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FUTURE

VOLUME 7

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Welcome to

HOW IT WORKS

The Collection

Volume 7

For our seventh edition of the How It Works collection, we're opening with something a little bit different in the form of Weird Science, a compilation of the funniest, strangest and most trivial scientific studies from around the world, courtesy of the annual Ig Nobel Prize awards. Is it possible to unboil an egg? And what music do mosquitos hate? Learn more on page 8. Venture deeper into this volume to explore the asteroid belt and discover where that big crater on the Moon came from. Learn about the most resiliant animals on the planet and how they survive in extremes, take a tour of a bomb factory, see how cars are recycled, and visit the world's mega ports. Plus, there are many more fascinating science, technology, history, space, environment and transport articles stuffed with cool cutaways and photos, carefully selected and brought to you by the How It Works team. Enjoy!

FUTURE

HOW IT WORKS

The Collection
Volume 7

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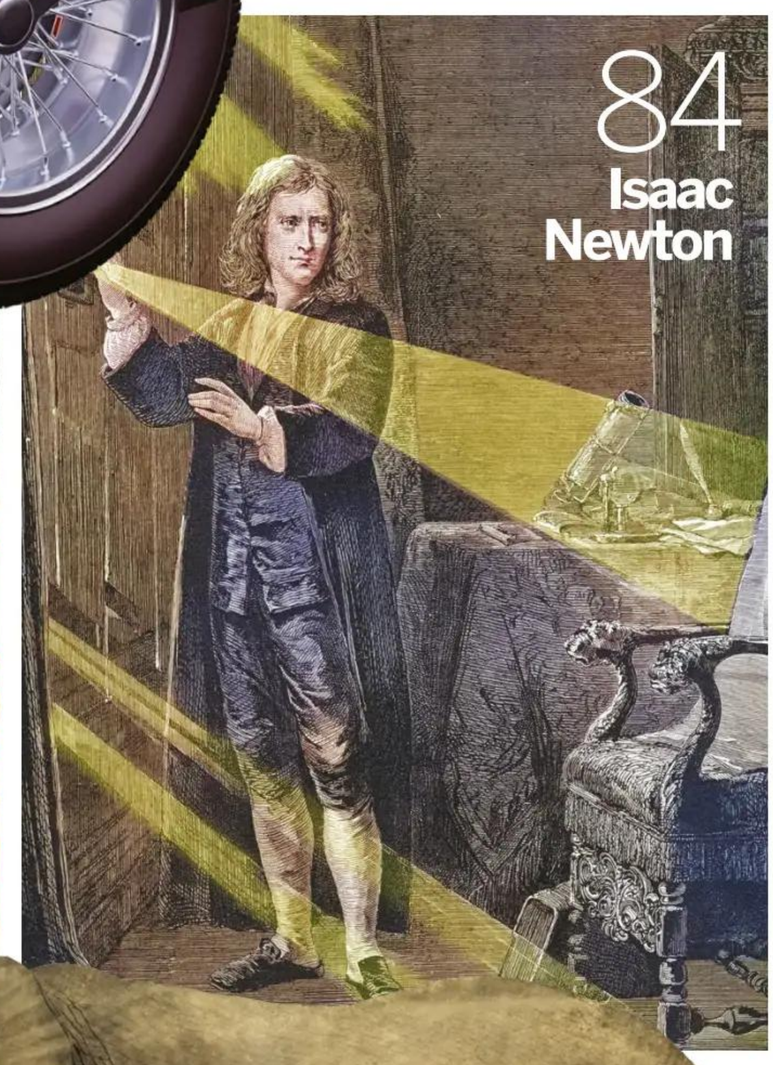
CONTENTS

SCIENCE

SPACE

ENVIRONMENT

82
How formula 1 racing formed



84
Isaac Newton

20
What makes things biodegradable?

38
Inside the asteroid belt

70
Inside the womb

74
How storm supercells form

44
What's that big crater on the Moon?

Pointless body parts 21

18
Why do we sleep?

48 The future of space travel

73 What are rip currents?

10
Weird science

HISTORY

TECHNOLOGY

TRANSPORT

SCIENCE

WEIRD SCIENCE

WORDS **SCOTT DUTFIELD**

Discover the strange scientific studies that answer the questions you didn't know needed answering

WALKING LIKE A DINOSAUR


Given the right anatomy, chickens will walk like dinosaurs

How do you figure out how dinosaurs walked? For a group of researchers at the University of Chile and the University of Illinois, the answer came from artificially changing the anatomy of a distant living cousin: the chicken. Birds are the descendants of giant bipedal dinosaurs called theropods that roamed Earth millions of years ago. Some of the closest living avian relatives to the *T. rex* are chickens. But the two don't have quite the same anatomy, such as a chicken's lack of a heavy tail. It was thought that moving a living bird's centre of mass would recreate the posture of extinct dinosaurs, so a plunger-like tail was added to chicken test subjects to redistribute their centre of mass in a similar way to the *T. rex*.

In this study, researchers raised 12 domestic chicks for 12 weeks, split into three groups of four. One group of chickens was left alone as the control group, the second was given a weight to carry around on their backs and the third group was fitted with an experimental tail that weighed around 15 per cent of the chicken's overall mass. Over the 12-week period, the tail-wearing chickens had a more posteriorly located centre of mass than the other chickens, along with a more vertically orientated femur and elongated gait. The new chicken strut resembled that of a velociraptor walking through Jurassic Park.

Did you know?

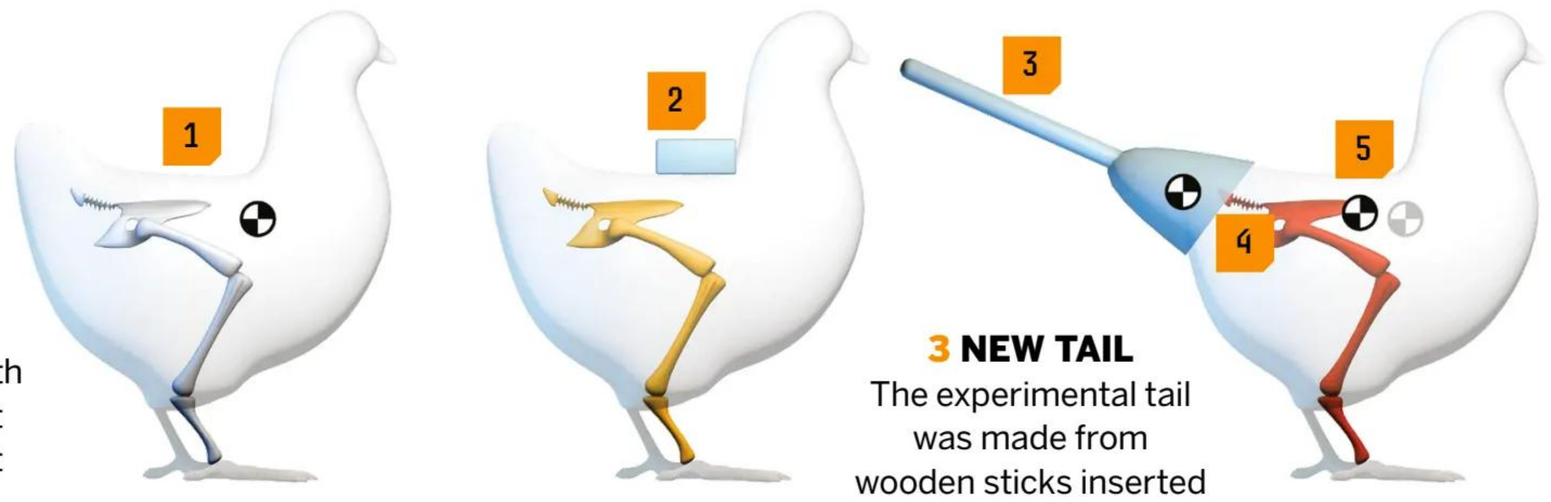
A *T. rex* could run at around 12 miles per hour

RECREATING THE DINOSAUR WALK

How a chicken's body changes when you give it a tail

1 UNADAPTED CHICKENS
One group of chickens was reared without modifications as a control group.

2 WEIGHTED CHICKEN
A group was reared with extra back weight but no tail to see if weight over the pelvis alone changed their posture.



3 NEW TAIL
The experimental tail was made from wooden sticks inserted into a solid modelling clay base.

4 CENTRE
In chickens equipped with a new tail, the centre of mass moved from in front of the hindlimbs to the base of the tail.

5 POSTURE
Among the tail-enhanced chickens, the orientation of the femur became more vertical and the knee joint was more extended.


Harvestmen have elongated legs that scientists wanted to understand better by making them shorter

MAKING DADDY SHORTLEGS

Harvestmen are small invertebrates that are often mistaken for spiders, with gangly legs to scale walls and ceilings. But what would they look like if they were shorter? Researchers at the University of Wisconsin isolated the genes linked to the growth of a harvestman with long flexible legs and turned them off in developing embryos. Over two years, researchers mapped out 580 million base pairs of a species of harvestman called *Phalangium opilio*. Comparing those base codes to those of another species, the fruit fly, helped pinpoint which portion of their genes were encoded for the growth of their legs. Using a process called RNA interference, they were able to disrupt the expression of the leg-growing genes. The results were newborn harvestmen with shorter and deformed legs. The newly stunted harvestman wasn't created just for the sake of it; the researchers will use the data to further understand arachnid development and their evolutionary journey.

Boiling an egg isn't quite as permanent a process as you'd think

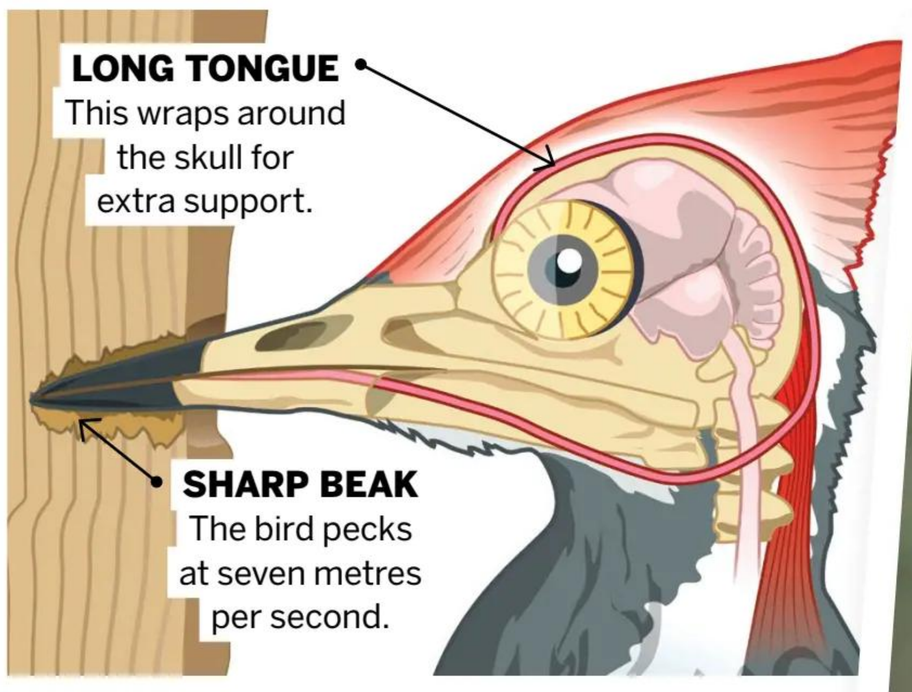
'UNBOILING' EGGS

With the help of a super spinning machine called a Vortex Fluidic Device (VFD), researchers at the Australian Academy of Science discovered a way to undo the work of a pot of boiling water. During the process of boiling an egg, knot-like proteins called lysozymes that make up the egg whites break apart and form new bonds with neighbouring proteins until they ultimately gel together into solid egg whites.

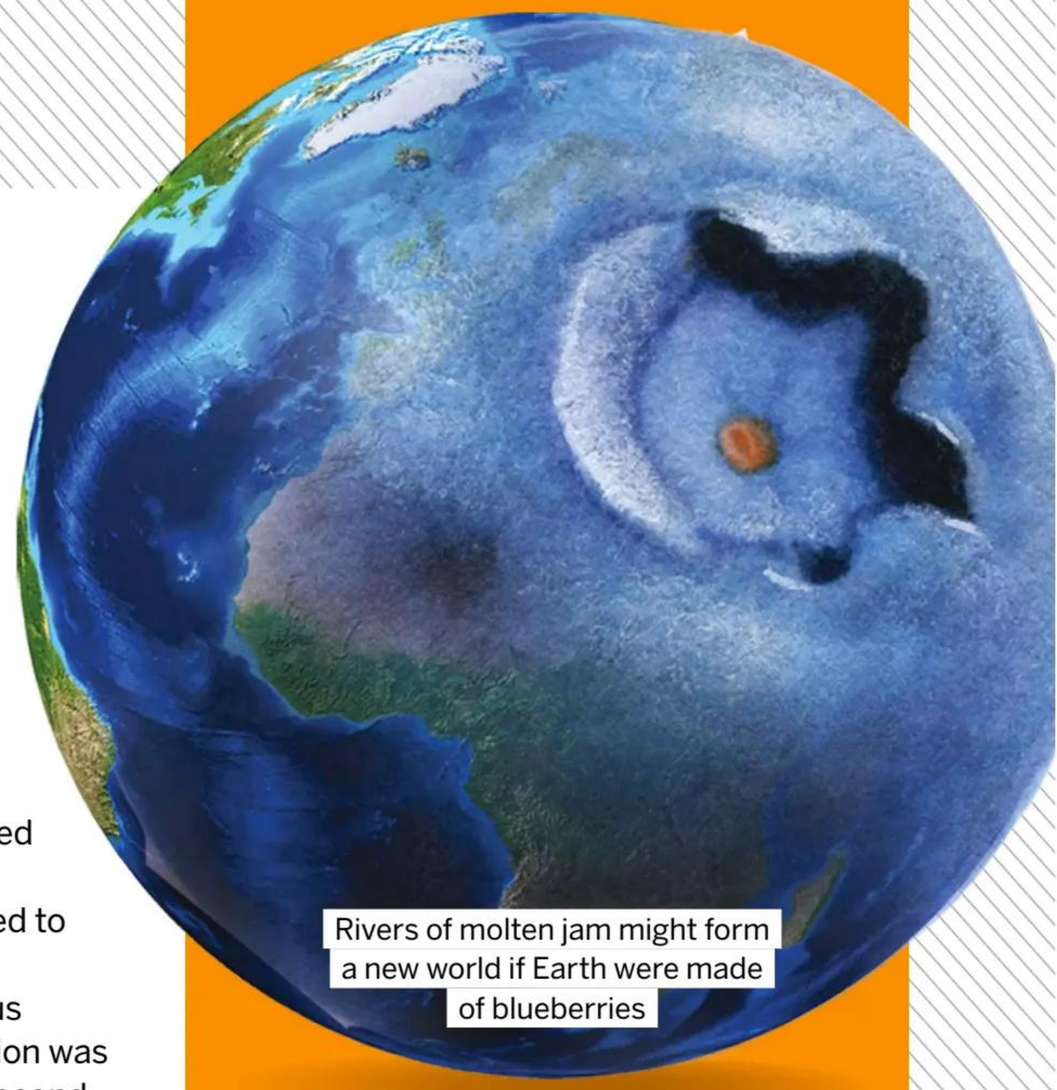
Researchers chopped up a boiled egg, added a chemical called urea – found in urine – and dissolved everything in water. The urea worked to break down the protein bonds again, but the lysozymes didn't yet reform into their previous knot-like state. Using the VFD, the eggy solution was then spun at speeds of 5,000 rotations per second in a test tube. As the solution span, the proteins were stretched and contracted until they returned to the knot-like shape they held before being boiled.

DO WOODPECKERS GET HEADACHES?

Because they spend most of their time hammering their heads against the trunks of trees, you might think that woodpeckers spend the rest of their time nursing a headache. However, scientists have discovered that their bodies are built for impact. In a 2002 study entitled 'Cure for a Headache', researchers at the University of California revealed that pileated woodpeckers (*Dryocopus pileatus*) have evolved specific anatomic features that stop their brains banging around their skull. Along with a thick skull made of spongy bone, there's a piece of cartilage that sits in the skull's mandible that partially cushions the impacts of repeated pecking. There are also dense muscles in the neck that contract one millisecond before impact to reduce the force applied to the skull. To prevent the acceleration of each strike tearing away at the bird's retinae and forcing their eyes to pop out, woodpeckers have strong eyelids that act like seat belts holding everything together.



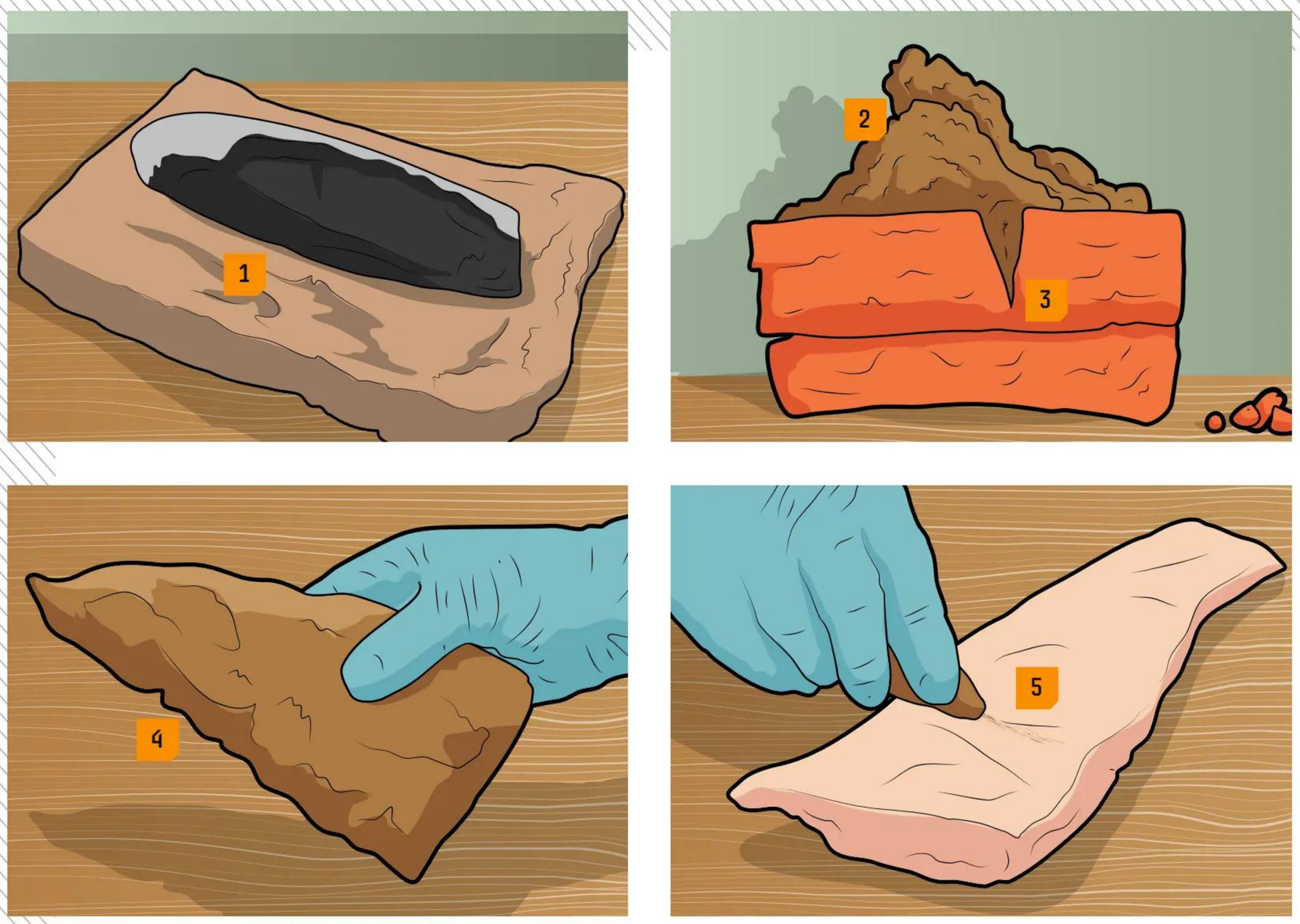
During mating season, male woodpeckers will drum on a tree up to 12,000 times a day



Rivers of molten jam might form a new world if Earth were made of blueberries

WHAT IF THE EARTH WAS A BLUEBERRY?

Have you ever wondered what the world would be like if it suddenly and unexpectedly transformed into a planetary pile of blueberries? Of course not, but a researcher at the University of Oxford's Future of Humanity Institute has, and the conclusion is quite explosive. Computational neuroscientist Anders Sandberg set out to answer what would happen if the entire Earth was instantaneously replaced with an equal volume of closely packed but uncompressed blueberries. What would happen from the perspective of a person on the surface? The answer is the unravelling of Earth physics as we know it. First, gravity would drastically reduce – you'd lose about 87 per cent of your weight in this new blueberry world. However, it wouldn't be long before the air trapped between the blueberries escaped and the berries collapsed under their own weight. The berries would eventually burst under pressure and form a planetary sphere of jam. As the blueberry-flavoured planet continued to collapse, the jam would heat up by 143 degrees Celsius. The oceans of boiling jam would lead to the creation of a fruity scented steam atmosphere, likely tinged blue. At the centre of the newly formed blueberry planet would be a compressed and extremely hot blueberry 'pulp ice'.



MAKING A KNIFE MADE OF POOP

How scientists recreated one of the most unusual tools in history

1 CREATING MOULDS
Ceramic moulds were created by pushing carved stone blades into the potter's clay. The impressions of the blades were then fired in a kiln to harden.

2 RAW MATERIALS
One of the researchers ate an Arctic diet similar to the Inuit people for eight days. After the fourth day of the diet, 'raw materials' were collected.

3 PACKED
This 'raw material' was frozen at -20 degrees Celsius and packed tightly into the ceramic moulds.

4 SHARPENING
Once the knives were completely frozen, the edges were sharpened using a metal file before being buried again in -50 degree Celsius dry ice to ensure they were frozen.

5 CUTTING
The fully formed and frozen knives were then subjected to cutting tests on pig hides.

FROZEN POOP KNIVES DON'T WORK

You might not be dumbfounded to discover that human waste isn't the best material for creating knives. However, a team of researchers at Kent State University and the Cleveland Museum of Natural History gave this study their best shot, just to double check. The unique research topic wasn't plucked from thin air, coming from a well known but likely apocryphal tale. In 1998 renowned anthropologist Wade Davis published *Shadows in the Sun*, in which he tells the story of an old Inuit man who refused to join a settlement and remained living alone on the ice. To force his hand, his family reportedly took away his tools in the hope he'd have no choice but to join the settlement. However, the man is said to have forged a knife from his own faeces that was sharp enough to kill and dissect a dog. The researchers wanted to put this story to the test by creating their own version. The resulting knife, however, was unable to cut through pig hide, muscle or tendons. Rather than cutting the flesh, the knife merely melted on contact, leaving faecal streaks behind... seems the story might have been total crap.

Did you know?
Poop is mostly water and bacteria, not digested food

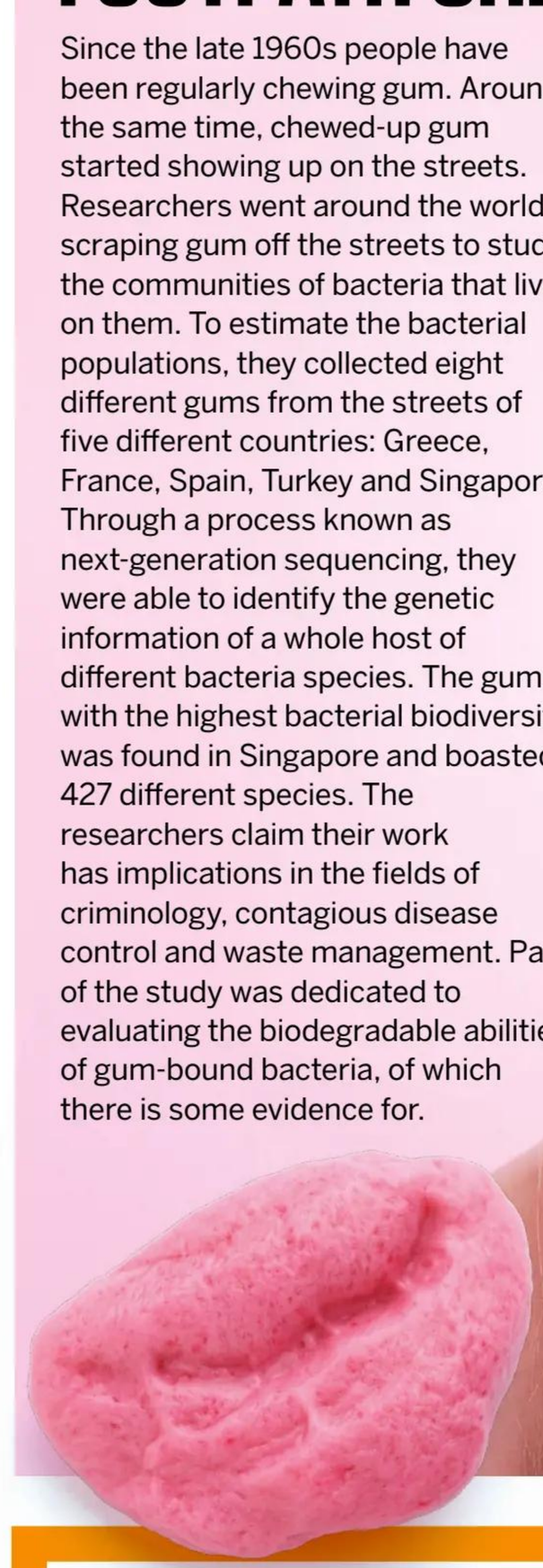
MOSQUITOS DON'T LIKE SKRILLEX

If you're a big fan of a certain kind of electronic dance music, there's a chance you might not be bothered by pesky mosquitoes quite so often. As bloodthirsty insects, mosquitoes transmit deadly diseases such as malaria, yellow fever and the Zika virus. In the fight to curb their appetite for human blood, researchers in Malaysia investigated the potential role that music could play as a deterrent and management tool for yellow fever mosquitoes (*Aedes aegypti*). While playing Skrillex's song *Scary Monsters and Nice Sprites*, researchers observed changes in how mosquitoes foraged, attacked a host and mated. What researchers discovered was that the mosquitoes that were exposed to Skrillex were less likely to feed on a host and visited a host less often when compared to a group of mosquitoes that weren't exposed to the music. Mosquitoes also mated less often while listening to Skrillex.


Skrillex might have won awards, but not the hearts of mosquitoes

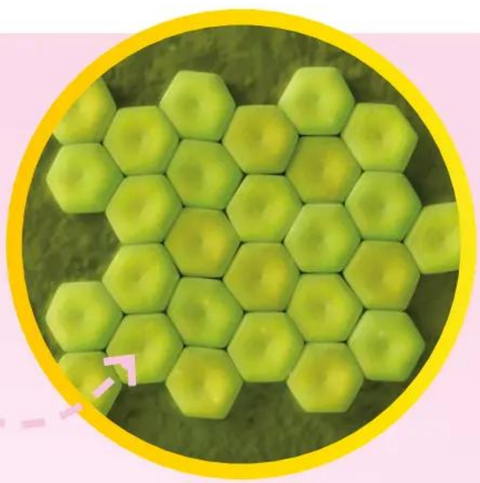
EXPLORING THE BACTERIOME OF FOOTPATH CHEWING GUM

Since the late 1960s people have been regularly chewing gum. Around the same time, chewed-up gum started showing up on the streets. Researchers went around the world scraping gum off the streets to study the communities of bacteria that live on them. To estimate the bacterial populations, they collected eight different gums from the streets of five different countries: Greece, France, Spain, Turkey and Singapore. Through a process known as next-generation sequencing, they were able to identify the genetic information of a whole host of different bacteria species. The gum with the highest bacterial biodiversity was found in Singapore and boasted 427 different species. The researchers claim their work has implications in the fields of criminology, contagious disease control and waste management. Part of the study was dedicated to evaluating the biodegradable abilities of gum-bound bacteria, of which there is some evidence for.



LIVING ON GUM

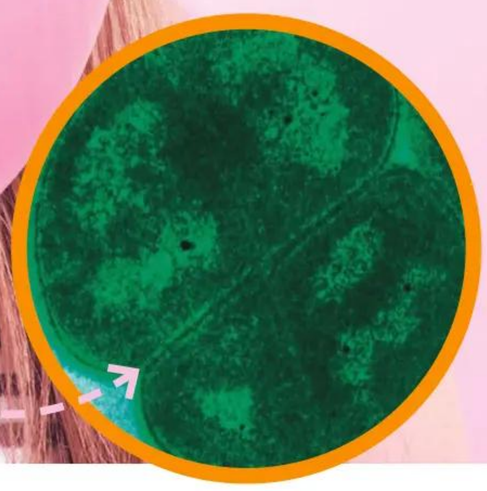
Some of the bacteria that commonly make a home on pavement chewing gum



ACINETOBACTER
This group of bacteria is widespread. They are the most common causes of infections in humans.

PSEUDOMONAS
Common bacteria found in the environment, they can cause illness to those with a weakened immune system.

SPHINGOMONAS
A rod-shaped bacterium that rarely causes infection in humans and is widely found in soil and water.



DEINOCOCCUS
Found in organic material such as sewage and in meat, these hardy bacteria are remarkably resistant to a range of radiations, including ionising and ultraviolet radiation.

THE OPPOSITE-ITCH MIRROR SCRATCH

The next time you get an itch on your arm, run to the mirror and scratch the opposite arm and you might find the itch disappears without being scratched. Researchers at the University of Luebeck in Germany injected 26 volunteers with itch-inducing chemicals into their forearms. They then placed a red dot over the injection site and a corresponding dot on the opposite arm in the same position. A mirror was then placed between the arms, obscuring the participants' views of their itch-induced right arms. Participants were then asked to look at the reflection of the non-itchy left arm in the mirror while a researcher scratched the concealed itchy right arm. Researchers then switched arms, scratching only the non-itchy left arm, and surprising the participants with perceived relief from the itch. There are some practical uses for the discovery, including the development of treatments for chronic itching conditions.

Mirrors can confuse how we locate itches on our bodies

DID YOU KNOW? It takes 1,000 licks to reach the centre of an average-sized lollipop

VANILLA ESSENCE CAN BE EXTRACTED FROM COW PATS

Vanillin is a chemical compound used in medicines, scents and flavourings. Typically, vanillin is extracted from the vanilla bean plant. However, a small portion of the world's vanillin comes from an alternative source, such as lignin, a wood-derived polymer. In 2008, a group of Japanese researchers found an unlikely potential source of vanillin and developed a way to extract it from livestock excrement. To extract the vanillin, the researchers combined one gram of cow pat with water, placed it into a reactor and heated the manure in intervals up to 300 degrees Celsius under high pressure for 60 minutes. During this time, the chemical compositions of the slurry were analysed using a chromatography device, a machine that separates the chemical components of a solution. At temperatures above 200 degrees Celsius, vanillin was detected, amounting to 50 micrograms per gram of cow dung.

Although it's not suitable for food products, cow-dung-derived vanillin could be used in scents

Godzilla stomping through San Francisco in the 2014 motion picture

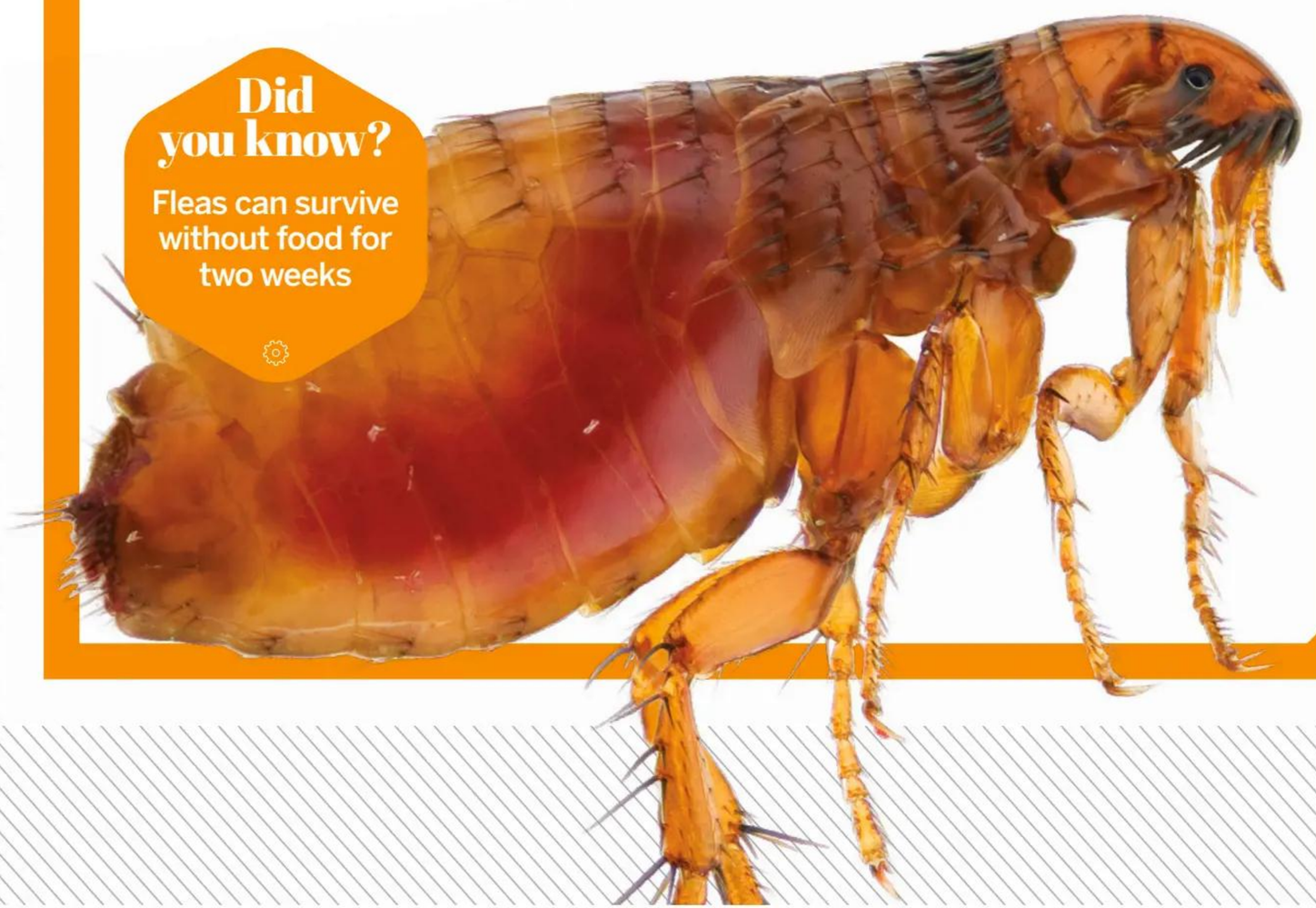
DOG FLEAS JUMP HIGHER THAN CAT FLEAS

Ctenocephalides canis fleas can outjump their feline counterparts

Two different species of fleas can live on our favourite household pets. *Ctenocephalides canis* live on dogs, whereas *Ctenocephalides felis* reside on cats. Researchers at the National Veterinary School of Toulouse, France, wondered which of the two could jump the highest. To find an answer, the researchers put ten of the species' finest athletes to the test in a series of jumping trials that involved jumping out of tubes at different heights. The species that came out on top was the *C. canis* team for the mean highest jump. It was a close call, but the highest jump for *C. felis* was 17 centimetres, whereas the dog fleas outperformed cat fleas by leaping to a mean height of 25 centimetres.

Did you know?

Fleas can survive without food for two weeks



ANXIETY MADE GODZILLA GROW

Godzilla has been stomping on cities since 1954. Over the years there have been many different versions of the giant tyrannical lizard, and each one has grown incrementally. At his inception, Godzilla was 50 metres tall. However, in the latest depiction seen in *Godzilla: King of the Monsters*, he has grown to be 119.8 metres tall. In 2019, researchers at Dartmouth College in New Hampshire published a paper to explain why Godzilla has evolved 30 times faster than any real organism on Earth. Researchers concluded that cultural anxiety was likely the cause of Godzilla's rapid growth in his movies. Using US military spending as a proxy for the nation's anxiety, researchers found strong correlations between spending and the size of Godzilla. "Whether reacting to geopolitical instability, a perceived threat from terrorists or simply fear of 'the other,' many democracies are electing nationalist leaders, strengthening borders and bolstering their military presence around the world," they wrote.

IG NOBEL WINNERS

Meet the Ig Nobel Prize winners of 2022

A month before the prestigious Nobel Prizes are handed out to some of the world's greatest minds and their pioneering work, another less groundbreaking awards ceremony takes place. Founded in 1991 by journal editor Marc Abrahams, the Ig Nobel Prize parodies its namesake with "achievements that make people laugh, then think". Here are the winners of the latest awards, given to STEM research.

HOW CONSTIPATION AFFECTS SCORPION MATING

Biology Prize

Researchers at the Universidade de São Paulo in Brazil took a deep dive into the mating success of male scorpions (*Ananteris balzanii*) that amputate their own tails, the process of which also permanently removes their anus. As a defensive response to predators known as autotomy, many scorpions will purposefully detach their tails in the hope that predators will be satisfied with a portion of the scorpion, allowing the rest of the animal to escape. There is one drawback, however. They also lose the end of their digestive tract and their anus. Without the ability to defecate, tailless scorpions will die from constipation after several months. This still leaves plenty of time to find a mate, if they are quick enough to find them. By looking at the maximum running speed of automised scorpions, researchers found that the loss of a tail and the inability to poop didn't slow scorpions enough to prevent them from finding a mate.

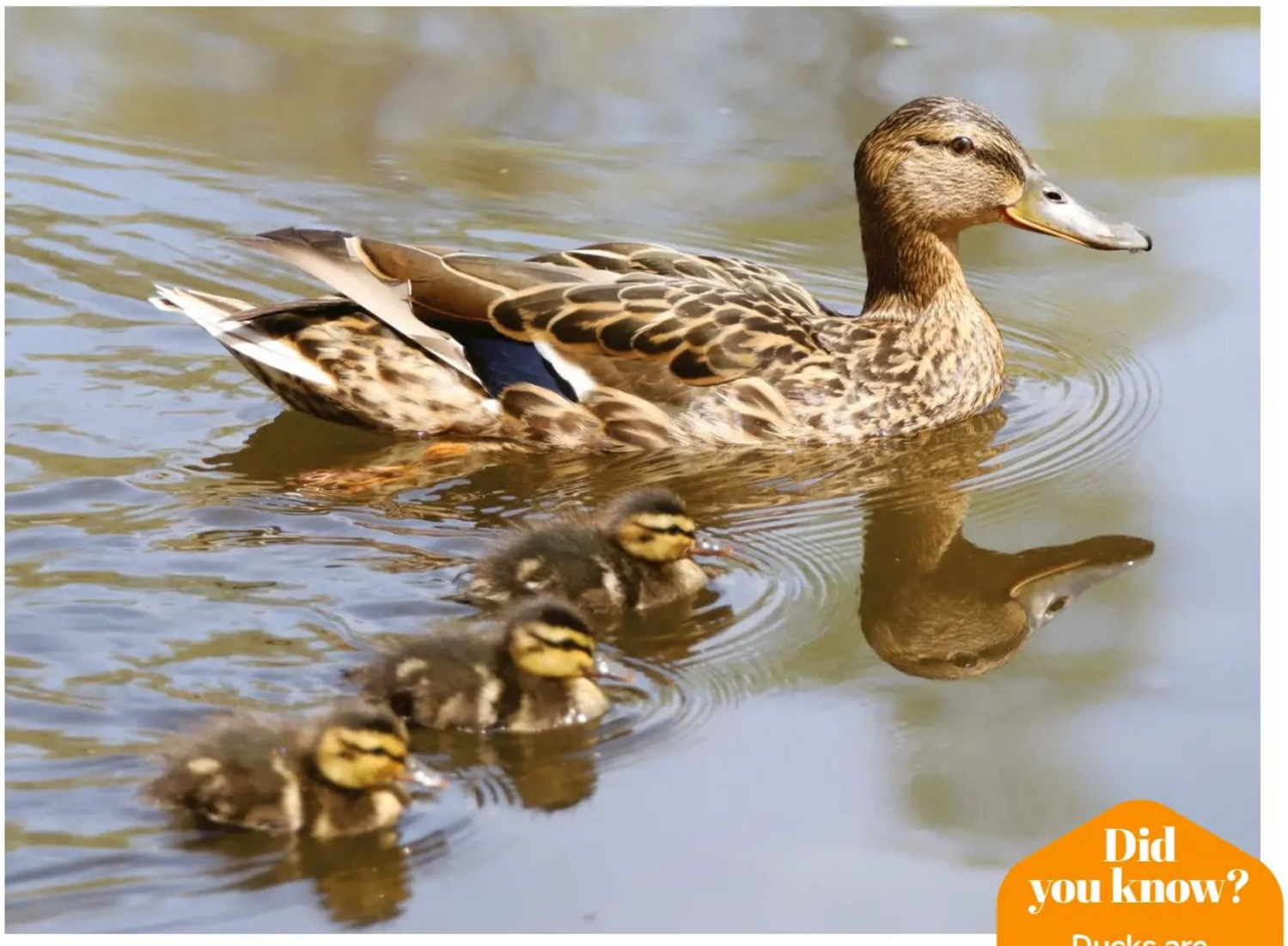
LOVE AT FIRST SIGHT MAKES HEARTS SYNCHRONISE

Applied Cardiology Prize

Scientists in the Netherlands investigating the physiological dynamics of attraction discovered that love is in the air when two hearts beat as one. Heterosexual participants took part in a series of real 'blind dates' in a cabin set up by the researchers. During each date, the participants were fitted with an array of sensors to monitor their bodies' responses to prospective partners. The sensors used included a pair of smart glasses to monitor eye movements, laughing and smiling, as well as a heart rate monitor and an electrodermal sensor to track skin perspiration. Couples were asked to firstly look at each person and rate them on attractiveness, then talk freely for two minutes, followed by another rating, then instructed to look at each other for another two minutes without talking.

Among the couples who found each other attractive, their heart rates synchronised, even to the point that if one person's heart rate increased, the other's sped up to meet it.

DID YOU KNOW? Horses prefer banana-flavoured grain to carrots



HOW DUCKLINGS SWIM IN FORMATION

Physics Prize

Did you know?

Ducks are omnivores, eating fish and insects as well as plants

Researchers at Jiangsu University of Science and Technology in China have answered the age-old question of why ducklings swim in a line. Mother ducks and ducklings are often seen paddling along the river in a single-file line. In 1994, a biologist called Mark Fish suggested this was to conserve energy for the ducklings, which researchers have now confirmed. Ducklings instinctively follow their mother while in the water and position themselves in a line behind her tail. The duckling closest to her begins to ride the waves she creates behind her, reducing the amount of 'water drag' that ducklings have to paddle against to keep up. Moving down the line, each duckling will continue to 'ride the wave', using less energy to move forward the farther down the line they are.

THE BEST WAY TO TURN A DOORKNOB

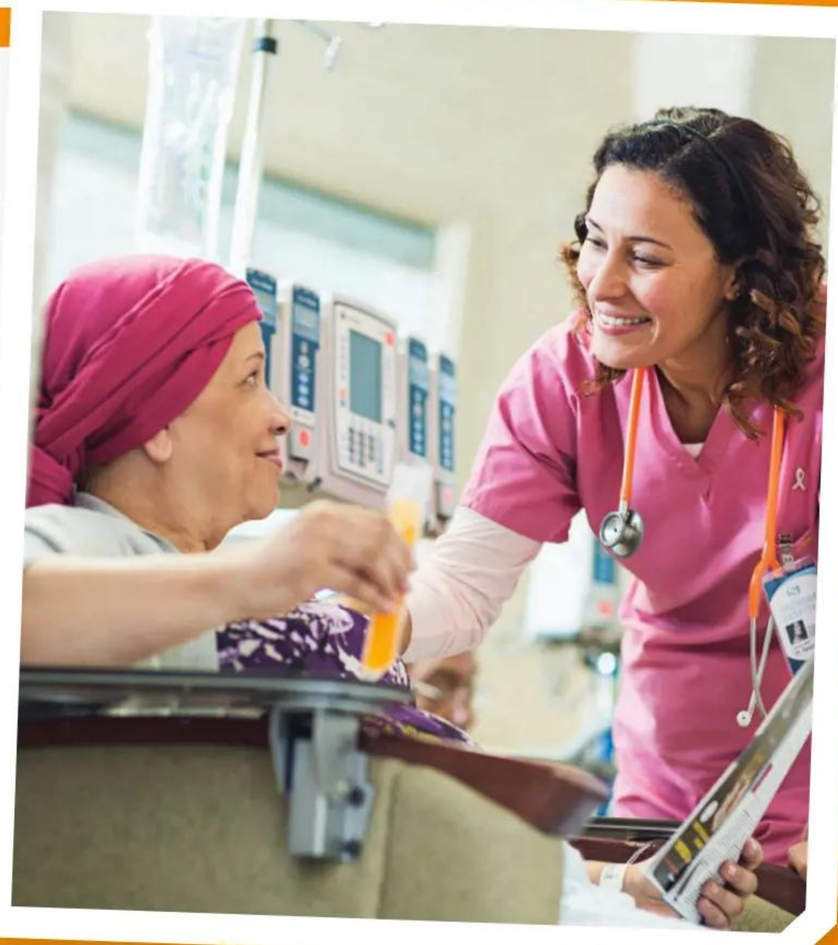
Engineering Prize

Japanese industrial design researchers tested out the most efficient way to turn a doorknob. 32 participants were tasked with turning 47 assorted knobs. The results indicated that for a knob wider than one centimetre, the turner would need to use at least three fingers. For doorknobs that exceed two-and-a-half and five centimetres, the fingers required to turn the knob increases to four and five respectively. It was also identified that the two most used fingers for opening door knobs are the thumb and pointer finger. The researchers simply concluded that the bigger the doorknob, the more fingers you need to grab it. Researchers will use the data from the study to design and manufacture more ergonomic doorknobs, particularly for elderly people and those with physical difficulties.

ICE CREAM'S POSITIVE EFFECTS ON CHEMOTHERAPY

Medicine Prize

A common side effect of chemotherapy and radiotherapy, oral mucositis causes pain and inflammation in the mouth and gut during some treatments. To help prevent mucositis, doctors use ice through cryotherapy. However, researchers at the University of Warsaw in Poland hypothesised that shop-bought ice cream could replace the cryotherapy step during some treatments. Currently, ice cream is used to help treat the symptoms of mucositis, but not as a preventive method. The study called on 74 patients undergoing a particular cancer treatment called melphalan infusion. 52 patients received ice cream cryotherapy during treatment, and the remaining 22 did not. The researchers discovered that only 15 out of 52, or 28.85 per cent, of the patients that received ice cream cryotherapy developed mucositis, whereas 13 of 22, or 59.09 per cent, of those that received none developed the condition.

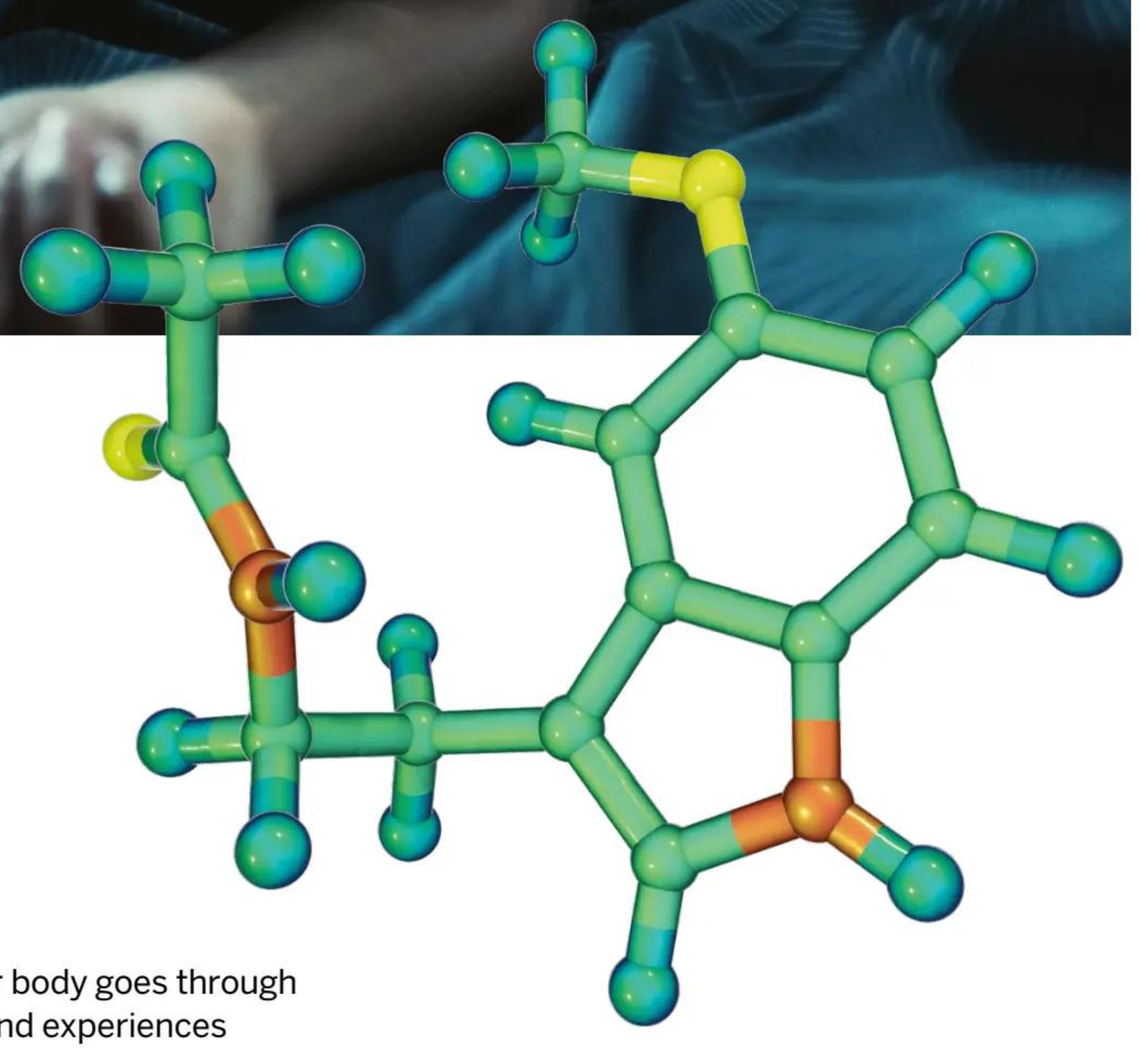


Sleeping helps regenerate damaged cells in your body

WHY DO WE SLEEP?

The science behind your body's ability to power down at night

WORDS **SCOTT DUTFIELD**



The release of a sleep hormone called melatonin helps us drift off each night

Humans spend about a third of their entire lives asleep, but scientists still aren't entirely sure why. The human body is governed by a 24-hour sleep-wake cycle known as circadian rhythm. This internal clock coordinates the body's physical and mental systems as the body transitions from alertness to sleep. It does this by responding to the changes in natural light in your environment. As natural light dims and night falls, the circadian rhythm kicks the body's melatonin production into gear. Melatonin is a hormone that helps the body enter the sleep portion of the sleep-wake cycle. And humans aren't alone in having an internal body clock – countless species, including plants, fish and insects, all experience their own circadian rhythm.

Did you know?

Most adults need seven to nine hours of sleep per night

Once we're asleep, our body goes through four to six sleep cycles and experiences physical changes in temperature, heart rate and brain activity. It's also a regenerative time for the body. During sleep, many different growth hormones are released to repair and replace any cells that have been damaged or that have died.

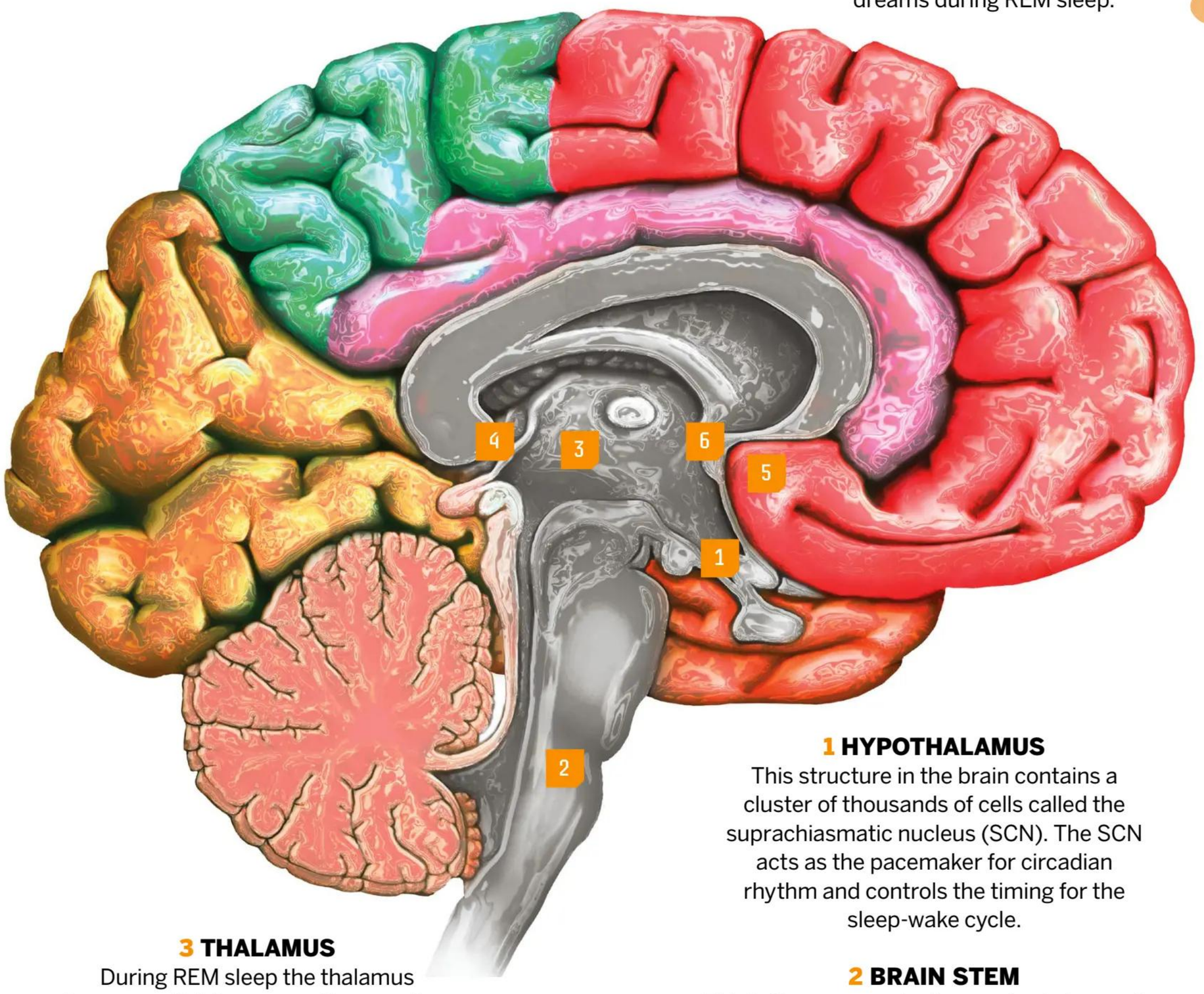
Sleep has also been linked with immune system support and the consolidation of memories. Some studies have even shown that sleep helps the brain flush out some toxins that build up inside it during the daytime.

A lack of sleep can prove fatal. A series of rodent studies conducted in the late 1980s revealed the negative impacts of sleep deprivation. Researchers discovered that all study rats that had been completely deprived of sleep died or were "sacrificed when death seemed imminent" between 11 and 32 days. All other basic needs, such as food and water, were met, and no other physical causes of death were identified. The benefits of getting a good night's sleep are abundant, but the answer to why we and the majority of other animals on Earth evolved wake-sleep cycles remains unclear. Some evolutionary theories suggest that sleep may be a survival function to keep animals out of harm's way during the night, conserve energy and reduce competition for resources.

DID YOU KNOW? The average person spends around 26 years asleep during their lifetime

INSIDE THE SLEEPING MIND

What parts of the brain are involved with sending us to sleep?



4 PINEAL GLAND
The SCN signals the pineal gland to produce melatonin to induce sleeping. This typically occurs in the absence of natural light.

5 BASAL FOREBRAIN
Cells in the basal forebrain release a chemical called adenosine that increases a person's need for sleep, known as a sleep drive.

6 AMYGDALA
An almond-shaped portion of the brain that provides the emotional content of dreams during REM sleep.

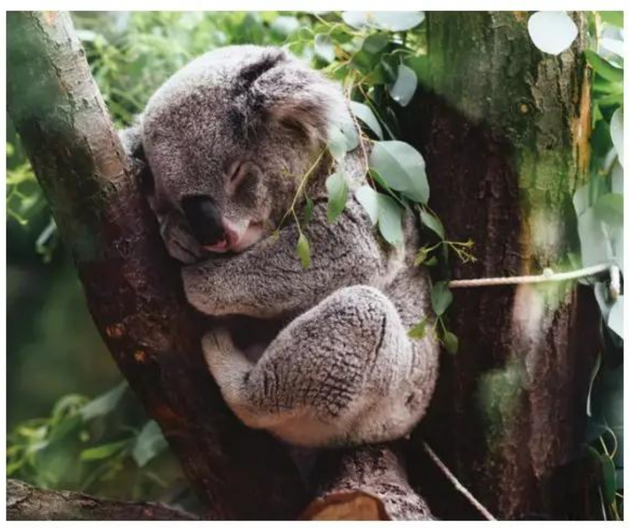
1 HYPOTHALAMUS
This structure in the brain contains a cluster of thousands of cells called the suprachiasmatic nucleus (SCN). The SCN acts as the pacemaker for circadian rhythm and controls the timing for the sleep-wake cycle.

2 BRAIN STEM
This is the communication centre between the hypothalamus and the body's muscles, sending signals for them to relax during sleep.

3 THALAMUS
During REM sleep the thalamus becomes slightly more active, sending signals to the cerebral cortex about images and sounds for dreams.

THE LONGEST SLEEPER

Snoozing more than any other animal on Earth is the koala, which clocks up to 22 hours of sleep per day and uses the remaining few hours to eat eucalyptus leaves. The reason these nocturnal feeders spend so much time asleep is because of their diet. The typically toxic leaves of the eucalyptus tree contain cyanide-like compounds that are fatal for some, but not koalas. Koalas are able to break down the toxic compounds among the 500 grams of leaves they consume per day. However, this comes at a cost. Metabolising the toxic eucalyptus leaves takes up a lot of energy, and they're also very low in nutrients. It makes you wonder why they love them so much.



Koalas snooze away the majority of their day

THE FOUR STAGES OF SLEEP

1 NON-RAPID EYE MOVEMENT (NREM)
The initial transition from consciousness to unconsciousness. During this light sleep stage, muscles relax and heart rate slows down along with breathing and brain waves. This stage can last for up to five minutes.

2 SECOND NREM
Over the next hour or so, sleepers enter a deeper stage in the sleep cycle. Heart rate and breathing patterns are reduced, along with the body's temperature. During this stage, eye movements also cease.

3 THIRD NREM
The deepest sleep stage, all vital signs reach their lowest levels and the muscles are fully relaxed. This stage typically lasts for up to 40 minutes. It's believed that this is the most restorative stage in the sleep cycle.

4 RAPID EYE MOVEMENT (REM)
Brain activity picks up during this stage, but the muscles enter atonia, or temporary paralysis. The eyes also enter a state of rapid movement beneath the eyelids. This is the stage where dreaming typically occurs.

SCIENCE

WHAT MAKES THINGS BIODEGRADABLE?

The chemistry and biology behind the natural breakdown of organic matter

WORDS SCOTT DUTFIELD

Most vegetables will decompose within a month

DID YOU KNOW? Despite being a natural fibre, it takes silk four years to even begin the process of biodegradation

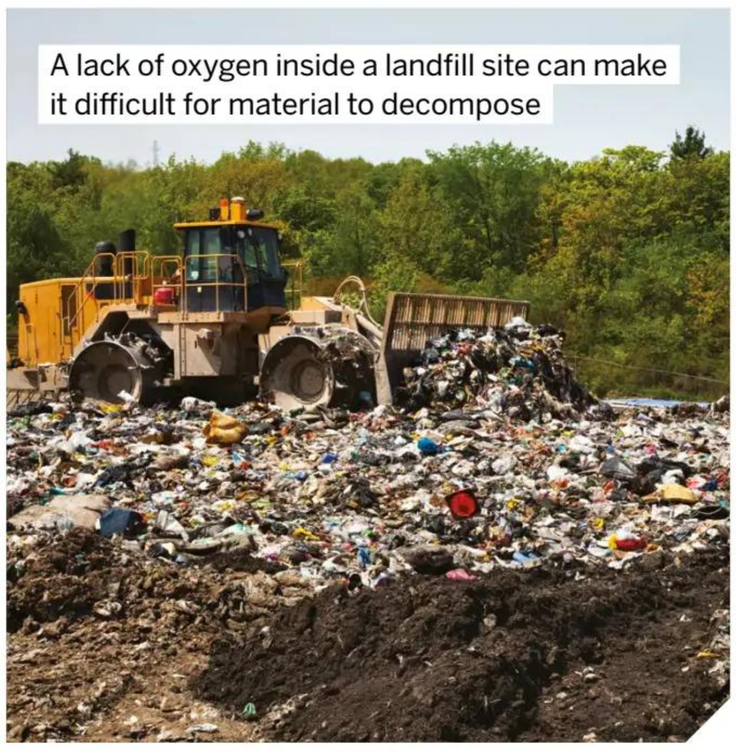
The term 'biodegradable' is often used to describe a material's ability to be broken down naturally by the environment through a process known as biodegradation. During this process, organic matter, such as that found in plants and animals, is torn apart, broken down and digested by fungi and microbes. What remains is a nutrient-rich biomass that fuels the growth of new plants and animals in a repeating and self-sustaining process – it's quite literally the circle of life.

One of the most important aspects of biodegradation is the transfer of carbon. Often referred to simply as the carbon cycle, this natural undertaking helps regulate the planet's temperature, as well as provide food and energy to its inhabitants. During the cycle, carbon is exchanged with oxygen in the atmosphere through plant photosynthesis, which is then stored in plant matter. That carbon is passed on to the animal that eats the plant, then to the animal that eats that animal, and so on, up through the food chain. When plants and animals die, that carbon is returned to the earth through biodegradation, whereby countless microorganisms chow down on organic matter, releasing carbon dioxide into the atmosphere to restart the cycle.

Outside of the natural order of things, the word 'biodegradable' is used as a label to describe products and packaging that are capable of undergoing the process of biodegradation, as opposed to non-biodegradable materials such as plastic, glass and metals. When we toss away our rubbish, it typically ends up in one of three places: an incinerator, landfill site or recycling centre. As the name suggests, incinerators torch waste and convert it into ash and gas, whereas recycling centres seek to transform materials into something useful. Landfill sites, on the other hand, are places where biodegradation can occur. It occurs under one of two conditions: aerobically, with the help of oxygen,

Did you know?

It takes chewing gum five years to biodegrade



A lack of oxygen inside a landfill site can make it difficult for material to decompose

CYCLING CARBON

How biodegradation puts carbon back into the earth to release it again

1 ORGANIC MATERIAL
Organic matter is filled with carbon atoms that are recycled into the environment through biodegradation.

2 DECOMPOSITION
Organic matter decomposes into smaller pieces, either through physical forces such as wind and rain or from living organisms in the soil, such as fungi and invertebrates.

3 DIGESTION
Over time, microbes such as bacteria finish off and metabolise what remains of the organic matter.

4 BYPRODUCTS
Once organic matter has been completely broken down and devoured, what remains are three byproducts: carbon dioxide, water and a carbon-rich substance called biomass.

5 ASSIMILATION
The byproducts of biodegradation are then assimilated back into the environment and used to promote the new growth of organic matter.

Pseudomonas are one of the many groups of bacteria in the environment involved in the biodegradation process

Bioplastics are often used in food packaging and bags

5 MATERIALS THAT ARE BIODEGRADABLE

1 CARDBOARD
Around 72 million tonnes of cardboard is produced each year worldwide. Cardboard is made from natural fibres that take around two months to break down.

2 PAPER
Paper packaging takes around two to six weeks to decompose. A commonly recycled material, the cellulose fibres that make up paper can be recycled five to seven times before they become too weak to form paper.

3 BAMBOO
Made from the fast-growing bamboo plant (*Bambusa vulgaris*), this type of biodegradable material can become compost in up to six months.

4 CORNSTARCH
As a replacement for polystyrene peanuts, cornstarch packing peanuts take around 90 days to decompose and even dissolve in water.

5 ORGANIC FABRIC
Organic materials such as cotton or hemp biodegrade at different rates. Cottons may take several months to decompose, whereas hemp takes only a couple of weeks.

or anaerobically, without oxygen. Because of the compacted structure of a landfill site, biodegradation often occurs anaerobically, the slowest of the two conditions. Some studies have found that food items such as grapes and corn cobs are still recognisable 25 years after entering a landfill. Meanwhile, in an oxygen-rich compostable environment, it would take only weeks for them to decompose.

The phrase biodegradable is often used interchangeably with compostable, but the two are very different. For a product or material to be considered compostable there needs to be no harmful chemicals or substances that release during the process of biodegradation. There are some instances where materials such as plastics are classed as biodegradable, but in the process they release toxic chemicals into the environment.

Each year we produce around 380 million tonnes of non-biodegradable plastics, and only 50 per cent of this is recycled. Traditional petroleum-based plastics are made from oils and gases that form robust molecular chains called polymers. These chains are so robust that they are unable to be broken down through biodegradation alone. However, some biodegradable plastics are more environmentally friendly.

Bioplastics and biodegradable plastics are two different things. Bioplastics are made from natural plant matter that's usually chemically treated to form strong polymer plastics called polylactic acid or polylactide.

Though biodegradable plastics still use raw materials such as oil, different chemicals are added that allow the plastic to 'biodegrade' in the right circumstances, such as in high temperatures and under ultraviolet light. Although biodegradable plastics will break down much faster than the non-biodegradable versions, taking between three and six months, they release harmful chemicals and substances into the environment if they are not disposed of correctly. Bioplastics, on the other hand, release no such toxic chemicals. In the same way that organic materials shed carbon during decomposition, bioplastics also release carbon stored in the plant matter within them. Despite the risk to the environment, the popularity of bioplastics has struggled to match that of non-biodegradable alternatives. In 2022, only 1,142 tonnes of bioplastics were produced globally.

Did you know?
10 million tonnes of plastic reaches the ocean each year

BIODEGRADABLE GLASS

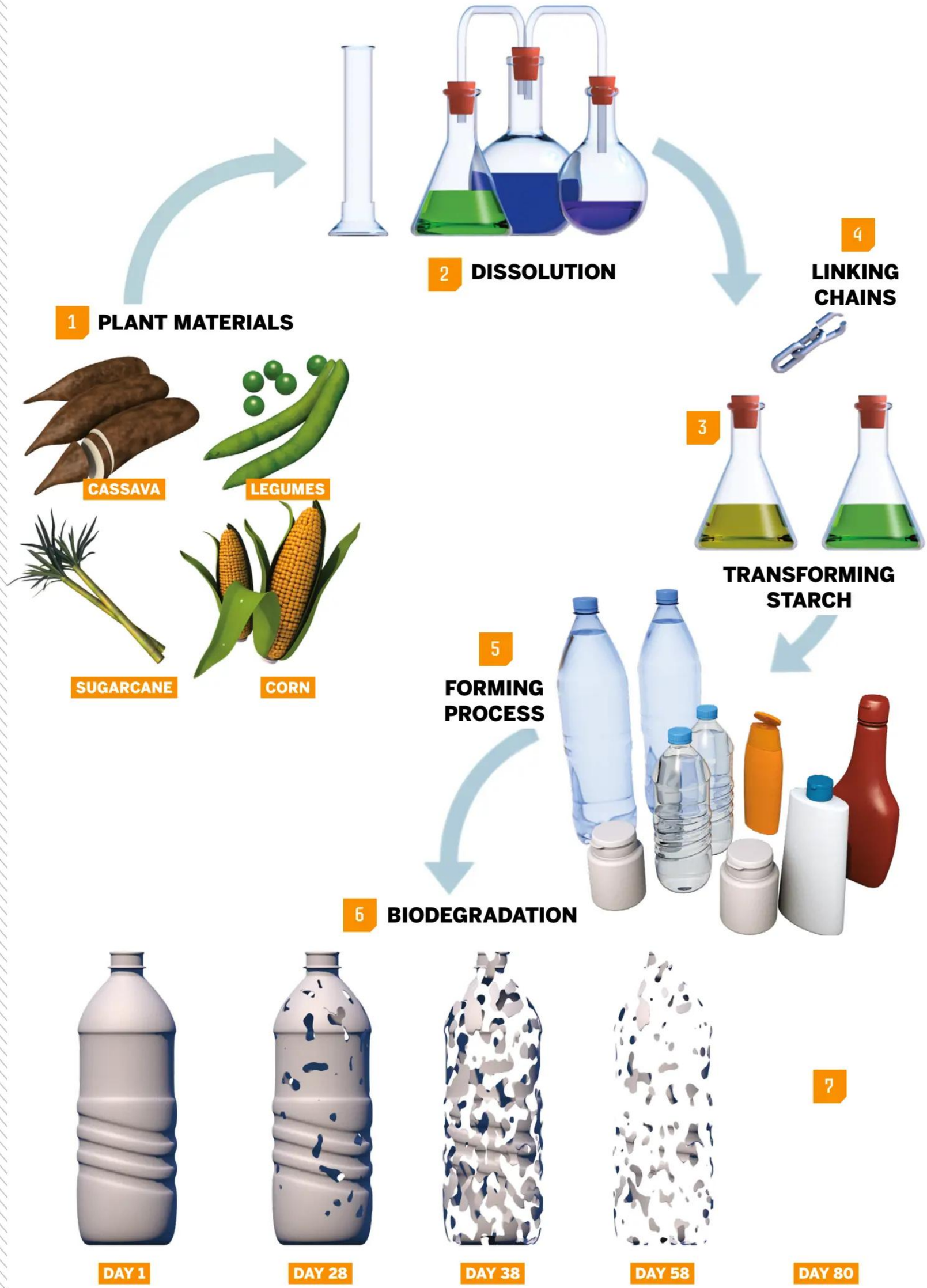
Glass is typically made by heating natural raw materials such as sand or limestone. As a rigid non-biodegradable material, the only way glass can break down in the environment is through physical forces such as wind and water, which can take up to 4,000 years. In March 2023, researchers at the Chinese Academy of Sciences created an experimental glass made from modified amino acids and peptides. In the novel method, amino acids are heated and subjected to a supercooling treatment, then doused in water, rapidly forming a clear, glass-like material. When put to the biodegradability test, researchers discovered that the new glass material was broken down by microbes in soil within around three to seven months. Glass beads were also ingested by mouse subjects without causing harm and appeared to biodegrade in the body, suggesting there's scope for its use in drug delivery.

