, and some of these have been found to have a high water content.

Part of the asteroid sample collected by Hayabusa2 in 2019


Scientists from NASA and Arizona University inspecting the sample-return capsule after its landing

96.5%
Most of Earth's surface water is in the oceans

4.6%
A fraction of meteorites are carbonaceous chondrites

23
Around two dozen planets and moons in the Solar System are known to have water

2019
The year of the first detection of water vapour in an exoplanet's atmosphere

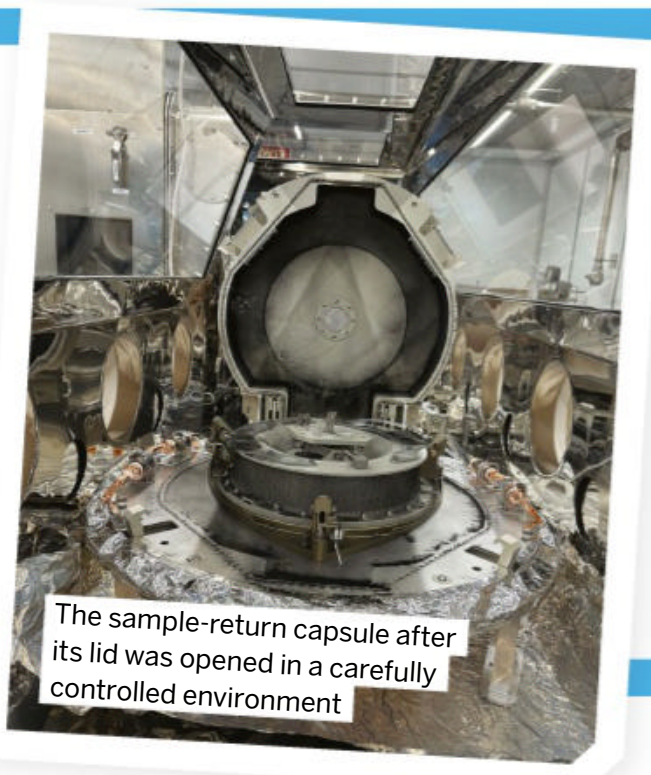
0.007%
Less than one-ten thousandth of Earth's water is accessible for human consumption

2.5 CENTIMETRES
An average of an inch of rain would fall if atmospheric water vapour suddenly condensed

SIX GRAMS
The total weight of asteroid samples collected by Japan's Hayabusa probes

SAMPLES FROM AN ASTEROID

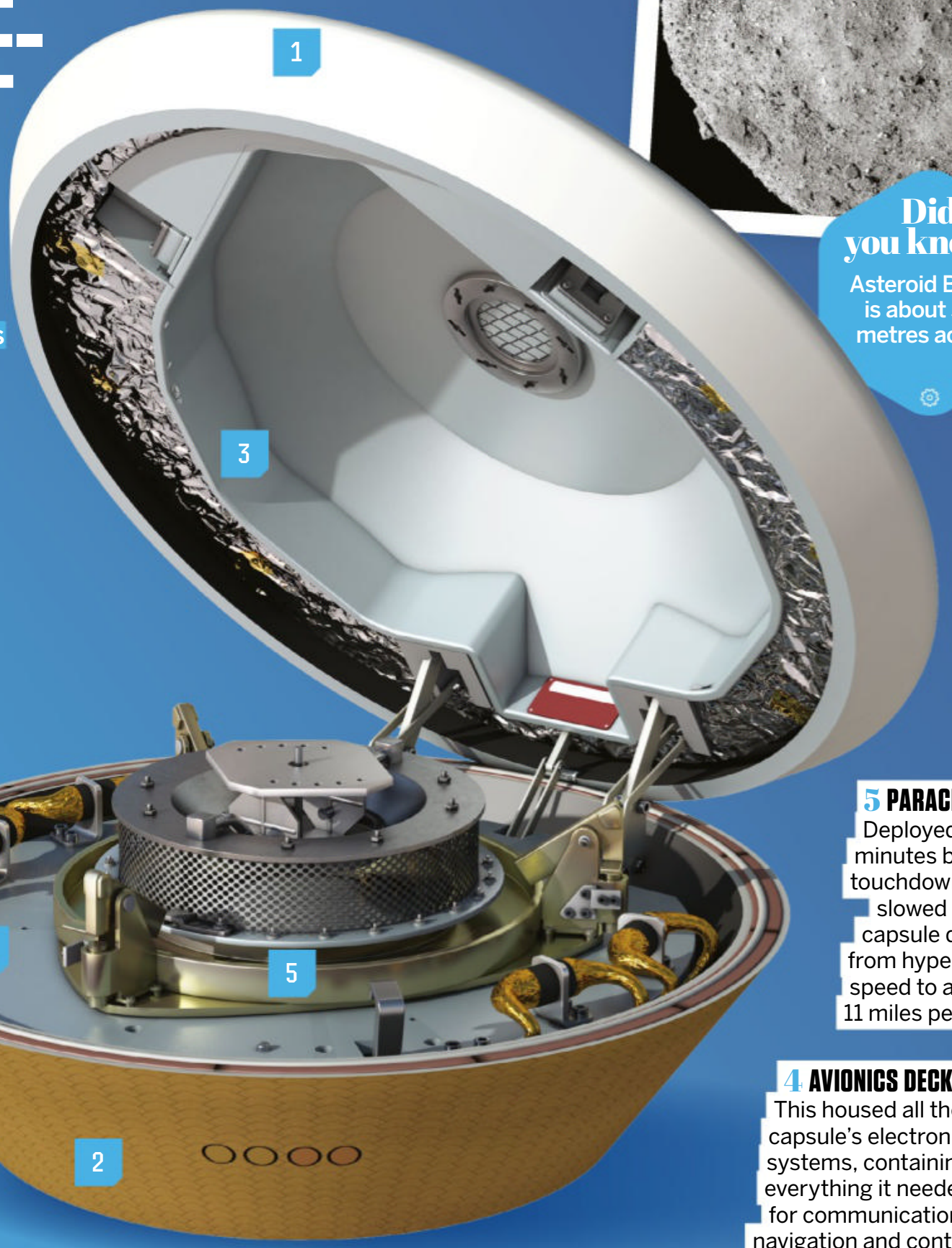
Before OSIRIS-REx collected its sample from the asteroid Bennu, it carried out a survey of the asteroid to help scientists choose the best landing spot. They shortlisted several possibilities, with the one eventually selected being located close to Bennu's north pole; this was chosen because it contained the largest quantity of unobstructed fine-grained material. After a few hundred grams of this material was collected, it was carefully stowed inside the sample-return canister until its arrival back on Earth three years later. It will be a while before NASA fully extracts the canister's contents and distributes it for analysis. However, long before they looked inside the return vehicle three days after its landing, scientists found tiny 'samples' from Bennu in a place they weren't expecting them in the form of a dark, powdery deposit scattered all over the vehicle's avionics deck. Preliminary analysis of this material revealed the abundant presence of water-bearing clay minerals.


The sample-return capsule after its lid was opened in a carefully controlled environment

DID YOU KNOW? The rings of Saturn are made up of particles of 99.9 per cent pure water ice

THE SAMPLE-RETURN CAPSULE

This small vehicle, 81 centimetres in diameter, came back down to Earth in September 2023



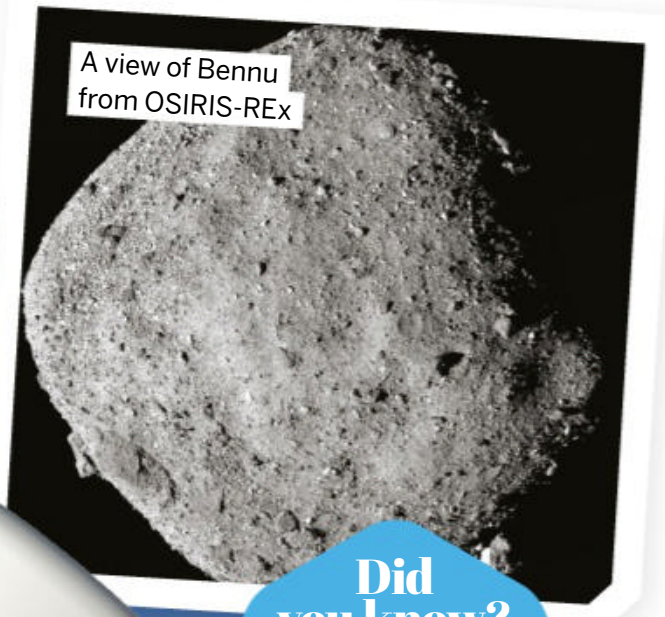
1 HEATSHIELD
Made from lightweight phenolic-impregnated carbon ablator (PICA), this protected the capsule's delicate contents from the heat of re-entry.

3 SAMPLE CANISTER
Made from aluminium and securely nestled between the heatshield and backshell, this is where the asteroid sample was kept.

2 BACKSHELL
Experiencing less heat because it formed the rear of the descending capsule, this is made from a thinner material called SLA-561V.

5 PARACHUTE
Deployed five minutes before touchdown, this slowed the capsule down from hypersonic speed to a mere 11 miles per hour.

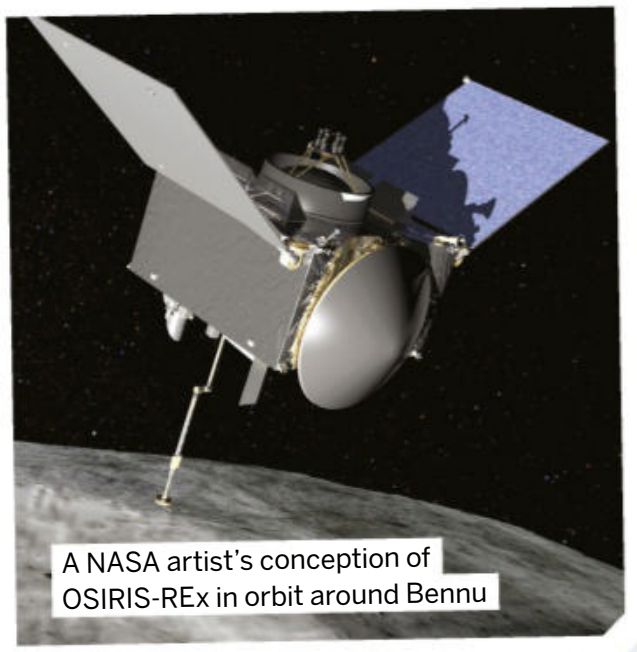
4 AVIONICS DECK
This housed all the capsule's electronic systems, containing everything it needed for communication, navigation and control.


A view of Bennu from OSIRIS-REx

Did you know?
Asteroid Bennu is about 500 metres across

THE OSIRIS-REX SAMPLE-RETURN MISSION

NASA's OSIRIS-REx made headlines when its sample-return capsule landed in the Utah desert containing fragments of rock collected from Bennu. This wasn't the first time that samples from an asteroid had been returned to Earth – the Japanese space agency had already achieved that with its two Hayabusa missions – but NASA's sample is larger and provides more scope for scientific analysis of the asteroid's make-up, including any water it may contain. The spacecraft was launched in September 2016 and arrived at Bennu in December 2018, after which it studied it for almost two years before collecting its rock sample in October 2020. Although it takes its name from an ancient Egyptian deity, it's also an acronym describing the spacecraft's scientific aims: the Origins, Spectral Interpretation, Resource Identification and Security Regolith Explorer. It's now embarked on a second mission, as OSIRIS-APEX – for Apophis Explorer – to another asteroid named Apophis.


A NASA artist's conception of OSIRIS-REx in orbit around Bennu

VENUS: EARTH'S EVIL TWIN

The second planet from the Sun is a hellish place of boiling temperatures and acid rain, but can it teach us about our future?

WORDS IAN EVENDEN

Shrouded in mist and mystery, the second planet from our Sun is a rocky world of similar size and composition to Earth. But that's where the parallels between the two end. Venus is hot. Extremely hot. The planet is hotter than Mercury, even though it's twice as far from the Sun. Standing on the surface of Venus would expose you to pressures similar to being almost 1,000 metres underwater on Earth, and temperatures of up to 480 degrees Celsius – high enough to melt lead.

These high pressures and temperatures are a result of the planet's thick, dense atmosphere, made up largely of carbon dioxide with billowing clouds of sulphur dioxide and sulphuric acid. The cloud layer on Venus is almost four times thicker than that on Earth. This atmosphere is also highly reflective, and while this means Venus shines brightly in our morning and evening skies, it also has the effect of making it hard to observe the gloomy surface beneath, even from orbit around the planet. Satellites have gotten around this by using radar to penetrate the clouds, revealing a landscape rich in craters, geological features and volcanic activity.

Venus turned out this way as a result of a runaway greenhouse effect. It's thought by some to be a warning about what could happen here on Earth in the future if we don't get our emisions in check. Findings from the European Space Agency's Venus Express probe tell us that the planet must have once had water on its surface – possibly, computer modelling suggests, for over a billion years of its history. Its undoing was the planet's close proximity to the Sun. The high temperatures caused water on the planet's surface to evaporate, and water vapour is even more of a powerful greenhouse gas than carbon dioxide. Ultraviolet light from the Sun then broke the water molecules apart into hydrogen and oxygen. The hydrogen escaped into the atmosphere and the oxygen combined with carbon to form carbon dioxide.

NEAR NEIGHBOUR TO EARTH

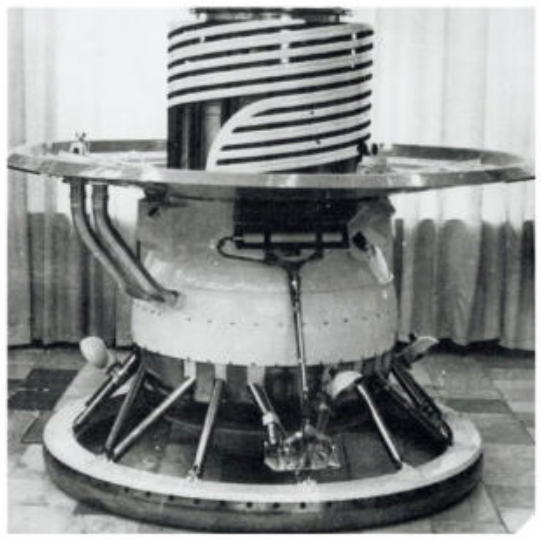
Venus gets closest to Earth, but it's a very different world

Did you know?

In 1962, Venus became the first planet visited by a probe

LENS CAP TROUBLES

Soviet probe Venera 9 sent back the first pictures from the surface of another planet in 1975, but both it and Venera 10 failed to separate the lens caps from one of their two cameras. Venera 11 and 12 also had issues with lens caps not releasing. Venera 14 was even more unlucky. Its cap fell in the area targeted by its soil probe, so it took a reading from the cap instead of the planet.



Eight different Venera probes successfully landed on the planet

"These high pressures and temperatures are a result of the planet's thick, dense atmosphere"

DID YOU KNOW? Venus is the brightest object in the night sky after the Moon – bright enough to cast shadows on the ground

1

2

3

4

1 CRATERS

Venus actually has few craters compared to Earth and the Moon, as the thick atmosphere burns all but the largest rocks up before they can hit the surface. This means the craters that do get made are likely to be huge.

2 NO MOON

Venus is unusual among large Solar System bodies in having no natural satellite. In 1672, astronomer Giovanni Cassini thought he spotted one. Others agreed, and the object was named Neith. However, they were all mistaken.

3 RIVERS

These may look like rivers, but they are really the channels made by molten lava flowing over the planet's surface. With no tectonic plates, volcanoes can erupt anywhere on Venus.

4 ARACHNOIDS

These bizarre structures are found only on Venus and are named after their resemblance to spiders' webs. The oval shape is surrounded by hundreds of fractures in the ground, thought to be formed by volcanic activity.

LIFE ON VENUS?

The question of whether women are, in fact, from Venus was answered in the 1960s and 1970s when Soviet-launched probes flew by and landed on the planet ahead of those launched by the US. The probes lasted between 20 minutes and two hours before the scorching conditions destroyed them. The crushing atmosphere that obliterated these probes also makes it impossible for life as we know it to exist on the planet's surface. However, as it's thought Venus may have hosted oceans of liquid water in the past, microbial life could have evolved.

If it did, then the thick, stable atmosphere of the planet we see today may now be its home. A band of cloud far enough away from the surface to be at a low enough temperature and pressure could provide ideal conditions. Indeed, Geoffrey Alan Landis, a NASA scientist who specialises in planetary exploration, says there is a sweet spot 31 miles above the sweltering surface where humans could one day live in floating cities. This is the most Earth-like environment we know of in our Solar System. But we won't know for sure until the planet is explored more thoroughly. Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy (VERITAS) will be the first NASA spacecraft to explore Venus since the 1990s. It will discover the secrets of a past habitable world on Venus, gathering data to reveal how the paths of Venus and Earth diverged.

A balloon-based mission could examine the planet high above the deadly surface

HOW THE INTERNATIONAL SPACE STATION WAS BUILT

The football-pitch-sized science lab presented the toughest engineering challenge of modern times, but a historic level of international cooperation and an innovative modular design made this remarkable satellite a reality

WORDS MATTHEW BOLTON

Orbiting over 248 miles above Earth and travelling at over 16,800 miles per hour, the ISS is the most expensive object ever constructed. It stands as testament to the progress that can be made when nations work together. This research laboratory, which has living quarters for six residents, was described by NASA as "the most complex scientific and technological endeavour ever undertaken". It is the largest artificial satellite ever created and has provided continual life support and shelter for astronauts for over 23 years. The ISS was only possible because of the cooperation of the many countries involved, working together to create an inspirational scientific venture and an engineering marvel.

At 109 metres wide and 73 metres long, it's larger than an average football pitch, with a total mass of over 400 tonnes. Despite this considerable size, the ISS travels around eight times faster than a bullet, circling our planet in around 90 minutes. Its huge size also means that it's visible with the naked eye from sea level. However, you need to be in the right place at the right time. The station's inception started in earnest in 1993, when the Russian Federal Space Agency, NASA and the European Space Agency began to merge their space station programs to avoid the huge costs falling on one space agency. The ISS also received significant contributions from Canada and Japan for its eventual construction. To date, it's estimated to have cost over $150 billion (£123 billion).

Did you know?

The first crew stayed on board for four-and-a-half months

Construction of the ISS was only possible because of its modular design, which enabled it to be taken into orbit in sections. Orbital construction began in 1998, and its first crew arrived on 2 November 2000. The station consisted of just three modules initially, but the Integrated Truss Structure was added shortly after – the huge crossbeam that holds most of the solar panels on the ISS. Its vast solar wings provide over 60 kilowatts of power in total – enough for 30 average-sized homes on Earth. Since the first crew's arrival, many more modules have been added, including several dedicated to science.

