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ISSUE **145**

WELCOME

The magazine that feeds minds!

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"We will use the Moon as a test bed because Mars is a difficult mission"

Back to the Moon, page 20

Most of us aren't old enough to remember the day the first astronaut set foot on the Moon, though this human achievement has become the stuff of legend for us all. In over 50 years of space missions since, nothing has captured the zeitgeist in the same way that Armstrong and Aldrin's moonwalk did. It's quite something to think that in 2024, astronauts could return to the lunar surface, this time paving the way for a possible mission to Mars and breaking new ground with the first woman on the Moon. This issue we've explored the Artemis program's goals, its impressive new technology and we've spoken to a NASA astronaut about what it's like to be so far from Earth. Enjoy!

Ben Editor

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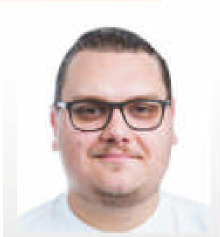
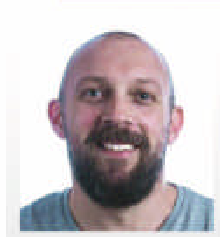
Meet the team…

Nikole
Production Editor
We take electricity for granted as it powers our homes and gadgets, but how does it reach us? Follow its journey on page 66.



Scott
Staff Writer
From towering termite hills to a spider silkhenge, meet some of nature's greatest constructions on page 40.

Baljeet
Research Editor
We speak with the creator of GPS about its development, applications and why the US Air Force were against it at first on page 60.



Duncan
Senior Art Editor
Explore the Japanese drilling ship Chikyu, which delves into the depths of the ocean floor from above the waves, on page 84.

Ailsa
Staff Writer
A hypernova instantly releases more energy than the Sun will in its lifetime. See what causes them on page 28.

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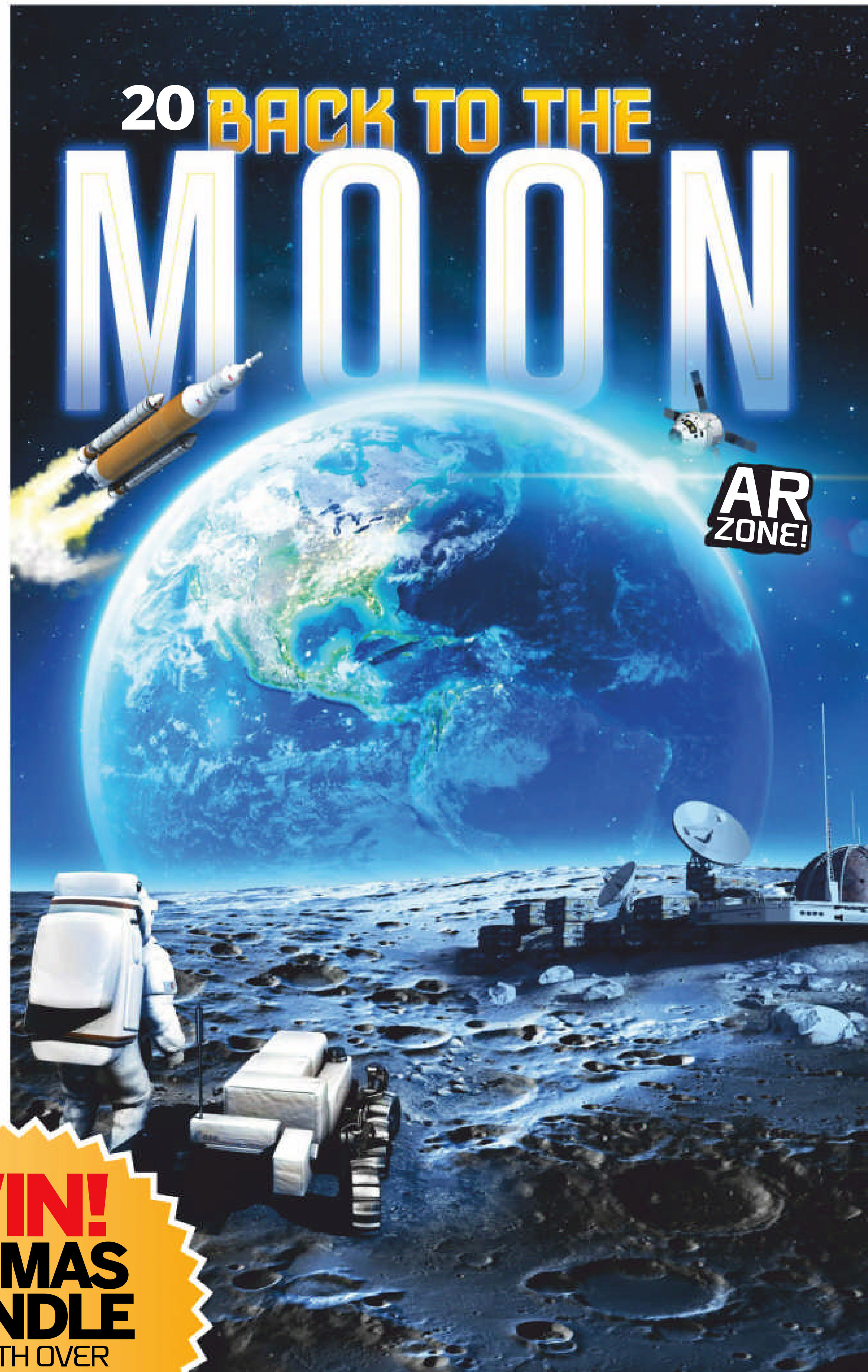

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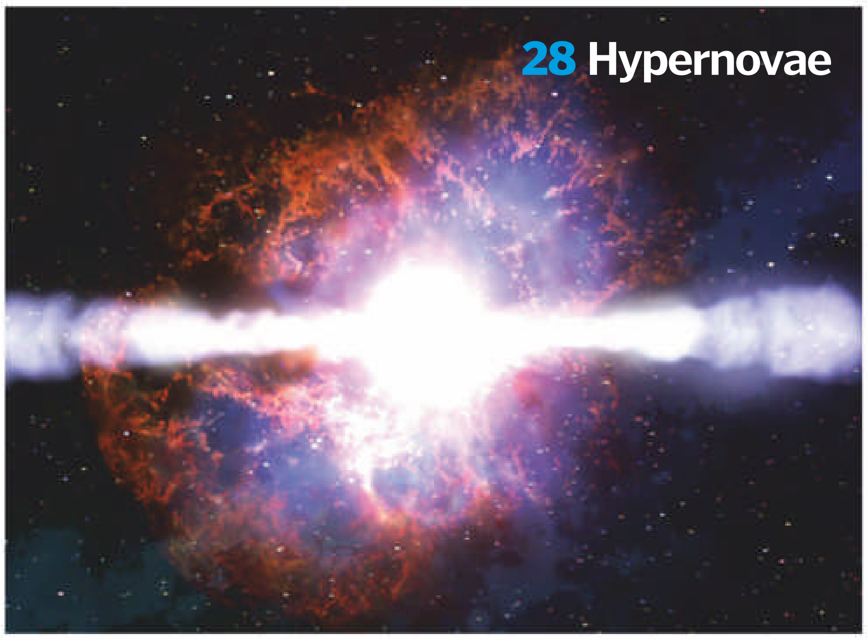

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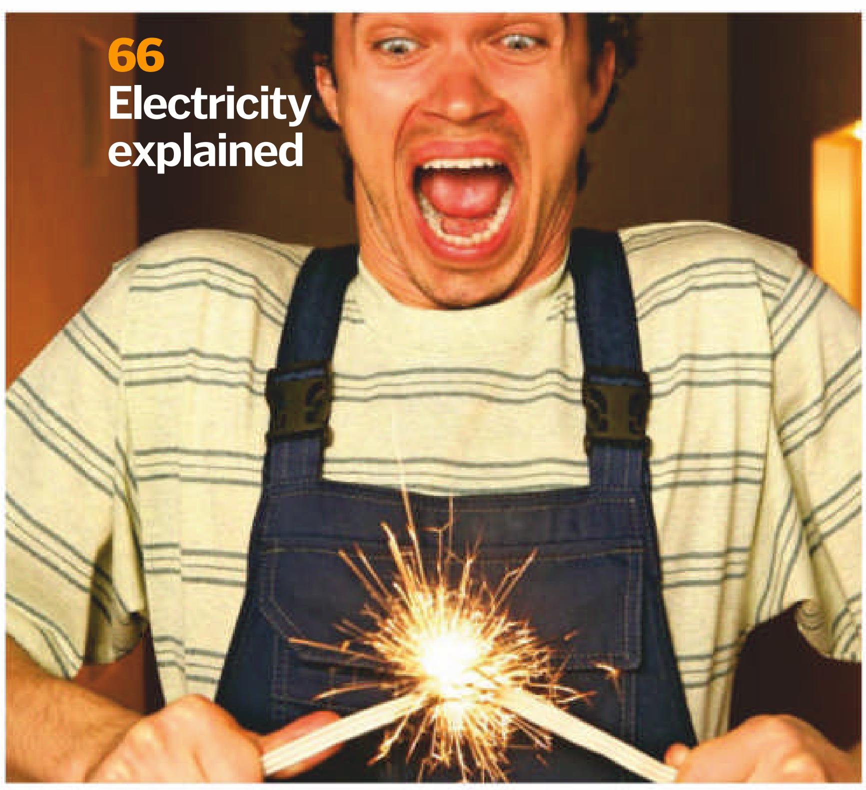

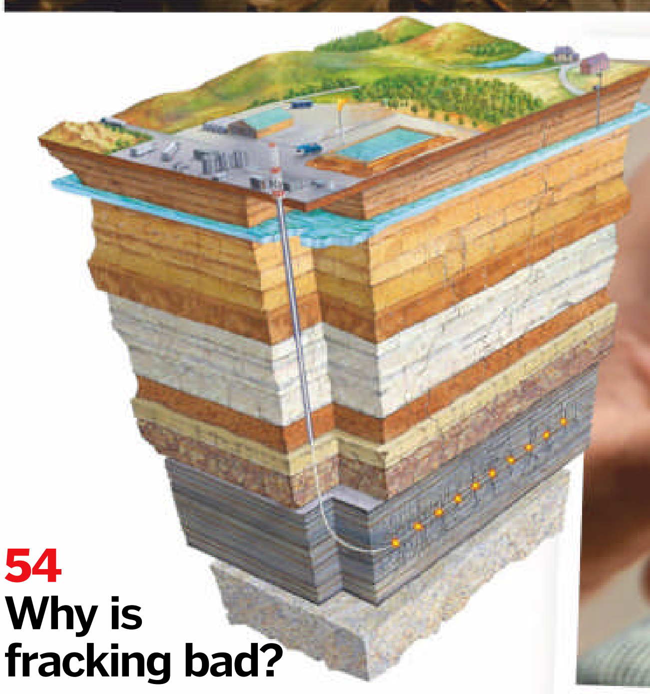

REGULARS

AR ZONE!

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When you see the AR ZONE! logo at the top of a page, use your phone to scan the QR code, which looks like this

Hold your mobile device over the image and watch it come to life! Your device needs to be connected to the internet for this to work

HOW THE AUGMENTED REALITY WORKS

After being launched by the QR code, the app reads anything you point your device's camera at 30 times a second, searching for distinctive shapes we've trained it to recognise. When it sees a familiar picture, it overlays the augmented-reality 3D image we've previously uploaded on your screen.


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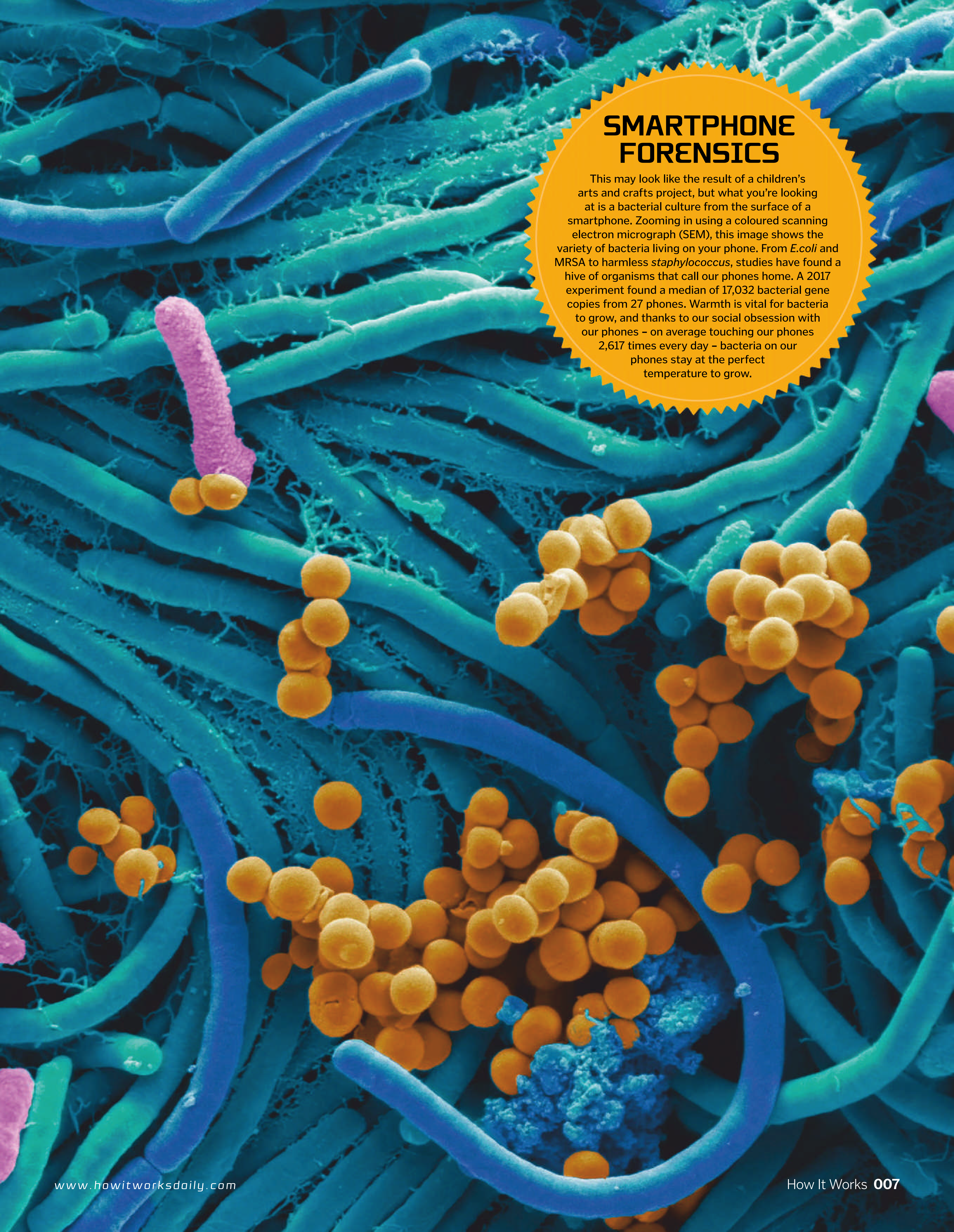

SMARTPHONE FORENSICS

This may look like the result of a children's arts and crafts project, but what you're looking at is a bacterial culture from the surface of a smartphone. Zooming in using a coloured scanning electron micrograph (SEM), this image shows the variety of bacteria living on your phone. From *E.coli* and MRSA to harmless *staphylococcus*, studies have found a hive of organisms that call our phones home. A 2017 experiment found a median of 17,032 bacterial gene copies from 27 phones. Warmth is vital for bacteria to grow, and thanks to our social obsession with our phones – on average touching our phones 2,617 times every day – bacteria on our phones stay at the perfect temperature to grow.

RAINBOW MOUNTAINS

Looking like they've been plucked from the pages of a Dr Seuss book, these multicoloured mountains are far from fiction, found in China's Zhangye Danxia National Park. The rock that makes up this colourful array is predominantly sandstone and siltstone from the Cretaceous Period, between 145.5 and 65.5 million years ago. These rocks were deposited alongside trace minerals which create their vibrant appearance. For example, the predominant red comes from the inclusion of iron, which when exposed to oxygen in the air turns red, or when combined with sulphur creates a yellow hue. The presence of chlorite or iron silicate clay produces green stripes on the mountain face.