Advancements in bioglass could one day provide a new delivery system for medicines

DID YOU KNOW? It's estimated that a typical glass bottle will take around a million years to biodegrade

GROWING PLASTIC

How bioplastics are chemically engineered from crop plants



1 PLANT MATERIALS
The building blocks for bioplastics come from natural sources such as corn, legumes, cassava and sugarcane.

2 DISSOLUTION
Plant matter is broken down into starch, proteins and fibres using different acids.

3 TRANSFORMING STARCH
The starch is then separated from the rest of the solution, fermented and turned into lactic acid.

4 LINKING CHAINS
Starch is made up of lots of carbon chains, similar to those found in non-biodegradable plastics.

5 FORMING PROCESS
The long molecule chains of lactic acid are injected into a mould and heated to set them into the desired shape.

6 BIODEGRADATION
Microorganisms are able to break down bioplastics naturally, releasing carbon dioxide, water and biomass in the process.

7 GOING, GOING, GONE
Bioplastics take around 12 weeks to break down.

SCIENCE

POINTLESS BODY PARTS

Discover the anatomical echoes of our evolutionary journey to the modern day

WORDS SCOTT DUTFIELD

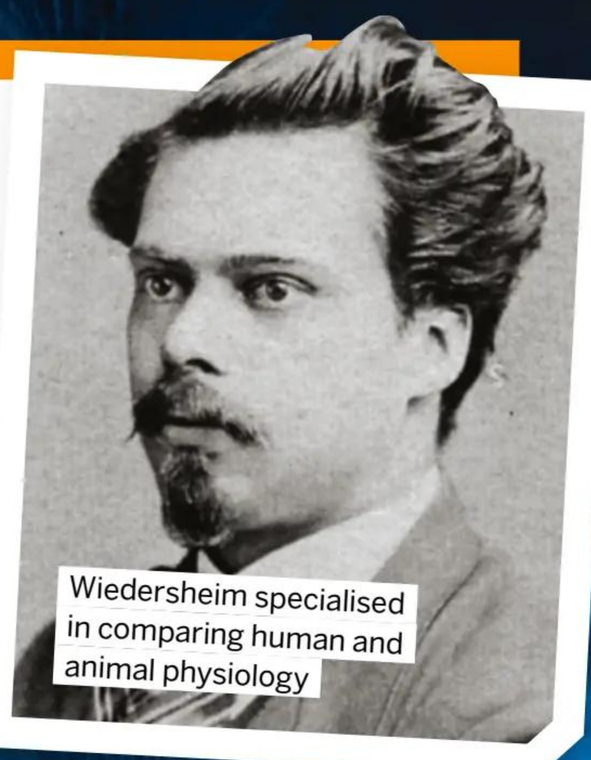
Life on Earth has spent the last 3.7 billion years growing, changing and evolving in response to the changing environment, so it seems likely that there might be some evolutionary leftovers picked up along the way. Vestigial structures are typically organs, tissue or bones that once served a purpose for our ancestors. However, over time their usefulness has waned, such as hind leg bones in whales or wings among flightless birds.

It's largely accepted that an organ or structure that appears to lack a certain function in at least two other closely related species is deemed vestigial. These vestiges aren't always anatomical; they can also be genetic or behavioural. For example, when a baby is born their tiny hands and feet can quickly and robustly grip objects. This is known as the palmar reflex and is thought to be the instinctual leftovers of a time when the babies of our prehistoric ape ancestors had to hold onto their mothers' fur for transport.

Vestigial structures can be useful to scientists tracking the evolutionary journey of some species. As inherited features, vestigial structures allow scientists to piece together the lineage of species by comparing them to functioning anatomy. When they have strong similarities, they're known as homologous structures. Some structures that are now largely redundant for one species were once essential for their ancestors. For example, hoatzin birds (*Opisthocomus hoazin*), found in the tropical forests of South America, are born with tiny claws at the ends of their wings, the only birds in the world to have them. By adulthood the birds lose these claws, but it illustrates their relation to the prehistoric bird archaeopteryx, which used similar claws to capture prey and climb trees.

POINTING OUT THE POINTLESS

The connection between vestigial organs and evolution was first proposed by Charles Darwin in 1859. In both *On the Origin of Species* and *The Descent of Man*, Darwin outlines the concept of rudimentary organs as common features in nature that once served a purpose, but have lost functionality. Inspired by Darwin, German anatomist Robert Wiedersheim penned a list of 86 vestigial organs "which were formerly of greater physiological significance" in his 1893 book *The Structure of Man: An Index to His Past History*. While the functionality of some of the organs on Wiedersheim's list remain in question, others, such as the thymus and the pituitary gland, can be stricken from a list of vestigial organs.



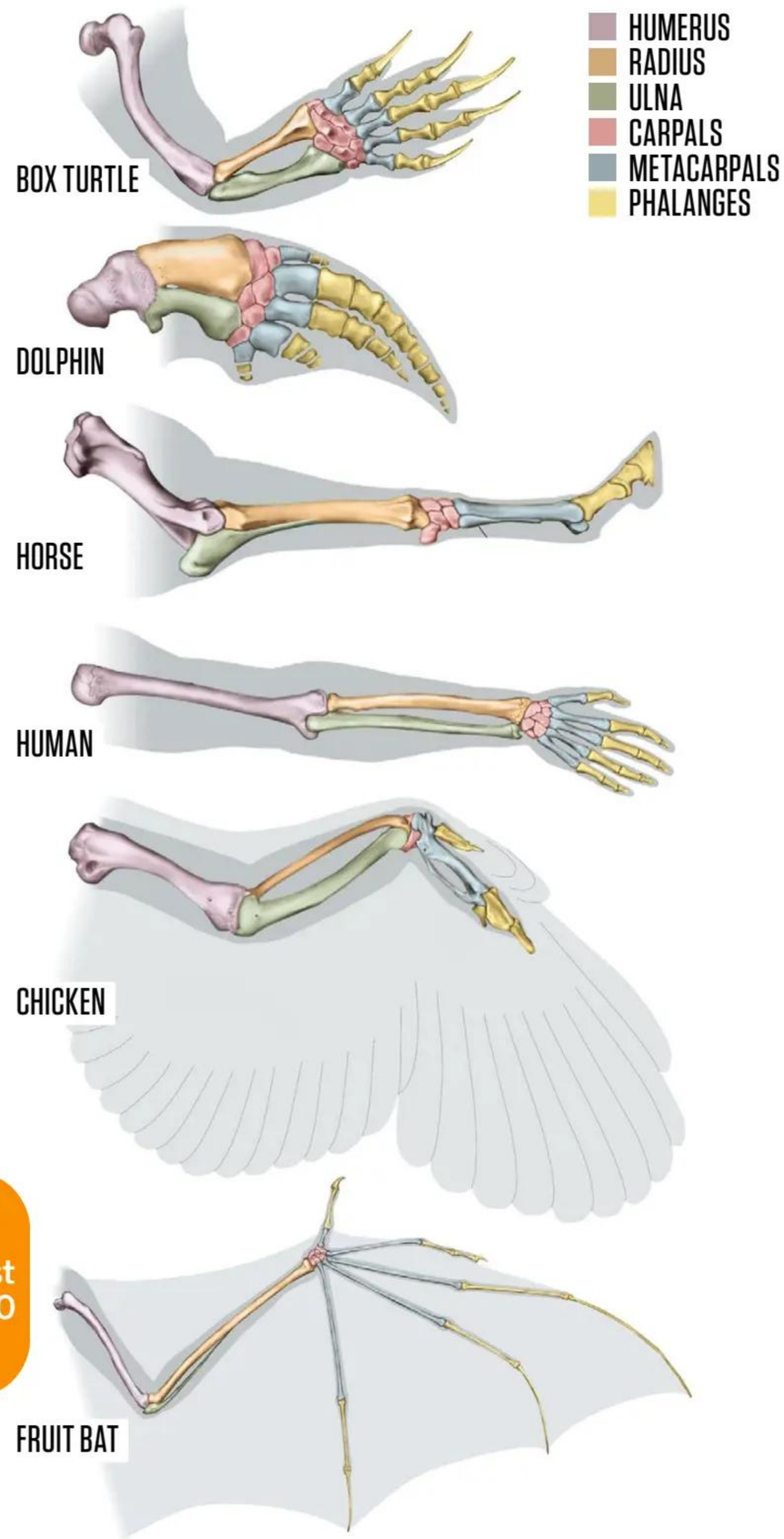
Wiedersheim specialised in comparing human and animal physiology

DID YOU KNOW? The first surgical removal of an appendix was performed in 1735

SAME STRUCTURES, DIFFERENT BEASTS

How homologous structures help link animal relatives

Homologous structures are anatomical similarities between species that share a common ancestor, whereas vestigial structures are similar but have little to no function. The skeletal structure of the forearm is comparable across a range of species, such as turtle, human, dolphin and bat. Here you can see the different individual bones that make up the forelimb and how they have evolved and changed to function for each animal. However, if one of these homologous structures became nonfunctional, it would be deemed vestigial.



Did you know?

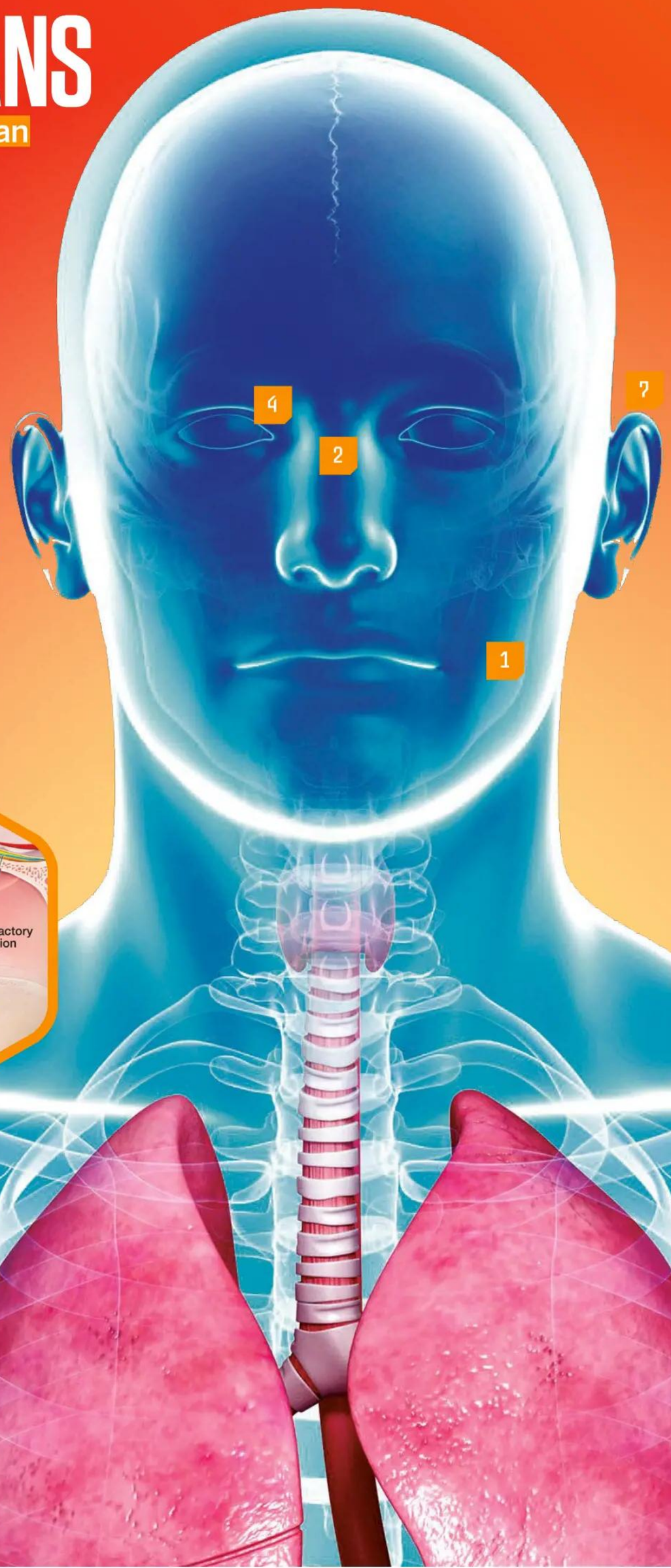
Homo sapiens first appeared 300,000 years ago

REDUNDANT ORGANS

Are these vestigial structures of the human body truly useless?

4 THIRD EYELID

In the corner of your eye is a fold of a clear membrane called the plica semilunaris. In other animals such as birds and cats, this membrane develops into a wiper-like eyelid, called a nictitating membrane, to protect the eye. For us, the plica semilunaris doesn't form a third eyelid, and is therefore thought to be pointless.



7 AURICULAR MUSCLES

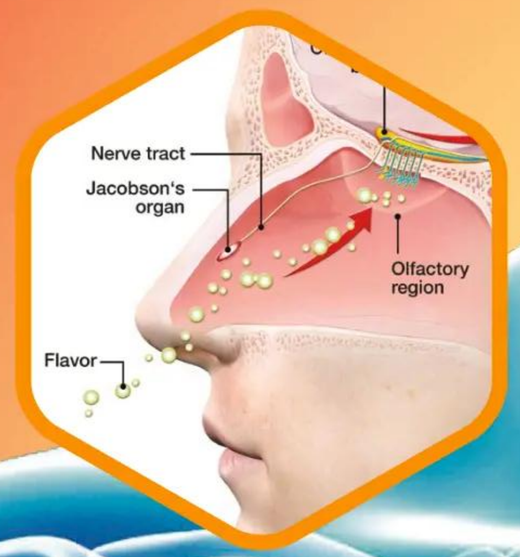
A small portion of people – around ten per cent of the population – have the ability to voluntarily move their ears back and forth by engaging their auricular muscles. In other animals such as dogs and cats, these muscles are used to direct large ears towards the source of a sound. However, humans have generally lost this ability.

1 WISDOM TEETH

Sitting at the back of the jaw are our third molars, also known as wisdom teeth. More often than not, as wisdom teeth grow they become impacted, or they get stuck below the surface of the gums and do not emerge. The human jaw is often too small to accommodate these vestigial teeth. However, some research suggests that childhood diets lack hard raw food, such as nuts and vegetables, that stimulate jaw growth.

2 JACOBSON'S ORGAN

Also known as the vomeronasal organ, for many animals, such as snakes, the Jacobson's organ is a useful tool for detecting pheromones in the air. The tube-shaped organ can be found on the roof of the nasal cavity, but its functionality is highly contested. Some genetic evidence suggests that it's useless in humans and the genes that code for receptor proteins in the organs are mutated and nonfunctional.



Did you know?

The coccyx is around four centimetres long

DID YOU KNOW?

22 per cent of adults are missing one or more of their four wisdom teeth

3

3 GOOSEBUMPS

When you're cold, scared or listening to a great singer, you might experience a strange puckering of the skin called goosebumps. During these moments, tiny muscles beneath the skin known as arrector pili contract, tugging on hair follicles that stand on end. For our furry cousins, making the hair stand up creates air pockets and traps warmth near the body, as well as making them appear larger when threatened. However, humans no longer have enough hair for arrector pili to serve a purpose.

6

6 PALMARIS LONGUS

A strip of muscles that runs between the wrist and the elbow, called the palmaris longus, is a remnant of a time when prehistoric humans used it for support while tree climbing. Although the muscle is involved with the flexibility of the wrist, it's estimated that for around 15 per cent of the population this muscle is missing, without any impedance to their wrist flexibility or movement.

8 THE APPENDIX

Connected to the body's large intestine is a thin tube called the appendix. For decades scientists have debated whether or not this small extension of the digestive system serves a purpose and whether or not it's a vestigial structure. Darwin was the first to suggest its pointlessness, saying it may have once been used to digest robust plants in a similar way to the working appendix of modern-day rabbits. However, scientists have discovered that in humans it may be involved in making and training immune cells for the body's immune response to pathogens.

8

5 THE TAILBONE

Around 25 million years ago, prehistoric humans lost their tails. However, we've retained a small vestigial tailbone called the coccyx. During our development, foetuses grow a tail like many other animals. However, after eight weeks of gestation the tail cells self-destruct and are removed, leaving humans tailless. Nevertheless, the tailbone remains fused to the vertebrae.

5

VESTIGIAL KINGDOM

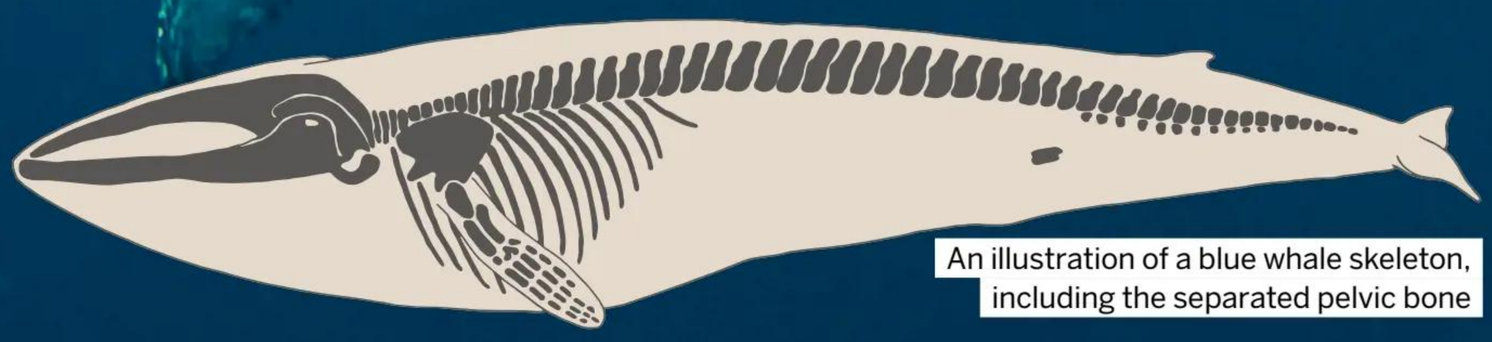
Plants and animals that have clung onto some of their ancestral anatomy

Did you know?

A whale's closest living relative is a hippo

WHALE LEGS

The evolutionary journey of the whale has been long, involving emerging out of the water onto land and then returning to the ocean around 50 million years ago. Common ancestors of cetaceans – the group of animals that includes whales, dolphins and porpoises – were amphibious creatures that walked over land and into the ocean on four legs. Over millions of years those legs evolved into fins, leading to the existence of modern-day whales. However, a piece of their land-dwelling past remains in their bodies – a pelvic bone. The free-floating, shrunken bone isn't attached to the whale's vertebrae and sits among muscles. Although these bones no longer form part of a leg, they may serve some other purpose. Some studies suggest that because the pelvic bone is attached to muscles attached to whale genitalia, it may support reproductive success.



An illustration of a blue whale skeleton, including the separated pelvic bone

PRETTY BUT POINTLESS

During spring you might see the vibrant-yellow petals of dandelion plants (*Taraxacum officinale*) sprouting up around gardens and fields. Unlike other plants that have evolved bright and beautiful petals to attract pollinators to reproduce, dandelions are able to do it alone. Through a process called apomixis, dandelions can reproduce asexually, creating seeds that are genetic clones of themselves. So although dandelions grow petals, pollinators aren't required for a dandelion to grow seeds, but dandelions still supply them with food through nectar.

SLUG SHELLS

Around 150 million years ago, land snails evolved from their aquatic ancestors, and shortly after diverged into land-dwelling snails and the shell-less slug. However, slugs aren't technically without a shell. For snails to build their shell homes, they take in calcium carbonate from their environment. Then an organ called the mantle crystallises the carbonate and makes a hard shell. Slugs do have a vestigial mantle. However, it does not produce the spiralling shell seen on the backs of snails. Instead it makes a tiny shell beneath the skin of slugs.

Slugs do have shells, they're just hidden from view

DID YOU KNOW? Ostriches descend from the flightless elephant bird, which was three metres tall

SEEING WITHOUT EYES

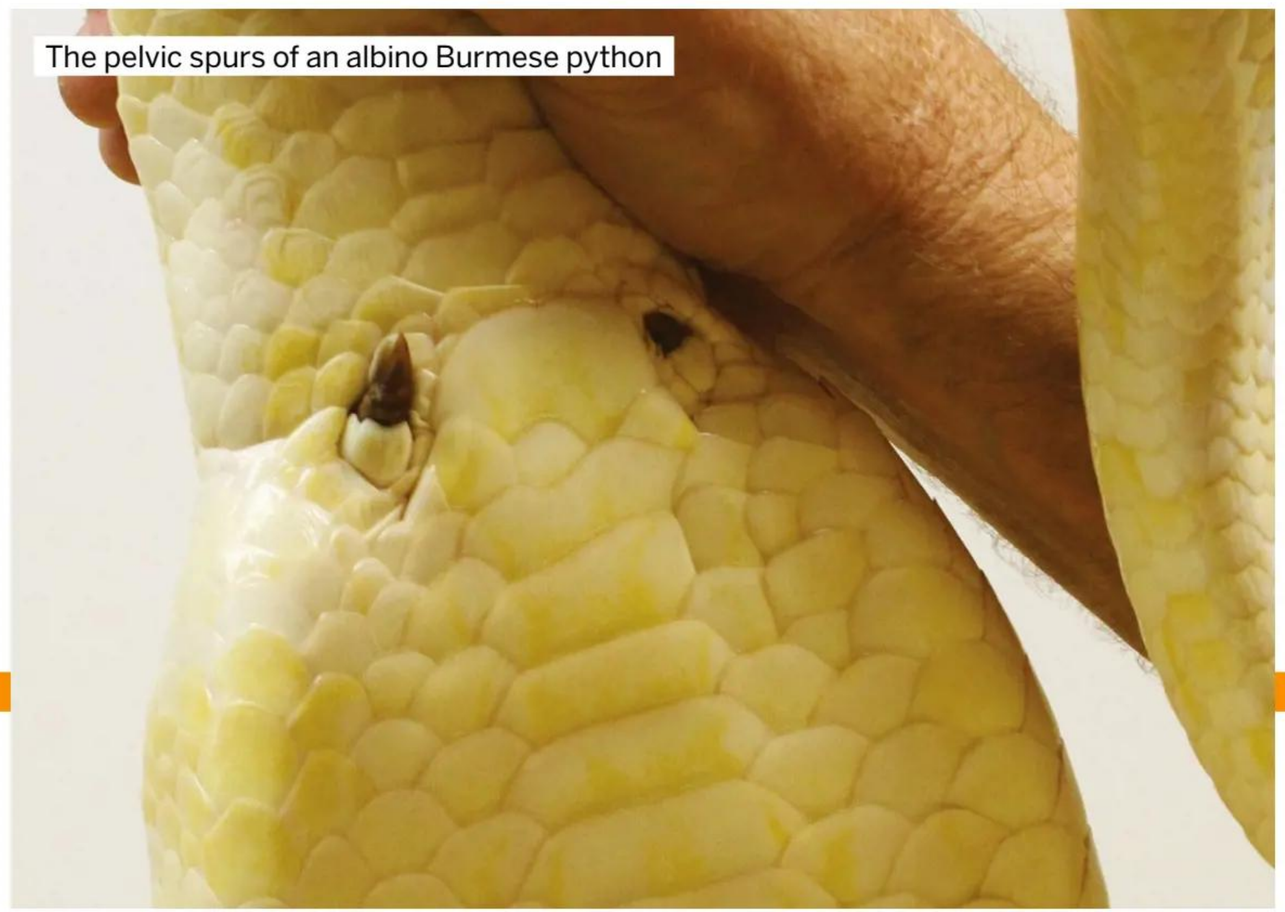
Blind cave fish (*Astyanax mexicanus*) are found off the coast of Mexico, but look a little different to their surface-swimming cousins, mainly because they are missing a pair of eyes. When you're swimming at the bottom of a pitch-black cave, a good pair of eyes isn't exactly a necessity, so these blind cave fish got rid of them.

During the first 24 hours of embryonic development, these fish do grow a rudimentary eye. However, shortly after the underdeveloped eye is cut off from the blood supply and a layer of skin forms over it. Researchers have discovered that a slight mutation in the cave-dwelling fish has caused the formation of the vestigial eye structure hidden beneath the skin. Instead of relying on their vision, cave fish pucker their mouths and release bursts of suction to monitor changes in water pressure in a similar way to how bats detect sound waves for echolocation.

SNAKE LEGS

During the Cretaceous period, around 100 million years ago, snakes lost their legs and evolved their serpentine method of movement. It's thought that the lizard ancestors of snakes born with smaller legs were able to navigate different types of terrain and enter new areas that others couldn't. Over time these ever-decreasing leg lengths led to their complete removal.

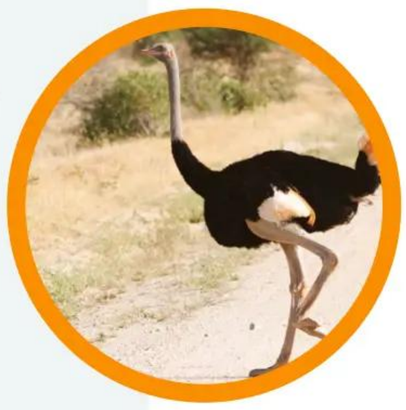
However, some snakes have kept small pieces of hind leg bones from their lizard ancestors. Pythons and boa constrictors have tiny bumps on the sides of their pelvis, called pelvic spurs, where the legs would have once developed. These vestigial structures aren't connected to the snakes' vertebrae and instead sit between the muscle mass of the animal.



The pelvic spurs of an albino Burmese python

5 FACTS FLIGHTLESS BIRDS

1 OSTRICH (*STRUTHIO CAMELUS*)



Although their wings can no longer fly, ostriches have repurposed them for balance and navigation when they run at speeds of up to 43 miles per hour. Males also use their impressive wings during courtship displays to attract a mate.

2 KIWI (*APTERYX AUSTRALIS*)

Instead of the light, hollow wings of other birds, kiwis have tiny marrow-filled wings that are around three centimetres long and are hidden beneath their fur-like feathers. DNA evidence suggests kiwis descended from prehistoric birds that flew from Madagascar to New Zealand.

3 STEAMER DUCK (*TACHYERES*)

Out of the world's four species of steamer ducks, three are flightless. During the Late Pleistocene epoch, the flightless species diverged from their flying relatives. Some of the species found in South America have been seen using their wings like paddles in the water.

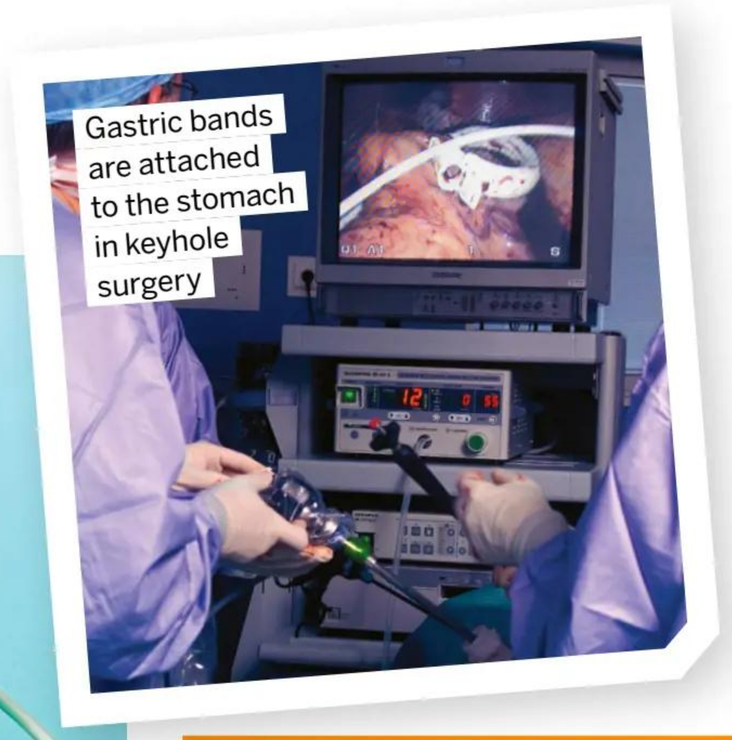
4 KĀKĀPŌ (*STRIGOPS HABROPTILUS*)

Native to New Zealand, these flightless parrots use their short wings for balance as they climb and leap from trees in the forest. Due to their inability to fly, their feathers have also become soft and are unable to sustain flight.

5 CASSOWARY (*CASUARIUS*)

Although cassowary species can't fly, they use their wings to help them navigate through the forest. At the ends of their tiny wings are long, bare quills that they use to move obstacles, such as tough thorns and branches, out of their way.

HOW DO GASTRIC BANDS WORK?


Gastric bands are attached to the stomach in keyhole surgery

In this weight-loss procedure, surgeons tighten the stomach with a ring

WORDS **AILSA HARVEY**

There are more than a billion people in the world who are obese. To be classed as obese, a person has to have a body mass index (BMI) of 30 or higher. This is a measurement calculated using height and weight, and isn't always applicable to athletes or people with large muscle mass. Obesity increases the chances of developing cancer, diabetes, heart disease and other deadly diseases, and this is the main reason that many people seek a quick solution to lower their BMI.

There are many diet, exercise and other lifestyle changes that can be made to lose weight naturally, but these require commitment and consistency over a long period of time, and aren't always practicable.

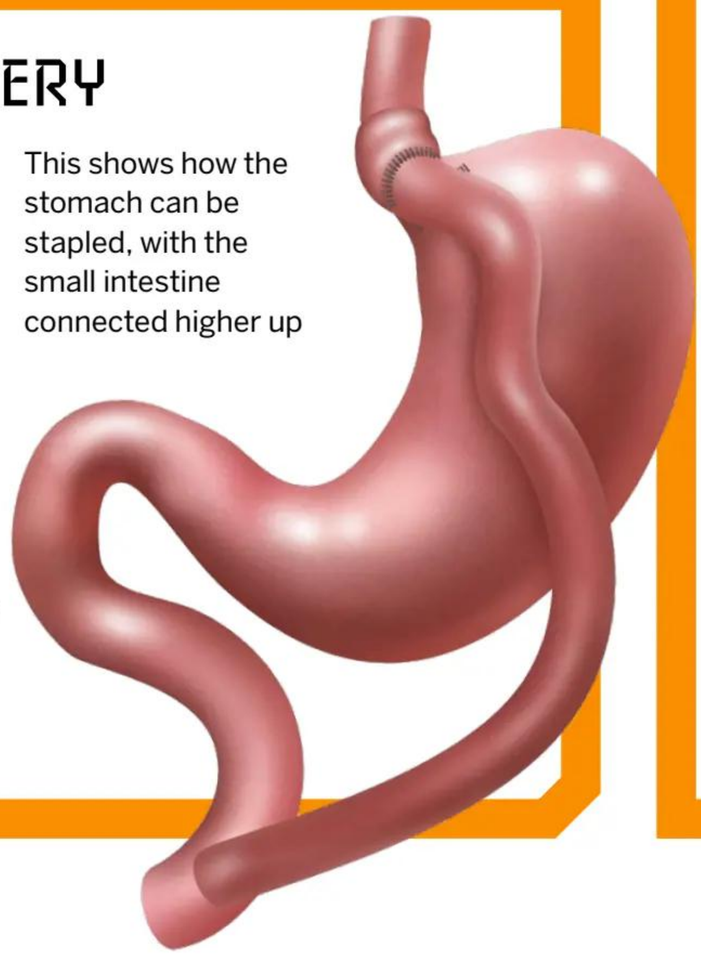
If losing weight by making lifestyle changes proves unsuccessful, some people opt for weight-loss surgery instead. Gastric banding is one form of weight-loss surgery, and works by physically reducing how much a person can eat by clasping the top of the stomach. It means that food and drink fill up the stomach more quickly. For this reason, people who undergo gastric band surgery need to eat slowly to learn the stomach's new limits and prevent it from overflowing.

Did you know?

In six months, gastric band patients lose up to 50 per cent of weight

TYPES OF WEIGHT-LOSS SURGERY

Gastric banding isn't the only way in which obese patients can reduce their weight rapidly. Another similar surgery is the gastric bypass, which skips the stomach stage of digestion completely. This process, called malabsorption, involves a surgeon cutting or stapling the top of the stomach to prevent food from entering. Instead, a small pouch is made at the top of the stomach. The surgeon then connects the small intestine directly to this pouch. The gastric bypass method sees results very quickly, but is more difficult to reverse. The third weight-loss surgery is a sleeve gastrectomy. For this procedure, around 80 per cent of the stomach is stapled together. This stops one side of the stomach from taking part in digestion and is a non-reversible procedure.


This shows how the stomach can be stapled, with the small intestine connected higher up

WHAT ARE THE RISKS?

Gastric bands can help people who have reached an unhealthy weight to lower it and improve their health. However, these devices make the body work in an unnatural way and are only recommended by doctors when patients have a high body mass index of at least 40. They must also have tried other natural weight-loss options, like exercise and dieting.

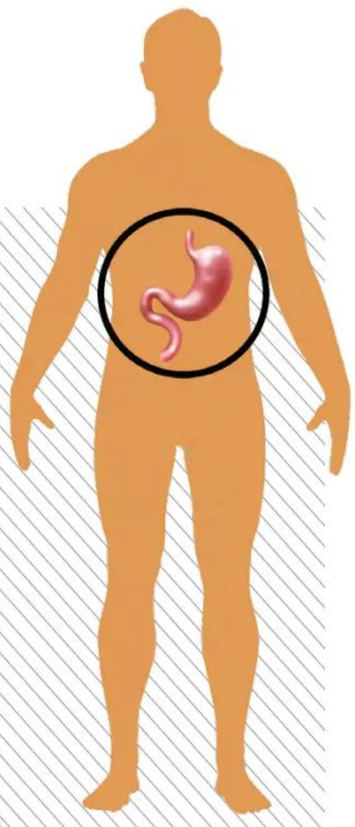
In some cases, the gastric band can move over time. If the band moves too far up or down the stomach, patients can suffer from heartburn, feeling nauseous and vomiting. Between 15 and 60 per cent of people who have had a gastric band fitted need to have a follow-up operation to put the band back in place. Another risk factor is the small chance of the gut being blocked. A gastric band can reduce the blood flow to the stomach and small intestine, making them narrower and increasing the chance of blockages. Lastly, due to the limited absorption of nutrients into the body that comes from restricting part of the stomach, gastric band wearers should put in the effort to follow a balanced, nutrient-rich diet. Without including all the nutrients in their limited consumption, patients risk suffering from malnutrition.

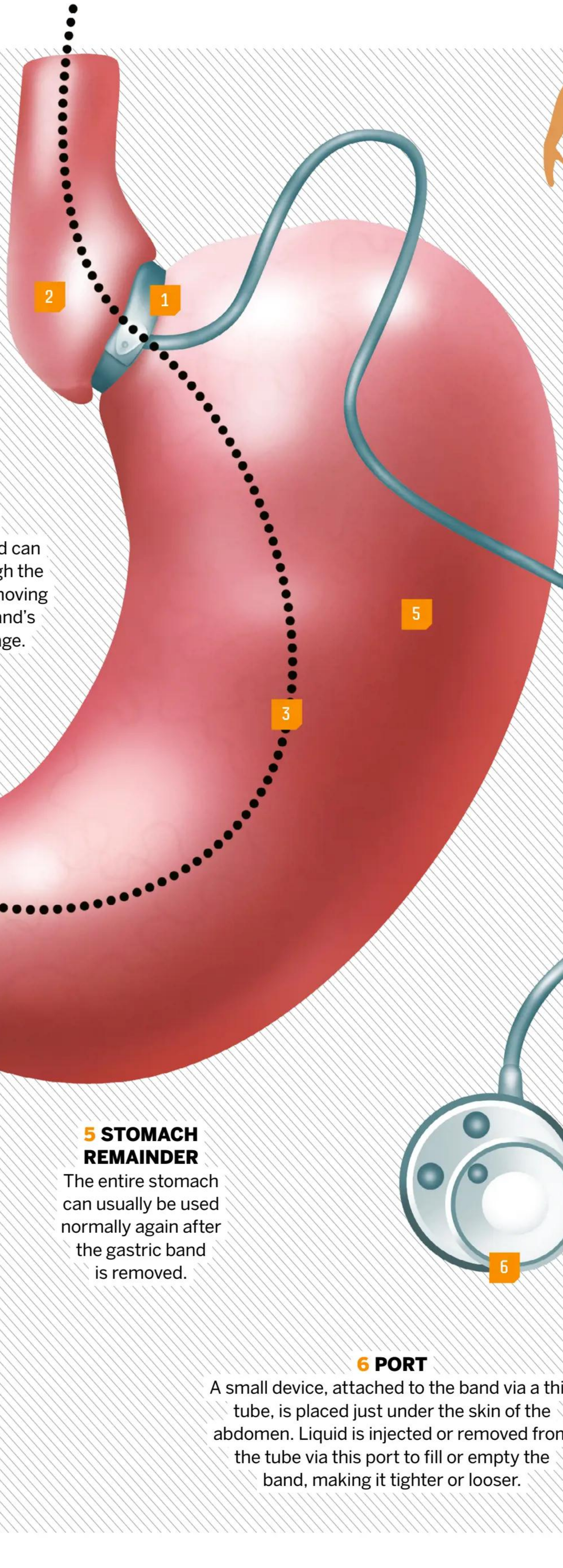

Doctors may suggest a gastric band if your BMI is between 35 and 40 but you also have a serious condition that the procedure could help with

DID YOU KNOW? 650 million adults, 340 million adolescents and 39 million children are obese worldwide

A SMALLER STOMACH

What does the stomach look like after gastric band surgery?





1 GASTRIC BAND
A silicone rubber band is tightened around the top of the stomach.

2 STOMACH POUCH
The top section of the stomach fills up quickly when eating, creating the sensation of feeling full after a smaller portion of food.

3 FOOD
Consumed food can still pass through the stomach after moving through the band's narrow passage.

4 DIGESTIVE JUICES
The lower section of the stomach still secretes digestive juices, helping break down the food after it passes through the band.

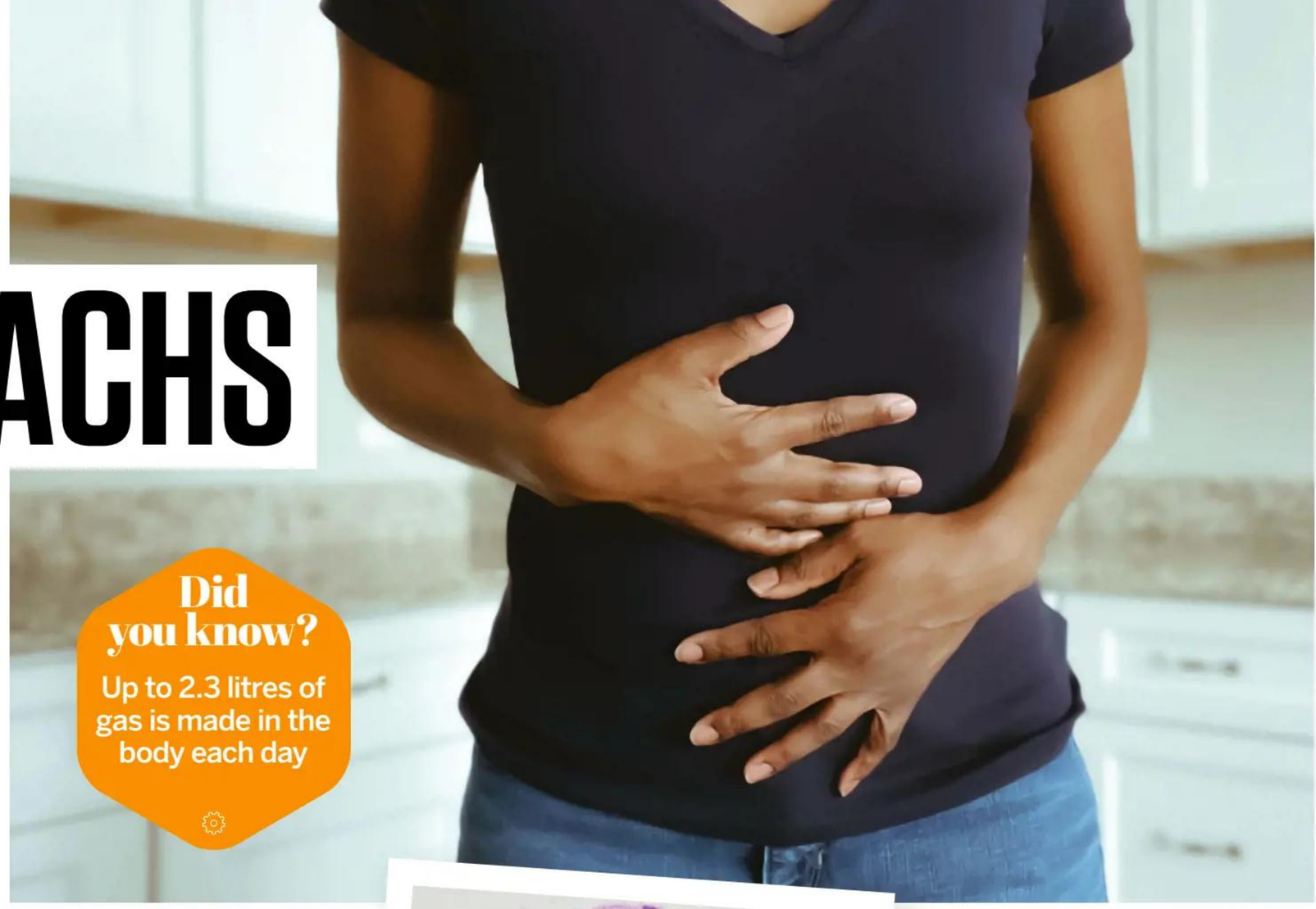
5 STOMACH REMAINDER
The entire stomach can usually be used normally again after the gastric band is removed.

6 PORT
A small device, attached to the band via a thin tube, is placed just under the skin of the abdomen. Liquid is injected or removed from the tube via this port to fill or empty the band, making it tighter or looser.

WHY STOMACHS RUMBLE

What's your gut trying to tell you with its growling and grumbling?

WORDS **AILSA HARVEY**



Did you know?

Up to 2.3 litres of gas is made in the body each day

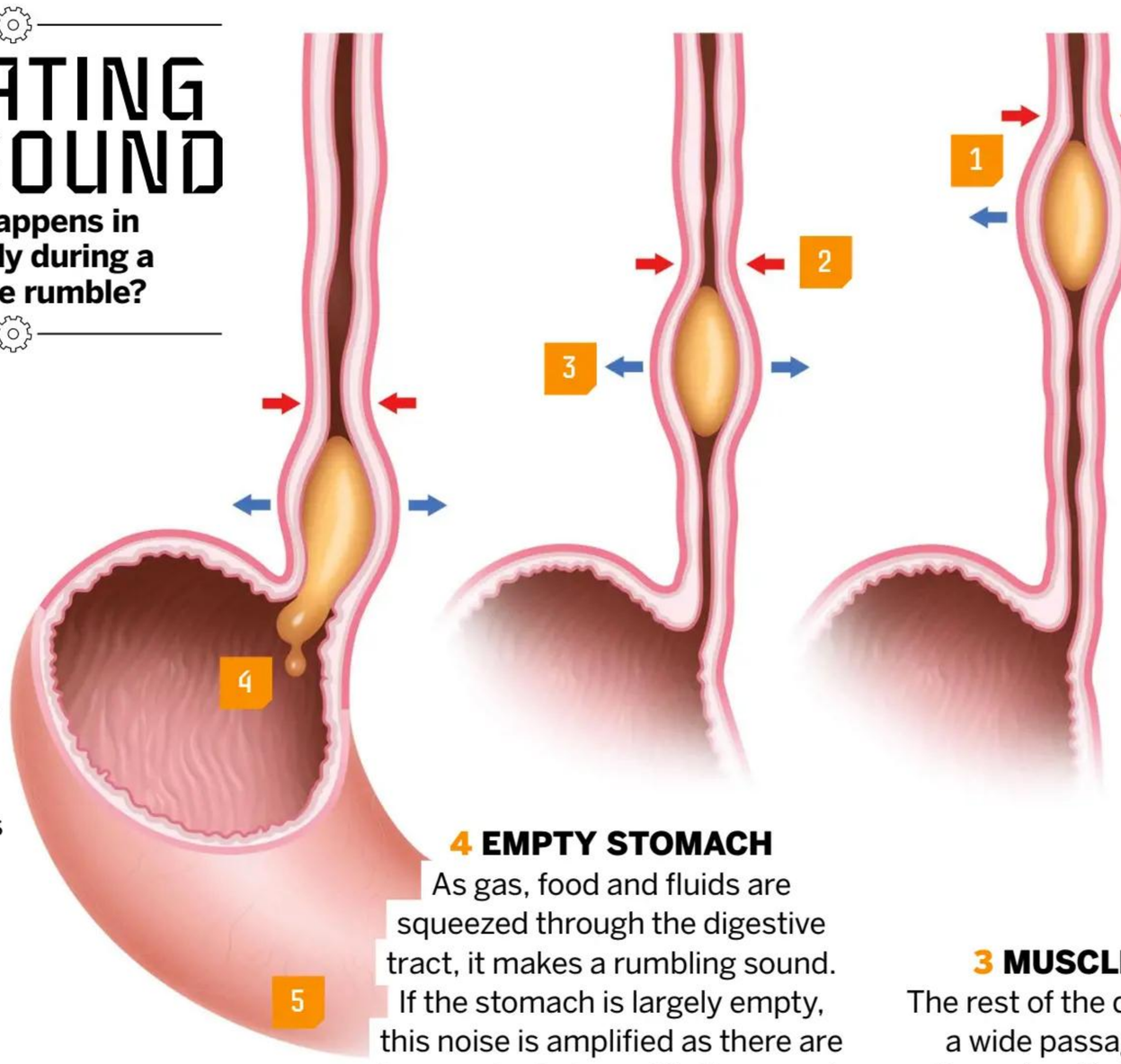
Most of the time your stomach doesn't make its presence known. But every now and then, especially if you're sitting in a quiet room, it might begin talking to you. This could be in the form of a rumble, gurgle or tiny roar. So what is this organ trying to tell you? The technical term for these abdominal noises is borborygmi. Most of the time, borborygmi are caused by a combination of an empty stomach and activity in the digestive system. This means that the noise can serve as a beneficial reminder that you haven't eaten much food in a while.

However, stomach rumbles aren't exclusively caused by hunger. When they occur without any discomfort or pain, it's just a natural noise made by your body processing its contents. If this changes and growls are coupled with discomfort, your gut is communicating that something isn't right. This could be an intolerance to a certain food, while the addition of bloating could indicate indigestion or, when occurring regularly, irritable bowel syndrome. If discomfort continues in the abdomen, you should consult a doctor to find out its cause and how to treat it.

This smooth layer of muscle (dark pink) in the small intestine contracts to push food through

CREATING THE SOUND

What happens in your body during a digestive rumble?



1 FOOD'S JOURNEY
As soon as you swallow food or fluid, your digestive tract begins a process called peristalsis to push it through the body.

2 INVOLUNTARY CONTRACTIONS
Circular muscles in the oesophagus or intestine contract behind the food, controlling its movement through the digestive tract.

3 MUSCLE RELAXATION
The rest of the digestive tract remains a wide passage for food to travel through, with the muscles relaxed.

4 EMPTY STOMACH
As gas, food and fluids are squeezed through the digestive tract, it makes a rumbling sound. If the stomach is largely empty, this noise is amplified as there are less contents to muffle the sound.

5 VOLUME DIFFERENCE
Rumbling doesn't just occur in the stomach, but throughout the whole digestive tract. In narrower sections there is less space for echoing sound waves.

5 WAYS TO REDUCE RUMBLING

1 DE-STRESS
If you are stressed about something, your body releases hormones that increase the muscle contractions of the digestive tract.

2 EAT SOME FOOD
As the most common reason for a rumbling sound is an empty stomach, listen to your body's call for food.

3 SIP WATER
Drinking water helps your body break down food, reducing the gas created during digestion.

4 EAT SLOWER
If you eat too quickly, you'll swallow more air with your food. Taking your time can prevent gas buildup.

5 REDUCE GASSY FOODS
Consuming high-fibre foods such as beans or carbonated drinks increases your chances of a rumbling stomach by producing gas.

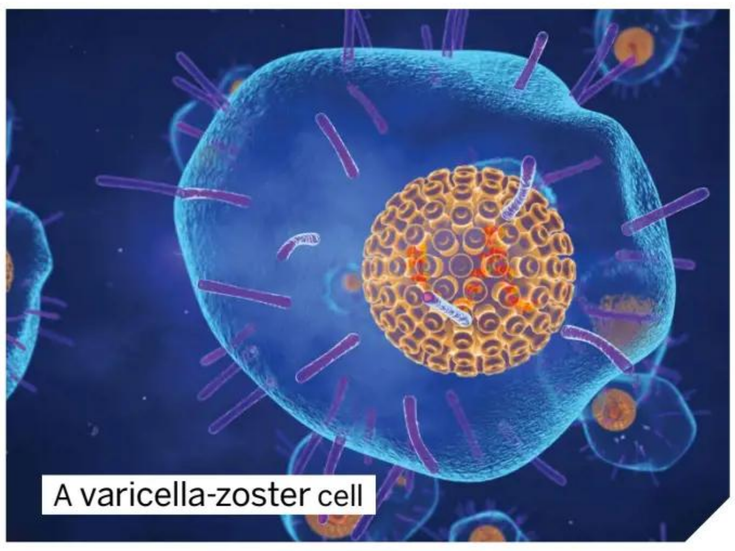
WHAT IS SHINGLES?

This painful rash is the result of a lingering virus

WORDS **AILSA HARVEY**

Shingles is a viral infection that can emerge anywhere on the body in the form of a painful, blistering rash. Usually, the rash forms as a stripe that wraps around one side of the body. What makes this viral infection different from many others that you may have experienced is that you don't contract the virus immediately prior to getting shingles symptoms. Instead, it has been living inside you, and could have been there for many decades. This is because shingles is a result of the varicella-zoster virus – the same one that causes chickenpox.

Rather than completely flushing the virus from your body when you overcome chickenpox, some of it stays in your nerves, dormant and unproblematic. When your body is busy fighting another illness or condition, or as your immune system weakens with age, the virus is more likely to reactivate and resurface. The varicella-zoster virus travels along nerve paths to reach the skin and create the nasty rash we call shingles.



A varicella-zoster cell

The shingles rash commonly stretches around one side of the torso

IS SHINGLES CONTAGIOUS?

The varicella-zoster virus is highly contagious between people who have not been exposed to it yet and is spread through direct contact with the fluid from the rash's blisters. However, if you have already contracted chickenpox, you won't get symptoms from being in contact with someone with shingles. Those who contract the virus for the first time from someone with shingles won't catch shingles, but will flare up with chickenpox instead.

Many purposely expose their children to the varicella-zoster virus, and even host 'chickenpox parties' when a child has the symptoms so that others can catch it too. This is because the symptoms of the virus are usually much more mild when exposed at a young age, and you can only contract the virus in its chickenpox form once.

SHINGLES IN THE NERVES

How this virus makes a comeback

1 CHICKENPOX EXPOSURE
Most people are exposed to chickenpox at a young age, causing an itchy rash across the whole body.

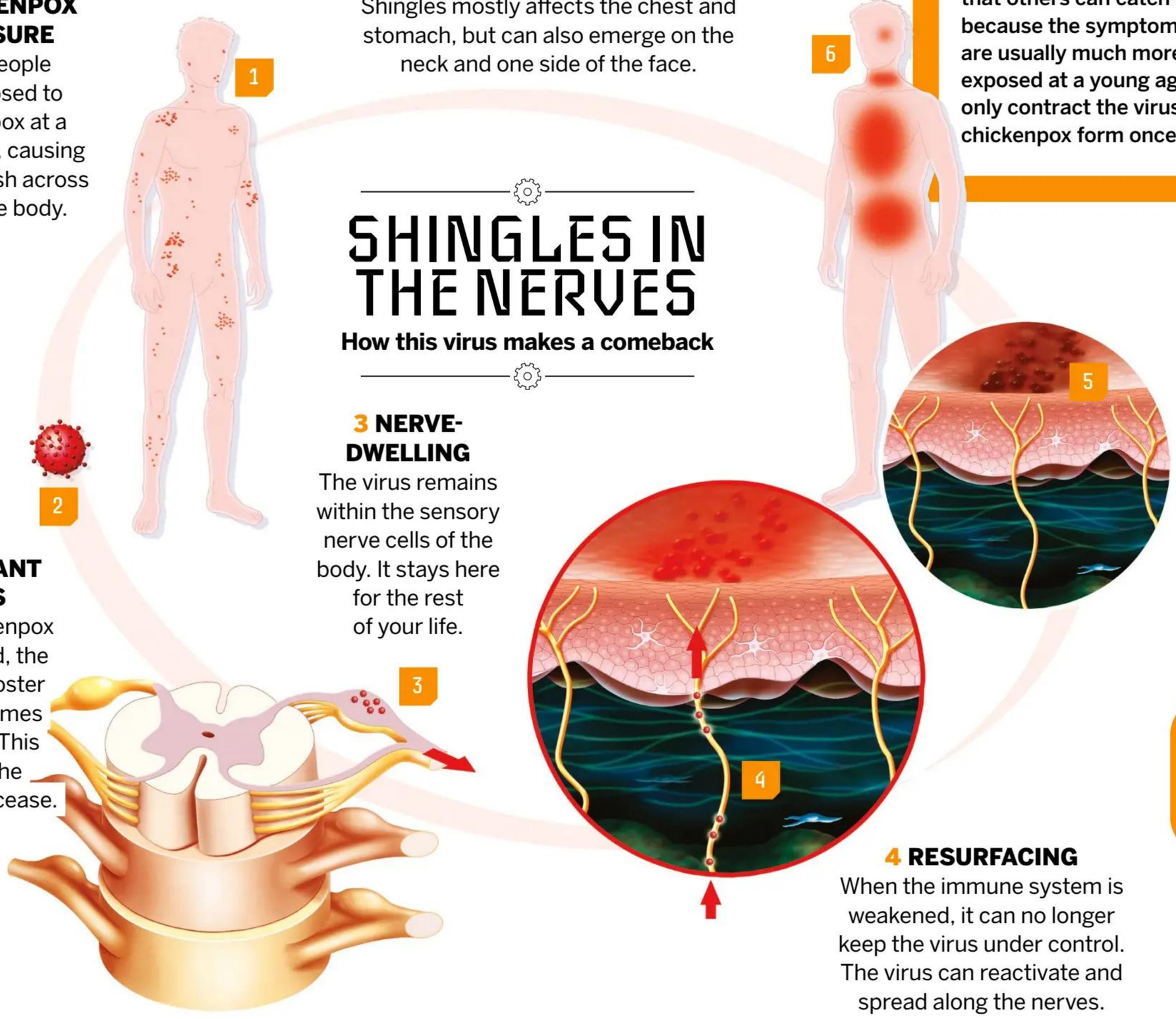
2 DORMANT VIRUS
After chickenpox has cleared, the varicella-zoster virus becomes dormant. This means the symptoms cease.

3 NERVE-DWELLING
The virus remains within the sensory nerve cells of the body. It stays here for the rest of your life.

4 RESURFACING
When the immune system is weakened, it can no longer keep the virus under control. The virus can reactivate and spread along the nerves.

5 SHINGLES SYMPTOMS
The varicella-zoster virus returns, with more severe symptoms. The painful rash is usually confined to specific areas of the body.

6 AFFECTED AREAS
Shingles mostly affects the chest and stomach, but can also emerge on the neck and one side of the face.



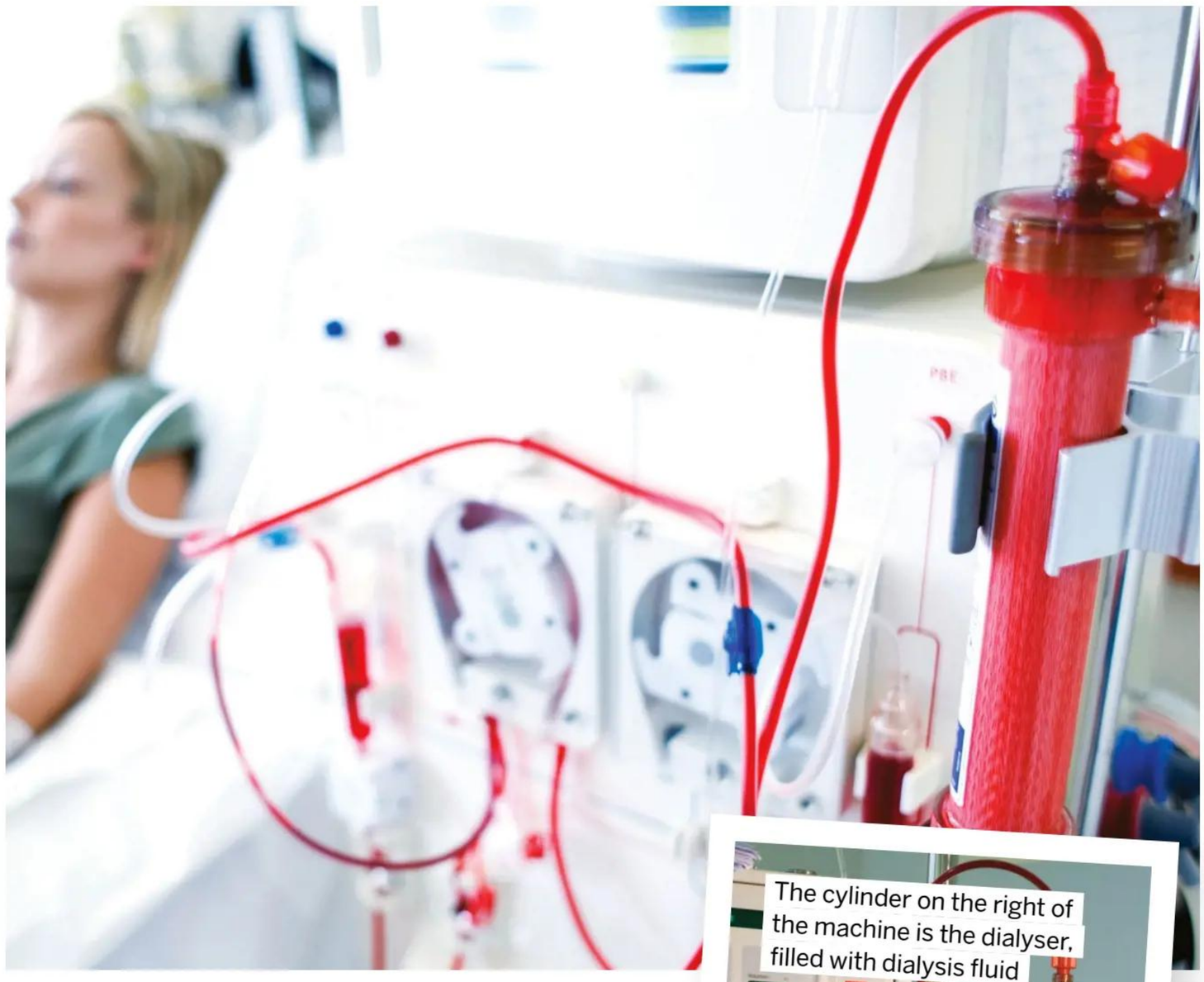
Did you know?

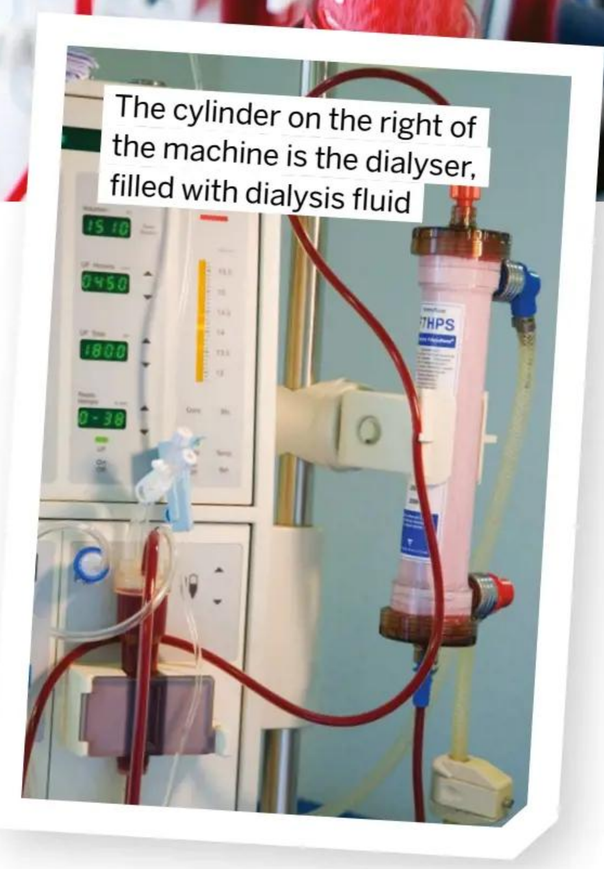
Around half of people who live to 85 will experience shingles

HOW DIALYSIS MACHINES WORK

These lifesaving devices take over the role of failing kidneys

WORDS **AILSA HARVEY**





The cylinder on the right of the machine is the dialyser, filled with dialysis fluid

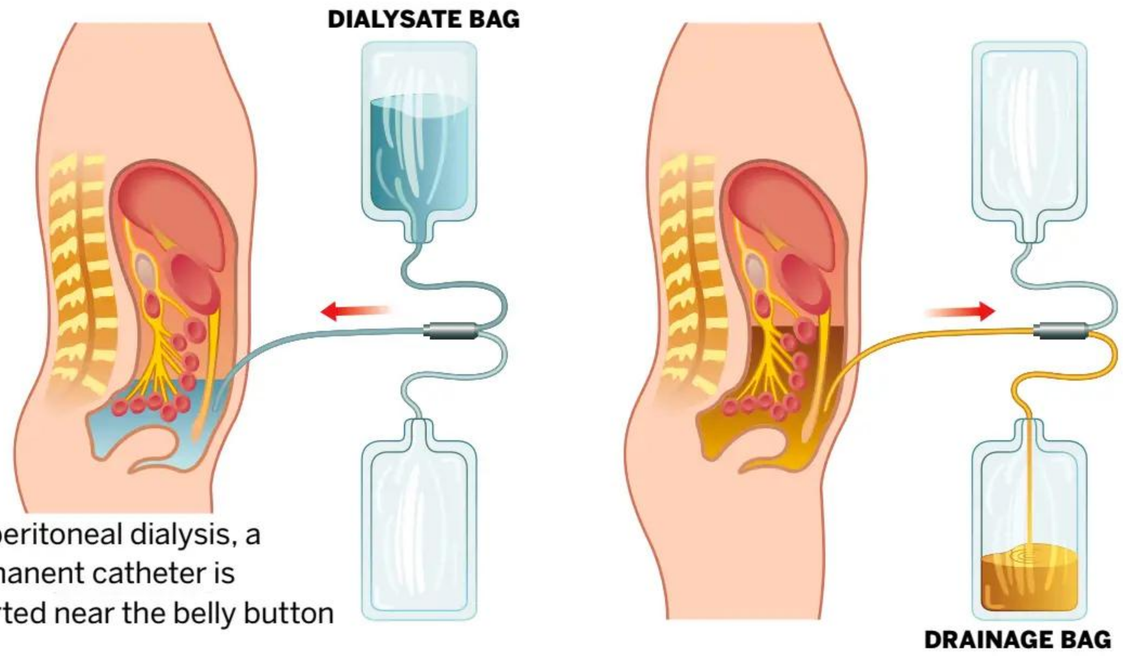
Without healthy kidneys, your body would quickly fill with toxins, causing it to shut down. To prevent this buildup, these two fist-sized organs are continuously working to filter out waste substances from biological processes and pass them out of the body in your urine. For people who suffer from kidney failure, an alternative method is needed to emulate this essential task. Dialysis machines, which were invented in 1943, divert blood out of the body to be cleaned before being returned to the body. Because the body is continually producing waste, patients who depend on dialysis usually undergo four hours of treatment approximately three times a week.

During the process, the machine is attached to a needle, often placed in the arm, through which blood can be extracted and returned. As the blood enters the dialysis machine, it passes along a layer of membranes. These membranes have microscopic holes that only water and waste molecules can filter through. Because of this, no blood cells are lost to the machine – they simply take a diversion on their circulatory course.

The dialysis machine's fluid, called dialysate, consists of water, electrolytes and salts. Mimicking the concentration of body fluid found outside of your body's cells, dialysate draws waste products across the membrane in a process called diffusion. Because the waste molecules are in higher concentrations in the blood, they pass from an area of high concentration to an area of low concentration. When the blood is returned to the vein, it's in a similar condition to filtered blood that has passed through the kidneys.

INSIDE AND OUTSIDE THE BODY

There are two types of dialysis: haemodialysis and peritoneal. The former involves an external dialysis machine, while peritoneal dialysis takes place mostly inside the body. Dialysis fluid is pumped into a space in the abdomen known as the peritoneal cavity, and the membrane lining the abdomen carries out the usual role of the kidneys. Waste products diffuse out of the blood and into the abdominal cavity, ready to be pumped back out of the catheter tube into a separate bag. This form of dialysis is ideal for people who need regular treatment and want to fit it around their busy schedules. Instead of clocking significant hours in hospital while hooked up to a haemodialysis machine, portable peritoneal dialysis machines can be used at home or while travelling.

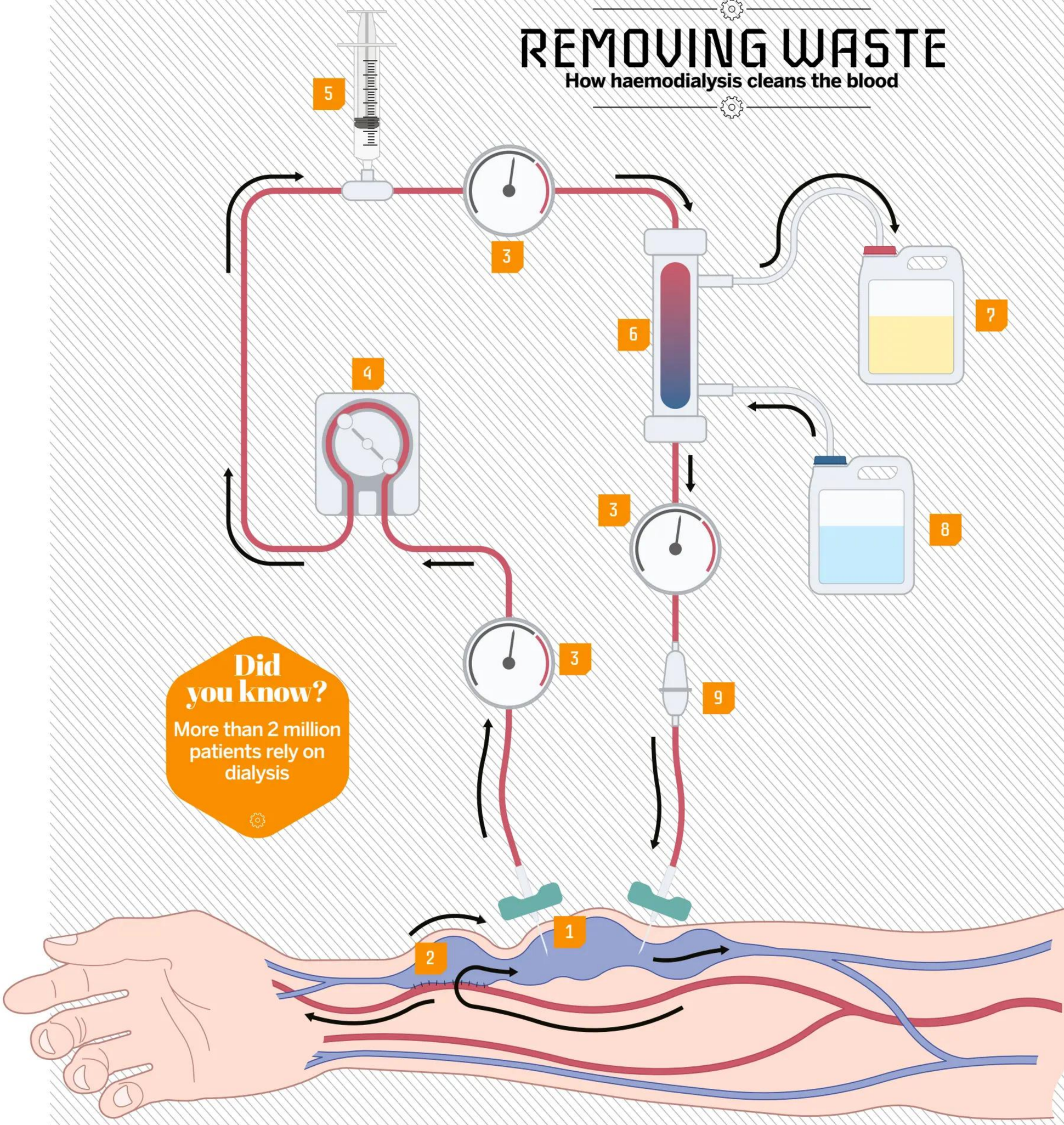


For peritoneal dialysis, a permanent catheter is inserted near the belly button

DID YOU KNOW? Around ten per cent of the world's population suffers from chronic kidney disease

REMOVING WASTE

How haemodialysis cleans the blood



Did you know?