Though the station is a weightless environment, gravity on board is actually about 90 per cent of Earth's. The ISS is in a continual state of free fall as it orbits Earth, meaning the environment is weightless without being zero gravity. This microgravity has been used to conduct experiments in

DID YOU KNOW? In May 2016 the ISS completed its 100,000th orbit of Earth

areas such as vaccines, medical diagnosis techniques and cancer treatment delivery. Equipment on board the ISS has even detected particles that may prove the existence of dark matter. The ISS is able to house unique particle-detection experiments because of its position in low-Earth orbit, where the disruptive influence of Earth's protective magnetic field is much weaker. However, this leaves the astronauts who inhabit it more vulnerable to cosmic radiation. The ISS is still shielded significantly by the magnetic field, but astronauts receive much higher doses of background ionising radiation than you would on the surface – though still within safe levels, which are monitored carefully from Earth.

One of the largest concerns for the ISS is damage from human-made space debris and micrometeorites. Larger objects are tracked from Earth, and the station can adjust its orbit to bypass these threats, but not everything can be planned for. With the ISS travelling almost fast enough to travel to the Moon and back in a day, even the smallest fragment could cause catastrophic damage. It's equipped with protective shielding, but its defences are surprisingly low-tech; half of the station just uses aluminium sheeting placed slightly away from the hull to shatter any debris that strikes it into dust, while the other half features overlaid honeycomb structures of plastic, metal and glass.

The space station was intended to continue operation into the 2020s: Russia's newest primary research module docked in 2021 along with the European Robotic Arm. When the station's mission is over, it's likely to be de-orbited to burn up in the atmosphere, although several modules may be disconnected and repurposed as part of a new space station. The new station is expected to be used for the assembly of manned interplanetary spacecraft, so the spirit of the ISS will live on as it helps to launch even more ambitious journeys into our Solar System.

> **"Construction of the ISS was only possible because of its modular design, which enabled it to be taken to orbit in sections"**

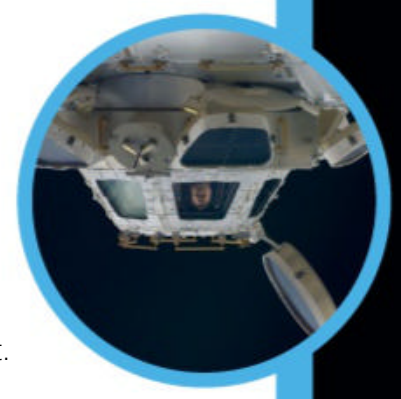
THE MANY MODULES OF THE ISS

These sections house everything from experiments to sleeping quarters

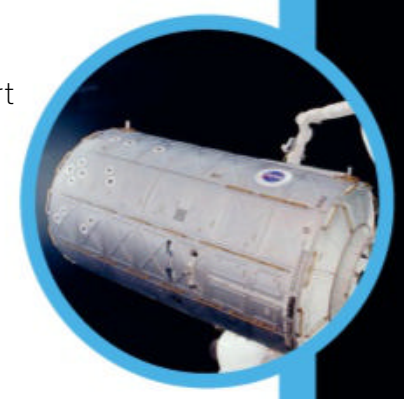
ZVEZDA
Also known as DOS-8, this Russian-made module was the third to be added to the station, and it made it habitable for the first time. Its contents include oxygen filters, sleeping quarters, toilet facilities and exercise equipment.

KIBŌ
Officially named the Japanese Experiment Module, this was added in 2008. It runs a range of important experiments, both inside the station and in a large exterior section. It's the largest single module to date.

COLUMBUS
This laboratory was built by the European Space Agency to house various research activities. Columbus supports the installation of International Standard Payload Racks, which are easily integrated equipment platforms.



CUPOLA
This observation module offers a view of the station's Earth-facing side, as well as an 80-centimetre window onto Earth itself – the largest one ever used in manned spaceflight.



DESTINY
This research facility from NASA contains an array of life-support systems as well as scientific facilities. Its most famous feature is a 51-centimetre optically pure window, through which the crew have taken scientifically crucial photos of Earth.

GREAT ANIMAL MIGRATIONS

WORDS AILSA HARVEY

Taking to the skies, sea or land, what drives certain animal communities to make long voyages across the globe?

DID YOU KNOW? In a 9,942-mile round trip, grey whales make the farthest of all mammal migrations

The animal kingdom is always on the move. Conditions in the wild can be unpredictable, with environmental disasters and ever-changing ecosystems causing species to flee their habitats. However, some moves occur on schedule, and many species have adapted to take advantage of whichever part of the planet suits them best at certain times of year. Animal migrations include any regular or seasonal movement of animals that also incorporates a return journey, forming a cyclic pattern. The animals proceed from one habitat to another to find better food availability, a more comfortable living climate or suitable locations to reproduce.

Did you know?

Monarch butterflies have multi-generational migrations

Depending on their size, method of movement and reasons for migration, animals travel a range of distances. And for some short-lived animals – especially insects – this venture takes most of their lifetime. Size doesn't always dictate a species' migration capabilities, though. Take the Arctic tern, for example. This is one of 4,000 regular bird migrators, enduring the longest migration of all of the world's animals. This bird, with a wingspan of just 64 to 76 centimetres, flies in a zig-zag pattern, covering 24,855 miles between the Arctic and Antarctic annually.

OCEAN MOVERS

Some of the seas' great migrators are baleen whales, sea turtles and devil rays. Many species of baleen whales travel from the colder waters they use for feeding for four to six months of the year to warmer waters for breeding. The warmer water is safer for whale calves, who have less insulating blubber, and also keeps their killer whale predators away. Sea turtles can migrate 9,942 miles in one year. These migrations are to find food, ideal temperatures and good nesting spots. Some turtle species, such as loggerhead sea turtles, find their way back to the exact beach that they were born on. Meanwhile, devil rays migrate annually in large groups of several thousand. These three-metre-wide creatures glide through the water as they migrate from Mexico's Yucatán Peninsula to Florida seeking food and sheltered waters.

Two humpback whales migrating to warmer waters surrounding Australia

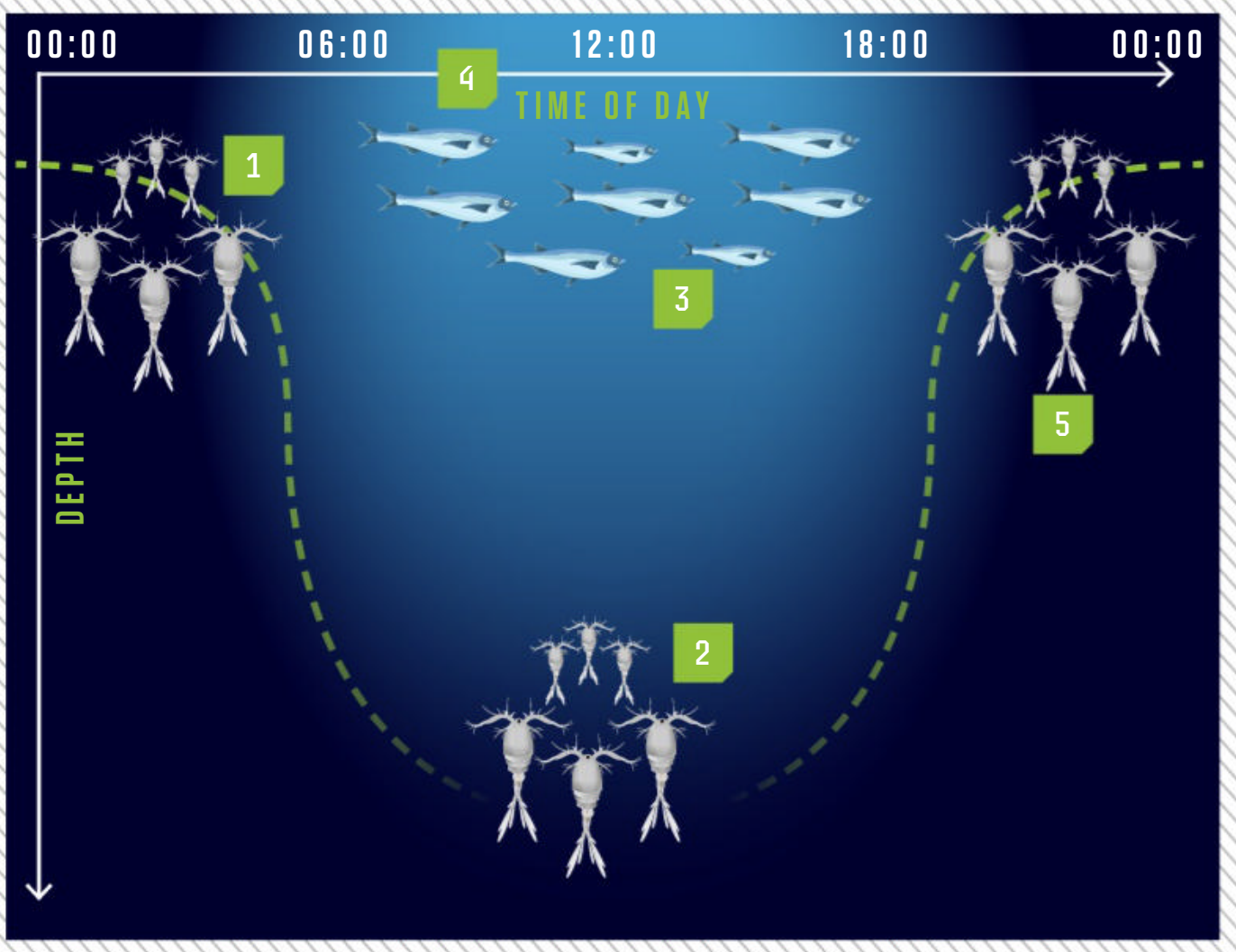
Zambia's straw-coloured fruit bats can travel more than 1,555 miles during a migration

FRUIT-FRENZIED BAT POLLINATORS

Zambia's straw-coloured fruit bats participate in the world's largest mammal migration every year between October and December. More than 10 million of these bats flitter into the skies as they travel from the Congo in Central Africa to Zambia's Kasanka National Park. The reason that these sizable bats – with wingspans up to 80 centimetres across – target the small national park is due to its abundance of Masuku fruits, or sugar plums. The adult bats weigh around 350 grams, and when they arrive at the park they eat twice their body weight of the sweet fruits in just one night. By the time they leave the park, after around three months, the bats will have demolished around a billion fruits. This gorging not only sustains their long flights across Africa, but helps in the pollination of plants and seed dispersal.

VERTICAL MIGRATION

By biomass, zooplankton perform the largest daily migration of any animal, rising from the deep and sinking again



1 CLIMB TO SURFACE

Zooplankton migrate towards the water's surface at night, where there's more food.

2 MIDDAY PROTECTION

While the Sun is shining on the water during the day, the zooplankton migrate to the ocean's depths. This protects their DNA from ultraviolet (UV) light.

3 PREDATOR AVOIDANCE

Fish that prey on zooplankton lurk at the surface. During daylight hours it is unsafe for zooplankton as they are visible to predators.

4 LIGHT-DODGERS

At just 100 metres below sea level, light is only one per cent of that at the surface.

5 WHAT ARE THEY?

Zooplankton are microscopic aquatic animals that include krill, sea snails and pelagic worms.

DID YOU KNOW? During its 30-year life span, an arctic tern travels the distance of three trips to the Moon and back

Did you know?

Wildebeests born mid-migration join the march

MULTI-GENERATIONAL MIGRATION

The green darner dragonfly requires three generations to migrate across the US, but not all need to travel

7 CHEMICAL SIGNATURE

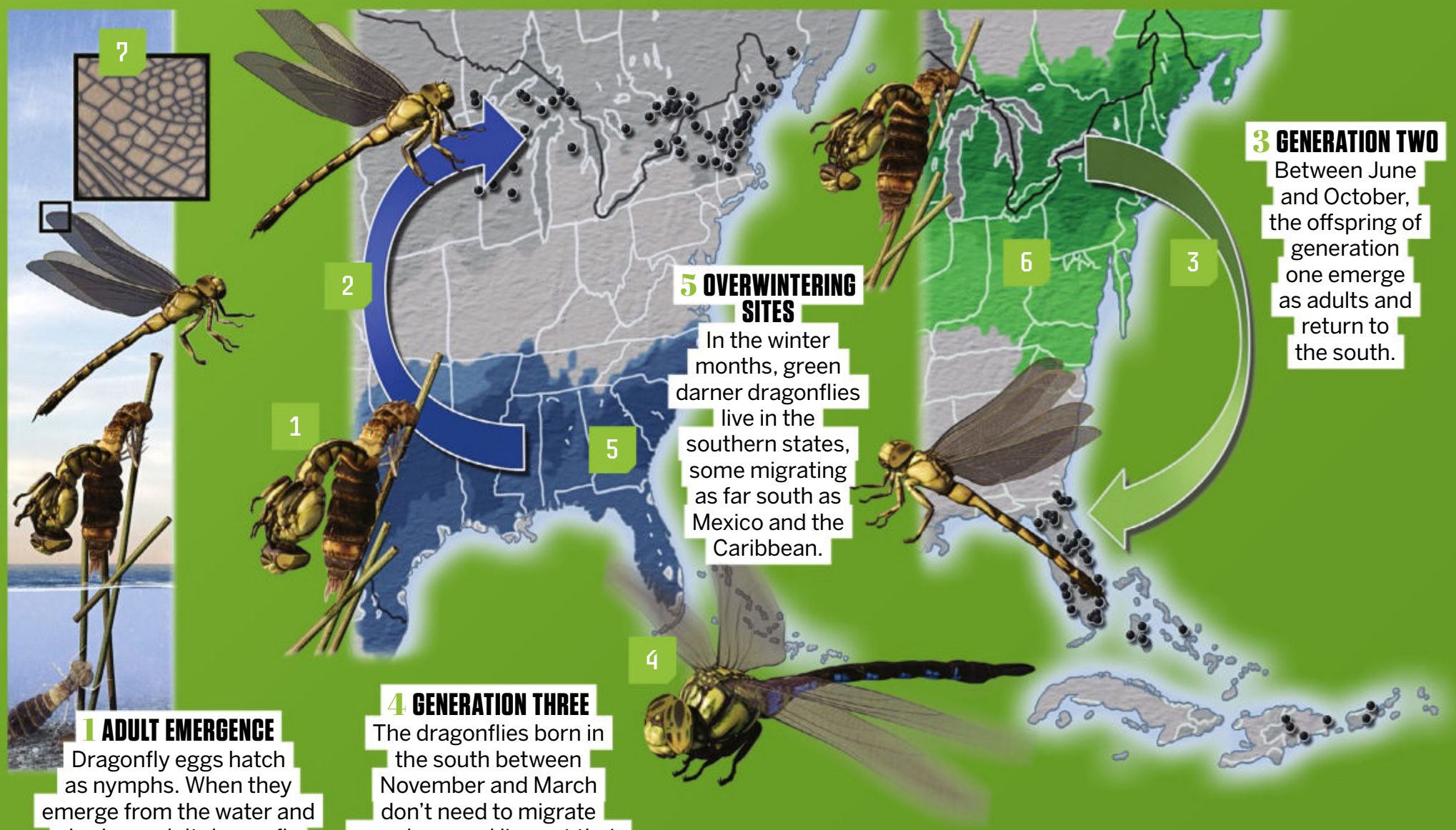
Hydrogen from the water they were born in is locked into their wings. The chemical structure of this element differs depending on the latitude that their bodies grew at. Scientists used this data to map this dragonfly species' movements.

2 GENERATION ONE

Between February and August, adult dragonflies that emerge in the south begin their migration north to reproduce.

6 COOLER TEMPERATURES

These dragonflies migrate north, as far as Canada. The 405-mile journey takes up most of their adult life, and soon after reproduction the dragonflies die.



3 GENERATION TWO

Between June and October, the offspring of generation one emerge as adults and return to the south.

5 OVERWINTERING SITES

In the winter months, green darner dragonflies live in the southern states, some migrating as far south as Mexico and the Caribbean.

1 ADULT EMERGENCE

Dragonfly eggs hatch as nymphs. When they emerge from the water and shed, an adult dragonfly is ready to migrate.

4 GENERATION THREE

The dragonflies born in the south between November and March don't need to migrate anywhere and live out their full lives in one location.

Christmas Island crabs are endemic to the island and have been named a protected species

THE CHRISTMAS ISLAND CRABS' SEA SCUTTLE

In the Indian Ocean, on Australia's Christmas Island, the native red crab species takes part in an annual spectacle as the entire population scuttles in synchrony from the forests to the shores. More than 120 million of the 11-centimetre-wide crabs cover the roads, rocks, forest floors and beaches as they migrate to the ocean to breed – amassing in a sheet of red shells as they do so. The male crabs begin migrating first, and females emerge to join the march along the way. This event takes place in October or November, in time for the first rainfall of the wet season. The red crabs breed before dawn, during a receding high tide and the last quarter phase of the Moon.

Reindeer usually migrate in long lines, going single file

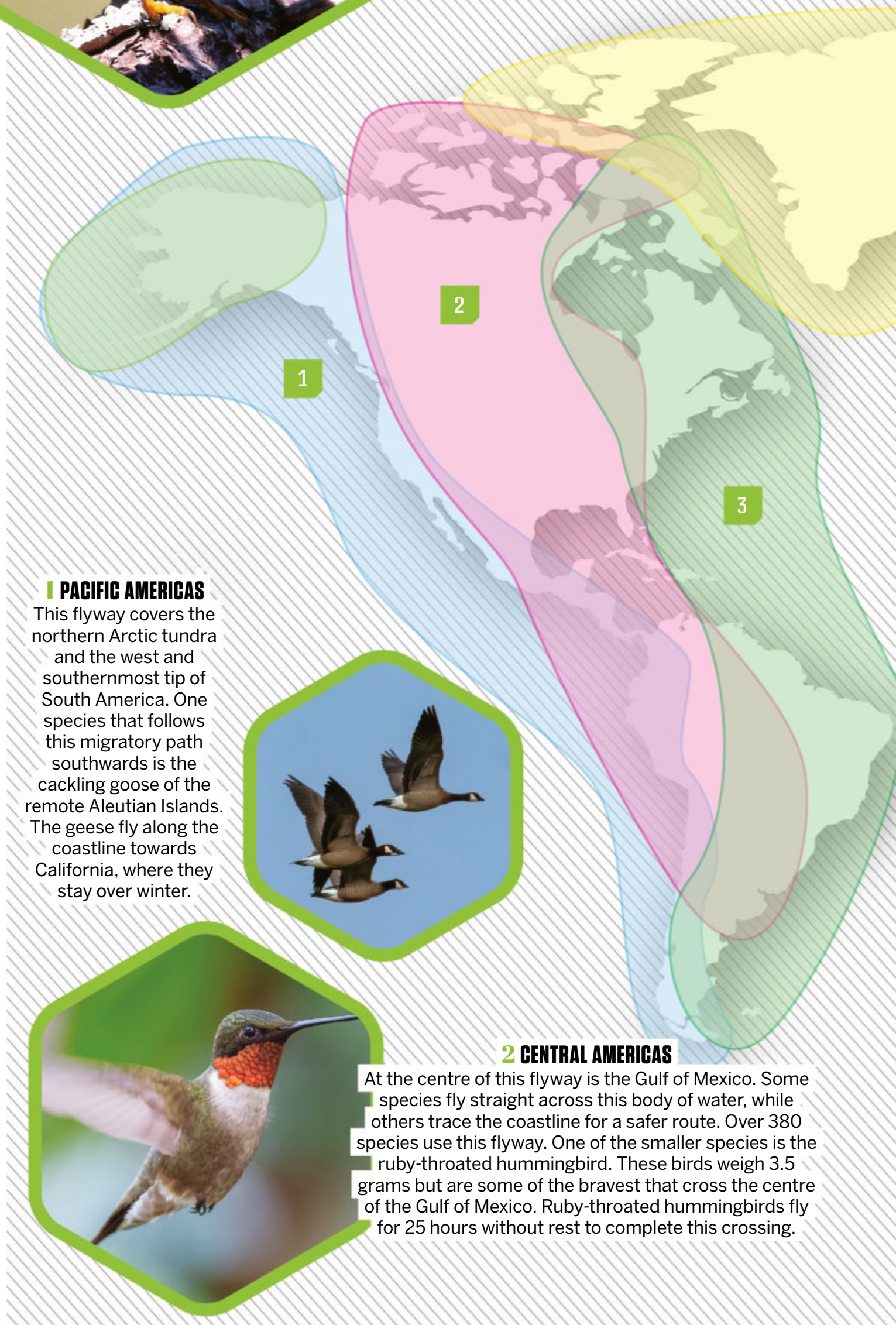
TERRESTRIAL MAMMAL TRACKS

Caribou, or reindeer, earn the title for the farthest terrestrial mammal migration, covering an annual round-trip distance of 745 miles. These treks take place through Arctic terrain as caribou walk southwards and northwards across Alaska and Canada. In the spring, caribou usually migrate to the northern coasts to birth their young and avoid the insect pests that begin to emerge further south. Then, when snow begins to fall, a synchronised continent-wide migration takes place southward to find more sheltered areas. Over 620 miles makes a huge difference in the availability of moss and lichens to feed on.