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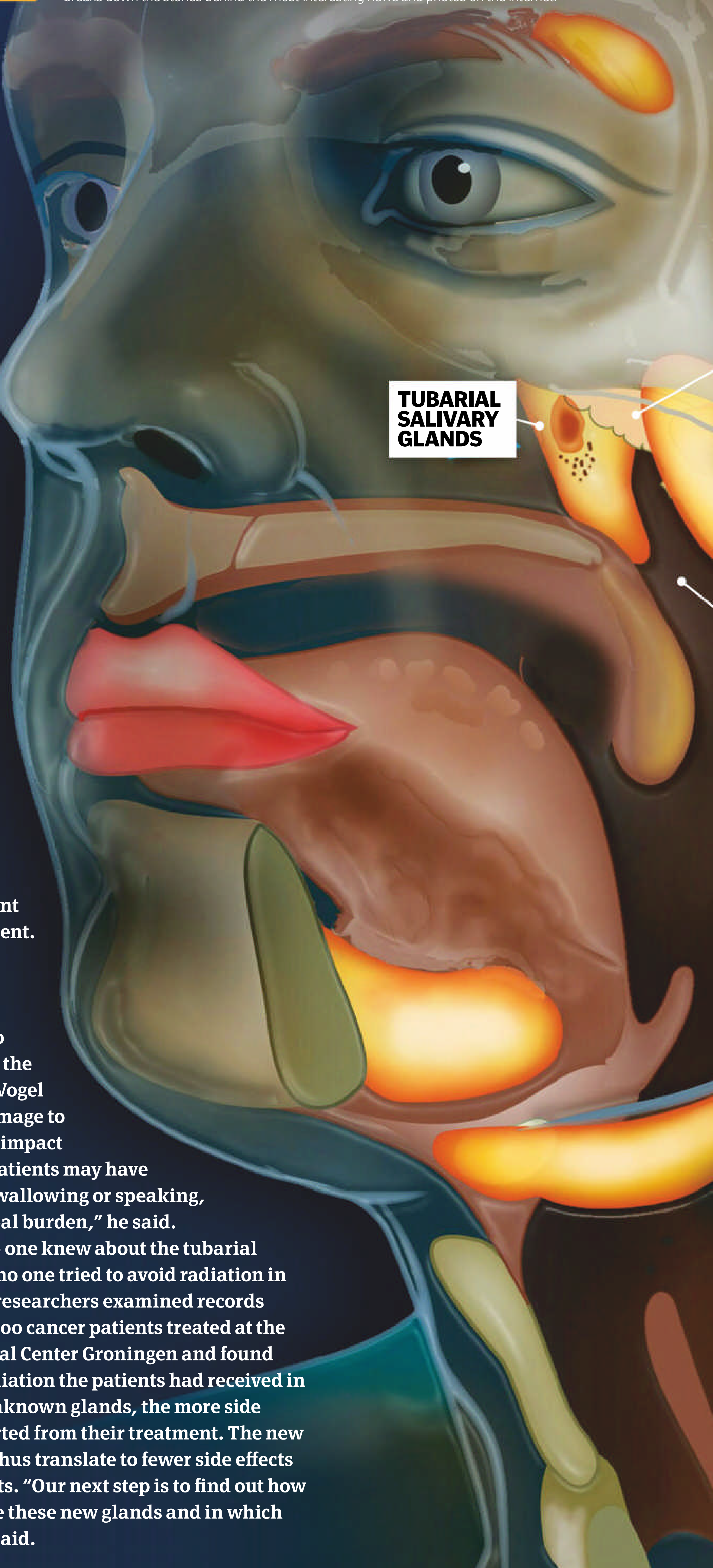
HEALTH

Scientists discover new organ in the throat

Words by **Stephanie Pappas**



Scientists have discovered a new organ, a set of salivary glands set deep in the upper part of the throat. This nasopharynx region, behind the nose, was not thought to host anything but microscopic, diffuse salivary glands, but the newly discovered set are about 3.9 centimetres in length on average. Because of their location over a piece of cartilage called the torus tubarius, the discoverers of these new glands have dubbed them the tubarial salivary glands. The glands probably lubricate and moisten the upper throat behind the nose and mouth.

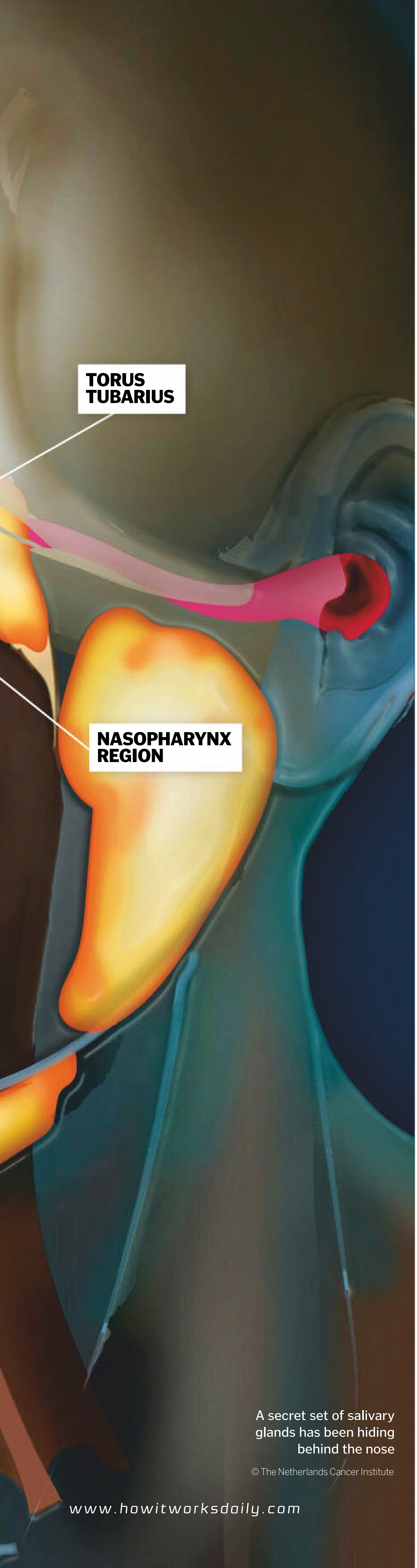
The discovery was accidental. Researchers at the Netherlands Cancer Institute were using a combination of CT scans and positron emission tomography (PET) scans called PSMA PET-CT to study prostate cancer. In PSMA PET-CT scanning, doctors inject a radioactive 'tracer' into the patient. This tracer binds well to the protein PSMA, which is elevated in prostate cancer cells. Clinical trials have found that PSMA PET-CT scanning is better than conventional imaging at detecting metastasised prostate cancer.

PSMA PET-CT scanning also happens to be very good at detecting salivary gland tissue, which is also high in PSMA. Until now there were three major pairs of salivary glands in humans, which are found under the tongue, under the jaw and at the back of the jaw, behind the cheek. Beyond those, perhaps 1,000 microscopic salivary glands are scattered throughout the mucosal tissue of the throat and mouth, Netherlands Cancer Institute radiation oncologist Wouter Vogel said. "Imagine our surprise when we found these," Vogel said.

To confirm the discovery, Vogel and his colleagues imaged 100 patients and found that all of them had the newly discovered glands. They also dissected that nasopharynx region from two cadavers from a human body donation program and found that the newfound region consisted of mucosal gland tissue and ducts draining into the nasopharynx.

The discovery could be important for cancer treatment. Doctors using radiation on the head and neck to treat cancer try to avoid irradiating the salivary glands, Vogel said, because damage to these glands can impact quality of life. "Patients may have trouble eating, swallowing or speaking, which can be a real burden," he said.

But because no one knew about the tubarial salivary glands, no one tried to avoid radiation in that region. The researchers examined records from more than 700 cancer patients treated at the University Medical Center Groningen and found that the more radiation the patients had received in the area of the unknown glands, the more side effects they reported from their treatment. The new discovery could thus translate to fewer side effects for cancer patients. "Our next step is to find out how we can best spare these new glands and in which patients," Vogel said.



A secret set of salivary glands has been hiding behind the nose

© The Netherlands Cancer Institute

Part of the Very Large Telescope, operated by the European Southern Observatory in Chile's Atacama Desert, which was instrumental in watching the spaghettification event

© Y. Beletsky (LCO)/ESO

SPACE & PHYSICS

Black hole turns a star into spaghetti

Words by **Rafi Letzter**

A black hole in a galaxy not far from Earth has gobbled up a star like it was a big, exploding noodle, and astronomers got a front-row seat to the action. The 'unfortunate star', as the researchers called it in their paper, was orbiting in the dense nucleus of a galaxy with the unwieldy name 2MASX J04463790-1013349 about 215 million years ago when it found itself on a doomed path. It had wandered too close to the galaxy's central supermassive black hole, and that stretched it out like spaghetti and swallowed it in one big gulp – scientists literally call this process spaghettification. Light from this act of stellar cannibalism reached Earth in 2019. Researchers have detected events like this before, but never so soon after the destruction and never so nearby. The black hole ate its plasma noodle dinner just 215 million light years from Earth.

Spaghettification happens because of how sharply gravity increases as you approach a large black hole. If you dropped feet-first down a black hole's gravity well, at some point the gravity at your feet would be much stronger than the gravity at your head. It would stretch you out until all your skin, skeleton and guts looked like a long string. The same thing happens to stars as they plunge into supermassive black holes.

Astronomers have still never actually watched the initial stretching process itself, but this is the closest they've ever gotten. Wide-view telescopes spotted a flash of light from the system, the signature of a tidal disruption event.

As a star is ripped apart, some of its innards end up in the disc of swirling matter around the black hole and shine brightly before they're swallowed. At the same time, clouds of dust and other material blast out into space, shrouding regions of the black hole from view. Soon after the first flash, telescopes all over the world whirled around to watch this happen.

"Because we caught it early, we could actually see the curtain of dust and debris being drawn up as the black hole launched a powerful outflow of material with velocities up to 10,000 kilometres per second," said Kate Alexander, a Northwestern University astrophysicist.

Over the course of six months researchers watched the material flow into space and then watched the tidal disruption fade. The astronomers also confirmed for the first time the direct link between the flash of light and the outflowing material.

"It had wandered too close to the galaxy's central supermassive black hole"

SPACE AND PHYSICS

‘Starman’ passes Mars in decaying Tesla Roadster

Words by **Rafi Letzter**

Starman, the dummy riding a cherry-red Tesla Roadster through space, has made his closest approach ever to Mars. The electric convertible and its mannequin passenger were bolted to the top of a Falcon Heavy rocket as a stunt during the SpaceX rocket’s first test launch on 6 February 2018. It’s common for test launches to include heavy payloads, but they’re usually more boring than cherry-red sports cars.

Two years later, the Falcon Heavy upper stage and the vehicle at its tip are making their second trip around the Sun. Jonathan McDowell, a Harvard astrophysicist who tracks space objects as a side project, found that Starman passed 7.4 million kilometres from Mars at 06:25 GMT 7 October. That’s about 19 times the distance from Earth to the Moon, and 35-times closer than anyone on Earth has gotten to Mars.

The closest recent approach between the Earth and Mars was 56 million kilometres in 2003, though the planets are often hundreds of millions of miles apart depending where they are in their orbits. No one can see the Falcon Heavy upper stage at its current distance, and the strange, beautiful images it once beamed home to Earth have long since ceased. But orbits over periods of a few years are fairly straightforward to predict, and McDowell used data about how the rocket was moving when it left Earth’s gravity behind to pinpoint its recent movements.

The Roadster-bearing rocket stage is on an asymmetrical orbital course that takes it as far as 1.66 times Earth’s distance from the Sun at one end of its trek – out beyond the orbit of Mars – and then back within Earth’s orbit at the other end, 0.99 times Earth’s distance from the Sun.

> “No one can see the upper stage at its current distance”

Last time Starman circled the Sun, McDowell said, it crossed Mars’ orbit while the Red Planet was quite far away. But this time the crossing lined up with a fairly close approach, though still not close enough to feel a strong tug of Martian gravity.

At this point in time, if you were able to go look at the Roadster, it would probably look pretty different. The harsh solar radiation environment between the planets would probably have wrecked all the exposed organic materials – red paint, rubber tyres, leather seats and the like – breaking the carbon bonds that hold them together.

Without Earth’s protective atmosphere and magnetic shielding, even the robust plastics in the windshield and carbon-fibre materials would start to disintegrate. Over the course of decades or centuries, the car should be reduced to its aluminium frame and sturdiest glass parts – that's assuming that none of them get destroyed in impacts with passing space rocks.

Starman sent pictures home before leaving Earth orbit

© Getty

Bar-tailed godwits are impressive flyers, scaling thousands of miles without stopping

© Alamy

ANIMALS

Record-breaking bird flies 12,000 kilometres nonstop

Words by **Yasemin Saplakoglu**

An international traveller just broke the world's record for the longest nonstop flight – among birds that is. A bar-tailed godwit (*Limosa lapponica*) just flew for 11 days straight from Alaska to New Zealand, traversing a distance of 12,000 kilometres without stopping and breaking the longest nonstop flight among birds known to scientists.

Bar-tailed godwits are known to undertake impressive migrations between Alaska and New Zealand, flying thousands of miles without stopping. But one particular bird, driven by easterly winds that prolonged his journey, flew longer than any of his kind known to date.

Scientists tracked this particular male godwit, known as '4BBRW' for the coloured identification rings on its legs – stacked blue, blue, red and then white – through its onboard satellite tag. In 2019 they caught and tagged 4BBRW along with 19 other bar-tailed godwits in the Firth of Thames, southeast of Auckland.

The endurance flyer set off from southwest Alaska on 16 September after having spent a couple of months feeding in Alaska's mudflats. Though the godwits pack on weight during this time, they are known to shrink their internal organs for their migration in order to travel light.

After leaving Alaska the godwit flew south over the Aleutian Islands, landing in a bay near Auckland in New Zealand 11 days later. His satellite clocked in at 12,854 kilometres, but rounding errors likely mean that the journey actually extended over about 12,200 kilometres. Sometimes the godwit flew up to 89 kilometres per hour.

The journey isn't only impressive, but holds a cultural significance for people in New Zealand. To the Maori, the indigenous Polynesian people of New Zealand, godwits – which they call 'kuaka' – are signs that good fortune is coming, and the return of the kuaka marks the beginning of spring. 4BBRW and others of his kind are expected to start their journey back to Alaska in March, but first they will likely take a pitstop near China in the Yellow Sea for about a month to feed.

PLANET EARTH

Hidden tectonic plate has been reconstructed

Words by Stephanie Pappas

Scientists have reconstructed a long-lost tectonic plate that may have given rise to an arc of volcanoes in the Pacific Ocean 60 million years ago. The plate, dubbed Resurrection, has long been controversial among geophysicists, as some believe it never existed. But the new reconstruction puts the edge of the rocky plate along a line of known ancient volcanoes, suggesting that it was once part of the crust in what is today northern Canada.

Geologists used a computer model of Earth's crust to 'unfold' the movement of tectonic plates since the early Cenozoic Era, the geological era that began 66 million years ago. Geophysicists already knew that there were two plates in the Pacific at that time: the Kula Plate and the Farallon Plate.

Because lots of magma is present east of the former location of these plates in what is today Alaska and Washington, some geophysicists argued there was a missing piece in the puzzle, a theoretical plate they called Resurrection. This magma would have been left behind by volcanic activity at the plate's edge.

All of these plates have long since dived beneath Earth's crust in a process called subduction. The researchers used the computer reconstruction to undo this subduction, virtually raising the plates back to the surface and rewinding their motion over millions of years. When they did, they found that Resurrection did indeed fit into the picture.

© Getty

New research suggests that there are remains of the Resurrection plate under northern Canada

IN ASSOCIATION WITH LIVESCIENCE

HISTORY

New cat Nazca Line discovered

Words by Laura Geggel

Archaeologists have discovered a gigantic feline geoglyph adorning a hillside in southern Peru, making it the latest of the Nazca Lines – a group of mysterious and enormous human-made outlines of animals, plants and fantastic figures in the desert dating to pre-Columbian times – to be uncovered in recent years. The cat was found while archaeologists with the Nazca-Palpa Management Plan, supported by Peru's Ministry of Culture, were remodelling a natural viewpoint.

At first the workers could barely see the cat – natural erosion on the hillside had almost erased the ancient feline outline. However, after about a week's worth of conservation, archaeologists restored the geoglyph, which dates to between around 200 and 100 BCE. Like other Nazca Lines, including a monkey, hummingbird and human, the cat is so huge it's better seen from above, such as from a plane or drone. The cat's 'lines' are between 30 and 40 centimetres wide, and the feline is about 37 metres long. The cat's style indicates it was made in the late Paracas period – the Paracas culture predated the Nazca culture, which began in about 100 BCE.

In recent years researchers have found 80 to 100 previously unknown geoglyphs in the Nazca and Palpa valleys, all of which predate the Nazca culture. "It might seem surprising that new designs are still being found, but we know there are more out there," said archaeologist Johny Isla.

© Peru Ministry of Culture, Communication and Image Office

It took archaeologists about a week to refurbish the ancient cat outline

Planet Nine is a world about ten-times more massive than Earth that may lie in the outer Solar System

© Caltech/R. Hurt (IPAC)

SPACE

Astronomers find a new way to hunt for the elusive Planet Nine

Words by **Mike Wall**

Finding Planet Nine may require looking at telescope images in a different light.

Astronomers are vetting a 'shifting and stacking' technique that could aid the hunt for the putative world, which some researchers think lurks undiscovered in the far outer Solar System, way beyond Pluto's orbit.

The strategy involves shifting space telescope images along sets of possible orbital paths, then stacking the photos together to combine their light. The technique has already been used to discover some moons in our Solar System, and it could potentially spot Planet Nine, also known as Planet X, Giant Planet Five or Planet Next, and other extremely far-flung objects. "You really can't see them without using this kind of method," said Malena Rice, an astronomy PhD student at Yale University in Connecticut. "If Planet Nine is out there, it's going to be incredibly dim."