More than 2 million patients rely on dialysis

5 FACTS REASONS FOR DIALYSIS

1 DIABETES
Diabetes is a condition that can lead to high blood sugar. Over time this can cause damage to the kidneys' blood vessels, preventing the organs from working well.

2 HYPERTENSION
High blood pressure causes blood vessels in the kidneys to narrow, weakening them over time and reducing the kidneys' function.

3 INFLAMMATION
Infections can cause inflammation of the kidneys. Inflamed kidneys leak proteins into urine, stopping it from absorbing water from body tissues.

4 CYSTS
When fluid-filled sacs form in the kidneys, the membranes they protrude from are unable to filter waste from the blood.

5 INHERITED DISEASE
There are around 300 genetic kidney disorders. Some of these conditions require the use of dialysis machines.

1 CATHETER
A tube is inserted into a large vein in either the leg, arm or chest.

2 ARTERIOVENOUS FISTULA
A surgeon carries out a procedure to connect an artery and vein together. This creates a strong site for dialysis.

3 PRESSURE MONITORS
When too much fluid is removed from the blood, patients can suffer from low blood pressure. This monitor sounds an alarm when this occurs.

4 BLOOD PUMP
This device drives blood around the dialysis machine when outside the body, directing blood out of and back into the body.

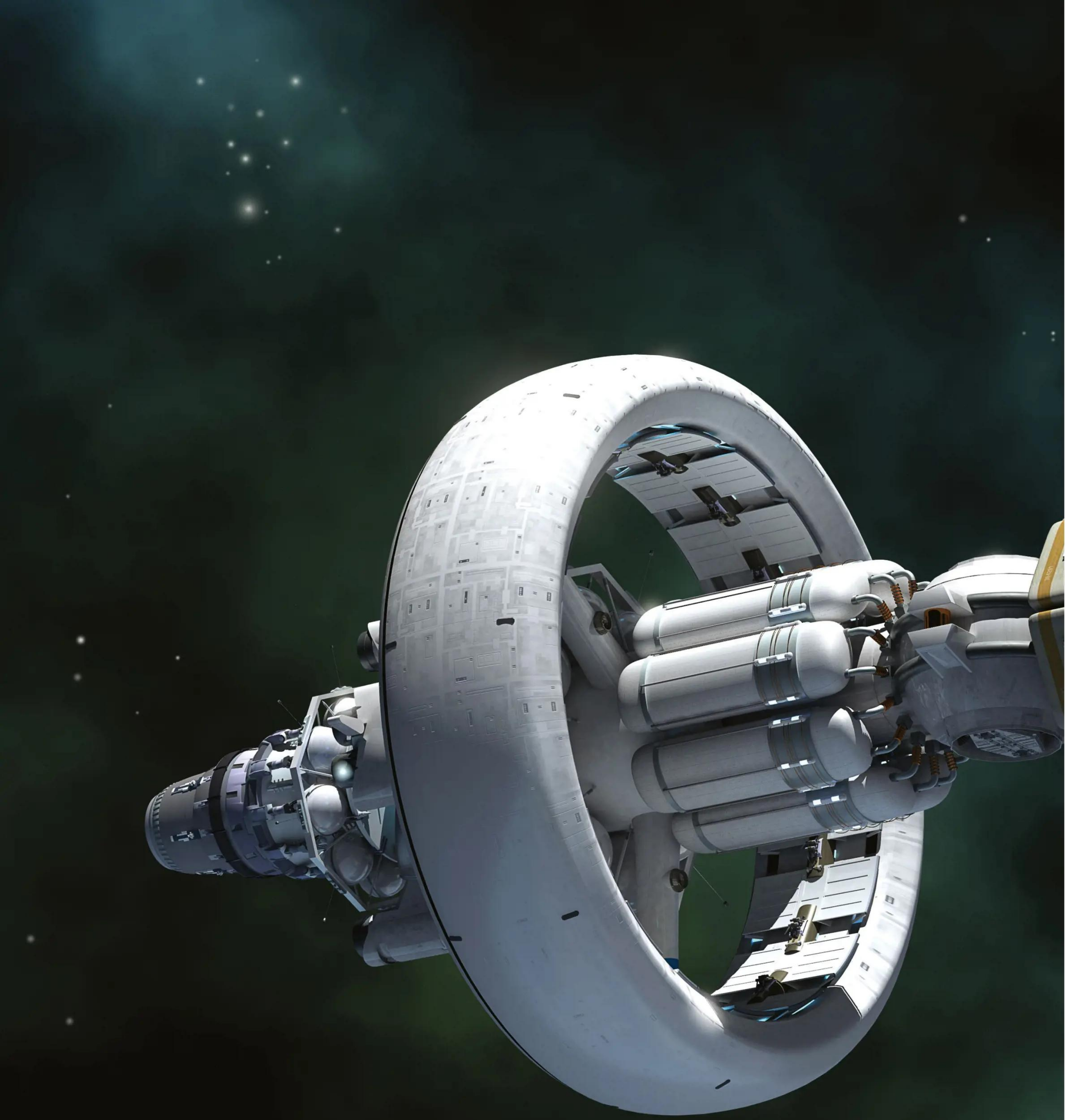
5 HEPARIN PUMP
A blood-thinning medication called heparin is added to the blood through a syringe. Heparin prevents the blood from clotting when outside the body.

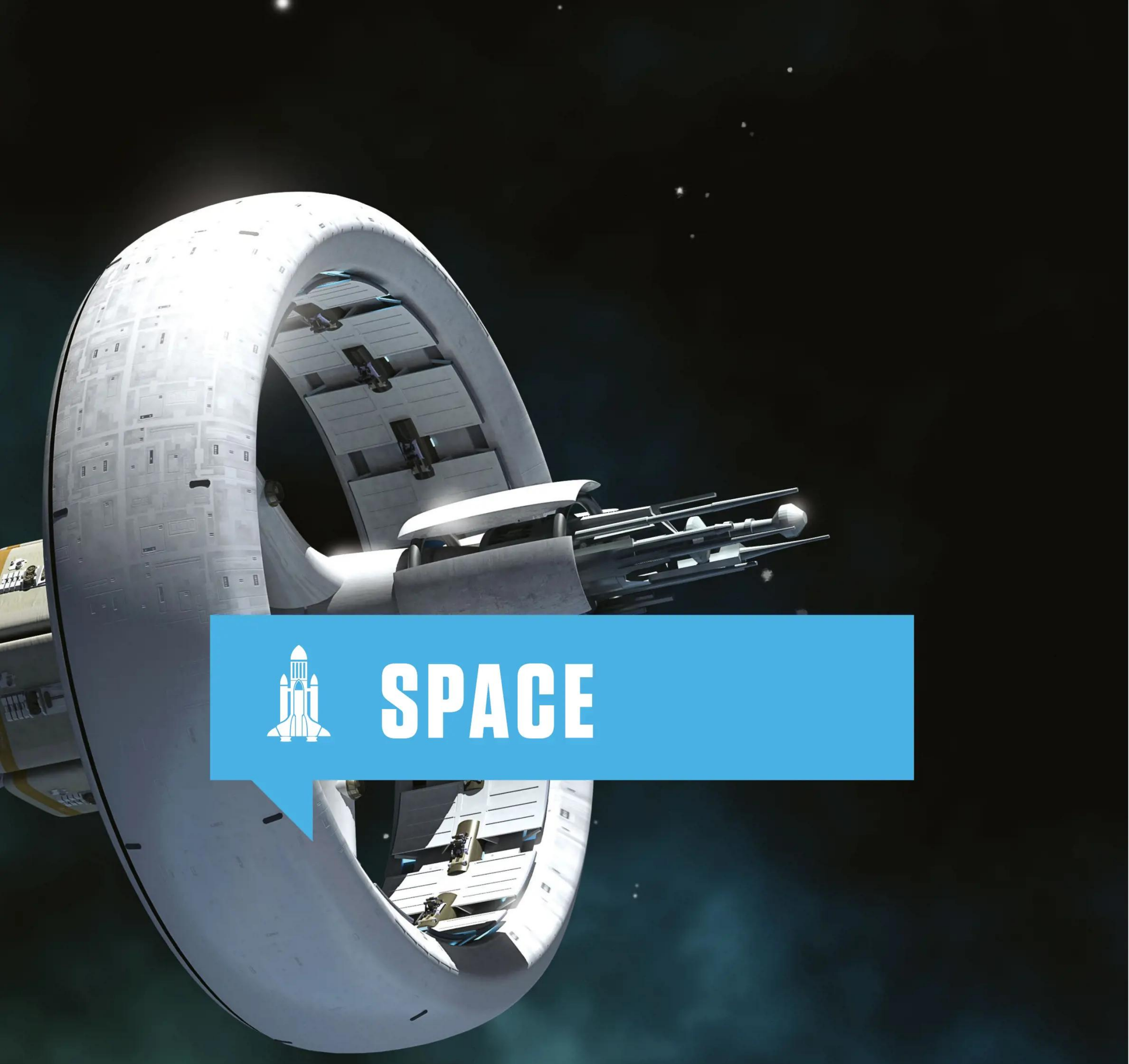
6 DIALYSER
Membranes in the main machine filter waste products out of the blood, but keep blood cells separate from the dialysis fluid.

7 WASTE DIALYSIS FLUID
Waste drains out of the blood, through a membrane, into a bag.

8 CLEAN DIALYSIS FLUID
Fresh dialysis fluid is pumped in the opposite direction of the blood flowing through the machine.

9 AIR TRAP
This device detects any air in the blood and prevents it from passing into the body.





SPACE

INSIDE THE ASTEROID BELT

The gap between Mars and Jupiter has no planets, and it's surprisingly interesting for it

WORDS **ANDREW MAY**

DID YOU KNOW? One of the asteroid-hunting groups of the early 19th century called themselves the Celestial Police

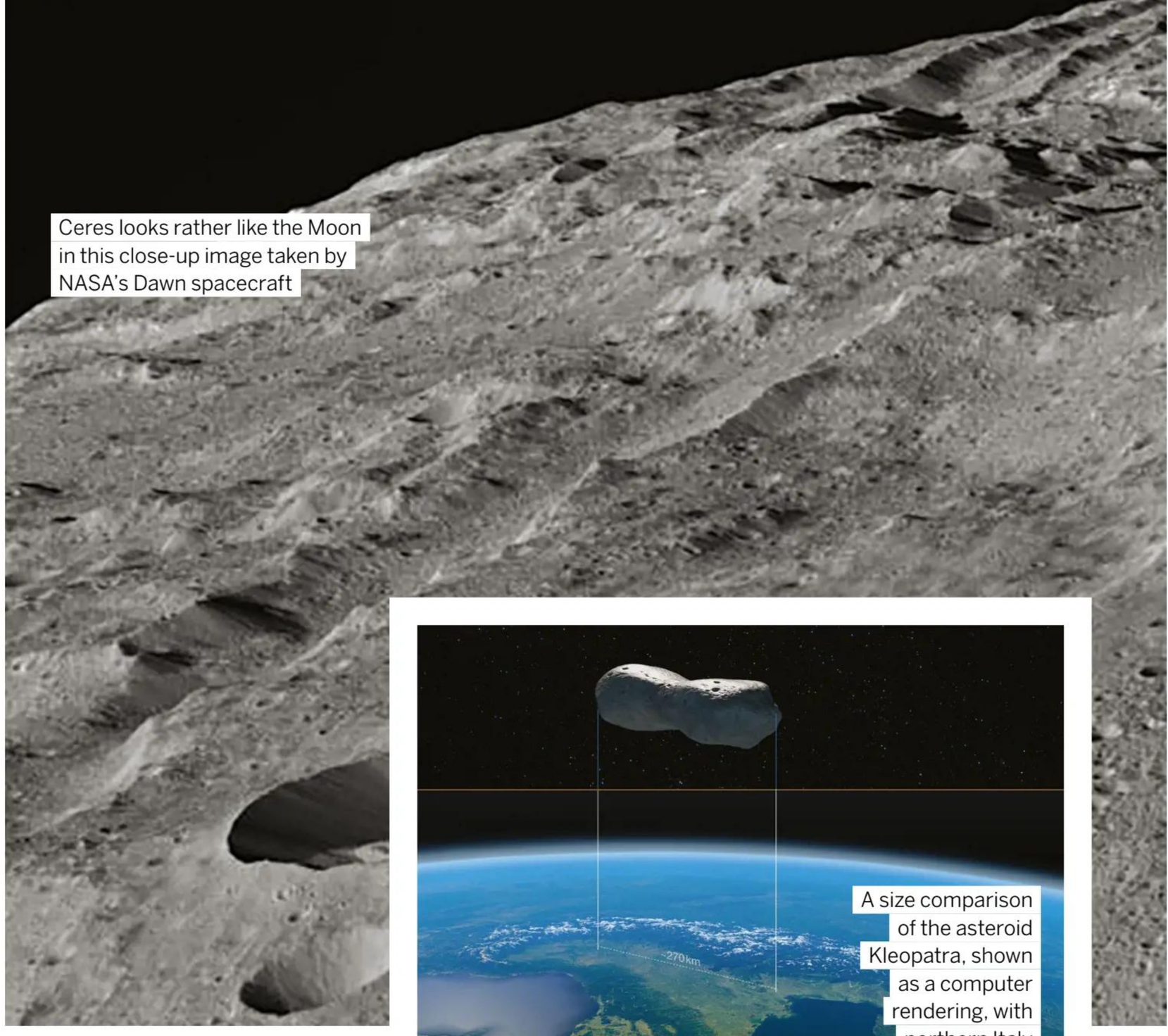
Asteroids are chunks of rock, ranging in size from hundreds of miles down to a few metres across, that orbit the Sun like miniature planets. While a few of the largest asteroids have a roughly spherical shape, most of them are much more irregular in appearance. To date, more than a million asteroids have been discovered – the majority of them in the main asteroid belt sitting between the orbits of Mars and Jupiter. The asteroid belt is one of the Solar System's most important features, marking the boundary between the two different types of planets: the rocky inner planets Mercury, Venus, Earth and Mars, and the giant outer planets Jupiter, Saturn, Uranus and Neptune. It's also the widest swathe of the Solar System between the orbits of Mercury and Neptune that is entirely planet-free.

The lack of planets in the region between Mars and Jupiter was a puzzle for early astronomers, and many of them were convinced there had to be a hitherto unknown planet there. By the end of the 18th century, the hunt for this supposedly missing planet had become something of a competition between rival groups of astronomers. The apparent winner was Giuseppe Piazzi of Palermo Observatory in Sicily, who found a planet-like object in the right sort of area on 1 January 1801. But doubts were cast almost immediately.

For one thing, the new object – which Piazzi called Ceres – appeared much too small to be a proper planet. For another, Ceres wasn't alone. Over the next few years, astronomers found three more objects – Pallas, Juno and Vesta – in the same region of space. What had been discovered wasn't the expected 'missing' planet, which didn't exist, but something completely new to science: the asteroid belt. By 1850, ten objects had been found there, and over 200 more were identified in the 30 years after that. By the 20th century, so many asteroids were known that they were referred to as the 'vermin of the sky', and new discoveries continue to this day.

The word asteroid means 'starlike', but this refers to their appearance through a telescope as small points of light rather than their physical nature. Even through a telescope the difference soon becomes obvious, because asteroids – like planets – move relative to the backdrop of the much more distant stars. Asteroids are also like planets in that they only shine by reflecting light from the Sun.

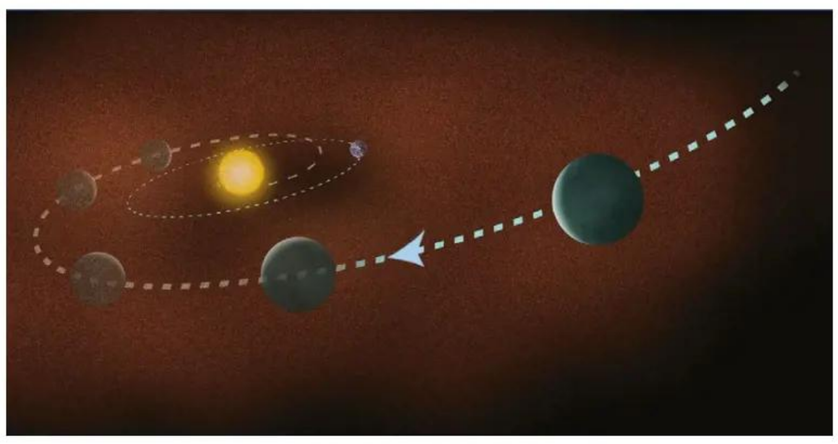
The upper and lower size limits of asteroids are relatively vague. At the low end they merge with meteoroids – pebble-sized pieces of rock



Ceres looks rather like the Moon in this close-up image taken by NASA's Dawn spacecraft

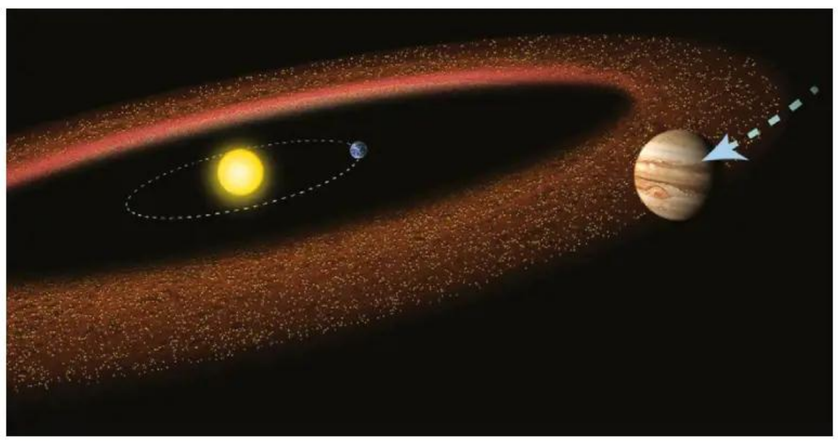
A size comparison of the asteroid Kleopatra, shown as a computer rendering, with northern Italy

EVOLUTIONARY THEORIES



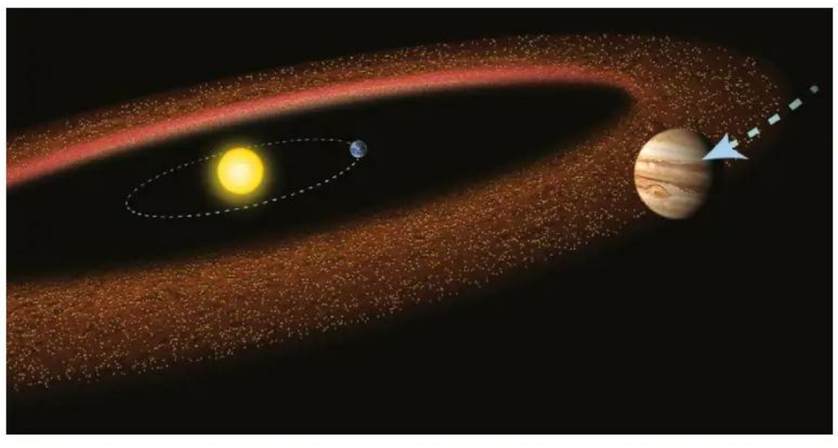
Disrupted belt

If a large Jupiter-like planet was formed on the outskirts of a planetary system and then migrated inwards through the asteroid belt, it would deflect material onto the inner planets. Impacts would likely inhibit the development of life on these planets.



Solar system belt

This is the situation in our own Solar System. Jupiter did migrate slightly inwards, but stopped outside the main asteroid belt. This allowed the planets further in to remain stable and undisrupted.



Dense belt

If Jupiter didn't migrate inwards at all, the resulting asteroid belt would be denser. It's likely that material from it would periodically bombard the inner planets, and this again would inhibit any life from evolving on them.

HOW DENSE IS THE ASTEROID BELT?

Because there are millions of objects in the belt, it's tempting to picture it as a densely packed, crowded place. That's how it's often portrayed in science fiction and even scientific visualisations. But the asteroid belt occupies a huge volume of space, so all those objects are spread out very thinly. It's likely that, seen from one asteroid, its nearest neighbour would be too far away to be seen without a telescope. The huge gaps between asteroids also mean it's highly unlikely that a spacecraft passing through the asteroid belt would collide with anything larger than a grain of interplanetary dust.

Visualisations make the asteroid belt look much more crowded than it is

DID YOU KNOW? NASA has detected not one, but two asteroid belts around the star Epsilon Eridani, ten light years away

found everywhere in the Solar System – and at the upper end with full-blown rocky planets. Piazzi's original discovery, Ceres, remains the largest object in the asteroid belt, and for a long time it was simply thought of as a very large asteroid. However, in 2006 it was reclassified as a dwarf planet due to its unusual size; Ceres actually contains a quarter of the entire mass of the asteroid belt.

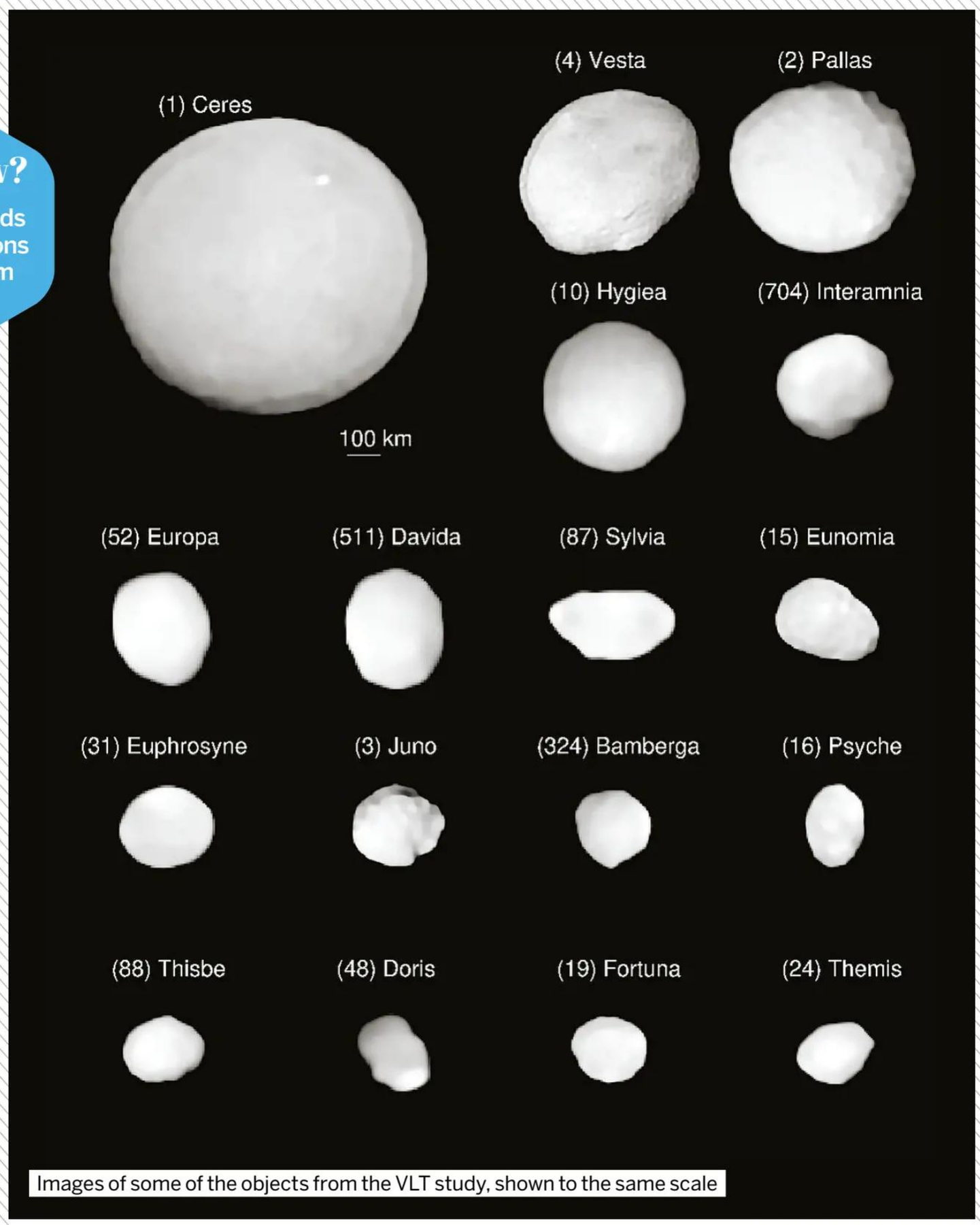
Asteroids in general come in a variety of types depending on their chemical composition. The most common type, encompassing more than three-quarters of all known asteroids, are carbonaceous, or C-type, asteroids. These are particularly prevalent in the outer regions of the asteroid belt. The inner region, on the other hand, has more siliceous, or S-type, asteroids, while metallic, or M-type, asteroids are found in the central regions of the asteroid belt.

Not all asteroids are confined to the main asteroid belt between the orbits of Mars and Jupiter. While the asteroids there tend to travel on more or less circular orbits, others appear to have been diverted onto smaller and more elliptical orbits that take them past Mars into the inner parts of the Solar System, close enough to the orbits of the inner planets – including Earth – that they can occasionally pose a collision risk. Scientists believe these rogue asteroids did originate in the main asteroid belt, but were subsequently deflected by the substantial gravitational effects of the giant planet Jupiter onto their current much more eccentric orbits.

Jupiter's gravity is an important key to understanding the current appearance of the asteroid belt. It probably originated very early in the history of the Solar System – a few tens of millions of years after the Sun was born – when the entire inner part of the Solar System would have been filled with rocky asteroid-like bodies. Many of these eventually coalesced to form the planets Mercury, Venus, Earth and Mars – and the real mystery is why the same process didn't result in another similar planet between Mars and Jupiter. The most important reason seems to be that the strong pull of Jupiter's gravity is constantly stirring things up in the asteroid belt and preventing any further planet formation. On top of that, despite the large number of individual asteroids, the actual quantity of matter in this region is very small, with all the asteroids put together only amounting to around four per cent of the Moon's mass. It's likely that this paucity of material can be attributed to the effects of Jupiter too, which slowly stripped the original asteroid belt of most of its mass.

Did you know?

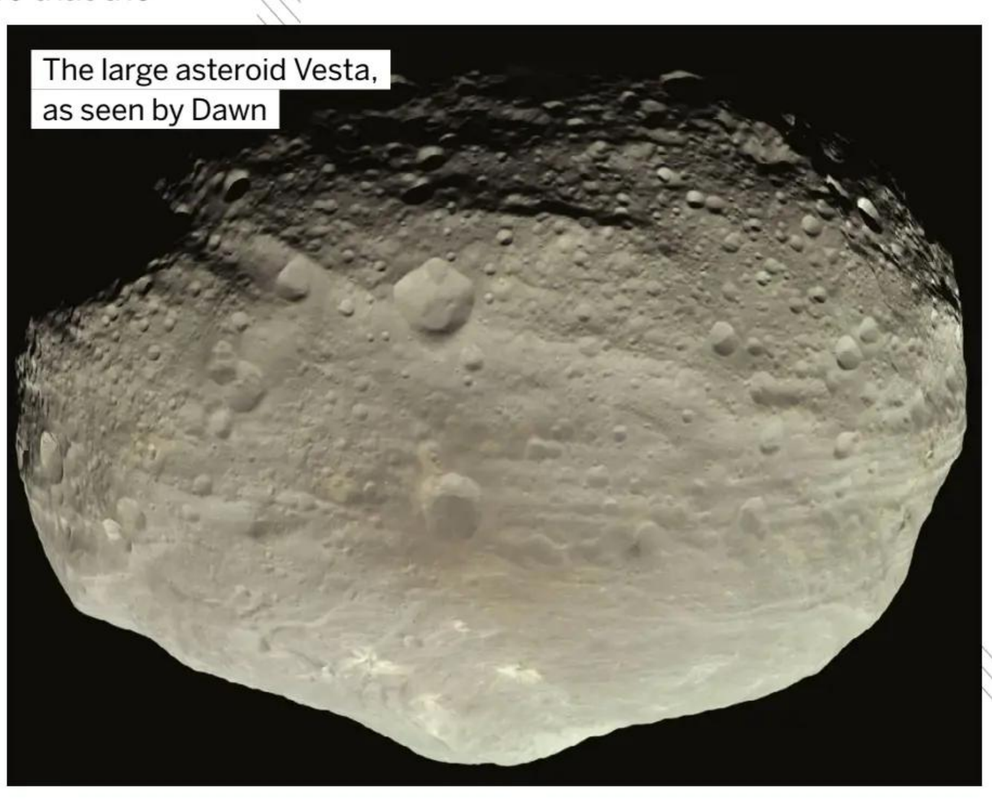
Some asteroids have tiny moons orbiting them



Images of some of the objects from the VLT study, shown to the same scale

THE LARGEST OBJECTS IN THE ASTEROID BELT

We know much more than we did a few years ago about the largest objects in the asteroid belt thanks to a 2021 study that used data from the European Southern Observatory's Very Large Telescope (VLT) to characterise their three-dimensional structures. In particular, the study measured an object's diameter, density and flattening – the latter being the ratio of its smallest dimension to its largest. The biggest object, as expected, was the dwarf planet Ceres, with a diameter of 584 miles, a density of 2.2 grams per cubic centimetre and a flattening ratio of 0.92. The closeness of the flattening ratio to 1.0 means that Ceres is relatively spherical, although Hygiea, with a flattening ratio of 0.94, is even rounder. The most elongated object the study measured was Kleopatra, with a flattening of just 0.18, while the densest was the metal-rich asteroid Psyche, at 3.9 grams per cubic centimetre.


The large asteroid Vesta, as seen by Dawn

VISITING THE ASTEROID BELT

Several previous and planned NASA missions have been designed to explore this part of the Solar System

> "Dawn contributed to a greater understanding of how early planetesimals formed"

MISSION TO A METAL ASTEROID

Psyche is one of the largest objects in the asteroid belt, measuring some 140 miles across. It's also one of the most intriguing because it appears to be composed largely of metal. That's the main reason why NASA has chosen it as the destination for its next mission to the asteroid belt, which will likewise be called Psyche. While using cameras to show us what the asteroid looks like, the Psyche spacecraft will also carry a number of scientific instruments to probe its surface composition, which is believed to include iron, nickel, silicon and oxygen. These resemble what might be found in the core of a small planet, and it's possible that's just what asteroid Psyche is, having had its outer layers stripped off by collisions early in the Solar System's history.

As well as exploring the asteroid to learn everything it can tell us about planetary formation, the Psyche mission also has a secondary objective to test a new technology called 'deep-space optical communication'. This uses infrared laser beams to carry messages between the probe and Earth, allowing more data to be transmitted in a given time than traditional radio communication.

NASA's original plan was to launch the Psyche spacecraft in 2022, but this wasn't possible due to teething problems with its flight software. It was eventually launched on 13 October 2023, which has put it on track to arrive at its namesake asteroid some time in August 2029.

The Psyche spacecraft being assembled in a cleanroom at NASA's Jet Propulsion Laboratory

ASTEROID PROBE

NASA's Psyche spacecraft will study the similarly named asteroid from close quarters

5 GAMMA-RAY AND NEUTRON SPECTROMETERS
These sensors provide data on the chemical abundances of metals in the asteroid.

6 MAGNETOMETER
This instrument measures the magnetic field strength around the asteroid.

7 MULTISPECTRAL IMAGER
This uses the same technology as the Mastcams on NASA's Mars rovers.

4 OPTICAL COMMUNICATIONS
This is a prototype system designed to test laser-based communications as an alternative to radio.

3 HIGH-GAIN ANTENNA
This traditional radio dish is the spacecraft's primary means of communication with Earth.

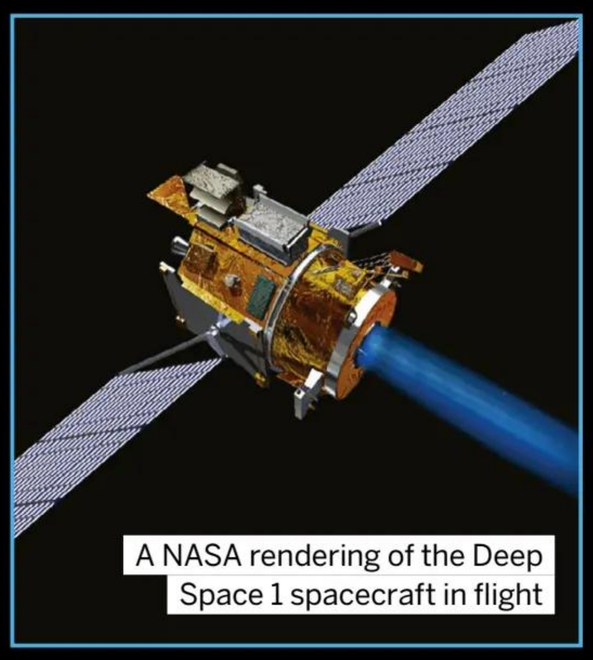
1 ASTEROID
The spacecraft will orbit around Psyche at distances down to 53 miles.

2 SOLAR PANELS
These provide power both for the spacecraft's internal electronics and its solar-electric propulsion system.

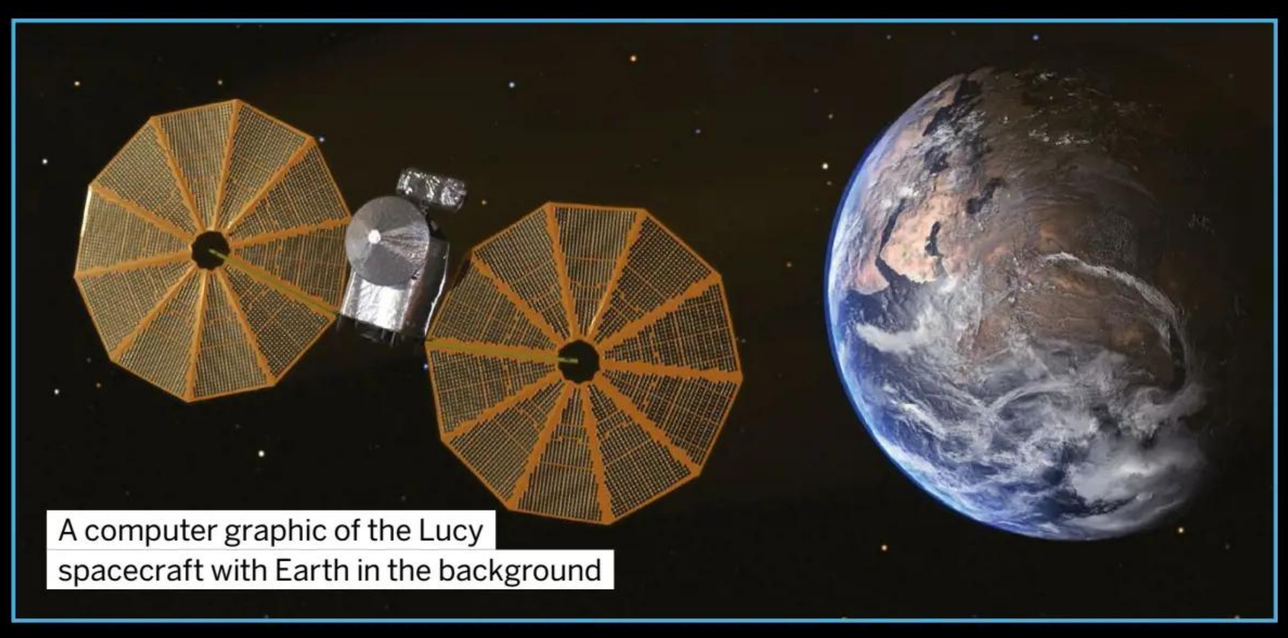
DID YOU KNOW? Based on its probable metal content, asteroid Psyche is worth an estimated 10 quintillion dollars

Deep Space 1

Launched in October 1998, NASA's Deep Space 1 used a novel form of ion propulsion called solar-electric propulsion, the power for which comes from a large array of solar panels. This approach, now common in deep-space missions, provides significant mass savings over more traditional propulsion methods. As well as successfully demonstrating the new technology, Deep Space 1 performed flybys of both a comet and an asteroid. The latter, named Braille, moves on an eccentric orbit from inside the orbit of Mars to the outer regions of the main asteroid belt.



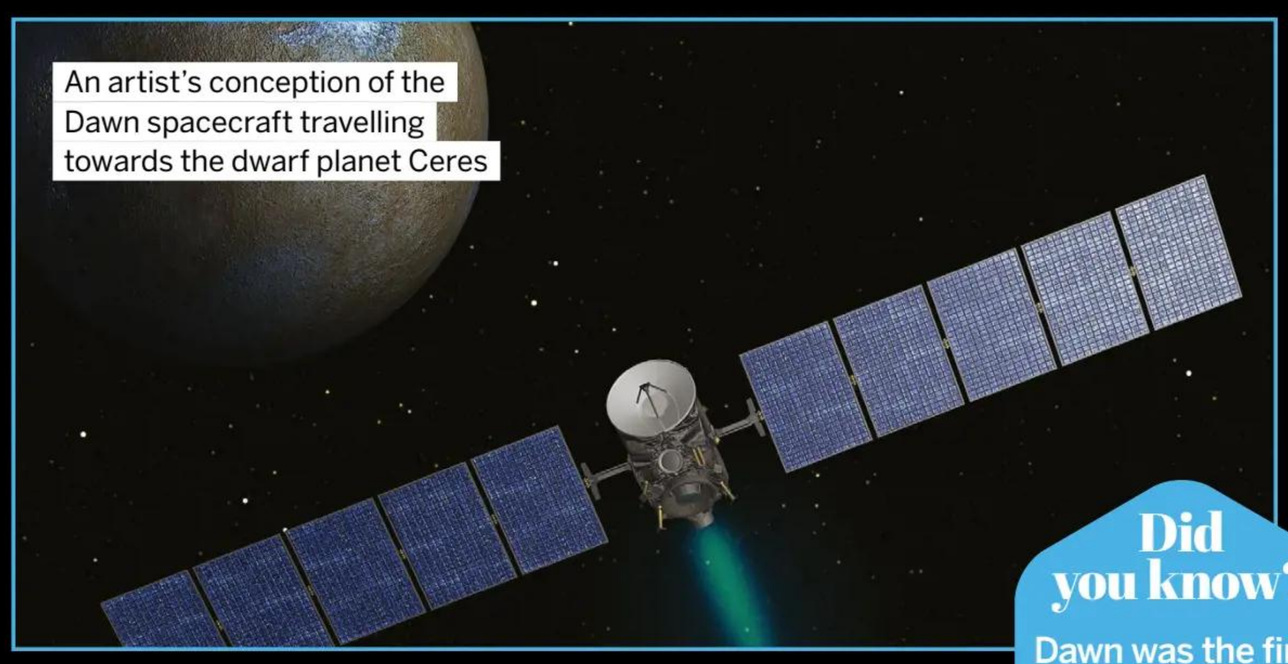
A NASA rendering of the Deep Space 1 spacecraft in flight



A computer graphic of the Lucy spacecraft with Earth in the background

Lucy

Launched in October 2021, NASA's Lucy probe is heading off to study a number of asteroids – but most of them aren't in the main asteroid belt. They're called 'Trojan asteroids', and they share the same orbit around the Sun as Jupiter, though in two groups travelling ahead of and behind the planet itself. However, Lucy's first destination, as it files en route to the Trojans, is a small main-belt asteroid named Donaldjohanson, after a fossil hunter who found the skeleton of a prehistoric human ancestor he called Lucy. The spacecraft is expected to get there in 2025.



An artist's conception of the Dawn spacecraft travelling towards the dwarf planet Ceres

Did you know?

Dawn was the first craft to orbit two destinations

Dawn

Launched in 2007, Dawn remains NASA's most important mission to the asteroid belt so far. Using similar ion drive technology to Deep Space 1, it was able to visit the belt's two largest objects – Ceres and Vesta – and rather than simply flying past, it spent time orbiting them so it could study them in detail. Arriving at Vesta in July 2011, Dawn orbited that asteroid for 14 months before moving on to dwarf planet Ceres, where it arrived in March 2015. It remains in orbit there now, although its active mission ended in 2018 when it ran out of fuel.

Carol Raymond and Julie Castillo-Rogez, senior scientists at NASA's Jet Propulsion Laboratory

HIGHLIGHTS OF THE DAWN MISSION

Two of the scientists involved in this major mission to the asteroid belt give us their insights

When Dawn arrived at Vesta, did it look the way you expected?

Vesta looked very familiar since it had been observed extensively by telescopes. Hubble data had shown a giant crater near Vesta's south pole. Dawn's examination revealed there were two overlapping impact basins, one very old and the other relatively young. Vesta was known to be very bright, but a dark patch rich in hydrated minerals was discovered that is the remnants of the earlier, carbon-rich impactor.

Is Ceres similar to Vesta?

Ceres and Vesta differ in fundamental ways, largely due to when and where they formed. Vesta formed very early in the inner Solar System and experienced melting, leaving it dry and differentiated into core, mantle and crust. Ceres formed less than 2 million years later in the outer Solar System from ice-rich material and didn't experience temperatures high enough to melt it. As Ceres evolved, water-rock reactions resulted in a global subsurface brine layer beneath a crust rich in ice and clay-like minerals. Patches of bright material that dot Ceres' relatively smooth surface are from these subsurface brines.

How has Dawn contributed to our understanding of the asteroid belt?

Dawn contributed to a greater understanding of how early planetesimals formed. These results support the idea that large protoplanets formed rapidly from collapsing clouds in the protoplanetary disc. Many, if not all, water-rich asteroids likely migrated from colder regions. The discovery of brine activity on Ceres persisting to recent times provides new constraints on how other large icy bodies evolve and may create habitable environments.

MASSIVE MOON CRATER

How Tycho, our Moon's most prominent crater, formed

WORDS **SCOTT DUTFIELD**

It's estimated that there are millions of craters sprawled across the surface of the Moon. However, one stands out among all the lunar impact sites visible from our vantage point here on Earth. Named after the Danish astronomer, Tycho Brahe, the Tycho crater has long intrigued astronomers. Its high walls, flat floor and central peak make it seem like a city on Earth's natural satellite. Even the Victorian selenographer (someone who charts the Moon) Thomas Gwyn Elger called it "the Metropolitan crater of the Moon".

The walls of the crater span 51 miles wide and plummet around 2.92 miles to its floor. Incredibly, this is small in comparison to the Moon's biggest impact site, the South Pole-Aitken basin, which stretches 1,550 miles in diameter.

At its centre is a rocky peak that reaches 1.24 miles into the absent air. The curious peak is characteristic of large craters, the result of rock that was compressed by the massive force of the impact, then immediately rebounded upwards.

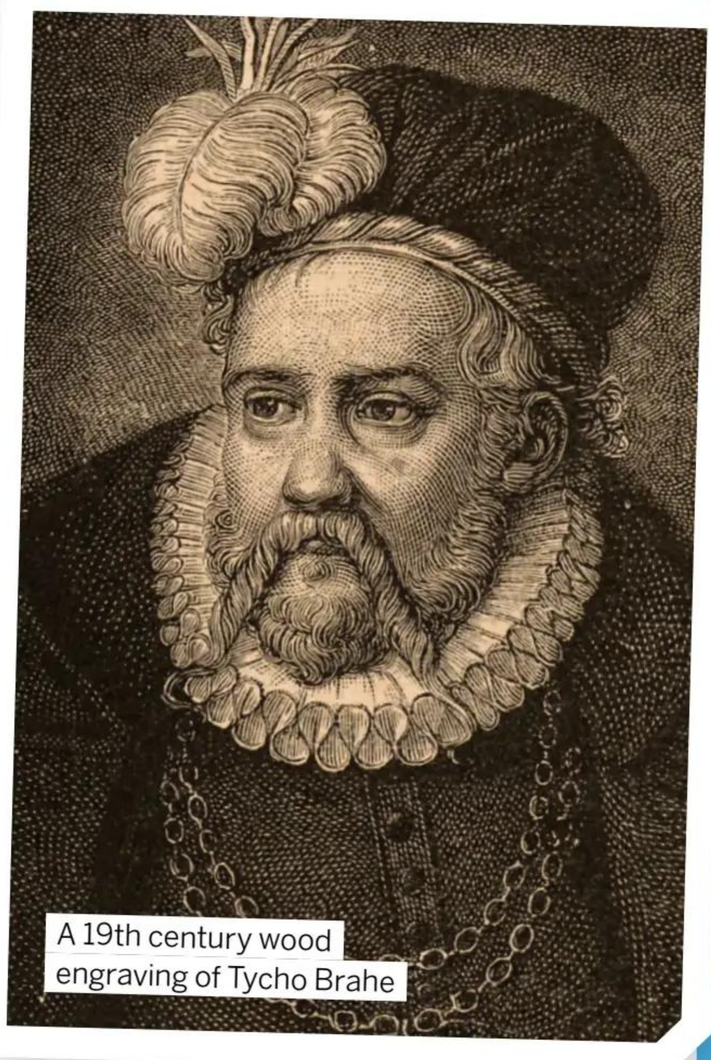
Although scientists can't say for sure, it's been suggested that the meteorite that created the crater came from a fragment of the asteroid Baptistina 298. Part of the same asteroid is also believed to have wiped out the dinosaurs and created the Chicxulub crater on Earth around 34 million years after Tycho crater formed.

Following the lunar impact, enormous amounts of rock and broken meteorite, known as ejecta, were thrown from the crater site, creating rays of heated rubble that span around 1,200 miles from the site. Due to the force and heat generated by the impact, the rays of lunar rock, along with the crater's floor, were liquified before solidifying into impact glass.

Astronauts on the Apollo 17 mission were able to snag a rocky sample of the Tycho crater's rays and bring it back to Earth. Upon radiometric analysis, the lunar samples were dated to 108 million years ago. This makes the Tycho crater one of the youngest of all the lunar craters, many of which were formed billions of years ago. Discovering the age of Tycho crater not only helps scientists understand more about the history of this impact site, but helps to unravel the mystery behind the terrain on rocky planets throughout the Solar System.

WHO WAS TYCHO BRAHE?

During the 16th century, Tycho Brahe made some of the most accurate observations possible at the time – before the telescope was invented – about the Solar System. These observations included the order of the Solar System and the positions of more than 777 fixed stars. However, he did not take the same view as fellow astronomer Nicolaus Copernicus, who placed the Sun at the centre of the Solar System. Instead, Brahe believed that the Sun and the Moon orbited Earth, despite also embracing the fact that the other five known planets in the Solar System orbited the Sun. Brahe's observations of the movements of Mars also assisted German astronomer Johannes Kepler's realisation that planets orbit elliptically (a squashed circle) rather than in perfect circles.



A 19th century wood engraving of Tycho Brahe

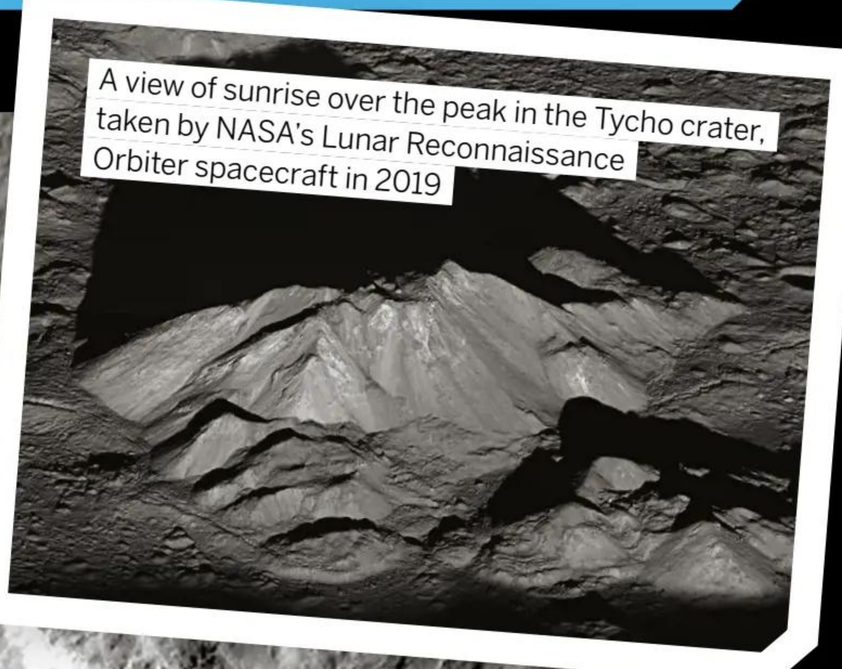
DID YOU KNOW? The unmanned Surveyor 7 spacecraft landed just 18 miles north of Tycho crater's rim in 1968

A mosaic image of the Tycho crater taken by NASA's Lunar Reconnaissance Orbiter

HOW TO SPOT A CRATER

The Tycho crater is found in the southern hemisphere of the Moon, and can be best seen during a full moon. During this phase, the rays around the craters are particularly bright and are easily spotted without the aid of a telescope or binoculars. Under the gaze of a telescope and at a low magnification of 50x, you'll see a closer view of the entire Moon. If you want to explore the finer details of the Tycho Brahe crater, you will need a telescope with a magnification of at least 150x. At this magnification, you'll get a look at details such as the crater's wall, which encompasses a 200,000-square-mile patch on the Moon.

For the best view of the Tycho crater, wait for a full moon



A view of sunrise over the peak in the Tycho crater, taken by NASA's Lunar Reconnaissance Orbiter spacecraft in 2019

Did you know?

Tycho's lunar coordinates are 43.3°S, 11.2°W

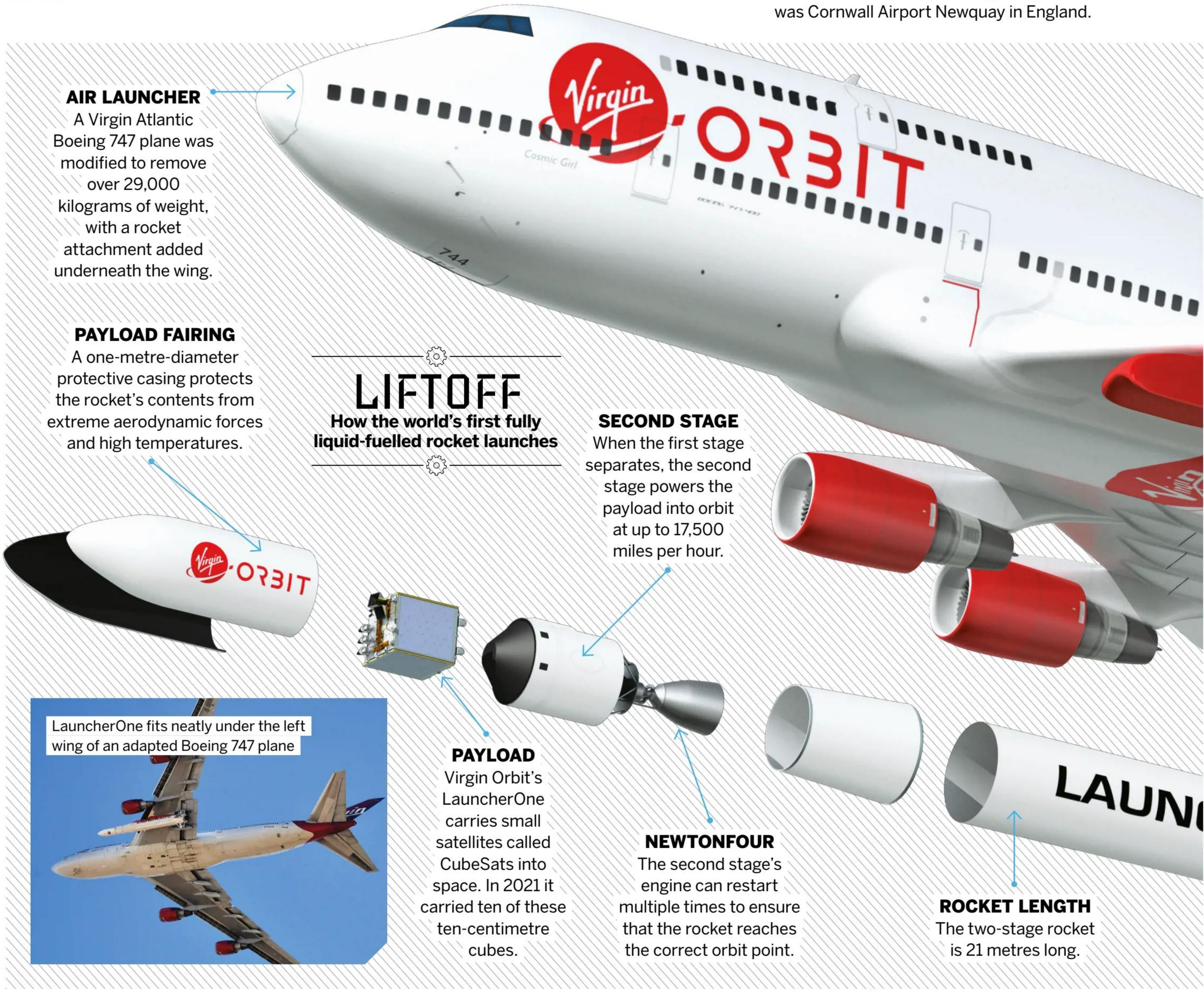
HITCH A RIDE ON LAUNCHERONE

How does Virgin Orbit's rocket launch multiple satellites into space without a launchpad?

WORDS **AILSA HARVEY**

Designed for small unmanned missions, Virgin Orbit's LauncherOne is a medium-sized rocket that can be launched from the air. The rocket is first carried into the sky by a modified aeroplane named Cosmic Girl before it detaches and begins its journey to space. While being carried by the aircraft, its engines remain off. Then, seconds after it has been dropped, its engines roar into action and continue the journey into Earth orbit.

LauncherOne was completed in 2018, and its first successful launch took place in January 2021. Because the rocket takes off from the sky, it isn't limited to launch locations with a launchpad. However, the same large-scale evacuations and safety precautions are required. One of the locations that the rocket was launched from at the beginning of 2023 was Cornwall Airport Newquay in England.



AIR LAUNCHER
A Virgin Atlantic Boeing 747 plane was modified to remove over 29,000 kilograms of weight, with a rocket attachment added underneath the wing.

PAYLOAD FAIRING
A one-metre-diameter protective casing protects the rocket's contents from extreme aerodynamic forces and high temperatures.

LIFTOFF
How the world's first fully liquid-fuelled rocket launches

SECOND STAGE
When the first stage separates, the second stage powers the payload into orbit at up to 17,500 miles per hour.

LauncherOne fits neatly under the left wing of an adapted Boeing 747 plane

PAYLOAD
Virgin Orbit's LauncherOne carries small satellites called CubeSats into space. In 2021 it carried ten of these ten-centimetre cubes.

NEWTONFOUR
The second stage's engine can restart multiple times to ensure that the rocket reaches the correct orbit point.

ROCKET LENGTH
The two-stage rocket is 21 metres long.

DID YOU KNOW? When LauncherOne's engine starts, around 75 per cent of Earth's atmosphere is already below the rocket

Before the rocket is released, Cosmic Girl needs to reach an altitude over 10,000 metres and be facing skywards at an angle of 27 degrees. The first of two engines then runs for three minutes to carry the rocket out of Earth's atmosphere, using an autonomous flight safety system to remain pointed in the right direction. The rocket, which is propelled by liquid oxygen and liquid kerosene, is designed to carry small satellites into orbit, with a maximum total payload of 500 kilograms. Some of the applications that the service will assist include earth observation, telecommunications and climate monitoring.

Stages separate in space

FIRST STAGE
When the rocket is released, the first stage powers the rocket at a maximum speed of 8,000 miles per hour.

NEWTONTHREE
The rocket free falls for four seconds before the first stage's engine ignites.

Did you know?
LauncherOne weighs 25,000 kilograms

LAUNCH FAILURE

In January 2023, during LauncherOne's first launch from the UK and with 75,000 people watching the action live, the rocket failed to reach orbit. This was because the rocket shut down too early. The fault is believed to have been maintained solely in the rocket's second stage, since the first stage carried the rocket into space and separated from the upper stages as scheduled. Issues began when the ignition unexpectedly cut out at an altitude of 180 kilometres. This caused LauncherOne, as well as the five satellites it was carrying, to come crashing back down to Earth. After the post-launch inspection, engineers discovered the fault was due to an engine filter coming loose and being mispositioned, preventing other engine components from working properly.

LauncherOne at Spaceport Cornwall before its failed launch

Universities will be able to pay Virgin Orbit to send their satellites into space

SMALL SERVICE

LauncherOne is designed to take small satellites into space. As a commercial service, Virgin Orbit's aim is to give those outside of government agencies access to space to run their own experiments. Some of the main target customers are students, and LauncherOne offers the choice of three orbital routes depending on which parts of Earth the satellites need to monitor: high, low or medium inclinations.

Small cubed satellites with a mass no greater than two kilograms and with dimensions of ten by ten by ten centimetres are called CubeSats. These were first developed in 1999 to allow students to conduct their own research as part of their studies. Being less expensive to make, they can be used for experiments that are higher risk. This includes riskier orbits that are more likely to lead to a spacecraft's early demise. Because financial loss is lessened, these experiments are more worthwhile. NASA's GeneSat-1 is one example of a CubeSat experiment, which was sent to space in 2006 to test the impact of space conditions on bacterial cells.

The future of SPACE TRAVEL

Discover possible future spaceship technologies, from the practical to the far-fetched

WORDS ANDREW MAY

Did you know?

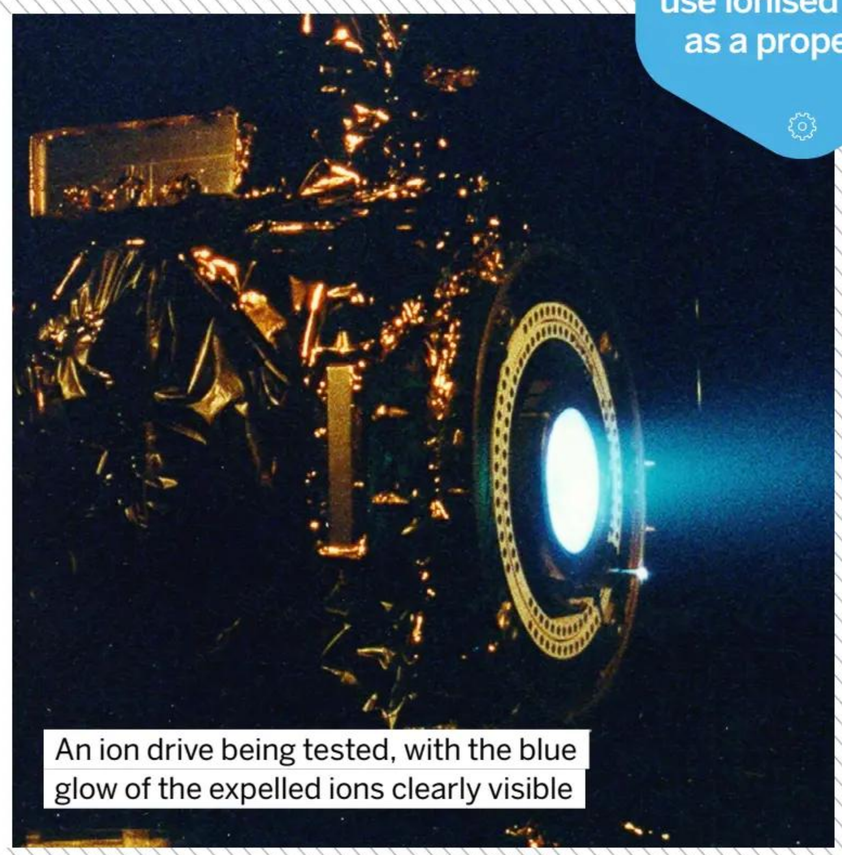
NASA's ion drives use ionised xenon as a propellant

ION DRIVE

STATUS: **TESTED IN SPACE**

RANGE: **INTERPLANETARY**

A conventional rocket works by expelling exhaust gases from a combustion reaction through a rear-facing nozzle, resulting in a forward thrust via the conservation of momentum. An ion drive also generates thrust by expelling material, but in this case it's a stream of ions – atoms that have had electrons stripped off to create a positive electric charge. Before being ejected, these ions are accelerated to high speeds using an electric field. The energy to maintain this field – as well as that needed to ionise the propellant atoms – comes from solar panels. For this reason, ion drives are sometimes referred to as solar-electric propulsion. Ion drives powerful enough to propel a crewed spacecraft still lie in the future, but NASA has used them in some of its smaller interplanetary probes, such as the Dawn mission to the asteroid belt and the Double Asteroid Redirection Test, which slammed into an asteroid last year.



An ion drive being tested, with the blue glow of the expelled ions clearly visible

MACH-EFFECT DRIVE

STATUS: **SPECULATIVE**

RANGE: **INTERSTELLAR**

Propulsion systems such as rockets and ion drives work by the conservation of momentum, ejecting propellant in one direction to produce thrust in the opposite direction. This means that their range is always limited by the amount of propellant they can carry. But a few scientists believe in 'reactionless' space drives that don't conserve momentum, and hence don't need any propellant. One such drive, proposed by James Woodward of the Space Studies Institute, uses what he calls the 'Mach effect', which draws on the ideas of a 19th-century philosopher named Ernst Mach. Most academic physicists believe that Woodward's space drive is unworkable, but he claims to have tested it in a laboratory and is seeking further research funding from NASA. If the system works in the way that Woodward hopes, he says it could power a probe all the way to the nearest known exoplanet, Proxima b.

Artist's impression of an interstellar space probe based around a hypothetical Mach drive

TESTING A REACTIONLESS DRIVE

Conventional physics says reactionless motion is impossible, but here's how a Mach drive might work

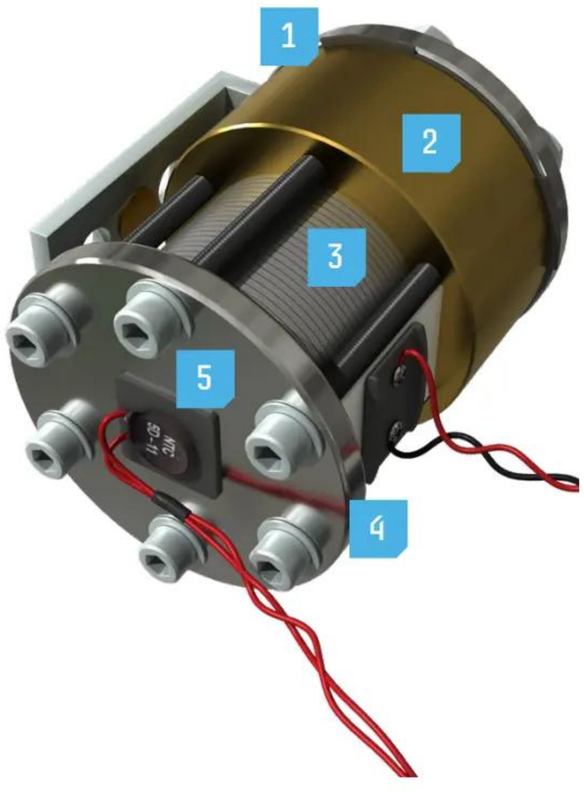
1 LABORATORY PROTOTYPE
A small test thruster demonstrates that the basic principle works before scaling up.

2 CONSTANT MASS
The test thruster contains a solid brass foundation of constant mass, standing in for the body of a real spaceship.

3 VARIABLE MASS
This stack of piezoelectric discs acts as both the source of mechanical movement and the varying reactive mass.

4 VIBRATIONS
Because piezoelectric material expands when electrified, this will cause the whole stack to vibrate against the brass foundation.

5 REACTIONLESS THRUST
Using the controversial concept of 'variable mass', the device produces a forward thrust without expending propellant.



A BRUIE-type robot submarine could search for life in the oceans of Europa or Enceladus

UNDER-ICE EXPLORER

STATUS: **RESEARCH PROJECT**

RANGE: **PLANETARY OCEAN**

If there's life in the Solar System, many scientists believe it's most likely to be found on one or more of the icy moons of the giant outer planets. This wouldn't be on the icy surface itself, but in the large, liquid-water ocean that's believed to lie beneath. The most direct way to test this theory is by exploring those oceans with a robotic submarine – and that's just what a vehicle currently being developed at NASA's Jet Propulsion Laboratory is. Called BRUIE, which stands for Buoyant Rover for Under-Ice Exploration, it's initially intended for research in ice-covered seas on Earth, but it could easily be adapted for use on a future mission to an icy moon like Europa or Enceladus, where it could search for signs of life at the ice-water boundary.

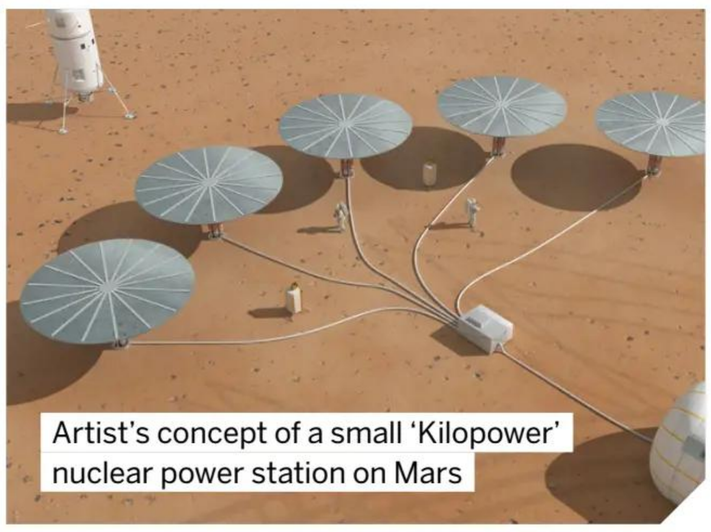
The atmosphere on Mars is thin enough that a vacuum-filled airship might be feasible

VACUUM AIRSHIP

STATUS: **NASA PROPOSAL**

RANGE: **PLANETARY ATMOSPHERE**

On Earth, an airship floats because it's filled with a lightweight gas like hydrogen or helium. Theoretically, an even more efficient airship could be built if it was filled with nothing at all – a complete vacuum. That's not possible on Earth because of atmospheric pressure. On Mars, on the other hand, where the atmosphere is much thinner, such a design might be possible, and NASA scientists have proposed building such a vacuum-filled airship.