However, not all caribou species migrate. There are two gene subgroups that materialised during the last ice age, when a large ice sheet divided reindeer populations. Those north of the ice sheet were living in areas with few trees, requiring them to move to less snow-covered land in the winter. However, caribou living separately in the south were in forest landscapes, where trees protected food from the snow. As a result, today some caribou migrate, while others have evolved to stay put.

3 ATLANTIC AMERICAS

The red knot bird flies the full 9,320-mile length of this flyway, from Canada's Arctic Archipelago to the tip of South America, twice a year. The ocean crossing at the centre – between North and South America – is a greater distance compared to the other American bird flyways. Birds such as the blackpoll warbler fly for 88 hours to cross over the 1,864-mile ocean gap. Before migrating, the warbler doubles its body mass. It has evolved an efficient metabolism to maintain energy and loses just 0.06 per cent of its weight as every hour goes by.



1 PACIFIC AMERICAS

This flyway covers the northern Arctic tundra and the west and southernmost tip of South America. One species that follows this migratory path southwards is the cackling goose of the remote Aleutian Islands. The geese fly along the coastline towards California, where they stay over winter.

2 CENTRAL AMERICAS

At the centre of this flyway is the Gulf of Mexico. Some species fly straight across this body of water, while others trace the coastline for a safer route. Over 380 species use this flyway. One of the smaller species is the ruby-throated hummingbird. These birds weigh 3.5 grams but are some of the bravest that cross the centre of the Gulf of Mexico. Ruby-throated hummingbirds fly for 25 hours without rest to complete this crossing.

DID YOU KNOW? Salmon can swim against river currents for 250 miles

BIRD FLYWAYS OF THE WORLD

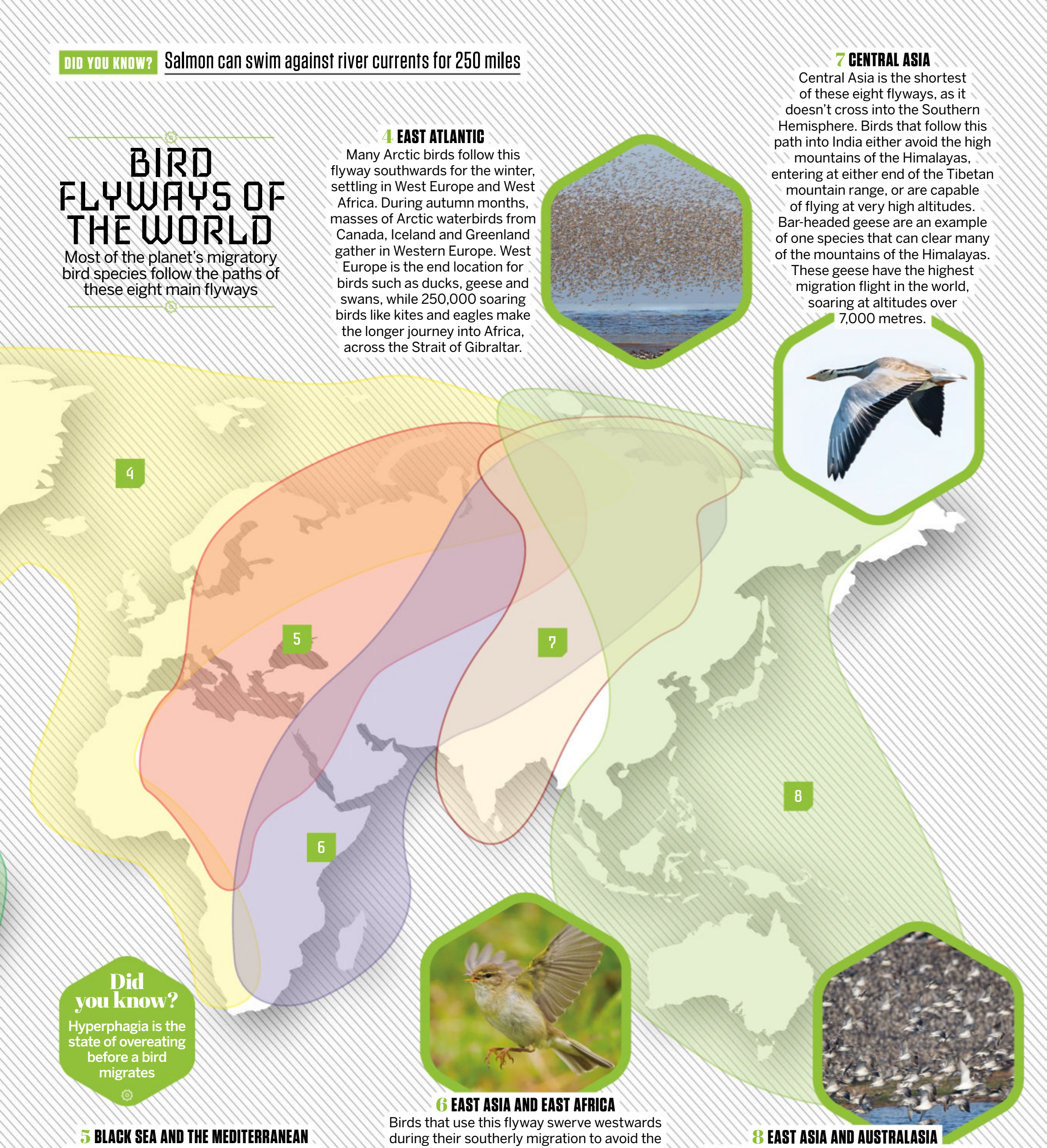
Most of the planet's migratory bird species follow the paths of these eight main flyways

4 EAST ATLANTIC

Many Arctic birds follow this flyway southwards for the winter, settling in West Europe and West Africa. During autumn months, masses of Arctic waterbirds from Canada, Iceland and Greenland gather in Western Europe. West Europe is the end location for birds such as ducks, geese and swans, while 250,000 soaring birds like kites and eagles make the longer journey into Africa, across the Strait of Gibraltar.

7 CENTRAL ASIA

Central Asia is the shortest of these eight flyways, as it doesn't cross into the Southern Hemisphere. Birds that follow this path into India either avoid the high mountains of the Himalayas, entering at either end of the Tibetan mountain range, or are capable of flying at very high altitudes. Bar-headed geese are an example of one species that can clear many of the mountains of the Himalayas. These geese have the highest migration flight in the world, soaring at altitudes over 7,000 metres.



Did you know?

Hyperphagia is the state of overeating before a bird migrates

5 BLACK SEA AND THE MEDITERRANEAN

This flyway connects the Russian Arctic and North Africa. For birds that migrate across its entirety, the Mediterranean Sea is the biggest challenge. Luckily there are 'land bridges' in this area providing stop-off opportunities. Birds migrating from Italy can use the Strait of Messina to Sicily, while others arrive in Africa via Malta.

6 EAST ASIA AND EAST AFRICA

Birds that use this flyway swerve westwards during their southerly migration to avoid the Himalayas' mountain barriers. In addition, Africa can sustain a greater influx of bird species than the smaller landmass of India. One bird that endures an especially long migration due to this detour is the willow warbler. They travel 7,020 miles, from northeast Siberia to South Africa, which is the longest journey taken by any songbird.

8 EAST ASIA AND AUSTRALASIA

Over 50 million migratory waterbirds use this flyway. Some, like the bar-tailed godwit, make impressive journeys over 6,200 miles. The bar-tailed godwit flies from Alaska to New Zealand, which is the longest non-stop flight of any bird. This species also holds the record for the longest journey made without stopping to feed by any animal.

WHY ARE SEA LEVELS RISING?

How civilisation and natural processes are turning Earth into a water world

WORDS SCOTT DUTFIELD


Homes close to the water are no longer inhabitable

Since 1880, the average global sea level has risen around 21 to 24 centimetres, and it's currently rising at a rate of 3.6 millilitres per year. Scientists have estimated that by 2100 the average sea level will increase by as much as 0.8 metres. Drastic fluctuations in the world's sea levels have been a natural part of Earth's history. Around 20,000 years ago, the average sea level was around 120 metres lower than it is today. After a 10,000-year-long period of naturally occurring global warming, the world's sea levels rose to modern levels at a rate of around 1.2 centimetres per year. However, the rapid rise seen in recent history coincides with an increase in human activities that involve the burning of fossil fuels and release of enormous amounts of greenhouse gases, which contribute to global warming and climate change. The melting of polar ice and the expansion of the world's water as a result of increasing global temperatures are the primary causes of the acceleration in sea level rise. Antarctica, for example, is currently losing 146 billion tonnes of ice each year on average, while Greenland's ice sheet is shedding around 270 billion tonnes of ice annually.

Did you know?

There's around 3,210,003,271 cubic miles of water in the oceans

It's estimated that over the next 200 years, the global mean sea level could rise by three metres if the world warms by 1.5 degrees Celsius – an avoidable target that may be reached as soon as 2027. However, tipping just over that 1.5-degree-Celsius threshold would double that estimation to around six metres. The consequences of excess global sea level rise will be catastrophic. Eight of the ten largest cities in the world are situated near the coast, putting millions at risk of losing their homes and livelihoods. And more than 200 million people around the world live in areas that are below sea levels predicted for 2100. It's not just humans that face an uncertain future as a result of rising sea levels, but also the world's coastal wildlife. Sea turtles would eventually lose their sandy breeding grounds, the ice sheet habitats of polar bears will continue to melt away and whales won't be able to raise their young in shallow waters.

WHAT'S CAUSING THE RISE?

The ways that water is creeping up the coast

1

1 GLACIERS MELTING

Rising global temperatures driven by human activity cause glaciers and the frozen water that forms massive ice sheets to melt, releasing trapped water back into the ocean. Even if just the world's smallest glaciers were to collectively melt, sea levels would rise by around 50 centimetres.

2

2 RAINFALL

With higher atmospheric temperatures comes an increased amount of evaporation among not only the world's oceans, but also its land-bound water supplies, such as lakes and reservoirs. Changes in weather patterns in relation to climate change mean it isn't guaranteed that rain will return the water over the areas it's taken from, leading to droughts on land and more water in the oceans.

3

3 THERMAL EXPANSION

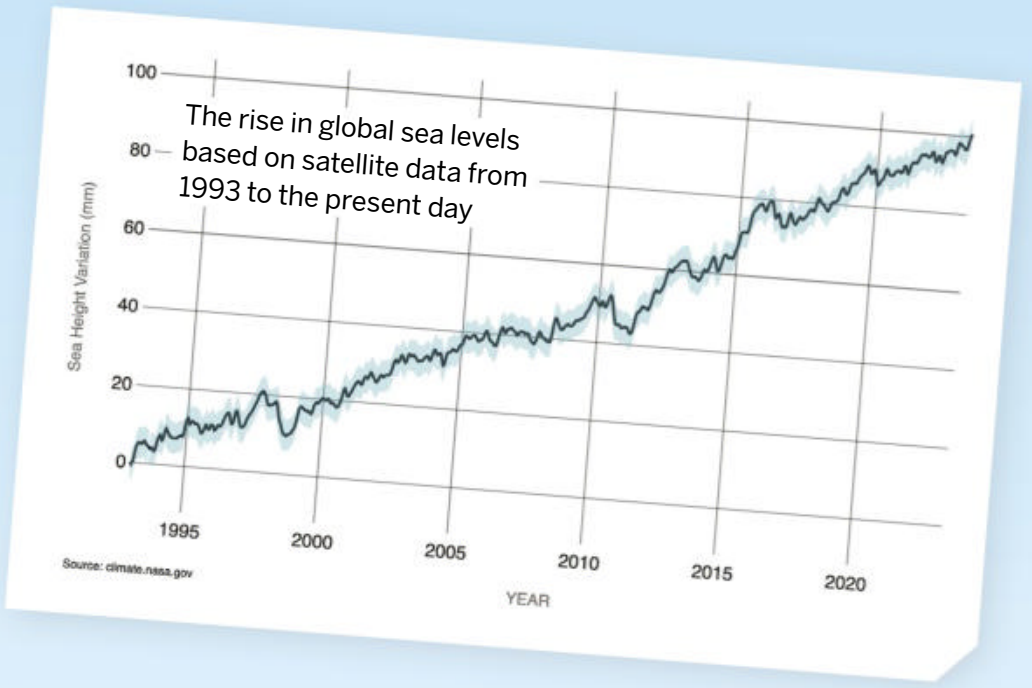
While Earth's atmosphere warms, so do its oceans. Around 90 per cent of the heat trapped by greenhouse gases is absorbed into the ocean, which causes the space between the particles that make up water to expand and increase in volume. Since 2004, a third of global sea level rise has been caused by thermal expansion.

DID YOU KNOW? In 2022, the average global sea level hit a new record at ten centimetres above the levels recorded in 1993

RECORDING THE RISE FROM SPACE

To monitor the world's changing sea levels, space agencies including NASA and the European Space Agency have employed a series of observational satellites, such as Sentinel-6 and Jason-3. These satellites use a technique called ocean altimetry to determine the rises and falls of the world's oceans. The technique works by sending pulses of radio waves from an instrument on board a satellite called an altimeter and recording the time it takes for the waves to travel down to the ocean, bounce off the surface and return to the satellite. At the same time, the satellite is recording its precise location to determine the sea level directly beneath it. Some satellites use a laser altimeter as an alternative and send flashes of laser light to the surface instead of radio waves for a more accurate measurement.

A 3D illustration of the Sentinel-6 satellite in orbit around Earth



The rise in global sea levels based on satellite data from 1993 to the present day

4 TECTONICS

Deep beneath the water's surface, seafloor volcanoes and their eruptions between continental tectonic plates release massive amounts of molten igneous rock into the water. The volume of the igneous rock displaces ocean water, causing sea levels to rise.

5 STORING WATER ON LAND

The construction of dams and reservoirs has a negative impact on rising sea levels. The more water stored on land, the less there is in the ocean to raise sea levels. It's estimated that the construction of global dams has captured the same amount of water that would otherwise rise sea level by three centimetres, so the water released from dams contributes to the increase in sea level.

6 PUMPING WATER

Tapping into underground springs and aquifers for consumption or use in agriculture puts more water into the global water cycle. The more water that's pumped out of these aquifers and released in the cycle will eventually lead to more water in the oceans and an increase in sea level.

FROM FANG TO PHARMACY

Venoms are often associated with sickness and death, but they're actually packed with chemicals that can cure our ills

WORDS DAN COSSINS

The deadly venoms delivered by snakes, spiders and scorpions aren't the most obvious source of ingredients to soothe our aches and pains and make us well. After all, these toxic cocktails are made to incapacitate and kill. And yet animal venoms are proving to be a wellspring of molecules that could become powerful new drugs for everything from chronic pain to multiple sclerosis and cancer.

Venom is a rich broth of thousands of different molecules designed to evade the victim's immune system and seek out their targets. They stick onto cell fragments in the blood to prevent clotting, for example, or block surface receptors on nerve cells to shut down the nervous system. "These peptides [the building blocks of proteins] have been optimised over hundreds of millions of years of evolution to hit their molecular targets with high potency and selectivity," says Dr Eric Lingueglia of the Institute of Molecular and Cellular Pharmacology in Valbonne, France.

Lingueglia is one of a band of scientists searching these raw materials to find molecules that have an effect on human physiology. And his team isolated a pair of peptides from black mamba venom that could become potent painkillers. They began by testing venoms on a cellular target – in this case a gateway on the surface of nerve cells that's involved with pain sensing.

The researchers found two active molecules, dubbed 'mambalgins'. When each mambalgin was injected into injured mice, both peptides relieved pain as effectively as morphine, and with fewer side effects. "We were expecting some analgesic effect, but we were surprised by the potency," says Lingueglia. His team is trying to figure out whether mambalgins exert the same analgesic effect in humans and how the molecular structures might be tweaked to make even more potent versions that could be developed into painkilling drugs. "We have evidence that the cellular gateway blocked by these peptides is important in humans," he says, "so we expect mambalgins to work."

Did you know?