> "If Planet Nine is out there, it's going to be dim"

Researchers found the faint signals of three known trans-Neptunian objects (TNOs), small bodies that circle the Sun beyond Neptune's orbit, in shifted and stacked Transiting Exoplanet Survey Satellite (TESS) images. Then a blind search of two distant patches of sky was conducted, turning up 17 new TNO candidates. "If even one of these candidate objects is real, it would help us to understand the dynamics of the outer Solar System and the likely properties of Planet Nine," Rice said. The researchers are currently working to confirm the 17 candidate TNOs using imagery captured by ground-based telescopes.

TNOs are bread crumbs that could lead the way to Planet Nine. The hypothetical world's existence has been inferred from the odd orbits of some TNOs, which are clustered in a way that strongly suggests sculpting by a big, far-flung 'perturber'. Data indicates a planet five to ten times more massive than Earth, orbiting the Sun hundreds of times farther away than our world does. Not everyone is on board with this interpretation, however. Some scientists think the TNOs' odd clustering arises from the combined gravitational influence of their many minuscule neighbours, not a single big object.

© Getty

As the Arctic Ocean warms, researchers have observed an acceleration of ice flow into the ocean

SPACE & PHYSICS

Physicists clock the fastest possible speed of sound

Words by **Stephanie Pappas**

Scientists have discovered the fastest possible speed of sound: about 36 kilometres per second. Sound waves move at different speeds in solids, liquids and gases. Within those states of matter they travel faster in warmer liquids compared with colder ones. Physicist Kostya Trachenko of Queen Mary University of London and his colleagues wanted to figure out the upper limits of how fast sound could travel.

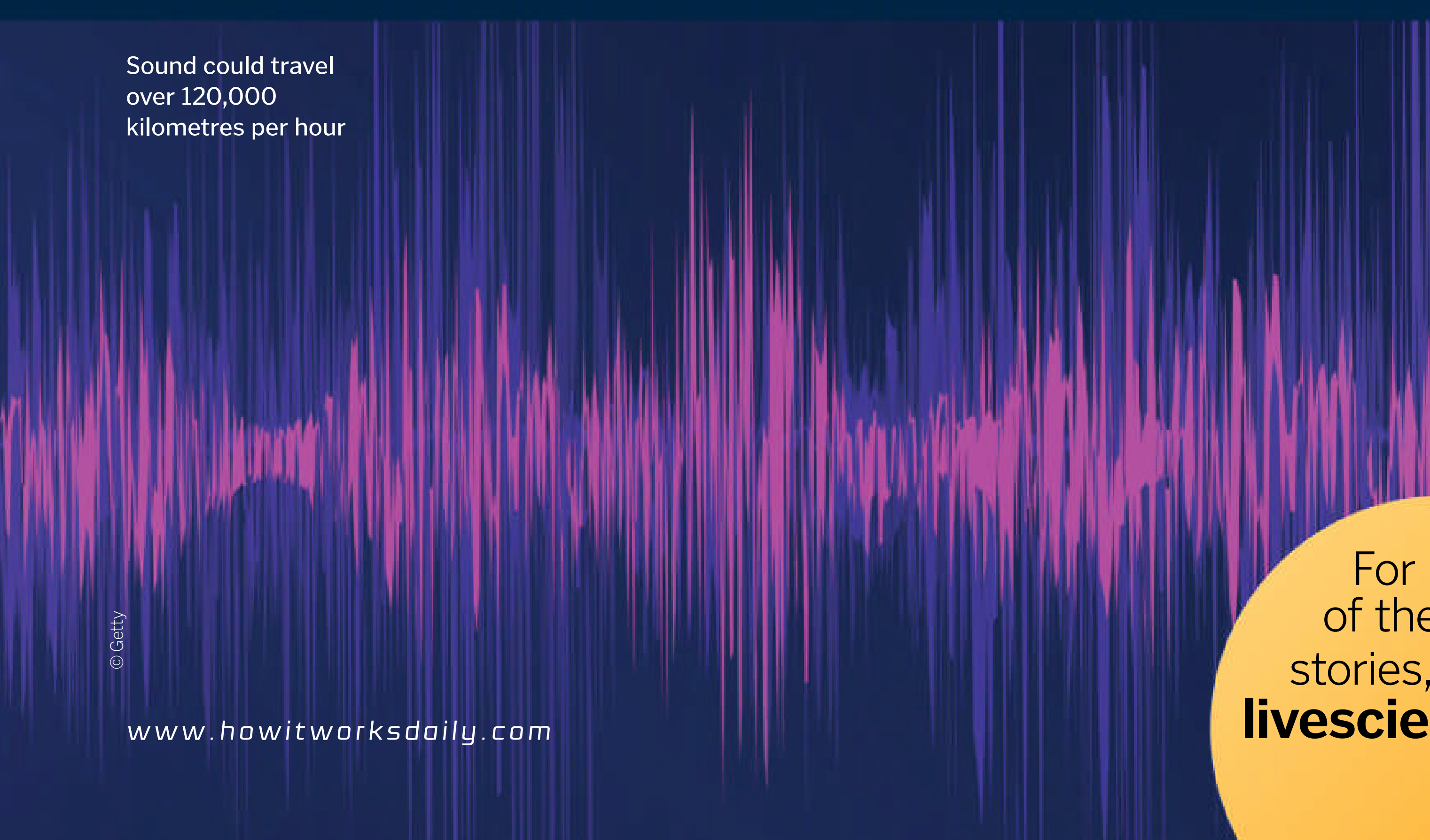
This exercise was largely theoretical. The researchers found that the answer, which is about twice as fast as sound moves through solid diamond, depends on some fundamental numbers in the universe. The first is the fine structure constant, which is a number that describes the electromagnetic force that holds together elementary particles such as electrons and protons. The second is the proton-to-electron mass ratio of a material, which, as it sounds, is the ratio of mass from protons and mass from electrons within the atomic structure of the material.

It's not possible to test this theoretical top speed in the real world, because the maths predicts that sound moves at its top speed in the lowest mass atoms. The lowest mass atom is hydrogen, but hydrogen isn't solid, unless it's under super-high pressure that's a million times stronger than that of Earth's atmosphere. That might happen at the core of a gas giant like Jupiter, but it doesn't happen anywhere nearby where scientific testing is possible. Instead Trachenko and his colleagues turned to quantum mechanics and maths to calculate what would happen to sound zipping through a solid atom of hydrogen. They found that sound could travel close to the theoretical limit of 127,460 kilometres per hour, confirming their initial calculations. In contrast, the speed of sound in air is roughly 1,235 kilometres per hour.

The movement of sound in such extreme and specific environments may seem unimportant, but because sound waves are travelling vibrations of molecules, the speed of sound is related to many other properties of materials, such as the ability to resist stress. Understanding the fundamentals of sound could help illuminate other fundamental properties of materials in extreme circumstances.

For instance, previous research has suggested that solid atomic hydrogen could be a superconductor. Knowing its fundamental properties could be important for future superconductivity research. Sound could also reveal more about the hot mix of quarks and gluons that made up the universe an instant after the Big Bang, and could be applied to the strange physics around the gravity wells that are black holes. Other researchers have studied 'sonic black holes' to gather insight into these cosmic objects.

"We believe the findings of this study could have further scientific applications by helping us to find and understand limits of different properties, such as viscosity and thermal conductivity, relevant for high-temperature superconductivity, quark-gluon plasma and even black hole physics," Trachenko said.



Sound could travel over 120,000 kilometres per hour

© Getty

PLANET EARTH

Ice melt is changing Greenland's coastline shape

Words by **Stephanie Pappas**

Rapid melt is reshaping coastal Greenland, potentially altering the human and animal ecosystems along the country's coast. Greenland is losing 500 gigatonnes of ice each year, more than can be replenished by new snowfall. Annual ice loss is 14 per cent greater today than it was between 1985 and 1999. The meltwater is lubricating the ice sheet so that it slides more easily on its underlying bedrock, hastening the continued melt.

Researchers combined two types of data from satellite imagery: how fast the ice sheet is moving and where glaciers terminate on their path downhill. When a glacier retreats, its terminus doesn't reach as far downvalley as it once did. They found that glacier retreat is now the norm in Greenland. Around 89 per cent of glaciers had retreated substantially within the last decade. Virtually none had advanced.

However, this reshaping of glaciers translated into a variety of changes in glacier movement. Some glaciers were speeding up, flowing more rapidly towards the sea, while others were flowing more slowly. Over several years to a decade, a single glacier could do both, depending on the topography around it.

The Kjer and Hayes glaciers in northwestern Greenland sped up at their primary outlets to the sea from the 1990s to 2010, but other ice outlets to the ocean nearby slowed down. In one case the southerly portion of one of those outlets sped up, then slowed again. There is evidence of ice channels narrowing, of rerouting meltwater paths and even of the slowing of new ice so that glaciers are stranded in place, more like lakes than rivers.

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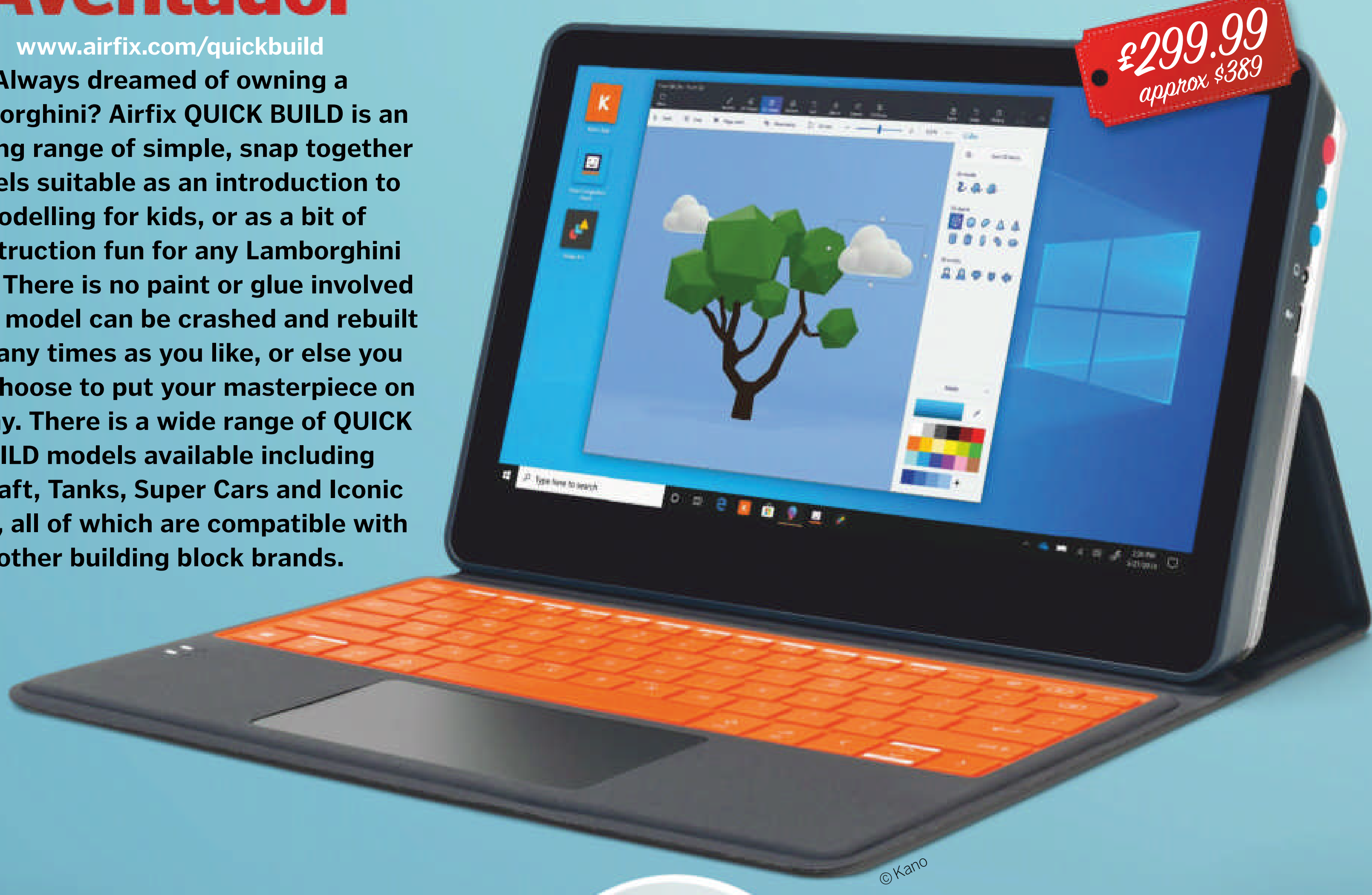

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Christmas READING LIST

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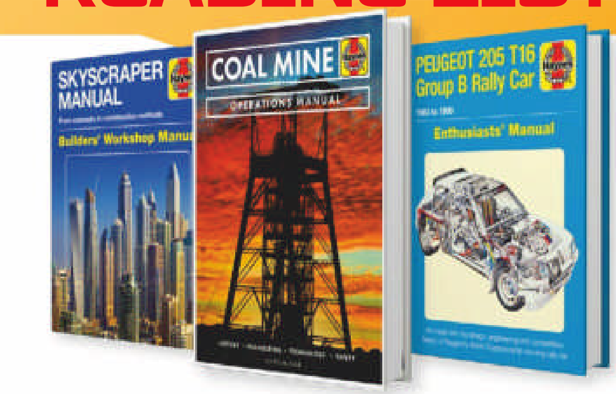

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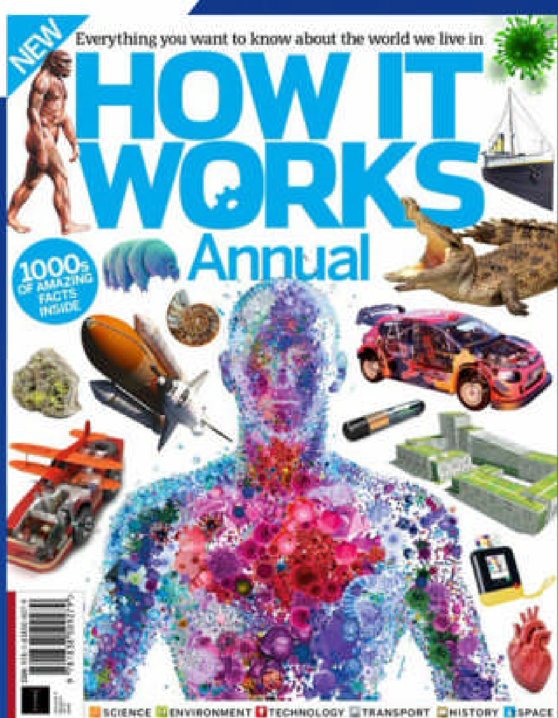

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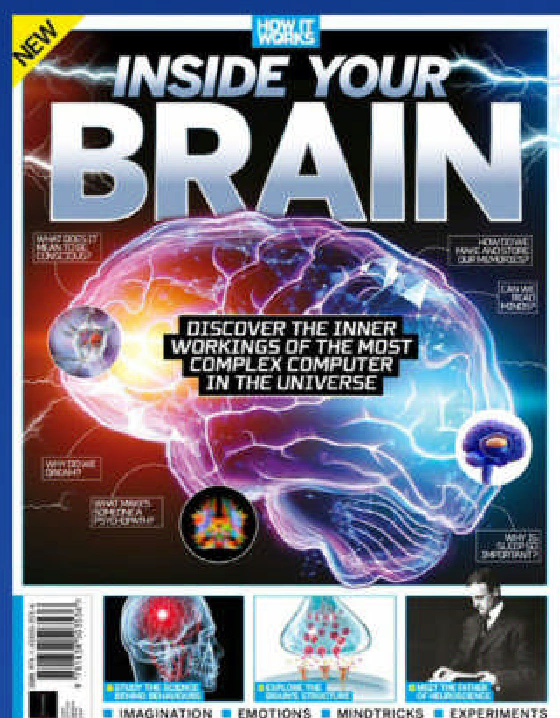

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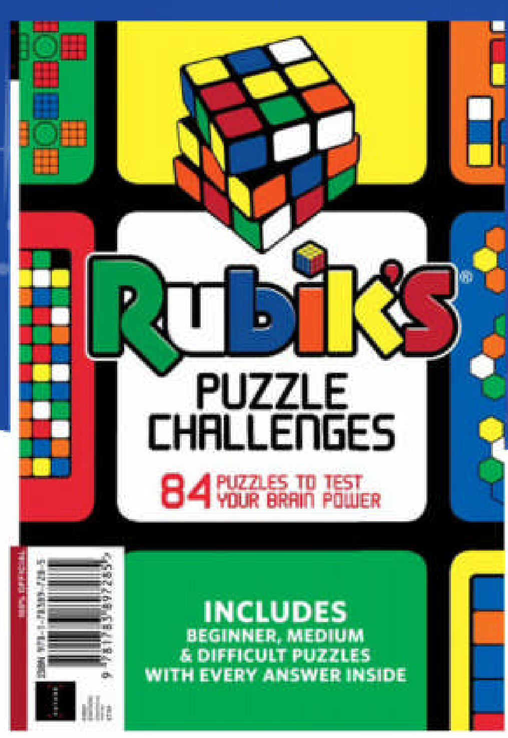

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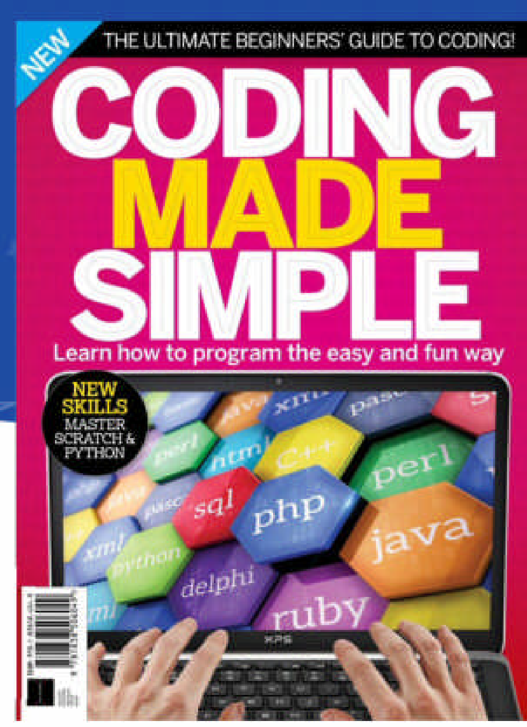

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BACK TO THE MOON

NASA'S BIGGEST MISSION IN OVER 50 YEARS WILL PUT BOOTS BACK ON THE MOON AND BRING US ONE STEP CLOSER TO MARS

Words by **Ailsa Harvey**

The Moon has captured the attention of humans for as long as we have gazed upon the stars. Reflecting the Sun's light into each dark night, its presence reminds us of the worlds beyond our own. But explorers in the form of astronauts have done much more than simply look upon it.