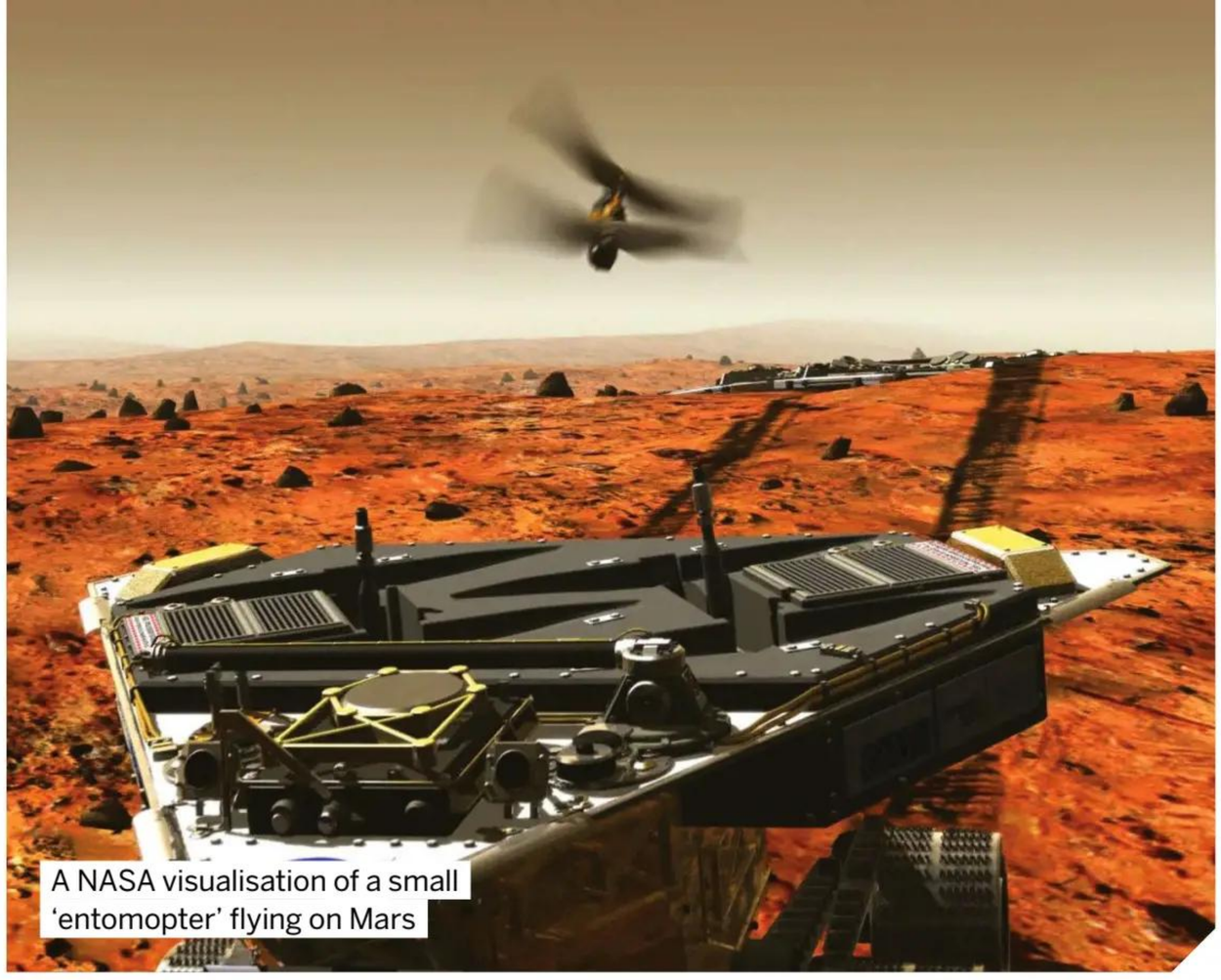
Artist's concept of a small 'Kilopower' nuclear power station on Mars

SUPPORT TECH: MARS POWER STATION

STATUS: **RESEARCH PROJECT**

RANGE: **N/A**

Any future settlement on Mars will require a source of electrical power, and the most compact solution would be a small nuclear power station. The Kilopower project team at the US Department of Energy's Los Alamos National Laboratory's proposed solution employs a heat pipe running around the reactor to circulate hot fluid to a device called a Stirling engine. This uses the heat to pressurise a gas and drive a piston, powering an electrical generator.



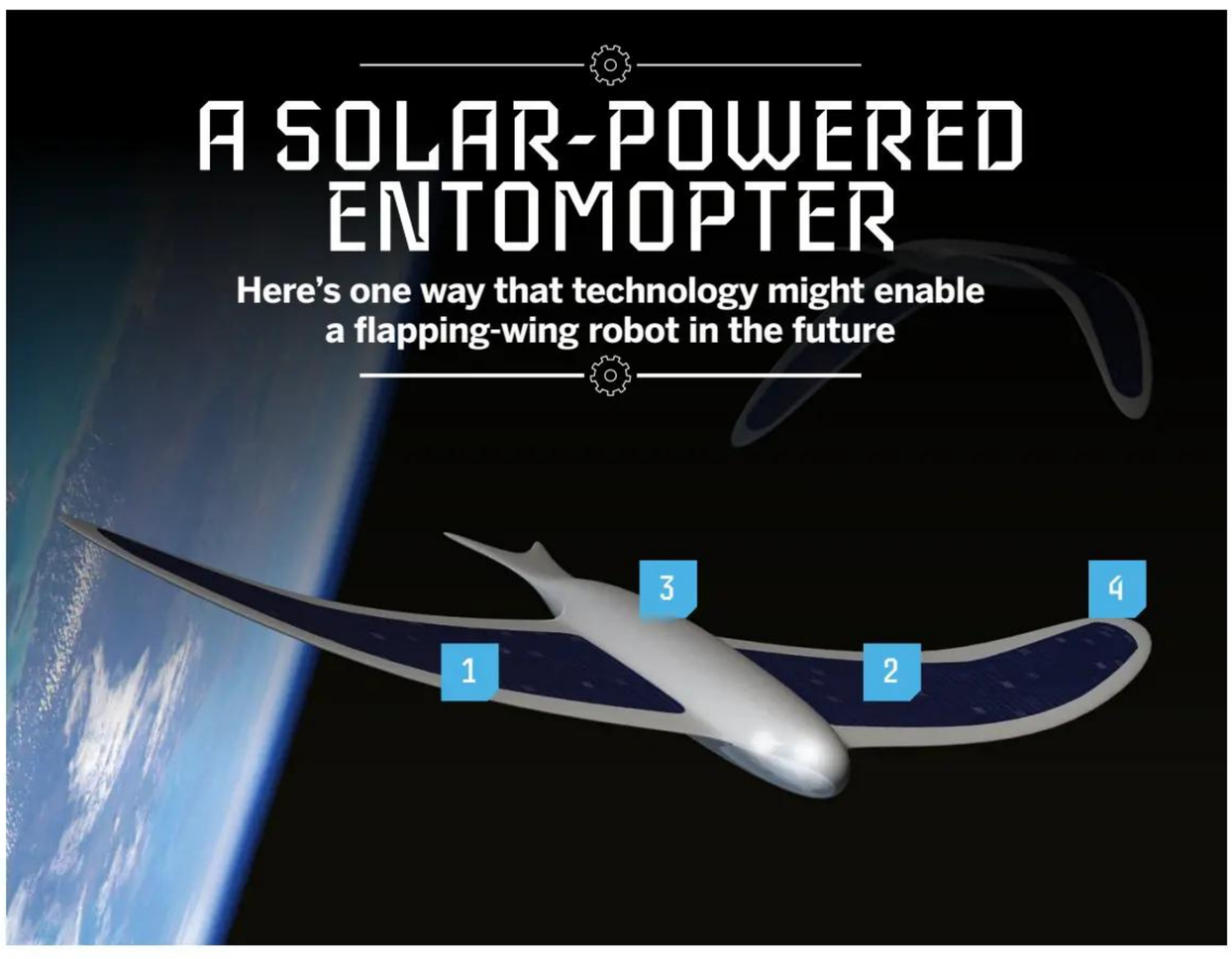
A NASA visualisation of a small 'entomopter' flying on Mars

FLAPPING WINGS ON MARS

STATUS: **RESEARCH PROJECT**

RANGE: **PLANETARY ATMOSPHERE**

We've already seen Ingenuity flying on Mars, but what about an entomopter? That's the technical term for a robotic vehicle that flies by flapping its wings like an insect. Theoretical studies have shown this to be an ideal way of flying in the thin atmosphere and low gravity of the Red Planet. NASA recently allocated research funding to a team working on 'Marsbees', which one team member, Chang-kwon Kang, described as "robotic flapping-wing flyers of a bumblebee size". The idea is that the tiny robots would operate in swarms, using a surface rover as a charging point and communications hub while observing their environment with miniaturised sensors.



1 FLEXIBLE WINGS
An ionic polymer-metal composite can display muscle-like behaviour under an applied voltage.

2 SOLAR PANELS
These provide all the electrical power for the wings and payload.

3 PAYLOAD
This could include a range of environmental sensors to study the atmosphere and surface of the planet.

4 COLLAPSIBLE DESIGN
The construction means that the structure can be folded up into a very small volume for transportation.

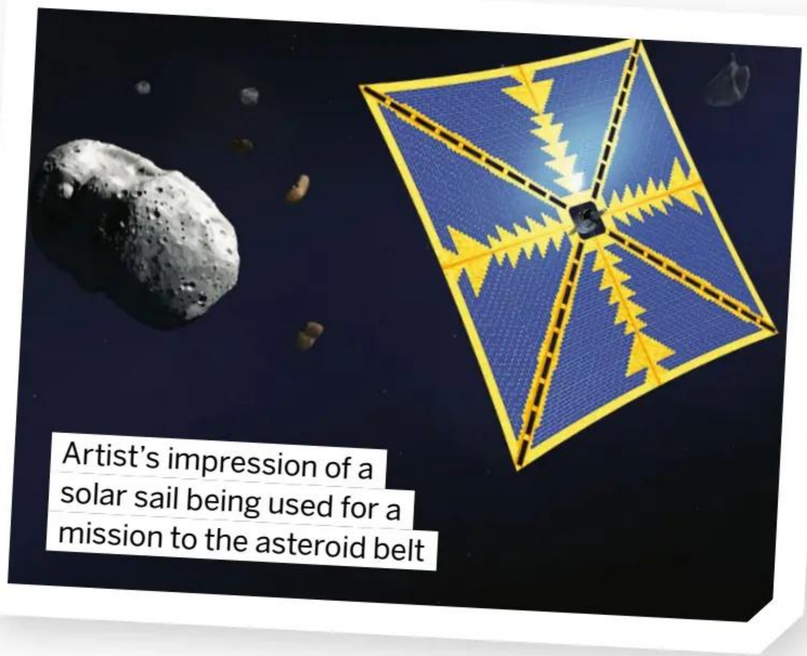
DID YOU KNOW? The Apollo astronauts were exposed to harmful radiation on the Moon

SOLAR SAIL

STATUS: **TESTED IN SPACE**
RANGE: **INTERPLANETARY**

Speculative physics like the Mach effect aside, there's only one way that a ship can be driven through space without expending any propellant and still obey the law of conservation of momentum, and that's if it acquires its additional momentum from an external source – the same way that a sailing ship on Earth gets its momentum from the wind. Within the boundaries of the Solar System there's an endless – and completely free – source of momentum in the form of the photons of light streaming out from the Sun. In theory it's possible for a spacecraft to pick up this momentum using a solar sail: a large piece of lightweight fabric with a highly reflective surface to bounce the photons off.

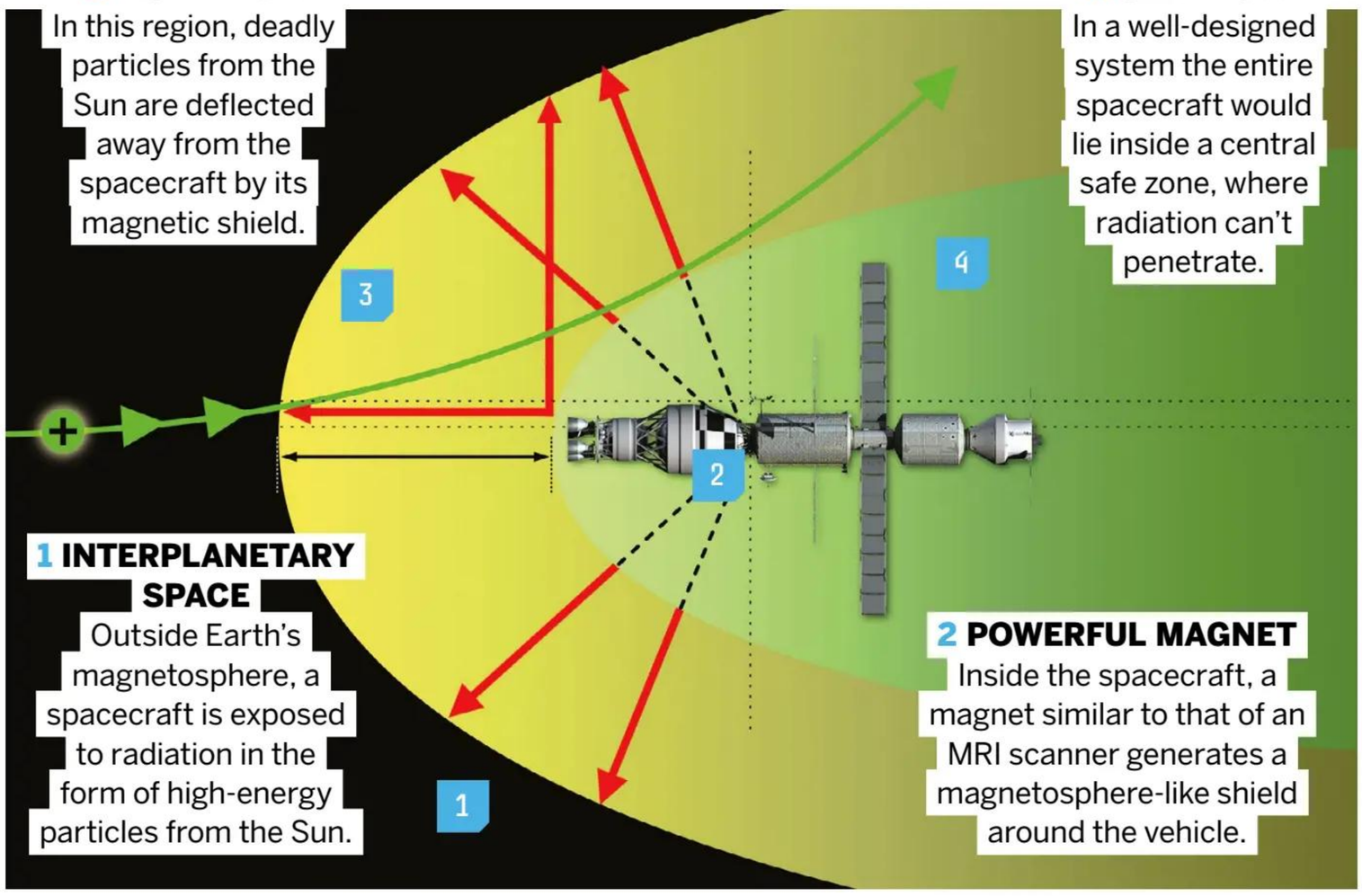
Although not used for a serious interplanetary mission yet, the basic principle has been demonstrated in Earth orbit by the Planetary Society, whose LightSail 2 spacecraft successfully flew between June 2019 and November 2022.



Artist's impression of a solar sail being used for a mission to the asteroid belt

MAGNETIC DEFLECTOR SHIELD

Astronauts could be protected from deadly radiation by an artificially generated shield around their spaceship



SUPPORT TECH: MINI-MAGNETOSPHERE

STATUS: **RESEARCH PROJECT**
RANGE: **N/A**

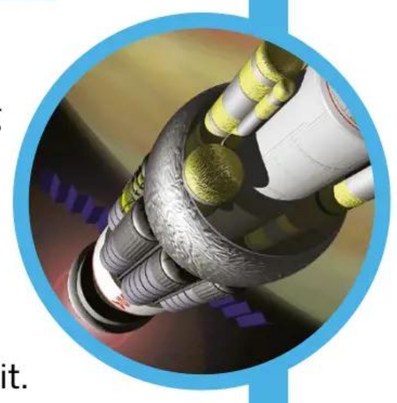
Did you know?
A solar sail could reach Neptune in under three years

Fortunately for us, Earth's magnetic field creates a protective shield around the planet called the magnetosphere. This deflects the harmful radiation coming from the Sun in the form of high-energy charged particles. Spacecraft close to Earth also lie within the magnetosphere, like the International Space Station. Once a ship is in interplanetary space, it no longer has this shield and the crew will need some other form of radiation protection. Researchers at the UK's Rutherford Appleton Laboratory are looking at the possibility of creating an artificial 'mini-magnetosphere' around the ship to serve this function.

FOUR CRAZY-BUT-TRUE PROPOSALS

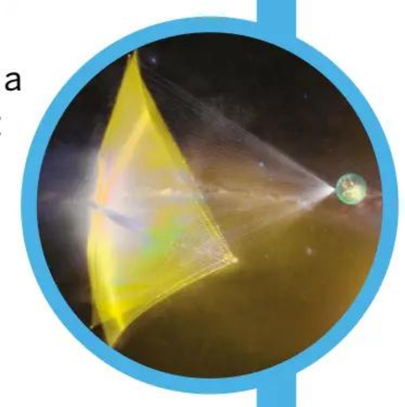
PROJECT ORION

This research project, which actually saw some hardware testing by General Atomics in 1959, considered powering a deep-space mission by exploding a series of nuclear bombs behind it.



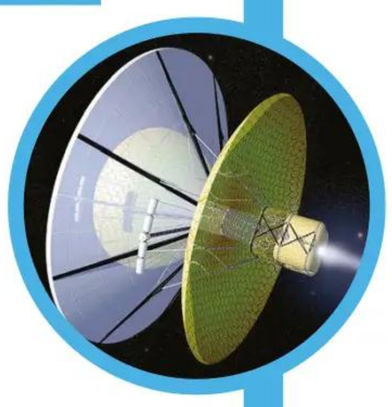
BREAKTHROUGH STARSHOT

This proposal involves a fleet of tiny spacecraft on a flyby mission to Alpha Centauri using light sails powered not by the Sun but by a super-powerful laser beam.



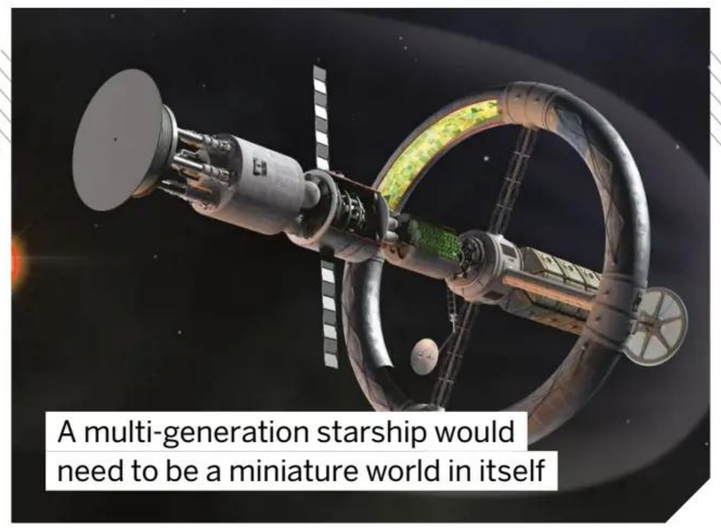
BUSSARD RAMJET

Proposed in 1960 by physicist Robert W. Bussard, this scientifically feasible interstellar propulsion system would be fuelled by the ultra-tenuous gas that permeates space.



SPACE ELEVATOR

This grandiose concept, which is being researched by several groups around the world, would see an elevator cable stretching all the way from Earth's surface to a geostationary satellite.



A multi-generation starship would need to be a miniature world in itself

GENERATION SHIP

STATUS: **THEORETICAL**

RANGE: **INTERSTELLAR**

A craft heading for another star system will take several centuries to reach its destination. This inevitably means that its passengers will go through many generations that are born, live and die during the trip. The possibility of a multi-generation starship was discussed early in the 20th century by spaceflight pioneers Robert Goddard and Konstantin Tsiolkovsky, and has subsequently featured in numerous science-fiction stories.

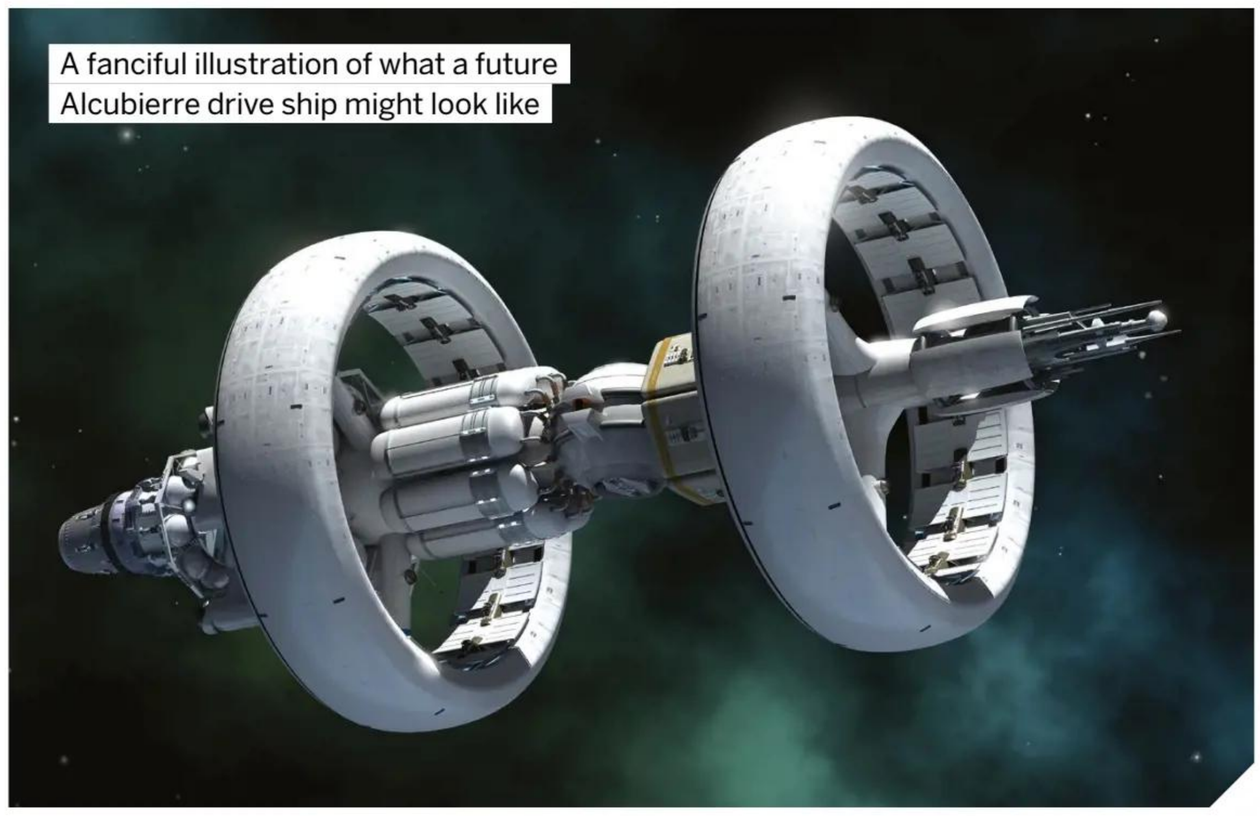
Von Braun station would spin on its axis to produce artificial gravity at its circumference

VON BRAUN STATION

STATUS: **PROPOSAL**

RANGE: **N/A**

Wernher von Braun is best known as a rocket designer, but in the 1940s and 1950s he envisioned a giant wheel-shaped space station in Earth orbit. This would spin on its axis to provide artificial gravity, with centrifugal force pressing people against the wheel's outer rim much as gravity presses us against Earth's surface. In 2019, a private organisation called the Gateway Foundation proposed building a luxury orbiting hotel of similar design, which they appropriately refer to as Von Braun Station after the man who conceptualised the idea.



A fanciful illustration of what a future Alcubierre drive ship might look like

ALCUBIERRE DRIVE

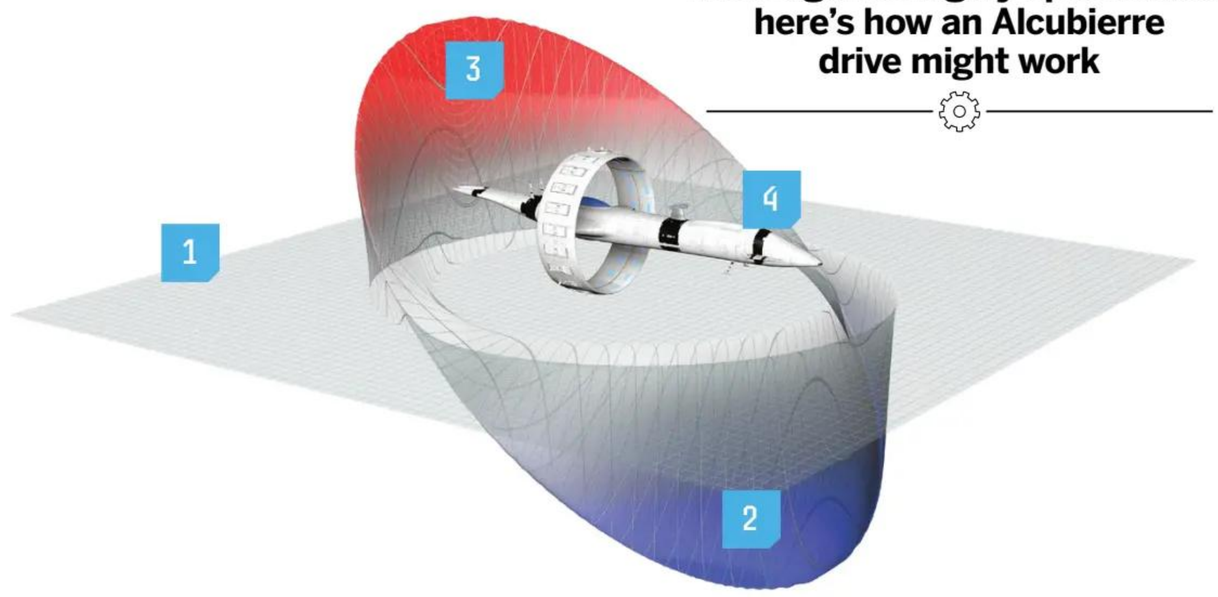
STATUS: **SPECULATIVE**

RANGE: **INTERSTELLAR**

According to Einstein's theory of general relativity, the underlying structure of space and time can be distorted – or warped – by a strong gravitational field. It was likely with this in mind that the creators of *Star Trek* used the term 'warp drive' for a starship's propulsion system in the 1960s, but it wasn't until 1994 that physicist Miguel Alcubierre showed how such a drive might actually work. His idea was to create a mechanism that would distort the fabric of space-time in such a way that the space ahead of the ship would contract while the space behind it expands. This would produce a 'warp bubble' in which the ship is pushed along through an otherwise undistorted space. Alcubierre showed such a mechanism to be possible in theory, although it's so fraught with engineering problems that it's unlikely that anyone will ever be able to build one.

A REAL WARP DRIVE

Although it's highly speculative, here's how an Alcubierre drive might work



1 UNDISTORTED SPACE
For simplicity, ordinary three-dimensional space can be pictured as a flat two-dimensional sheet.

2 COMPRESSED SPACE
The space ahead of the ship is distorted in such a way that it shrinks.

3 EXPANDED SPACE
To balance the compressed space ahead of the ship, the space behind it expands.

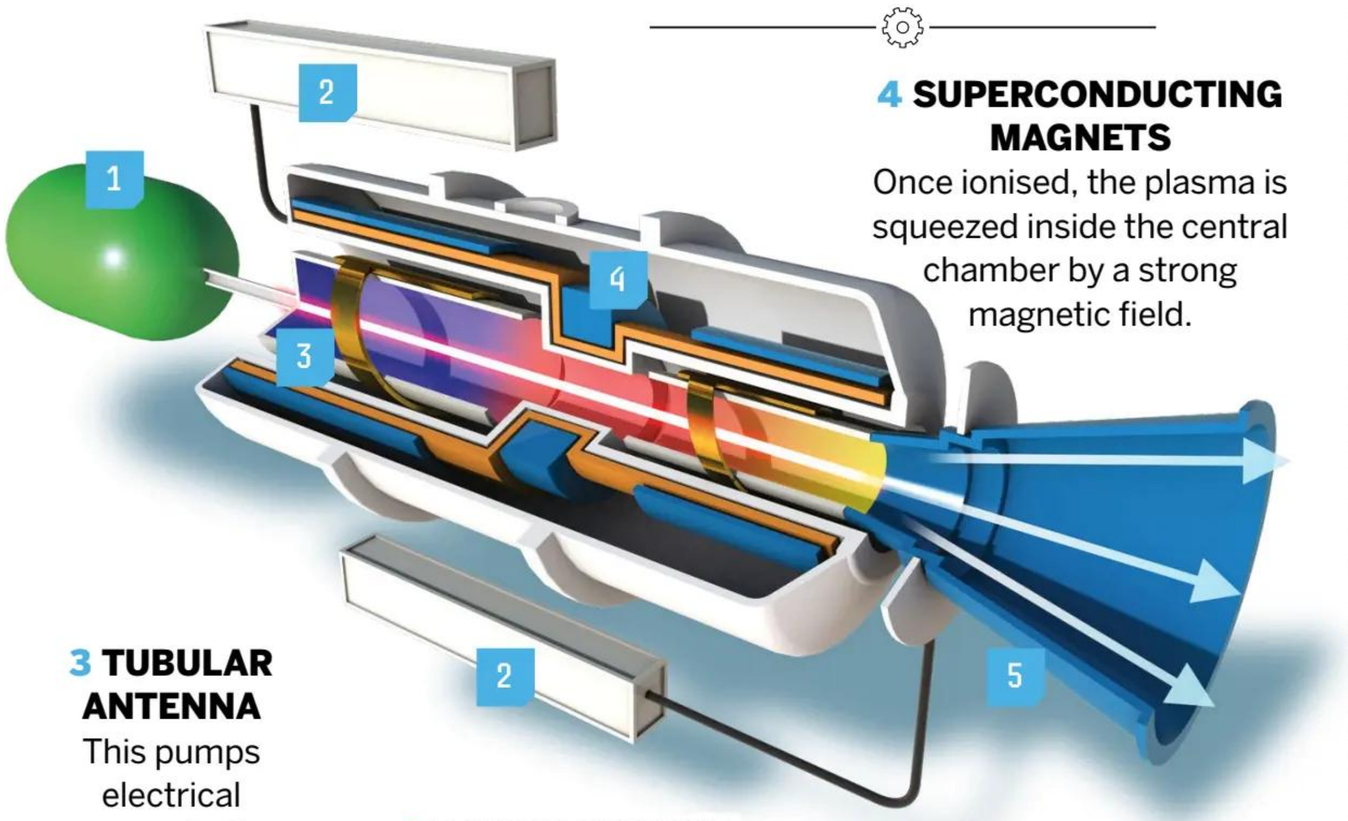
4 SPACESHIP
The ship effectively remains stationary inside its 'warp bubble', but the bubble itself is pushed forwards at high speed.

DID YOU KNOW? A 76-metre-diameter space station rotating three times a minute would produce a third of Earth's gravity at its rim

INSIDE THE PLASMA ROCKET

Drawing on 25 years of research by Ad Astra, this is how VASIMR would work

1 PROPELLANT TANK
This would typically be an inert gas like argon or xenon, stored in neutral form prior to ionisation.



4 SUPERCONDUCTING MAGNETS
Once ionised, the plasma is squeezed inside the central chamber by a strong magnetic field.

3 TUBULAR ANTENNA
This pumps electrical energy, in the form of radio waves, into the propellant to ionise it.

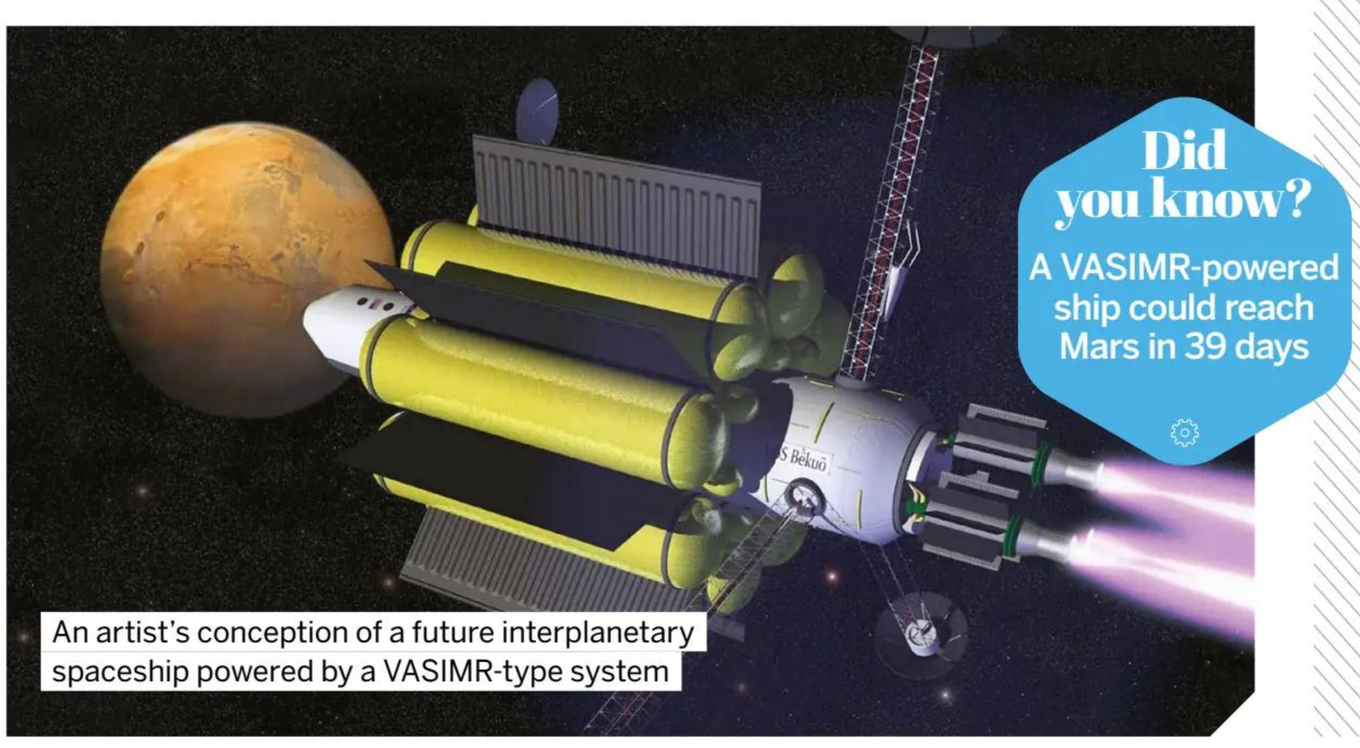
2 POWER SOURCE
Either solar or nuclear power could be used to generate electricity, depending on the amount needed.

5 MAGNETIC NOZZLE
After being heated to a high temperature, the plasma is ejected from the back of the engine to produce thrust.

VASIMR

STATUS: **UNDER DEVELOPMENT**
RANGE: **INTERPLANETARY**

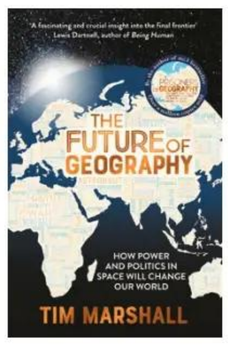
VASIMR is a spacecraft engine under development by the Ad Astra Rocket Company. It stands for Variable Specific Impulse Magnetoplasma Rocket; it's comparable to an ion thruster insofar as it uses electricity as the main energy source, although its mode of operation is different. It starts in the same way by ionising a gas, but instead of using just positively charged ions as the propellant it employs a neutral plasma containing both positive ions and electrons. This is channelled through a magnetic field and ejected at high speed to provide a much greater thrust than a standard ion drive. Using either solar panels or a nuclear reactor to generate electricity, VASIMR could power a wide range of space vehicles, from small robotic spacecraft to much larger human-crewed ones, including deep-space missions to Mars and beyond.



An artist's conception of a future interplanetary spaceship powered by a VASIMR-type system

COLONISING SPACE

Tim Marshall is the author of *The Future of Geography: How Power and Politics in Space Will Change Our World*



Is a second Space Race already happening?
Definitely. There are similarities to the previous one, but it's different. In the 1960s and 1970s the Soviets and Americans were each trying to demonstrate that their technology was superior to the other as part of proving their political systems were superior. There's an echo of that now with China and the US, but it's much less ideological and less pronounced. The new race is driven by commercial prospects and military planning. No great power can allow another to be the only one trying to gain the potential advantages of mining the Moon, nor of militarily dominating space.

When space technology allows us to more easily explore and colonise other planets, do you envisage an orderly division of territories backed by international agreements?
Unless and until the outdated existing international agreements on space are completely overhauled and made relevant to the 21st century, it will be a land grab by individual powers and/or blocs. The Artemis Accords have a clause talking about 'safety zones'. Fine, the 20 signatories could agree on one, but why should the other 173 countries? Starlink's terms and conditions for service on Mars say any disputes "will be settled through self-governing principles". Frontier America? For Texas 1836 read Mars 2086.

How will we progress to exploring our galactic locale?
2030 looks ambitious, but ten years from now could be possible. During this period the Chinese and possibly the Russians will show up. Both blocs will have basic Moon bases and commercial activities up and running by the late 2030s. By then China and SpaceX may well have sent crewed missions to Mars, but Elon Musk's original idea of a million people living there by 2050 looks completely unrealistic.

FINDING MOON ROCKS

Why astronauts brought lunar rubble back to Earth

WORDS **SCOTT DUTFIELD**

More than 200,000 miles from Earth is a round lump of rock that has fascinated humankind for thousands of years: our natural satellite, the Moon. In 1969, humans made the valiant journey beyond our atmosphere and across the vacuum of space to bring some of it home. Before astronauts walked on the Moon's surface, it was widely believed that Earth's natural satellite was merely a space rock that had drifted too close to Earth's gravitational grasp and become trapped within it. However, thanks to the rocks brought back to Earth for study, the theory behind the Moon's origin has shifted in favour of the giant impact hypothesis.

The majority of the Moon is made up of anorthosite, a calcium-rich rock that consists mostly of a mineral known as plagioclase feldspar. These minerals are formed from the solidification of hot molten lava. It's thought that throughout the Moon's existence, countless impacts from crater-forming meteorites have pockmarked its surface, which was once a raging ocean of molten rock before it cooled and solidified. Moon rocks brought back by astronauts have also revealed the biggest collision in the Moon's history.

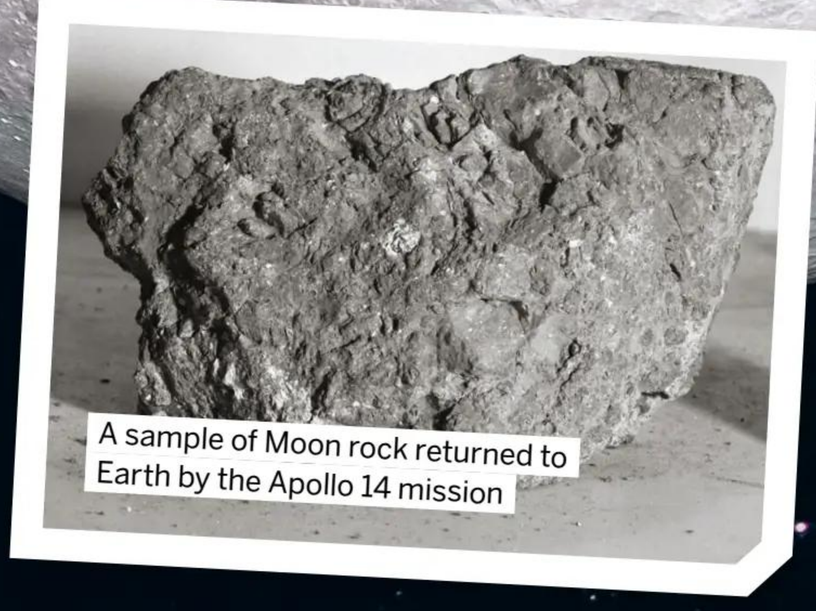
Rather than simply gravitationally leashing it, Earth played a part in the Moon's creation when it collided with a huge extraterrestrial object known as Theia. The collision chipped away at Earth's surface, the fragments of which came together with broken pieces of Theia and formed the Moon around 4.5 billion years ago.

Did you know?

The Moon formed in a matter of hours

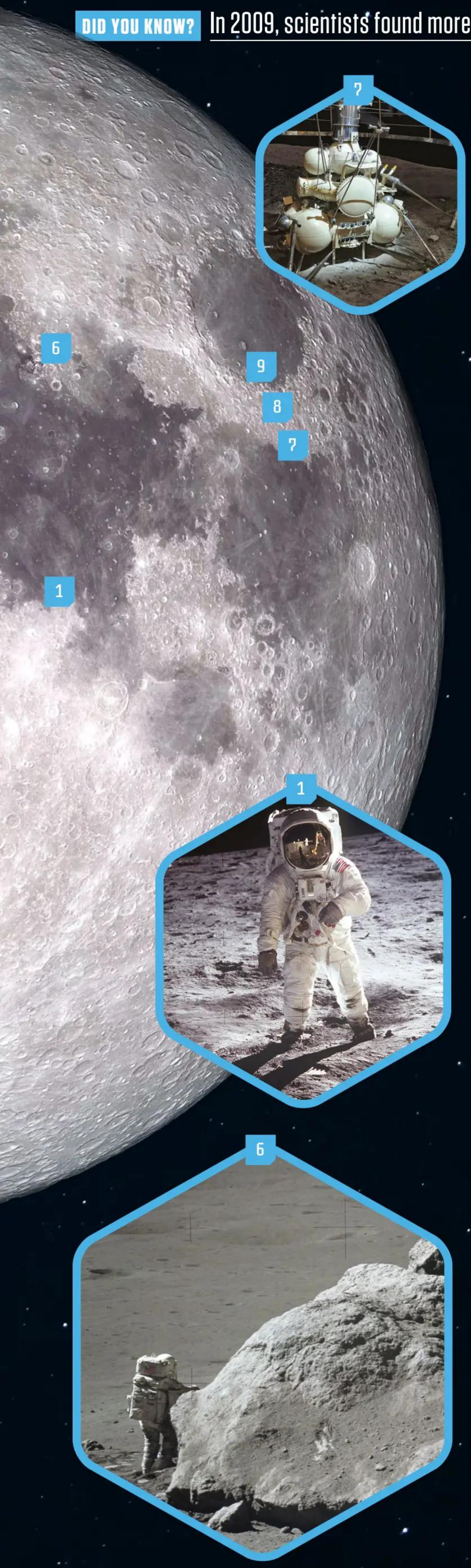
In 2019, scientists studying a breccia sample – a rock consisting of fragments of other stones and material – from the Apollo 14 mission discovered that some pieces of the sample didn't originate from the Moon, but from terrestrial rock found on Earth.

Discoveries about the history of the Moon are continually being made from the samples retrieved by astronauts and space robots over the last few decades. Almost 50 years after the Apollo 17 mission, scientists studying some of the retrieved lunar samples at the University of Hawaii have discovered the Moon may have cooled down much quicker after its formation than thought. It's been accepted that the Moon spent 100 million years cooling down, but chemical variations in some of the sample's minerals suggest that it only took 20 million years for the Moon to cool down. Each year around 400 lunar samples from the Apollo missions are distributed to institutes for further research across the globe.



A sample of Moon rock returned to Earth by the Apollo 14 mission

DID YOU KNOW? In 2009, scientists found more than 40 craters thought to contain water ice



MOON ROCK MISSIONS

Where have astronauts and space robots collected lunar samples from?

1 APOLLO 11
TRANQUILITY BASE
16 TO 24 JULY 1969

Astronauts Neil Armstrong and Buzz Aldrin became the first people to walk on the Moon. During their 21 hours and 36 minutes on the surface, they collected around 22 kilograms of lunar samples.

2 APOLLO 12
OCEANUS PROCELLARUM
14 TO 24 NOVEMBER 1969

On the second successful mission to the Moon, astronauts Alan Bean and Charles Conrad retrieved 12 lunar samples weighing a total of 34 kilograms.

3 APOLLO 14
FRA MAURO
31 JANUARY TO 9 FEBRUARY 1971

Astronaut Alan Shepard trekked more than 2,700 metres across the Moon's surface, using a hand cart to collect samples that amounted to around 43 kilograms.

4 APOLLO 15
HADLEY-APENNINE
26 JULY TO 7 AUGUST 1971

Around 77 kilograms of lunar rock was ferried around the Moon in a space car called the Lunar Roving Vehicle (LRV) by astronauts David Scott and James Irwin.

5 APOLLO 16
DESCARTES HIGHLANDS
16 TO 27 APRIL 1972

Using the LRV, astronauts Charles Duke and John Young travelled over 16 miles across three moonwalks to collect a whopping 95 kilograms of lunar samples.

6 APOLLO 17
TAURUS-LITTROW
7 TO 19 DECEMBER 1972

In the last Apollo mission that retrieved rock samples, astronauts Gene Cernan and Harrison Schmitt spent three days on the surface and collected 110 kilograms of samples to bring home.

7 LUNA 16
MARE FECUNDITATIS
12 TO 24 SEPTEMBER 1970

During a trip to the Moon by the Soviet Union, an unmanned robotic probe scooped up 101 grams of lunar soil and successfully returned it to Earth.

8 LUNA 20
TERRA APOLLONIUS
14 TO 25 FEBRUARY 1972

Similarly to Luna 16, another unmanned probe landed on the Moon's surface and grabbed 30 grams of lunar soil.

9 LUNA 24
MARE CRISIUM
9 TO 22 AUGUST 1976

Around 170 grams of soil was taken by a probe with the use of a robotic arm and rill. This was the third and final mission by the Soviet Union to retrieve Moon rock.

10 CHANG'E 5
MONS RÜMKER
23 NOVEMBER TO 16 DECEMBER 2020

In China's first lunar sample-return mission, the unmanned Chang'e 5 probe dug as deep as two metres into the surface to extract around two kilograms of rock to bring back for study on Earth.

CHANG'E 6
SOUTH POLE-AITKEN BASIN
MAY 2024

Next year, China could become the first nation to reach a previously unexplored part of the Moon. Chang'e 6 will be the first mission to take samples on the far side of the Moon, from the lunar south pole. It's particularly difficult to safely land on that side of the Moon because it never faces Earth. To get a better view of where Chang'e 6 will land, China will send out a scout satellite called Queqiao 2 to act as a communications middleman between the spacecraft and the team back on Earth. The entire Chang'e 6 mission is set to last 53 days and aims to collect up to two kilograms of lunar material.

ENVIRONMENT

EXTREME EARTH

From natural death traps to human-made danger zones, here are some of the most hostile places on our planet

WORDS AILSA HARVEY

DID YOU KNOW? Antarctica hasn't always been cold – 90 million years ago it was as warm as Italy is today

WORLD'S HOTTEST PLACE

DEATH VALLEY, CALIFORNIA

Did you know?

Death Valley is the lowest place in North America

Mountain ranges surround Furnace Creek

If you were to step outside on one of the hottest days in Death Valley, you wouldn't be able to feel the sweat on your skin due to its almost-instant evaporation. The tall mountain ranges that surround Death Valley – a desert valley that stretches over the border of California and Nevada – trap intense heat throughout the summer season. Here, less than five centimetres of rain falls annually, meaning the ground heats up quickly and the temperature builds between the mountains.

The valley regularly produces an air temperature of 49 degrees Celsius in shaded areas and is the site of the world's highest recorded air temperature of 57 degrees Celsius. This event took place at Furnace Creek on 10 July 1913. As Earth's changing climate produces higher temperatures, the number of days that some residents of Death Valley are forced to spend inside air-conditioned homes is increasing. Contrary to its name, there is life in Death Valley. One of the most common animals that lives there is the roadrunner. Roadrunners are small birds with high body temperatures, helping them endure the heat of the valley. Because their body temperatures are naturally 40 degrees Celsius, the intense heat doesn't impact their biology as much.

Stones appear to move by themselves in Death Valley

EARTH'S COLDEST CORNERS

ANTARCTICA

Because of the little direct sunlight hitting the icy landscapes of Antarctica, this continent is where the coldest spot in the world can be found, with temperatures low enough to freeze human skin within minutes.

1 EASTERN ANTARCTIC PLATEAU
-94 DEGREES CELSIUS
At this Antarctic location, frostbite occurs in humans after just two minutes of skin exposure.

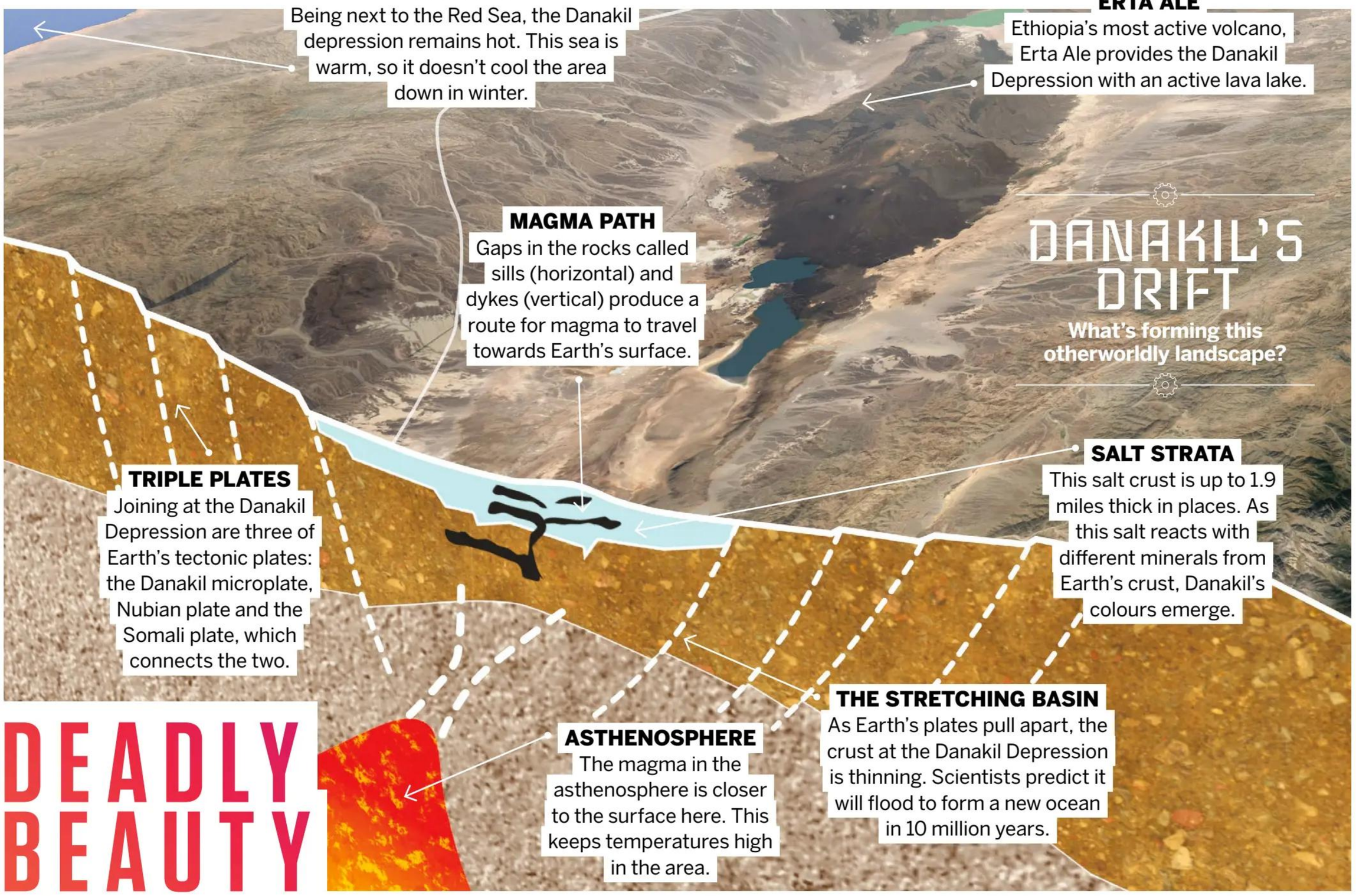
4 DOME FUJI
-93.3 DEGREES CELSIUS
When precipitation falls on Dome Fuji, the water turns to ice crystals before it reaches the ground.

3 AMUNDSEN-SCOTT STATION
-82.8 DEGREES CELSIUS
This area receives six months of sunlight in the summer, followed by six sunless months throughout winter.

2 VOSTOK STATION
-89.2 DEGREES CELSIUS
In 1983, this was the lowest temperature ever recorded on Earth, being 30 degrees colder than the average winter in the area.

5 DOME ARGUS
-82.5 DEGREES CELSIUS
This is the highest ice dome in Antarctica. It's often referred to as the 'inaccessible pole' due to the extreme cold and its central location.

The Amundsen-Scott South Pole Station is 2,835 metres above sea level



DEADLY BEAUTY

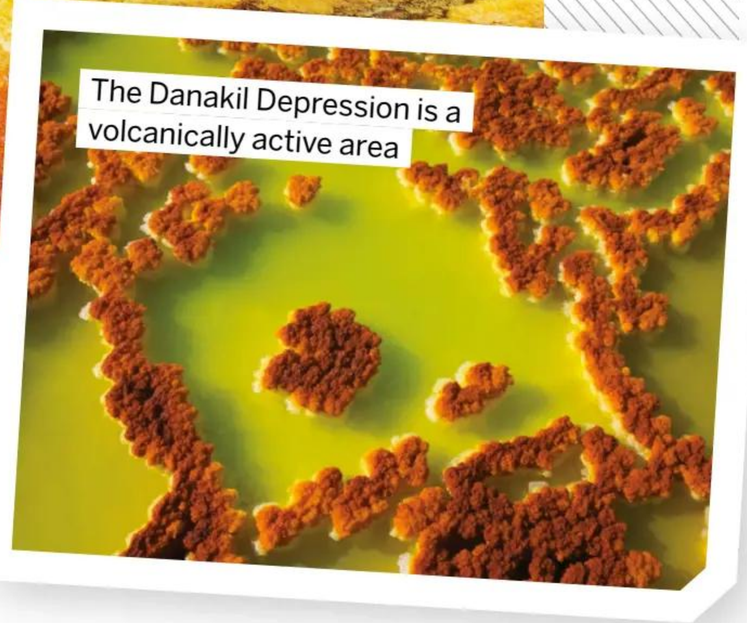
THE DANAKIL DEPRESSION, AFAR, ETHIOPIA

The vibrant landscape of the Danakil Depression looks like a painting created by an abstract artist. The Sun highlights the fluorescent spatterings that decorate red-tinged rocks as they protrude from the still green waters. However, this place is as deadly as it is mesmerising. At 125 metres below sea level, the area has high hydrothermal activity and an impressive collection of Earth's overflowing elements, and it's these that produce its rainbow appearance.

The reddened rocks are a result of high volumes of iron oxide, the yellow deposits are a range of sulphates, while copper sulphates are the cause of the blue-green water. Above these steamy springs, plumes of chlorine and sulphur vapour produce a toxic fog, while the waters are heated to temperatures near boiling.

Despite the volatile cocktail of chemicals in one of the world's hottest and driest patches, some extremophiles – organisms that live in environments that are usually hostile to life – can be found in the Danakil Depression. But what can survive in a land where exceptionally salty pools are more acidic than battery acid?


These acidic springs look like the surface of another planet


The Danakil Depression is a volcanically active area

Two types of bacteria have been found here, one of which lives in the salt springs and another in the nearby lakes. The bacteria are categorised as polyextremophiles as they are adapted to life in an environment that is hostile to life in a number of ways.

DID YOU KNOW? Animals in Chernobyl have high levels of radioactive caesium-137 in their bodies

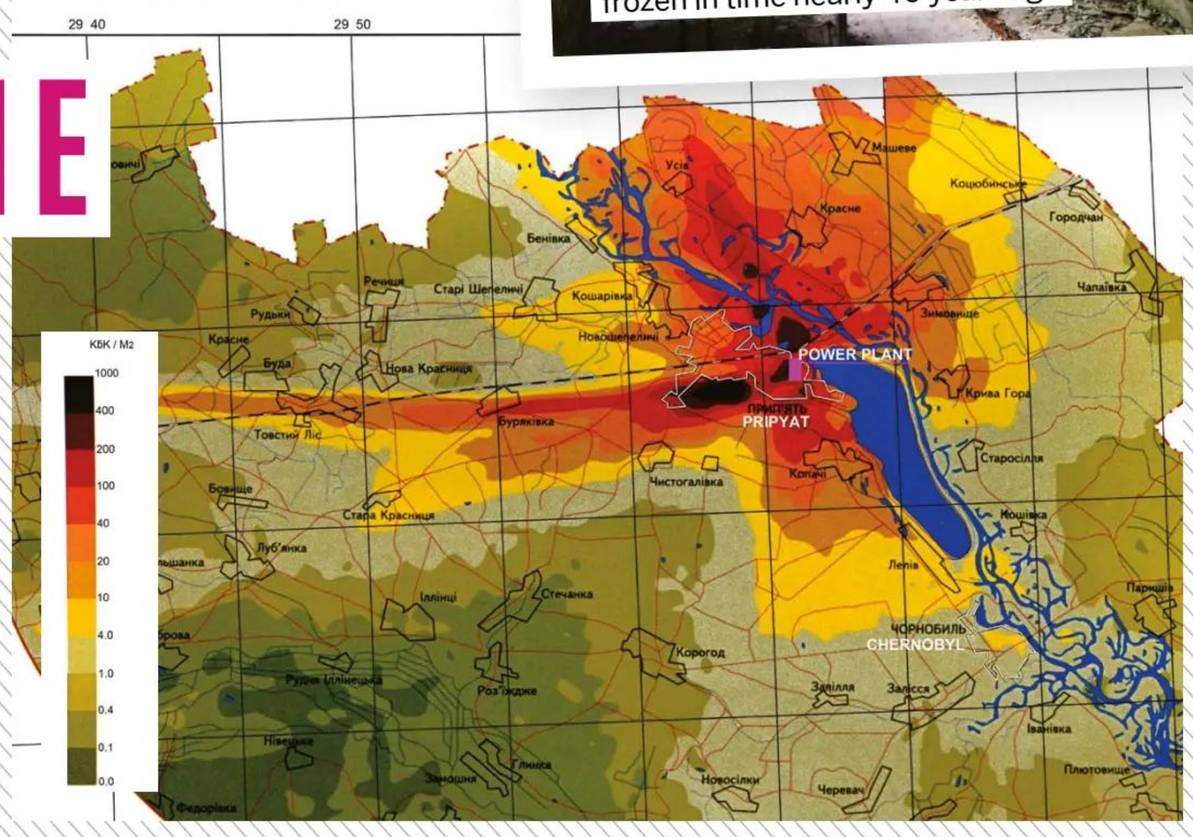
RADIOACTIVE EXCLUSION ZONE

PRIPYAT, UKRAINE

When the Chernobyl Nuclear Power Plant went into meltdown on 26 April 1986, the immediate radioactive fallout could kill an exposed person in just over a minute. It was the world's worst nuclear disaster, and the scale meant that the detriment to life couldn't be hidden. In fact, radioactive clouds could be seen from as far away as Sweden. After trying to hide the extent of the disaster from the world, the Soviet Union eventually plotted an official 'exclusion zone', evacuating everyone in the area due to the deadly radiation levels. This zone has an 18-mile radius, including the nearby city of Pripyat, which became a ghost town overnight as the entire population of 49,000 people was evacuated.

While radioactive levels are naturally diminishing, the area still has multiple dangerous 'hotspots'. Security guards who restrict access to these hotspots can only work for 15 days before spending the following 15 days away from the area to recover from radiation exposure. High radiation levels will remain in the exclusion zone for 300 years, but animals and plants have since moved into the places that humans no longer inhabit.

Abandoned buildings in Pripyat, frozen in time nearly 40 years ago



This colour-coded map shows the density of plutonium contamination in the power plant's surrounding areas. This ranges from the highest contamination (black) to relatively low contamination (green)

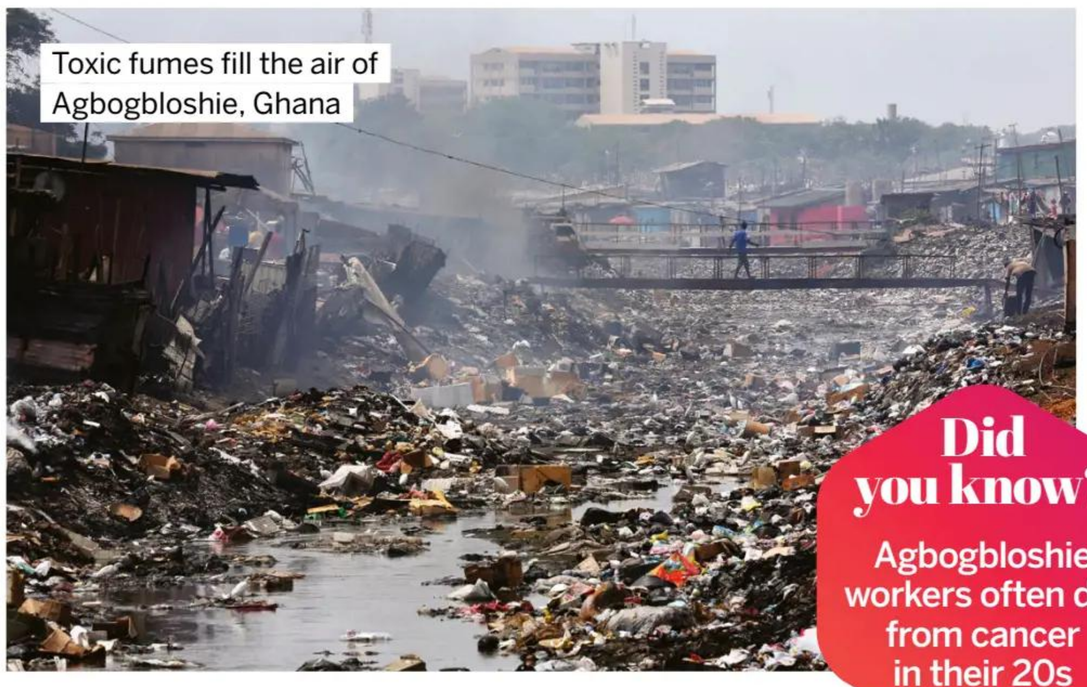
ROMAN 'GATE TO HELL'

PAMUKKALE, DENIZLI, TURKEY

2,000 years ago in the ancient city of Hierapolis, Romans were drawn to a cave that caused everything from small birds to large mammals to drop dead when they approached its entrance. The science behind this deadly cave was unknown at the time, and so ancient Romans believed the cave released the 'breath of death' from the god of the underworld. This led to a temple being built over the cave, attracting frequent visits to the spectacle.

In reality, scientists have now discovered that deep below this cave is a crack in Earth's crust, releasing toxic concentrations of carbon dioxide gas through the cave's narrow opening. At the opening of the cave, carbon dioxide levels are between 4 and 53 per cent, up to 91 per cent at deeper points inside the cave. Concentrations of just over seven per cent of this gas can render a person unconscious and kill them due to a lack of oxygen.

The Romans built a temple over the 'gate to hell'



Toxic fumes fill the air of Agbogbloshie, Ghana

Did you know?

Agbogbloshie workers often die from cancer in their 20s

TOXIC E-WASTE DUMP

AGBOGBLOSHIE, ACCRA, GHANA

This Ghanaian wetland used to be a lush land that served as a fresh water supply, an open area for cattle to graze and home to one of the largest food markets in Accra. However, ships have been sailing to illegally dump electronic waste here since 2000, leading to the soil, water and air becoming gravely contaminated by toxic heavy metals and chemicals. From discarded electronic equipment, metals such as beryllium, mercury and cadmium leach into the environment.

Some locals use the dump as a workplace to dismantle and burn electronics to extract valuable metals to sell. This highly dangerous job has devastating health implications. Similarly, those living in Agbogbloshie have no choice but to use the toxic environment for producing food – but the products can be just as deadly. One free-range egg that was hatched by an Agbogbloshie chicken exceeded the European Food Safety Authority's maximum chlorinated dioxin levels by 220 times. This deadly compound can cause cancer and damage the immune system, and it's just one of over 1,000 harmful substances killing residents of Agbogbloshie.

Around 50 volcanic eruptions take place annually around the world

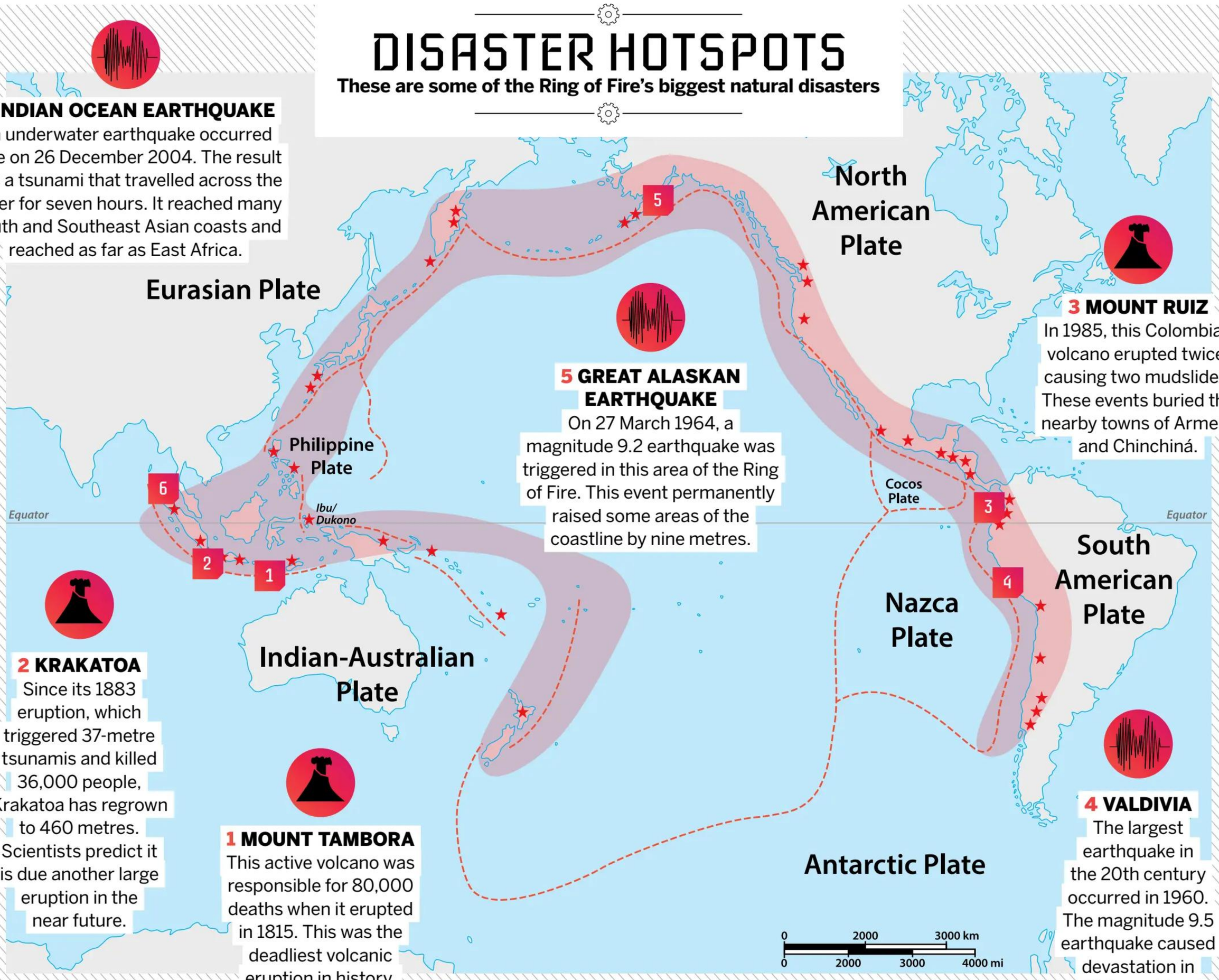
RING OF FIRE

PACIFIC COAST

Tectonic plates are a giant jigsaw covering the surface of our planet. These 17 major pieces of Earth's crust appear to fit together neatly on a map. However, they don't fit as perfectly in reality as the huge slabs are constantly moving, often causing friction between two adjacent plates. When two plates collide, pull apart or slide past each other, earthquakes and erupting volcanoes can result. Two jolting plates can send rippling vibrations across 60 miles of land, while two separating plates can create a route for magma to leak above ground. The Ring of Fire is the name given to a border of the Pacific Ocean that surrounds several tectonic plates. The movement of these plates means that most of the world's earthquakes and volcanic eruptions occur somewhere along this volatile path. In total, 452 volcanoes lie on the Ring of Fire – 75 per cent of the world's volcanoes. Meanwhile, 90 per cent of all earthquakes occur in this region.

DISASTER HOTSPOTS

These are some of the Ring of Fire's biggest natural disasters



6 INDIAN OCEAN EARTHQUAKE
An underwater earthquake occurred here on 26 December 2004. The result was a tsunami that travelled across the water for seven hours. It reached many South and Southeast Asian coasts and reached as far as East Africa.

5 GREAT ALASKAN EARTHQUAKE
On 27 March 1964, a magnitude 9.2 earthquake was triggered in this area of the Ring of Fire. This event permanently raised some areas of the coastline by nine metres.