The box jellyfish is the most venomous creature in the world

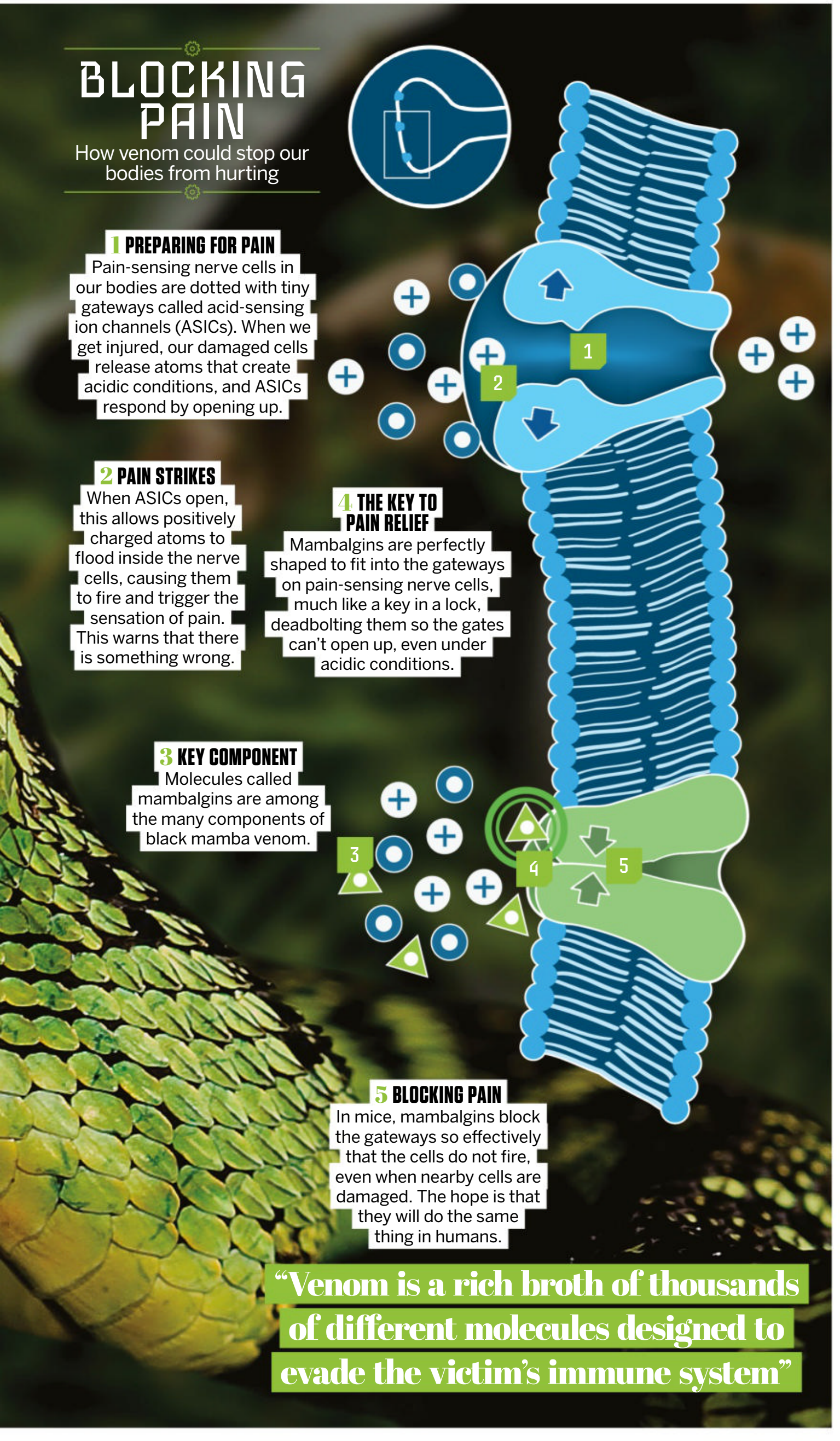
HOW TO MASS-PRODUCE VENOMS

Researchers need a ready supply of venom-derived molecules for drug development. It's relatively simple – clone the peptide-producing gene and insert it into bacteria. These serve as factories and churn out an infinite number of the peptide. But the more expensive option is for chemists to produce a synthetic version by piecing together its component parts.

DID YOU KNOW? Black mambas average 2.4 metres in length and can grow up to four metres long

BLOCKING PAIN

How venom could stop our bodies from hurting



1 PREPARING FOR PAIN
Pain-sensing nerve cells in our bodies are dotted with tiny gateways called acid-sensing ion channels (ASICs). When we get injured, our damaged cells release atoms that create acidic conditions, and ASICs respond by opening up.

2 PAIN STRIKES
When ASICs open, this allows positively charged atoms to flood inside the nerve cells, causing them to fire and trigger the sensation of pain. This warns that there is something wrong.

3 KEY COMPONENT
Molecules called mambalgins are among the many components of black mamba venom.

4 THE KEY TO PAIN RELIEF
Mambalgins are perfectly shaped to fit into the gateways on pain-sensing nerve cells, much like a key in a lock, deadbolting them so the gates can't open up, even under acidic conditions.

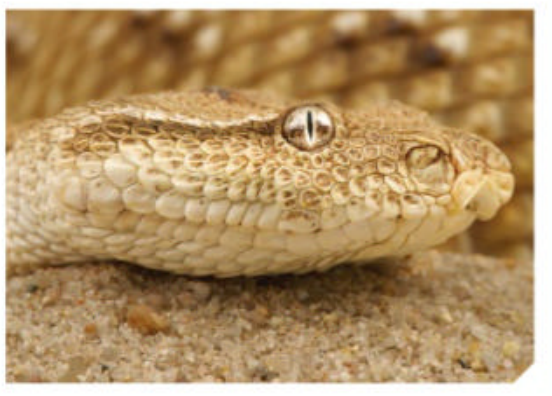
5 BLOCKING PAIN
In mice, mambalgins block the gateways so effectively that the cells do not fire, even when nearby cells are damaged. The hope is that they will do the same thing in humans.

"Venom is a rich broth of thousands of different molecules designed to evade the victim's immune system"

OTHER VENOM CURES FOR DISEASE

DIABETES
Exenatide, a synthetic version of a peptide isolated from the saliva of a venomous lizard called the Gila monster, improves blood sugar control in patients with type 2 diabetes. The US Food and Drug Administration approved the drug, sold as Byetta, in 2005.

MULTIPLE SCLEROSIS AND DIABETES
The peptide ShK-186 is a slightly modified version of a molecule found in the venom secreted by the soft tentacles of the Caribbean sun anemone. It was developed as a treatment for autoimmune diseases such as MS and type 1 diabetes and is now known as the drug Dalazatide.



CANCER
Eristostatin, a molecule isolated from the venom of the Asian sand viper, is an anticoagulant. But because it also binds to melanoma cells and appears to attract the immune cells that clear tumours, researchers investigated eristostatin as a potential lead for new cancer drugs.

HOW TO GROW PLANTS WITHOUT SOIL

Hydroponics is a method of growing plants in a water-based nutrient solution

WORDS **AILSA HARVEY**

In most instances, when you see a growing plant, its body below the stem is submerged in soil. When organic matter lives and dies in the soil, it releases nutrients which surrounding plants can absorb and thrive on. In nature this is the ideal location for plants to grow, but for agriculture and mass-produced crops, there are other options. One alternative method is hydroponics, which involves submerging or spraying the roots of plants with water and essential nutrients.

Without requiring soil space, more plants can be grown using the same surface area. They can be densely packed, meaning more food is produced in agricultural spaces. Because the process involves mostly water, you might assume that more water is used as a result. However, hydroponics uses one tenth of the water that natural soil growth uses. Unlike standard practices, which cause excess water to run off fields and into the environment, water in hydroponic systems is collected and reused.

The roots of a plant absorb the nutrients dissolved in water

Did you know?

Four times more crops can be grown than in soil

Without the need for soil, crop farms can be built vertically, saving space

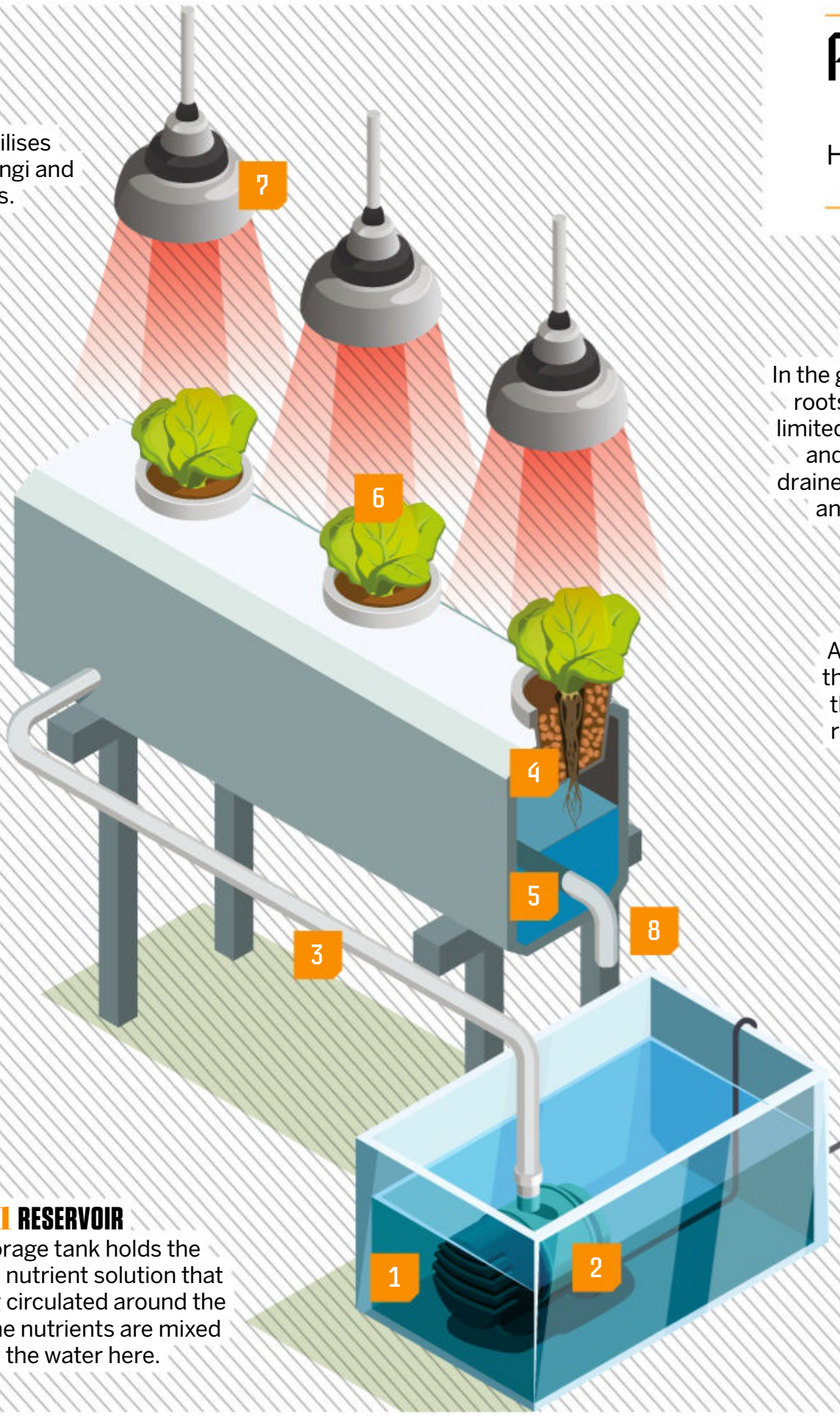
WHAT NUTRIENTS ARE USED IN HYDROPONICS?

Most plants require 17 main nutrients to function well. Three of these – carbon, hydrogen and oxygen – come from the water and air in hydroponic systems. These are macronutrients, which are required in larger quantities. Other macronutrients that need to be added to hydroponic systems for plant growth are nitrogen, phosphorus, potassium, sulphur, calcium and magnesium. The micronutrients plants need are iron, manganese, zinc, boron, molybdenum, chlorine, copper and nickel. Using hydroponics is an easy way to tailor the nutrients to the conditions of the plants. Adding nutrients to water lowers the pH of the solution. For the optimal crop-growing pH, it's normally recommended that the water begins at a pH of 7.0 before nutrients are added. This generally lowers the pH to about 5.8. This is an ideal acidity to enable optimal nutrient intake by the plants.

DID YOU KNOW? By controlling nutrient concentrations, plants grown without soil can grow 30 to 50 per cent faster

A SOILLESS SYSTEM

How plants get nutrients and water using hydroponics



7 UV LAMPS

Ultraviolet (UV) light sterilises crops, eliminating pests, fungi and other microorganisms.

6 PLANT TYPES

Most plants can be grown hydroponically, but the most common types are strawberry, cucumber, tomato, pepper and watercress plants, leaf lettuce and some herbs.

5 ACCESSIBLE WATER

In the grow tray, the water that the roots can draw up needs to be limited. Depending on the system and the plants, water will be drained from the tray periodically and its volume controlled.

8 RETURN HOSE

Any excess nutrient solution that hasn't been absorbed by the plants is returned to the reservoir through this hose.

4 PLANT ACCESS

The plants' roots hang down into the water instead of being embedded in soil. Through these extensions, the plant draws up life-sustaining nutrients.

3 NUTRIENT HOSE

The water and nutrients are pumped along this pipe.

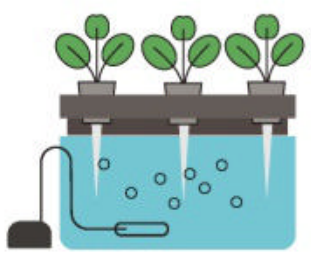
1 RESERVOIR

This storage tank holds the water and nutrient solution that isn't being circulated around the plants. The nutrients are mixed into the water here.

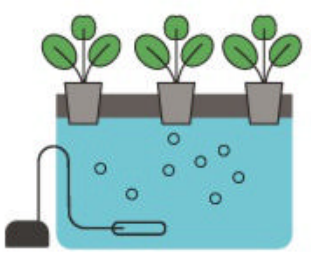
2 WATER PUMP

A mechanical pump pushes water from the nutrient reservoir to the grow tray.

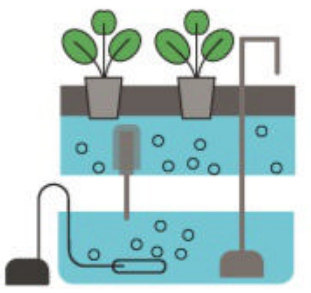
SIX TYPES OF HYDROPONICS



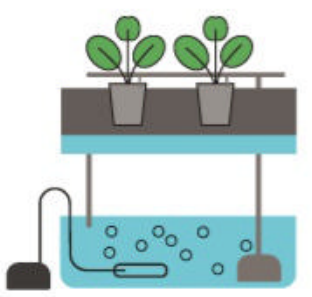
1 WICK SYSTEM
This is the only electricity-free hydroponic system. A cotton or nylon wick attached to a plant draws water and nutrients up from a container below.



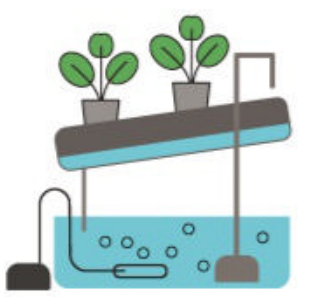
2 WATER CULTURE
This is similar to the wick system, but involves placing the plants' roots directly into the water solution.



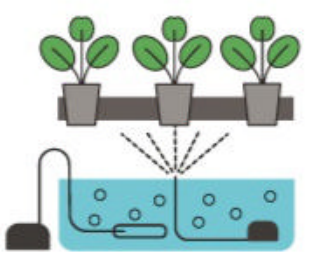
3 EBB AND FLOW
This continually floods and drains the plants' roots. When the water reaches a certain level, it's drained so plants get just the right amount of nutrients and aren't flooded.



4 DRIP SYSTEM
The nutrient solution is pumped into a tube and directed to the plants' base. The end of the tube releases drips at rates that can be altered based on the plant type.



5 NUTRIENT FILM TECHNOLOGY
The solution is pumped up to containers of plants. These are sloped so that water and nutrients flow over the roots and any excess is returned.



6 AEROPONIC SYSTEM
Plants in these systems are suspended in the air. An air pump combines with the water to spray water droplets onto the plants' roots.

CLIMATE CONCERNS

Concrete manufacturing raises concerns for the environment. One of its most significant impacts is the release of greenhouse gases that occurs when the raw materials are heated. The process, called calcination, releases 0.9 kilograms of carbon dioxide for every kilogram of concrete produced. When too much carbon dioxide enters Earth's atmosphere, it acts like an insulating blanket and traps heat, causing global warming. Water use in the concrete industry is also significant, with ten per cent of global industrial water demands coming from its production. The effect of concrete on the environment doesn't end after the material is formed. When it lines the streets in the shape of roads and buildings, concrete absorbs more of the Sun's energy, rather than reflecting it. This heats up the surrounding air, making cities a higher temperature than rural landscapes.

Seven per cent of the carbon dioxide produced by humans comes from the cement industry

MAKING CEMENT AND CONCRETE

Discover how these strong building materials are produced, and the price the planet pays for it

WORDS AILSA HARVEY

After water, concrete is the second most used material in the world. It is made of cement, air, water, sand and gravel to produce a strong and durable construction material. Cement's limestone content, alongside other minerals, gives concrete its long-lasting properties and enables it to harden quickly. Concrete is used to make the foundations and walls of our homes, in bridges, roads, pavements and a myriad of other constructions.

Its broad applications come with various requirements. Because of this, it's mixed differently to give the material slightly different qualities. The main types of concrete include plain, high-density, lightweight and rapid-setting. Largely, the differences between concrete types are the ratio of concrete, sand and gravel, as well as the specific minerals added.

Plain concrete has a ratio of 1:2:4 parts of cement, sand and gravel. This type is relatively weak, as it could easily give way under constant vibration. It is cheap and can be used for shed and garage bases. Heavy-density concrete is made using more stronger mineral ingredients, such as silica. This concrete is suitable for high-rise buildings. Lightweight concrete, in contrast, is suitable for smaller support features such as beams and slabs.

Did you know?

Rome's Pantheon is the largest unsupported concrete structure

As the name suggests, rapid-setting concrete hardens faster than standard concrete due to the higher percentage of cement added to the mixture. This type is chosen when potholes in the road need to be filled, emergency repairs are made to structures like water pipes and when laying cement in very cold weather. Rapid-setting concrete can set in as little as 20 minutes. Reducing the time it takes to set, along with its reduced water content, means that in freezing weather conditions there's less time for water in wet cement to freeze and expand.