On 20 July 1969 the first humans landed on the Moon. As part of a series of missions dubbed the Apollo program, NASA astronauts returned to Earth with more knowledge of the rocky orb than our species had ever acquired before. But to think that a handful of missions to this world could make us experts of this foreign terrain would be a mistake. We have only explored a tiny portion of the Moon, and there is still so much more to learn.

It has been just under half a century since we last visited the Moon, and NASA has now revealed its plans to place the next astronauts on its surface by 2024. At least two more people will follow in the few dusty footsteps of the Apollo program's moonwalkers.

When the Apollo program was launched, we knew few details about the silvery sphere that graces our skies. Upon the astronauts' successful return to Earth with samples from the Moon, we were able to learn the majority of what we know today about our planet's natural satellite. We learned that the surface of the Moon has a dust covering and the structure contains a core, mantle and crust just like Earth's. For Apollo, putting humans on the Moon was the main and final goal. It provided us with a better understanding of what was previously an uncharted and unimaginable environment. Soon this territory is to be further explored, and humanity's achievements in space travel to be expanded upon.

"A prime goal is to send the first woman to the Moon"

Apollo's successor is Artemis – a program aptly named after the mythological Greek goddess of the Moon: Artemis is the twin sister of Apollo. While the Apollo missions were executed solely by men, a prime goal of Artemis is to send the first woman to the Moon. In keeping with the theme, the vehicle that will carry the next astronauts to the Moon is a capsule called Orion, the name of the goddess Artemis' hunting partner. Successfully placing a female astronaut on the farthest place we've been from Earth will be an important step for the global space industry.

Perhaps the most ambitious of the Artemis mission's objectives involves using the 2024 Moon landings as a stepping stone to a mission to Mars. This is a planet that scientists believe could have once been home to life – or may still be hosting it. Robots have done all the detective work on Mars so far, but NASA now aims to send astronauts there by the 2030s.

With a future exploration target set on the Red Planet, the return to the Moon will be used to provide us with the knowledge and tools to better navigate our Solar System. But how exactly can the Moon help prepare us for a mission to Mars, an entirely different and more

The US won the Space Race by landing on the Moon first

© Getty

THREE-PART PLAN

2021

Artemis I

The first mission will be uncrewed to test the safety of takeoff, the capsule's ability to travel around the Moon, descent and splashdown. The rocket will also carry 13 small satellites into deep space to perform experiments and technology demonstrations. For six days the spacecraft will orbit the Moon, collecting data about its performance.

2023

Artemis II

Carrying the first four Artemis astronauts, the Orion capsule will take the crew further than humans have ever travelled before in space. Over the approximate ten-day mission, the crew will complete a lunar flyby and return to Earth, evaluating the spacecraft's systems while carrying humans.

2024

Artemis III

This is the mission that will see the next man and first woman step onto the lunar surface. Providing previous missions have been successful, the astronauts will shoot towards the Moon, using the lunar lander to lower two people to the Moon's south polar region. They will remain on the Moon for around a week.

AR ZONE! SCAN HERE

unpredictable mission? Part of this logic is to maintain a gradual progression towards Mars, ensuring that astronauts are as experienced as they can be.

Humans have evolved to thrive on Earth, and they can't survive by themselves outside its atmosphere. In order to cheat nature and explore space, astronauts rely on science and technology, with NASA planning and preparing extensively. Much of what we know about how the human body reacts to low gravity, the hostility of outer space and how humans can survive in space comes from ongoing experiments on the International Space Station (ISS).

Living 400 kilometres above our planet's surface is unimaginable to most of us, but a two-day journey to the ISS from Earth is nothing compared to the months it would take to travel to Mars. The Moon is a stepping stone – in both time and distance – towards the Martian dream.

The Artemis plans are well underway, and the first three missions are likely to be the catalyst for many more. Although NASA's sharpest minds will have the trip meticulously calculated, exactly what the astronauts will find remains to be seen. As the mission draws closer, a recent discovery has added significance to this ambitious plan. A NASA aircraft, called the Stratospheric Observatory for Infrared Astronomy (SOFIA), discovered that the Moon has a higher abundance of water than previously anticipated and across a much greater area. The water was found on a sunlit surface of the Moon, meaning any available water isn't limited to the coldest, darkest regions, as previously suggested. There could be more of this life-supporting resource trapped within the lunar surface for Artemis explorers to utilise. If this vital resource can be spotted using distant telescopes, time will only tell what we will learn when the Moon is back beneath our feet.

EARTH TO MOON

Jump on board the Orion as we follow the route planned for the Artemis astronauts

The SLS rocket will be the first to launch the space capsule, astronauts and cargo to the Moon at one time

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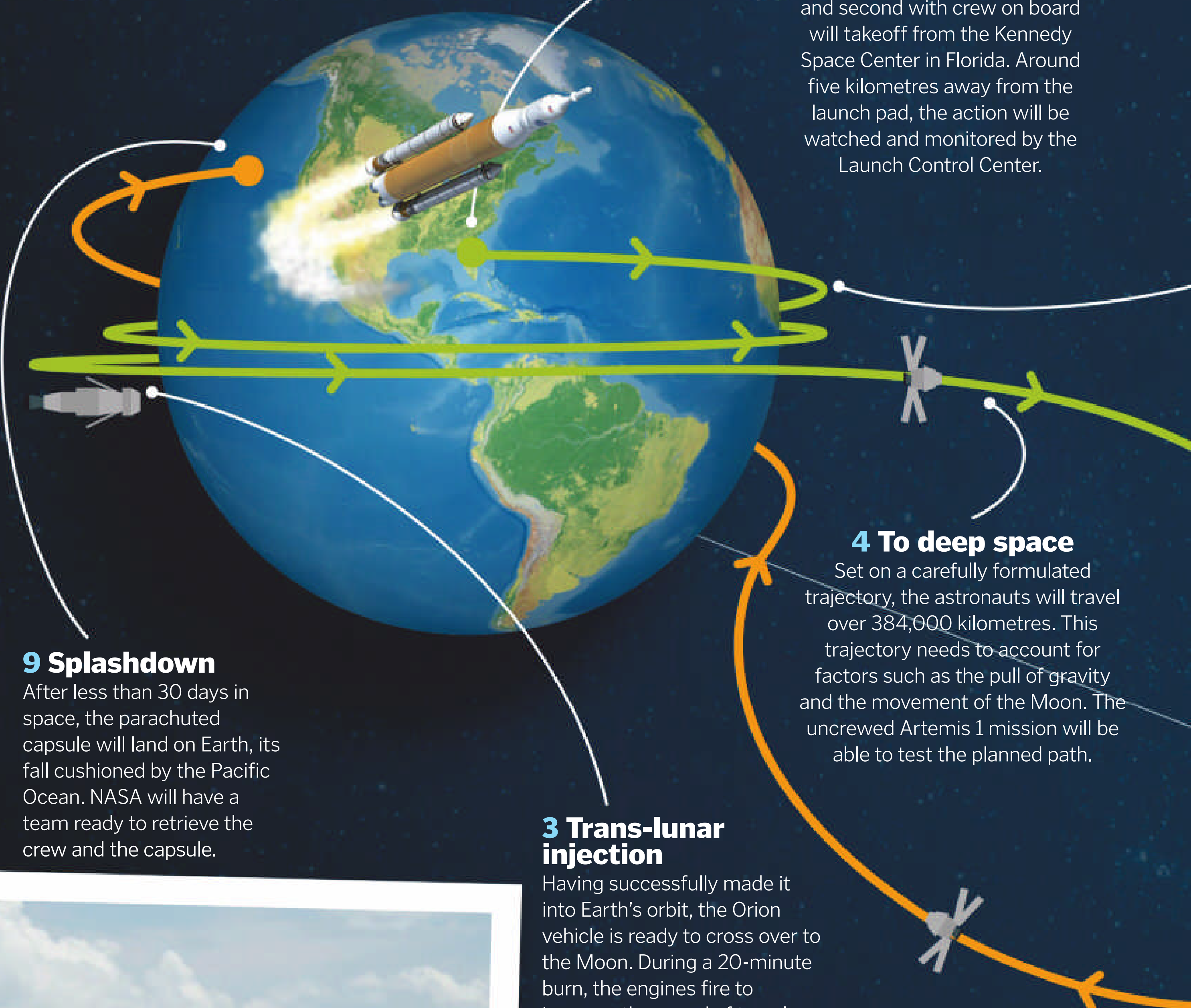
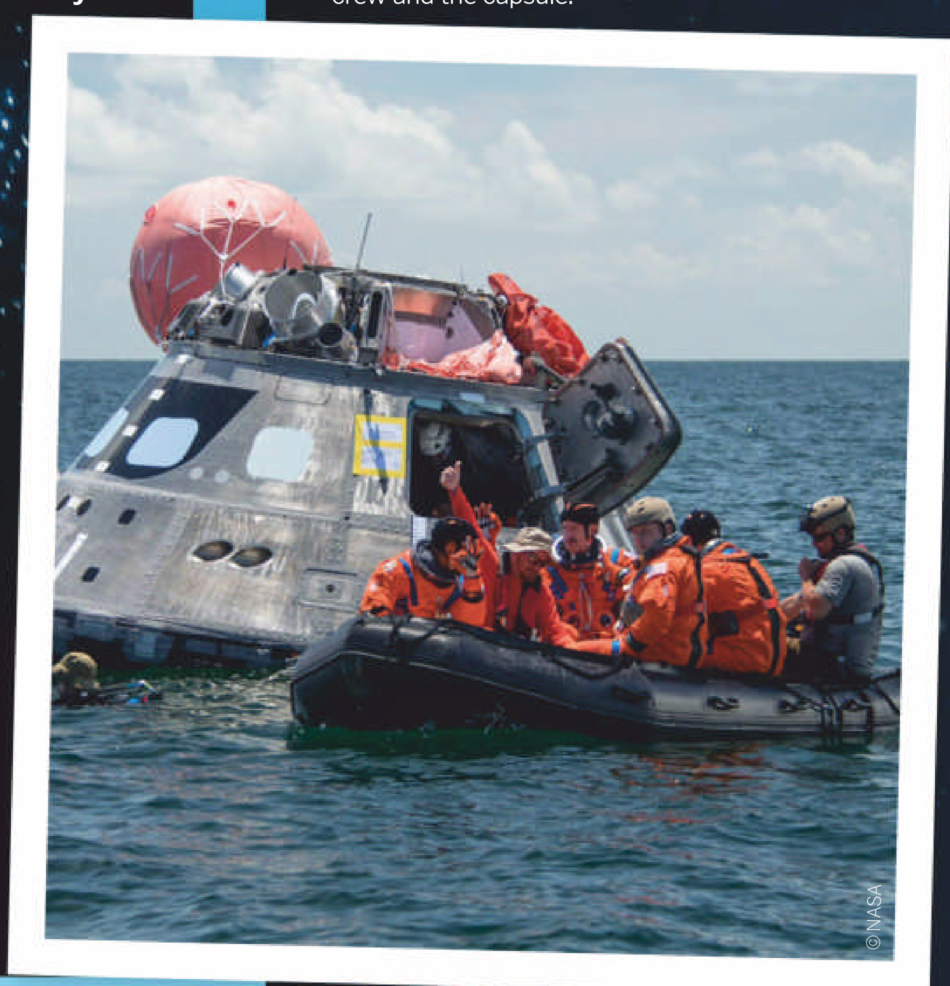


1 Launch day
Scheduled to launch in October 2024, the third Artemis mission and second with crew on board will takeoff from the Kennedy Space Center in Florida. Around five kilometres away from the launch pad, the action will be watched and monitored by the Launch Control Center.

4 To deep space
Set on a carefully formulated trajectory, the astronauts will travel over 384,000 kilometres. This trajectory needs to account for factors such as the pull of gravity and the movement of the Moon. The uncrewed Artemis 1 mission will be able to test the planned path.

9 Splashdown
After less than 30 days in space, the parachuted capsule will land on Earth, its fall cushioned by the Pacific Ocean. NASA will have a team ready to retrieve the crew and the capsule.

3 Trans-lunar injection
Having successfully made it into Earth's orbit, the Orion vehicle is ready to cross over to the Moon. During a 20-minute burn, the engines fire to increase the speed of travel, displacing the spacecraft from its low orbit.



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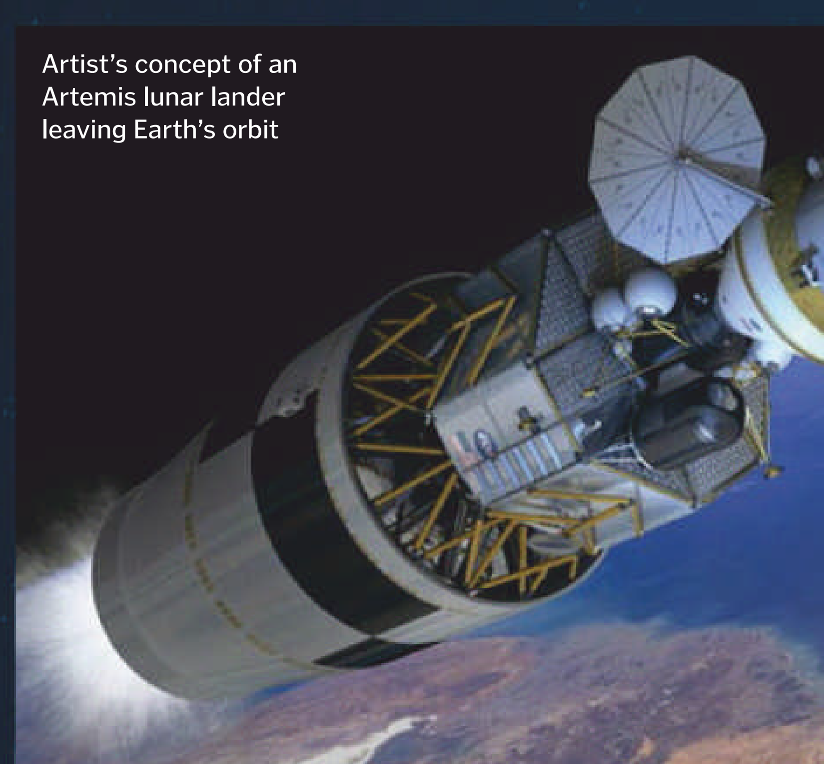
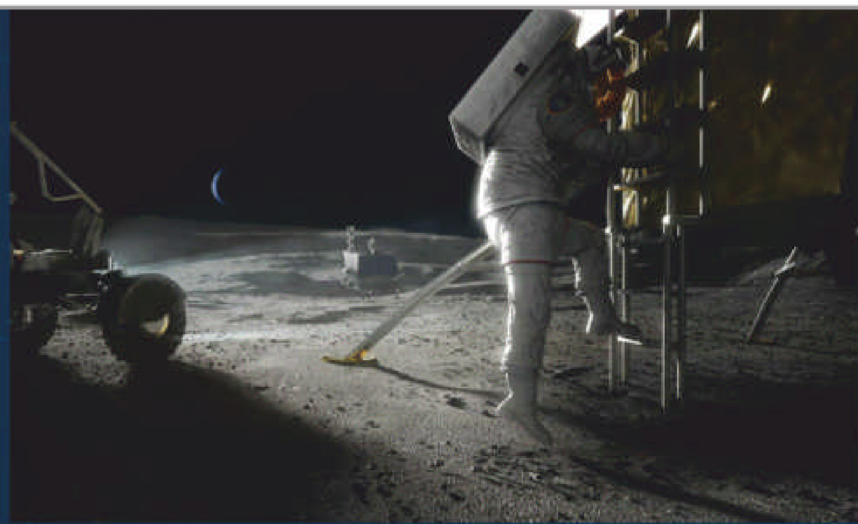
NASA tests exit procedures from an Orion spacecraft