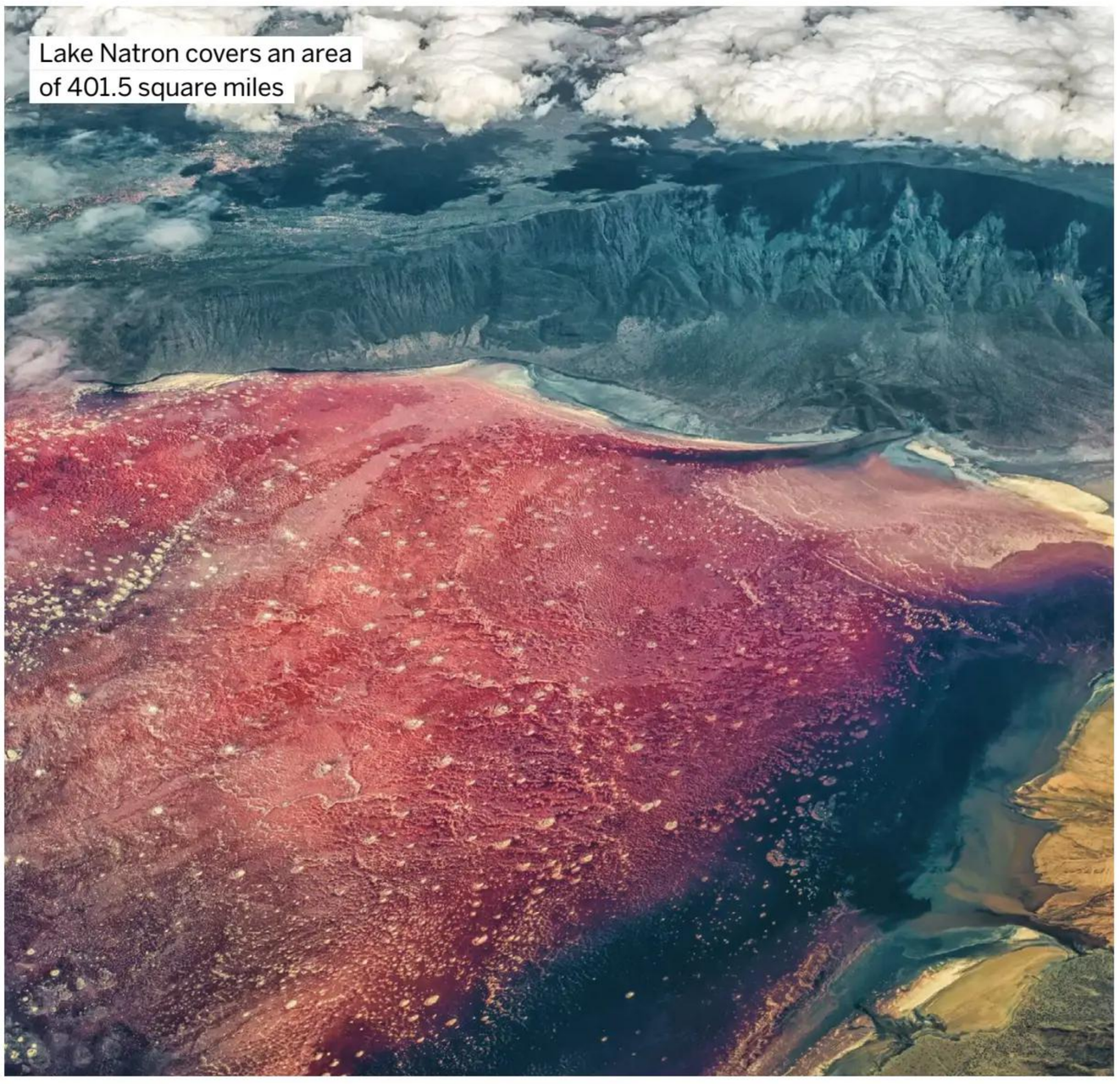
3 MOUNT RUIZ
In 1985, this Colombian volcano erupted twice, causing two mudslides. These events buried the nearby towns of Armero and Chinchiná.

2 KRAKATOA
Since its 1883 eruption, which triggered 37-metre tsunamis and killed 36,000 people, Krakatoa has regrown to 460 metres. Scientists predict it is due another large eruption in the near future.

1 MOUNT TAMBORA
This active volcano was responsible for 80,000 deaths when it erupted in 1815. This was the deadliest volcanic eruption in history.

4 VALDIVIA
The largest earthquake in the 20th century occurred in 1960. The magnitude 9.5 earthquake caused devastation in Chilean cities.

DID YOU KNOW? More active volcanoes are located on the west side of the Ring of Fire


Lake Natron covers an area of 401.5 square miles

DEADLY RED LAKE

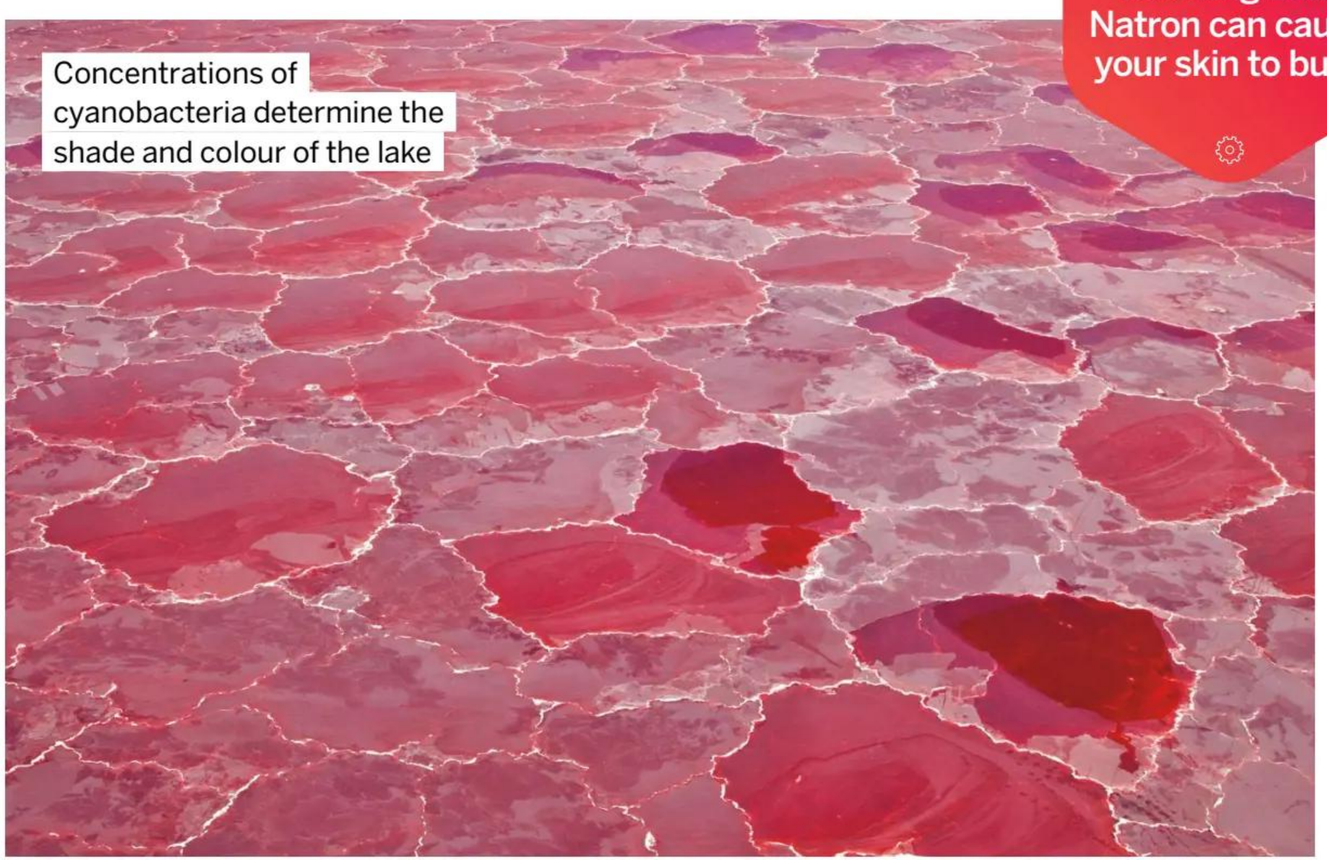
LAKE NATRON, NGORONGORO, TANZANIA

Occasionally littered with calcified corpses, this bright-red body of water gives a clear warning to any life that approaches its shores. While the majority of this lake belongs to Tanzania, the very tip crosses the border into Kenya.

At the opposite end lies its source – Mount Ol Doinyo Lengai. This volcano releases runoff water from its slopes, mixing it with volcanic material. As a result, the lake's water becomes highly salty and alkaline. The high salt concentration limits the animals and plant life that can survive in the waters. However, one organism that thrives in its salty waters is the extremophile cyanobacteria. This is a red algae that colours the lake and makes it toxic to other life. When consumed, cyanobacteria attack the cells, nervous systems and organs of animals and humans. And if an animal dies in these waters, there's a high chance that it will become calcified as the salty lake hardens its body.

Did you know?

Touching Lake Natron can cause your skin to burn


Concentrations of cyanobacteria determine the shade and colour of the lake

5 MOST EXTREME WEATHER LOCATIONS

1 STORMIEST
Lake Maracaibo in Venezuela experiences around 1.2 million lightning strikes every year. These strikes occur 28 times a minute and can last for nine hours at a time. Out of a year's 365 days, lightning will hit this lake on 300 of them.

2 WINDIEST
With regular wind speeds of 150 miles per hour, Commonwealth Bay in Antarctica is regarded as the windiest place on Earth. This is due to its crescent shape, which forces wind through the bay.

3 WETTEST
The village of Māwsynram is the rainiest place to live on Earth. Situated in northeastern India, the residents are used to an annual rainfall of around 12,000 millimetres. Homes regularly suffer battered roofs and landslides are a common threat.

4 DUSTIEST
The Bodélé Depression in Chad is the largest single source of dust on Earth. The strong surface-level winds blow small mineral particles into the air. More than half of the minerals that fertilise Amazon soil were blown from Bodele.

5 DRIEST
In stark contrast to Māwsynram, the Atacama Desert in Chile receives less than one millimetre of rain annually. In some areas of the desert there has been no rain for 500 years.

Undersea vents form where magma meets seawater

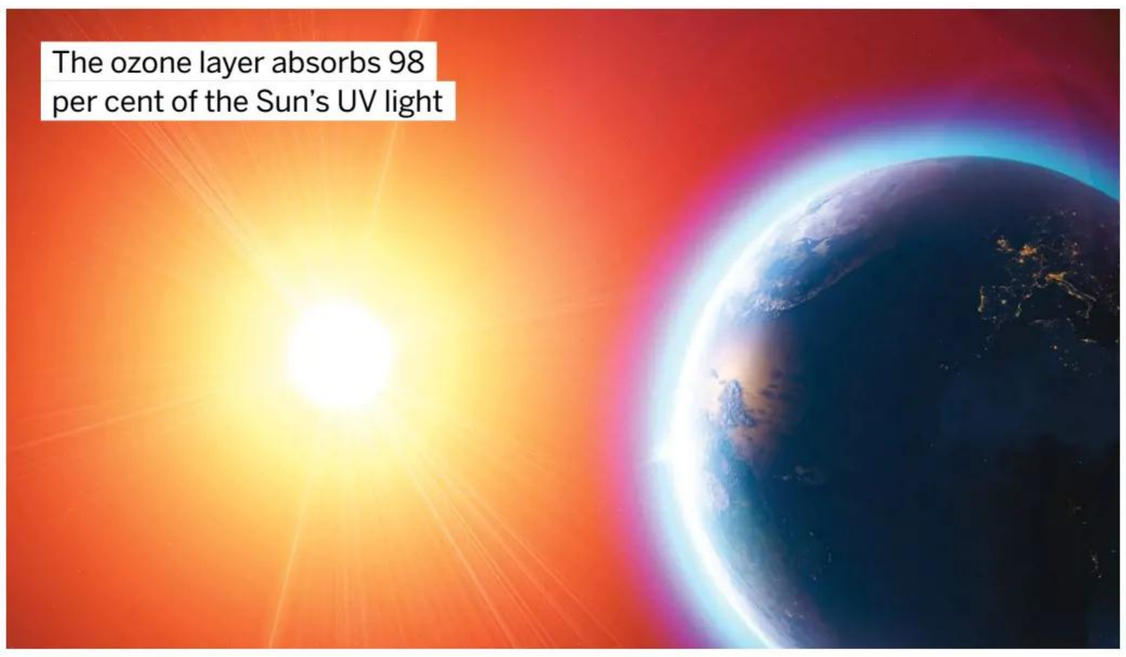
CRUSHING OCEAN DEPTHS


The light-producing organs on a hatchetfish's belly are called photophores

CHALLENGER DEEP, MARIANA TRENCH, PACIFIC OCEAN

The deepest point in the ocean is 10,929 metres underwater. It's called the Challenger Deep and is located at the bottom of the Mariana Trench. At these depths, most life forms fail to survive. The trench is devoid of natural light and has a water pressure 1,000 times that experienced at sea level.

Although life is limited, some creatures do call this isolated chasm their home – and these creatures are nothing like those near the surface. To combat the pressure, fish such as the Mariana snailfish have a gap in their skulls. This is because a fully formed skull would crack under the extreme pressures of the deep. Another trench-dweller is the deep-sea hatchetfish. These fish have light-producing organs lining their bellies to help them see in the total darkness. Amphipods, which are shrimp-like crustaceans, also inhabit the deepest parts of the Mariana Trench, such as *Hirondellea gigas*.


The ozone layer absorbs 98 per cent of the Sun's UV light

BEYOND THE OZONE

EARTH'S UPPER ATMOSPHERE

Earth ends and space begins in the exosphere. This is the final layer of Earth's atmosphere, between 3,700 and 6,200 miles from Earth's surface. Despite being part of Earth's atmosphere, the conditions are too harsh for most life forms to survive. Instead, most exist below the ozone layer – a section of the stratosphere around 9.3 to 18.6 miles above Earth's surface, largely composed of ozone molecules. These molecules are made of three oxygen atoms, forming a layer of gas that surrounds the planet and protects life by absorbing the high levels of ultraviolet (UV) radiation emitted by the Sun.

Some microorganisms may be living over 30 miles above Earth in the stratopause layer of the atmosphere. Organisms could have reached these heights by riding storms or the upthrust from a volcanic eruption. Having been elevated past the protective ozone layer into layers of intense radiation, only UV-resistant strains of organisms, such as the bacterial species *Micrococcus luteus*, have the potential to survive.

ACIDIC IRON MOUNTAIN

REDDING, CALIFORNIA

The world's most acidic water isn't a result of natural processes, but human activity. In this case, the cause is mining. Iron Mountain is a site with ten different mines that were in operation for nearly a century between 1879 and 1963. This incessant work provided a path for some of the mined metals to contaminate the surrounding waterways. In one of the copper and zinc mines, extremely acidic water was discovered. Dripping from the stalactites, this water, with a pH of -0.7, seeped through the mine and entered rivers. Water with this level of acidity is strong enough to kill most aquatic life within several miles of the entry point.


Iron drained from mines can produce red, yellow or orange sediment in rivers

DID YOU KNOW? In the past Boiling Lake has cooled, its water levels have changed and it has temporarily dried up

THE BOILING LAKE

BOILING LAKE, DOMINICA

After the four-hour hike needed to reach this lake from the nearby village of Laudat, you may be tempted to take a refreshing swim in its waters. However, this could result in serious injury or death, because this lake can turn into a deadly cauldron without warning. Boiling Lake, as its name implies, can begin to naturally boil as its water is heated by hot gas released from deep underground. The lake is classified as a fumarole – a vent in Earth's surface – that releases volcanic gases. This makes the water acidic and grey-blue in colour. There's usually an eerie cloud surrounding Boiling Lake, which you are likely to see before arriving at the vent. Due to the unpredictability of this boiling natural wonder, its depth has never been measured. When boiling, the edges of the water have been measured at 91.5 degrees Celsius, but the exact temperature at its centre remains unknown.

1 MOLTEN LAVA
The lava at the base of the vent heats any surrounding water in the rock.

2 TRAPPED WATER
Once water has seeped down through the porous rock and is trapped close to the lava, its temperature rises.

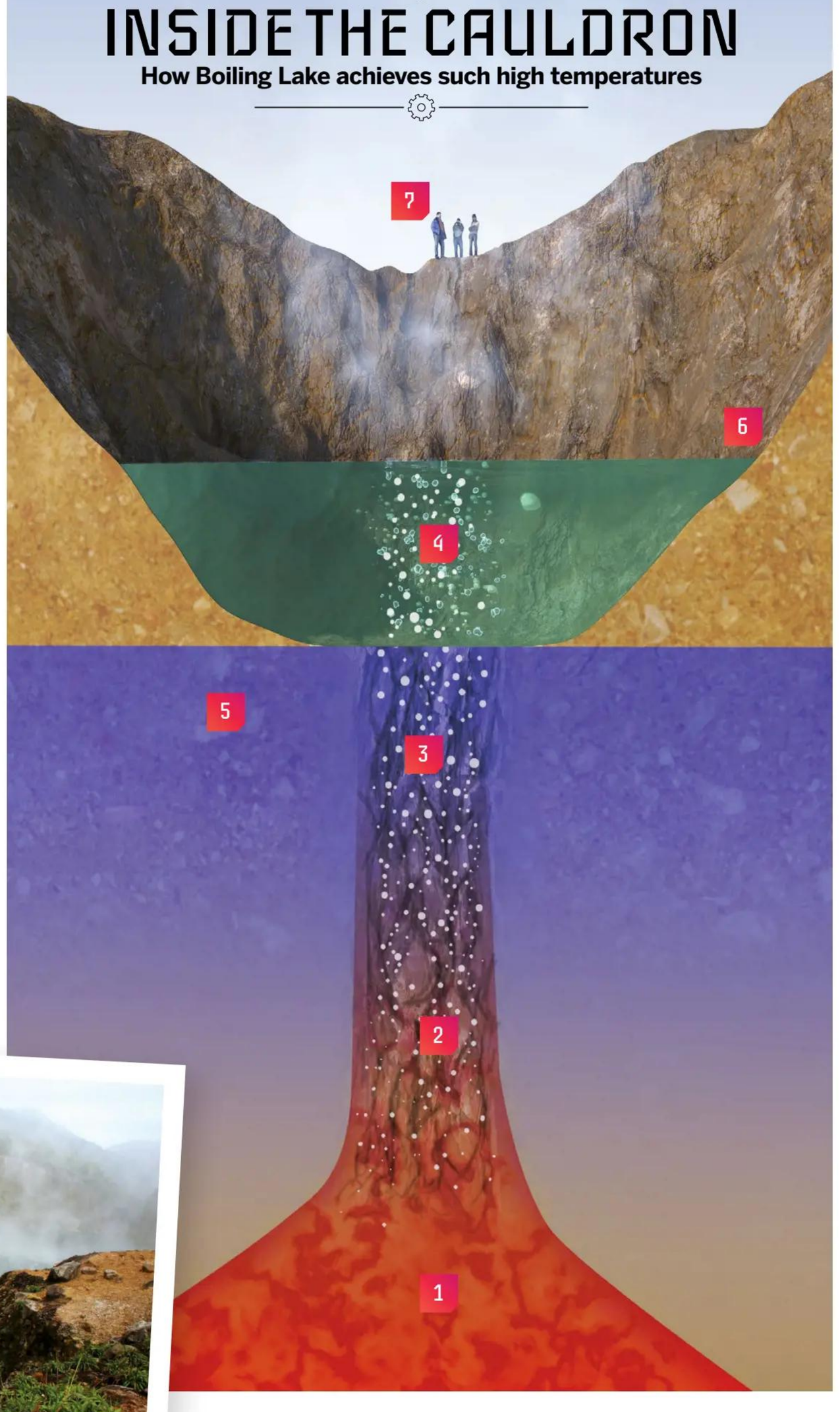
3 PERMEABLE LAYERS
After the trapped water has been heated to boiling point, it bubbles up towards the lake through the many gaps in the rock.

4 BUBBLING UP
Bubbles form mostly at the centre of the lake, where the volcanic gases are released.

5 LAKE SIDES
The rock surrounding the lake mostly consists of clay, pumice and stone and has low permeability.

6 REFILLING STREAMS
Two small streams run into the boiling lake.

7 VISITOR PLATFORM
It's important to stay away from the edge of the lake. Depending on the conditions, the water level can drastically change.




Boiling Lake is surrounded by steep rocky sides

5 DEADLY ISLANDS

1 SNAKE ISLAND, BRAZIL
The golden lancehead viper exists only on this small, unpopulated island. With one bite from this snake, there's a seven per cent chance of death.

2 BIKINI ATOLL, MARSHALL ISLANDS
Between 1946 and 1958, this island was used to test the United State's nuclear weapons. Bikini Atoll is still scattered with radioactive material, and it's deemed unsafe for Bikinians to return.

3 MIYAKE-JIMA ISLAND, JAPAN
This island is largely dominated by the volcano Mount Oyama, which erupted in the year 2000. Because the volcano can release harmful sulphuric gas at any time, those who live on Miyake-jima Island carry gas masks everywhere.

4 GRUINARD ISLAND, SCOTLAND
In 1942, bombs filled with anthrax were detonated on the island as part of a germ warfare experiment. Anthrax is a lethal disease, so the island is now uninhabited.

5 RAMREE ISLAND, MYANMAR
Saltwater crocodiles are the largest reptilian predators on Earth, and on Ramree island there are thousands of them. During World War II, around 500 of 1,000 Japanese troops were killed by the island's crocodiles.

HOW MARINE ANIMALS SLEEP

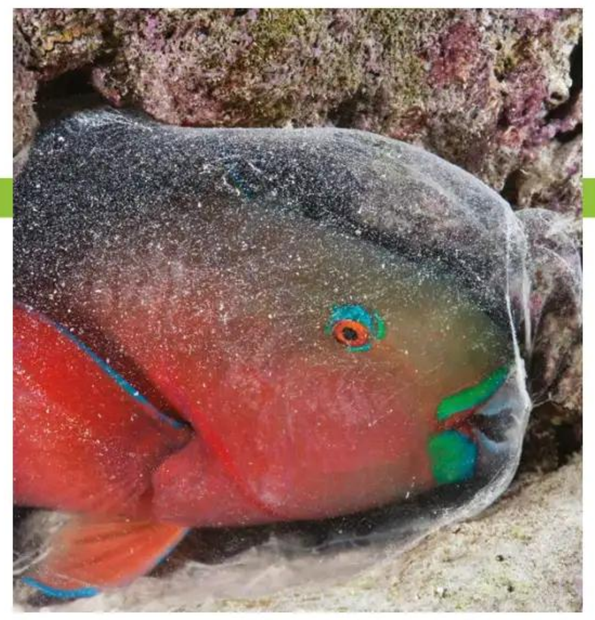
The ways whales, sharks and other sea creatures get a good night's sleep

WORDS **SCOTT DUTFIELD**

The world of underwater slumber is unlike what we see on the surface. For mammals, a good night's sleep sends an animal into a state of unconsciousness during hours of restorative sleeping that helps heal the body and cement memories firmly in the mind. For fish, however, 'sleep' isn't such a well-defined process. Instead, many fish species have taken to spending short periods in a state of reduced activity or rest while keeping their eyes open to scan the water for potential predators. During these periods of reduced activity, a fish's metabolic processes slow down and its alertness drops.

The breadth of animals in the ocean that exhibit this type of reduced activity is wide-reaching. Among the hundreds of thousands of creatures in the sea, some merely float along with the current, such as jellyfish. Others find rocky bedrooms for the night, while those such as stingrays bury themselves in the sand to rest. However, it must be really hard to get a good night's sleep when you breathe air but live in water. This is something that the world's marine mammals have to contend with.

To prevent themselves from drowning in their sleep, marine mammals such as dolphins and manatees have evolved the ability to 'turn off' one hemisphere of their brain to rest, known as unihemispheric sleep. While one hemisphere is fast asleep, the other keeps all the animal's vital functions running, such as breathing. Manatees, for example, love to sleep, spending up to 12 hours a day in a deep doze. However, as air-breathing animals, manatees need to surface every 20 minutes or so for oxygen. To achieve this, the half of the brain that's still awake sends the snoozing manatee to the surface to get some air.



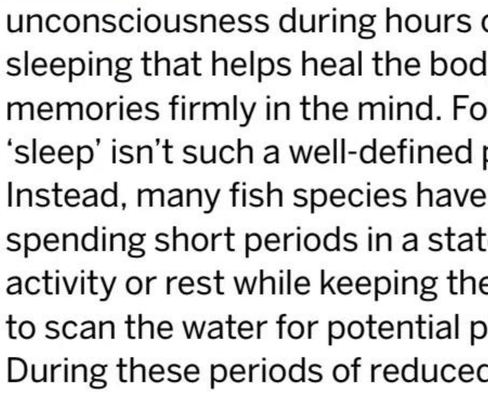
A parrotfish tucking up in its mucus pest-control duvet for the night

MUCUS DUVETS

When the Sun sets and it's time for parrotfish (*Chlorurus*) to settle in for the night, they swim down to the seafloor and find a nice spot among the rocks to sleep. Having found somewhere to rest, these vibrant tropical fish secrete mucus from glands behind their gills that form a cosy cocoon around the entire fish. The snotty duvet takes about 30 minutes to make, but surrounds the parrotfish for the whole night. In the same way that a mosquito net protects you during the night, a parrotfish's mucus cocoon protects the fish from blood-sucking parasites called Gnathiidae isopods. Along with being a physical barrier, the cocoon also locks in the fish's scent, preventing other animals from sniffing it out while it sleeps.

SPERM WHALE SLUMBER PARTY

How these ocean giants spend some of their time sleeping vertically



STAYING AFLOAT
A waxy substance in the head cavity called the spermaceti helps keep sperm whales buoyant while they sleep.

DEEP SLEEPER
These whales snooze around 20 metres below the water's surface.

POWER NAP
Sperm whales don't sleep for long; they rest one half of their brain at a time for only 10 to 15 minutes.

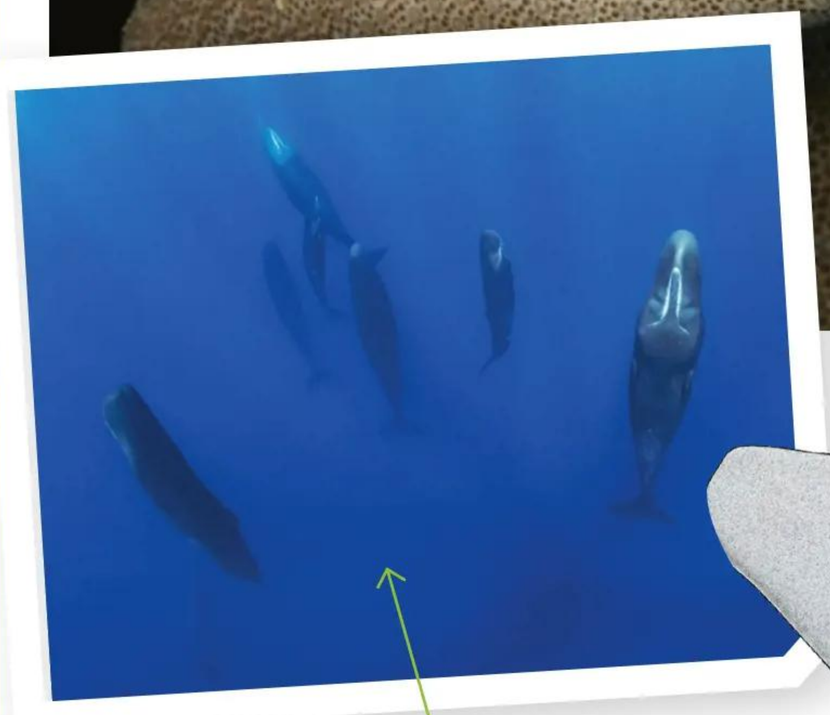
DID YOU KNOW? At night, clownfish snuggle between the stinging tentacles of anemones to sleep

OCTOPUS DREAMS

Since most fish aren't fully unconscious when they sleep, it's safe to assume that dreaming is a rarity underwater. However, researchers have discovered a short window where an octopus' mind might drift off to dreamland. Octopus subjects were observed to have cycles of sleep that included elongated moments of peaceful rest and short bursts of activity. For humans, these short bursts might be comparable to tossing and turning, but octopuses' skin changed colour and tentacle suckers contracted. For around 40 seconds at a time, octopuses changed their skin colour and texture, suggesting they might be having short, simple dreams that are triggering these changes.

Perhaps this octopus is dreaming of catching a tasty crab

An African Blenny sleeping in the contours of a smooth coral



GROUP SNOOZE
Clusters of whales, known as a pod, sleep together in groups of five or six.

UPRIGHT
Around seven per cent of a sperm whale's sleeping time is spent in a vertical position.

OPTIMAL OXYGEN
Sperm whales absorb around 90 per cent of the oxygen in each breath to keep their organs filled with oxygen-rich blood while they sleep.

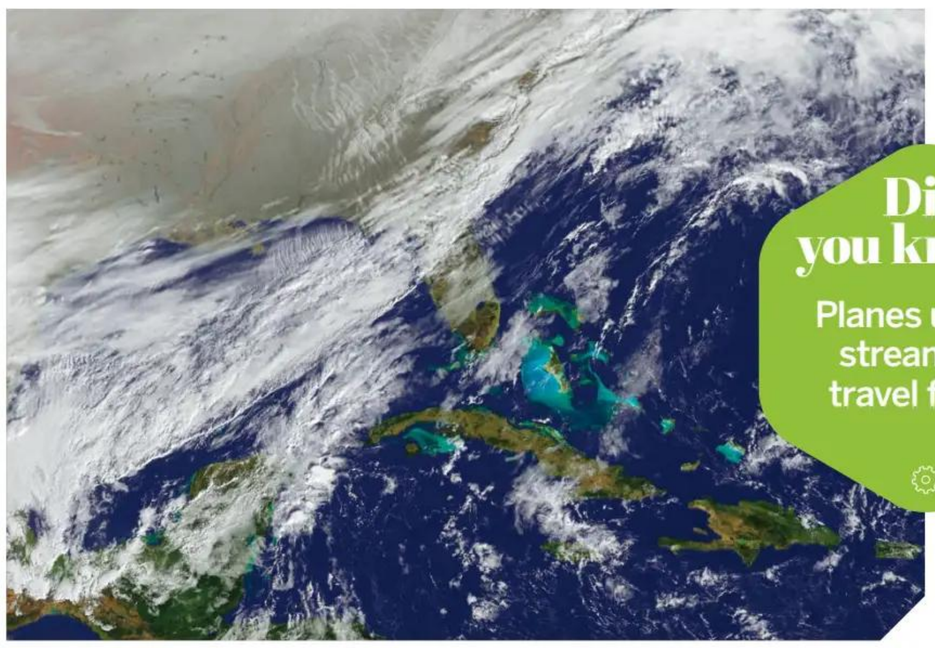
Did you know?
Humpback whales can sleep for up to 30 minutes at a time

A pair of manatees taking a nap on the seafloor

THE POLAR VORTEX EXPLAINED

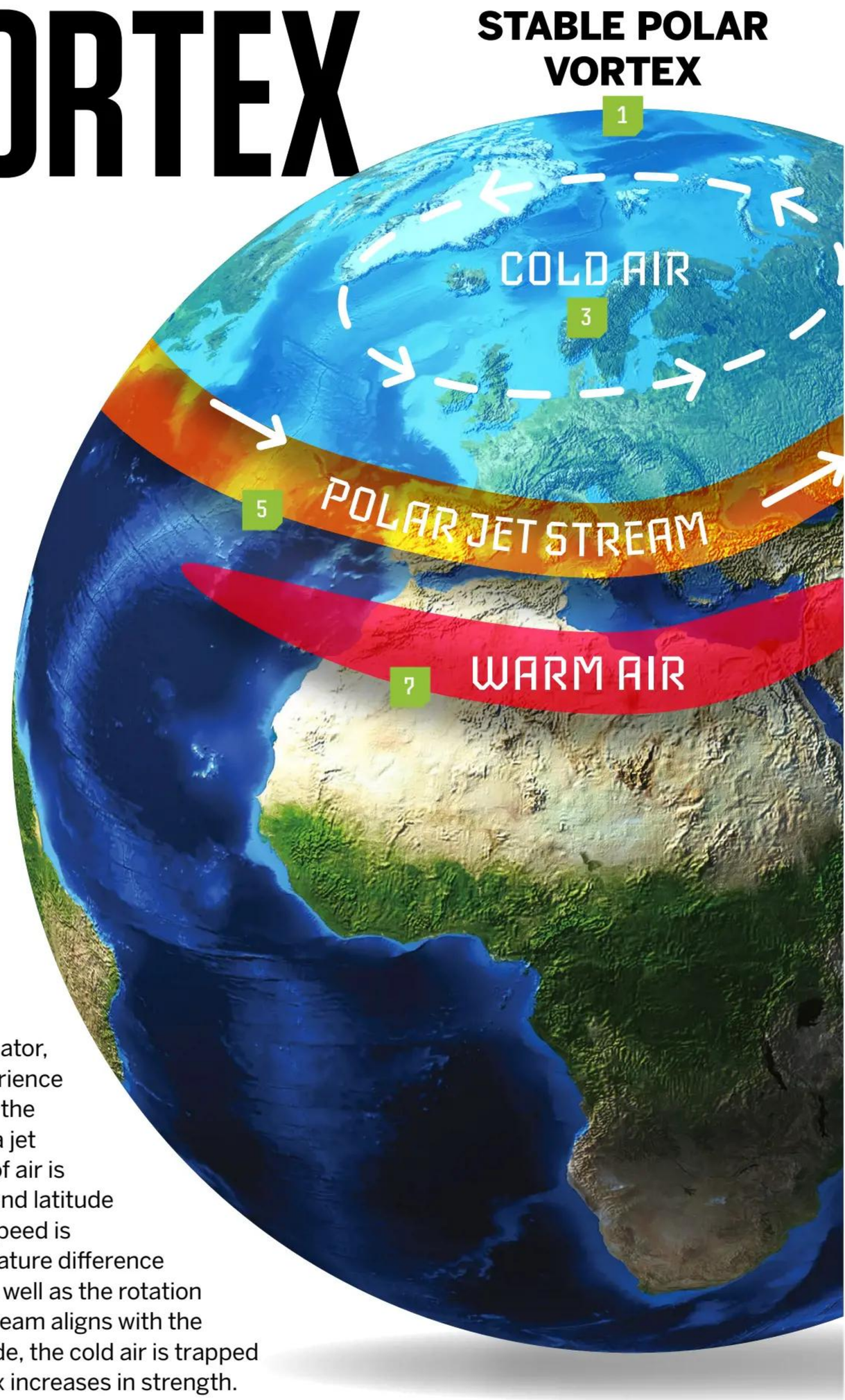
What is the polar vortex, and how does it keep the climate in check?

WORDS **AILSA HARVEY**



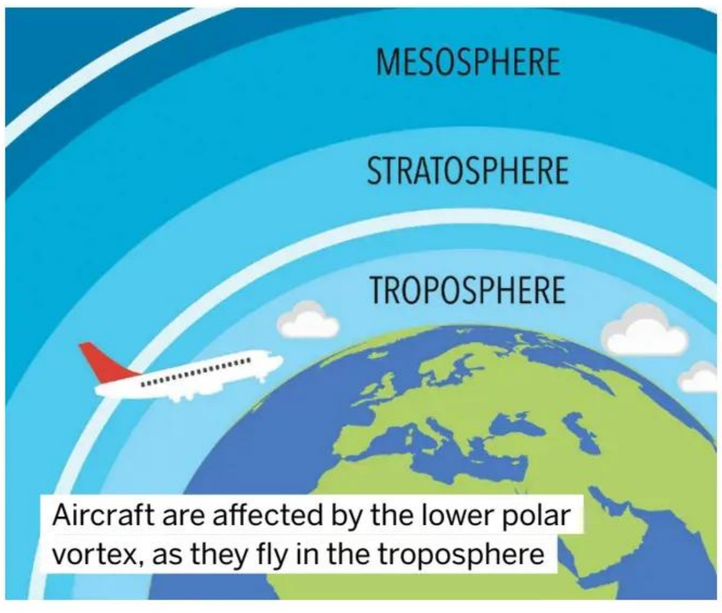
Did you know?

Planes use jet streams to travel faster



The Arctic has a reputation for frigid temperatures and dark, icy winters. These extreme conditions are disproportionately allocated to Earth's poles, but why is this? These cold traps are created by an incessant vortex of cold air that spins anti-clockwise around the planet in the atmosphere above the Antarctic and Arctic. These low-pressure bands of air are called the polar vortex.

Most of the time, the Arctic polar vortex stays near the pole. But its strength is always changing, causing its border to alter in shape and size. When it edges closer to the equator, the regions below it experience sudden gusts of wind. At the edge of a polar vortex is a jet stream. This circulation of air is usually lower in altitude and latitude than the vortex, and its speed is controlled by the temperature difference of the surrounding air, as well as the rotation of Earth. When the jet stream aligns with the vortex at the same latitude, the cold air is trapped at the pole and the vortex increases in strength.



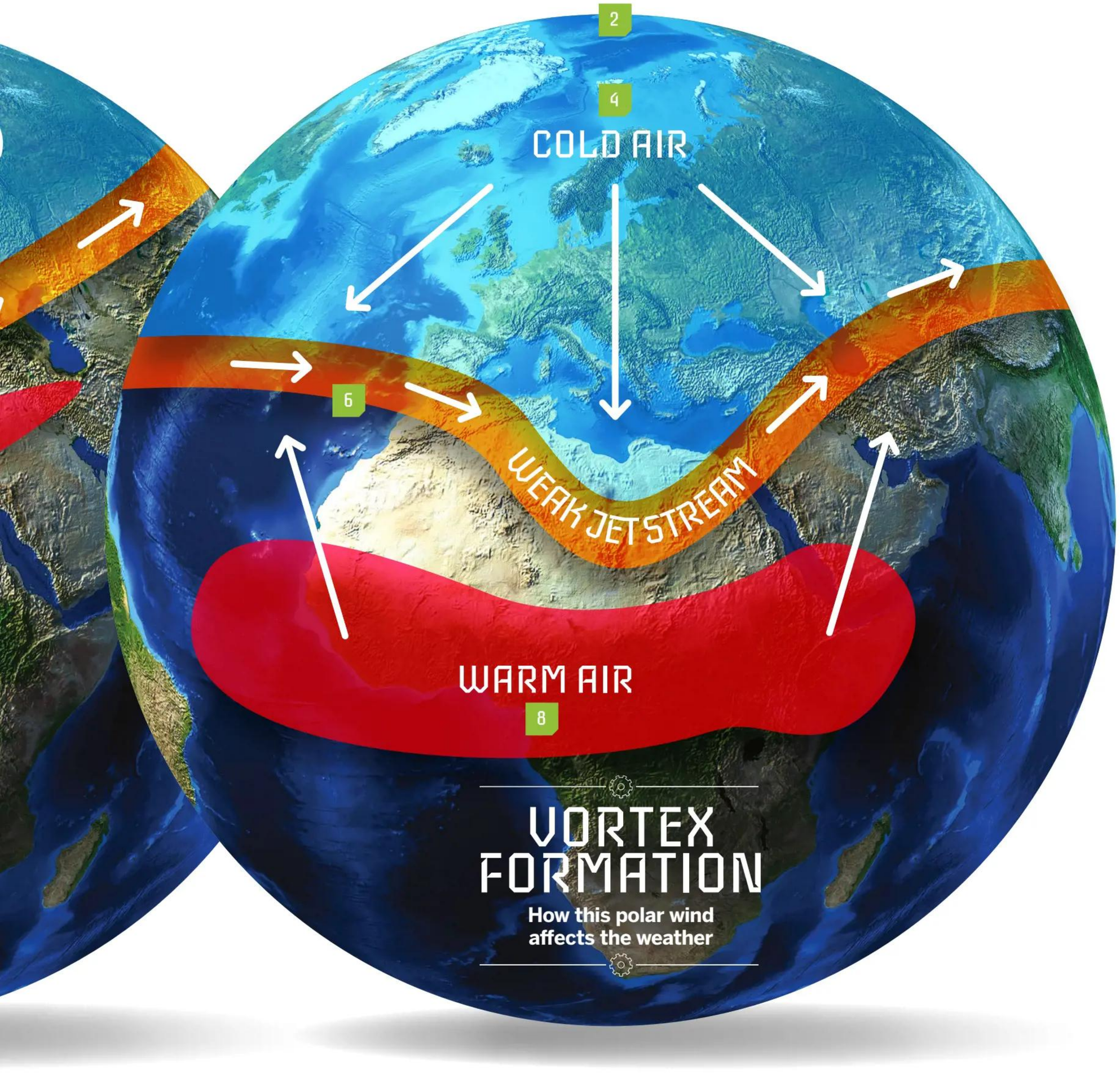
Aircraft are affected by the lower polar vortex, as they fly in the troposphere

DOUBLE TROUBLE

There are two polar vortices in each of Earth's hemispheres – one in the stratosphere and one in the troposphere. The troposphere is the lowest altitude layer of Earth's atmosphere, and the stratosphere is the second lowest. The vortex that's highest in the atmosphere is usually the more circular because it faces fewer obstacles. Meanwhile, the lower altitude vortex is more undulating, as there's mountainous terrain and more contrasting pressure systems to overcome. Being closer to Earth's surface, the tropospheric vortex has the greatest influence on the weather. In the Arctic, although this vortex is mostly constrained to the North Pole, when the jet stream is weakened it can drift further south. As this happens, it brings bitterly cold weather conditions. The stratospheric vortex isn't permanent. It usually disappears between March and September. When this vortex forms and holds a strong rotation, the coldest Arctic temperatures are less likely to venture southwards to more populous land.

DID YOU KNOW? In 2019, 21 people died from drastic weather changes after the polar vortex moved southwards

WAVY POLAR VORTEX



VORTEX FORMATION

How this polar wind affects the weather

1 STABLE VORTEX
When the polar vortex is strong, the jet stream moves northwards, with wind travelling straight and smoothly.

2 WAVY VORTEX
If the polar vortex weakens, the jet stream isn't pulled northwards as tightly, making the wind's path more wavy.

3 COLD AIR
When fast-flowing air creates a tight band near the pole, the cold air is contained above it.

4 AIR DISPERSAL
A weak jet stream allows the cold air to move away from the pole and some warmer air to move towards it.

5 STRAIGHT JET STREAM
When the temperature difference across the jet stream is large, the jet stream is stable.

6 WEAK JET STREAM
During summer, the jet stream weakens and diverts further from the pole.

7 WARM AIR ZONE
The warm air is kept away from the polar vortex.

8 WARMING THE ARCTIC
When warm air is free to move towards the poles, it can cause ice to melt.

A weaker vortex reduces Arctic sea ice, as the warmer air causes it to melt

WARMING POLES

Global warming affects the entire planet, but the rate of warming varies at different latitudes. The Arctic's surface temperature, for example, is warming twice as quickly as Earth's surface average. This impacts the polar vortex because the stability of the vortex is maintained by the temperature difference on either side of the jet stream. If the pole increases in temperature much more than areas at lower latitudes, the temperature difference won't be as great. As a result, the polar vortex becomes weaker and more warm air can creep into the poles, warming them further.

INSIDE THE WOMB

Take a look inside the mammalian womb and discover how unborn cubs, kittens and calves grow

WORDS **SCOTT DUTFIELD**

Within the animal kingdom, there are three types of mammals: placentals, marsupials and monotremes. Placentals, like humans, carry a foetus within their uterus, also known as the womb. Once a fertilised egg attaches to the lining of the uterus, it develops over several weeks into an early embryo. Along with the development of an embryo, a new temporary organ called the placenta grows.

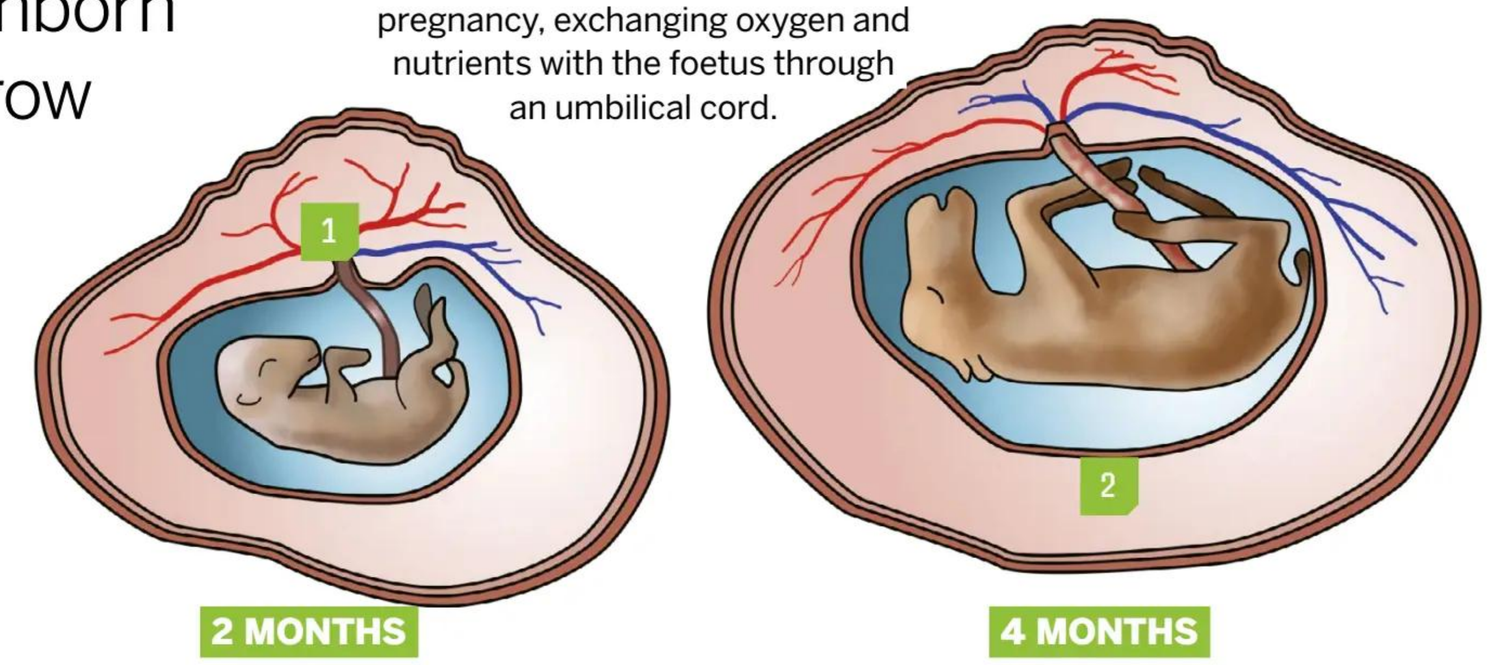
During development, the embryo produces root-like structures called villi, which anchor it in the womb. These villi grow, eventually connecting to the blood vessels of the mother, and the placenta starts to grow. The purpose of the placenta is to deliver nutrients and oxygen to the foetus. The connection between the foetus and the placenta is called the umbilical cord, which leaves a belly button after birth.

To keep the foetus safe during gestation, an encompassing sac of fluid called an amniotic sac also develops to cushion it before it's ready to be born. A placental pregnancy can last anywhere from 11 days to almost two years, depending on the species. But mammals aren't alone in having placental young. Many species of fish, such as sharks, and some reptiles, including skinks, also rely on a placenta to grow their offspring.

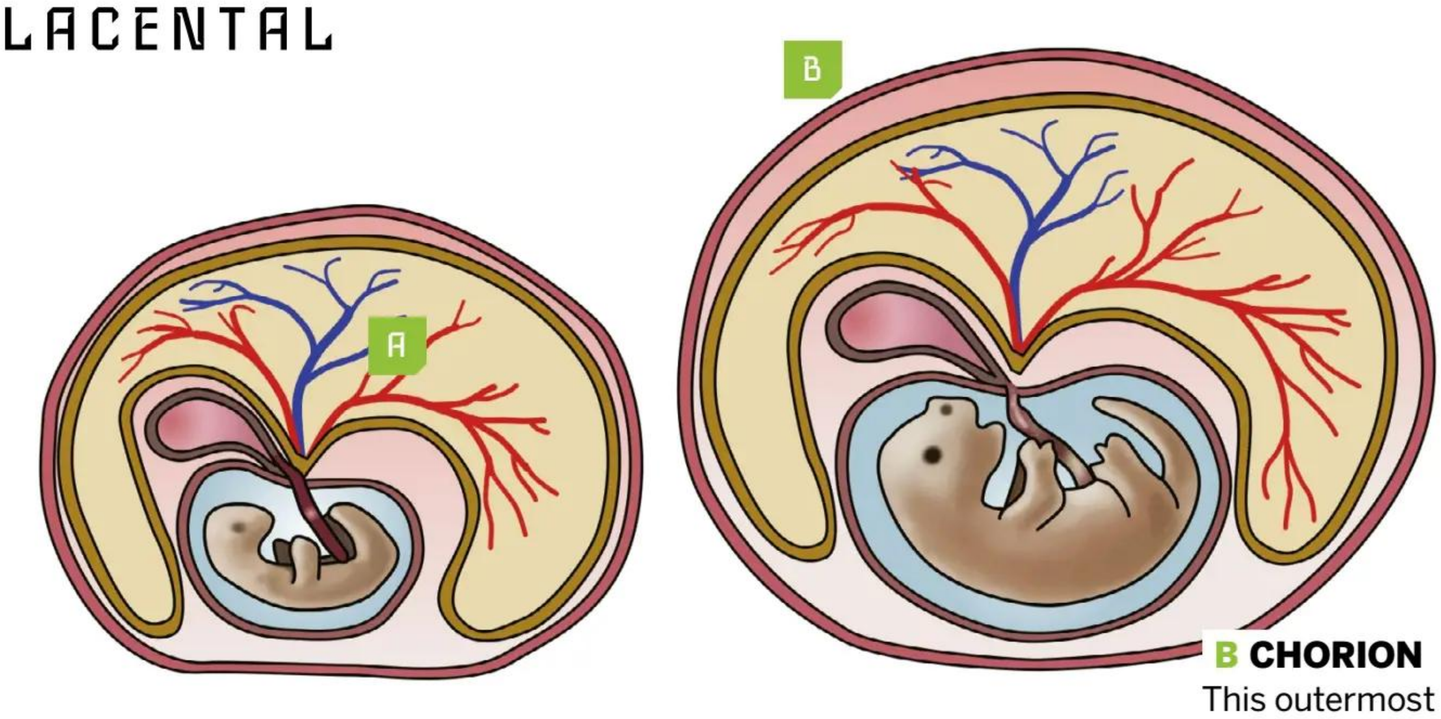
Marsupials have a shorter gestation time than placental mammals, but provide their young with an extended period of lactation. Once a marsupial foetus has spent anywhere from 8 to 42 days in the womb, they make their way into a marsupium, an internal pouch that protects the offspring, and latch onto an available nipple for a lactation period that can last up to 300 days. Monotremes are a class of their own. Only five species are included in this strange group of mammals, including platypus and echidnas. Ditching a womb altogether, these animals pass eggs through an organ called a cloaca.

1 PLACENTA
This organ develops during pregnancy, exchanging oxygen and nutrients with the foetus through an umbilical cord.

2 AMNIOTIC SAC
This thin-walled sac is filled with amniotic fluid to protect the foetus as it grows.



PLACENTAL



A YOLK SAC
Instead of a typical placenta, marsupial foetuses extract their nutrients from a yolk sac.

B CHORION
This outermost membrane of a developing foetus encapsulates the yolk sac and the amniotic fluid.

MARSUPIAL


A stripe-faced dunnart carrying its offspring on its back

SHORTEST PREGNANCY

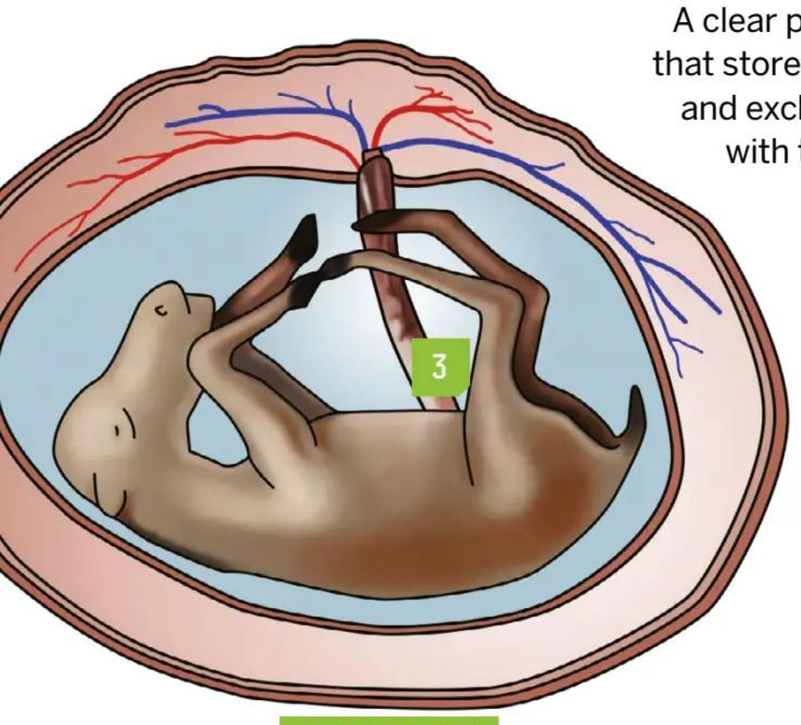
Found in the shrublands of Australia, the stripe-faced dunnart (*Sminthopsis macroura*) is a mouse-sized marsupial that wastes no time when having children. Once a female dunnart reaches adulthood, it finds a mate and produces a litter of around eight young. As a marsupial, foetuses doesn't stay in the womb for long, crawling out after only 11 days of development. The offspring will then suckle on their mother's milk within their protective pouch for a further 40 days before emerging. During low temperatures in winter, these dunnarts enter a hypometabolic state called torpor to conserve energy. This mini-hibernation allows them to survive when food sources are few and far between.

DID YOU KNOW? Madagascan tailless tenrecs can have as many as 32 offspring at a time

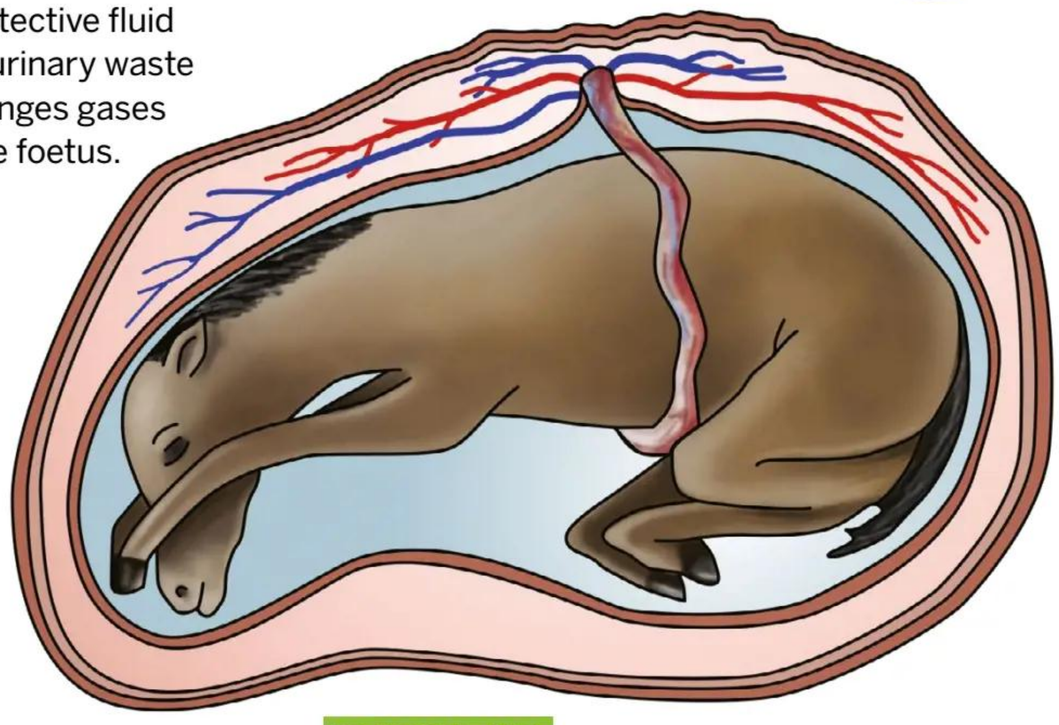
PLACENTAL VS MARSUPIAL

How these two different mammals grow their offspring

3 ALLANTOIC FLUID
A clear protective fluid that stores urinary waste and exchanges gases with the foetus.

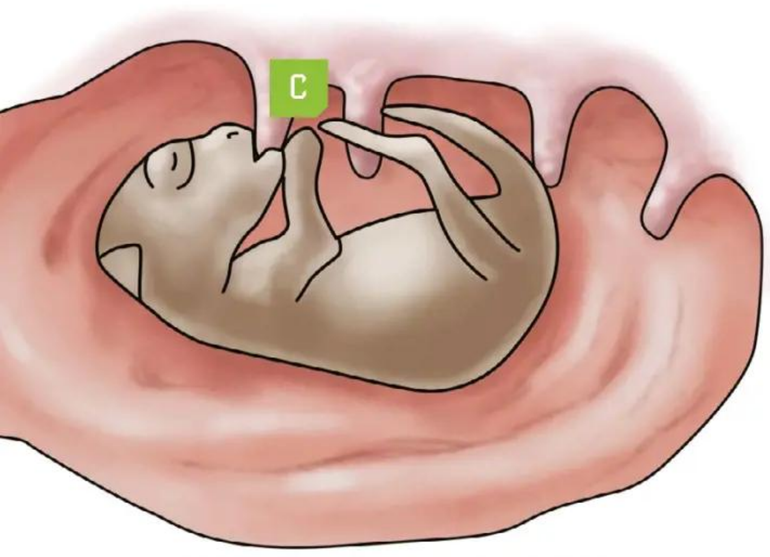


8 MONTHS

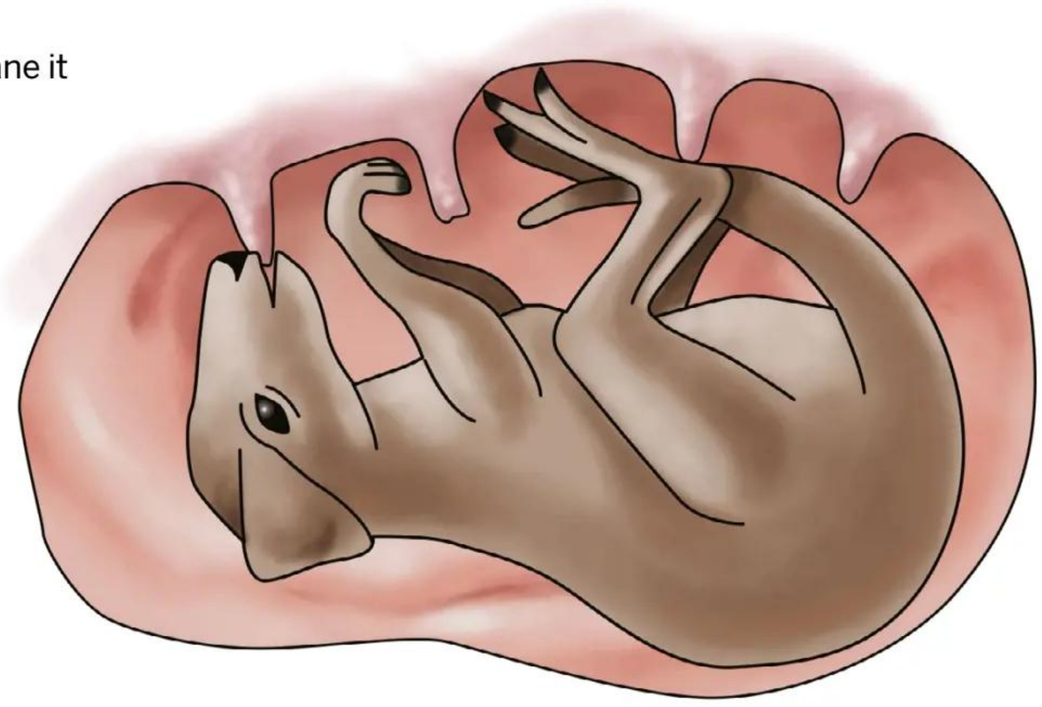


11 MONTHS

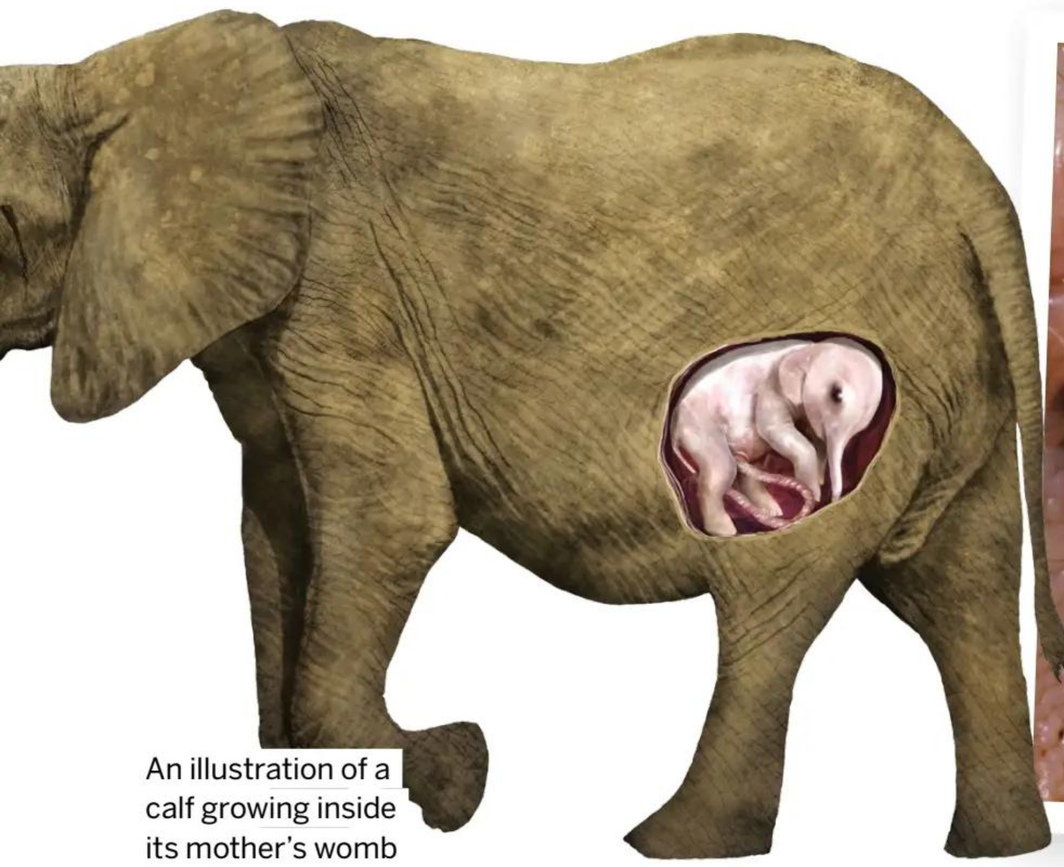
C MARSUPIUM
Once a foetus has left the chorion membrane it enters its mother's pouch, known as the marsupium, for several weeks.



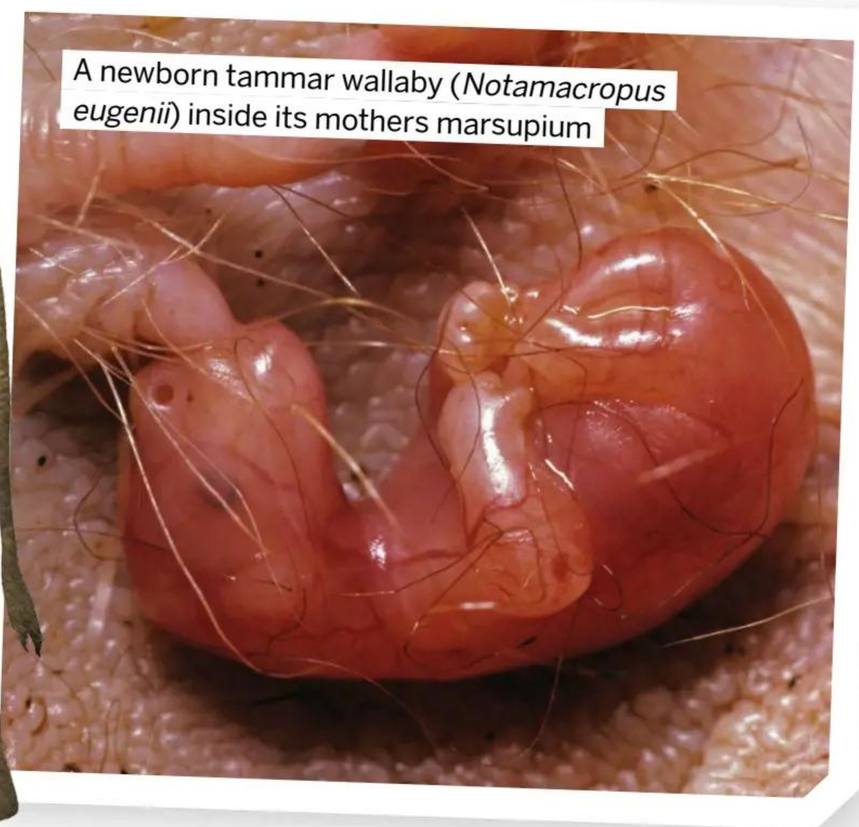
4 WEEKS AFTER BIRTH



12 WEEKS AFTER BIRTH



An illustration of a calf growing inside its mother's womb



A newborn tammar wallaby (*Notamacropus eugenii*) inside its mothers marsupium

Did you know?
Placental mammals diverged around 160 million years ago

GESTATION TIMES

HUMAN
Gestation time:
280 days
Average offspring per pregnancy:
One

ELEPHANT
Gestation time:
669 days
Average offspring per pregnancy:
One

GREY WOLF
Gestation time:
63 days
Average offspring per pregnancy:
Six

BOTTLENOSE DOLPHIN
Gestation time:
365 days
Average offspring per pregnancy:
One

EURASIAN RED SQUIRREL
Gestation time:
39 days
Average offspring per pregnancy:
Seven

ORANGUTAN
Gestation time:
258 days
Average offspring per pregnancy:
One

WHY NETTLES STING

The science behind the sting of these common countryside plants

WORDS **AILSA HARVEY**

Did you know?

Nettles can grow up to 1.2 metres tall

On first impression, stinging nettles (*Urtica dioica*) aren't a particularly threatening-looking plant. However, if you've ever brushed against their leaves, you'll know all too well the pain they can inflict.

What gives nettles their stinging power is a cocktail of chemicals held within tiny hair-like structures along the plant's leaves. When these structures are broken they release their chemical contents, which penetrate the skin and cause several painful symptoms such as itching, swelling and redness. The initial skin irritation felt when you are stung by a nettle is caused by histamine, which is also responsible for causing other allergic reactions.

Like many other plants, nettles have evolved their stinging abilities as a defence mechanism against herbivorous animals such as deer and rabbits. Nettle venom isn't strong enough to seriously harm a hungry herbivore – it merely teaches them a lesson in avoiding nettles.

Commonly found around hedgerows, woodlands and fields, stinging nettles are much more than vicious plants, as they also play an important role in their ecosystem. Butterflies, for example, use nettles as a place to lay their eggs, and ladybirds and aphids use nettles for shelter and as a source of nutritious food.

CHEMICAL COCKTAIL

How nettles deliver their irritating venom

1 BREAKAWAY TIP
Across the nettle leaves are spiny hairs called trichomes. The bulbous tip of the trichome breaks off when it's brushed against, revealing the needle-like tube below.

2 INJECTION
The trichome's inner needles are filled with a stinging cocktail of chemicals including formic acid, histamine, serotonin and acetylcholine.

3 ITCHING
An itching sensation and a burning rash can occur following a sting, lasting up to 12 hours.

4 CHEMICAL FACTORY
At the base of the trichome are specialised cells that secrete the stinging chemicals into the trichome needle.

Dock leaves have large, flat leaves and grow in fields and woodlands

DO DOCK LEAVES REALLY WORK?

It's long been believed that grabbing a dock leaf and rubbing it on a wound after a nettle sting will help ease the pain. Dock plants, also known as bitter dock (*Rumex obtusifolius*), are said to produce a sap that contains an antihistamine to combat the effects of nettle stings. However, there's no evidence of such antihistamines or healing chemical properties. The placebo effect has also been cited as a possible explanation for why some people believe dock leaves help treat the stinging sensation and lower the perception of pain.

One way that the dock leaf sap can offer some relief is through evaporative cooling. As the dock sap evaporates over the sting, the skin beneath can experience a cooling sensation that relieves some of the burning irritation on the skin.

A view of a nettle leaf and its many trichomes under a scanning electron microscope

WHAT ARE RIP CURRENTS?

Understanding these powerful channels can help prevent you from swimming into danger

WORDS **AILSA HARVEY**

Rip currents are like the rivers of the sea, transporting water near the shore back out into the ocean depths. The presence of these currents can be hidden by the hectic movements of the surrounding waves. This means that as well as carrying seaweed and debris quickly out to sea, they can rapidly sweep away even the strongest swimmers. Around 80 per cent of all lifeguard rescues are prompted by powerful rip currents pulling a swimmer into danger.

If you find yourself being pulled out to sea by an unsuspected rip current, you should remain calm, focus on staying afloat and, if you can, swim parallel to the shore. Your instincts might tell you to swim towards land, as this is where you're aiming to get to, but the current will be too strong to swim against. Instead aim to move across the current and into slower flowing water next to it. A rip current may only pull you just past the breaking waves, but in some cases they can take you hundreds of metres offshore. The strength of currents can be hard to predict, so it's safest to stay on lifeguarded beaches and not to swim if you see any indication of a rip current.

A similar force to a rip current is a rip tide. The difference between these comes down to their cause and location. While rip currents form between the breaking waves of a beach, rip tides are a result of flowing water entering the sea from rivers and harbours.

Did you know?

Rip currents travel faster than an Olympic swimmer

HOW THEY FORM

What causes the sea's fast-flowing shortcut through the surf?