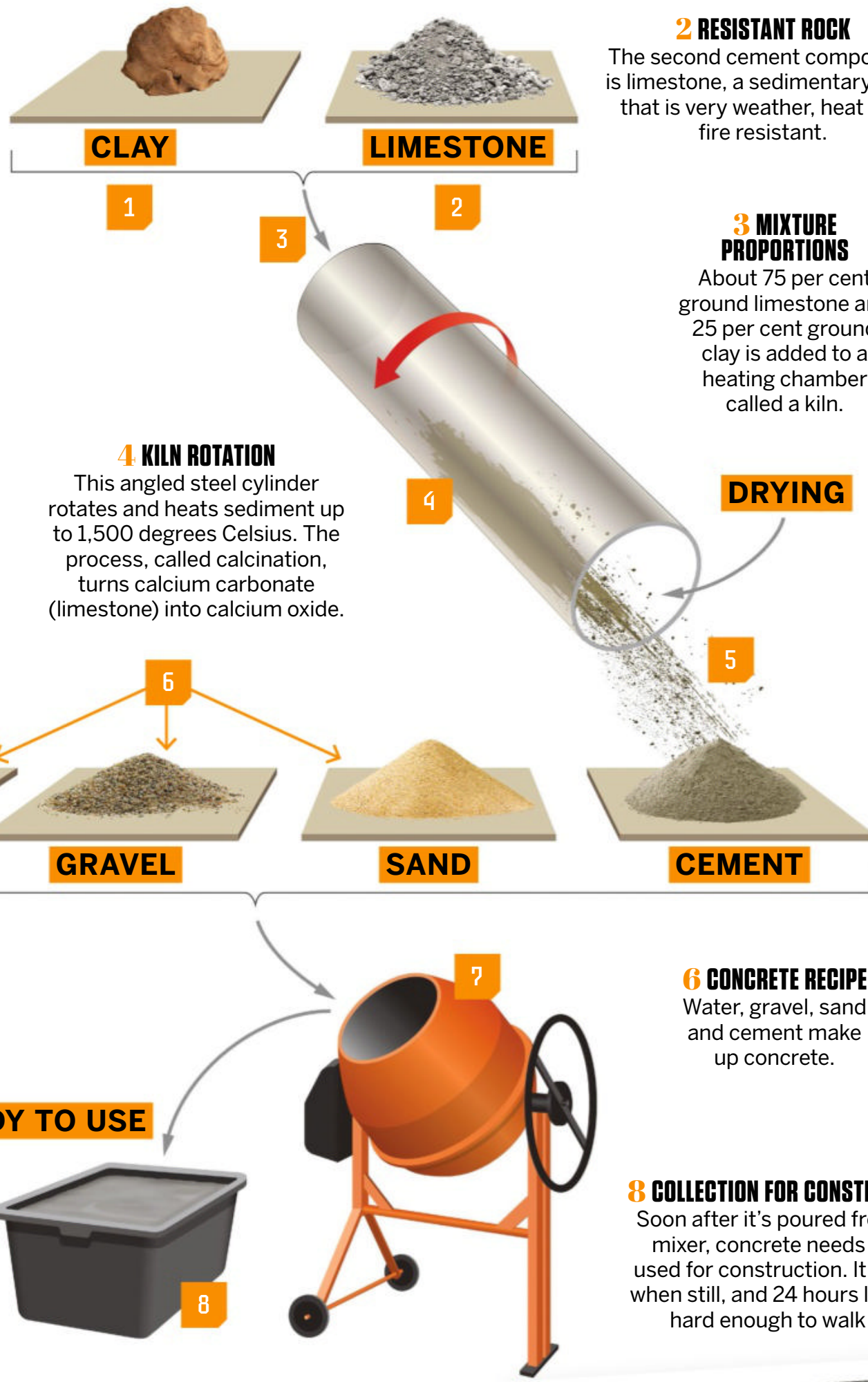
DID YOU KNOW? China produced about 2.1 billion tonnes of cement in 2022

THE PRODUCTION PROCESS

From clay and limestone, cement is mixed to become a strong and flexible construction material

1 MALLEABILITY
Clay is a sedimentary rock that becomes malleable when heated. It is mixed with limestone to make cement.

2 RESISTANT ROCK
The second cement component is limestone, a sedimentary rock that is very weather, heat and fire resistant.



3 MIXTURE PROPORTIONS
About 75 per cent ground limestone and 25 per cent ground clay is added to a heating chamber called a kiln.

4 KILN ROTATION
This angled steel cylinder rotates and heats sediment up to 1,500 degrees Celsius. The process, called calcination, turns calcium carbonate (limestone) into calcium oxide.

5 CLINKER
Out of the kiln comes a fine, hard and ground-up material called clinker. This is the main ingredient of cement, made of fused limestone and clay.

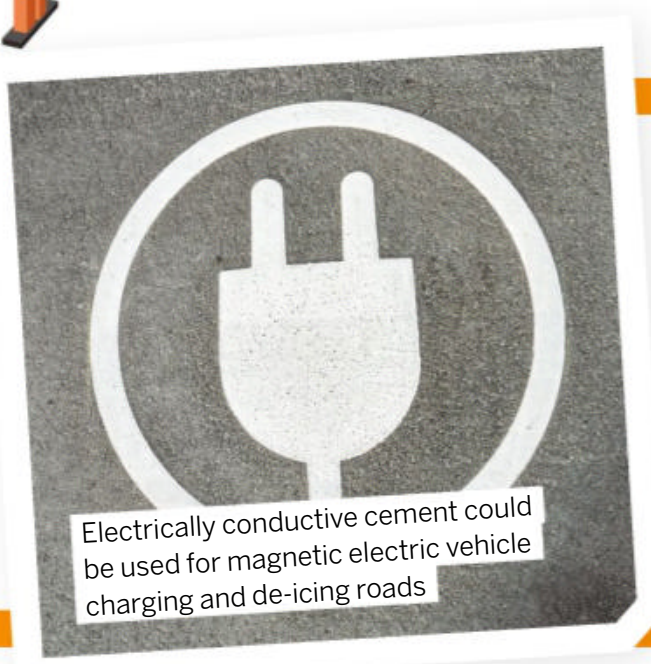
6 CONCRETE RECIPE
Water, gravel, sand and cement make up concrete.

7 CONSISTENT MIXING
As the materials are blended together in a concrete mixer, the cement absorbs the water, binding the minerals into a smooth consistency.

8 COLLECTION FOR CONSTRUCTION
Soon after it's poured from the mixer, concrete needs to be used for construction. It will set when still, and 24 hours later it's hard enough to walk on.

ELECTRIC STREETS

In a bid to transform a strictly structural material into a battery, scientists are exploring how to electrify cement. Usually, concrete isn't electrically conductive, as the water binds with cement evenly throughout the structure. But some cement makers have started adding powdered carbon into the mixture. These particles repel water, which causes the carbon to settle together. This produces a path of electrically conductive material, acting like wires through the concrete. If this cement was used in the full foundations of a house, the energy it could store is estimated to be able to power the average household for one day. This cement could also be used in car park ground construction and one day enable the wireless charging of electric vehicles.



Electrically conductive cement could be used for magnetic electric vehicle charging and de-icing roads

FIVE UNEXPLAINED THINGS ABOUT YOUR BODY

Our knowledge of this collection of skin and bone that we call home has some surprising gaps in it

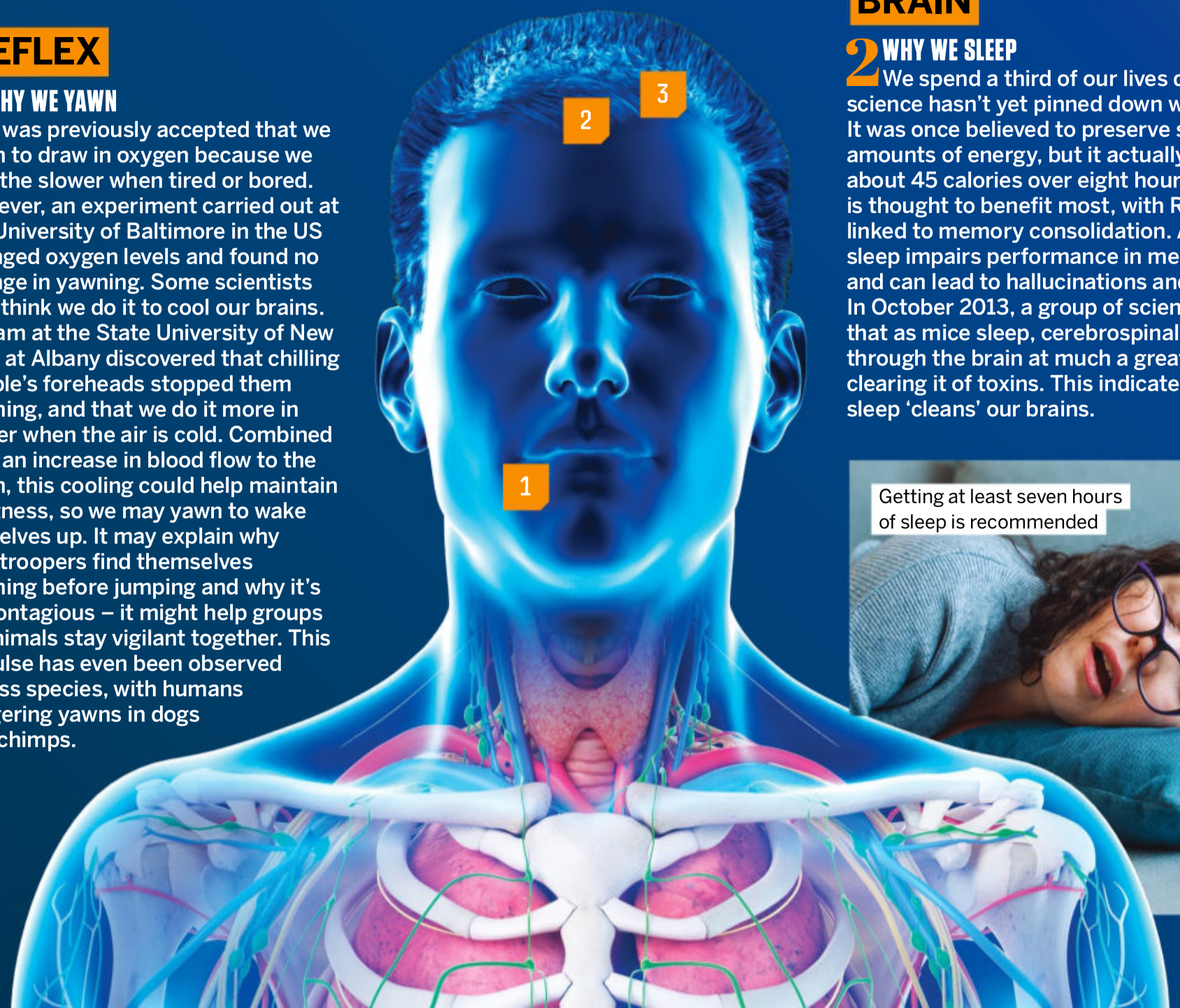
WORDS AMIT KATWALA

Did you know?
Appendices are found in mammals like rodents and shrews

REFLEX

1 WHY WE YAWN

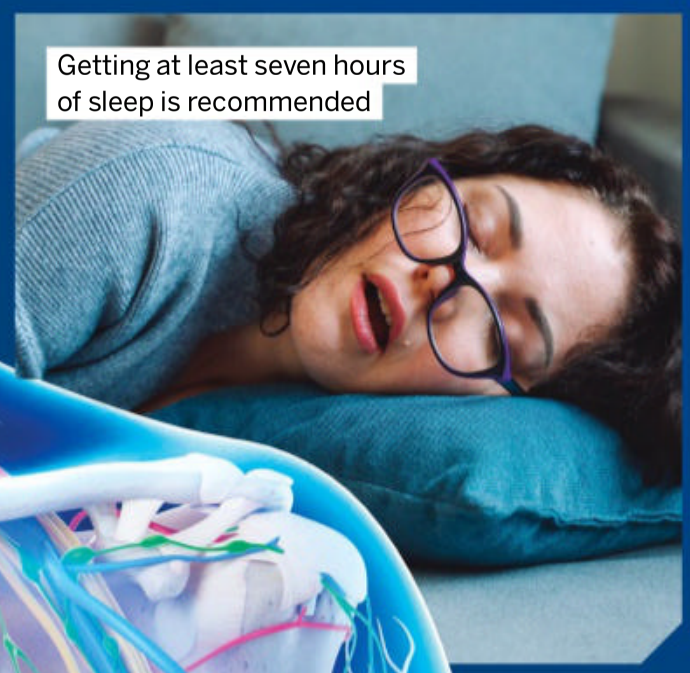
It was previously accepted that we yawn to draw in oxygen because we breathe slower when tired or bored. However, an experiment carried out at the University of Baltimore in the US changed oxygen levels and found no change in yawning. Some scientists now think we do it to cool our brains. A team at the State University of New York at Albany discovered that chilling people's foreheads stopped them yawning, and that we do it more in winter when the air is cold. Combined with an increase in blood flow to the brain, this cooling could help maintain alertness, so we may yawn to wake ourselves up. It may explain why paratroopers find themselves yawning before jumping and why it's so contagious – it might help groups of animals stay vigilant together. This impulse has even been observed across species, with humans triggering yawns in dogs and chimps.



BRAIN

2 WHY WE SLEEP

We spend a third of our lives doing it, yet science hasn't yet pinned down why we sleep. It was once believed to preserve significant amounts of energy, but it actually only saves about 45 calories over eight hours. The brain is thought to benefit most, with REM sleep linked to memory consolidation. A lack of sleep impairs performance in mental tasks, and can lead to hallucinations and even death. In October 2013, a group of scientists found that as mice sleep, cerebrospinal fluid washes through the brain at much a greater rate, clearing it of toxins. This indicates that sleep 'cleans' our brains.


Getting at least seven hours of sleep is recommended

MEDICINE

3 HOW OUR BODIES ARE TRICKED BY THE PLACEBO EFFECT

A 2013 survey of UK GPs discovered that 97 per cent of them have prescribed placebos to patients. These are drugs that have no direct medical effect but nevertheless appear to improve someone's condition. Some studies show the brain's pain relief system being activated when people are told they're taking a painkiller, suggesting it's our brains that are tricked by the placebo. However, research into depression has found that placebos activate a different area of the brain to actual treatments, so how a placebo works its 'magic' is far from clear. One theory is that placebos somehow act as mental triggers to the immune system, which normally lies dormant for small problems because it consumes so much energy. A study carried out on Siberian hamsters found that they were more likely to fight off low-level infections when their cage lights simulated summer, with its plentiful resources, than when the lighting resembled winter.

HANDS

4 WHY WE'RE PREDOMINANTLY RIGHT-HANDED

About 90 per cent of people are right-handed, and no one knows why. There are cultural aspects, but it starts in the womb – nine out of ten foetuses prefer to suck their right thumb. The leading theory is that handedness is linked to language, which is largely processed in the brain's left hemisphere – the region also in control of the right side of the body. This could be because language evolved from hand gestures, or because keeping two complex areas of the brain close together is more efficient. But why did language originally develop on the left side? It could simply have been a random genetic mutation millennia ago.

In September 2013, scientists discovered potential links between the PCSK6 gene and handedness, only to be contradicted by another piece of research that studied almost 4,000 twins and found no strong genetic element. Researchers from the University of Kansas have found marks on teeth that suggest that ancient humans were mostly right-handed, too. But despite the long-prevailing nature of this trend, it's a mystery that has scientists throwing both hands up in the air.

4

5

ABDOMEN

5 WHAT OUR APPENDICES ARE FOR

For most people, the appendix is only really relevant when it swells up and needs removing. It was thought that our ancestors needed it to digest plant matter, but the true purpose of this narrow 11-centimetre offshoot of the large intestine remains a mystery. The leading theory, proposed in a 2007 research paper published by a team at Duke University in Durham, North Carolina, is that it's ideally constructed to provide a safe haven for friendly bacteria. They survive there, then repopulate the bowels after they've been emptied of something nasty. In developed countries this makes appendices almost redundant. In parts of Africa without modern sanitation, however, the appendicitis rate is far lower than in the US. Researchers think this shows the appendix still has a key role in these places.

DID YOU KNOW?

Colour can affect the efficacy of a placebo pill – red is best for stimulants, and yellow for antidepressants

Win!

A SCIENCE KIT BUNDLE

WORTH £150

This month we're giving you the chance to win a bundle of three science and technology kits by Thames and Kosmos: build your own artificially intelligent KAI robot, gravity-defying Newton's Apple gyrobot and a confectionary laboratory to make your own gummy candies

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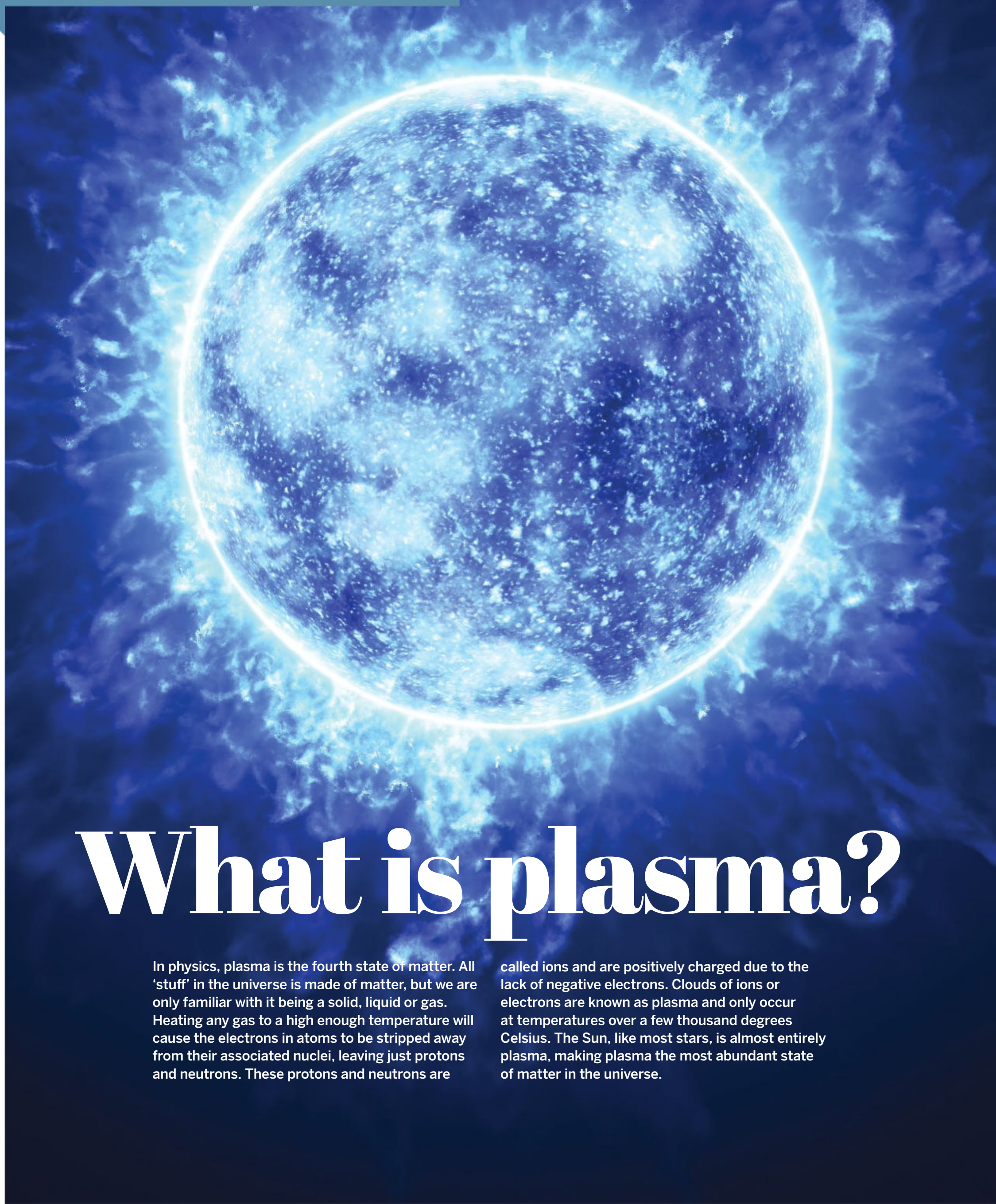
BRAINDUMP

Amazing answers to your curious questions

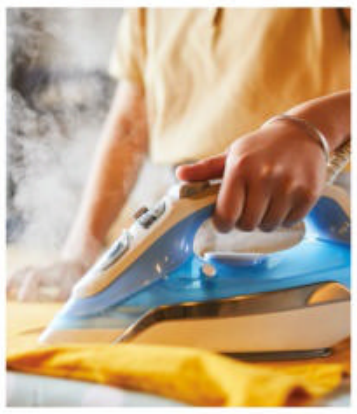


What is plasma?