Artist's concept of an Artemis lunar lander leaving Earth's orbit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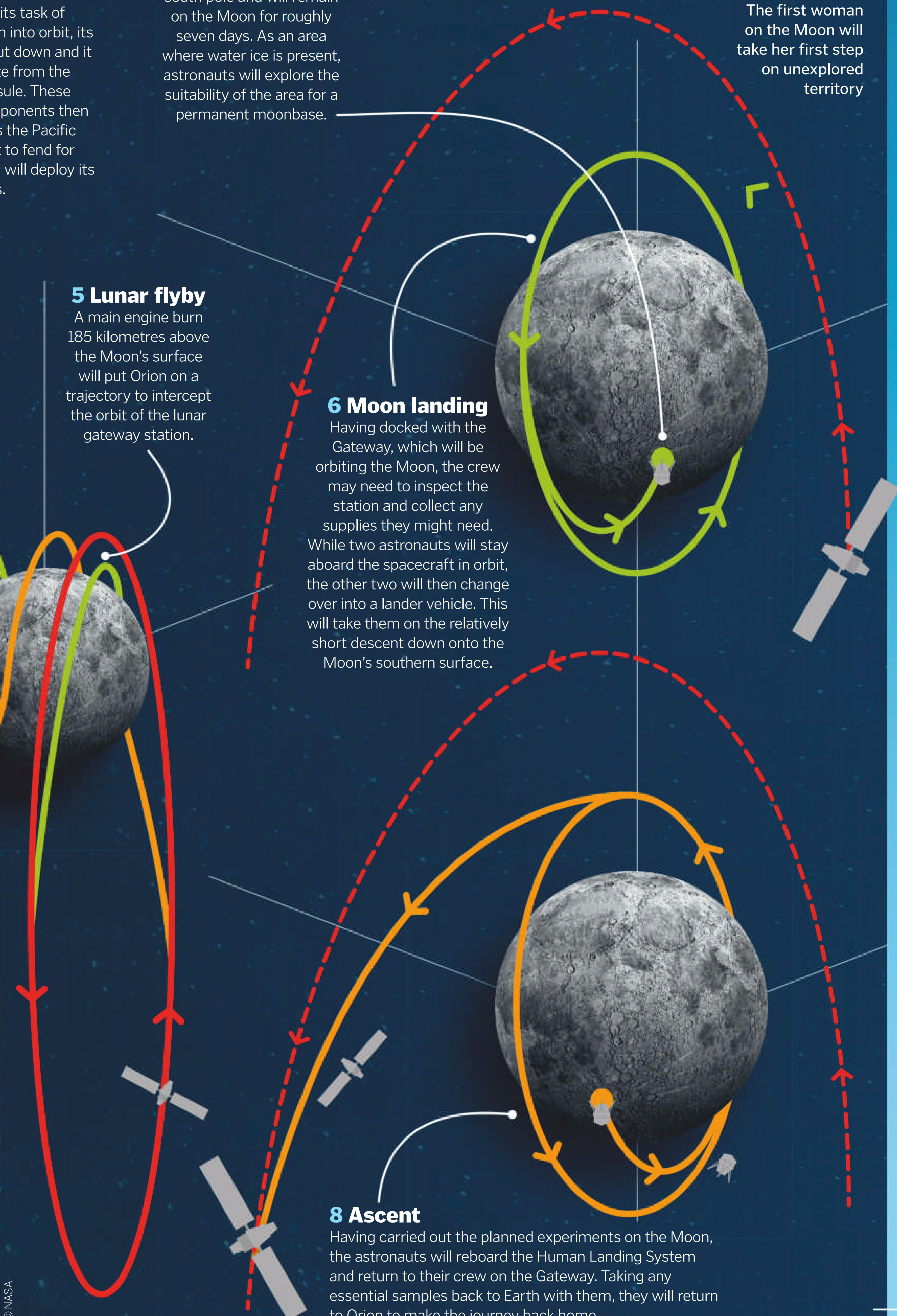
The first woman on the Moon will take her first step on unexplored territory



2 Entering orbit
Once the rocket has completed its task of taking Orion into orbit, its engines shut down and it will separate from the crew's capsule. These rocket components then fall towards the Pacific Ocean. Left to fend for itself, Orion will deploy its solar arrays.

5 Lunar flyby
A main engine burn 185 kilometres above the Moon's surface will put Orion on a trajectory to intercept the orbit of the lunar gateway station.

6 Moon landing
Having docked with the Gateway, which will be orbiting the Moon, the crew may need to inspect the station and collect any supplies they might need. While two astronauts will stay aboard the spacecraft in orbit, the other two will then change over into a lander vehicle. This will take them on the relatively short descent down onto the Moon's southern surface.

7 Spacewalk
Before exiting the lander, the astronauts will have changed into their extravehicular spacesuits. These will allow them to spend many hours patrolling the Moon, collecting samples and conducting experiments. They are likely to explore Shackleton crater at the south pole and will remain on the Moon for roughly seven days. As an area where water ice is present, astronauts will explore the suitability of the area for a permanent moonbase.

8 Ascent
Having carried out the planned experiments on the Moon, the astronauts will reboard the Human Landing System and return to their crew on the Gateway. Taking any essential samples back to Earth with them, they will return to Orion to make the journey back home.


© NASA

MAIN MISSION OBJECTIVES

Long-term presence
Following Apollo 17's three-day presence on the Moon, Artemis will send astronauts there for weeks at a time.

Equality
A female astronaut hasn't set foot on the Moon yet, and this mission will demonstrate the increasing role women have played in space missions since the Apollo era.

Partnerships
NASA has collaborated with private companies such as SpaceX and Boeing. These partnerships show space travel's shift towards commercialisation.

Technology
NASA is always learning from past missions; the spacecraft and astronauts' suits have been tailored to the Moon mission to exhibit the latest in space technology.

Knowledge
Collecting further information about the lunar surface and deep space, NASA hopes to become better prepared for later missions back to the Moon and further afield.

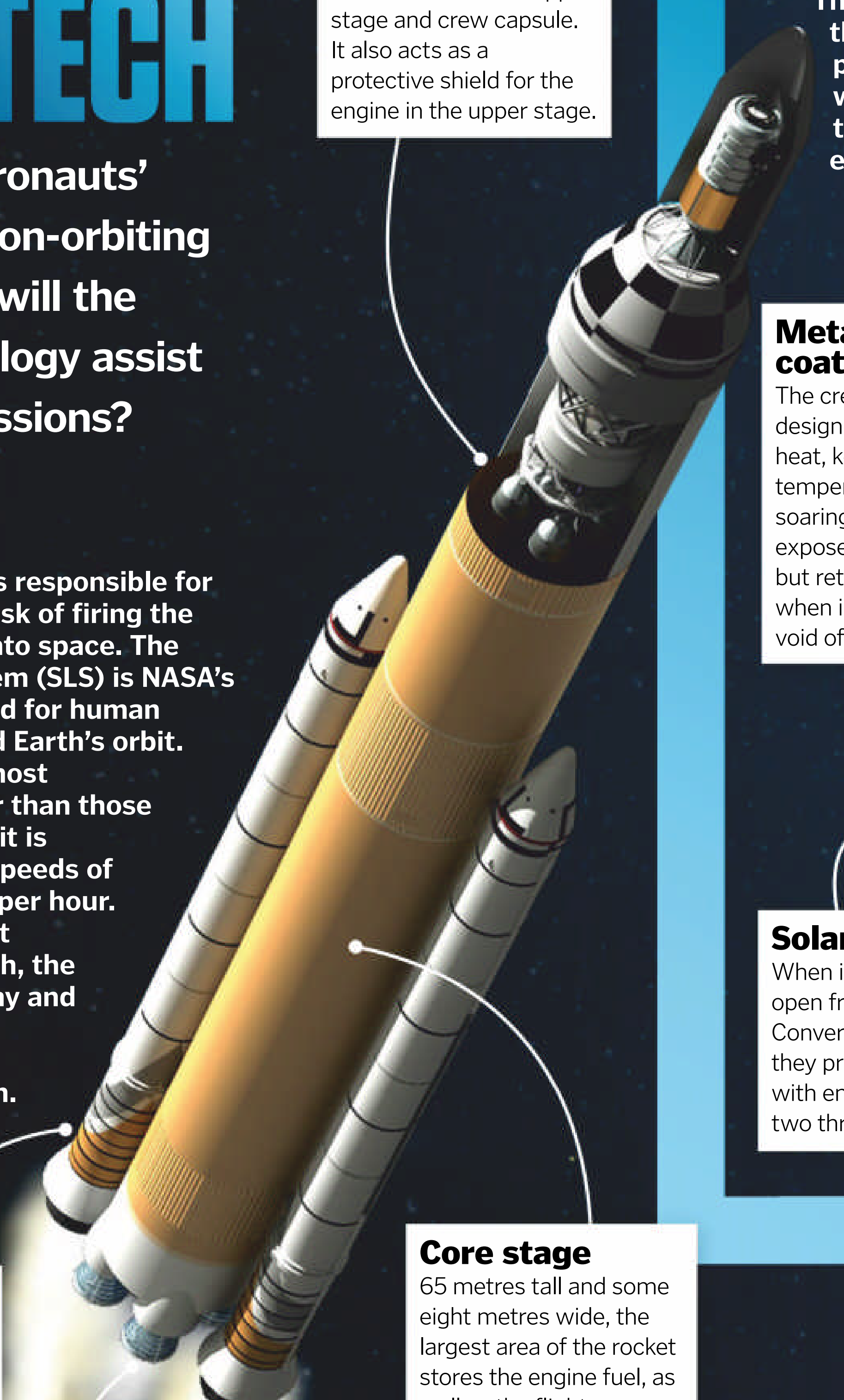
Resources
Access to the lunar surface provides the opportunity to search for rare mineral deposits and exploit resources. Depending on their abundance, any hydrogen and oxygen could be used as rocket fuel to travel from the Moon.

CHECK THE TECH

From the astronauts' suits to a Moon-orbiting station, how will the latest technology assist the Moon missions?

Launch

The launch rocket is responsible for the all-important task of firing the capsule and crew into space. The Space Launch System (SLS) is NASA's new rocket designed for human space travel beyond Earth's orbit. Having to travel almost 1,000-times farther than those headed for the ISS, it is designed to reach speeds of 40,000 kilometres per hour. Approximately eight minutes after launch, the core stage falls away and the astronauts can continue with their journey to the Moon.



Launch vehicle stage adapter

The nine-metre-tall cone-shaped structure connects the core stage of the rocket to the upper stage and crew capsule. It also acts as a protective shield for the engine in the upper stage.

Solid rocket booster

These provide 75 per cent of the rocket's thrust during launch. After the initial ascent, the boosters separate from the SLS and fall back to Earth.

Core stage

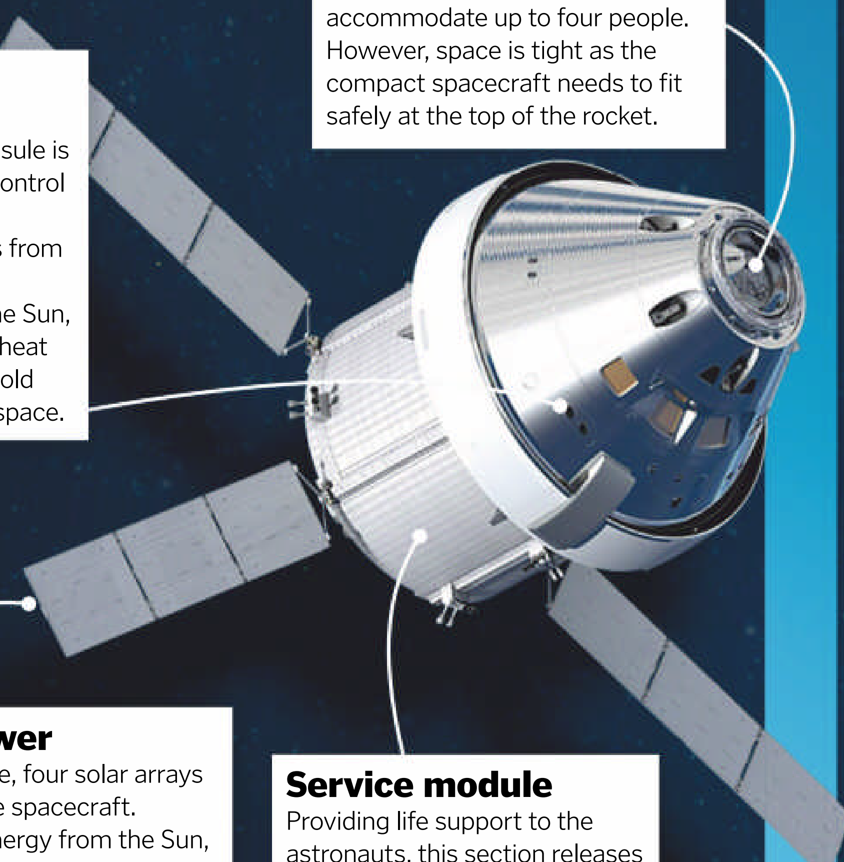
65 metres tall and some eight metres wide, the largest area of the rocket stores the engine fuel, as well as the flight computers needed to control the rocket.

RS-25 engines

Four liquid hydrogen and liquid oxygen-fuelled engines are evenly distributed in a square pattern to add stability, as they produce nearly 9 million newtons of force. It takes five seconds for the engines to reach 100 per cent power.

Travel technology

The Orion spacecraft that will deliver astronauts to the Moon is designed to have the lowest mass possible, while still being strong enough to withstand the conditions of space. This will enable the capsule to carry the astronauts and their equipment using minimal fuel.



Habitat

The capsule is designed to accommodate up to four people. However, space is tight as the compact spacecraft needs to fit safely at the top of the rocket.

Metallic coating

The crew capsule is designed to control heat, keeping temperatures from soaring when exposed to the Sun, but retaining heat when in the cold void of deep space.

Solar power

When in space, four solar arrays open from the spacecraft. Converting energy from the Sun, they provide the service module with enough energy to power two three-bedroom houses.

Service module

Providing life support to the astronauts, this section releases oxygen and water into the crew module. After separation from the rocket, this section holds the energy to transport the capsule through space.

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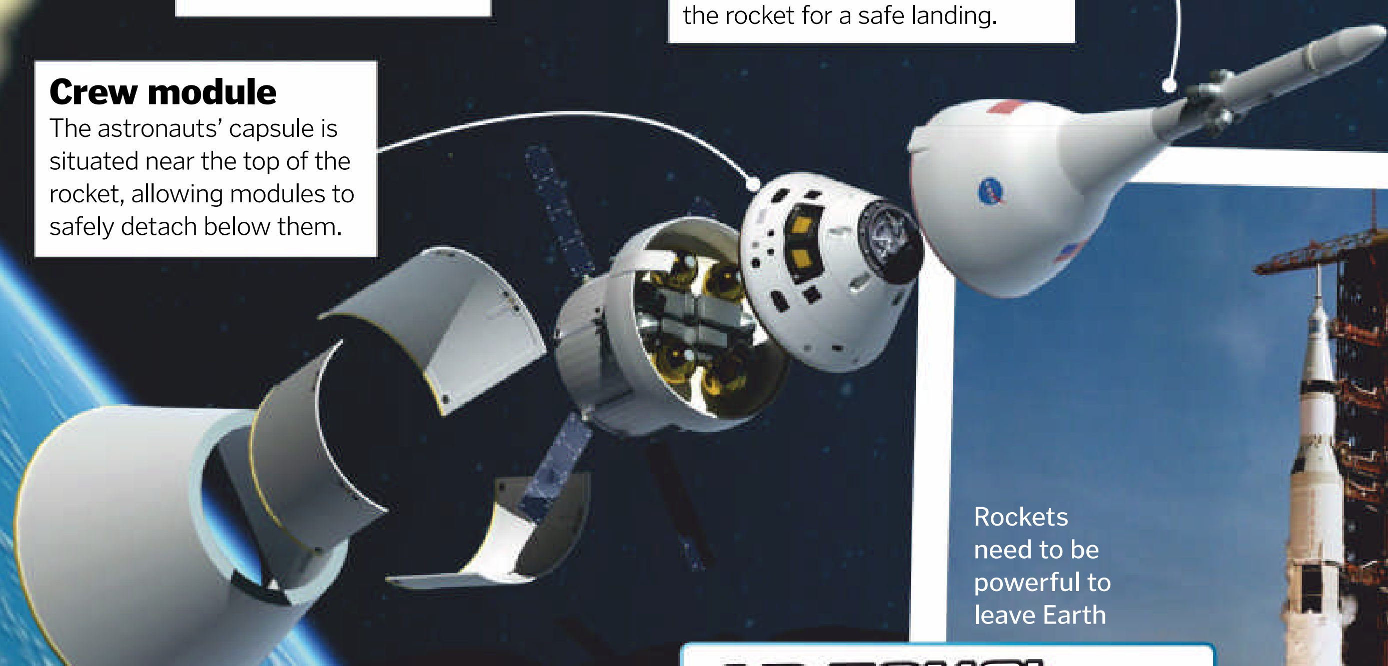

Launch abort system

Coming into play if a problem arises, the top of the rocket has a motor that will pull the Orion spacecraft away from the rest of the rocket for a safe landing.