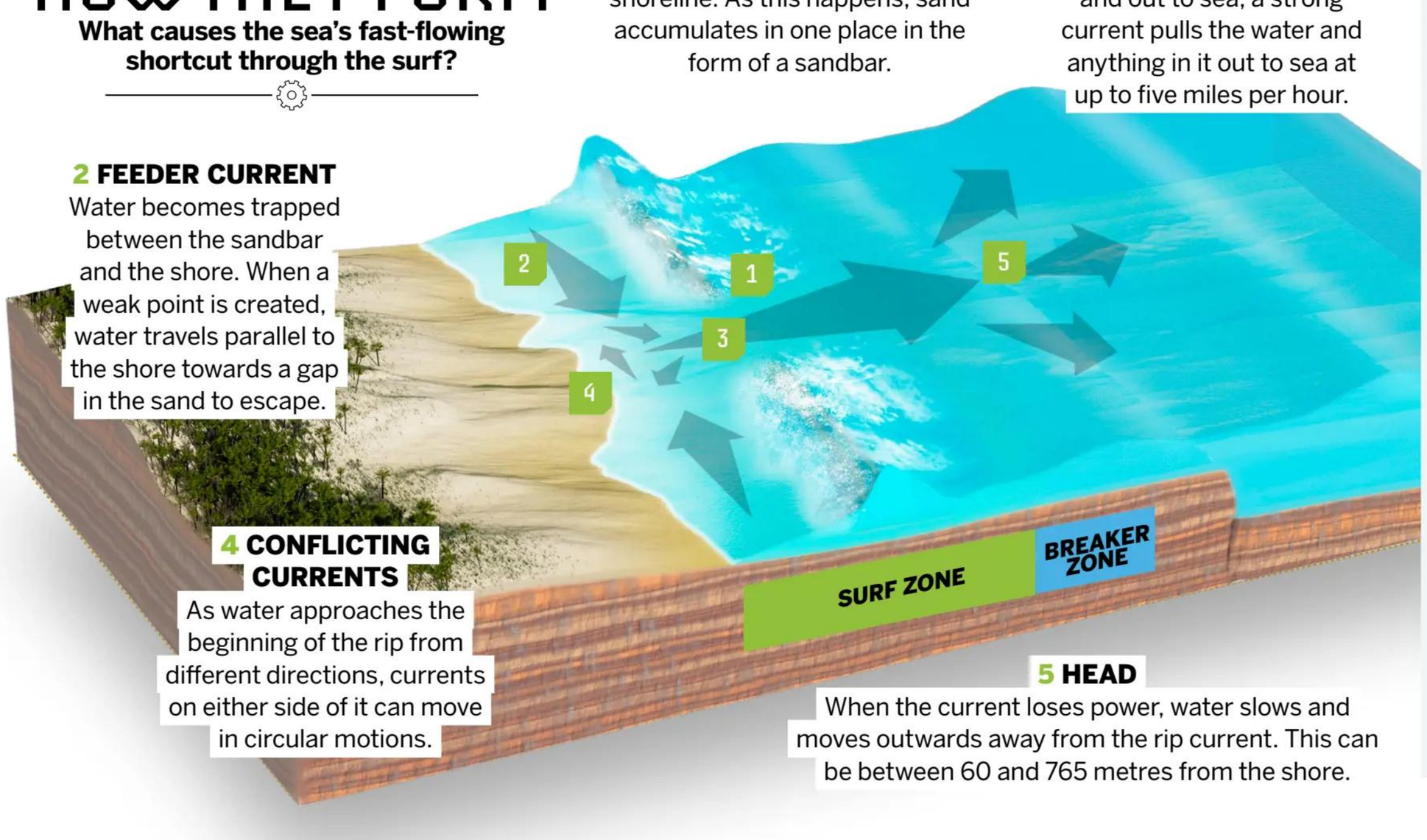
1 CRASHING TO SHORE
Waves break towards the shoreline. As this happens, sand accumulates in one place in the form of a sandbar.

2 FEEDER CURRENT
Water becomes trapped between the sandbar and the shore. When a weak point is created, water travels parallel to the shore towards a gap in the sand to escape.

3 NECK
As water rushes to this point and out to sea, a strong current pulls the water and anything in it out to sea at up to five miles per hour.

4 CONFLICTING CURRENTS
As water approaches the beginning of the rip from different directions, currents on either side of it can move in circular motions.

5 HEAD
When the current loses power, water slows and moves outwards away from the rip current. This can be between 60 and 765 metres from the shore.



5 SIGNS OF A RIP CURRENT

1 DARKER WATER
Where the water is deeper, the water also appears darker. Dark lines sometimes show the path of a rip current.

2 FEWER BREAKS
A rip current often prevents waves from breaking. Gaps in white water can indicate the presence of a rip.

3 SANDY WATERS
If the water appears sandy past the breaking waves, this is a sign that a current is moving offshore and bringing sand up to the surface.

4 DEBRIS EVIDENCE
Follow the movement of floating debris or seaweed. Rip currents will pull these towards them and then out to sea with the current.

5 SURFACE MOVEMENT
As water is rushing towards a single point from different directions, more ripples form at the surface than in the surrounding water.

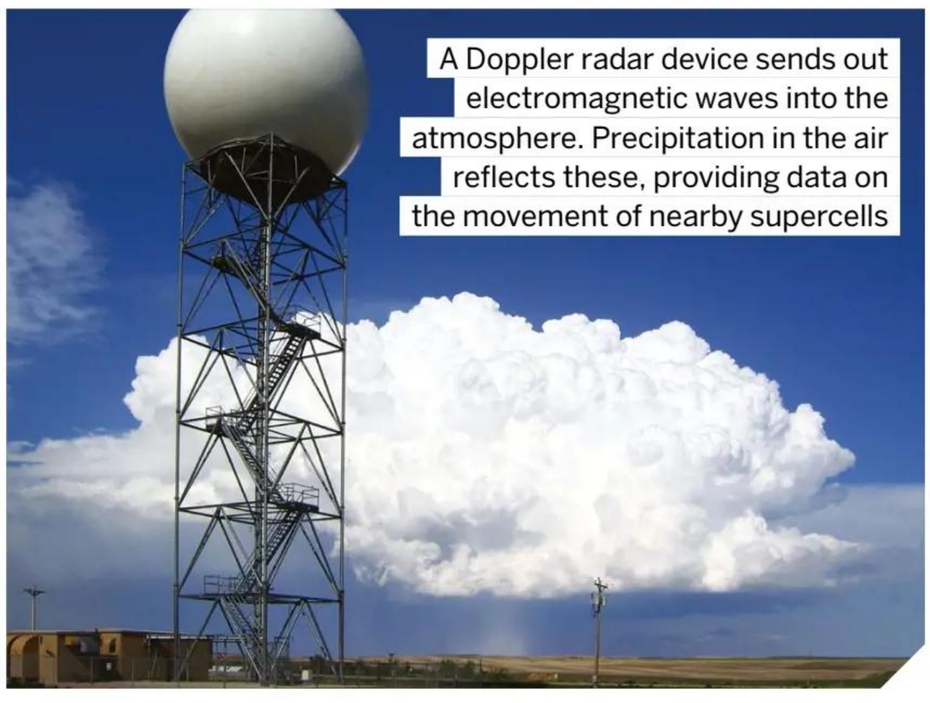
HOW STORM SUPERCELLS FORM

What turns an ordinary storm into a whirling maelstrom?

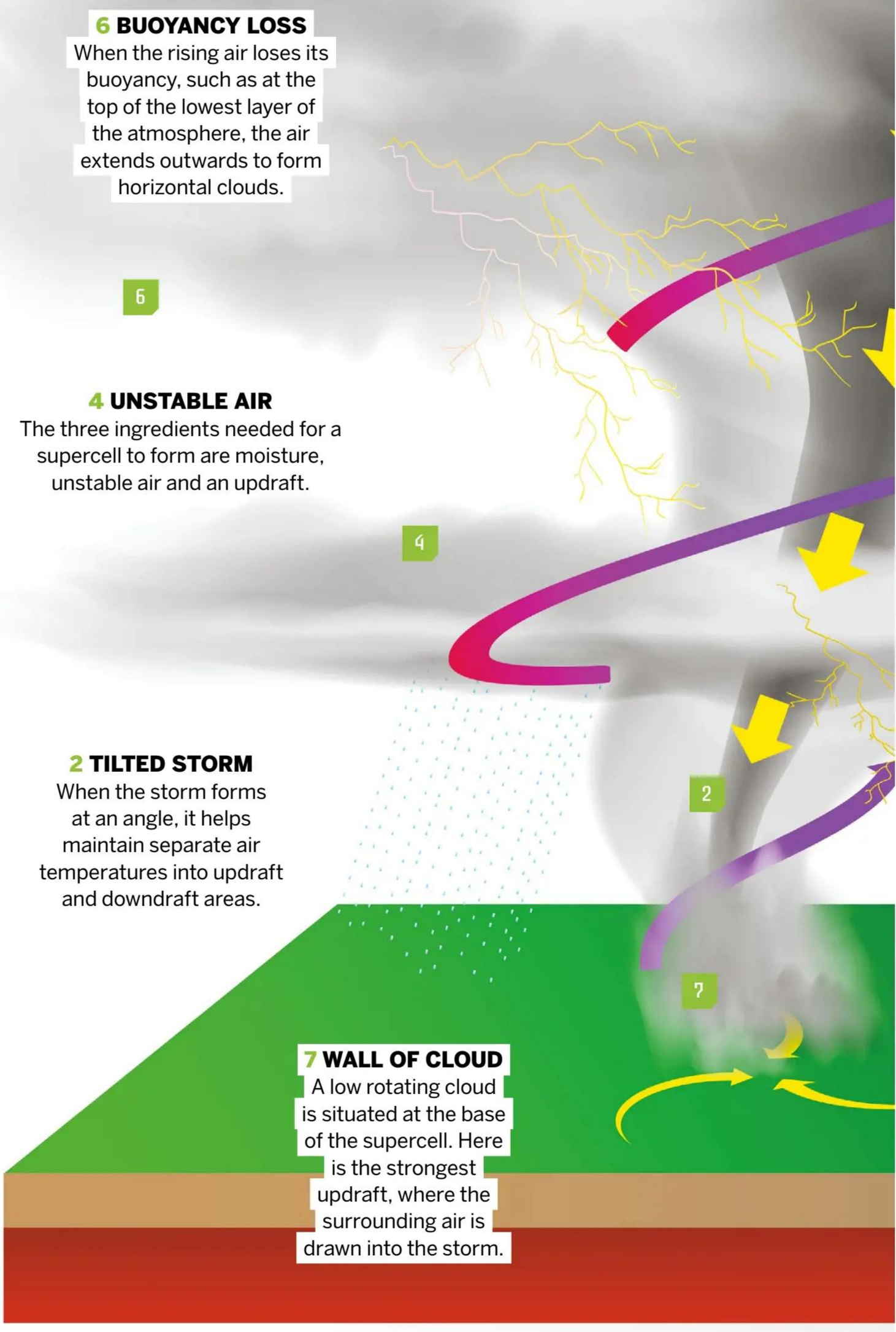
WORDS **AILSA HARVEY**

On a stormy day, if you can see a towering rod of clouds topped with a funnel-shaped horizontal cloud, there's a chance you are looking at a supercell. What separates supercells from regular thunderstorms is the rotating movement of air at the centre as it's drawn upwards to the top of the storm. Supercells are the least common form of thunderstorm. To spot a supercell in the distance, you need to observe the shape and movement of the clouds decorating them.

The most important factor that causes a supercell to form is wind shear. Wind shear is conflicting wind direction and speed that stops the air travelling smoothly straight across Earth's surface. The force of wind shear manipulates this movement into a rotating cycle. The strong winds, giant hailstones and potential to form tornadoes can make supercells a very destructive form of weather. They're most common in the central plains of the US and regularly occur during the spring season. Knowing what combination of factors form a supercell can help you stay safe and prepared for changing weather. Today, emergency services can send wireless alerts to everyone in an affected area when a severe supercell or tornado is due to pass through the region.



A Doppler radar device sends out electromagnetic waves into the atmosphere. Precipitation in the air reflects these, providing data on the movement of nearby supercells



6 BUOYANCY LOSS
When the rising air loses its buoyancy, such as at the top of the lowest layer of the atmosphere, the air extends outwards to form horizontal clouds.

4 UNSTABLE AIR
The three ingredients needed for a supercell to form are moisture, unstable air and an updraft.

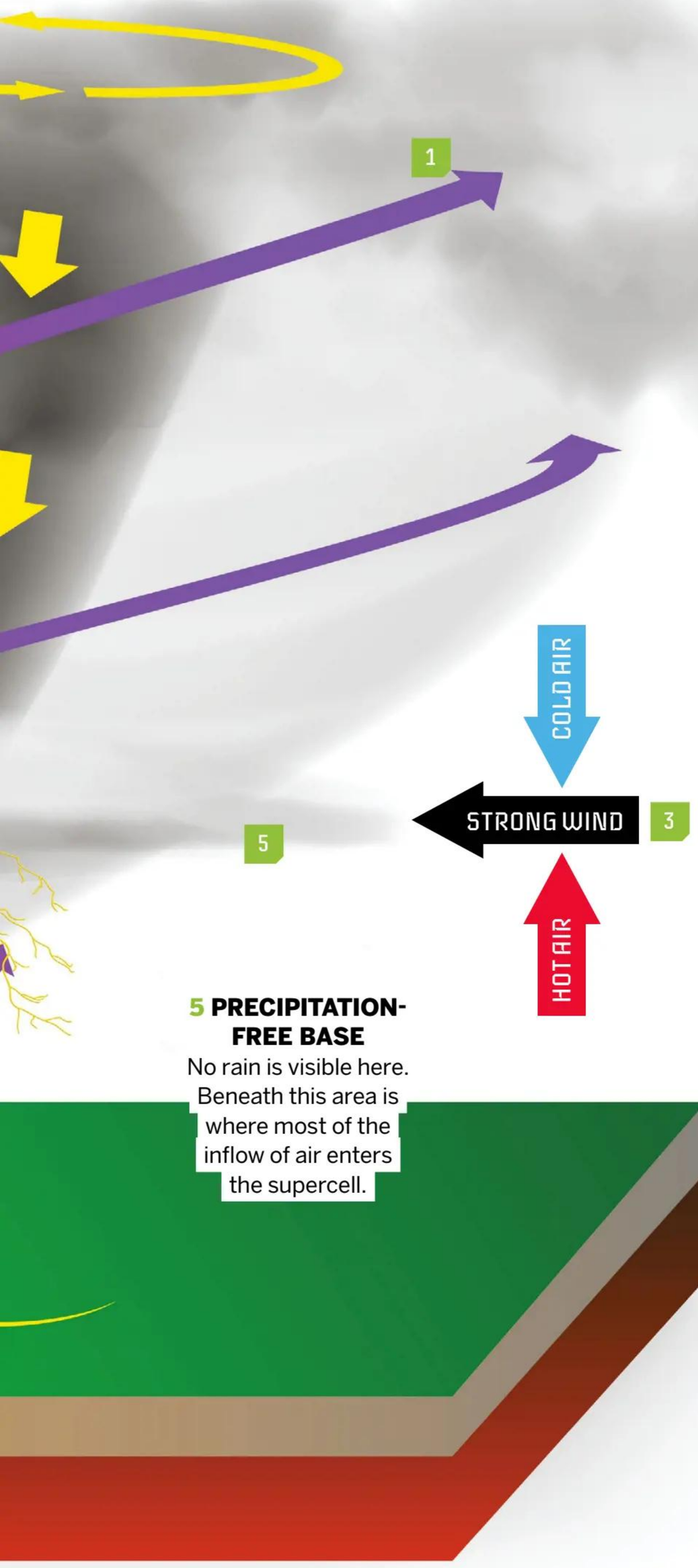
2 TILTED STORM
When the storm forms at an angle, it helps maintain separate air temperatures into updraft and downdraft areas.

7 WALL OF CLOUD
A low rotating cloud is situated at the base of the supercell. Here is the strongest updraft, where the surrounding air is drawn into the storm.

DID YOU KNOW? The largest recorded hailstone had a circumference of 47 centimetres

SUPERCELL STRUCTURE

Explore the anatomy of these surging storms



1 MESOCYCLONE
A storm is classed as a supercell when it has a continuous rotating updraft called a mesocyclone.

3 CHANGE IN WIND
When strong horizontal wind suddenly changes direction or height, the two opposing forces contort the moving air and cause it to travel in a spiral motion.

5 PRECIPITATION-FREE BASE
No rain is visible here. Beneath this area is where most of the inflow of air enters the supercell.

SUPERCELL TYPES

LOW PRECIPITATION
When the winds in the upper level of a supercell are 70 miles per hour or faster, it's classed as a low-precipitation supercell. These high wind speeds push precipitation far from the updraft of air. Low-precipitation supercells are generally more tilted and are less likely to lead to tornado formation than other types.

CLASSIC
Between 45 and 70 miles per hour, the winds of a classic supercell are slower than in a low-precipitation one. This category is where the majority of supercells form. Significant precipitation falls next to the updraft of these storms and large hailstones commonly form.

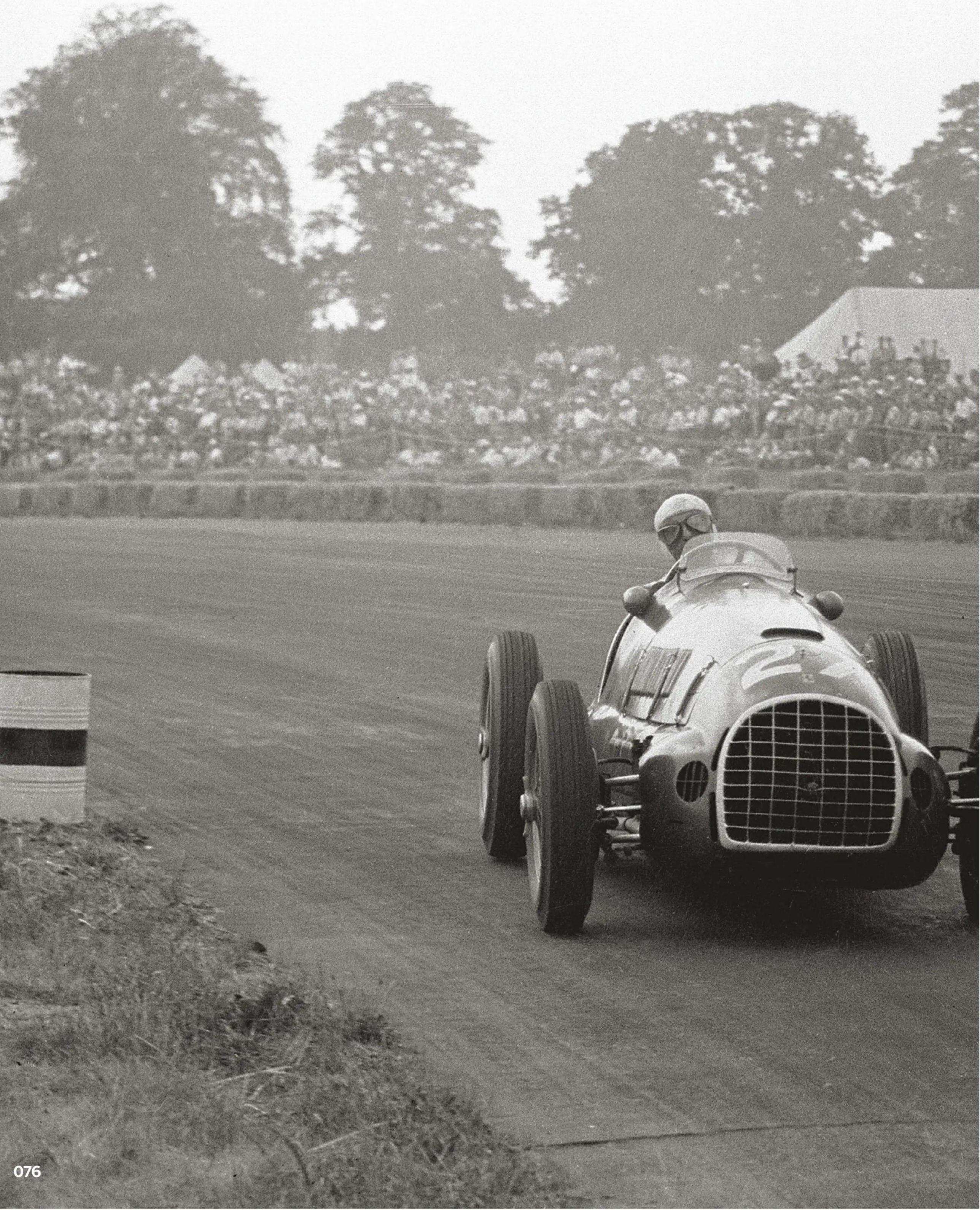
HIGH PRECIPITATION
With winds travelling slower than 40 miles per hour, high-precipitation supercells have an updraft that's surrounded by heavy rain. This type of storm commonly produces tornadoes, which the high precipitation can make difficult to see.

CREATING TORNADOES

Although many rotating storms may look like tornadoes, only some supercells transition into them. Tornadoes need a specific set of conditions to form. As they are defined as rotating air columns that make contact with Earth's surface and a thundercloud, tornadoes require the air of a supercell to spin very close to the ground in order to form. For this to occur, warm air needs to rise above the cool air at a higher altitude, which then needs to drop down to the surface enough to push the air out horizontally in gusts of wind. When this happens continuously, the air at the ground will start to spin, just as it does further up in the atmosphere in a supercell. Not all supercells that form near the ground result in tornadoes. If the air is rotating too slowly, the tornado structure will not form, while if the air is too cold near the ground, it will dissipate away from the storm's centre.

Did you know?
Less than 20 per cent of supercells lead to tornadoes

A typical tornado's damage path is around 1.2 to 1.8 miles



HISTORY

HUMAN POPULATION

Why it took just 200 years for the world's population to increase eightfold to 8 billion

WORDS **AILSA HARVEY**

On 15 November 2022, the human population reached 8 billion. The United Nations' population projection is able to calculate this using a model that incorporates fertility rates, mortality rates, migration behaviour and other factors. In each country or geographic region, different living situations influence the death and birth rates of an area. For example, access to effective healthcare increases a population's average life expectancy. Meanwhile, countries that provide good education to their female population usually have a lower fertility rate.

The planet hasn't always been dominated by humans. At the time *Homo sapiens* first evolved, there were only 100 to 100,000 of us. We were exposed to very different dangers, like large predators and exposure to the elements. Our ancestors required better survival skills to aid their hunter-gatherer lifestyles. In fewer numbers and with lower life expectancies, growth in population wasn't as rapid as today. In fact, it took 35,000 years for this early human population to double in size.

In 2022, our extensive population can be seen as a triumph of modern medicine and technological advancement, with many thousands of years of lifestyle changes. However, the environmental impact of this great number should also be considered. An increase in population is directly related to the demand for food and shelter. And for both food to be produced and homes to be made available, land is needed.

Deforestation is constantly taking place to remove native plant life – and the animals that live in these wild habitats – replacing it with farmland to grow crops to feed to people or livestock. At the same time, natural landscapes are being replaced by urban settlements. We can limit our use of Earth's resources by replacing fossil fuels with renewable energy, cut down on meat and dairy intake to decrease greenhouse gas emissions, reduce food waste and use biodegradable products. To feed 8 billion people using less land space, some scientists suggest vertical farming. By growing food in layers, surface area is added vertically, rather than taking over even more of the remaining wild landscapes.

Did you know?

There are around 140 million births a year

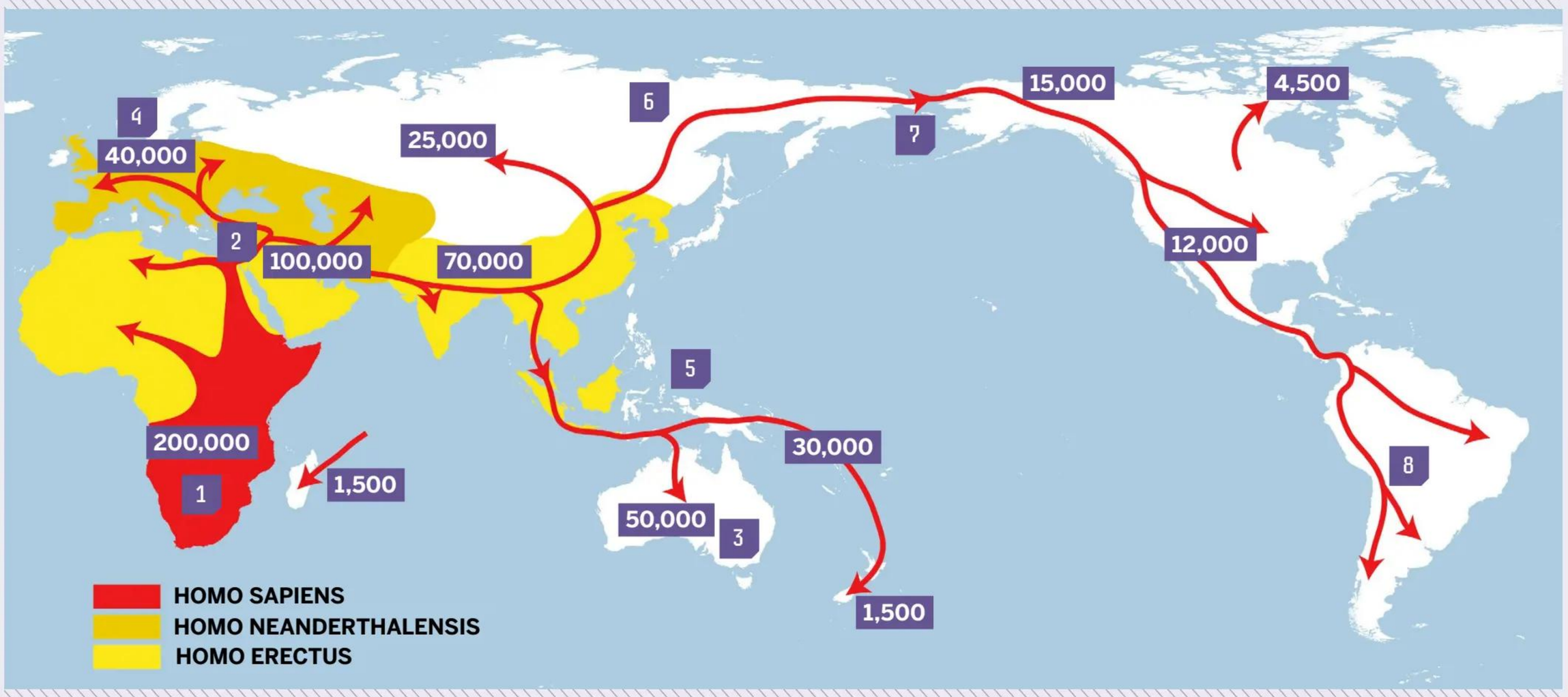
Our population is experiencing a surge in numbers due to technology tackling the main life-limiting factors, such as disease and access to food and safe water. Exactly how much more our species will expand and when Earth's human population will begin to level off is yet to be determined.

Our early hunter-gatherer ancestors numbered just a fraction of the human race today

DID YOU KNOW? Countries with the highest populations are India, China, the US, Indonesia, Pakistan, Nigeria and Brazil

THE ORIGIN OF HUMANS

Modern humans originated 200,000 years ago and began to spread across continents



1 HUMAN EVOLUTION
Around 200,000 years ago, modern humans evolved in Sub-Saharan Africa.

2 GREAT MIGRATION
Humans began to migrate across the globe 100,000 years ago. The population remained under 1 million.

3 REACHING AUSTRALIA
Around 1,000 humans sailed to Australia 50,000 years ago. After an ice age, which drastically reduced the population, numbers increased to around 1.2 million by the time European settlers arrived in 1788. Violence against Aboriginals and new diseases introduced by colonists reduced the Indigenous Australian population by up to 90 per cent.

4 NEANDERTHAL RIVALS
Homo sapiens entered Europe around 40,000 years ago. There, modern humans had to compete with Neanderthals, who had occupied the continent for at least 100,000 years.

5 CLIMATE IMPACT
By 35,000 years ago, the increase in human population slowed with the arrival of an ice age. Humans migrated farther south to avoid emerging glaciers, seeking more temperate climates.

6 END OF THE ICE AGE
15,000 years ago, the ice age ended, and glaciers stopped their advances over northern continents. The human population began to increase and migrate again.

7 BRIDGE TO THE REST OF THE WORLD
Today's global population is around 2,000 times what it was 12,000 years ago. Due to increased volumes of water becoming trapped in glaciers, sea levels decreased and a bridge of land called the Bering land bridge formed. Around 16,000 years ago, humans migrated across this, allowing them to populate the Americas.

8 POPULATING SOUTH AMERICA
Human populations reached South America around 10,000 years ago. By this time, there were around 5 million people on Earth.

FARMING BOOST

Agricultural practices emerged in human societies around 12,000 years ago. Before this, people mostly adopted the hunter-gatherer lifestyle. This meant following their food and using their mobility to benefit their survival. When people began to construct farms, making more permanent homes became necessary. This lifestyle change caused an increase in settlements, which grew in size to form the beginning of some of today's large cities.

Farming allowed communities to produce their own food and have more control over the numbers that were fed. As farms grew in size, farm owners accumulated more food than their immediate families needed, leading to the trade of fresh goods. As more food and jobs became available, it became possible for populations to grow. Today, farmland makes up around 38 per cent of the planet's total land surface area in order to accommodate 8 billion people.

The first farms emerged in the 'Fertile Crescent', a long section of land that spans Iraq, Turkey, Syria, Lebanon, Israel, Palestine and Egypt

918
SQUARE MILES
If 8 billion people gathered in one place, they would cover an area a little bigger than Tenerife

31 YEARS OLD
The global median age has increased by a decade since 1970

60%
Most of the world's 8 billion live in Asia

< 15 YEARS OLD
Nigeria has the youngest population, with 50 per cent being young children

7 COUNTRIES
50 per cent of the world's population live in just a few countries

2023
This year, India is due to overtake China as the most populous nation

68,212 PER SQUARE MILE
Monaco is the world's most densely populated country

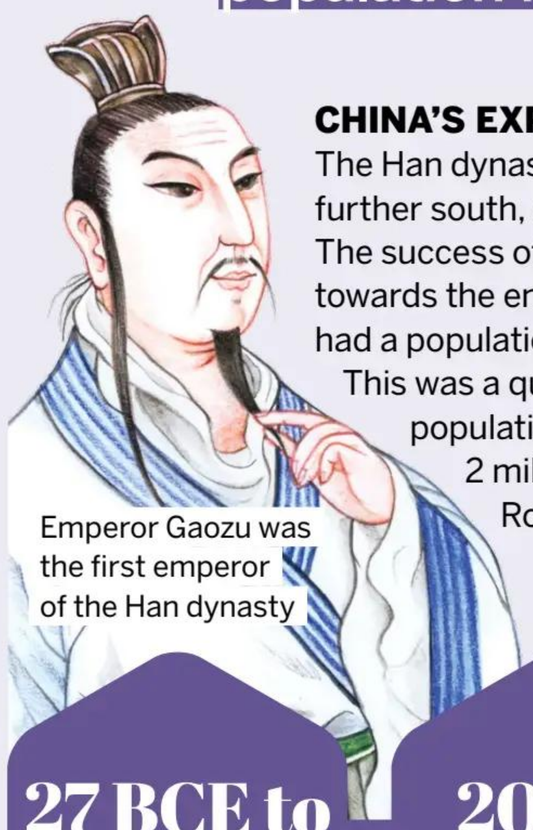
281 MILLION
In 2022, many millions live outside of their country of birth

3%
A tiny proportion of the world's population is under two years old

4 PER SECOND
Worldwide, there are 259 births per minute

THE HUMAN TAKEOVER

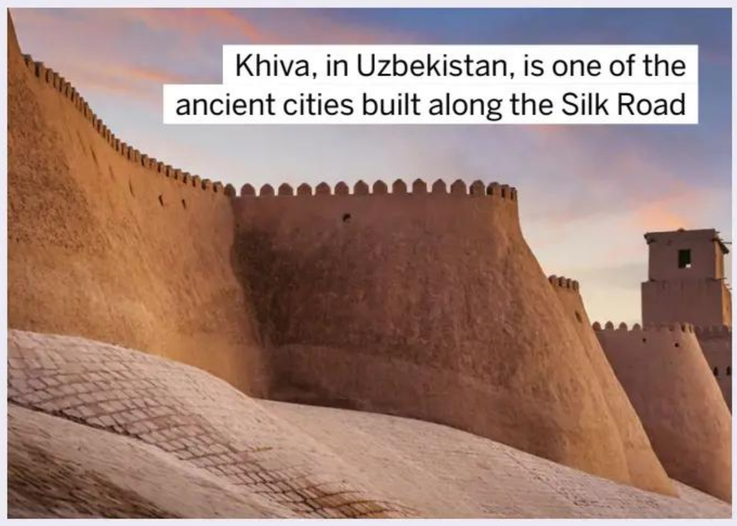
These events helped the human population reach 8 billion


Emperor Gaozu was the first emperor of the Han dynasty

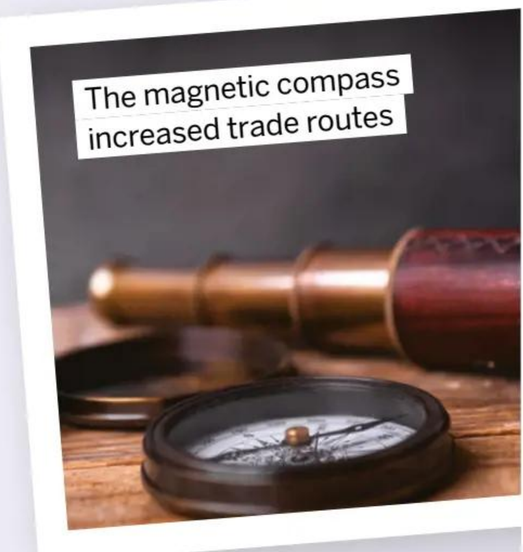
27 BCE to 476 CE — ROMAN RULE
The Roman Empire grew to be 1.93 million square miles in size and is estimated to have contained more than one-fifth of the world's total population. The empire grew largely by offering citizenship as a Roman to nations it conquered. However, there were other methods used by the Romans that helped the global population to grow from 150 million to around 190 million. With the growth of the empire came the expansion of the city, and new engineering was developed in order to sustain such large populations.


Over five centuries, the Romans built 11 aqueducts

206 to 220 CE — CHINA'S EXPANSION
The Han dynasty saw the Chinese go further south, down the Yangtze River. The success of this empire meant that towards the end of this growth, China had a population of around 60 million. This was a quarter of the total world population at the time – around 2 million greater than the Roman Empire.


Khiva, in Uzbekistan, is one of the ancient cities built along the Silk Road

500 to 800 CE — THE SILK ROAD CONNECTION
When the Han dynasty opened trade with the West, goods and cultural ideas could be shared along a long trade artery. Called the Silk Road, this route comprised 4,000 miles of numerous paths and diversions, extensively travelled by traders. The Silk Road was monumental in sharing technologies and information that could support growing populations.


The magnetic compass increased trade routes

12th century — COMPASS NAVIGATION
By the 1300s, compasses were in widespread use, helping sailors travel overseas with higher accuracy. In turn, this meant shorter and more predictable voyages. Europeans used this device to explore, colonise and trade in other continents.

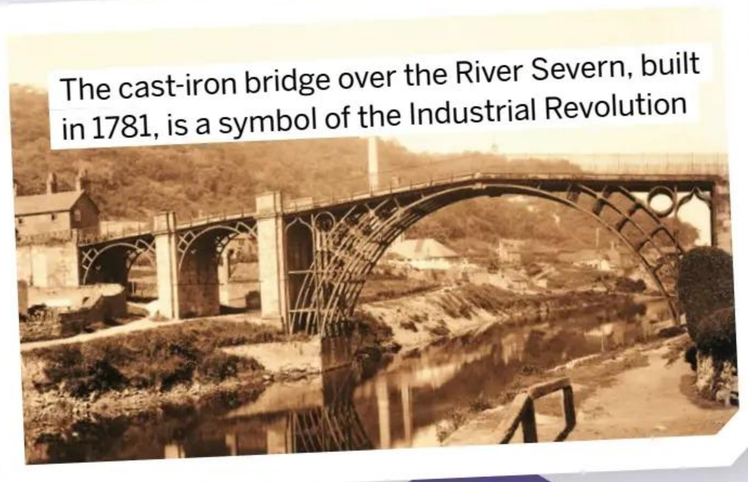
Did you know?

50.5 per cent of the population is male

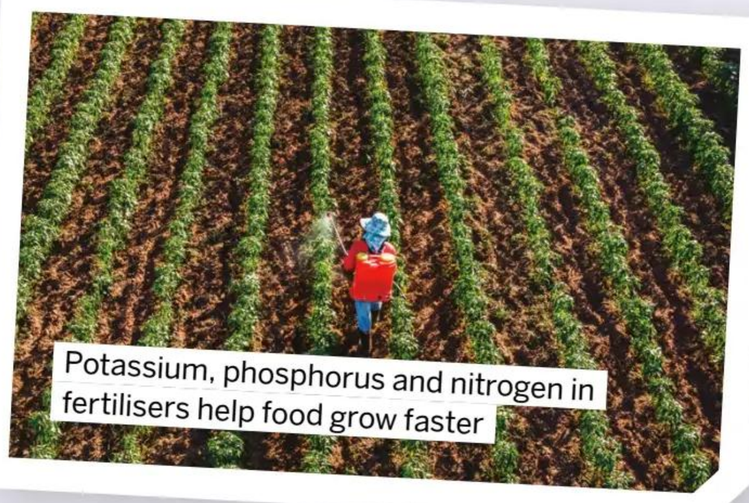
DID YOU KNOW? It took just 11 years for the world population to go from 7 to 8 billion people

THE INDUSTRIAL REVOLUTION

This period of technical innovation changed the way people lived through the invention of new machines and technology, reducing manual labour and improving the speed of production and other chores. During this period, the global population rose from around 800 million to 1.2 billion.



The cast-iron bridge over the River Severn, built in 1781, is a symbol of the Industrial Revolution



Potassium, phosphorus and nitrogen in fertilisers help food grow faster

THE GREEN REVOLUTION

During this period, not only did the area of farmland increase, but so did the methods used to improve crop growth and yield. Farming practices used in Western countries were adopted by India and other Asian countries to increase available food. Before the Green Revolution, one farmer produced enough food to feed just 2.5 people. Today, each farmer can feed around 130 people.

1750 to 1840 | 1918 | 1967 to 1978 | The future

MODERN MEDICINE

Vaccines, antibiotics and complex medical treatments have greatly reduced the number of disease-related deaths and increased human life expectancy from 30 to 80. By more than doubling the lives of the world's population, more generations can live alongside each other than ever before. By preventing death, modern medicine inevitably has a significant and direct impact on the number of people on Earth.

As more children are living into adulthood, the average number of children per family is decreasing

2.1 per cent of the global population died during the Spanish flu pandemic

PREDICTING POPULATIONS

In 1952 the world population reached 2 billion, and it has since grown by 6 billion. According to recent predictions by the United Nations, there will be 8.5 billion people on the planet in 2030, 9.7 billion in 2050 and 10.4 billion by 2080. From the 2080s, the population is estimated to remain at around 10.4 billion until the year 2100. This is due to fertility rates falling and stabilising.

5 POPULATION-BUSTING EVENTS

1 WORLD WARS
During times of war, death rates are high and fertility rates are low. In World War II, around 50 million people died in combat, while 20 to 30 million were lost to war-related famine and disease.

2 THE BLACK DEATH
The Black Death was a bubonic plague pandemic that first emerged in the 1300s. In Europe, it took 80 years for the population to recover. Worldwide, the Black Death reduced the population from 475 million to between 350 and 375 million.

3 SMALLPOX
Since 1900, this contagious disease has claimed more than 300 million lives. Today, however, vaccination has eradicated the disease so that it no longer poses a threat.

4 GUNPOWDER INVENTION
Gunpowder was accidentally invented when scientists were experimenting with making a life-lengthening medical drink. However, the explosive chemistry of gunpowder now makes up most of the world's deadly weapons.

5 POPULATION CONTROL
Many countries have national population control laws in place that dictate how many children each family can have. In 50 years, it's helped the average number of children per family to halve from 5.0 to 2.5.

HOW FORMULA 1 RACING FORMED

Discover the groundbreaking developments that put motor racing in pole position

WORDS **MARK SMITH**

Luigi Villoresi in the Ferrari 125 F1 during the International Daily Express Trophy race at Silverstone in 1949

With blistering speeds, incredible engineering and drivers who went on to become legends, Formula 1 has redefined what's possible when you combine human and machine and set them loose on a track. But the sport we see on our screens today, with its glamour and exotic locales, once looked very different. It can trace its roots back to the very early days of motor racing. In 1946 the first races were held, and a decision was made to launch a championship. It took until 1950 for the rules to be established and the first F1 race was held at Pau in France.

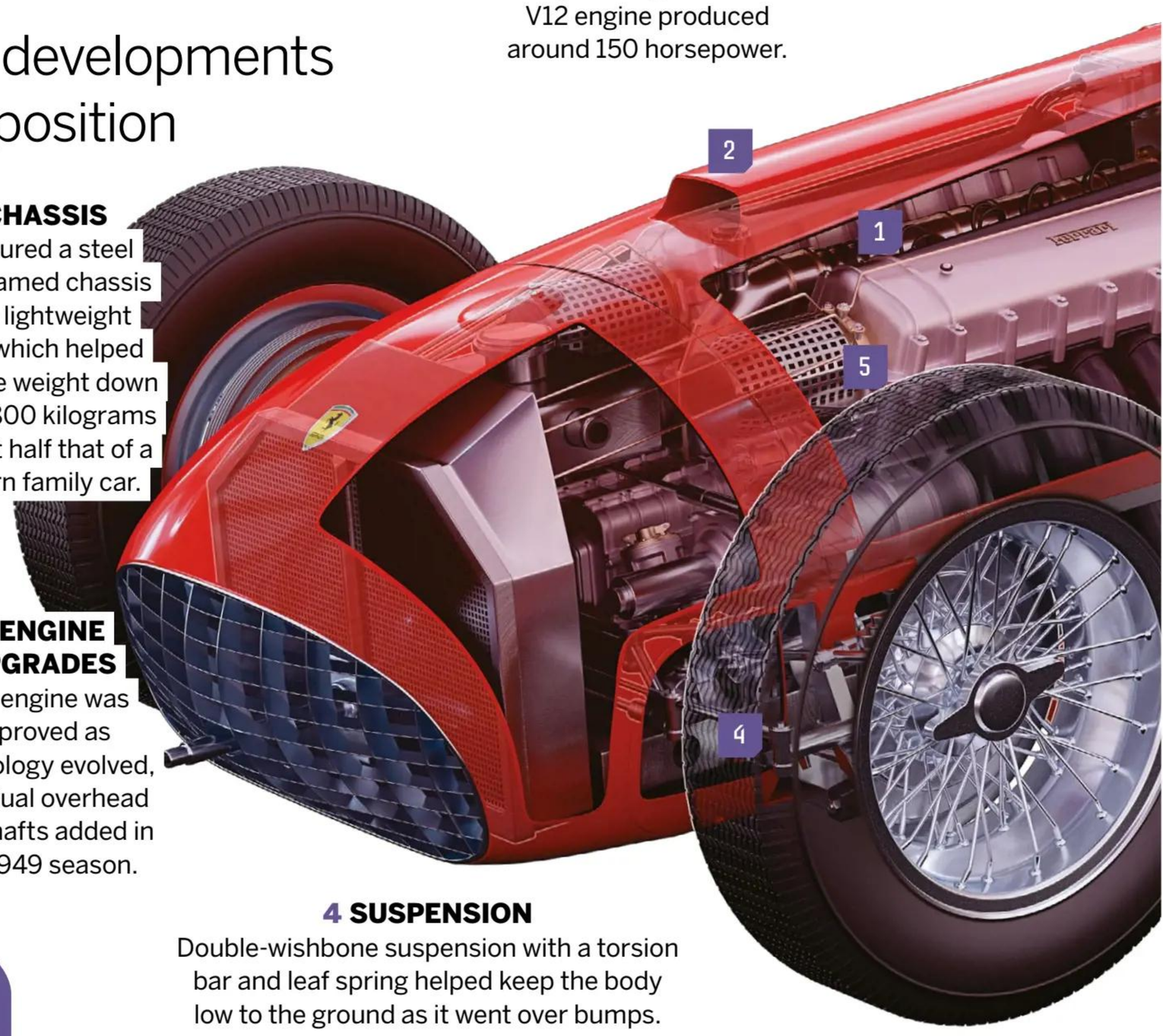
The first races saw the sport very much dominated by the big pre-war manufacturers like Ferrari and Maserati. But the early days were tough going, with a lack of entrants meaning the races weren't as big a spectacle as they are today. It was also much less safe, with 13 drivers being killed during the first decade of Formula 1. Technology advanced the sport, but was hampered when Mercedes Benz pulled out of motor racing following the 1955 disaster at Le Mans – a major crash that saw the death of French driver Pierre Levegh and 83 spectators.

The 1970s saw huge breakthroughs in vehicle design, with Lotus introducing innovations in aerodynamics that improved cornering speeds.

1 ENGINE
A supercharged 1.5-litre V12 engine produced around 150 horsepower.

2 CHASSIS
It featured a steel tube-framed chassis and a lightweight body, which helped keep the weight down to just 800 kilograms – about half that of a modern family car.

5 ENGINE UPGRADES
The engine was improved as technology evolved, with dual overhead camshafts added in the 1949 season.



4 SUSPENSION
Double-wishbone suspension with a torsion bar and leaf spring helped keep the body low to the ground as it went over bumps.

Did you know?
'Formula' refers to the set of rules made for the competition

Also in the early 1970s, British business mogul Bernie Ecclestone rearranged the management of Formula 1's commercial rights, turning the sport into a global billion-dollar business. Technology continued to evolve in the 1980s, with semi-automatic gearboxes and traction control. However, this started a discussion about whether Formula 1 was becoming too reliant on technology, rather than the wits and abilities of the drivers. The sport continues to enjoy enormous popularity today, with global viewing figures reported to be a staggering 1.55 billion in 2021.

RACING THROUGH TIME

1906
'Grand Prix' was first used to describe a race in 1901, but the 1906 race outside Le Mans was the first real international Grand Prix.

1933
Starting positions on a grid were decided by qualifying times for the very first time at the Monaco Grand Prix.

1946
Formula 1 was agreed as a recognised formula – marking its official beginning.

1950
Silverstone hosted the British Grand Prix, which marked the launch of the drivers' world championship.

1958
The legendary Sterling Moss won the first race in a rear-engine car.

DID YOU KNOW? F1 cars can accelerate from 0 to 60 miles per hour in 2.6 seconds and decelerate in under four seconds

FORMULA 1 LEGEND

The Ferrari 125 F1 was the iconic company's first Formula 1 car

7 WHEELBASE
The car had an 85-inch wheelbase. This was uprated to 91 inches in 1949.

6 BRAKES
The car had drum brakes on each of its four wheels to help it corner and reduce speed at crucial points of the race.

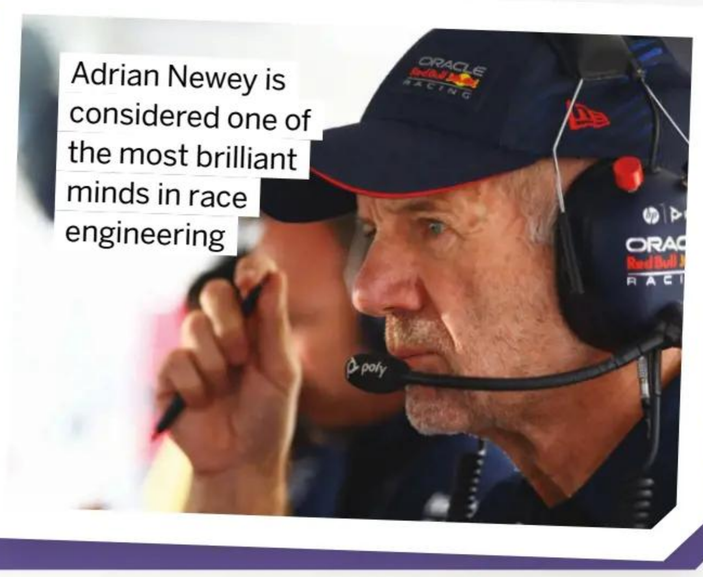
3 DESIGN
It was one of the first cars to feature a streamlined body that helped reduce drag and increase speed.

8 GEARS
This was a sophisticated gearbox for the time, with five speeds and one for reverse.

9 PERFORMANCE
The vehicle was capable of speeds up to 130 miles per hour, an incredible feat for that era.

RED BULL GENIUS

British Formula 1 engineer Adrian Newey is widely considered to be the most important designer in the sport's history. After studying aeronautics at Southampton University and following a stint in the American IndyCar series, he helped design some of the sport's most successful cars. These include those driven by the legendary German driver Michael Schumacher, in which he won five World Championships with Ferrari, and by Sebastian Vettel, who won four with Red Bull.


Adrian Newey is considered one of the most brilliant minds in race engineering

5 TYPES OF F1 TECH IN ROAD CARS

1 CARBON FIBRE
A material that was used to reduce weight while maintaining strength and rigidity compared to aluminium components.

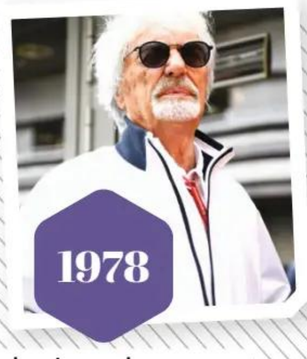
2 TURBO
Turbo hybrid power units featuring a turbocharged V6 engine and electric motor were first used in F1 in 2009. Today road cars use it.

3 REGENERATIVE BRAKING
A kinetic energy recovery system uses braking power to regenerate electric energy in the car's hybrid power units. Road models like the Toyota Prius use it.

4 ACTIVE SUSPENSION
Nigel Mansell's 1992 Williams FW14B featured active suspension, which is now widely used in mainstream vehicles.

5 STEERING WHEEL BUTTONS
Almost every modern vehicle has buttons for certain functions, but the original idea was pioneered on F1 cars.

1962
Lotus introduced a revolutionary new design: a car with an aluminium chassis.



1978
Ecclestone became president of the Formula One Constructors' Association.

1982
Lotus unveiled a new active suspension system, signalling the start of electronic driver aids.

1994
Ayrton Senna was killed at the San Marino Grand Prix, triggering a drive to improve safety standards.

2008
The Formula One Teams Association was formed on 29 July.

ISAAC NEWTON

The pioneering physicist that got to grips with gravity and set the world in motion

WORDS **SCOTT DUTFIELD**

Above: A painting of Sir Isaac Newton analysing the ray of light

Right: Sir Isaac Newton explained some of the most fundamental forces in physics

Right inset: Newton's apple-induced gravitational epiphany is likely a myth

On Christmas day 1642, Hannah Ayscough and Isaac Newton Sr welcomed their new child into the world. Little did they know at the time that he would grow up to be both a pioneering scientist and the greatest mathematician of his generation. Unfortunately, only three months after his birth, Newton's father, a wealthy farmer, passed away. His mother remarried, at which point Newton was left in the care of his grandmother.

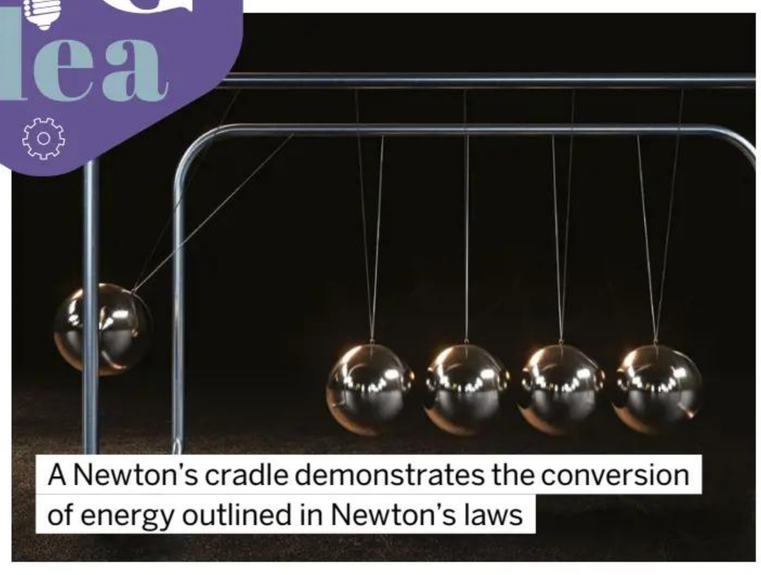
As a child, Newton attended a free grammar school in Grantham, Lincolnshire. However, his school reports were far from complimentary of Newton's academic abilities, describing him as 'idle' and 'inattentive'. Nevertheless, Newton persisted with his education, and in 1661 enrolled at Trinity College, Cambridge, intending to complete a law degree. However, after thumbing through the pages of an astrology book in 1663, Newton's academic journey was changed, and he headed straight for mathematics. In 1665, Newton completed his degree, specialising in mathematics and philosophy.

Throughout his life, Newton made countless contributions to the world of mathematics and the field of physics. One of his first major discoveries involved light. Using a glass prism, Newton was the first person to suggest that light was made up of different rays of colour that came together to form visible light. However, it was his work to uncover the fundamental laws of motion that propelled him into scientific stardom.

Among the many books Newton published during his life, *Principia* outlined the ever-present force of gravity and its ability to pull objects. Newton proposed that the more mass an object had, the stronger the pull of gravity, and the greater the distance between the two, the weaker the attraction between them.

Over time, Newton has become synonymous with a falling apple hitting his head. Long has the story of Newton tending to a sore head been told

The BIG idea



A Newton's cradle demonstrates the conversion of energy outlined in Newton's laws

DISCOVERING THE THREE LAWS OF MOTION

Newton is best remembered for the development of his three laws of motion. The first is Newton's law of inertia, in which every object will remain at rest or in uniform motion unless compelled otherwise by an external force. Then there's the law of acceleration, which defines that a force is equal to the change in the momentum per change in time. When more force is applied to an object, its acceleration increases, but when the mass of the object increases and the force remains the same, its acceleration decreases. Finally, the third law of action and reaction states that every action has an equal and opposite reaction.

5 THINGS TO KNOW ABOUT ISAAC NEWTON

1 NEWTON THE ALCHEMIST
Newton conducted several experiments to convert base metals into precious metals. He even attempted to create a philosopher's stone from mercury.

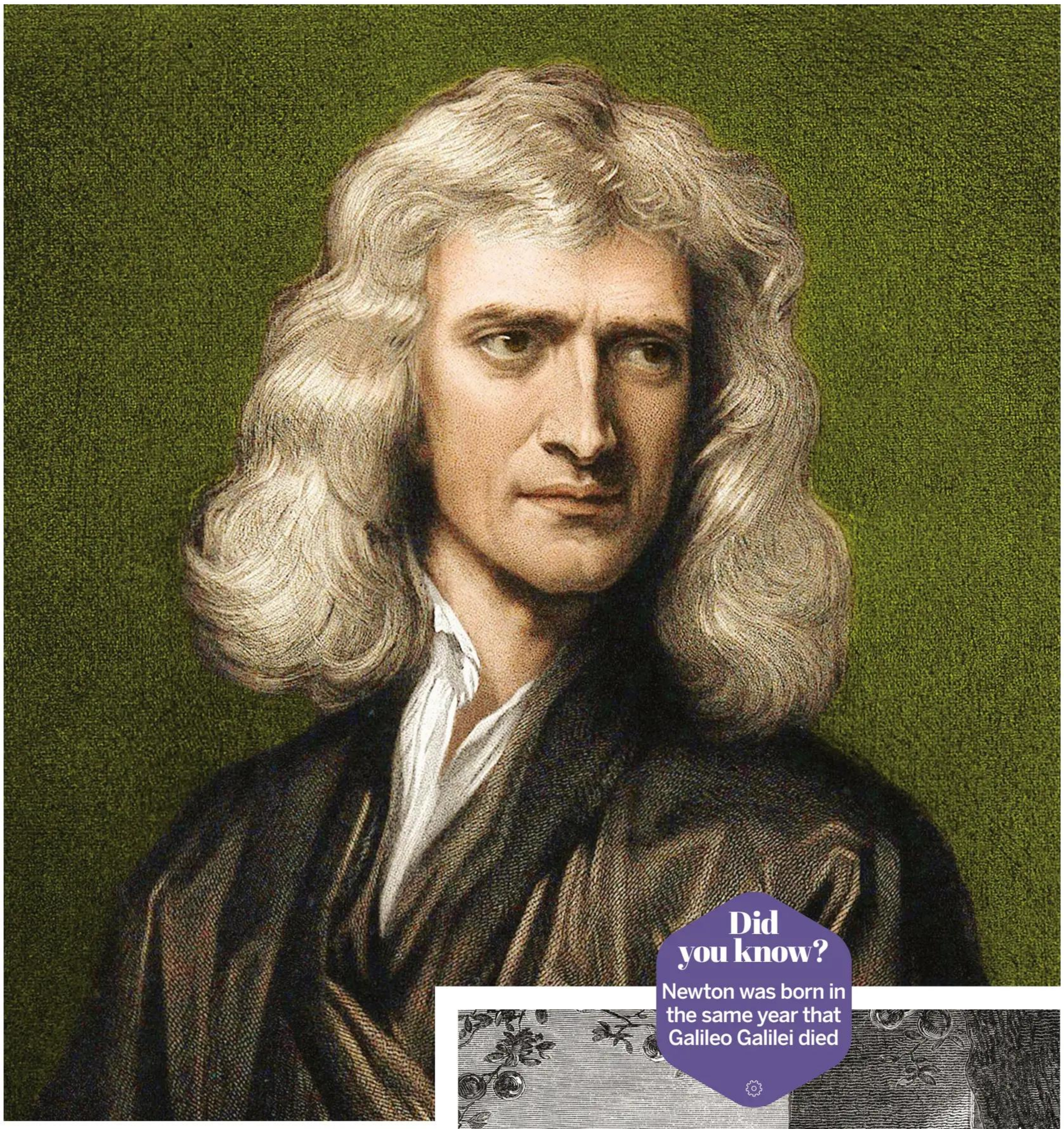
2 HE'S GOT TWO BIRTHDAYS
England used the Julian calendar, which put his birthday as 25 December 1642. However, when the Gregorian calendar was adopted in 1752, his birthday became 4 January 1643.

3 HE ALMOST GAVE HIMSELF A LOBOTOMY
As his own scientific guinea pig, a young Newton inserted a large blunt needle behind his eyeball to study the shape of his eye and measure the pressure exerted by this eyeball.

4 A DOG NEARLY DESTROYED EVERYTHING
Newton's dog Diamond is said to have knocked over a candle and set fire to his papers. Some of these charred notes sold at auction in 2020 for £378,000.

5 A BAD INVESTOR
In 1720, Newton invested £20,000 in the South Sea Company. However, the investment was far from fruitful, and he lost the lot, which would equate to over £3.3 million today.

DID YOU KNOW? The bubonic plague caused Newton to flea Cambridge back to Lincolnshire for two years in 1665



Did you know?

Newton was born in the same year that Galileo Galilei died

as the catalyst for his understanding of the world's forces, particularly gravity. However, this is largely disputed among historians, as the supposed apple accident occurred 20 years before he published his theories on gravity.

However, not all of Newton's ideas were revolutionary. In *Principia*, Newton describes how rarefied vapour from comet tails is pulled into Earth's gravitational grasp and enables the movements of the planet's fluids, along with the "most subtle and useful part of our air, and so much required to sustain the life of all things with us."

At the age of 84, Sir Isaac Newton died peacefully in his sleep at Kensington on 20 March 1727. He was buried in Westminster Abbey eight days later. His white and grey marble monument stands in the nave of Abbey's choir screen and boasts sculptures of Newton lounging surrounded by children using the many instruments, such as telescopes, that are associated with Newton's work.

A LIFE'S WORK

The academic milestones that made Isaac Newton a pioneering mathematician and physicist

1669
Newton first described his reflecting telescope to the Royal Society.

1672
The first of Newton's scientific papers on light and colour was published in the journal *Philosophical Transactions*.

1684
The first work on the subject of calculus, called *Novus methodus*, written by Newton, was published.

1687
Newton published his first book Principia, outlining the laws of motion and the law of universal gravitation.

1703
Newton was elected as the president of the Royal Society.

1704
The first edition of *Opticks: Or, A Treatise of the Reflections...* was published.

1705
Queen Anne knighted him, making him the first scientist to be bestowed this honour.

1707
Arithmetica universalis was published, in which Newton explores the essentials of algebra and geometry.

1728
Newton's work on universal gravitation and its consequences in astronomy was published in *De mundi systemate* (The System of the World).

THE ORIGINS OF WEIGHTS AND MEASURES

Left: An illustration of a standard metre hanging in the Petit Luxembourg, Paris, in 1799, following the end of the French Revolution

Below: The Anglo-Saxons used three barleycorns to measure an inch

Why did much of the world switch from the imperial to the metric system?

WORDS **SCOTT DUTFIELD**

Since civilisation began, humans have created ways to measure and standardise units of measurement for things. Typically for trade and agriculture, early measures in Mesopotamia – what is mostly Iraq today – utilised parts of the human body, seeds and stones to create standards of measure. Up until 1700 BCE, the people of the Harappan civilisation in Punjab, India, created intricate weighing scales and developed measurements such as the 'Indus inch', which is equal to 1.32 inches. Ten of these equalled a 'foot', although it's unclear whether or not the Harappa people had such big feet.

The first standardised system of units is believed to have originated in Great Britain and is known as the imperial system. However, this collection of units of measurement evolved from thousands of years of Roman and Anglo-Saxon influence – that is, ancient Italy and ancient England. For example, the Anglo-Saxons used a unit of length known as a barleycorn, which has now been standardised to 8.5 millimetres, that's still in use today to measure shoe size. The imperial system was formally standardised and adopted when the Weights and Measures Act of 1824 came into force. New measurements such as the imperial gallon became the norm, which is equal to ten pounds (around 4.5 kilograms) of water at 62 degrees Fahrenheit (16.7 degrees Celsius).

Over time, the world's measurements rapidly evolved, and more and more names for different weights and measures emerged. By the 18th century, it was estimated that there were more than 800 different units of measurement for traders and farmers to contend with around the world. That was the case until a new standardised system emerged, sweeping the world.

Did you know?

1,000 Roman paces is equal to a mile

The metric system, also known as the International System of Units, originated in France during the French Revolution, which ended in 1799. Ditching the imperial standard, French scientists and mathematicians developed a new decimal-based system that operated in multiples of ten. Taking inspiration from nature, the novel 'metre' was defined as one ten-millionth of the distance from the North Pole to the equator.

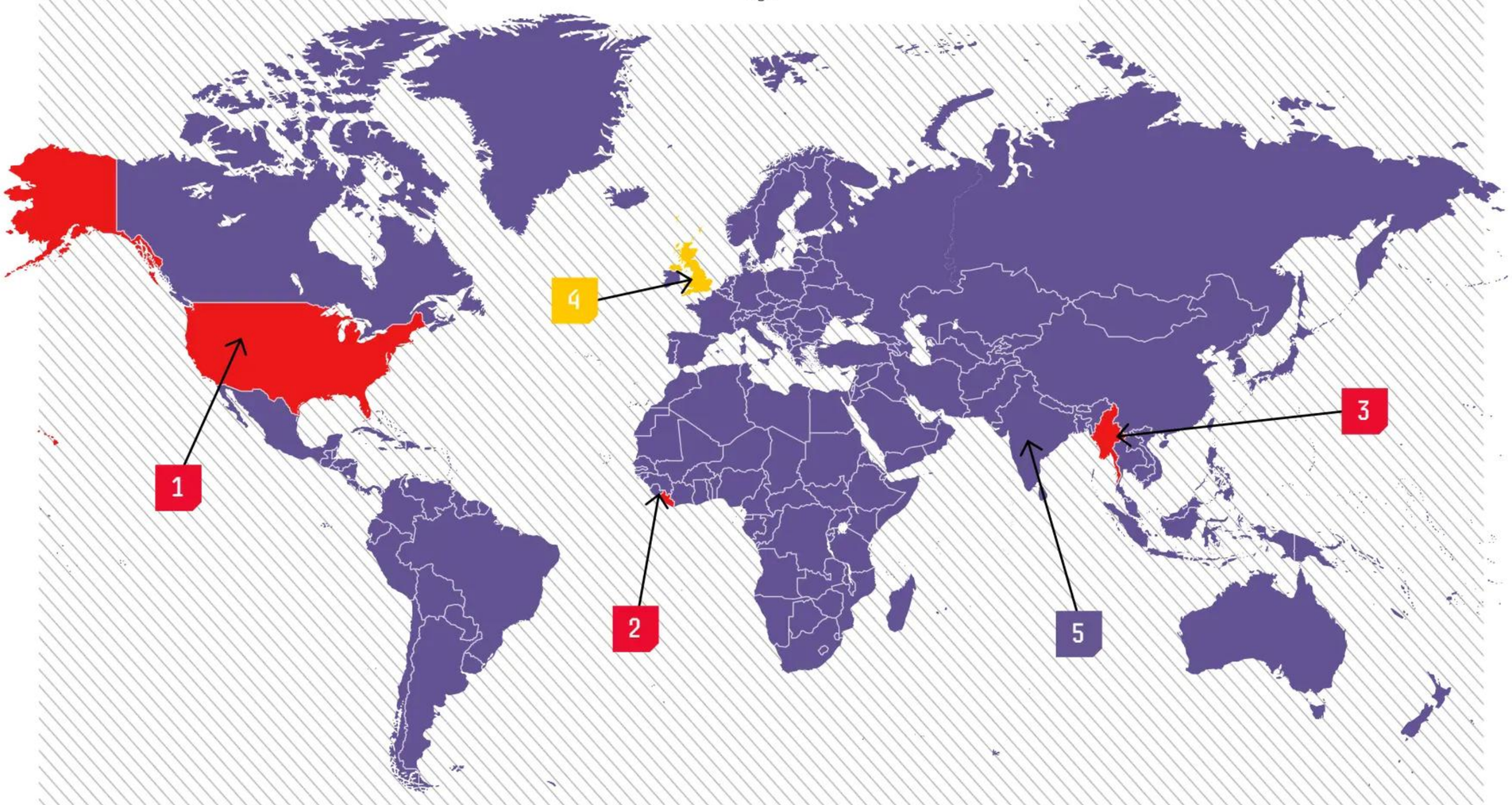
The new system wasn't an immediate success, and in 1812 was abolished by Napoleon, allowing people to use whichever method they wanted before France reinstated the metric system in 1840. For more than 200 years the metric system has been used by the majority of the world's countries, and its units have become universally used in engineering and manufacturing.

A collection of cubit measuring rods used in Egypt around 1550 to 1292 BCE

DID YOU KNOW? More than eight in ten Britons still use imperial measurements day to day

THE LAST IMPERIAL USERS

Some countries still favour the old system



1 US
Despite the metric system being declared lawful in the United States in 1866 and Congress voting it to be the preferred system of weights and measures, the majority of the American population still use the imperial system.

2 LIBERIA
As a former colony of the United States, this West African country inherited the imperial system. However, it's been reported that the country is looking to officially make the change to the metric system.

3 MYANMAR
This Southeast Asian country largely uses a combination of the imperial system, such as miles and gallons, and its own units of measure, such as 'viss' for weight, where one viss is equal to 1.68 kilograms.

4 UNITED KINGDOM
Unable to completely convert, many Britons still use imperial measurements today, such as 'stone' to measure weight and 'feet' for height, despite the government beginning a move towards metrication in 1965.

5 REST OF THE WORLD
By the mid-1970s the majority of the world had ditched imperial measurements and adopted the metric system.

THE EGYPTIAN CUBIT

Around 3000 BCE, ancient Egyptians developed one of the earliest known units of measure, called a cubit. Used as a unit of length, a cubit was equal to the length from the elbow to the fingertip. To standardise the length, a royal cubit rod made from black granite was created to use like a metre stick, equal to 45.7 centimetres. For smaller measurements, the royal cubit was broken down into the width of a finger, known as a digit. One cubit equalled 28 digits, four digits equated to a 'palm' and five digits to a 'hand'. Over time the cubit measuring system expanded to include 'large spans' (half a cubit) and 'small spans' (three palms) and reached new civilisations, with the Babylonian cubit emerging around 1700 BCE.

5 WEIRD MEASUREMENTS THAT ARE STILL IN USE

1 FURLONG
Used to measure the distance ran by a racehorse, one furlong is equal to 201.168 metres. Its origins come from the length of ploughed furrow that could be created by an ox without rest.

2 LEAGUE
Still used in several countries but brought to England by the Normans, a league is equal to the length a person can walk in an hour, which they estimated was around three miles.

3 KLICK
A klick is another way of saying a kilometre in the military. It's believed that its origin comes from the clicking sound made by rifle gas regulators when they were reset after 1,000 metres of trekking

4 ROD
Derived from the old English word 'rodd', meaning stick of wood, this agricultural unit of measurement is typically used to describe allotment sizes and equals 5.029 metres.

5 NAUTICAL MILE
Unlike a typical mile, this seafaring alternative is equal to one minute of travelling along Earth's latitude either side of the equator, or 1,852 metres.

TECHNOLOGY

TECHNOLOGY

DID YOU KNOW? Modern smoke bombs use pellets to release smoke over a 5,000-metre range

INSIDE THE BOMB FACTORY

We take a tour of a world-leading munitions factory to find out how bombs and bullets are made

WORDS **MIKE JENNINGS**

It's not every day that you get invited to visit a bomb factory, but that's exactly what happened to **How it Works**, so we jumped in the car and headed to Washington, in the north of England, to visit a plant operated by BAE Systems. Drive up to the building and you'd be hard-pressed to guess what gets made there. There's a security gatehouse, but beyond that it just looks like any other factory. On the inside, though, it's a very different story. Most of the armaments produced at Washington are sold to the British Ministry of Defence (MoD), but around 25 per cent of the factory's output is sold to militaries around the world – on the day we visited, the munitions on show were heading to Germany. The BAE group produces loads of products – from vast tank shells to tiny bullets – and the plant at Washington concentrates on medium-sized munitions, including 81mm mortar shells and 155mm bombs that are currently used in Ukraine.