In physics, plasma is the fourth state of matter. All 'stuff' in the universe is made of matter, but we are only familiar with it being a solid, liquid or gas. Heating any gas to a high enough temperature will cause the electrons in atoms to be stripped away from their associated nuclei, leaving just protons and neutrons. These protons and neutrons are called ions and are positively charged due to the lack of negative electrons. Clouds of ions or electrons are known as plasma and only occur at temperatures over a few thousand degrees Celsius. The Sun, like most stars, is almost entirely plasma, making plasma the most abundant state of matter in the universe.

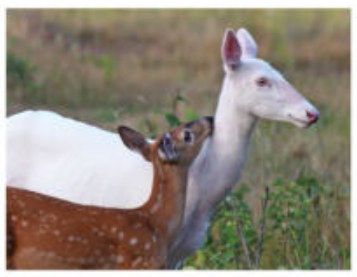
WHAT'S THE DIFFERENCE BETWEEN A DOLPHIN AND A PORPOISE?

Of the two marine mammals, porpoises are shorter and fatter – their name comes from the Latin porcopiscus, which means pig-fish. They also have a blunt jaw, rather than the beak of a dolphin. Dolphins also have a bulge at the top of the head, just in front of the blowhole, called the melon. This is filled with fat and acts as an acoustic chamber for echolocation. Porpoises have an echolocation sense too, but no melon, and are generally less acrobatic and playful than dolphins. They are both members of the toothed whales and evolved into different families about 15 million years ago.



WHY DO IRONS WORK SO MUCH BETTER WHEN HOT?

Cloth fibres are bound together by chemical bonds, with the polymer strands becoming fixed in unnatural shapes (wrinkles) as the fabric bends. These bonds are weakened by heat, so when a hot iron is applied, the cross-linking between the fibres is loosened, allowing the weight of the iron to force them into a new, flatter shape.



WHY ARE SOME ANIMALS ALBINO?

Although albinism is rare, many animals are at risk of it. Being albino refers to a complete absence, or in some cases a reduction, in melanin, which causes pigmentation of the skin, eyes and hair. This is due to a fault in the function of the enzyme that produces melanin. It is a genetic condition caused by the inheritance of two recessive genes – though this is a very rare occurrence.

ARE ASTRONAUTS ABLE TO BURP?

Burps, or belches, are caused by a vibration of the upper oesophagus as gas is expelled through it. This could be oxygen and nitrogen after breathing in too fast, or carbon dioxide after glugging a fizzy drink or suffering a bout of indigestion. There's nothing about space that would cause this natural bodily reaction to stop, but there would be fewer things to trigger it. For instance, astronaut diets are carefully formulated for easy digestion, and cola would certainly not be part of it. Even if it were, carbonated drinks don't fizz in space as there is no gravity to separate the gas from the water, leaving any air bubbles simply floating in the liquid.

Did you know?

Butterflies can taste things using their feet

What causes the 'butterflies in my stomach' feeling?

Having butterflies in your stomach relates to more than just that feeling you get when you're around someone you'd like to kiss, as the same feeling also comes when you're nervous, like before an exam or the first day on a new job. These feelings are most likely related to the fight or flight reflex. When something stressful is about to happen – in evolution this would be fighting a predator or rival – the body switches into 'action mode', which sends adrenaline speeding through your bloodstream. In addition, the autonomic nervous system diverts blood away from non-essential systems such as your stomach and intestines and sends it to the muscles and brain. The vagus nerve, which is a key mediator of this effect, slows stomach function, as well as increasing heart rate. This may be the reason that your stomach, which doesn't need to be active during these situations, reports a different sensation to your brain.

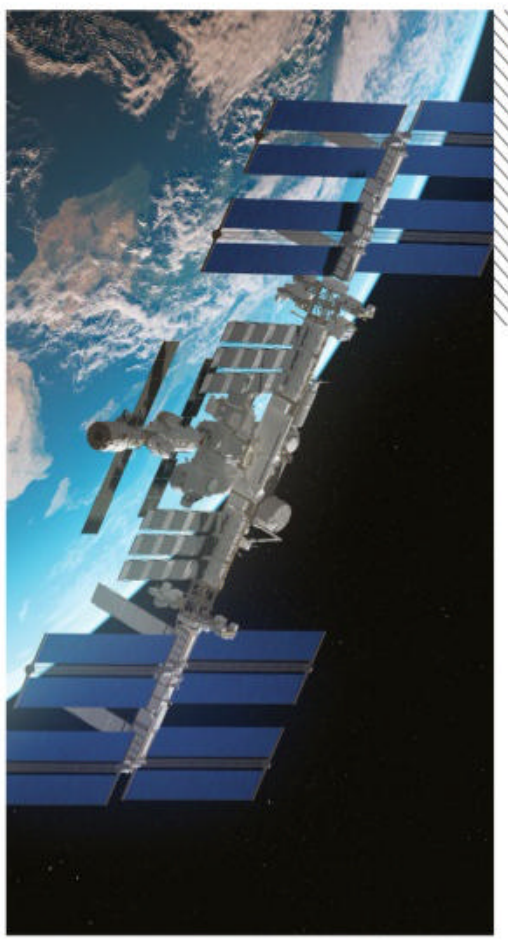
BRAINDUMP

COULD SCIENTISTS EVER DEVELOP A WAY FOR HUMANS TO EXTRACT THE OXYGEN FROM WATER?

Oxygen can be extracted from water in a process known as electrolysis. Water molecules consist of two hydrogen atoms paired with one oxygen atom. Connecting two electrodes to a power supply and placing them into salted water allows an electric current to flow. Electricity is the flow of electrons, therefore one of the electrodes – the cathode – becomes negatively charged due to the buildup of electrons, while the other – the anode – becomes positively charged because of an electron deficit. This difference in charge causes water molecules to separate into their constituent parts, with oxygen bubbles appearing on the anode and hydrogen bubbles accumulating on the cathode. Your question could also be referring to whether we might one day be able to 'breathe' in water. To do this, humans would need a system similar to fish gills in order to harness dissolved oxygen.

Did you know?

Oxygen-28 is the heaviest version of the element ever created



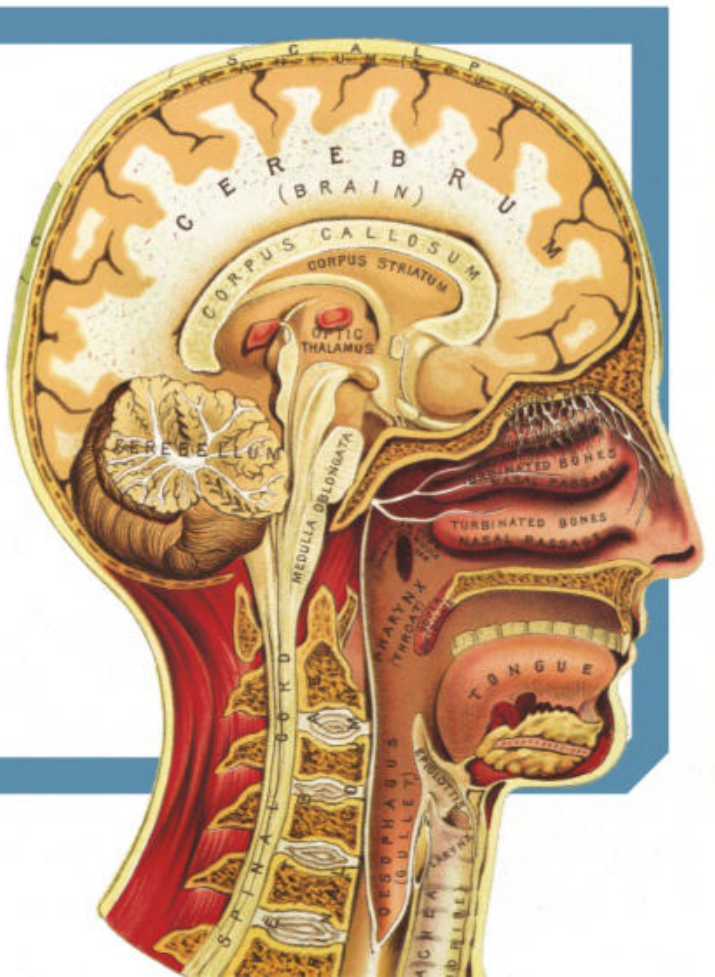
How would you put out a fire on the ISS?

Although there have been no fires on the International Space Station, it remains a dangerous possibility because even NASA has relatively little experience of fighting fires in space. Flames burn at a lower temperature in space as they receive far less oxygen. However, it is the absence of gravity that causes the most problems, making flames roughly assume the shape of the burning object, rather than rising straight up as they would on Earth.

Detection is another problem, as without gravity smoke will not rise, meaning smoke detectors must be located in the ventilation system. Once a fire is found, the actual extinguishing would be down to astronauts using either water-based foam extinguishers or compressed carbon dioxide units. In January 2012, the second phase of the Flame Extinguishment Experiment (FLEX) began. FLEX was designed to explore how flames react and how fuel moves in space – particularly in the Destiny module where the ISS' fuel and ignition systems are located.

DO WE CONTROL OUR BRAINS OR DO OUR BRAINS CONTROL US?

An experiment at the Max Planck Institute in 2008 showed that when you decide to move your hand, the decision can be seen in your brain before you're aware you have made a decision. The delay is around six seconds. During that time, your mind is made up, but your consciousness doesn't acknowledge the decision until your hand moves. One interpretation of this is that your unconscious brain and your body get on with running your life, and only report back to your conscious mind when necessary to preserve a sense of free will. But it's just as valid to say that when you make a decision, there's always a certain amount of background processing going on, which the conscious mind ignores for convenience.



DOES THE SOUND OF RUNNING WATER MAKE US WANT TO PEE?

It certainly can, although this is most likely due to an unconscious association from the sound of the running water, as there is no known medical explanation for it. When we hear the sound of a running tap, rainfall or a waterfall, it reminds us of the act of urination and thus makes us want to pass urine.

IF I LET A BALLOON GO, HOW HIGH CAN IT GET BEFORE IT POPS?

At sea level there's about one tonne of pressure exerted on you by the air at all times. This pressure comes from the 60 miles of air above weighing down the air below. As helium balloons rise, the atmospheric pressure drops as there's less air, causing the balloon to expand. This will continue until either the gas inside the balloon is of equal density to the air outside the balloon, or it pops due to the latex not being able to stretch any more.

What would Saturn's rings look like from the surface of the planet?

Since Saturn is a gaseous planet, it's not possible to send any sort of spacecraft to the surface. However, several probes have performed flybys – the first being NASA's Pioneer 11, which came within 13,048 miles of Saturn's cloud tops. It passed under the ring planes, and images showed a reversal of what we see from Earth through a telescope: the rings looked dark and the gaps between them looked bright. This is probably because sunlight was passing through the gaps and not reflecting off the icy dust particles in the rings.

Further probes, including the recent Cassini, have shown us there are seven main groups of rings, but the total number is unknown. There are also moons embedded in the rings, and the particles within the rings are always moving and reforming. Information from Cassini led astronomers to speculate that some of the rings even have their own atmosphere. Add to all this the fact that the rings move, some of them are tilted and that Saturn has its own movements going on, and you'll see why the planet's rings continue to be so mysterious... and why it's very difficult to say exactly how they'd look if you were able to stand on Saturn and look up. You'd probably see both light and dark depending on where you were located and what was happening in the various orbits and gravitational forces.

WHY DO PEACOCKS HAVE SUCH UNUSUAL FEATHERS?

The standard explanation, first posited by Charles Darwin, is that the peacock is advertising to the peahen what a good mate he will make. Peahens choose the males with the most impressive tails because it demonstrates that they are healthy and strong enough to drag such an encumbrance through the jungle, and also because the peahen wants to produce sons that will have big tails because then they will be successful in attracting mates themselves. This theory was recently challenged after a seven-year study in Japan found that large tails didn't make peacocks more successful in finding a mate. However, that research has been criticised for ignoring colour and eyespot density, and the consensus is still that the peacock tail is a result of sexual selection.

Why do the upper arm and upper leg have only one bone, while the lower arm and lower leg have two bones?

The make-up of the human skeleton is a fantastic display of evolution that has left us with the ability to perform incredibly complex tasks without even thinking about them. There are several different types of joints between bones in your body, which reflect their functions – some are strong and allow little movement, while others are weak but allow free movement. The forearm and lower leg have two bones that form plane joints at the wrist and ankle. This type of joint allows for a range of fine movements, including gliding and rotation. The hinge joints at your elbows and knees allow for less lateral (sideways) movement, but they are very strong. The shoulders and hips, meanwhile, are ball-and-socket joints, which allow for a wide, if not overly refined, range of motion.

CAN WE SEE BOTH THE SUN AND THE MOON OUTSIDE OF AN ECLIPSE?

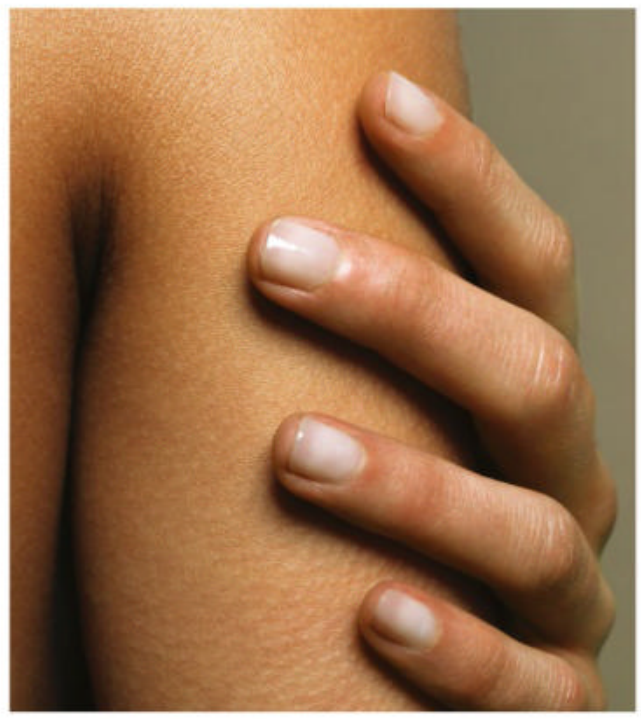
Yes! The Moon is actually the second-brightest object in the sky after the Sun, and you can see it most of the time... if you know when and where to look. How well you can see it depends on the phase of the Moon. It orbits Earth once every 28 days, called a lunar month, so there are times when it won't be visible during the day, or at all. But most of the time you can see it as it moves eastward, with the best visibility during third or last quarter. Check a lunar calendar and look in the southern sky in the early morning in the Northern Hemisphere.

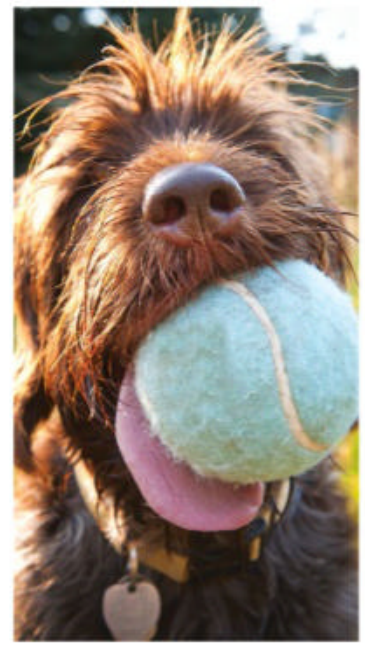
WHERE DO MAGGOTS COME FROM WHEN FOOD GOES BAD?

For hundreds of years, many scientists used the example of maggots 'magically' appearing in rotting meat as proof of spontaneous generation – the ability for life to form in a 'dead' object. But in reality, maggots are immature fly larvae. They hatch from eggs laid by flies, but the eggs are so tiny that they are invisible to the naked eye. Decomposing food is the perfect meal for maggots, so flies are great at finding that old piece of fruit on your counter. Get rid of rotting food, keep your bin sealed and you won't give flies a place to lay their eggs.

IF WE'RE CONSTANTLY SHEDDING SKIN, HOW MUCH DO WE LOSE OVER A LIFETIME?

Skin is our body's largest organ – on average, an adult has about two square metres of it, or in weight about 3.6 kilograms. It protects our internal organs, produces vitamins and minerals, provides tactile feedback and helps us retain water... that's why keeping it moisturised and well protected is so important. Since it's so hard-working and subject to so much, however, skin constantly needs to reproduce itself. For each minute that goes by, you've shed 40,000 skin cells, and your skin is entirely renewed every 35 or so days. If you live for 80 years, you'll have renewed your skin approximately 800 times, shedding up to 2,880 kilograms.





WHY DO DOGS LIKE CHASING THINGS YOU HAVE THROWN?

Dog are descended from wolves that chased after mammals and birds for food, so the chase instinct is already present from birth. But domestication has also created a link between dogs and humans. Dogs actively seek play opportunities with us because they want our approval. But now consider the question from the other perspective: why do we like throwing things for dogs to chase? We like it because the dog enjoys it and we find its happiness rewarding. Both the dog and owner are engaged in a mutual back-scratching exercise where the pleasure of one reinforces the pleasure of the other in a cycle.

Did you know?

The first train journey took place in 1804

I'm often delayed by signal failures – what exactly does this mean?

Signal failures are almost as old as the railway itself, with the first primitive wayside signalling systems being introduced in 1832. These days signalling relies on a combination of movable sections of track, known as points, track circuits that detect the position of the train and the signals themselves, which look like traffic lights positioned above or beside the track. These three elements must be routed via cables to a signalling centre, where each signal change must be coordinated. With such a complex system, the reasons for a signal failure could be anything from power outages and circuit failures to track points freezing or the increasingly widespread problem of stolen cables and vandalism. Identifying the cause of the problem often takes longer than fixing it.