Crew module

The astronauts' capsule is situated near the top of the rocket, allowing modules to safely detach below them.

Space Launch System (SLS)

What makes this NASA's most powerful propulsion system?


Rockets need to be powerful to leave Earth

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Gateway to the Moon

For exploration of another celestial body, astronauts need a station to call base camp. The Lunar Gateway will serve this purpose. Orbiting the Moon, Orion will be launched to synchronise with the path of this station. When the spacecraft reaches the Gateway it will dock, and the astronauts can leave Orion.

Serving a similar purpose to the ISS – but travelling in a completely different orbit – the Gateway is a place where astronauts can conduct science experiments and prepare for the main stage of their mission – the landing. Unlike the ISS, however, the Lunar Gateway will house astronauts for shorter periods, and won't be permanently occupied. Built with return trips to the Moon beyond the initial Artemis missions and long-term human presence in mind, this component will become vital for deep-space exploration.


The Human Landing System will allow vehicles to descend and ascend from the Moon

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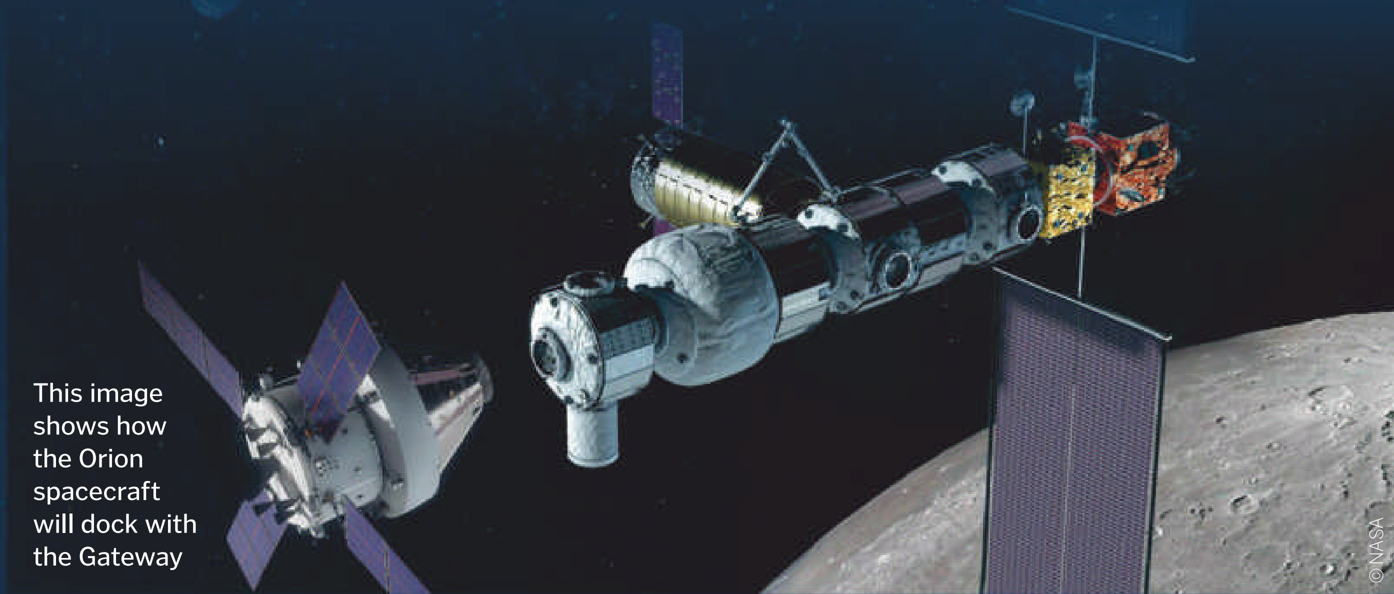

This image shows how the Orion spacecraft will dock with the Gateway

©NASA

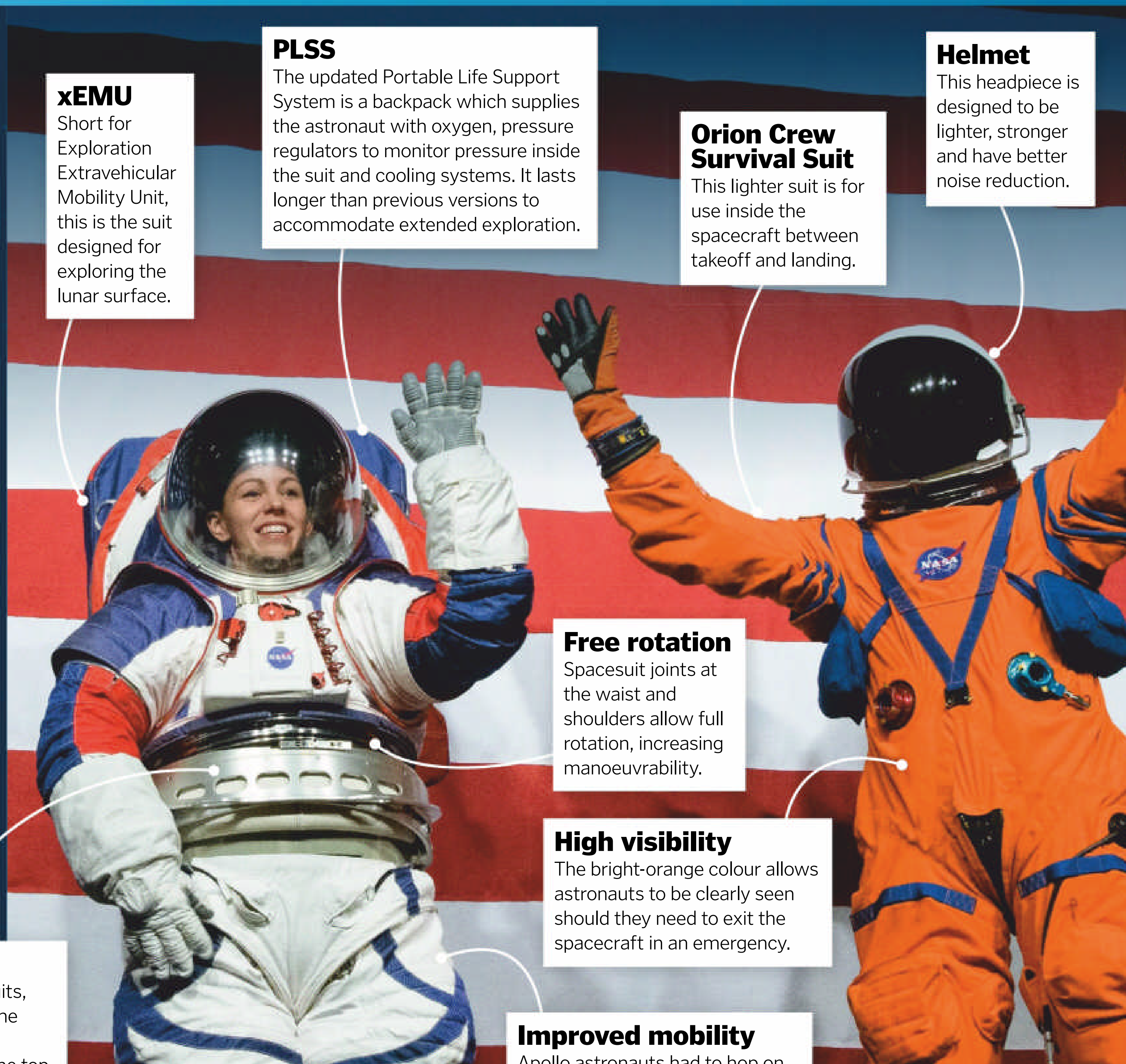
Moon landing

Transporting the astronauts to their lunar destination is the Human Landing System. This vehicle is designed with a pressurised crew cabin to dwell inside before stepping out onto the surface of the Moon. The companies working on the human lunar landers include Blue Origin, SpaceX and Dynetics. To safely make it onto the lunar surface, the vehicle will need to achieve a slow, soft landing.

Moonwalk

If we want to send astronauts to the Moon, they will need the latest technology to assist them. While astronauts have undergone multiple spacewalks since the Apollo missions, these have not required them to walk on the surface of a celestial body. The next astronaut to walk on the Moon will do so in a brand-new, updated spacesuit.

NASA has unveiled Artemis-generation spacesuits designed especially for the mission: one for the launch and landing, worn inside the spacecraft, and one to protect the bodies of those venturing outside the protection of the Orion capsule. The suits will be custom fit to their bodies with the aim of improving upon the comfort and practicality of previous versions of suits.



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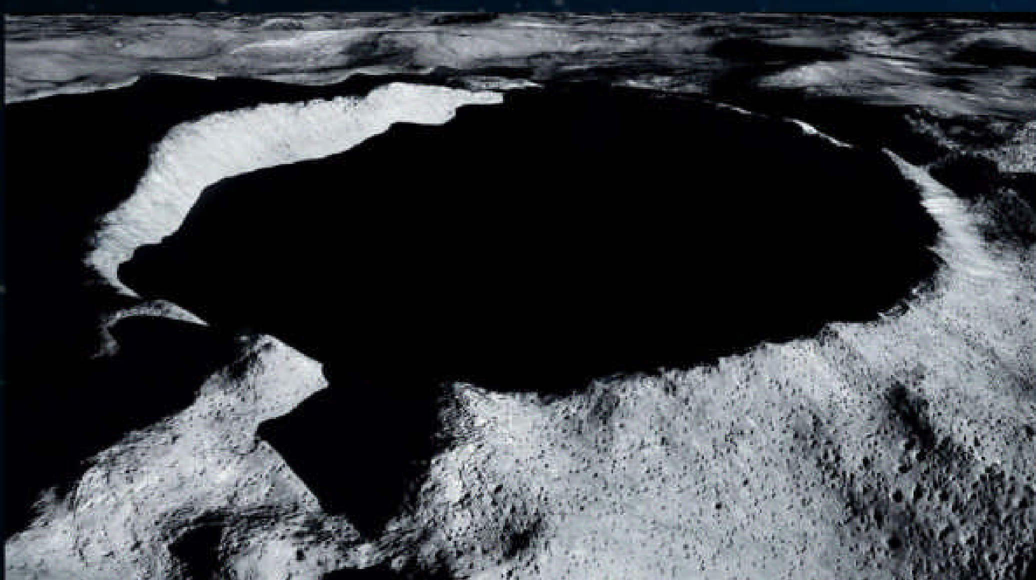
Where are we going?

For the initial Artemis Moon missions, the selected astronauts will likely fly to the Moon's south pole. This area has great potential as it is believed to be home to the highest abundance of water ice. If we can extract this water, it could be used to sustain human exploration farther into space, whether that's a human hydration source, rocket fuel resource or cooling system for equipment.

Shackleton crater is a huge 19-kilometre-wide depression in the Moon's surface and a feature well worth visiting. With a permanent shadow cast in the dips of the crater, the low temperatures make it a promising location for ice to form.

In fact, these permanently lightless areas maintain some of the coldest temperatures in the entire Solar System. Although it's possible that water can be found even on the Moon's lit surfaces, an area likely to have the highest abundance of water is the best spot to start looking for further natural resources.



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Shackleton crater is situated almost exactly on the Moon's south pole

First woman

Between 1969 and 1972, six missions took place in which 12 people stood on the surface of the Moon – all of them men. For such a high-risk mission, the most experienced astronauts were required, and at the time there were no women at NASA who had suitable test flight experience.

For a long time space was viewed as an industry primarily for men, and it wasn't until 1978 that NASA selected its first female astronauts. Today, 65 women have been to space, and this mission will serve as a reminder of changing times.

While it's currently undecided who will be chosen, it will be one of NASA's astronauts who has already worked aboard the International Space Station. The team of astronauts is expected to be announced at least two years prior to the mission launch.

The first class of astronauts to graduate under the Artemis program includes six women

© NASA

Steven Swanson (left) prepares for the Soyuz TMA-12M launch with Aleksandr Skvortsov (middle) and Oleg Artemyev (right)

Swanson has performed 27 hours and 58 minutes of extravehicular activity

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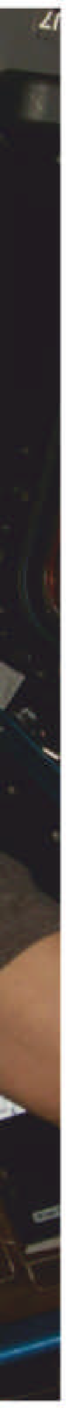


Q&A STEVEN SWANSON

The three-time NASA astronaut tells us about life in space and the significance of Artemis

During his career at NASA, Swanson logged over 195 days in space, undertaking five spacewalks. His three missions to the ISS include two Space Shuttle flights (STS-117 and STS-119) and one Soyuz flight (TMA-12M).

How does NASA select astronauts?
Nobody knows for sure. Really it's up to the chief of the astronaut office to make that selection, and sometimes others depending on how high profile the mission is. But it's partly just where you are in the queue, because we come in as a group together. The people who came in the group before will fly before you do. I didn't think about an astronaut career until I was about 25. It took 12 years from that point to become one, and I ended up working 11 of those years at NASA as an engineer.

What's it like to spend significant time away from Earth?
I spent about six months in space, and it's not tremendously difficult. Family and friends is the first thing you miss, but we could Skype and the communication with our families was good. You can get down periods, when you get a little tired of it – you haven't really gone outside and the food gets old after a while.

> *"Family and friends is the first thing you miss"*

How do you prepare for a spacewalk on Earth?
We have a big pool that we train in, with mock-ups of the outside of the International Space Station. Divers weigh us out to the point where we don't float up or down. We just stay floating right there in the water with all of the tools that we would have in space, and we learn how to move in this environment. You go through all the protocols over and over again, and it's a long training day. You do those six hours in the water uninterrupted and then a couple hours before and after for briefs and things. It's really worthwhile and helps tremendously for when you do the real spacewalk.

How much have the spacesuits improved for Artemis?
The biggest difference is in the shoulders. You get the ability to really reach around and have more movement, like you would without a suit on. They also have better mobility on the legs. On the International Space Station you didn't really use your legs much for anything, so it didn't matter how much mobility you had in your lower body. Now it's going to matter tremendously on the Moon, so they've modified the lower part to be more moveable.

What changes can the Artemis crew expect in their bodies?
The first thing we have to worry about is muscle and bone loss. Astronauts now work out two hours a day, so we do a pretty good job of mitigating that, but we still see some muscle loss. Bone loss is pretty much covered now. I only had one per cent bone loss from six months on board, and that was a good number. That comes back after about a year.

In our experiments while we were up there, we found that 30 to 40 per cent of the astronauts are getting major changes in their vision, and we haven't figured out exactly why. That's an ongoing process right now. There's just many things that change while you're up there. We've known for a while that the immune system gets degraded, so we're very careful about being quarantined before we go so nobody takes any germs or bugs with them on the way up. You don't want to get sick up there.

What's it like travelling in a space capsule?
Between the Soyuz and the Shuttle, the Soyuz was much smaller. The Orion is not as tight as the Soyuz, so they'll have a little more room, but it still won't be as roomy as the Shuttle. You don't have a lot of room to stretch out and move around in a capsule, but you're usually pretty busy during that time frame making sure all systems are working well. It's mainly a process of keeping the vehicle going to explore this destination correctly and keeping the vehicle safe.

How significant do you think the Artemis program is?
The real goal is Mars. And we will use the Moon as a test bed because Mars is a very difficult mission. It's going to take almost three years, and you can't come home early on a Mars mission. It's a seven- or eight-month journey to get there and you have to wait 15 months there for the planets to align correctly again before you return. It has to be very well thought out and the best way to do that is on the Moon.

As well as Mars, we can also use the Moon as a test bed for other things – to see how we can actually gather materials from the Moon itself and maybe use that to make our fuel.

Swanson was first selected as an NASA astronaut in 1998

© NASA/Bill Ingalls

Hypernovae

How a collapsing star is one of the most destructive forces in the universe

A hypernova, also known as a collapsar, is an extremely energetic supernova. The two are not to be confused, even if their formation is very similar. In a supernova, a star shears off its outer matter but leaves a new star at its centre, often a neutron star. In a hypernova, the force of the explosion tears the inner star apart too.

Hypernovae occur in stars with a mass greater than 30 times that of our Sun. Like in a supernova, as the star runs out of fuel it can no longer support itself under its own gravity. It collapses and subsequently explodes, sending out matter in all directions. This releases more energy in seconds than our Sun will in its entire 10-billion-year lifetime.

Hypernovae are incredibly rare. In fact, the rate of hypernovae occurring in the entire Milky Way is estimated to be one every million years, making the observation of these intense celestial explosions particularly difficult.