Did you know?

BAE Systems was founded in November 1999

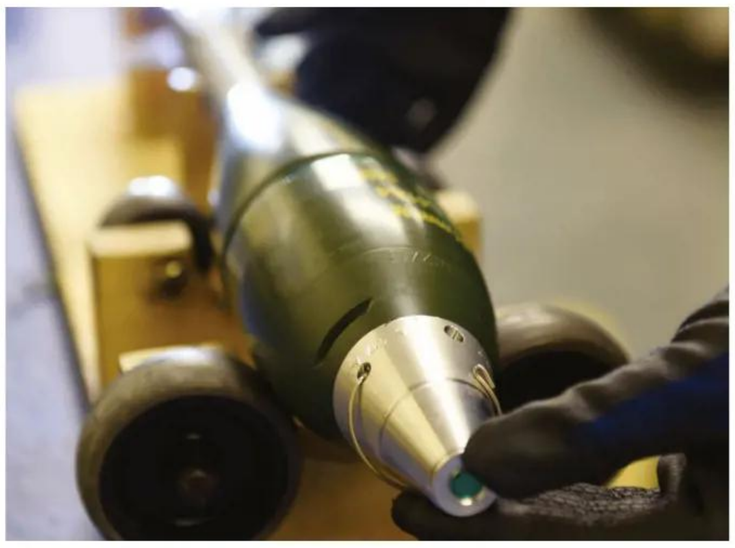
BAE has a £2.4 billion ($2.9 million) contract with the MoD that's set to last until 2038 called the Next Generation Munitions Solution (NGMS). It should allow the MoD to manufacture more arms in the UK, which reduces costs, makes manufacturing more secure and enables

155mm shells are used in the Archer Mobile Howitzer, a 33-tonne gun vehicle


BAE's Washington plant looks unassuming on the outside, but it's a world-leading armament facility

FROM WAR TO WASHINGTON

BAE's predecessors have been making mortar, artillery and tank ammunition in the North East of England since 1916, when the firm opened its first factory in a town called Birtley. That first facility employed 3,800 people, and 3,500 of those were Belgian soldiers who arrived in Britain after fighting on the front lines in World War I. At the time, two munitions factories were built, mostly staffed and managed by Belgian teams, because Belgium had a fantastic reputation for manufacturing armaments. The Belgian community in the North East was dubbed Elizabethville, and a new village was built alongside the factories. By 2009 an upgraded munitions factory was required, and in 2012 BAE moved from Birtley to Washington. The new £75-million ($90.3-million) factory sits on the site of an old Dunlop tyre plant next to a luxury car factory and currently employs 340 people.



Left: The Archer can fire three 155mm rounds in 20-second bursts, with a range of 30 miles

Below: BAE's Glascoed site was chosen because it's secluded, and thus hidden from enemy bombers

companies like BAE to export more products abroad. Over the course of the NGMS project, BAE plans to invest £91 million ($109.5 million) into equipment and improvements, and the biggest individual investment so far is a £5 million ($6 million) automated line at the Washington plant, which we saw during our factory tour. The NGMS project isn't just about crunching numbers, either. BAE is investing in new methods for mixing explosive material, updated explosive mixtures, lighter shell casing and improved accuracy across its production lines.

Before exploring the munitions factory, we had to squeeze our feet into steel-capped boots and put on shatter-proof safety goggles. We had to sit through a safety briefing too, and no wonder – the factory floor is a busy, loud place. BAE's facility is divided into three broad areas: one for forging a rectangular metal 'billet' into the rough shape of the shell, a second area for refining that 'bottle' into the precise design required and a third to finish the exterior of each unit. The forge is an absolute beast – it's certainly not the kind of small unit where one person stands with a hammer. It cost £13 million ($15.7 million) to build, weighs 250 tonnes and it's one of the most advanced devices in the world. That's no surprise when you see it in action: robots grab the dull metal billets and heat them until they're so hot that they're glowing and you can't get near them without feeling the extreme temperatures. More robots grab the heated blocks and start to squeeze, stretch and form the metal into a hollow bottle shape that will eventually become a 155mm calibre artillery round.

Did you know?

BAE has provided the MoD with munitions since 1940

It's a remarkable process to witness. Robots move in smooth and synchronised motions, steam hisses from machines and the white-hot metal progresses to another machine to cool down so humans can handle it again. The forge is the kind of thing you're used to seeing on industrial planets in *Star Wars*, not on the outskirts of Sunderland. At this point, expert technicians refine each shell on production lines of expensive, sophisticated machines – and the munitions are kitted out with different paints, markings and components. While the manufacturing process isn't finished at that point, the story is over for the Washington plant – the shells head to Glascoed in Wales to be filled, assembled and shipped at a different munitions factory.

TYPES OF AMMUNITION EXPLORED

SMALL ARMS AMMUNITION

These bullets range in size from 5.56mm to 7.62mm and work inside handheld guns. Tracer, armour-piercing and high-performance designs are available, and laser gauging ensures high accuracy in manufacturing.

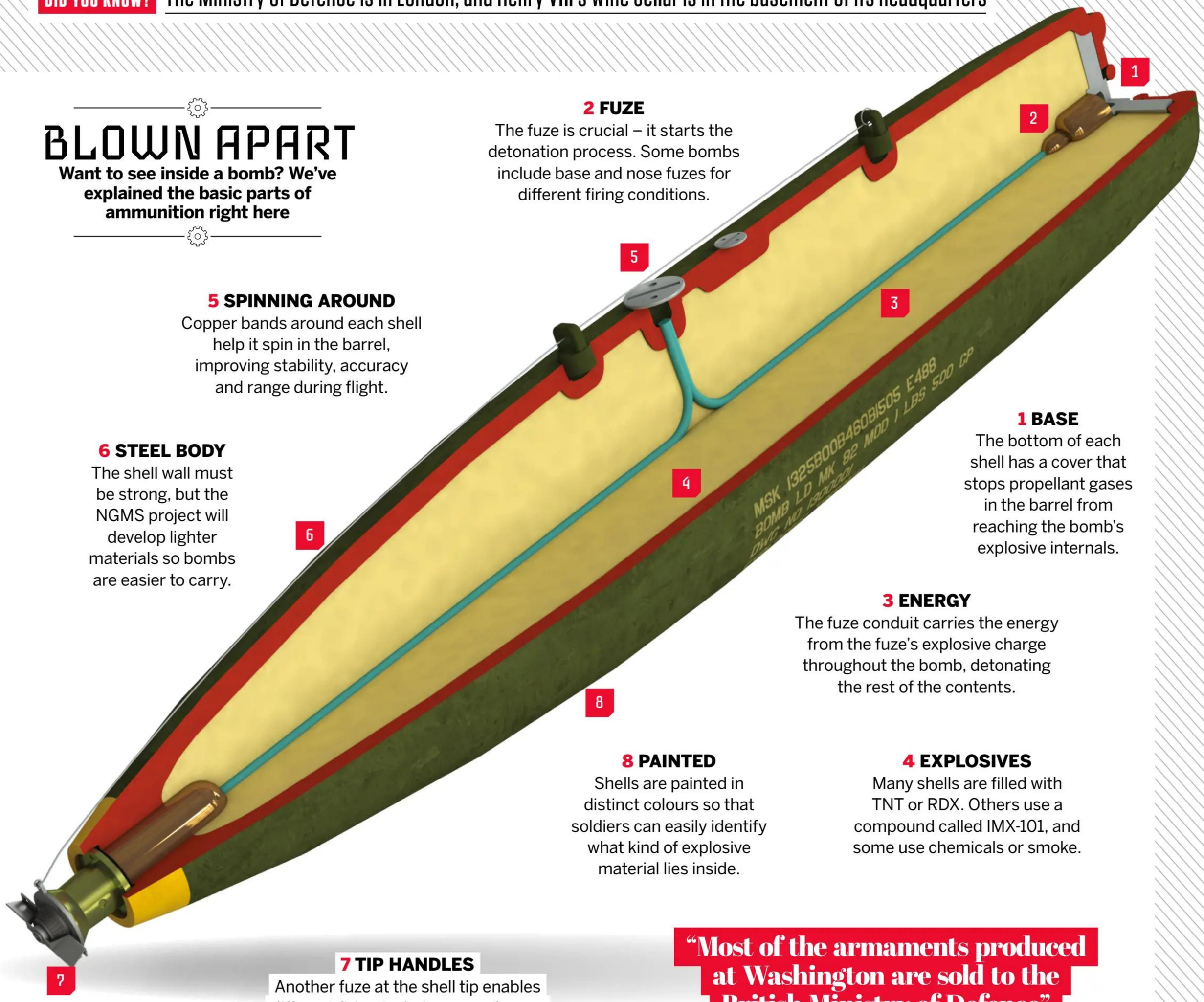
CASED TELESCOPED AMMUNITION

These 40mm shells are a world-first design, replacing existing 30mm rounds while offering more power. They're fired from vehicles and come in armour-piercing and anti-air varieties.

DID YOU KNOW? The Ministry of Defence is in London, and Henry VIII's wine cellar is in the basement of its headquarters

BLOWN APART

Want to see inside a bomb? We've explained the basic parts of ammunition right here



1 BASE
The bottom of each shell has a cover that stops propellant gases in the barrel from reaching the bomb's explosive internals.

2 FUZE
The fuze is crucial – it starts the detonation process. Some bombs include base and nose fuzes for different firing conditions.

3 ENERGY
The fuze conduit carries the energy from the fuze's explosive charge throughout the bomb, detonating the rest of the contents.

4 EXPLOSIVES
Many shells are filled with TNT or RDX. Others use a compound called IMX-101, and some use chemicals or smoke.

5 SPINNING AROUND
Copper bands around each shell help it spin in the barrel, improving stability, accuracy and range during flight.

6 STEEL BODY
The shell wall must be strong, but the NGMS project will develop lighter materials so bombs are easier to carry.

7 TIP HANDLES
Another fuze at the shell tip enables different firing techniques, and some tips also have handles to make transport easier.

8 PAINTED
Shells are painted in distinct colours so that soldiers can easily identify what kind of explosive material lies inside.

"Most of the armaments produced at Washington are sold to the British Ministry of Defence"

81MM MORTAR BOMB
Mortars are lightweight, handheld cannons. Their 81mm shells are available in high-explosive designs alongside smoke-filled and illumination variants, and infrared shells help soldiers using night-vision goggles.

120MM TANK AMMUNITION
As the name suggests, these shells fire from tanks and function in the widest range of climates. They have anti-armour capabilities and high-explosive properties for maximum impact.

PRODUCTION

Here's how a bomb factory navigates the tricky bomb-building process, from start to finish

Did you know?

BAE produces a million small arms rounds each day

1 DESIGN AND CONQUER

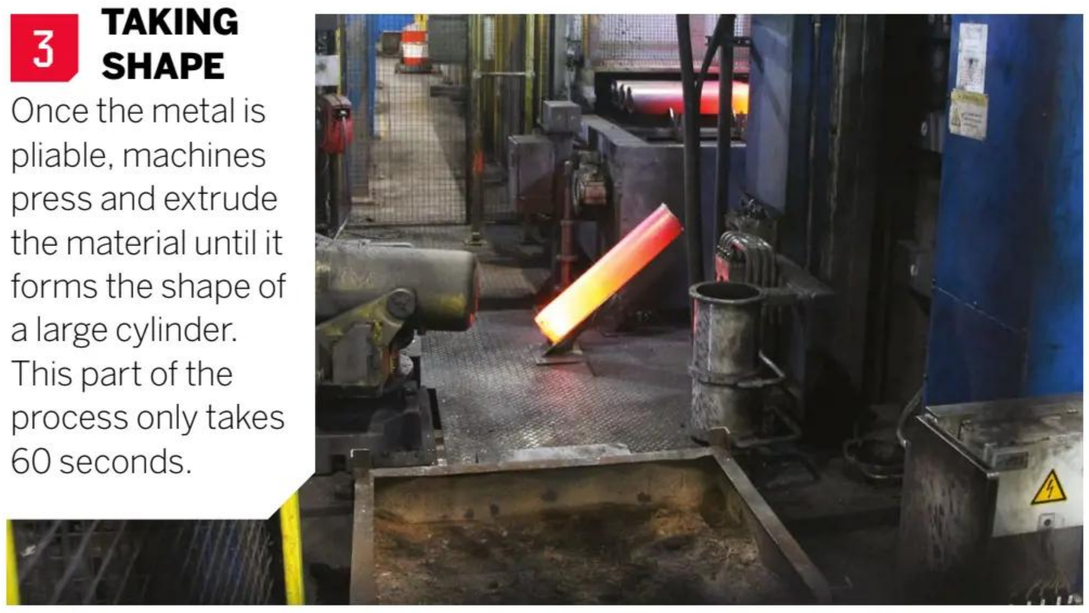
BAE Systems needs to design bombs before they can get building. Expert engineers get the job done in the office using complex software packages.

2 HEATING UP

Rectangular slabs of steel, called billets, are heated to 1,100 degrees Celsius so they're malleable enough to mould properly. This process is called induction, and the metal is red-hot after it emerges.

3 TAKING SHAPE

Once the metal is pliable, machines press and extrude the material until it forms the shape of a large cylinder. This part of the process only takes 60 seconds.



4 COOLED AND BLASTED

Bottles are cooled and shot-blasted to smooth the surface. The shell ends are heated to 1,150 degrees Celsius and compressed into a perfect tip in a process called swaging.

5 COLOUR CODING

At the other end of the factory, projectiles are painted and fitted with their copper rotation bands. Quality is checked before the shells are packed for transport.

6 FILLING UP

Staff at BAE's plant in Glascoed, Wales, fill the shells. The MoD partially chose the site because its damp microclimate was ideal for handling dangerous explosives.

7 PACKED AND STACKED

Shells aren't just filled at Glascoed – final assembly takes place here, including any extra modules required by customers. The bombs are carefully packed for final shipping.

8 SHELL TESTING

Some shells are sent to Ridsdale in Northumberland, where BAE tests its weaponry. It's a full-scale firing range where technicians can replicate battlefield conditions.

DID YOU KNOW? A standard 155mm shell has a range of 14 miles, but rocket-assisted shells can cover almost 18 miles

EXPLOSIVE REACTIONS

Explosions work because of complex chemical reactions that rapidly produce large quantities of gas. Take TNT, which is one of the oldest explosive materials. Its scientific name is 2,4,6-trinitrotoluene, and this explosive works by changing solid materials into a hot, expanding gas in an aggressive thermodynamic reaction. Its reaction produces carbon monoxide, carbon dioxide and nitrogen, and TNT's explosive nature doesn't just come from its pure energy output – it's the incredible speed at which it detonates, too.

Another popular explosive, RDX, is called cyclotrimethylenetrinitramine and is produced by the nitrolysis of hexamine with nitric acid. BAE has also developed a substance called IMX-101, and the US Army uses this instead of TNT in its incendiary munitions. It's safer to store and handle, but just as effective. No matter the material, safety is paramount when handling explosives, which is why companies like BAE take so much time to get things right when building the latest bombs.

HEAVY-METAL ENGINEER

Martin Coats is a graduate engineer at BAE. Here's how he got his start

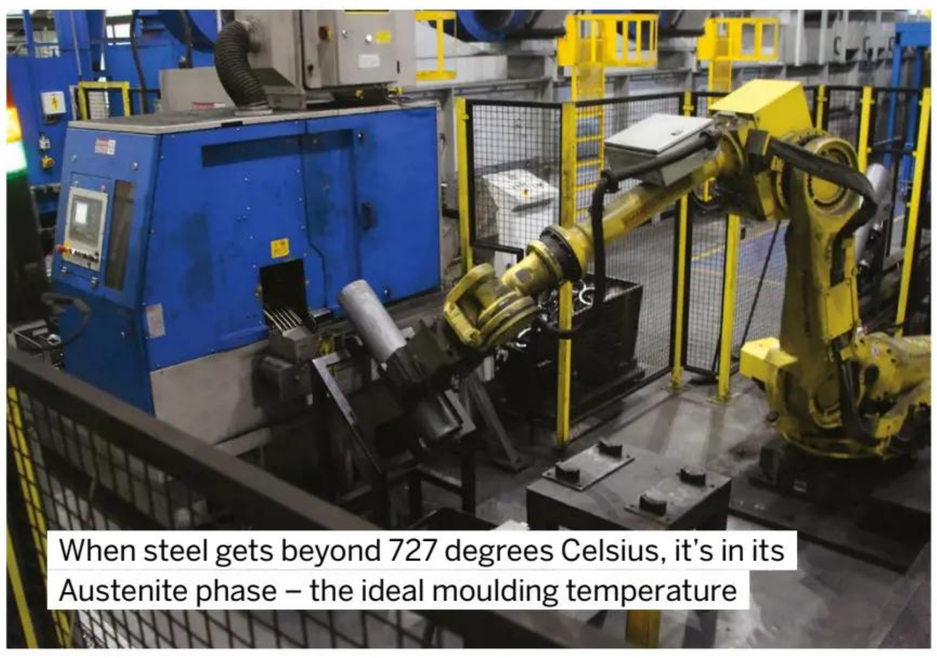
How did you get started, and what do you do at BAE?
I studied mechanical engineering at university, and I had an industrial placement at a local company. After that I got involved with materials research and simulation, which is where I saw this role. I applied for BAE's graduate scheme, and here I am. I support the shop floor; I figure out what systems we need for new products and how we maintain current systems. I'm working on Next Generation Adaptable Ammunition, which is really exciting. From a metallurgy point of view, we're trying to soften steel so it forges easier. The induction heater expands the lattice within the material to weaken bonds between crystals so we can form the parts in different presses and punches. But you need to align the grains too, because aligning grains improves the result.

What's your favourite part of the job?
The people, by a mile. Everyone has been welcoming. I've always wanted to be an engineer and it's fascinating to be involved in these projects, but the best thing is the people.

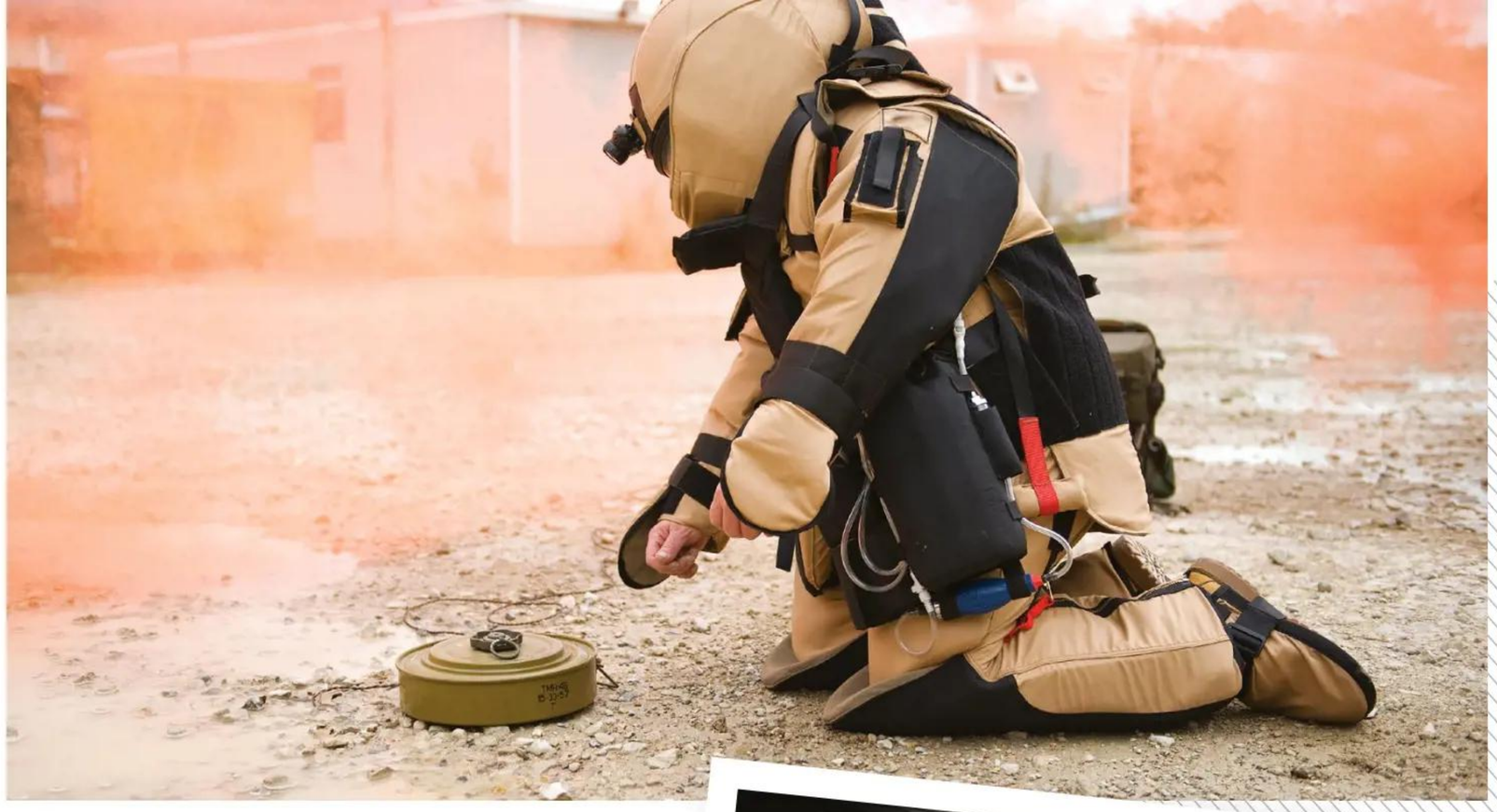
How does someone get into engineering?
Go for it, and don't be scared. Get as much experience as you can, ask questions, take whatever lessons you need. Try new things. I remember taking my bike apart – I had to do that to go riding, but it gave me a keen interest in how things work. I remember being young and intimidated because I was never the smartest person in class, but there's a place for everyone in engineering. A lot of people look the same around here, so it's really important we get new faces from new backgrounds. They can bring different experiences and approaches because that's how we solve problems. If we have the same people coming in, we just get the same solutions.


Coats specialises in metallurgy and non-destructive testing, with both subjects vital for bomb-building

Munitions manufacture and design requires lasers because precise control means reliable results


When steel gets beyond 727 degrees Celsius, it's in its Austenite phase – the ideal moulding temperature

BOMB SUITS EXPLAINED



Kevlar is five times stronger than steel by weight

How this bulky armour defends bomb disposal technicians from searing heat, violent explosions and flying fragments

WORDS **AILSA HARVEY**

What do you need to be part of a bomb squad? This team of engineers and technicians is specially trained in the manipulation of live explosive devices. Instead of running from danger, bomb disposal experts get kitted up and face explosives up close so that they can be safely dismantled and disposed of. Bomb technicians need to have good communication and problem-solving skills, the ability to work flawlessly in high-pressure environments and a steady hand.

However, this dangerous job can't expect every mission to be completed successfully and injury-free. In the event of a bomb detonating on the job, bomb squad members are required to wear armour in the form of bomb suits, also known as Explosive Ordnance Disposal (EOD) suits.

In the UK, bomb disposal is carried out by the British Army, Royal Navy and the RAF in former or current war zones and terrorist sites. In mass bombing events, such as those in World War I and II, a small percentage of dropped bombs remain undetonated today. During World War II, bombs dropped from aircraft became bigger and more sophisticated, so advanced training was needed for specialist groups within the British army. Today's bomb squads dispose of grenades, improvised explosive devices, nuclear devices and more.

Did you know?

Nomex takes twice as long to catch fire as cotton

Bomb technicians control communication systems on a device on their wrist

DIGITAL ARMOUR

Most bomb suits are designed so that the wearer can communicate with a base camp and receive guidance. This means that many suits are equipped with a communications device, such as a radio on the shoulder of the suit. This connects to the helmet so that the wearer can speak into the microphone and hear responses through the inbuilt speakers. A video camera is also installed near the technician's head to allow those providing instructions to see the bomb from the technician's perspective.

Modern bomb suits have a cooling system installed into the back of the suit. This creates air circulation around the body and removes hot air from the suit. Wearing this attire for prolonged periods can be intense and temperatures inside this substantial suit can soar. Cooling devices keep the wearer at a comfortable temperature, which is proven to reduce stress in an already mentally demanding situation. Some bomb suits are smart, presenting biometric data such as breathing rate, body temperature and heart rate. This can be closely tracked by observers to ensure that conditions are safe for the wearer to calmly complete a mission.

DID YOU KNOW? The helmet of a bomb suit alone weighs around seven kilograms

HEAVILY ARMOURED

What is a bomb disposal suit made of?

1 HELMET
The helmet protects the head from flying bomb fragments travelling at nearly 700 metres per second.

2 COLLAR
The collar overlaps the helmet to prevent the neck from being exposed. The wide neckpiece is there to prevent a blast from breaking the neck.

3 QUICK RELEASE STRAP
Pulling this strap quickly removes the suit so that injured technicians can be assisted and transported.

4 CHEST PLATE
This steel plate protects the wearer from the force of a bomb's blast.

10 OPTIONAL GLOVES
Bomb suit gloves aren't always worn because dismantling a bomb requires precision and dexterity.

6 KNEE PADS
Knee pads help protect the knees from the weight of the suit when the technician is kneeling next to a bomb.

7 OVERSHOES
A waterproof lining extends from the feet to the knees of the overshoes. These fit over the person's regular footwear.

8 SHIELDING MATERIAL
The suit has a Kevlar layer, which is a strong synthetic fibre, and a flame-resistant outer layer called Nomex.

9 HEAVY GARMENT
The suit weighs over 30 kilograms, so wearers need to be tested to make sure they can handle the load.

5 MODULAR PLATES
Extra groin and breast plates can be attached as modular systems in pouches on the suit.

5 INJURY TYPES CAUSED BY EXPLODING BOMBS

1 BLAST LUNG
Shockwaves from the explosion can cause bleeding into the lungs. Ballistic panels in the suit absorb the strong shockwaves to prevent this injury.

2 CONCUSSION
Blast waves from bombs can cause concussion in people nearby, even if there isn't a direct injury to the head. Helmets are shockwave and shrapnel resistant.

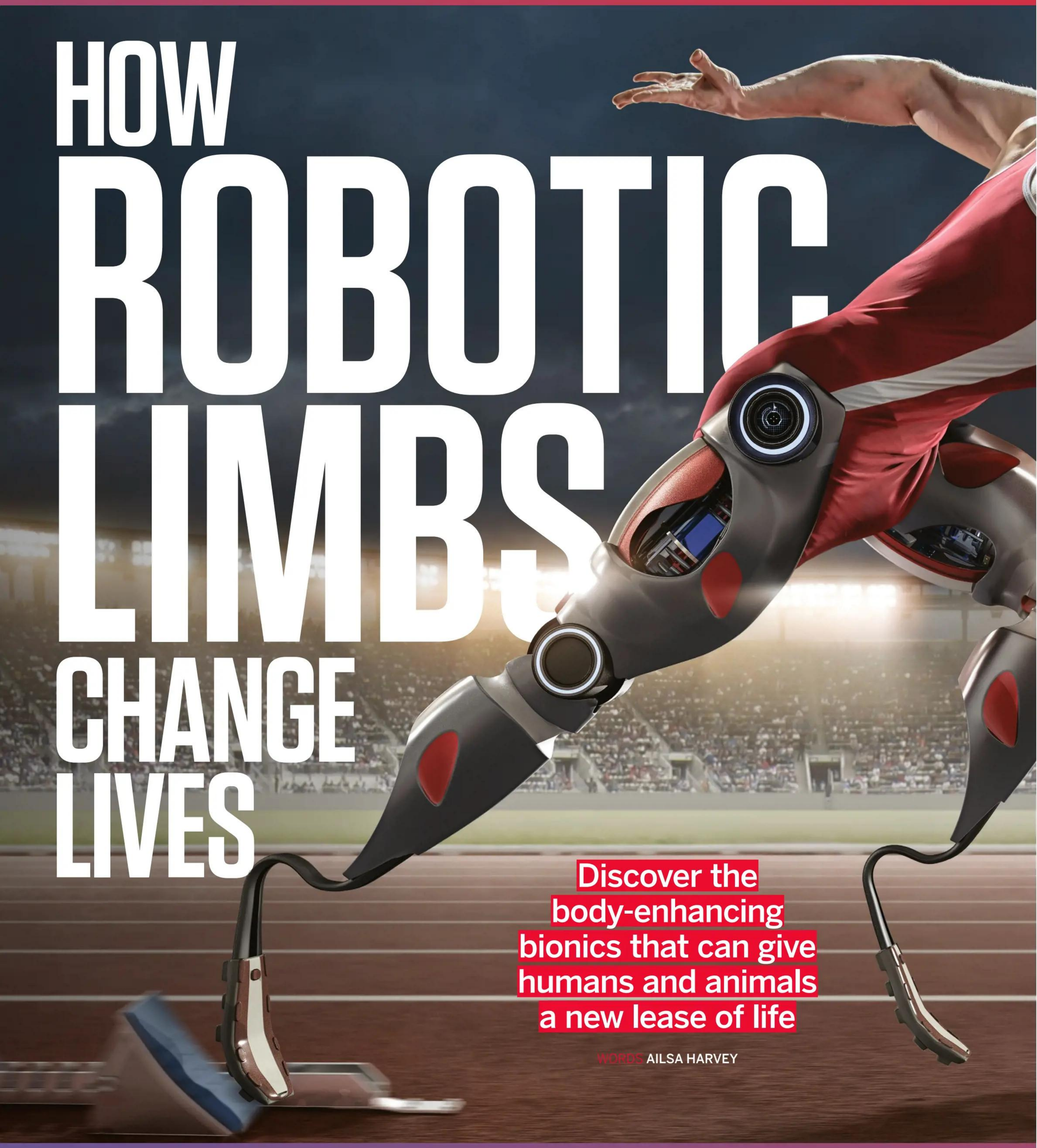
3 FRACTURE
When in close proximity to a bomb blast, people may be thrown into the air, increasing the chances of broken bones. The suit's material absorbs much of the landing impact.

4 BURNS
Thermal radiation released by explosions causes severe skin burns to unprotected bodies. The suit's exterior fibres swell when exposed to flames, forming a thicker barrier.

5 BLUNT INJURY
Flying debris launched from a bomb can pierce the skin and organs. The fibres of the suit are woven so tightly that shrapnel is unable to separate them and penetrate the body.

"Today's bomb squads dispose of grenades, IEDs, nuclear devices and more."

HOW ROBOTIC LIMBS CHANGE LIVES



Discover the body-enhancing bionics that can give humans and animals a new lease of life

WORDS AILSA HARVEY

DID YOU KNOW? Typically, robotic arms have seven segments and six joints

While some robots are intended to assist humans, robotics can also reproduce realistic limb-like functions for those that have lost arms, legs and other parts of their bodies. These prosthetics have existed in one form or another since at least ancient Egyptian times. Early limb replacements involved using materials such as wood or leather for support and balance. In the 1960s, the capabilities of prosthetics to enhance lives were explored. This included incorporating lightweight carbon-fibre material into prosthetics so that amputees could partake and succeed in sporting activities.

However, it wasn't until 1986 that electronic prosthetic limbs were explored. Scottish inventor David Gow began his mission to make existing pneumatic arms easier to use, lighter in weight and more functional. This led to the first bionic arm being ready for use in 1998. The first user of this bionic arm was a man named Campbell Aird, who lost his arm to cancer. After experiencing the benefits of an electrically powered, lightweight limb, Aird said at the time: "For the first time in 16 years I recently reached above my head to pick a book off a shelf. It was a great moment for me."

Today, the pioneering work in robotics is allowing those who are missing a limb to explore the world with better balance, accuracy, precision, speed and in some cases even touch. A new competitive event called the Cybathlon has been established to compare the speed, skills and efficiency of robotic limbs. The 'arm prosthesis race' is designed to rank new robotic arms in sensory feedback, palm rotation ability and coordination in handling objects of different sizes, shapes and weights. 20 countries partake in this event, further driving the innovation of life-changing technology.

Did you know?

'Prosthetic' is a Greek word meaning 'addition'

BIONIC BEGINNINGS

American inventor and entrepreneur Joseph Engelberger is widely known as the 'father of robotics' due to his part in producing the first robotic arm that could perform tasks too dangerous for humans. Engelberger was the face of the robotic arm, as he was the one who sold the concept of robotics in industrial settings. However, the first robotic arm was a joint effort alongside fellow American inventor George Devol, who was awarded the patent for the robotic arm and the technology behind it. This robotic arm was made in 1959, and the duo named it the Unimate #001. It was installed in factories that carried out die-casting – a process that involves handling hot metal and pouring it into different mould shapes. Before teaming up with Engelberger, Devol had named the invention the Programmed Article Transfer. Engelberger then used his passion for science fiction to find the best market and make the product exciting. He did this by being the first person to bring robotic arms into factories and helping people envision a future with robotics. While Devol mainly focused on the practical elements, Engelberger described an efficient robot takeover in the manufacturing industry.

The Unimate robotic arm pictured pouring a cup of coffee for a woman in 1967

5 WAYS WE USE ROBOTIC ARMS

1 FACTORY EFFICIENCY
Using robotic arms on factory lines makes manufacturing more reliable and timely. They also remove the chance of injury when handling dangerous materials.

2 LIMBS IN SPACE
The International Space Station (ISS) has three robotic arms on board. These can be controlled from inside the station to install, remove and replace ISS parts, as well as to conduct science experiments.

3 AUTOMOTIVE WORKERS
Robotic arms are used to weld metal together in automotive factories as well as for applying consistent coats of paint, cutting material and thoroughly polishing items.

4 AGRICULTURE
There are many repetitive and strenuous tasks required for a farm to run efficiently. This includes picking and packing crops and planting seeds. Some robotic arms have built-in sensors, helping them accurately carry out these roles.

5 LABORATORY HELPERS
Many experiments and processes are carried out in large batches. To make test tube dispensing, labelling and capping quicker, robots can be used to make dispensing accurate and reduce human error.

SOLDIER ASSISTANCE

Soldiers need to be very fit - enough to carry heavy loads while also moving quickly across large areas of the battlefield. But thanks to robotic exoskeletons, troops of the future will be able to carry more than ever before. Combining body strength and mechanical strength, the FORTIS Knee Stress Release Device, developed by Lockheed Martin, is worn around the outside of the soldier's legs. In-built sensors detect the overall weight of the load they are carrying and the movement of the soldier to determine when they need assistance. This mostly includes assistance with squatting, kneeling and dragging objects. When the device detects these movements, the motorised knees are put into action to help out with the increased physical demands. This assistance means that soldiers need to use less physical energy to carry or pull objects, making lighter work of the activity and putting less strain on their bodies - possibly making an otherwise impossible task possible. Depending on how the device is used, the exoskeleton can improve work rates between 2 and 27 times, making life easier for soldiers and reducing the likelihood of injury while performing these tasks.

Did you know?

Over 2 million people are missing at least one limb

EXOSKELETON POWER

How the FORTIS Knee Stress Release Device works

ADOPTING A THIRD THUMB

Humans have two opposable thumbs. These help us hold, grip and manipulate objects. If someone is born without a thumb, or loses one, thumb prosthetics can be strapped onto their hand to aid them. These need to be mechanical so that they can bend and lock in place, usually requiring the wearer to apply subtle pressure with the part of their natural hand in contact with the device. The invention of thumb prosthetics has also enabled scientists to experiment with the brain's interpretation of robotic limbs. In one experiment, researchers trained people to use prosthetic thumbs, even though they already had two natural thumbs – they had an extra thumb sticking out from the side of one hand.

By training their bodies to use their new thumbs, their brains began to associate the third thumb with their body, even beginning to believe that it was part of them. This research shows how technology can impact the brain, both allowing lost body functions to return and increasing the capabilities of natural anatomy – for example to carry more items at a time.


This shows how the thumb was attached

PET PROSTHETICS

Robotics aren't just used to emulate the movements of human limbs – animals are becoming bionic too. Technologically advanced prosthetics are becoming increasingly popular for pets and rescue animals. Four-legged animals such as dogs and cats balance easier than humans after losing a leg. However, these animals can still benefit from receiving a prosthetic replacement, as this can reestablish weight distribution. Without this, animals will overuse other parts of their body to compensate, causing other long-term injuries and reducing life expectancy.

At Auckland University of Technology, scientists used robotics to work out the best shape for a turtle fin prosthetic. This enabled them to return turtles that had been injured by natural causes, as well as fishing nets, to the water. To make manufacturing easier, the scientists tested different fin shapes on a robotic turtle. The results showed unanimously that the hydrofoil shape (a curved top) of a turtle's natural fins gave the animal the best swimming ability.


Prosthetics with a rounded end help dogs walk and run on four legs again

CAN YOU FEEL WITH A BIONIC ARM?

As robotic arms become more advanced, brain signals and technology can work together

LAB-GROWN NERVES
Stem cells can be manipulated in laboratories to grow nerves. These are used like a bridge to connect the body's nerves to the bionic arm.

SEVERED NERVE
The end of the cut nerve needs to be pulled apart slightly to stretch the long segment of the nerve cell, called the axon.

SIGNAL GENERATION
Sequences of brain neuron activity are generated to trigger a specific movement in the body.

MICROFILAMENT
An electrically conductive filament receives the electrical signals from the nerves and transfers them to the corresponding areas of the arm.

NERVE TRANSMISSION
Electrical signals travel through nerve cells, called neurons, towards the muscles that need to move.

RETURN SIGNAL
Just as nerve signals can be transferred to the arm, electrical signals in the bionic arm can be received by the nerves.

TOUCH SENSATION
Electrical signals triggered by contact of the bionic arm with an object can be redirected to the user's remaining skin and muscle cells to create the sensation of touch.

BIONIC ARM
The bionic arm can translate the nerve cell signals into mechanical movement.

IPHONE 13 PRO TEARDOWN

How It Works explores the tech behind this smartphone's three artistic eyes

WORDS **AILSA HARVEY**

The iPhone 13 Pro comes in Gold, Silver, Sierra Blue, Graphite and Alpine Green

Many people take their phones with them wherever they go. Phones help them communicate, navigate, research and capture their surroundings at the touch of a button. The iPhone 13 Pro, which was released in September 2021, can do all of these things, but with a heavy focus on the latter. It takes very realistic snapshots, improving on any iPhone to have come before it. With its three versatile cameras, its 3x optical zoom allows users to record more distant objects, while the ultra-wide lens packs more action into every shot.

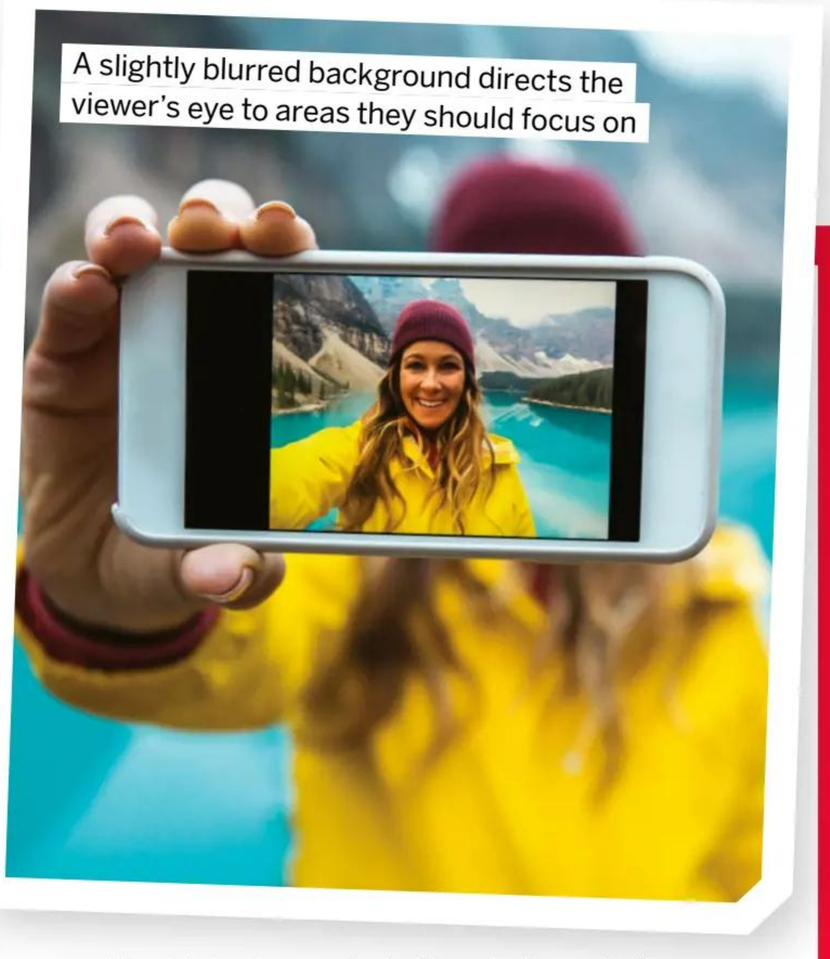
The phone has enhanced hardware and software to accommodate a wide range of conditions that photographs are taken in. This includes optimised night-vision cameras, drawing more light into the lens to brighten dark images, and new smart HDR 4 technology. HDR stands for high dynamic range, and is used to determine the exposure of a photograph.

This feature becomes useful when attempting to make photographs with contrasting exposures. For example, if your subject is standing with a bright light behind them, many phones display a silhouetted figure or have an overexposed background. When trying to edit the background to lower its exposure, the subject becomes too dark, while brightening the foreground results in the background turning bright white and losing its features. HDR 4 takes a combination of photos at the same time, all with different exposure levels. The resulting image combines multiple exposures to capture images with better clarity.

Did you know?

More than 40 million iPhone 13s sold in December 2021

Another improvement to this model when compared with previous iPhone Pro models is found in the screen's technology: this smartphone has a fast, 120 Hertz display. This means that the screen is able to refresh its display 120 times a second for smoother apps and video playback.


A slightly blurred background directs the viewer's eye to areas they should focus on

NEW CINEMATIC MODE

What sets the Pro models apart from standard iPhones is their camera quality. With an additional telephoto camera and higher optical zoom, the Pro model is for users who enjoy photography. One of the features of the iPhone 13 Pro that wasn't available in other Pro models is the new cinematic filming mode. With facial recognition technology and item detection, the phone analyses objects in the foreground and background. When someone or something enters the screen in the foreground, the depth-of-field effect works to slightly blur the background and focus on the foreground automatically. One of the more advanced features of the iPhone 13 Pro is that changes to the depth effect can be made after recording. After selecting the video in the photo gallery, you can edit which elements in the shot are in focus or blurred. For models before the 13 Pro, this element of the video's appearance is set as soon as the footage is produced.

8 TRIPLE LENS
The iPhone 13 Pro's three cameras are the wide-angle, ultra-wide-angle and telephoto cameras. The telephoto lens better captures details of more distant objects.

6 FRONT-FACING CAMERA
Above the phone's screen is a 12-megapixel front-facing camera.


The iPhone 13 Pro Max is similar to the iPhone 13 Pro, but is 0.6 inches bigger

DID YOU KNOW? The iPhone 13 Pro can survive being submerged at a depth of six metres for up to 30 minutes

BEHIND THE LENSES

The iPhone 13 Pro has three lenses, upgraded screen strength and much more under the hood

3 LIDAR MODULE
The light detection and ranging (lidar) sensor emits lasers to measure how far away objects that are in front of the camera are. This can be used to measure objects' dimensions with the phone camera.

4 LAYERED LOGIC BOARD
This board contains the central processing unit (CPU) and other controls such as Bluetooth and Wi-Fi. It's responsible for most of the phone's operation.

5 EARPIECE SPEAKER
This speaker slots in between the front-facing camera and the facial-recognition technology.

7 SIM CARD TRAY
The iPhone 13 Pro can hold a nano SIM card.

2 TAPTIC ENGINE
The iPhone 13 Pro has a much smaller Taptic Engine compared to the iPhone 12. This component is responsible for producing the phone's vibrations.

1 LARGE BATTERY
To improve battery life, the iPhone 13 Pro has an L-shaped battery. It is shaped so that it can fill up more free space in the phone, increasing its size and therefore increasing its energy-storing capacity.

E-WASTE
EARTH VS ELECTRONICS

How electronic waste is recycled and why it can be so harmful to our planet

WORDS **AILSA HARVEY**

More than 63 per cent of the world is now connected to the internet, and many workers require an electronic device to do their job. Even for activities that don't require an internet connection, such as blow-drying your hair, heating up your dinner or illuminating a room, there's always an electronic item waiting to be used.

Around 40 million tonnes of electronic waste, known as e-waste, is produced every year. This includes electrical or electronic equipment that has been discarded. But where does it all go? In the US alone, 100 million mobile phones, 41 million computers and over 20 million televisions are thrown into landfills in a year. Even for standard waste this is problematic, because any materials that are buried in the ground can't be easily retrieved and recycled. Recycling electronics can save energy and means that less of Earth's natural resources need to be mined. There are around 70 commonly used chemical elements that make up electronic devices, and many of these can be extracted from old electronics.

Failing to recycle e-waste is extremely detrimental to the environment due to the nature of the materials used in modern devices. Heavy metals and chemicals give electronics their fluorescence, conductivity and fire resistance. But while this improves a device's safety and user experience, these components become toxic if they're not disposed of properly. Your old phones, games consoles, kettles, microwaves and more can end up in landfills, leaking their harmful contents into the soil, water and air. Not only does this kill wildlife and destroy ecosystems, but the accumulation of toxins can impact human health too. As heavy metals and chemicals disperse into lakes and rivers, drinking water becomes contaminated. These toxins spread through the soil, impacting the health of crops and animals that people also rely on.

Did you know?

5 billion mobile phones will be thrown away this year

In some countries, e-waste isn't hidden out of sight in landfills but is incinerated in giant, open junkyards. Some countries ship waste electronics to other countries to deal with, and this often ends up in dumps across Africa and Asia. Workers in these scrapyards are exposed to polluted lands and chemical fumes.

The best solution to reducing the damaging and unsustainable side of e-waste production is to recycle electronic equipment. Rare earth metals, some plastics and chemicals can be recovered from e-waste and fed into the next generation of electronics in a process called urban mining. The steps to proper recycling of e-waste are extensive and need large investment, but as the technology improves, more and more countries around the world are turning to e-waste recycling.

DID YOU KNOW? E-waste takes up two per cent of landfill waste but 70 per cent of all toxic waste

TYPES OF HOUSEHOLD E-WASTE

How much do UK households throw away in a year?

183,704 TONNES

LARGE HOUSEHOLD APPLIANCES

Items such as washing machines and electric stoves make up the largest percentage of household e-waste.

135,681 TONNES

COOLING APPLIANCES

Air conditioners, drinking fountains, dehumidifiers, refrigerators, freezers and other cooling appliances contain refrigerants.

54,199 TONNES

DISPLAY EQUIPMENT

Some old computer monitors contain cathode ray tubes, which have hazardous phosphor powder inside to create luminescence.

48,563 TONNES

TELECOMMUNICATION AND IT EQUIPMENT

Telecommunication equipment transfers voice, data, text, sound and video. This e-waste includes mobile phones, antennae, cables, satellites and routers.

39,539 TONNES

CONSUMER EQUIPMENT

These are items people buy for personal use, such as headphones or televisions, and are often replaced despite working perfectly.

36,703 TONNES

SMALL HOUSEHOLD APPLIANCES

Toasters, hair dryers and coffee machines easily fit in bins, but taking the time to recycle them at specialist plants helps reduce the volume of harmful materials in landfills.

18,724 TONNES

ELECTRICAL AND ELECTRONIC TOOLS

Unlike consumer electronics, electrical tools such as multimeters have a low replacement rate.

5,369 TONNES

GAS AND LED LIGHTS

LED lights contain rare earth metals such as lutetium, cerium or europium and precious metals like gold and silver.

2,328 TONNES

TOYS, LEISURE AND SPORTS EQUIPMENT

125,000 video game consoles were sold in the UK in August 2022. Many of these replaced existing consoles.

141 TONNES

MONITORING AND CONTROL INSTRUMENTS

Heat and smoke alarms are just one type of monitoring and control equipment that make up e-waste. It's recommended that these be replaced every ten years for safety.

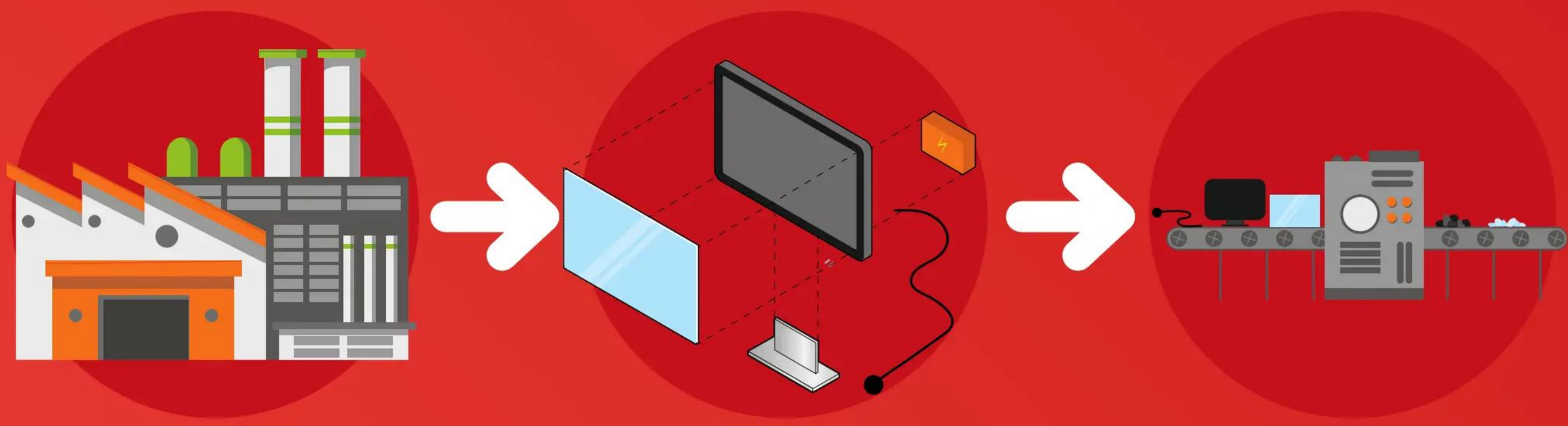
HOW IS E-WASTE RECYCLED?

Electronic recycling plants dismantle products to reuse their core materials

1 ORGANISED COLLECTION
When any electronic product breaks, loses efficiency or is no longer needed, it needs to be taken to a specialised electronic collection site.

2 ITEMISATION
Collection sites have different boxes so that you can dispose of your items by type.

3 TRANSPORTATION
Categorised electronics are taken to recycling plants. Items such as rechargeable lithium batteries are carefully packaged to prevent fires.



4 DELIVERY
There are specialised plants that can handle cathode ray tubes from computer monitors, mercury, circuit boards and batteries.

5 CAREFUL DISASSEMBLY
Electronics are broken down into their core materials, such as glass screens, plastic covers, metal wires and batteries.

6 BATTERY AND CARTRIDGE REMOVAL
These components can't be shredded, as their materials can explode when mixed together.

7 SHREDDING
Machines break the electronics into smaller pieces just a few centimetres wide so that their core materials can be separated.

8 MATERIAL SEPARATION
Metals such as iron and steel are separated using a giant magnet, while glass and plastics are separated from each other in water.

9 CERTIFICATION
A certificate of destruction shows customers that their electronic waste was recycled safely and effectively.

DID YOU KNOW? For every million laptops recycled, enough energy is saved to power 3,600 homes for a year

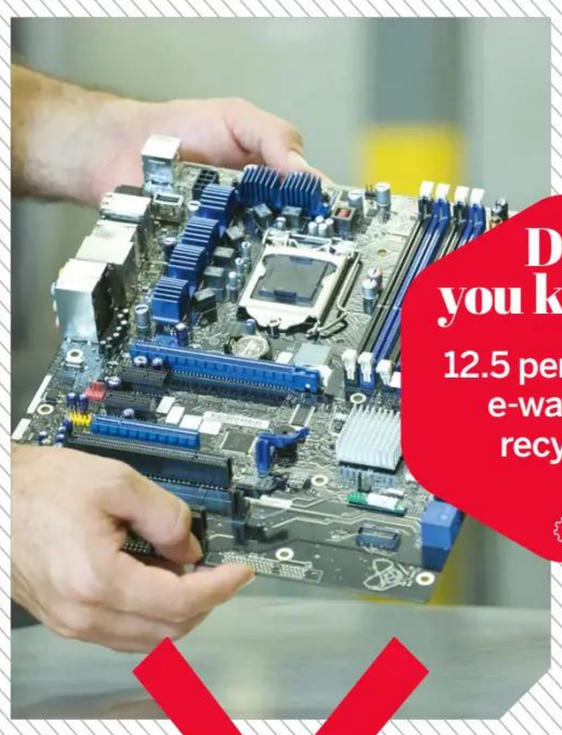
WHAT CAN E-WASTE BE RECYCLED INTO?

LAWN MOWERS TO MUSIC

The strong plastic acrylonitrile butadiene styrene (ABS), which is used to make hover lawn mowers, can be recycled to make car bumpers, musical instruments and pipe fittings.

GAMES TO ACCESSORIES

The circuit boards inside games consoles are made of gold, silver, palladium and other precious metals. By recycling e-waste, in their next form these metals can be used to make jewellery.

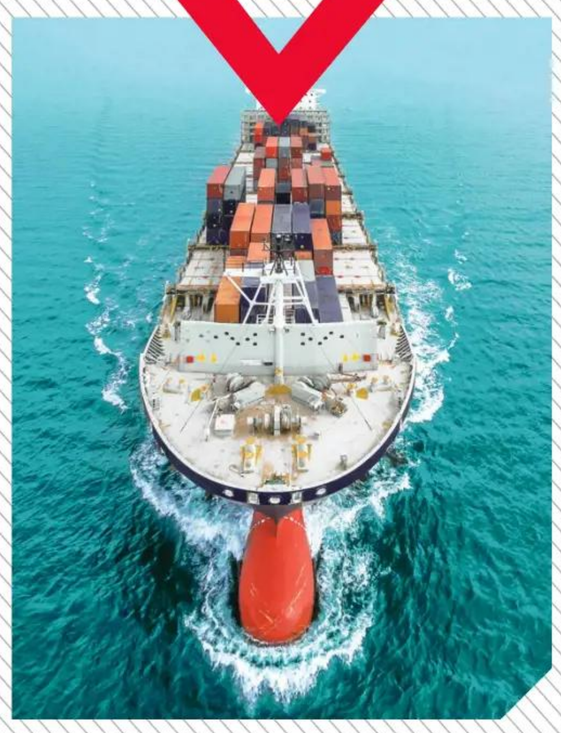


Did you know?

12.5 per cent of e-waste is recycled

SMARTPHONES TO SHIPS

The zinc in the electronics of smartphones can be dismantled and used to build ships. Zinc prevents ships from rusting as it corrodes 100 times slower than other metals.



5 TOXIC MATERIALS IN ELECTRONICS

1 BERYLLIUM
This metal exists in televisions, smartphone connectors, computer chips and thermostats, released in significant amounts as beryllium oxide. When this comes into contact with human skin and lungs, it can cause irritation and lung cancer.

2 CADMIUM
Cadmium is a protective metal coating often used as an outer layer on batteries and switches. It's highly toxic and contact with it can cause damage to the kidneys, lungs and bones.

3 MERCURY
This element is a component of liquid-crystal display (LCD) screens. Because mercury exposure can damage the nervous system, e-waste with mercury in it should be taken to a hazardous waste centre.

4 LEAD
Lead has a low melting point, so it is used as solder to connect components together in electronics. It's toxic to humans when ingested, as well as causing reproductive failure in plants and animals when released into the environment.

5 ANTIMONY
This silvery metalloid is toxic to humans and can irritate the eyes and skin in particular. It is present in laptop batteries, circuit boards and infrared detectors.

THE SHORT LIFE OF YOUR ELECTRONICS

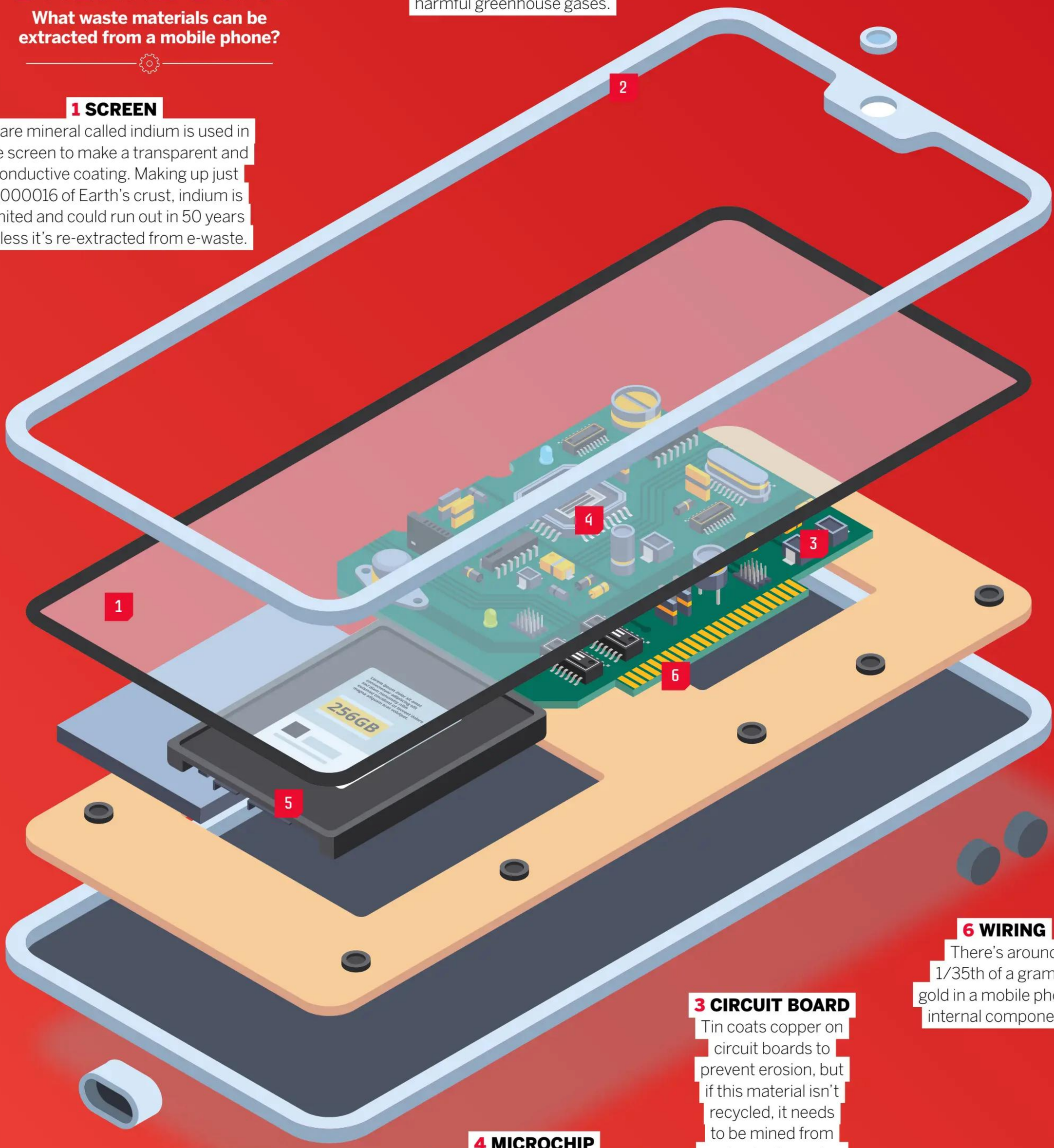
Even if you have taken good care of your mobile phone or other electronic device, you will still notice that it deteriorates over the years. This is because electronics become less efficient the more they are used. Although this can't be prevented, some phone manufacturers purposely aim to increase the deterioration rate of their devices to encourage customers to replace their phone with a newer model. Currently, the average smartphone is replaced after just two-and-a-half years of being used. The three biggest contributing factors to reducing a smartphone's life span are damage, reduced battery life and general usage.

SMARTPHONE BREAKDOWN

What waste materials can be extracted from a mobile phone?

1 SCREEN
A rare mineral called indium is used in the screen to make a transparent and conductive coating. Making up just 0.000016 of Earth's crust, indium is limited and could run out in 50 years unless it's re-extracted from e-waste.

2 CASING
Aluminium in smartphone casings is made from aluminium oxide. The production of this metal releases harmful greenhouse gases.



3 CIRCUIT BOARD
Tin coats copper on circuit boards to prevent erosion, but if this material isn't recycled, it needs to be mined from seabeds, damaging marine life.

4 MICROCHIP
Silicon, gallium, arsenic and antimony are needed to make microchips. In e-waste, less than one per cent of gallium is recycled.

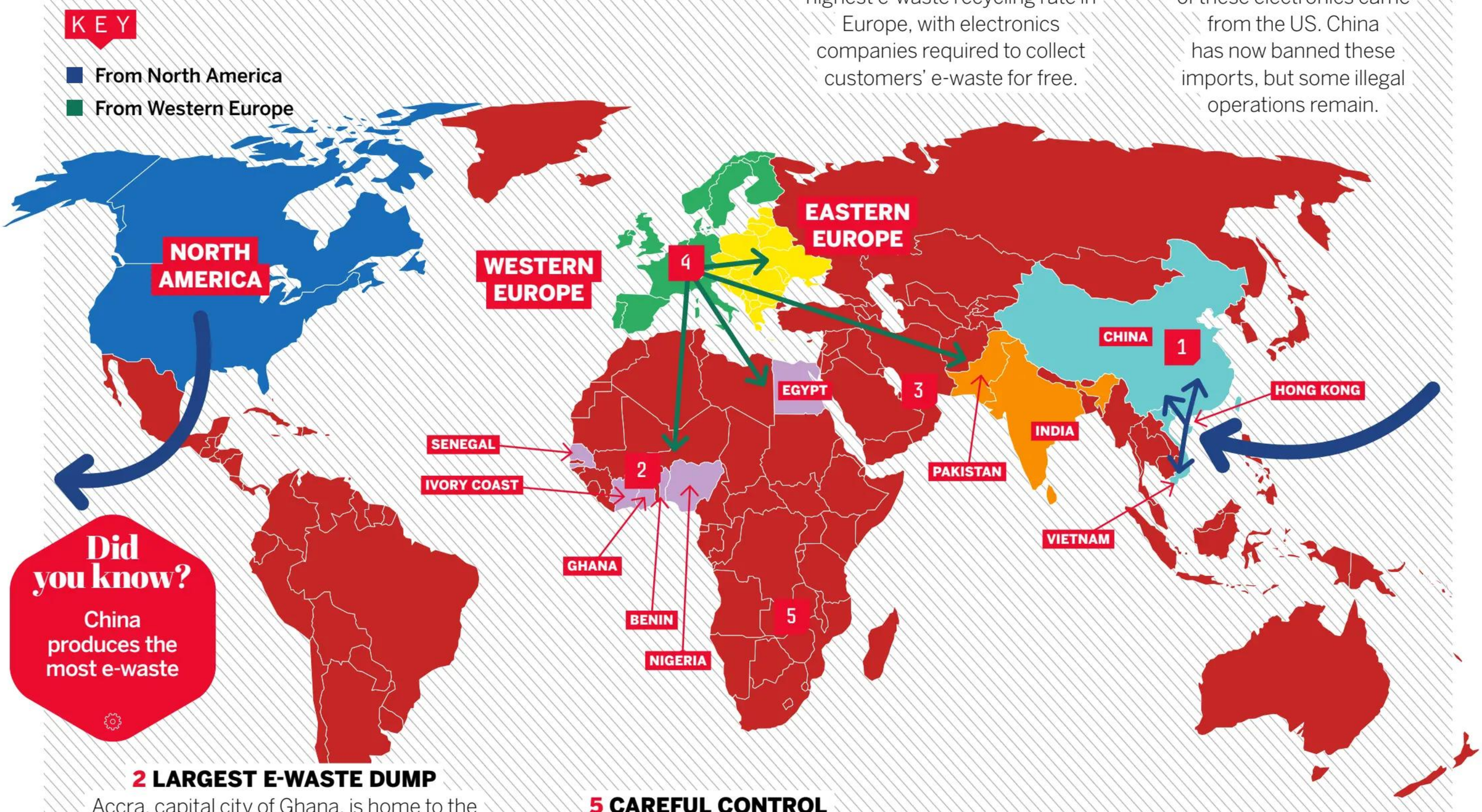
5 BATTERY
The demand for lithium used in smartphone batteries is expected to double by 2030.

6 WIRING
There's around 1/35th of a gram of gold in a mobile phone's internal components.

DID YOU KNOW? There's around 250 kilograms of silver and 24 kilograms of gold in a million mobile phones

THE JOURNEY OF E-WASTE

The countries that produce and process the most e-waste



4 HIGHEST ACTIVITY

Europe has the highest e-waste generation rate per person, but also the highest collection and processing rate. Croatia has the highest e-waste recycling rate in Europe, with electronics companies required to collect customers' e-waste for free.

1 CHINA E-WASTE BAN

China used to receive huge imports of e-waste to process from other countries. A high percentage of these electronics came from the US. China has now banned these imports, but some illegal operations remain.

2 LARGEST E-WASTE DUMP

Accra, capital city of Ghana, is home to the world's largest e-waste dump, where ships have sailed to import e-waste since 2000. This site is called Agbogbloshie, and the soil, water and air around it are gravely contaminated by toxins. Workers here burn the plastic sheaths on electric wires to recover and sell the metals inside.

5 CAREFUL CONTROL

Electronic items entering Zambia must meet strict safety standards. Careful tracking of these items helps the government predict e-waste statistics and better monitor environmental impact.

3 LARGEST RECYCLING PLANT

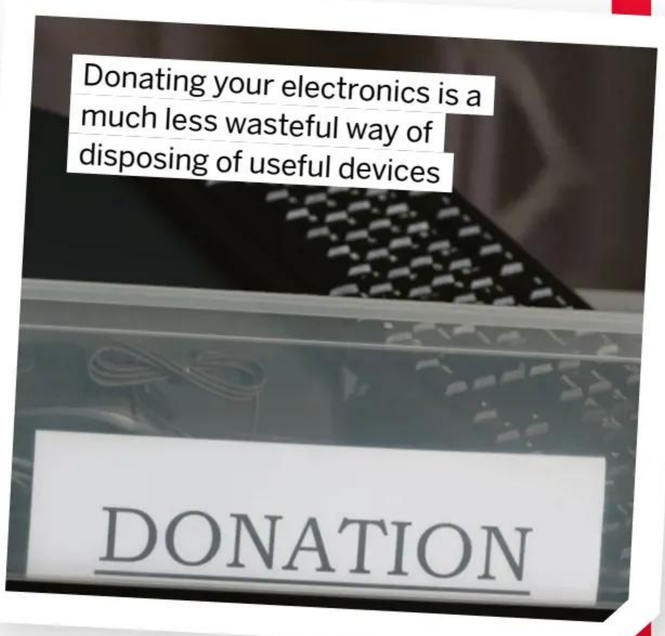
At 26,000 square metres, the Dubai Industrial Park e-waste recycling plant operates using the most advanced recycling technology. It can process 100,000 tonnes of e-waste per year.

HOW CAN YOU REDUCE YOUR E-WASTE?

If you want to minimise how much e-waste you produce personally, the most effective way would be to stop using electronic devices completely. However, today that might not seem like a practical solution. There are ways you can reduce your e-waste without giving up electronic devices. Firstly, not all new electronics are practical. Before buying, you should consider whether your purchase is actually necessary. It may be that you can combine more than one function into one device.

If you do buy a new electronic device, taking care of it will reduce your electronic turnover rate. Handle your phone and other electronics carefully and buy protective accessories such as a phone case to limit damage to your device during an accident. Keep an eye on the battery life of your electronics. This means not charging them all night so that they become overcharged and not letting the battery drain regularly.

Finally, when you no longer need an appliance or device, or it stops working, think about the next action you take. If it is broken, it might be cheaper and easier just to get it fixed before you look for an e-waste recycling bin or facility. If it still works, consider donating it to a social program so that a device's life is maximised by those who most need it.