THE LIBRARY

The latest book releases for curious minds

GUINNESS WORLD RECORDS 2024

FROM THE WORLD'S YOUNGEST PIRATE TO THE MOST PLAYED MUSIC ARTIST

AUTHOR **GUINNESS WORLD RECORDS**
ILLUSTRATOR **ALEX PANG AND ROD HUNT**
PUBLISHER **GUINNESS WORLD RECORDS**
PRICE **£22 / $29.95**
RELEASE **OUT NOW**

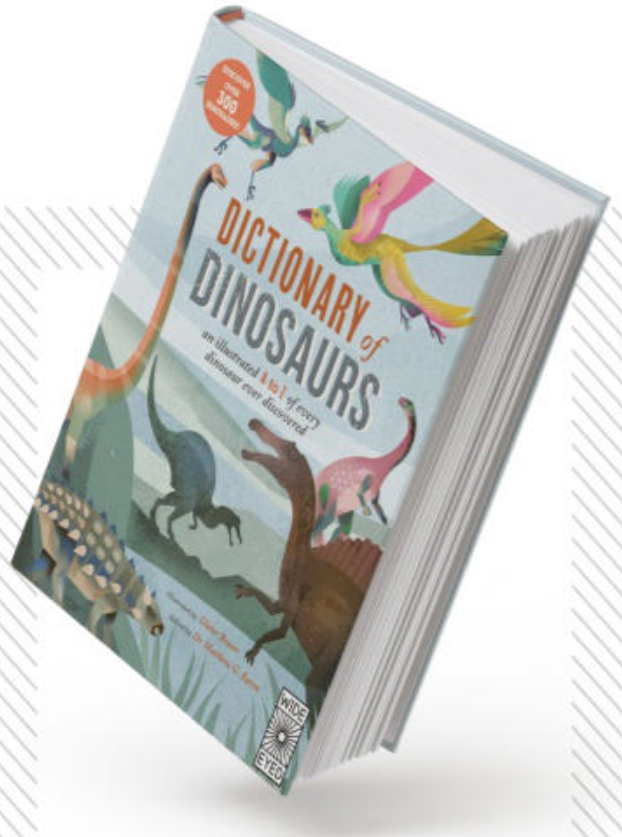
As the internationally recognised authority on who or what in the world is the biggest, fastest, strongest, longest and so on, Guinness World Records takes its role as registrar and curator of world records very, very seriously. For this year's edition of its hardback annual, 30,000 applications were reviewed by Guinness World Record's record managers – which may be a record in itself – a percentage of which were approved as world records. Meanwhile, less than one-tenth of those original applications, the crème de la crème, made it into *Guinness World Records 2024*.

It includes records like the one set by 11-year-old circus star Sofia Tepla, who rolled 20 metres in 10.49 seconds, which sounds like a pretty ordinary feat until you realise that Sofia was performing a contortion roll to set this record, with her legs bent backwards and over her head. Or Spotify's 'most streamed female act', which goes to pop princess Taylor Swift with a staggering 41.13 billion plays – that's five plays for every single living person on Earth. Or the all-time record for the 'most fingers and toes', which went to Akshat Saxena, a boy who was born with 14 fingers and 20 toes before he underwent surgery – though his impressive record still stands.

Of course, as much as we like reading about human records, *Guinness World Records 2024* is split into categories that include sections on the natural world, the blue planet and science and technology. This year there's a new history chapter featured, which is slimmer than we'd like given how much Guinness World Records could do with historical records, and how much we enjoyed this section. There are some surprises here, like the most expensive suit of armour, the deadliest medieval knight's tournament and the world's youngest pirate, who was estimated to be between eight and eleven years old!

"Includes sections on the natural world, the blue planet and science and technology"

There are some less surprising records too, like the 'most extensive burial hoard for a pharaoh' – no prizes for guessing correctly. But regardless of whether you already know who or what the record goes to, they're still fascinating and, perhaps more importantly, fun to read. The beauty of *Guinness World Records 2024* is that even if a particular record or section isn't lighting your synapses up, you're bound to find something else in the book to flick your switch.



DICTIONARY OF DINOSAURS

AN ILLUSTRATED A TO Z OF EVERY DINOSAUR

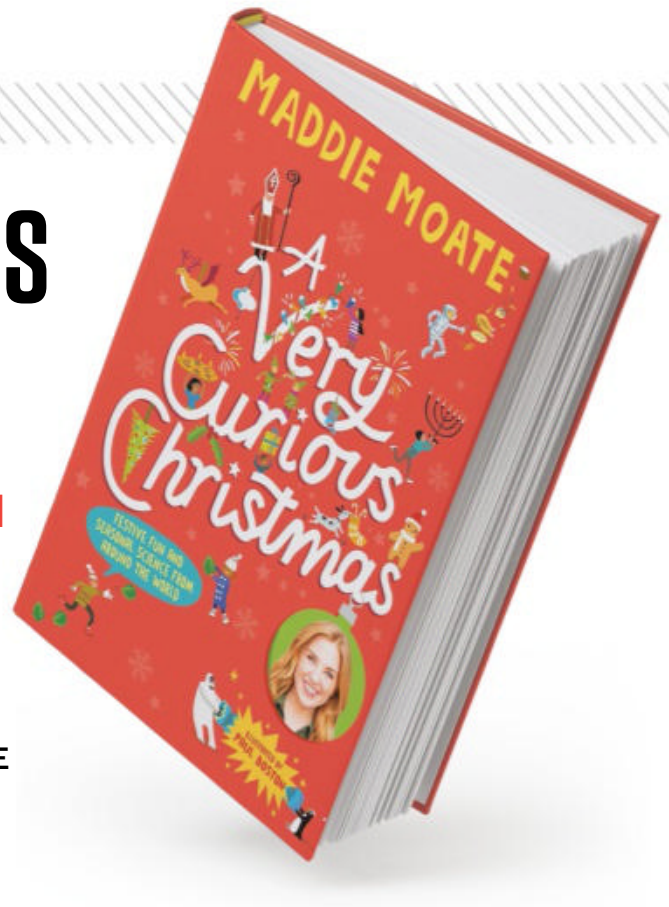
AUTHOR **NATURAL HISTORY MUSEUM**
ILLUSTRATOR **DIETER BRAUN**
PUBLISHER **QUARTO**
PRICE **£9.99 / $15.99**
RELEASE **4 JANUARY 2024**

Each dinosaur species is unique, ranging from small, bird-sized creatures to towering giants. For young readers who love exploring the long-lost world of the dinosaurs, *Dictionary of Dinosaurs* is ideal. You can flick through the pages to learn about species you've never heard of before or search for your favourites. Every dinosaur is illustrated with artistic licence while remaining accurate by depicting the shapes, textures and features known through archaeological finds. A snappy fact file, a visual human-to-dinosaur scale, the meaning of its name and pronunciation are included alongside each entry. The short paragraphs about each dinosaur provide concise information while including their most noteworthy features and traits. Put together by palaeontologists, it has been compiled using the most up-to-date and enthralling facts from the past.

A VERY CURIOUS CHRISTMAS

FESTIVE FUN AND SEASONAL SCIENCE FROM AROUND THE WORLD

AUTHOR **MADDIE MOATE**
ILLUSTRATOR **PAUL BOSTON**
PUBLISHER **PENGUIN RANDOM HOUSE**
PRICE **£14.99 / $24.50**
RELEASE **OUT NOW**



Over a third of the world celebrates Christmas, and this comes with many fascinating traditions, magical tales, seasonal foods and decorations. Around this time of year, you might have many questions about how Christmas really works. This book explores the science behind many aspects of Christmas festivities: Why do people celebrate Christmas? How do reindeer stay warm? Why is holly spiky? How do astronauts eat Christmas dinner in space? From the questions that have always been at the back of your mind to answers so unique you'd never have considered them, this fact-filled book will help you understand the scientific marvels that emerge in December. After reading *A Very Curious Christmas*, you will be able to tell your family and friends all about the chemistry of candy canes, how candles work and where each delicacy in your Christmas meal originated. Science can't explain the answers to all of the mysterious festive ongoings, but author Maddie Moate provides her theories to these as she unpacks this holiday in an engaging and visual experience.

SPYING ON SPIES

HOW ELIZABETH SMITH FRIEDMAN BROKE THE SECRET NAZI CODE

AUTHOR **MARISSA MOSS**
PUBLISHER **ABRAMS**
PRICE **£13.99 / $19.99**
RELEASE **11 APRIL**

Meet one of the world's greatest code-breakers, Elizabeth Smith Friedman, and follow her personal life and monumental achievements in this fast-paced and compelling read. With a sharp mind and unwavering nerves, Friedman not only became America's first female cryptanalyst, but during World War I cracked an estimated 12,000 enemy encryptions.

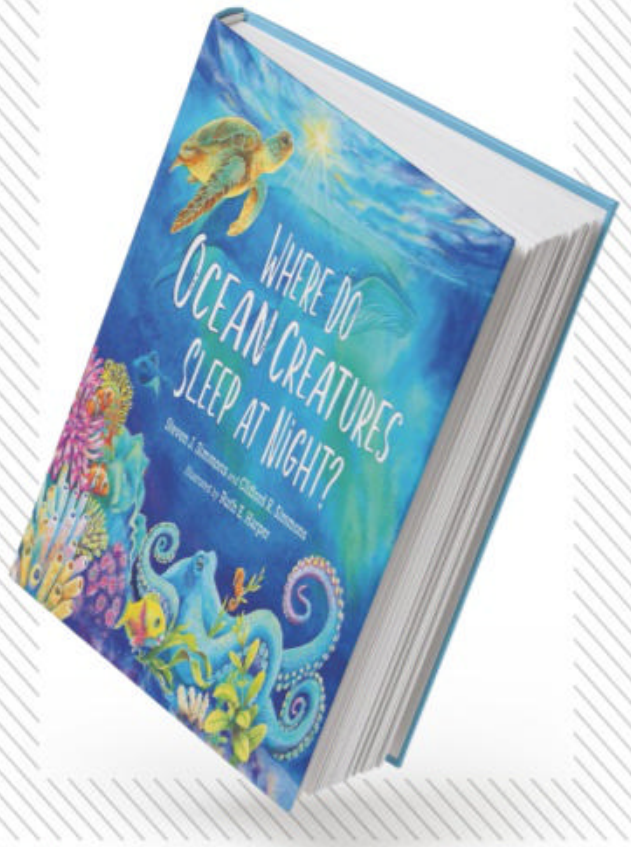
Then, during World War II, Friedman discovered a network of Nazi spies in South America and decrypted their messages to Germany, which ultimately led to the spies' arrest. It wasn't until 2008, when the records of her involvement in the war were declassified, that the world even knew about Friedman's amazing achievements. Award-winning author Marissa Moss has brilliantly brought the events of Friedman's life to readers in *Spying on Spies*, creating an immersive read.

WHERE DO OCEAN CREATURES SLEEP AT NIGHT?

A GUIDE TO UNDERWATER BEDTIME ROUTINES

AUTHOR **STEVEN J. SIMMONS AND CLIFFORD R. SIMMONS**
PUBLISHER **CHARLESBRIDGE**
PRICE **£16.99 / $17.99**
RELEASE **16 APRIL**

Journey under the ocean and discover how animals like clownfish sleep cosily in their anemone beds or how seahorses wrap their tails around coral anchors in this book. Along with some of the better known sleeping habits of fish, there are also some surprises, such as the mucus cocoon that parrotfish make when it's time to sleep and how sharks need to continually swim while they slumber. Each page is filled with vibrant illustrations that are sure to immerse children into the world below the waves. The book has a whimsical rhyming tone that makes it the perfect bedtime read for children to learn about animals sleeping in the wild – a great way to send your little ones off to dreamland.



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

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

MEDIUM

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

HARD

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

Word search

Find the following words

CRACKER
SANTA
JINGLE
SPRUCE
GREEN
RED
GOLD
PUDDING
SNOW
PRESENT
SPROUTS
LIGHTS

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

What is it?

Hint:
Woody fruit

A

Spot the difference

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

Answers

Find the solutions to last issue's puzzle pages

Q1 ASTEROID
Q2 ANT
Q3 SECOND NOSE
Q4 BLUE WHALE
Q5 5 BILLION
Q6 ISAAC NEWTON

What is it?

BROWN SUGAR

Spot the difference

QUICKFIRE QUESTIONS

Q1 What is the Milky Way said to smell like?

- Rum
- Eggs
- Cheese
- Bread

Q2 Which bird can fly backwards?

- Albatross
- Hummingbird
- Eagle
- Pigeon

Q3 Which electrical component stores electricity?

- Transistor
- Resistor
- Inductor
- Capacitor

Q4 What colour is a polar bear's skin?

- Red
- Blue
- White
- Black

Q5 Around how long would it take to drive to the Moon going 60 miles per hour?

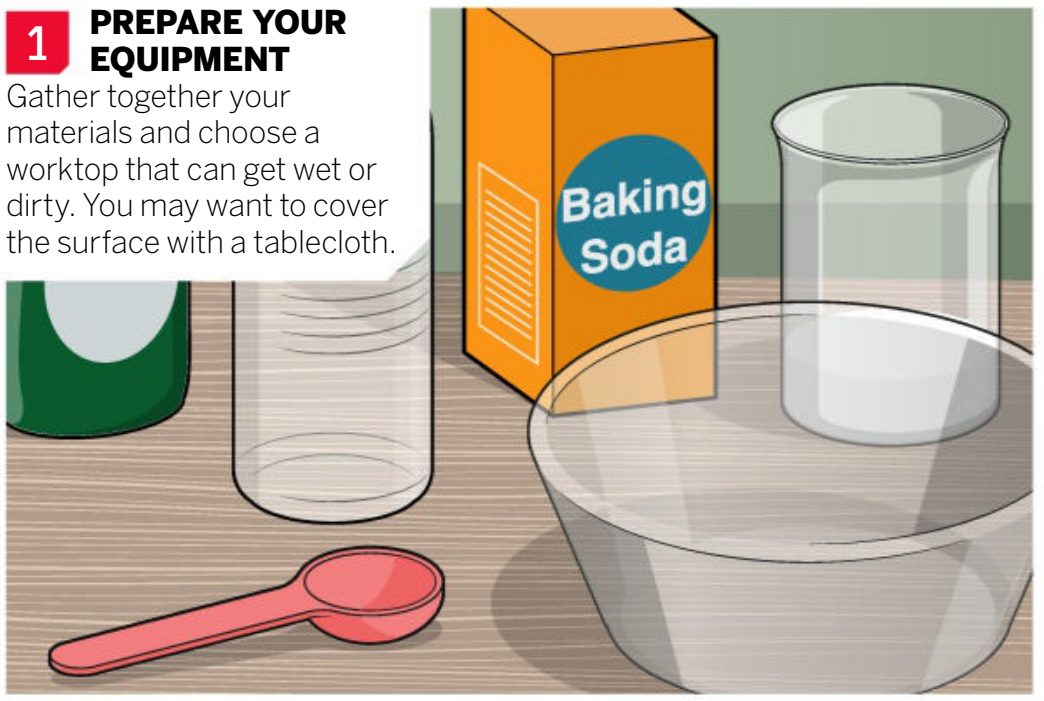
- A day
- A week
- A month
- A year

Q6 What animal was enlisted by the Polish army in WWII?

- A dog
- A cat
- A cow
- A bear

MAKE FOAMING FAKE SNOWMEN

Make realistic miniature snowmen and fake snow with kitchen ingredients



1 PREPARE YOUR EQUIPMENT

Gather together your materials and choose a worktop that can get wet or dirty. You may want to cover the surface with a tablecloth.

2 POUR THE SNOW POWDER

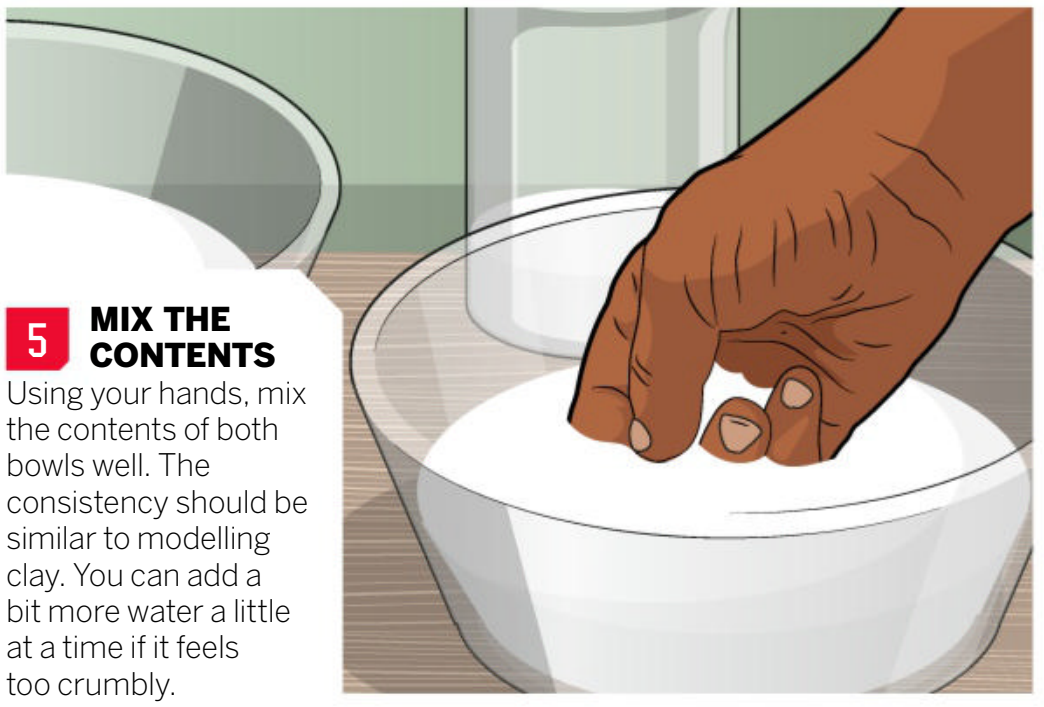
Measure out one cup of baking soda and pour it into one of the bowls. Repeat this for the second bowl.

3 ADD SOME MOISTURE

Add three tablespoons of water into each of the bowls with baking soda in them.

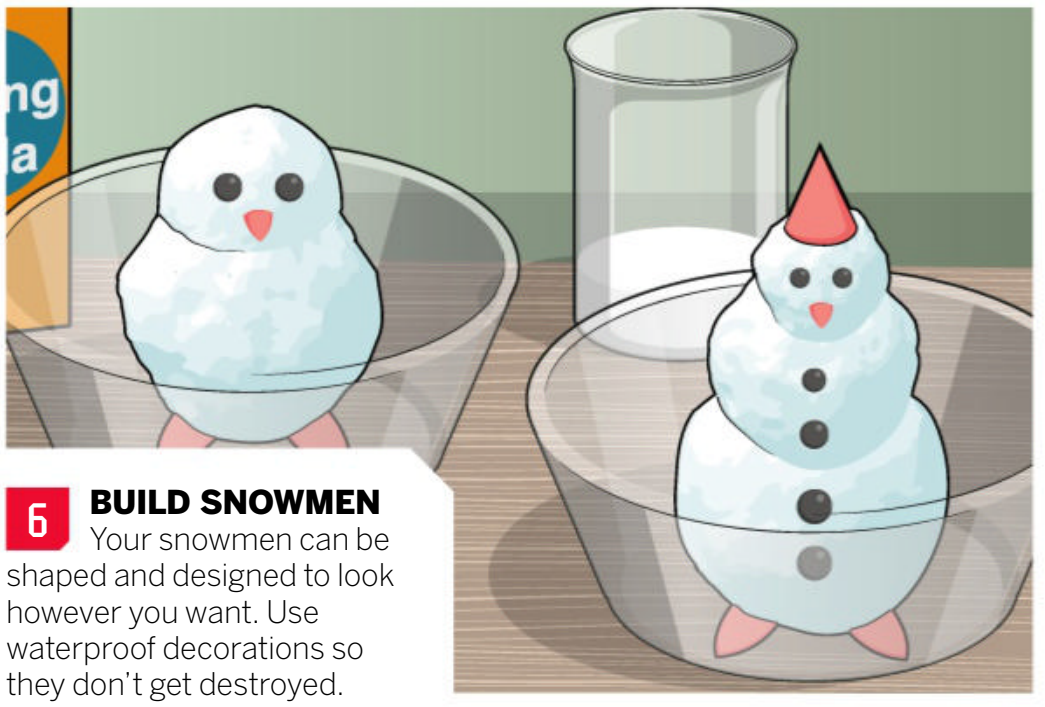
4 DISPENSE THE SOAP

Add one teaspoon of washing-up liquid into only one of the bowls. You can use your sticky notes to label which has soap in and which doesn't in case you forget later.