25 million light years from Earth, astronomers have found what appear to be the remnants of a giant hypernova, providing new information about these huge explosions, but currently there are several theories as to what actually causes them. One school of thought is that a massive star rotating at a very high speed or encased in a powerful magnetic field explodes, ripping apart the inner core. Alternatively, some believe a hypernova could be the result of two stars in a binary system colliding with each other, merging into one gigantic mass and subsequently exploding.

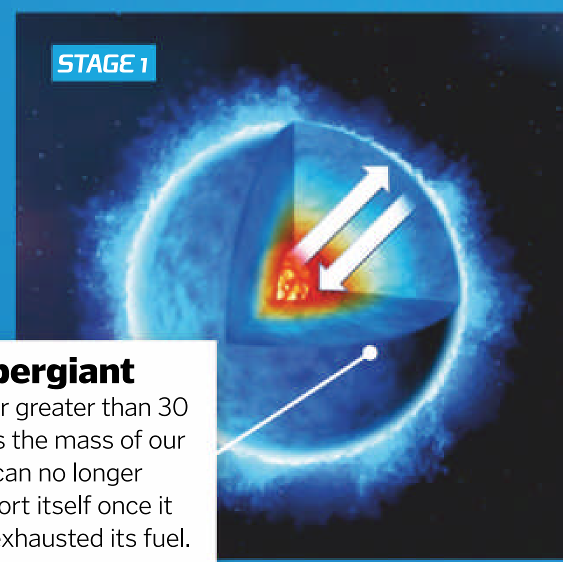
© NASA, GSFC, Dana Berry

The result is clear. A black hole is produced and a huge amount of energy is released in the form of a gamma-ray burst, one of the brightest known events in the universe. In fact, a hypernova releases several million times more light than all of the Milky Way's stars put together. In this image a massive star collapses to form a rotating black hole emitting twin energetic jets, surrounded by an accretion disc of debris. The star is subsequently torn apart by vigorous winds of newly formed isotope ^{56}Ni blowing off the accretion disc, and shock waves produced as the jets plough through the stellar material. The hypernova, whose luminosity is powered by the radioactive decay of ^{56}Ni, is the result of the explosion of the star.

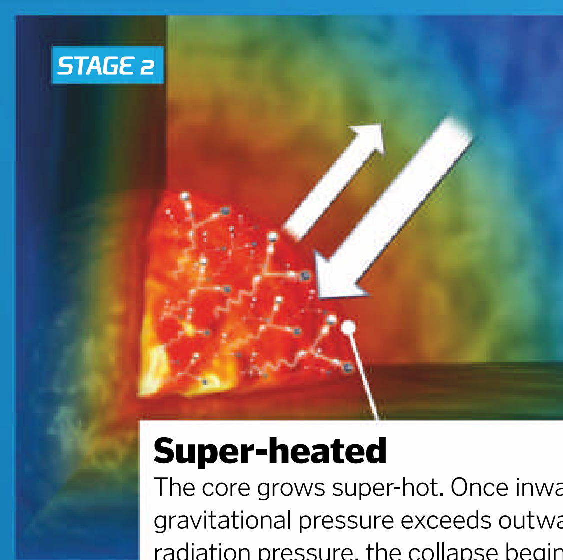
"A massive star rotating at a very high speed explodes, ripping apart the inner core"

Formation of a hypernova

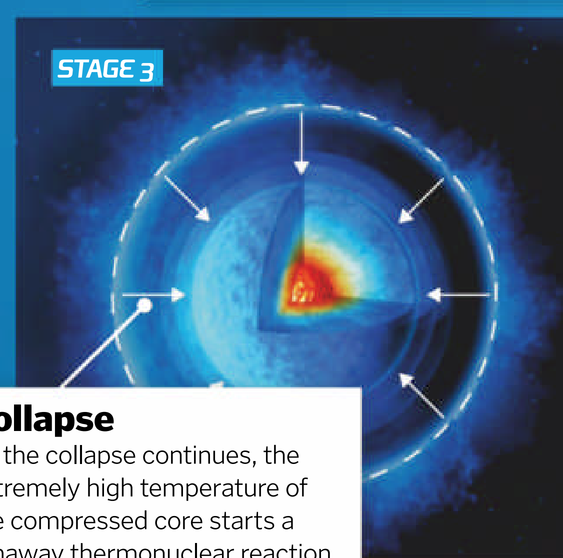
What's going on inside these huge explosions?



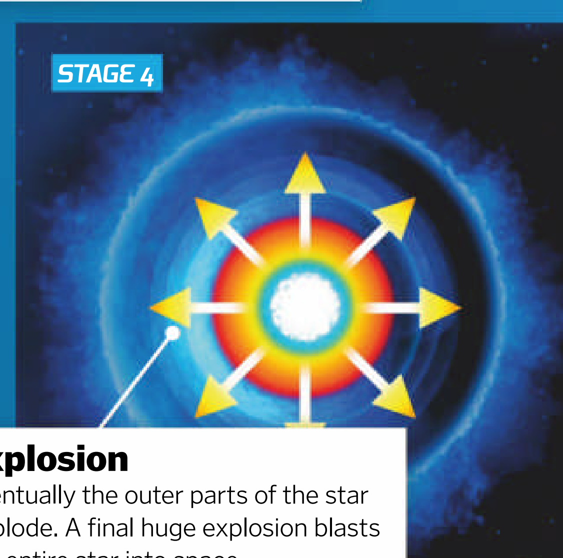
Hypergiant
A star greater than 30 times the mass of our Sun can no longer support itself once it has exhausted its fuel.



Super-heated
The core grows super-hot. Once inwards gravitational pressure exceeds outwards radiation pressure, the collapse begins.



Collapse
As the collapse continues, the extremely high temperature of the compressed core starts a runaway thermonuclear reaction.



Explosion
Eventually the outer parts of the star implode. A final huge explosion blasts the entire star into space.

4x © Science Photo Library

Asteroid collisions

What happens when one asteroid impacts another?

Throughout the Solar System there are potentially millions of asteroids – rocks left over from the formation of the Solar System some 4.6 billion years ago – just waiting to be discovered. Some will have been ejected from a planet following a collision, such as the Pluto-sized object believed to have crashed into Mars early in its formation. Others are the remnants of failed planetary formation, often unsuccessful due to the effects of a nearby body. One culprit, Jupiter, prevented the formation of another planet between itself and Mars, leaving the asteroid belt.

With millions of asteroids travelling through the Solar System – many of these confined to the Kuiper Belt beyond Neptune and the aforementioned asteroid belt – it is often thought that collisions between them are frequent. Indeed, many works of science fiction portray asteroid belts as dense areas of rock that are difficult for a spacecraft to traverse. However, this is anything but the case. Asteroid collisions are very, very rare. The chance of two colliding is roughly equivalent to winning the lottery seven times in a row. Only one direct collision between two asteroids has ever been observed, with thanks going to the Hubble Space Telescope in January 2010. It will most likely be many years before another is seen, but that doesn't make the study of these collisions any less important. On the contrary, by having an advanced knowledge of what to expect if we see two asteroids collide, or seeing the aftermath of a collision we may have missed, we'll be able to glean more information about their composition, origin and importance in the Solar System the next time we witness a collision.

> "Only one direct collision between two asteroids has ever been observed"

This image of P/2010 A2 (now 354P/LINEAR) was snapped by the Hubble Space Telescope in January 2010 – the first asteroid collision to be directly observed

© NASA, ESA and D. Jewitt (University of California, Los Angeles)

Types of collision

There are many more small asteroids in the Solar System than large ones, so it is extremely unlikely that two large asteroids of comparable size will ever hit one another. Instead the collision of a small asteroid with one that's more than 50,000-times bigger is much more common.

For every million asteroids that are 0.1 kilometres wide, there are only 1,000 wider than one kilometre and just one bigger than ten kilometres. For this reason, cratering is much more common than fracturing, which again happens more regularly than shattering. But what are the effects of each impact?

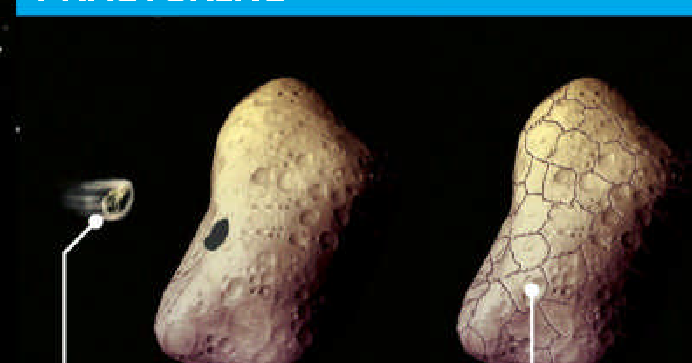
CRATERING

1 Approach
Cratering occurs when the incoming asteroid is less than 1/50,000th the size of the larger body.

2 Impact
A crater ten times the size of the impactor forms on the surface.

3 Debris
Ejected debris falls into the same orbit around the Sun as the asteroid, and thus can hit it again.

FRACTURING



1 Approach
If the incoming asteroid is exactly 1/50,000th the size of the larger asteroid, it will cause a fracturing collision.

2 Impact
Most of the energy in the collision is used up in breaking the larger asteroid into pieces, forming cracks across the surface.

Asteroids vs comets

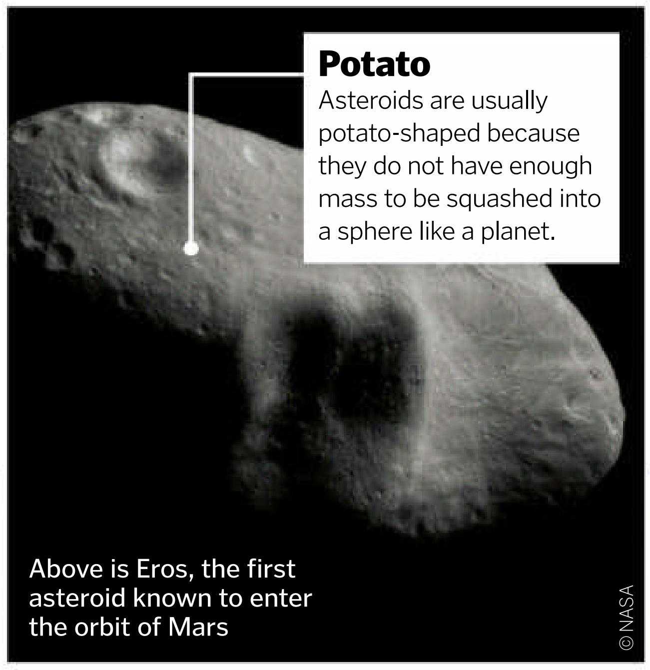
What's the difference between asteroids and comets?

Asteroids and comets are both remnants of the early formation of the Solar System about 4.6 billion years ago. As of July 2019 there were more than 6,600 known comets in the Solar System, compared to around 1 million known asteroids – and there are thought to be many millions more.

Asteroids are composed of rocky material and metals, while comets are made of ice. It's accepted that asteroids formed closer to the Sun than comets, because ice could not remain solid at that distance. Comets that formed farther out and later approached the Sun lose more material with each orbit because the ice melts, forming a tail behind the body. Asteroids do not lose material, so they do not have a tail.

Comets are often found in large, elongated orbits extending outwards up to 50,000 times the distance from Earth to the Sun. By comparison, Neptune – the farthest planet from the Sun in the Solar System – is 30-times farther from the Sun than Earth. Asteroids are usually found following a circular orbit around the Sun, grouping together in belts, like the asteroid belt between Mars and Jupiter, formed when the gravitational pull of Jupiter prevented the asteroids from coalescing into another planet.

© NASA

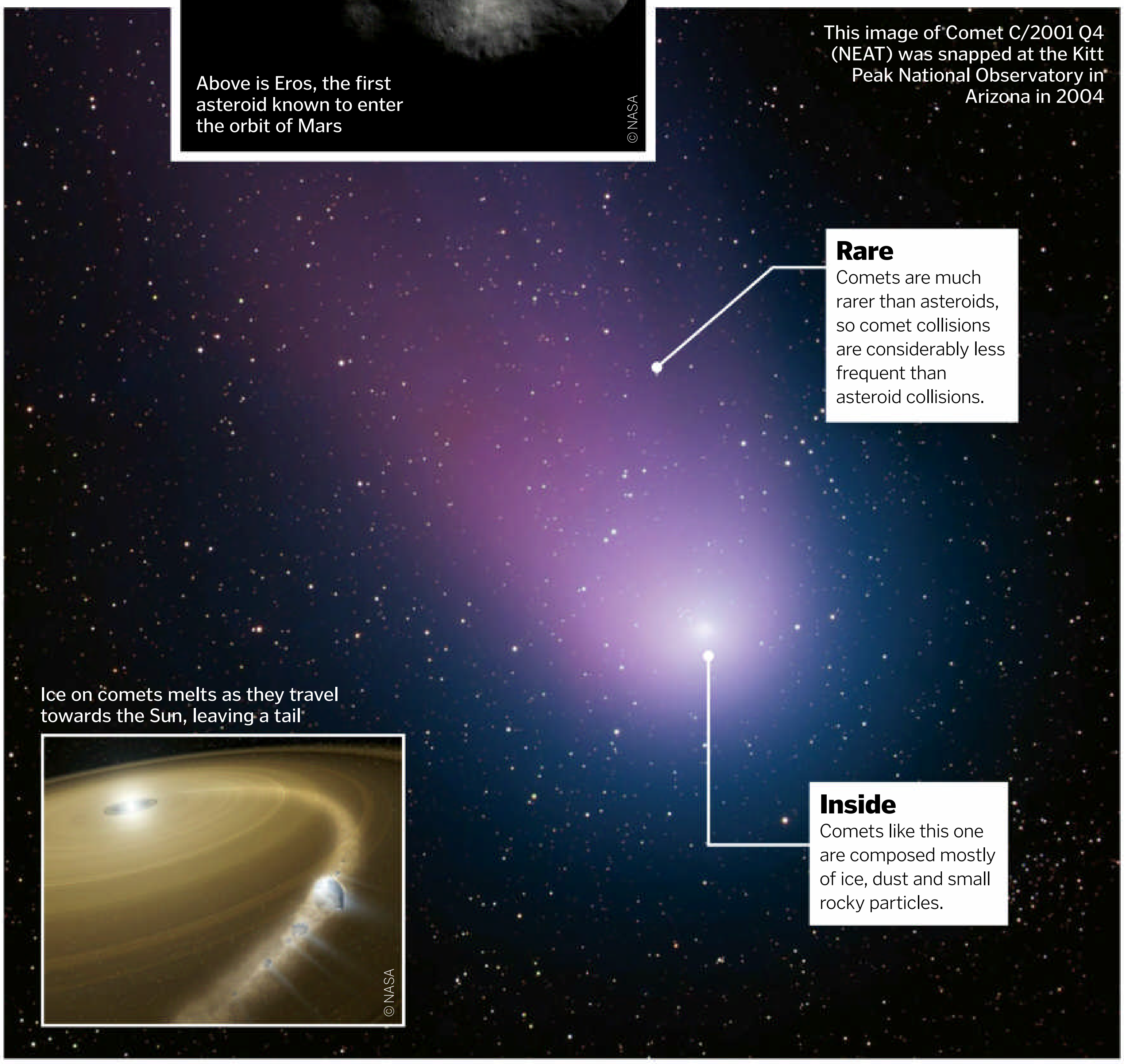


Potato
Asteroids are usually potato-shaped because they do not have enough mass to be squashed into a sphere like a planet.

Above is Eros, the first asteroid known to enter the orbit of Mars

© NASA

"Asteroids are composed of rocky material and metals, whereas comets are made of ice"



This image of Comet C/2001 Q4 (NEAT) was snapped at the Kitt Peak National Observatory in Arizona in 2004

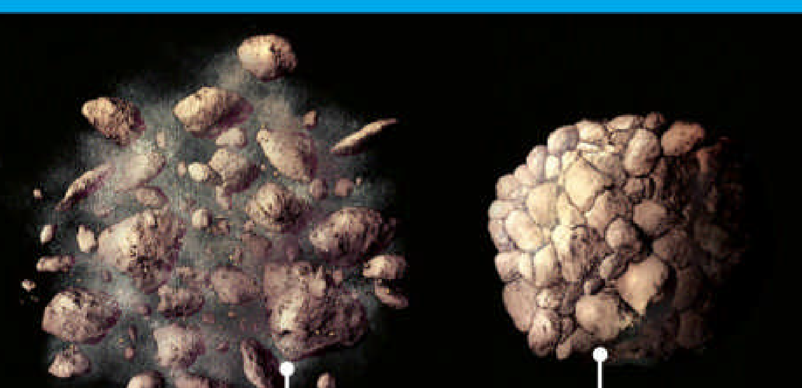
Rare
Comets are much rarer than asteroids, so comet collisions are considerably less frequent than asteroid collisions.

Inside
Comets like this one are composed mostly of ice, dust and small rocky particles.