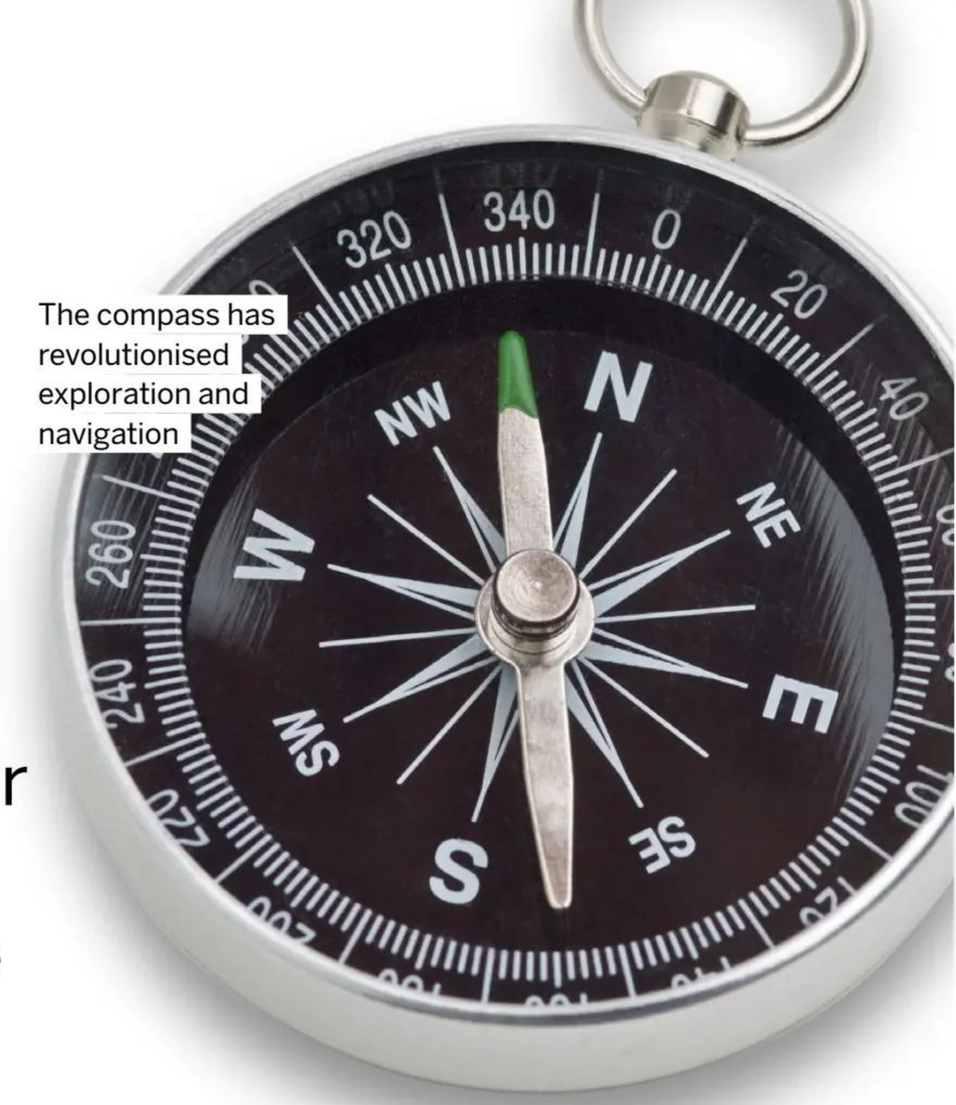


Donating your electronics is a much less wasteful way of disposing of useful devices

HOW DOES A COMPASS WORK?

The compass has revolutionised how we find our way, making it possible to reach a destination when other means of navigation aren't possible

WORDS **MARK SMITH**



The compass has revolutionised exploration and navigation

From great explorers sailing the seas to hikers trying to find their way home after a trek through their local hills, it's impossible to overstate just how revolutionary the humble compass has been for navigation. A compass is simply a device that indicates direction, and the earliest ones harnessed the power of one of the most powerful forces in nature: magnetism.

The original compass design used a magnetised needle that rotated until it lined up with Earth's magnetic field, with the ends pointing north and south. The part that pointed north would be coloured or marked in some way so whoever was using it didn't get confused.

The first compass designs just consisted of one of these magnetised needles attached to cork or wood, which was then floated in a bowl of water. When the needle settled, the marked end would point north and other directions could be worked out from there. Being able to use a compass revolutionised map reading, making it possible to follow a map's directions when other means of navigation such as the Sun, stars or landmarks were not visible.

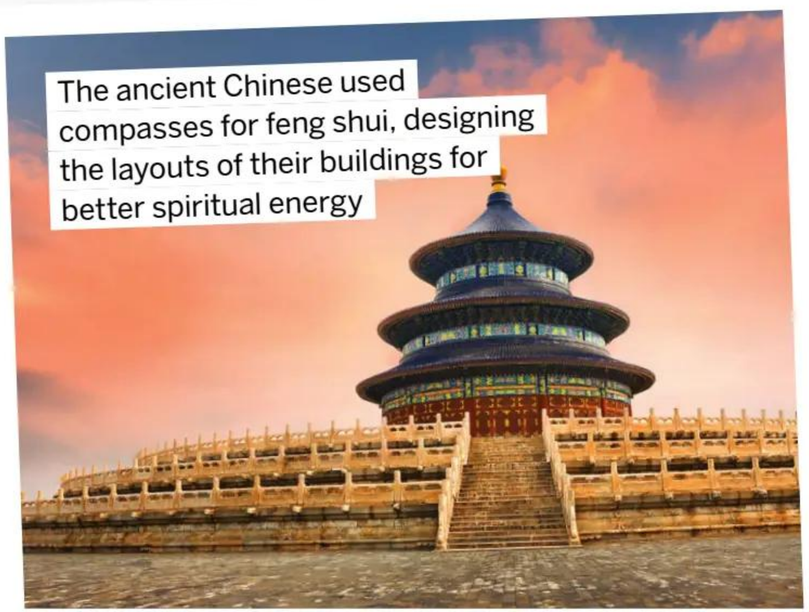
A digital compass works in a similar way to a traditional one. Because there's no shaky needle, they're the preferred option of serious hikers and the military. Instead of using magnetic pulses to find the right direction, which themselves can be unreliable, a digital compass finds direction by using the north pole as a guide. To help, it usually has some kind of global positioning system (GPS) features built in. GPS uses a network of satellites to pinpoint the user's location. They're found in smartphones, tablets and the built-in navigation systems of many modern vehicles. Despite these types of advancements, the humble compass is still widely used. Aircraft and ships still use them and they're a handy backup to the more sophisticated devices used by many adventurers today.

Did you know?

The magnetic north pole shifts position by about 40 miles a year

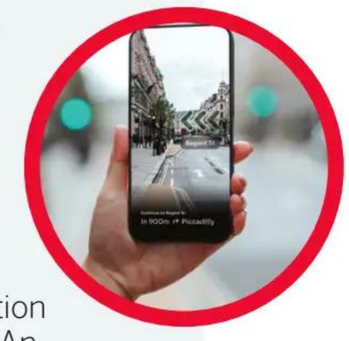
WHO INVENTED THE COMPASS?

Mystery still surrounds exactly when the compass was invented, but there are a few clues. The ancient Greeks understood the concept of magnetism around 2,000 years ago. But many historians think it was actually the Chinese who were the first to develop a practical working compass that could be harnessed for navigation. Chinese scientists may have developed navigational compasses as early as the 11th or 12th century. Western Europeans then followed in their footsteps at the end of the 12th century. But by the 15th century, scientists realised something strange was afoot – the 'north' indicated by a compass wasn't the same as Earth's true geographic north. This discrepancy is called 'variation' or 'magnetic declination', and varies depending on where you are in the world, with the problem being greater the closer you get to Earth's poles. Once they realised the problem, navigators had to start adjusting their compass readings to account for this variation, otherwise they could end up miles off course.


The ancient Chinese used compasses for feng shui, designing the layouts of their buildings for better spiritual energy

TYPES OF COMPASS

1 SMARTPHONE COMPASS

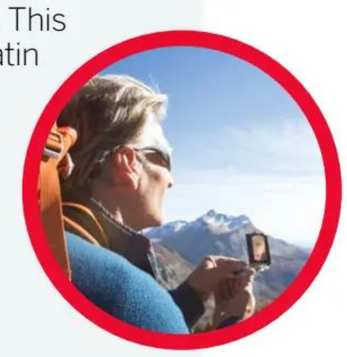


A smartphone contains a sensor called a magnetometer that's used to measure the strength and direction of magnetic fields. An app on your phone can harness it for use as a compass.

2 MARINE COMPASS

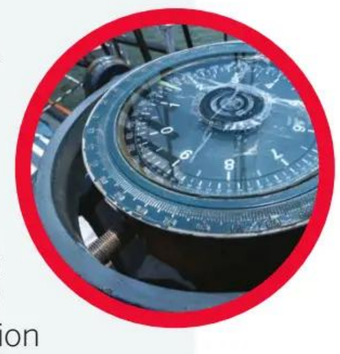
Compasses on ships are often mounted on stands in a binnacle, a type of protective housing. This derives from the Latin word habitaculum, meaning 'little dwelling place'.

3 SOLAR COMPASS



A solar compass uses the Sun to navigate, with the angle of the Sun indicating direction.

4 GYROCOMPASS



Invented in the early 20th century, this uses a spinning gyroscope to follow Earth's axis of rotation to point to true north.

DID YOU KNOW? Many birds have an innate compass in their brain and can follow Earth's magnetic field when they fly

SURVIVAL SITUATION

If you ever find yourself stranded in the wilderness without your smartphone, fear not – you can make your own compass to help navigate to safety. First you're going to need a compass needle. For this you can use something made from iron or steel such as a paper clip or safety pin. Magnetise it by tapping it on a steel or iron object at least 50 times. Failing that, you can just rub it against your hair, silk or animal fur. Find north by using the stars, the Sun or a landmark and mark the piece of your needle that points north. Then you need to put it on something that will float, like a leaf. Place the leaf in water and the needle will now point north.

Placing a magnetised pin on a leaf in water can give you a rudimentary compass

Earth's magnetic field is the force that underpins how compasses work

Compasses are frequently used with maps for ease of navigation by amateur and expert adventurers

INSIDE A MARINE COMPASS

The nautical compass must see off a number of challenges, meaning it must be built for the elements


CASE
8230

TRANSPORT

CAR CRASH ANATOMY

How today's technology can predict, prevent and assist in dangerous vehicle collisions

Police attending a collision

WORDS **AILSA HARVEY**

Today's motor vehicles provide people with a greater freedom of movement, with easier access to places of work and trips further afield from home. However, with the number of cars on the roads increasing over the years, car crashes are becoming more common.

When cars carry their passengers along a road, the engine provides the vehicle with kinetic energy. This is the energy of motion. In the event of a crash, vehicles lose kinetic energy and ultimately come to a stop, but this energy doesn't vanish. Instead it's transferred to other objects, vehicles and sometimes people, causing the damage seen in road collisions. An object that has been struck by the car may absorb the kinetic energy of the moving car or return it to the vehicle.

Today's cars are designed to take the brunt of this energy, transferring it into their metal frames which are crushed and distorted, breaking their internal components. However, despite this protective technology, the driver and passengers exposed to a collision will usually absorb a small percentage of the kinetic energy. Being much more fragile than the metal machine that surrounds them, at least one of a car's occupants will suffer from an injury in 43 per cent of car crashes.

Did you know?

Air bags were invented in the 1970s

PROTECTIVE TECHNOLOGY

The life-saving armour of modern vehicles

1 SAFETY GLASS
Instead of completely shattering when the car's windshield glass breaks, the glass fragments stick to a strong layer of plastic between the car occupants and the window.

6 SEAT BELTS
During a car crash, you're more likely to survive if you aren't thrown out of the vehicle. Seat belts are essential for securing the body to the seat.

2 AIR BAGS
When a sensor behind the dashboard detects a hard front-on impact, these bags inflate rapidly with nitrogen gas to cushion the driver and passengers' bodies.

DID YOU KNOW? Most car crashes occur less than three miles from the driver's home

WHAT CAUSES A CAR TO CRASH?

There are many ways that a car can experience a collision on the roads, each with different causes and varying levels of severity. The four most common types of car crashes are front-impact, side-impact, rear-end and car park collisions. Front-impact collisions – when two vehicles make a head-on impact with each other or a vehicle hits an object at the side of the road – are the most common form of crash. These collisions are often caused by distracted drivers or slippery roads and can be prevented by drivers keeping as focused as possible and reducing speed in wet and icy weather.

Collisions into the side of other cars can take two forms: a T-bone crash and a sideswipe. The former is most common at junctions and involves one car having a front-impact collision with the side of another. In contrast, sideswipes are lower impact and take place when two cars are parallel to each other and travel too close, making contact at their sides.

Rear-end collisions are caused by the front of one vehicle colliding into the back of another. When there's a lot of traffic this is more likely to happen, so drivers should keep their distance from other vehicles to make sure they have enough time and space to stop in an emergency. Car parks usually have a high number of vehicles in an enclosed space. Vehicles are constantly moving in different directions while navigating tight gaps, cars and pedestrians. An accumulation of these factors make low-speed collisions common here.

One in five car collisions occur in car parks

3 COLLISION STAGES

1 METAL ON METAL
The car collides with another object. This could be the collision that occurs when two cars come into contact with each other.

2 BODY ON METAL
The passengers inside travel at the same speed as the car. When the car suddenly stops, the passengers continue to move forwards and hit the inside of their vehicle.

3 BODY ON BODY
A third collision takes place inside the passenger's body. When the body hits the front of the car and stops travelling, the organs inside the body collide with tissue, bones or other organs.

7 RIGID SAFETY CELL
Unlike crumple zones, which are easily crushed to absorb an impact, the zone containing people is rigid stainless steel.

5 SIDEBAR IMPACTION
Stainless-steel bars along the sides of vehicles absorb the majority of the impact from a side-on collision.

3 CRUMPLE ZONE
The front and back of a car have crumple zones that extend outwards from the passenger cabin. During an impact, these areas 'crumple' up and absorb as much of the impact as possible.

4 ANTI-LOCK BRAKING
When drivers hit the brakes suddenly, the wheels can lock, causing the vehicle to skid. Anti-lock brakes help regain control of the vehicle by constantly releasing and applying the brakes until the vehicle comes to a stop.

IMPACT ON THE BODY

These are the most common injuries that result from road accidents

1 COUP-CONTRECOUP
Car crashes can cause high-impact head trauma such as coup-contrecoup injuries. This involves a head injury at the site of impact (coup) followed by an injury at the opposite side of the brain to the direct trauma (contrecoup). Both sides of the brain experience trauma when a sudden collision throws the head forwards then backwards.

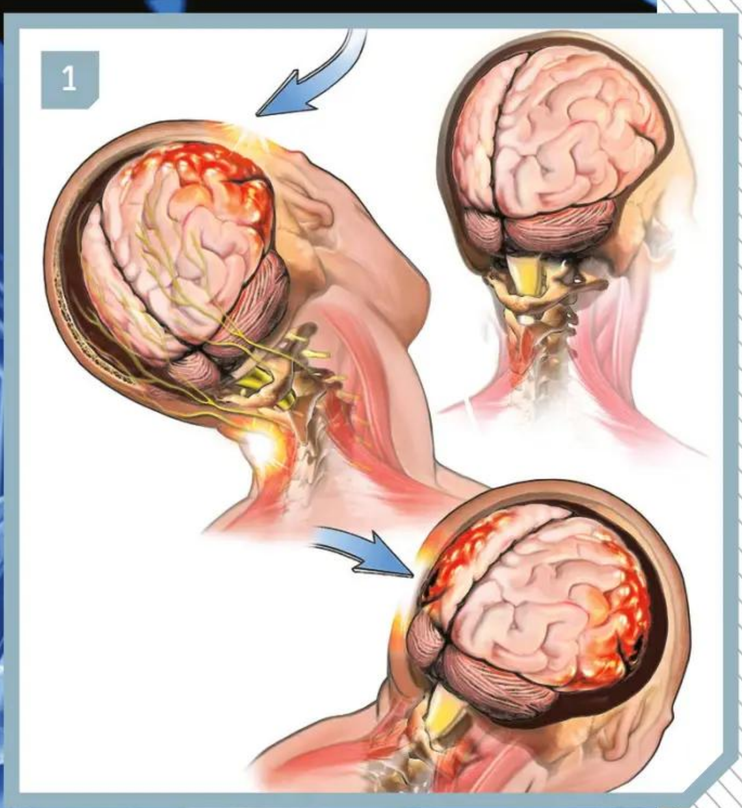
2 WHIPLASH
When the head is thrust forwards during a crash before quickly being jolted back again, the muscles and ligaments in the neck are stretched and the soft tissue is injured.

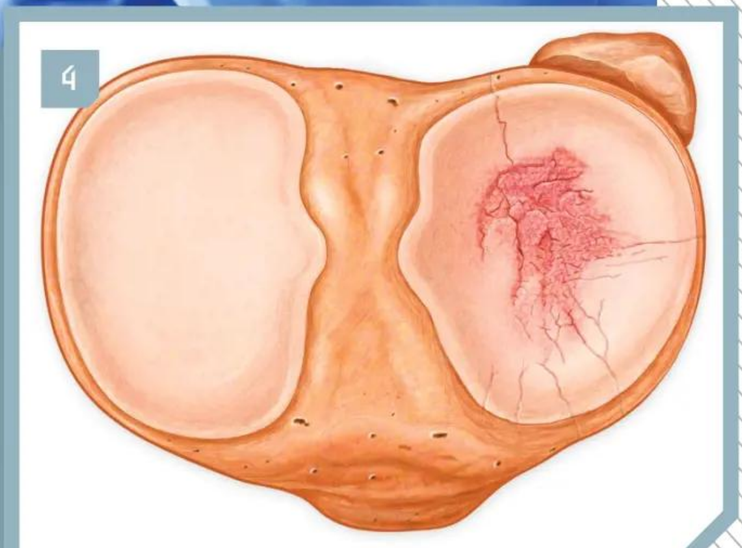
3 RIB FRACTURES
The ribs can collide with the steering wheel during high-impact crashes. Fractures and breaks in these bones can cause breathing difficulties following a car accident.

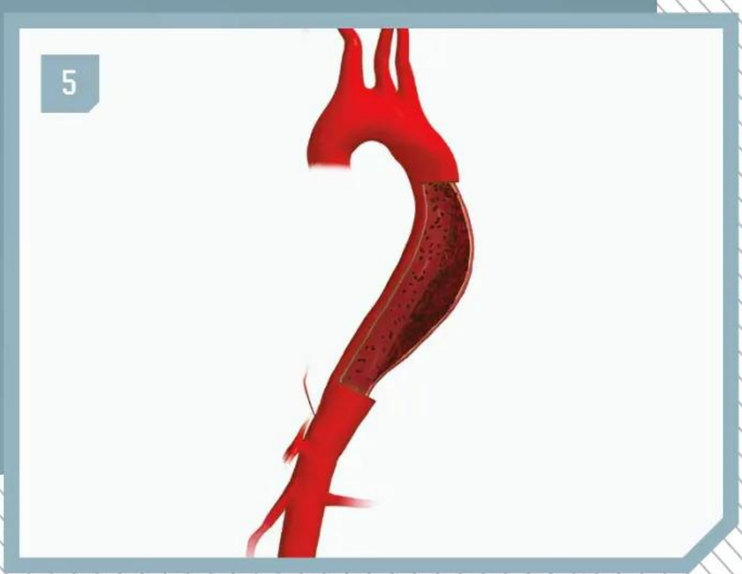
4 KNOCKING THE KNEES
The knee only bends in one direction. This means that when extreme force is applied to the knee, the bones in the middle of the leg are at risk of fracturing. The tibia – a bone of the lower leg – faces the front of the car when a person sits in the vehicle, making it a common fracture site.

5 TRAUMATIC AORTIC INJURY
One of the major causes of car crash deaths is injury to the aorta. When a seat belt isn't worn properly, the force applied to the edge of the seat belt can create a tear in the body's largest artery as it cuts through the body.

6 SKIN BREAKS
Broken glass and other car crash debris cut the skin first. Collisions often result in stitches and sometimes skin grafts being required.







CRASH PREVENTION

How the latest smart technology can predict and prevent a road collision

1 LANE DEPARTURE TRACKING

Cameras at the front of the car track the car's position in a lane. If the vehicle moves out of the lane without the driver indicating, a warning signal alerts the driver to return to the correct position on the road.

3 EMERGENCY BRAKING

Cameras and radar sensors at the front of the car detect when an object is too close to a moving vehicle. When this is the case, automatic emergency braking can be applied.

2 BLIND SPOT MONITORING

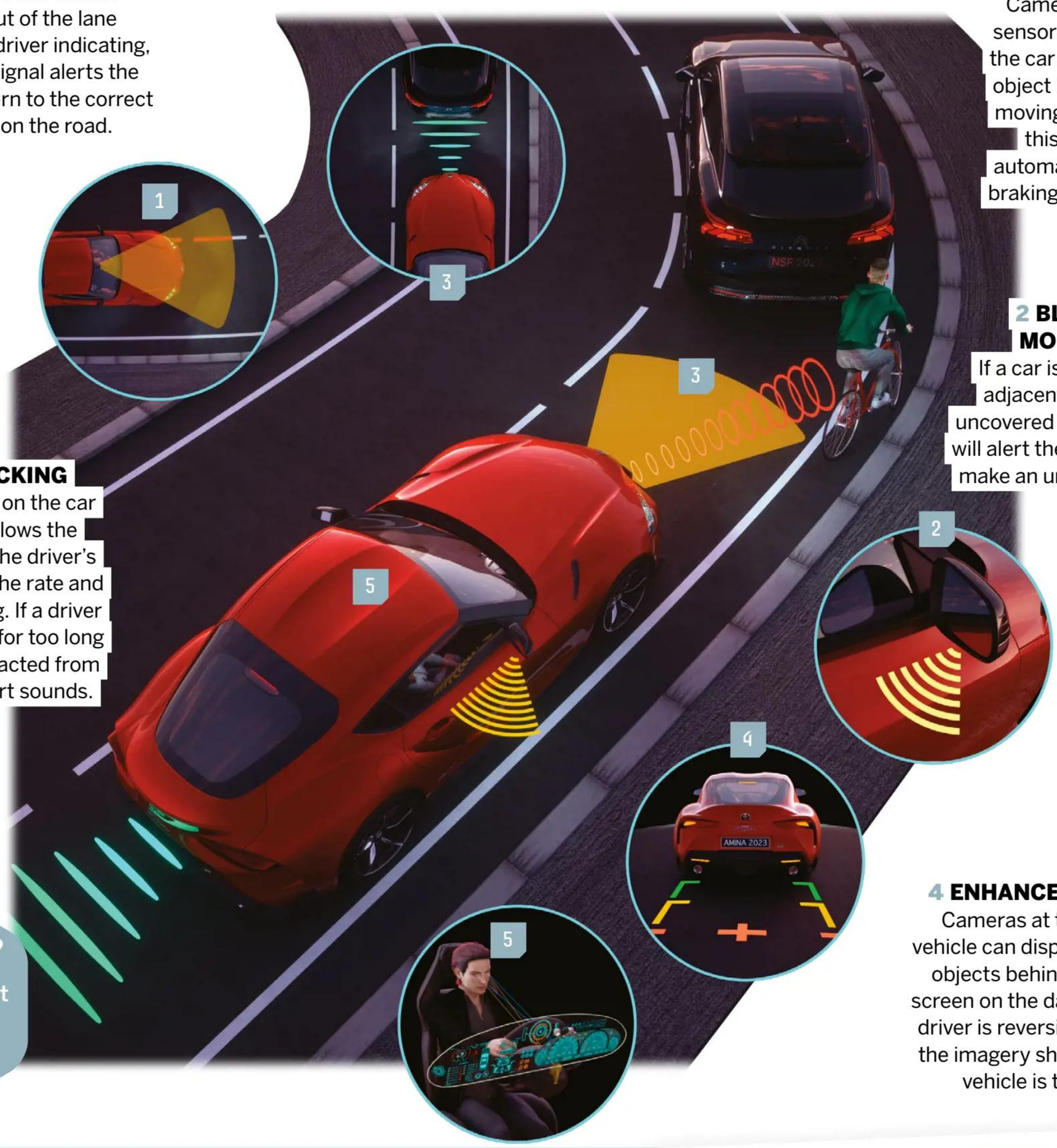
If a car is travelling in the adjacent lane in an area uncovered by mirrors, the car will alert the driver before they make an unsafe lane change.

5 EYE TRACKING

A small camera on the car dashboard follows the movements of the driver's eyes, as well as the rate and speed of blinking. If a driver shuts their eyes for too long or appears distracted from the road, an alert sounds.

4 ENHANCED REAR VIEW

Cameras at the back of the vehicle can display a clear view of objects behind the car onto a screen on the dashboard. When a driver is reversing, guidelines on the imagery show how close the vehicle is to a collision.



Did you know?

Whiplash is most common in rear-end car crashes

SMARTPHONE SAVIOURS

When a severe car crash occurs, injured drivers and passengers may rely on nearby witnesses to call the emergency services. But what happens if a crash takes place on a deserted road and the car's occupants are unresponsive? Many modern smartphones are now equipped with crash-detection technology that utilises data such as the speed that the phone is travelling, sound levels and pressure changes to determine when a car crash has occurred. The iPhone 14 and latest Google Pixel phones will play an alarm when data predicts that there's been a crash and automatically send an alert to the emergency services. If it's a false alarm, the phone owner can swipe to disable the alert, but in an emergency situation the device shares the location with first responders so that there's a speedy response and a higher chance of survival for the crash victims.

As well as the emergency services, smartphones can be programmed to inform friends and family after a collision

HOW ARE CARS RECYCLED?

Step into one of the UK's largest car recycling centres to discover the secrets of a vehicle disassembly line

WORDS **SCOTT DUTFIELD**

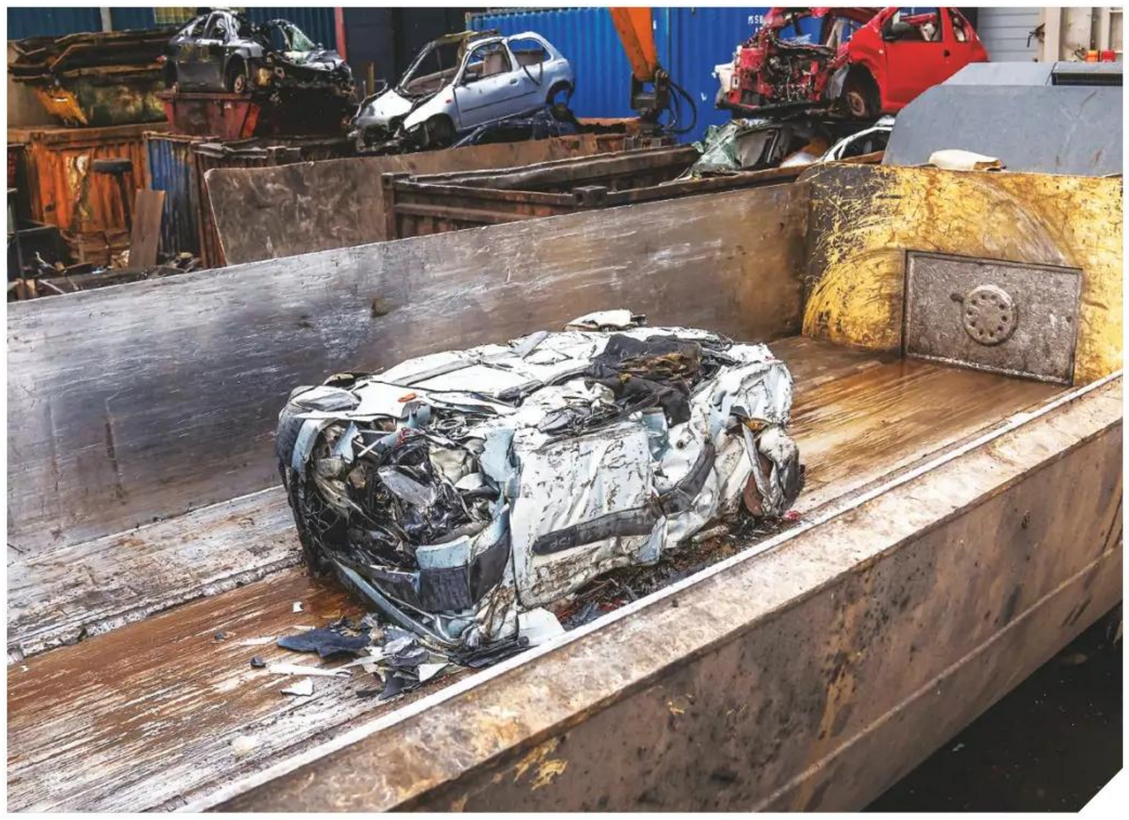
Where do cars go when their engines fail and their exhaust pipes are exhausted? Thousands of cars in the UK find themselves at the pearly gates of Charles Trent recycling centre in Poole, Dorset. Since 1926, Charles Trent has been taking unwanted cars and giving them a new lease of life. The recycling centre has recently added a 12-metre-tall, 8,500-square-metre facility that includes arguably the most advanced salvage and dismantling process in the country. Watching the production line is like seeing the assembly of a car in reverse. Although it's got some of the scrapyard staples, such as the forecourt full of cars awaiting the inevitable crushing by a compactor, the process that leads to them becoming a cube is efficient and leaves no good parts behind.

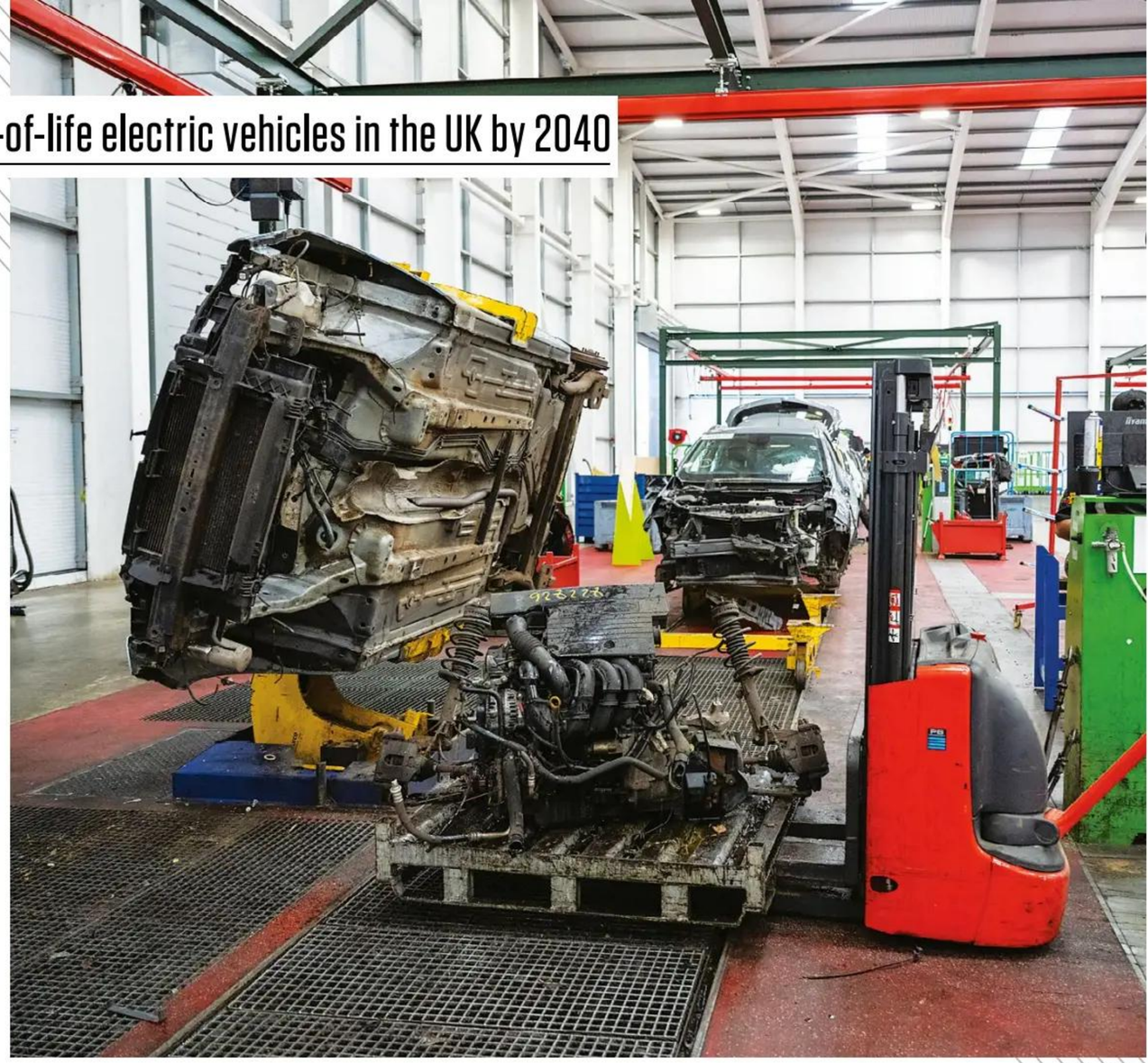
In the UK, legislation means that the automotive recycling industry must ensure that at least 95 per cent of a car's weight is either recycled, repurposed or resold when it comes to the end of its life. Charles Trent is operating slightly higher at around 96.3 per cent, but its main focus is to capitalise on the reusable parts, as well as what other materials can be recycled.

Upon arrival at the recycling centre, cars are analysed on their quality, and the sum of their saleable parts is evaluated. Generally, if a car has less than 20 resellable parts it continues through to Charles Trent's deproduction line. If a vehicle has more than 20, which are typically higher end motors such as Lamborghinis, then they are moved to a workshop where these parts are stripped by hand. For those left on the deproduction line, within the next hour they will be stripped down to their chassis, which is then compacted and the metal recycled.

Before parts are stripped from the car, its internal fluids must be drained. This process, known as depollution, removes any remaining fuel, oil and coolant from the vehicle and ships it off to a different recycling facility, where it is either cleaned for reuse or recycled into alternative

DID YOU KNOW? It's estimated that there will be 350,000 tonnes of end-of-life electric vehicles in the UK by 2040





products. It's also at this point that batteries and tyres are taken to be recycled. Typical lead-acid car batteries are a hot commodity and are quickly stripped and sold from used cars. When they are not viable for reuse, their components are broken apart. The sulphuric acid inside them is drained, and in some cases repurposed as an industrial chemical. Then the plastic casing is smashed and melted to make new batteries. Similarly, the rechargeable lithium-ion batteries in the body of an electric vehicle are recycled for use in alternative energy storage.

> "Before parts are stripped from the car, its internal fluids must be drained"

Another environmental hurdle to tackle while recycling a car is the tyres. Since 2002 there has been a ban on tyres from cars and agricultural vehicles being dumped in landfill sites in the UK. This is largely because of their inherent combustibility and the toxic leachate they can unleash into the environment. While some are repurposed in playgrounds, as go-kart track barriers and sold as 'part-worn' tyres for a discounted price, many tyres are too bald and broken to be reused. Millions of old tyres are either sent to the shredder to be broken down into the raw materials to make more tyres, or they are incinerated.

Once a car has been emptied and is ready to be picked apart, it makes its way over to the deproduction line. Over the next 24 hours, the car will pass through several stages of disassembly. From car doors to radio wires, there's not much left behind once it's gone through this part of the process. At each stage of disassembly, engineers are presented with a sort of shopping list to gather the parts suitable for reselling. Each part is given an ID tag that will stay with them through the rest of the process. Some parts, such as brake discs and scrap metal, are not saleable items and find themselves passed onto steel foundries to be melted down and repurposed.

After everything that's destined to be resold has been removed from the car, Charles Trent's staff perform a diligent quality check on each part, cleaning and preparing it for resale. The rest of the car is transported to the on-site crusher to be squashed down into compact cubes. Facilities such as this crush around 100 cars per day. The car cubes are then shredded into small pieces of metal and plastic, which are either again melted down and repurposed into new materials or sent to landfill.

Charles Trent has become one of the 81 vendors that are part of eBay's Certified Recycled scheme, which is certified by the Vehicle Recyclers Association (VRA). The company has adapted its process to include small photo booths and upload stations in order to image and digitally stock its eBay store. To house its eBay supply chain, Charles Trent has created a metropolis of shelving units 11 metres tall, all marginally spaced apart. Thousands of car panels, headlights, engines and more can be found on its well-stocked shelves, ready for online purchase. When a car part is purchased, a forklift driver needs only to use the part's ID tag to locate and unload it off the shelf before packing it ready for shipment.

The entire dismantling process is impeccably streamlined, which not only benefits production efficiency, but the wider environment, too. Sellers purchasing 'green' car parts through eBay's certified centres, such as Charles Trent, saved 16,000 tonnes of carbon dioxide from entering the atmosphere and 3 million kilograms of waste from landfill in 2022 alone. The facility's crusher is also run solely on renewable electrical power that's generated by connected solar panels.

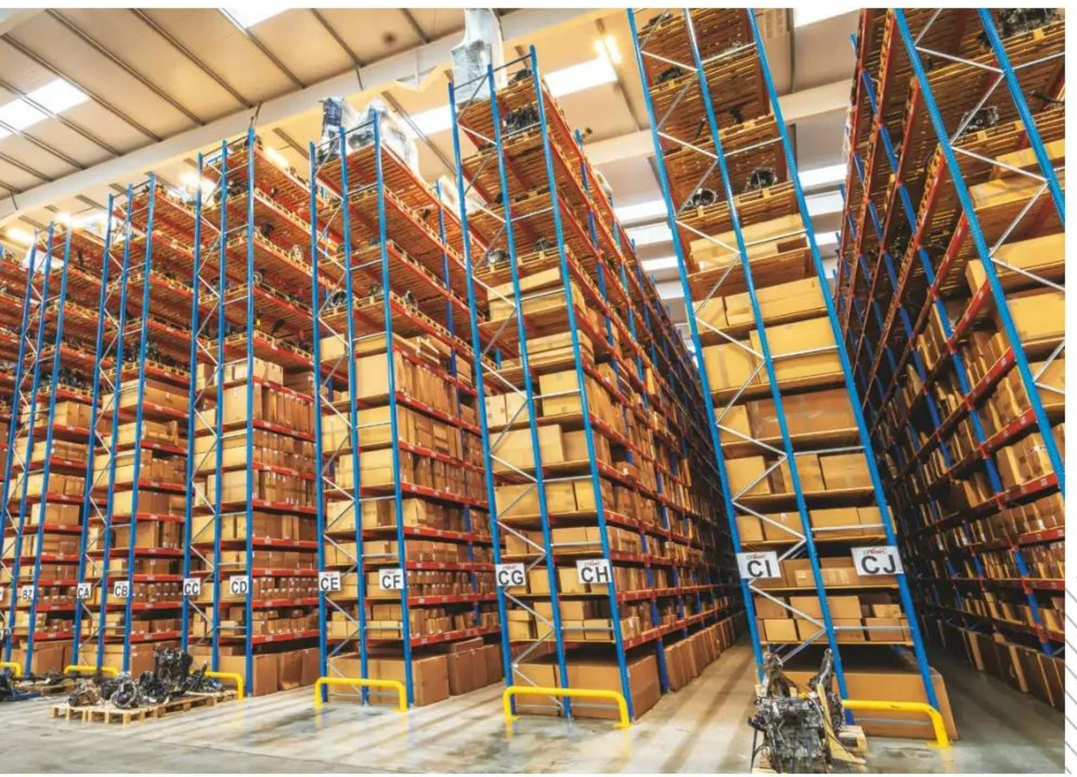
Below left: From door panels to engines, all car parts for sale are stored on palettes in a series of enormous shelves

Above left: What's left of a car is crushed into a neat little cube

Above: There's not much left after workers have stripped a car down

Did you know?

There are around 33 million cars in the UK



ON THE DISASSEMBLY LINE

How Charles Trent has streamlined scrapping cars to make the most out of each vehicle

1 ASSESSMENT
Cars are initially assessed for quality and a shopping list of parts is determined.

2 DEPOLLUTION
After assessment, all leftover fuel, oil and coolants are extracted and either shipped away for further treatment or repurposed.

3 WAITING ROOM
Vehicles are held on metal racking before they're placed on the disassembly line.

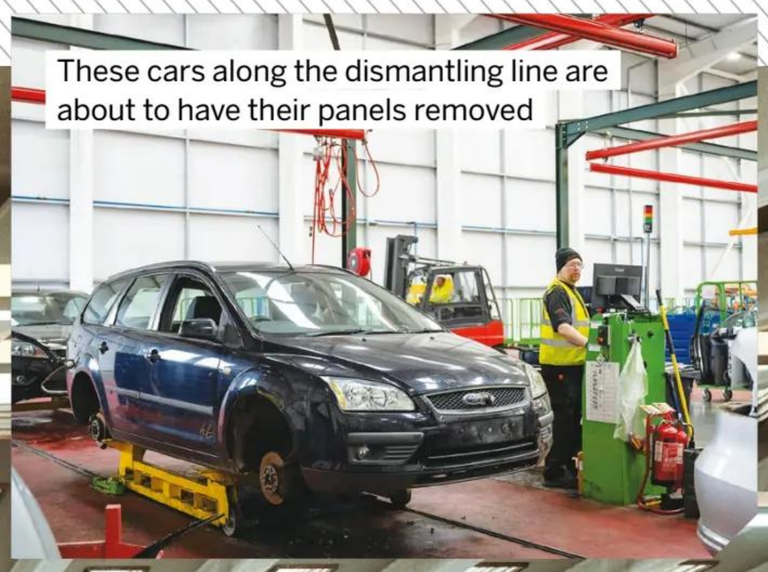
4 PANEL REMOVAL
The first pieces to be taken off the car are its panels, doors and bonnets.

5 ELECTRICAL REMOVAL
Centre consoles and lights are next to be removed.

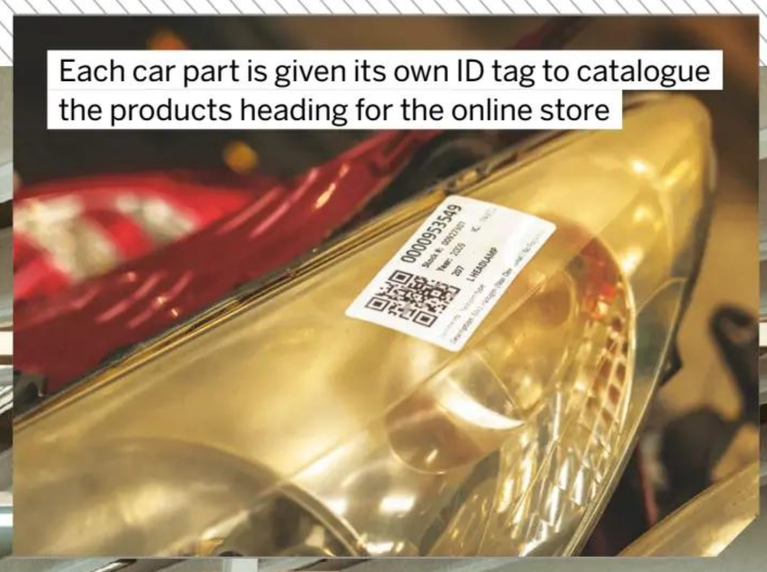
6 ENGINE REMOVAL
With the help of a mechanical arm, the car's engine, gearbox and catalytic converter are cut away.

7 WIRE STRIPPING
Internal dashboard wiring, heating controls and radio system electronics are stripped.

DID YOU KNOW? 1.6 billion tyres are made each year; 100 million are made of recycled materials



These cars along the dismantling line are about to have their panels removed



Each car part is given its own ID tag to catalogue the products heading for the online store

11 PHOTOSHOOT
Once a part is ready for sale, it's photographed and uploaded to eBay.

12 STORAGE
Parts are packaged and put on shelving units that have a capacity for 71,000 parts.

8 MECHANICAL DISMANTLING
At this part of the process, gearboxes are separated from the engine and the engine is inspected and cleaned.

9 PANEL PREP
Car panels are inspected and cleaned, as well as being repaired if necessary.

10 QUALITY CHECKS
Quality checks are made throughout. A final check is made before parts are set aside for resale.

Did you know?
The Ford Focus is the UK's most scrapped car

Engines and gearboxes being loaded into the engine washer

ENGINE CLEANER

Every engine that's removed from a car needs a good scrub before being resold, ready to be used in a new vehicle. To grapple against the grease and polish the pipes, car engines are placed into an enormous dishwasher-like machine. Once all the pipes and inlets have been plugged up, the engine is loaded into the machine and placed on a wash cycle, where it will be powerwashed with high temperature water that will evaporate once the engine has been cleaned.

These automated forklifts can ascend to around 11 metres high

A TIGHT SQUEEZE

With less than a couple of metres between the centre's towering shelving units, Charles Trent has employed equally tall forklift trucks that autonomously guide themselves through the narrow aisles. To minimise the risk of a domino effect of toppling shelves, a radio frequency identification (RFID) system replaces manual steering by human drivers. This works using a thin RFID strip that lines the floor around the shelves. When a forklift is manually driven to connect with the strip, its steering wheel is disabled, leaving the driver to concentrate on operating the lift to collect palettes, moving backwards and forwards along the RFID strip running along the centre of the aisle.

INSIDE A COMBINE HARVESTER

This specialist machine is a farmer's go-to vehicle for harvesting crops

WORDS **AILSA HARVEY**

8 DRIVER'S CAB
A combine operator sits in this section to direct the vehicle towards the crops that need harvesting.

1 REEL
As this metal reel rotates, its jagged teeth cut the crops.

2 GRAIN CONVEYOR
The cut grain is carried upwards on a segmented belt towards the centre of the vehicle for further processing.

Wheat, barley, soy and rye are crops commonly grown by farmers, but the grains you buy in the shops and the products that contain them are only a small part of the plant grown. The edible parts of the plants are the seeds, and to collect them, three processes are required: reaping, threshing and winnowing. All three are usually carried out by combine harvesters.

These vehicles can often be seen on modern-day arable, or crop-growing, farms. The first process carried out by a combine is 'reaping', or the cutting of the crops. As the vehicle is driven over the field, sharp blades at the front cut the crop plants into smaller pieces so that they can be drawn into the machinery. Next, the cut crops enter a rotating drum for threshing – beating the plants so that the grains loosen and become separated. Finally, the combine winnows the grain, whereby a blast of air removes the chaff of the seeds.

The chaff is the harder, external part, and can sometimes need additional force to encourage its separation. Incorporating these three core steps into one trip around the field, in a single vehicle, saves farmers a lot of time and money. Before the combine harvester was invented, much of this process was completed using handheld tools, making it significantly more time-consuming. The combine harvester's predecessor was a thresher, which could separate seeds from the straw, but relied on farmers to harvest the crops in advance.

Did you know?

Leftover straw is used to feed farm animals

WHO INVENTED IT?

The first patented combine looked vastly different to modern machines. It was designed by US inventor Hiram Moore, named a thresher and was drawn by horses. A thresher had a harvest rate of 20 acres per day, and since then modern vehicles have become more than twice as efficient. Up to 40 horses were needed to pull these early combine harvesters. In 1925, horses were replaced with tractors for the role of pulling combines. This milestone meant that farmers just needed to replace the hitch, which was the equipment connecting their combine to their horses. By replacing this with a tractor hitch, farmers could keep the same combine harvester and invest only in an accompanying tractor. The final significant milestone in the evolution of this farming vehicle was the first self-propelled combine harvester, invented by company Massey-Harris in 1939.

Farmers trial an early tractor-drawn Massey-Harris combine harvester

DID YOU KNOW? A combine harvester can be used to harvest around 80 different crop types

A VERSATILE VEHICLE

The mechanics of modern reaping, threshing and winnowing

7 GRAIN TANK
Once the grain is retrieved and cleaned, it's collected in this large tank.

9 UNLOADING AUGER
This drill-shaped component rotates to carry grain up and out of the tank.

6 SIEVE LAYERS
The grooves on these belts are tighter on the lower levels. They filter out and clean material from the grain, separating the largest down to the smallest pieces.

4 STRAW WALKER
After the grain is threshed from the crop, the waste straw is removed along a separate conveyor to exit at the back of the combine.

5 FAN
A central fan helps keep the air flowing from the front to the back of the vehicle, separating light objects from the grain and ejecting them.

3 STONE TRAP
At the top of the conveyor, only small pieces of grain fit into the rotating drum. Large objects like stones are collected here and filtered out.

SELF-DRIVING FUTURE

Autonomous farming may sound relatively futuristic, but self-steering GPS technology has been used since the mid-1990s. Following this invention, combine harvesters have become precision instruments that can treat field rows in straight lines and avoid missing any of the crop. Today combines are being developed that can autonomously navigate fields, as well as automatically adjust harvesting settings. This means that instead of an operator manually altering the settings based on the conditions they observe, cameras scan the field and monitor the condition of crops to maximise the quality of grain being harvested.

Autonomous harvesters use GPS to stay on track

MEGA PORTS

Almost everything you consume in your daily life comes through one of these complex facilities

WORDS **AILSA HARVEY**

DID YOU KNOW? At any time, there are around 20 million container ships at sea

One cargo ship can carry up to 24,000 containers

Over 80 per cent of all global trade is carried out by sea, transporting 11 billion tonnes of cargo annually. All of these goods need to be delivered efficiently to land, speedily sorted and sent to warehouses, showrooms, supermarkets and more. This is a massive operation, relying on over 800 active shipping ports around the world. But what equipment and processes keep these huge sites running smoothly?

Cargo ships can't turn up unexpectedly at ports, as they are often working to busy and well-mastered schedules. Instead, the ship's crew needs to communicate with the port to establish a safe berthing procedure and expected arrival time. The cargo contents and final destination is known to dock workers so that a plan can be established and equipment readied in advance.

Did you know?

The largest ships can store 745 million bananas

Transporting goods across the water is very cheap, and ports have been in place for thousands of years to assist trading. The oldest port in the world is Byblos Port in Lebanon, which is estimated to have been built in around 3,000 BCE. This port was mostly used for timber shipping across the eastern Mediterranean. As well as providing people and companies with the best products from around the world, ports are also hubs for employment. At some of the world's largest ports, over one thousand people are employed for various operational tasks. In the future, however, most of these jobs are likely to be replaced by smart, autonomous technology, so many people will lose their jobs or may be employed in more technical roles. This will increase the efficiency of ports, reducing their cost to run and limiting mistakes made by human error.

WORLD'S BUSIEST

The Port of Shanghai has been the busiest in the world for 13 years running after overtaking the Port of Singapore in 2010. The seaport, situated at the mouth of the Yangtze river, opened in 1842 and has grown to cover an area of 1.5 square miles. From here, over 2,000 ships depart every month, and 500 million tonnes of cargo is handled in a year. There's ample space at Shanghai to receive this huge influx of cargo. Most of the cargo delivered to the port consists of coal, metal ore, petroleum, steel and machinery. There are 19 terminals and over 125 docks built at the site.

13,546 people worked at the Port of Shanghai in 2021

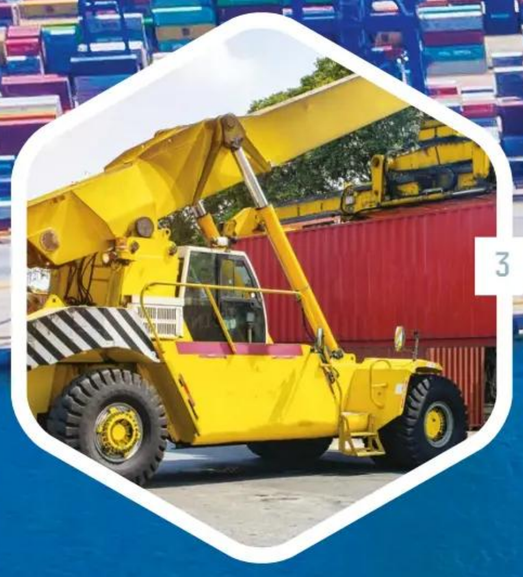
TYPES OF SHIPPING PORTS

INLAND
Situated away from the coast on rivers or lakes, many inland ports are used in similar ways to shipping ports at the coast. However, the types and sizes of vessels that can use them are more limited. Some are solely for recreational use.

DRY
Dry ports are land-based, connected to seaports by railway lines and roads. These are essential to ease congestion in some of the main ports. By sorting and storing large cargo temporarily, they free up space at seaports.

WARM WATER
A warm water port doesn't freeze over during the winter months. However, not all locations have a climate fit for a natural warm water port. Ports such as those in Finland use icebreaker ships, which are specially designed to sail through ice.

FISHING
Fishing ports can be inland or at the coast, but are always found where there is a high abundance of fish. These ports need to maintain controlled fishing rules to make sure that overfishing doesn't take place and deplete resources.



PORT TECHNOLOGIES

Discover the heavy-lifting, cargo-cradling machines that make port processes more efficient

1 STRADDLING STACKER
Rubber-tyre gantry (RTG) cranes have wheels on their bases, meaning that they're mobile. This is essential for their role as cargo stackers. They pick up containers and move forward on their wheels to stack them neatly on top of other containers, being controlled remotely by an operator. Their wide build allows them to straddle multiple rows of containers, while the lifting component of the crane moves horizontally to align with the desired stack.

2 TERMINAL TRACTOR
These vehicles are built to carry cargo containers individually around a port – from the lower sections of the ships to cranes and from cranes to storage facilities. Being relatively small compared with the other on-site machinery, terminal tractors can navigate tighter corners and efficiently transport each piece of cargo from one section of the port to another.

3 MATERIAL HANDLER
These vehicles have a crane arm overhanging their front. This puts the action right in front of the driver as they control the material handler's movements. At the end of the crane's arm is a long magnet that covers most of a cargo container's upper surface area. When turned on, the strong magnet attaches to the container so it can be lifted and moved elsewhere. The flexible arm can be lowered into ships and reached upwards to collect cargo from a range of heights.

4 RAILWAY CONNECTION
Cargo containers are loaded onto specially designed freight trains to be transported to distribution centres. These centres are where the cargo is individually packaged according to specific orders and sent to customers and consumers.

5 CONTAINER CRANE
Tall cranes need to tower over the largest ships that enter a port. This helps cargo get removed from ships safely and easily. Stacks up to 12 containers high can be packed onto these vessels.

6 AUTOMATED GUIDED VEHICLE
After being loaded with cargo, fully automated vehicles can transport containers between the quayside and the container yard. Many of these vehicles can be programmed to work simultaneously in some ports, reducing laborious jobs. These sometimes work in tandem with autonomous RTG cranes.

7 FORKLIFT
These can raise heavy cargo high above the vehicle using hydraulic force. The operator controls the height the cargo is raised depending on how tall the stack of containers is.

Did you know?
97 per cent of shipping containers are made in China

DID YOU KNOW? Container ship engines are 1,000 times more powerful than a typical family car

5 FACTS SMART PORTS

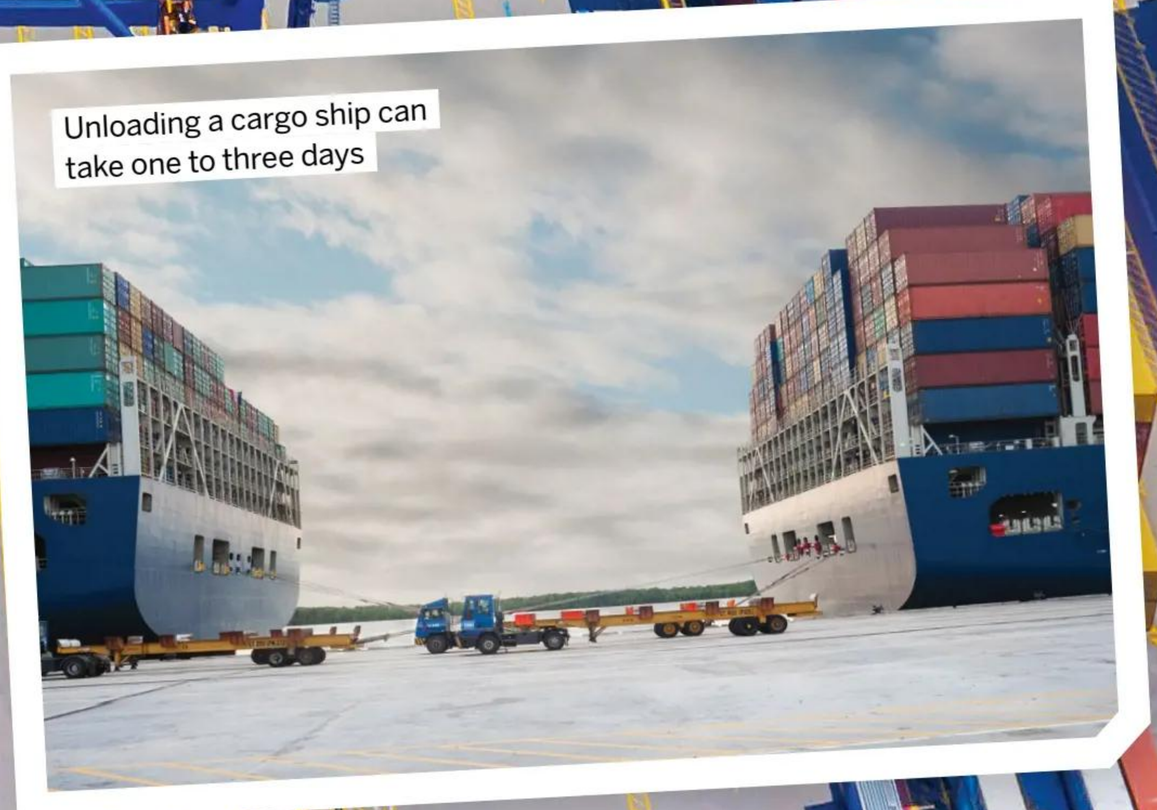
1 DIGITAL TWIN
ROTTERDAM, THE NETHERLANDS
The Port of Rotterdam has an accurate digital twin, a virtual computer model that includes all the statistics of the port's movements and earnings. It can be used to test the outcome of different scenarios before putting changes in place.

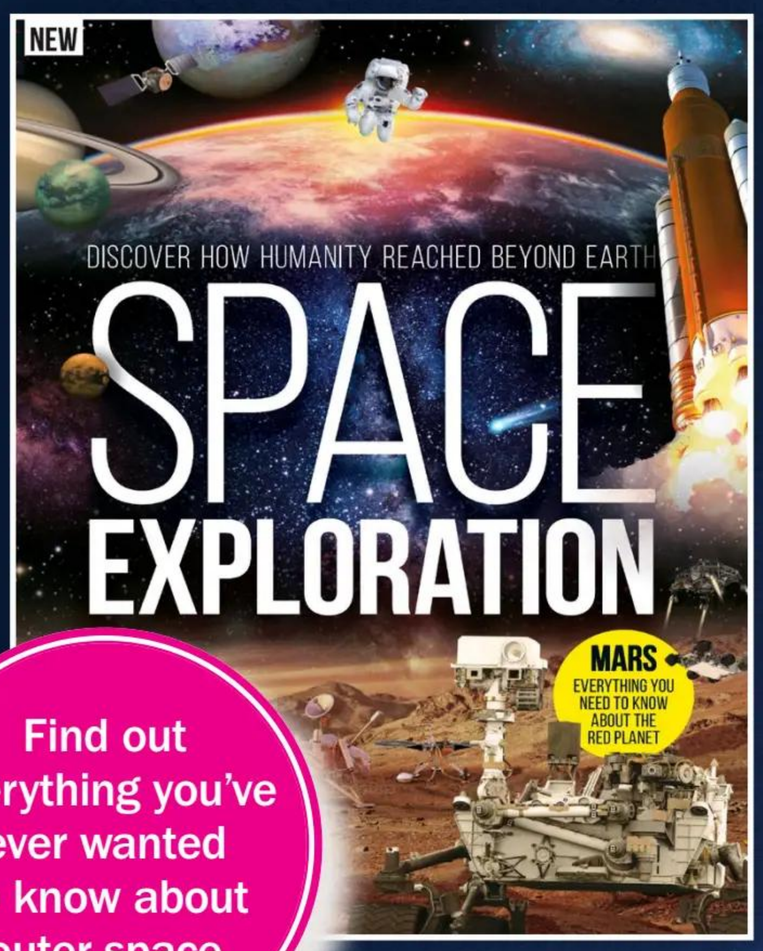
2 POLLUTION TRACKING
HAMBURG, GERMANY
The Hamburg Port Authority uses weather sensors to track the pollution levels in the air surrounding the port. The sensors relay levels of sulphur dioxide, nitrogen dioxide and fine dust particles to show how different operations impact the environment.

3 SUSTAINABILITY
ANTWERP, BELGIUM
Antwerp is considered to be Europe's most sustainable port, with all of its new terminals releasing near-zero emissions. To achieve this, the port is incorporating electricity and hydrogen-powered equipment.

4 FULLY AUTOMATED
SINGAPORE
Tuas Port in Singapore is on track to become the largest fully automated port in the world when it's completed in 20 years' time. Singapore's prime minister Lee Hsien Loong said the port will "almost double today's volumes" of cargo.

5 ADVANCED TECH
SHANGHAI, CHINA
The Port of Shanghai has the first centralised remote control and smart command centre. Located 62 miles from the equipment itself, workers can use cameras and controllers to move cranes remotely from inside their office.


Unloading a cargo ship can take one to three days



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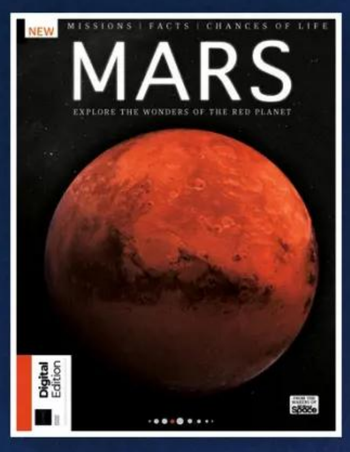
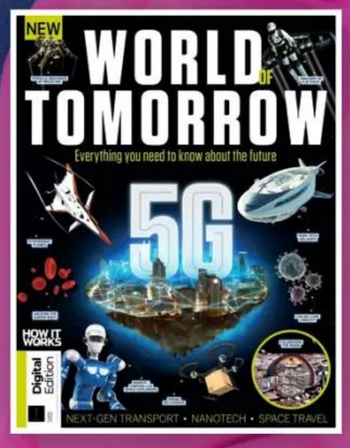
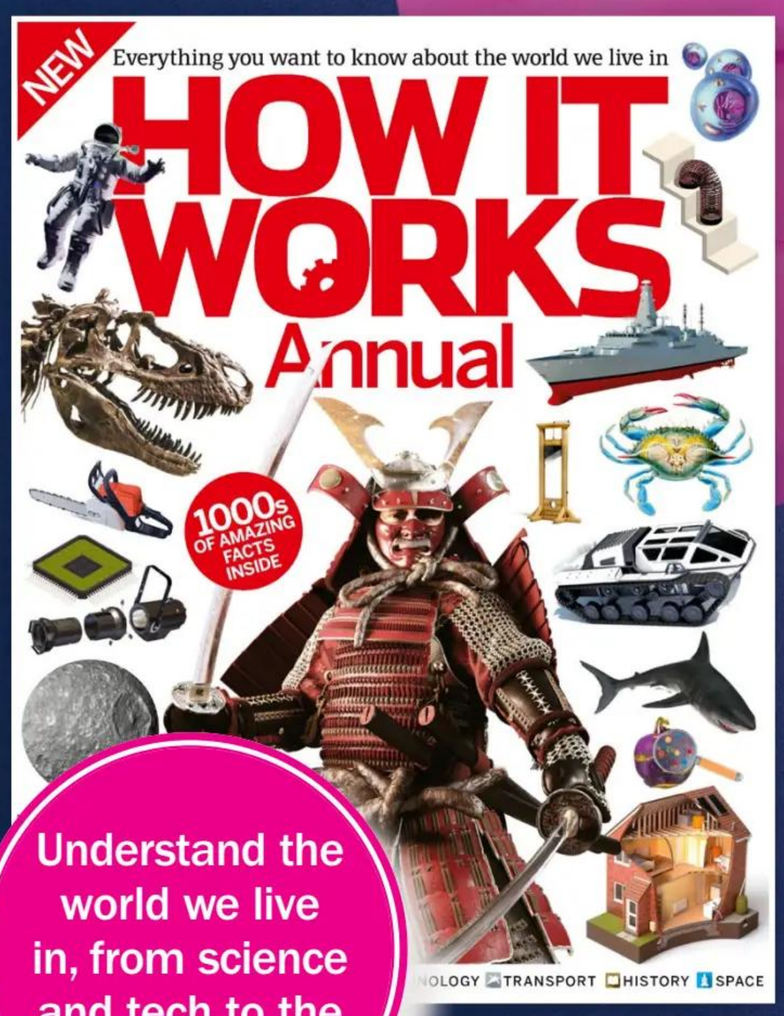
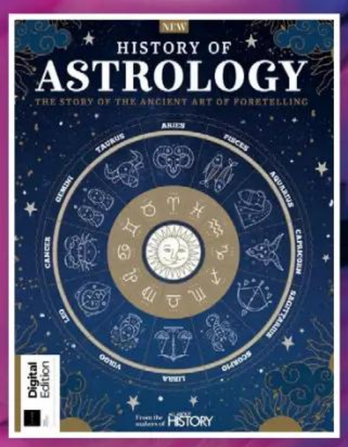


Explore our incredible planet and the secrets beneath the surface







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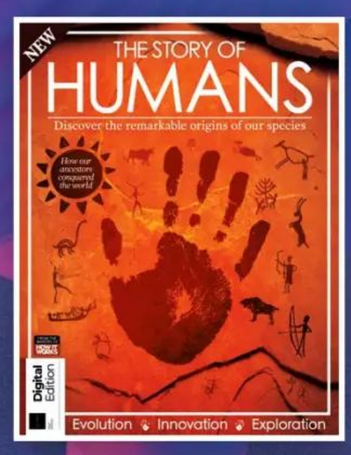

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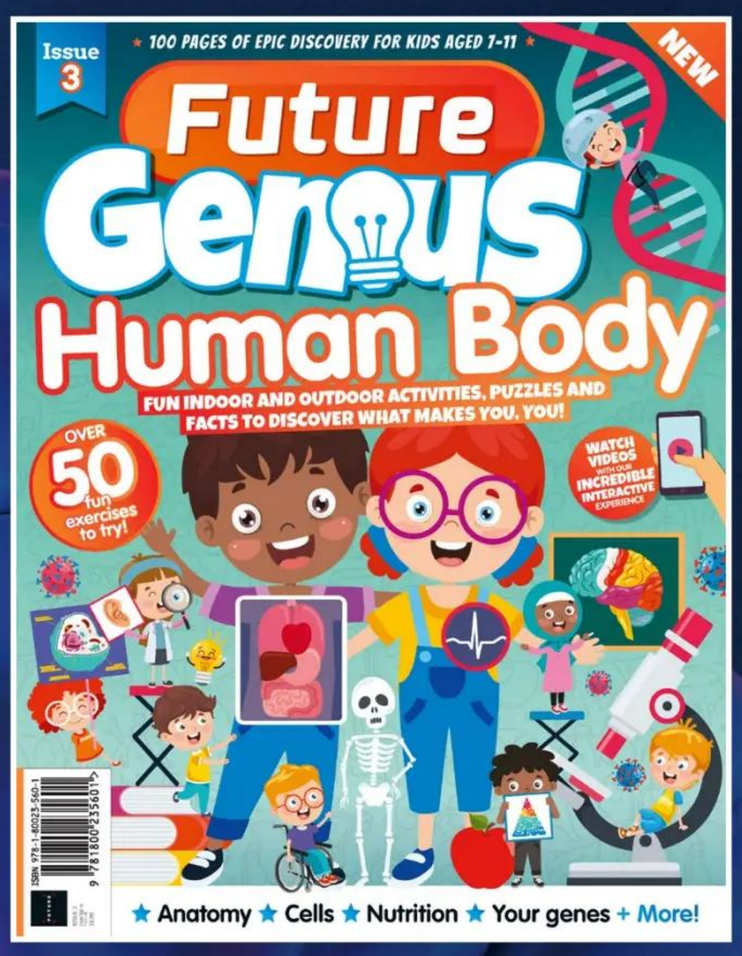

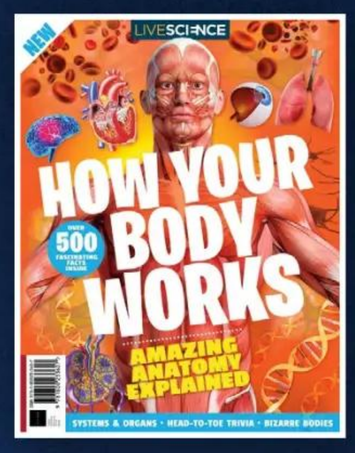

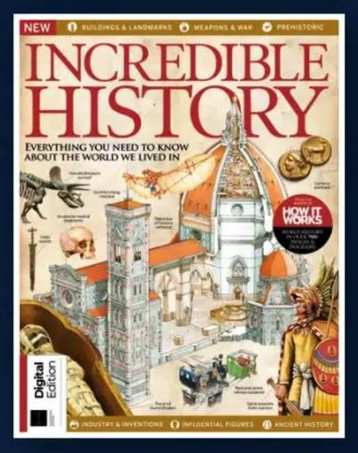

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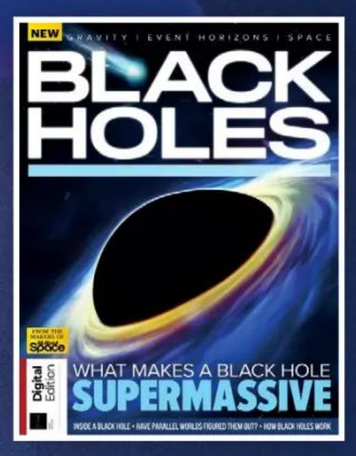

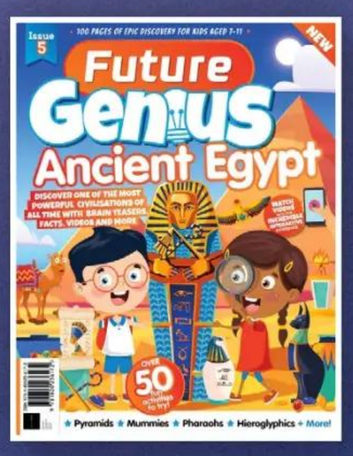

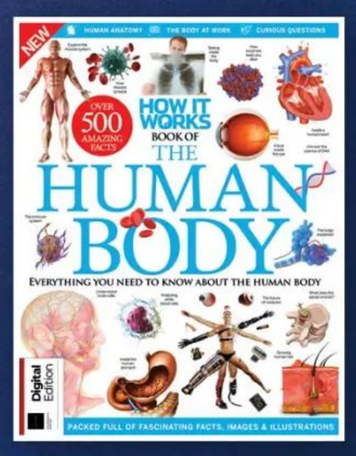

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