5 MIX THE CONTENTS

Using your hands, mix the contents of both bowls well. The consistency should be similar to modelling clay. You can add a bit more water a little at a time if it feels too crumbly.



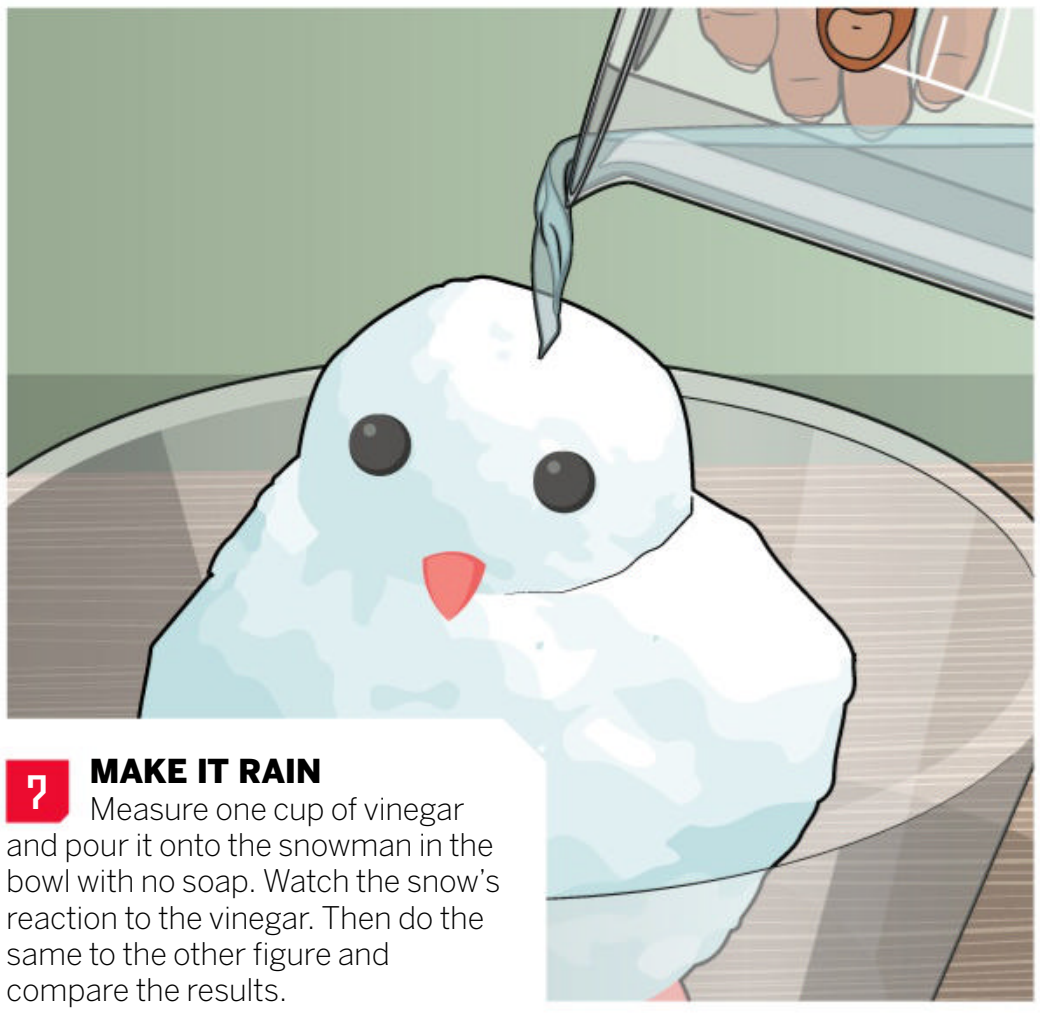
6 BUILD SNOWMEN

Your snowmen can be shaped and designed to look however you want. Use waterproof decorations so they don't get destroyed.

KIT LIST

- Two large glass bowls or containers
- Measuring cups and spoons
- Baking soda
- Sticky notes
- Pen
- Washing-up liquid
- Vinegar
- Small waterproof decorations

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



7 MAKE IT RAIN
Measure one cup of vinegar and pour it onto the snowman in the bowl with no soap. Watch the snow's reaction to the vinegar. Then do the same to the other figure and compare the results.

8 BUBBLE AWAY
Which snowman creates the biggest fizz as it melts away? And which lasts the longest? If one is partially melted, try holding it as you add more vinegar to feel the reaction.

SUMMARY

What was left in the two bowls after the experiment? Most likely, the snowman without soap was standing in a puddle of bubbly water, while the soapy snowman formed an expanding, foaming mass. This is because the chemicals in the washing-up liquid trapped the bubbles that formed in the experiment, preventing them from instantly popping. The reaction taking place is due to the acidic vinegar coming into contact with the baking soda, or sodium bicarbonate. The chemical reaction produces carbon dioxide and water as byproducts. The carbon dioxide gas causes the bubbles to grow in the foam. Meanwhile, the soap contains surface-active agents that lower the surface tension of the liquid. This enables the surface of the soapy liquid to stretch more and produce the impressive snowy froth.

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.

INBOX

Speak your mind

The bills of several species of Australian parrots are increasing in size

LETTER of the MONTH

CLIMATE CHANGE

Dear **HIW**,
I'm a frequent reader of your magazines and often read the same ones again and again. I was reading an article about evolution and found a part about human-driven evolution. That got me thinking, how would living beings grow to adapt to climate change? What would they grow in order to do that? Do you think that some animals would develop a tolerance of ultraviolet light somehow?
Muhammad

Any changes to animals' environments can cause a species to adapt and evolve, and as the impact of climate change affects so much life on Earth, many animals and plants will need to adapt to survive. The warming planet is already causing changes in animals. Sea lions in California have changed their hunting habits due to a decrease in food in their habitats. They have adopted a greater range in diet and now venture farther out to sea to search for food and new prey. Three-spined stickleback fish evolved to live in rivers and open water. Here the threat from predators was greater, so they evolved defensive bony plates at their sides. Because of warming conditions, the estuaries they used to live in have become like ponds. They have more plants to shelter in, so are beginning to lose their bony plates.

Australian parrots have evolved bills with a ten per cent larger surface area since 1871. This helps them lose body heat quicker. There are many ways that animals can adapt to better survive climate change. However, evolution is a slow process and not all species will be able to change significantly enough to survive in the new environments created by climate change.

WIN!

AN AMAZING PRIZE FOR LETTER OF THE MONTH

GUINNESS WORLD RECORDS 2024

This year's edition compiles the very best of the thousands of new records approved over the past year

WEIGHTLIFTING WONDER

Dear **HIW**,
People always go to the gym to get bigger, but how does lifting weights make muscles bigger? I would have thought it would waste them away or damage them.
Georgi Hammond

You're right that lifting heavy weights damages muscles, but it's in the form of very small tears in the muscle fibres. To repair these tears, muscles use nutrients to repair the tissue. The new muscle fibres are fused together with strands of protein called myofibrils. As people continue to work out, these strands grow thicker. Muscle growth doesn't take place when physically lifting weights, but in the rest period when protein strand production is occurring at a greater rate than muscle breakdown.

Weight training helps muscles, tendons and ligaments become stronger

SPIDER SCARE

Dear **HIW**,
I'm six years old and I'm scared of spiders. My teacher said we could learn more about them so I don't feel so scared. Do you have any articles on spiders we could share in school?
Ellis

Being scared of spiders is quite common, with between 6 and 15 per cent of the population having this phobia. But spiders do more good than harm, and by looking at their benefits you might start to admire them. When they spin their webs to catch insects, they stop pests from ruining crops and stop insects passing on diseases. Spiders are also very unlikely to bite humans. We write about spiders quite frequently in the environment section of our magazine, but one feature in issue 170 focuses solely on spiders and how misunderstood they can be. This includes fun facts about spiders and debunks myths. It's a great idea to learn more about these animals so that next time you come across one you will understand it better and hopefully feel less scared.

Only 0.5 per cent of spider species are dangerous to humans

ANIMAL FACES

Dear **HIW**,
Humans have so many different facial expressions. Is this the same in animals?
Janet Taylor

Animals have a range of facial expressions, but with such different facial structures and muscles, researchers are only just beginning to understand what they portray. Pain is one of the most common among animals, such as mice, rats, rabbits, horses and sheep. They tighten their eyes, tense their mouths and flatten their cheeks. Recently, researchers at the University of California identified that cats have 276 unique facial expressions, and some of these are similar to human expressions.

The muscles in cats' faces give them different expressions to humans

Extensive snowfall in Aomori, Japan, can be seen in this aerial shot

SNOW SEASON

Dear **HIW**,
Is there somewhere in the world where it snows all year around? Where are the snowiest places?
Ravi Coskun

Due to weather patterns, there isn't a place where snowfall is constant, but there are places with snowy landscapes all year round. In Antarctica there is always snow on the ground, but it doesn't actually snow very much. Instead, the temperatures are so low that any snow that falls remains and piles up. The snowiest seasons occur in Thompson Pass, Alaska, which had a record snowfall of 24 metres in 1952 to 1953. In general, the snowiest country is Japan, as half of it is covered in snow over winter. And the snowiest city in the world is Aomori in Japan, receiving around eight metres of snow each year.

WE ASKED YOU

This month on social media, we asked you:

What are your favourite Christmas traditions or holiday activities?

@DOODLENEWS
Building snowmen

SUNAM F
Gingerbread house competitions with my family. It's all about the architecture

JEN OWENS
My favourite is ice skating on Christmas Eve

@AESTHETICALLY_AJ
Decorating homes and gardens with lights during the dark winter months

EMMA D
Krampus in Austria; I saw him for the first time last year

THOMAS LENTON
Markets and gift giving

HOW IT WORKS

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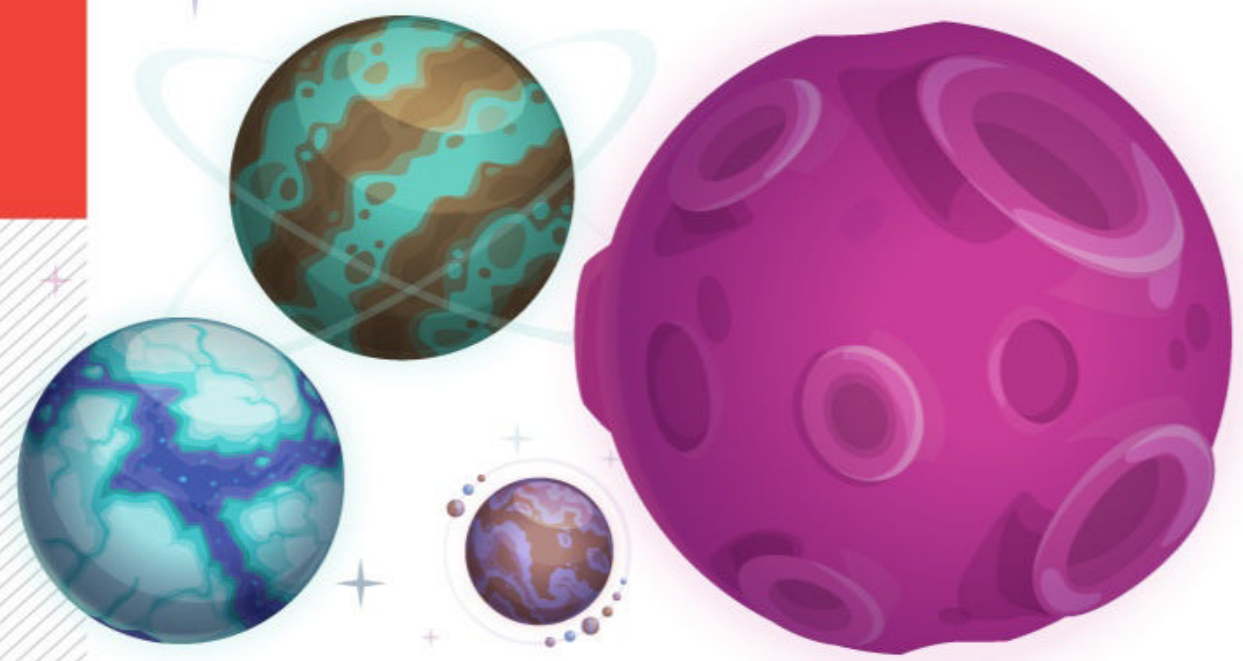
FAST FACTS

Amazing trivia that will blow your mind

DOGS SEE IN TWO COLOURS: BLUE AND YELLOW

Every year, the UK uses enough wrapping paper to cover the Moon



5,500

Astronomers have discovered thousands of exoplanets since 1992

1884

The first working electric car was built nearly 150 years ago

1 TRILLION

Your nose can distinguish between a staggering number of smells

200

Chickens communicate using hundreds of different noises

68.4 METRES

A Boeing 747's wingspan is longer than the distance of the Wright brothers' first flight

409 BILLION KWH

In 2022, the US used more electricity just on air conditioning than the whole of Africa used altogether

HUMAN BABIES CAN'T SHED TEARS UNTIL THEY'RE A MONTH OLD

200 TONNES

Every year, a nuclear power station reactor uses a huge amount of uranium

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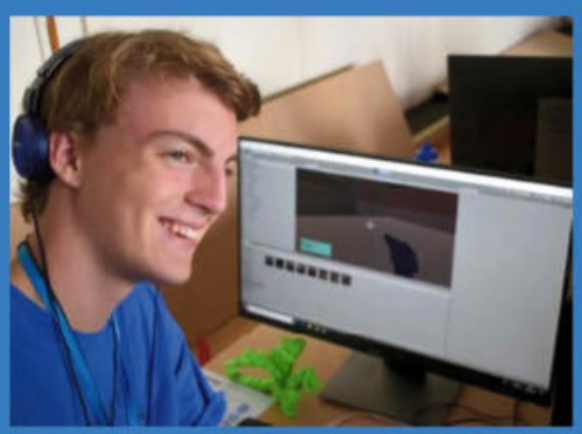

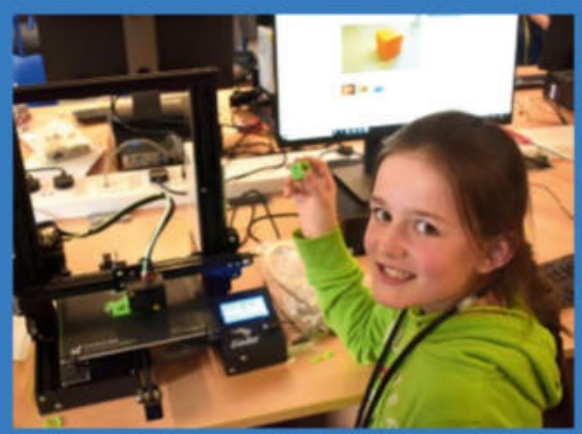

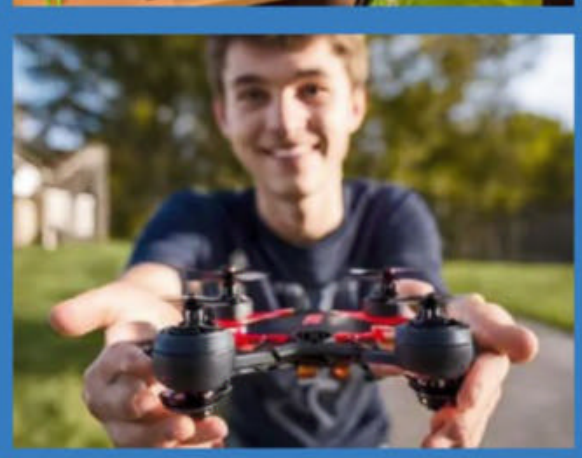

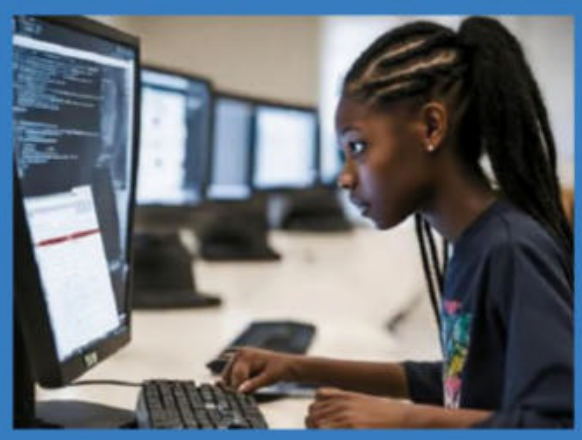

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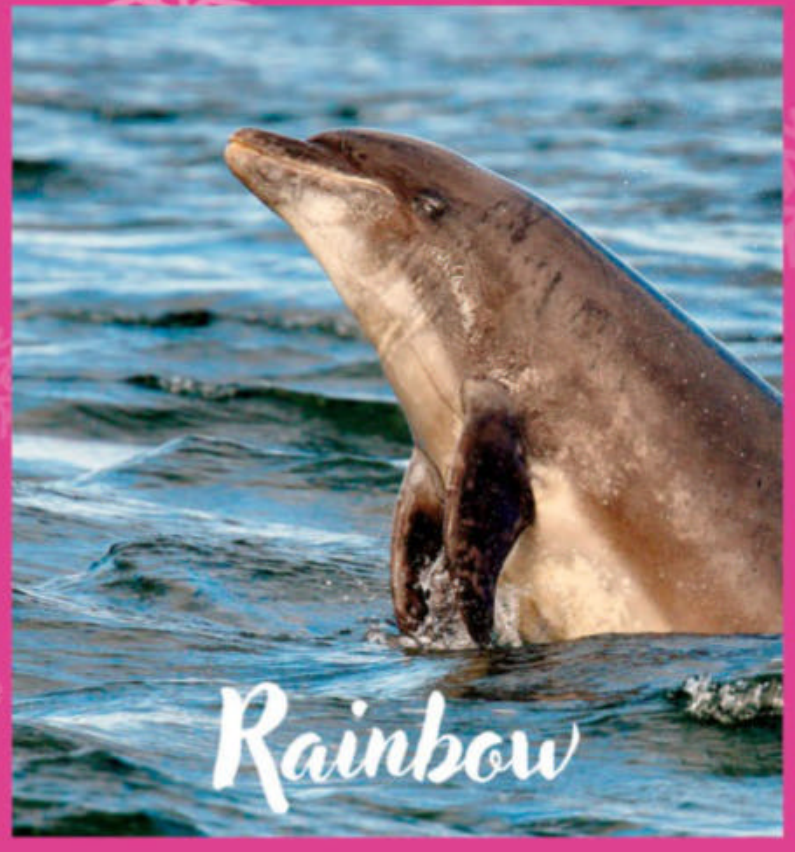

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