Ice on comets melts as they travel towards the Sun, leaving a tail

© NASA

© T. Rector (University of Alaska Anchorage), Z. Levay and L. Frattare (Space Telescope Science Institute) and National Optical Astronomy Observatory/Association of Universities for Research in Astronomy/National Science Foundation



3 Debris
The resultant fragments don't have enough energy to escape the gravitational field of the others, so they reform into a ball of rubble.

4 Whole
To an observer it is not obvious that the asteroid is in pieces, instead appearing to be an intact asteroid.

SHATTERING

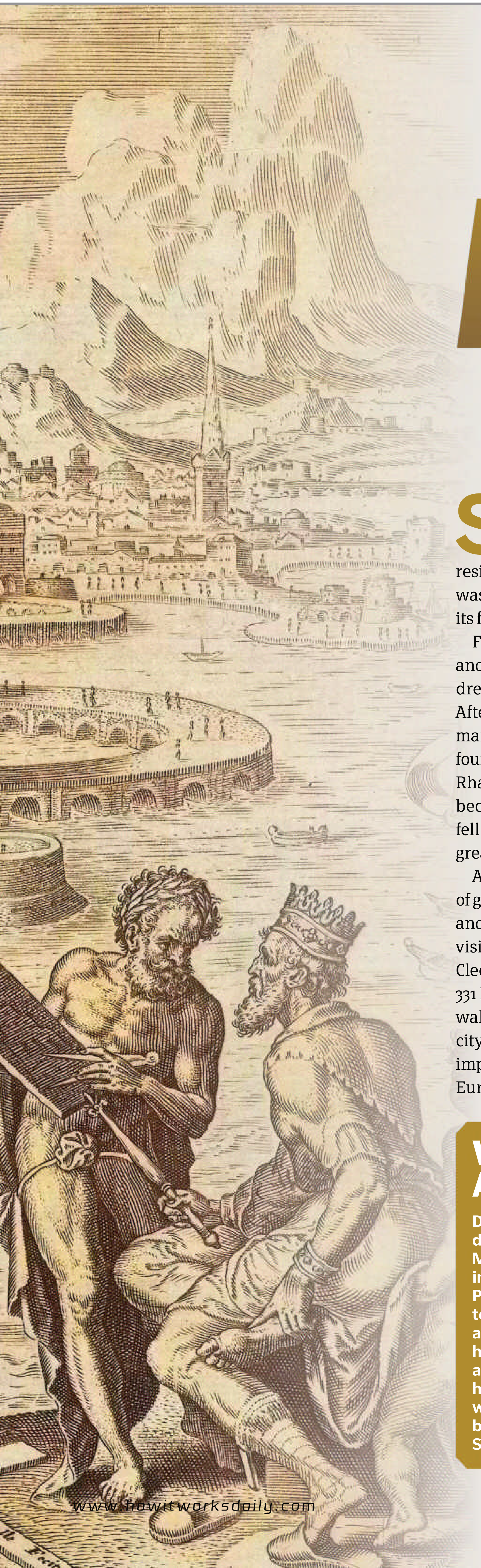
1 Approach
The larger asteroid will be shattered into pieces if the incoming asteroid is more than 1/50,000th its size.

2 Impact
Like fracturing, the asteroid is broken up into pieces, but there is enough energy for the fragments to escape its gravitational pull.

3 Debris
The resultant debris will form a group of smaller asteroids around the same orbit as the original asteroid.

© DK Images


Pharos
Martinus Heemskerck Inuentor
Philipus



Inside the lost city of ALEXANDRIA

As one of the crowning glories of the empire of Rome, what remains of this ancient Egyptian city?

Words by **Scott Dutfield**

Standing on the southern coast of the Mediterranean, Alexandria is a port metropolis filled with over 5 million residents. Thousands of years ago Alexandria was a very different place, though the echoes of its former glory have now fallen into the ocean.

Founded by Alexander the Great, king of the ancient Greek kingdom of Macedon, it was his dream to build a city linking Greece and Egypt. After conquering Syria in 332 BCE, Alexander marched to Egypt with his army in tow and found himself at a small port town called Rhacotis. Seeing the potential for his dream to become a reality, this once-small fishing town fell to the wayside for the creation of one of the greatest cities in ancient history: Alexandria.

Alexander would only see the first few months of growth of the city before marching to another ancient port city called Tyre. Entrusting his vision to the capable hands of his viceroy Cleomenes, Alexandria was built from around 331 BCE. Alexander died in 323 BCE, and in his wake general Ptolemy took control of the new city. Under Ptolemy's rule the port city became important for trade routes between Asia and Europe and the base for the new Ptolemaic kingdom, transforming it into the most powerful city of the time. The city was filled with ancient Greek scholars and scientists and quickly became a hub of knowledge thanks to the construction of its famed library. That was until Roman legions gained control of Egypt in 30 BCE. Octavian, who later became the Roman emperor known as Augustus, claimed the city and Egypt itself for Roman rule.

However, it wasn't just the Romans that brought Alexandria to its knees. What's left of ancient Alexandria now lies at the bottom of the city's harbour. Evidence suggests that during the late eighth century CE an epic earthquake rippled through the city. The land subsided and walls of water created by the earthquake may have cast it

Alexander the Great never lost a battle during 15 years of conquest

What made Alexander so great?

Drenched in blood, the story of Alexander the Great is a tale of death and destruction in the name of growing an empire. Alexander was born in Pella, Macedonia, in 356 BCE to King Philip II of Macedon. After his father's death in 336 BCE, Alexander inherited his royal duties and set out to conquer the Persian Empire. Along the way, through countless battles, he conquered territories in Asia Minor, Syria, Iraq and Egypt, adding Leader of the Greeks and Pharaoh of Egypt to his many titles – all by the age of 25. Throughout his life, Alexander founded more than 70 cities and expanded his empire across three continents. As a military mastermind and a fearless conqueror, he was seen as one of the powerful and influential leaders in the ancient world. Despite staring death in the face countless times on the battlefield, it's believed that he died of natural causes, possibly malaria, in 323 BCE aged 32. Some scholars suspect foul play, and that he may have been poisoned.

into the ocean. This single event may not have been solely responsible for creating Alexandria's watery grave, as several earthquakes and tsunamis wreaked havoc on the city in the years that followed, ultimately raising the sea levels around the Egyptian coastline.

REDISCOVERING ALEXANDRIA

Around 2,000 years after Alexandria was destroyed and dismantled by the Romans, its remains were uncovered after a French archaeologist, Jean-Yves Empereur took a dip in the Mediterranean ocean. During the mid-1990s, Empereur was exploring modern-day Alexandria's harbour after joining an Egyptian documentary film crew. In 1961 a massive, ancient statue had been dredged up from the waters by the Egyptian Navy, sparking the idea there might be remnants of the ancient city below the waves. Suited up in diving gear, Empereur and his team plunged into the harbour waters, discovering columns, sphinxes and obelisks lurking beneath.

Over the years Empereur and his team photographed and mapped more than 3,300 pieces below the water, revealing Alexandria's lost relics. Empereur was not the only one searching for remnants of Alexandria, however. Around the same time, underwater archaeologist Franck Goddio was trawling the seafloor on the other side of the harbour, discovering another collection of columns, statues and even the watery remains of the Ptolemys' royal quarter. Although the two were thought to be archaeological rivals, their combined work opened the world's eyes to Alexandria's past and returned it to the present.

© Getty

Ptolemy, also known as Ptolemy I Soter, sparked a dynasty of rulers that lasted for 275 years, the last dynasty of ancient Egypt

The Lighthouse of Alexandria was completed sometime between 300 and 280 BCE

© Alamy

© Getty

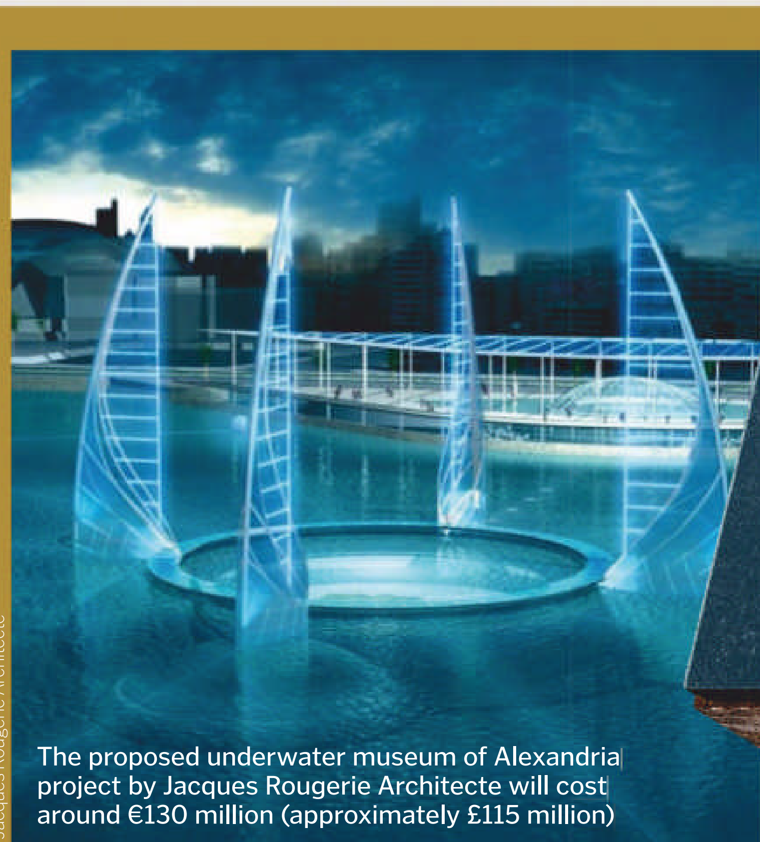
French divers haul a granite sphinx from Cleopatra's sunken royal quarter

The Great Library

This ancient library is thought to have held around half a million documents at its peak. It's possible that the library was an extension of the Temple of the Muses, which we would today refer to as a museum, housing more than 100 scholars translating and publishing manuscripts from Greek authors and conducting scientific research. Commonly believed to have been engulfed by flames, the mysterious fate of this ancient library is yet to be agreed upon.

Observing the past

Thousands of pieces of ancient Alexandria have been discovered sunken in the sand of its famous harbour, with many rescued from their ocean prison and displayed on land. However, there is still much more to see beneath the waves. Projects such as the underwater museum of Alexandria, launched by the Egyptian government and UNESCO, have sought to allow people to discover sunken treasure such as Cleopatra's palace. Located where the new Library of Alexandria sits, the project called for 37,000 square metres for onshore exhibitions and aquatic scenic areas. It's been in the works since 1996, but has faced many hurdles. In 2008 French architect Jacques Rougerie sought to make the project a reality, devising a network of fibreglass underwater tunnels for visitors to observe the lost palace and Pharos Lighthouse, which sits six metres below the surface. However, over the years plans for the project have continually been put on hold. Today the underwater museum remains unrealised.



© Jacques Rougerie Architecte

The proposed underwater museum of Alexandria project by Jacques Rougerie Architecte will cost around €130 million (approximately £115 million)

ALEXANDRIA REVISITED

Explore the monuments that made Alexandria the greatest city on Earth

Temple of Serapis
As Alexandria's most important pagan sanctuary, the Serapeum of Alexandria held the Temple of Serapis. People gathered at the Serapeum to worship the Graeco-Egyptian deity Serapis, who was associated with the Sun, fertility, and healing.

Heptastadion
This was a human-made causeway, around 1.2 kilometres long, connecting the Island of Pharos to mainland Alexandria.

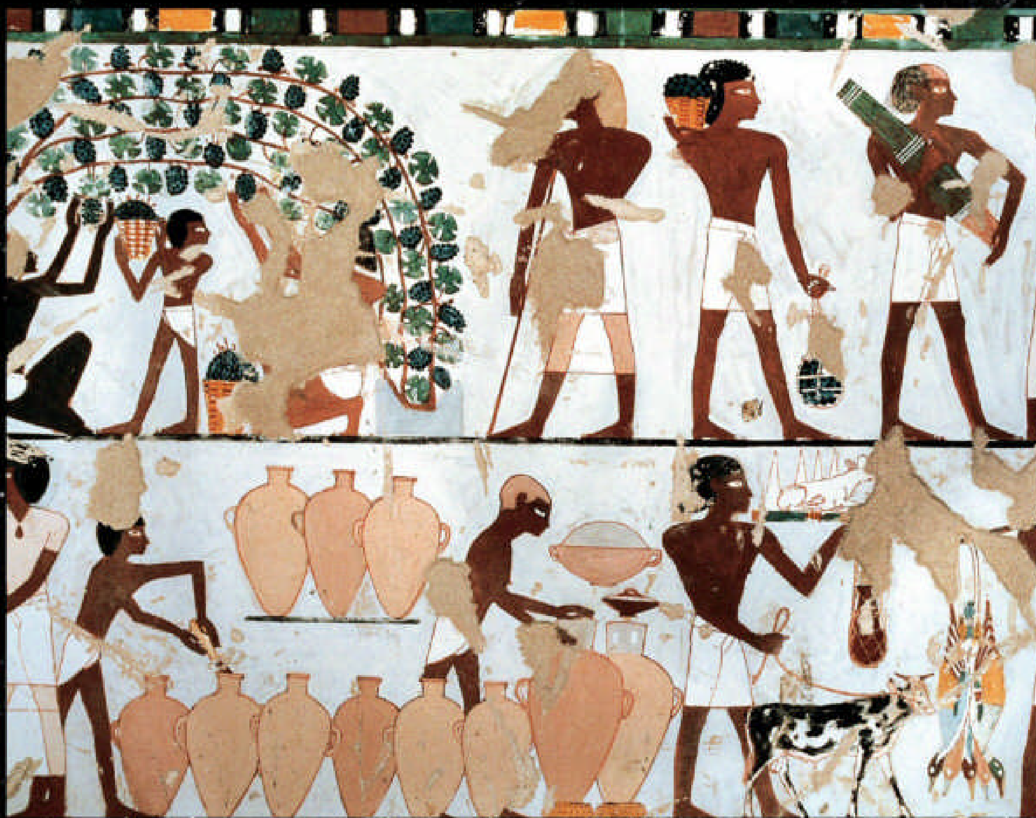
"Alexandria now lies at the bottom of the city's harbour"

Lighthouse of Alexandria
Also known as the Pharos of Alexandria, this lighthouse once stood over 100 metres tall overlooking the harbour's waters and the busy city below. The lighthouse stood for 1,600 years on a small patch of land called the Island of Pharos. The ancient iconic structure was created by the Greek architect and engineer Sostratus of Cnidus and is now deemed one of the Seven Wonders of the Ancient World.

Cleopatra's palace
The remains of a once-great palace belonging to Cleopatra lay deep off the coast of the Island of Pharos. Cleopatra ruled Egypt from this palace as the last emperor of the Ptolemaic dynasty between 51 and 30 BCE, before committing suicide on the eve of Octavian's conquest of Alexandria.

AR ZONE! SCAN HERE

© Illustration by Nicholas Forder



© Getty

The remains of an ancient wine press made between 516 BCE and 70 CE in Israel

© Getty

Mural depicting a scene of grape picking and wine production found in the tomb of Prince Khaemwaset of Egypt

Wine throughout time

Discover how the production of this tipple has changed over thousands of years

Words by **Scott Dutfield**

It's one of the world's most consumed alcoholic beverages, with 1.6 billion bottles drunk each year in the UK. But how long has wine been guzzled, and how is it made?

Wine is made from fermented grape juice, with an array of different fruits and spices added to diversify flavour. It undergoes several stages of production before reaching your table, such as crushing and pressing the grapes and fermenting the liquid by adding sugar before bottling. What gives wine its boozy punch is the fermentation that occurs when the yeast in the grape skin feasts on the added sugar, producing alcohol. This is the basis for winemaking, or vinification, which has remained relatively unchanged for thousands of years. From the clay vases of ancient Iran to the mass production of modern-day merlot, wine has been bottled throughout the ages.

The first instance of wine being made is still unknown, but some of the earliest evidence of wine production dates to around 6000 BCE. While excavating a site in the Georgian capital, Tbilisi, archaeologists discovered fragments of jars that contained residual compounds of ancient wine.

Though this indicates that wine was around at that time, we don't really know how people made it until we look towards Egypt around 5,000 years ago. As pioneers of so many industries, the people of ancient Egypt were also excellent winemakers, although only royalty had the pleasure of drinking it. Cultivating the land to grow bountiful vineyards, Egyptians are believed to have been one of the first civilisations to devise a system of crushing grapes – via foot-stomping – collecting the juices and fermenting with sugar to produce the boozy beverage. Ancient Egyptians were also the first to label and date their wine.

Using just their feet for hours of stomping, slaves of high-ranking members of society pummelled grapes in a large vat. The juice was then bottled and fermented before it was drank. This simple yet effective approach to winemaking continued for thousands of years, alongside more mechanical methods of mass production.

From 31 BCE, during the time of the Roman Empire, wine exploded in popularity and its production rapidly increased. One of the largest Roman wine presses was discovered in Piesport, Germany, measuring 44 metres in length and 20 metres wide. The press worked in a similar way to those of the ancient Egyptians. However, 130 workers could crush grapes at once to produce 30,000 to 40,000 litres of wine each year.

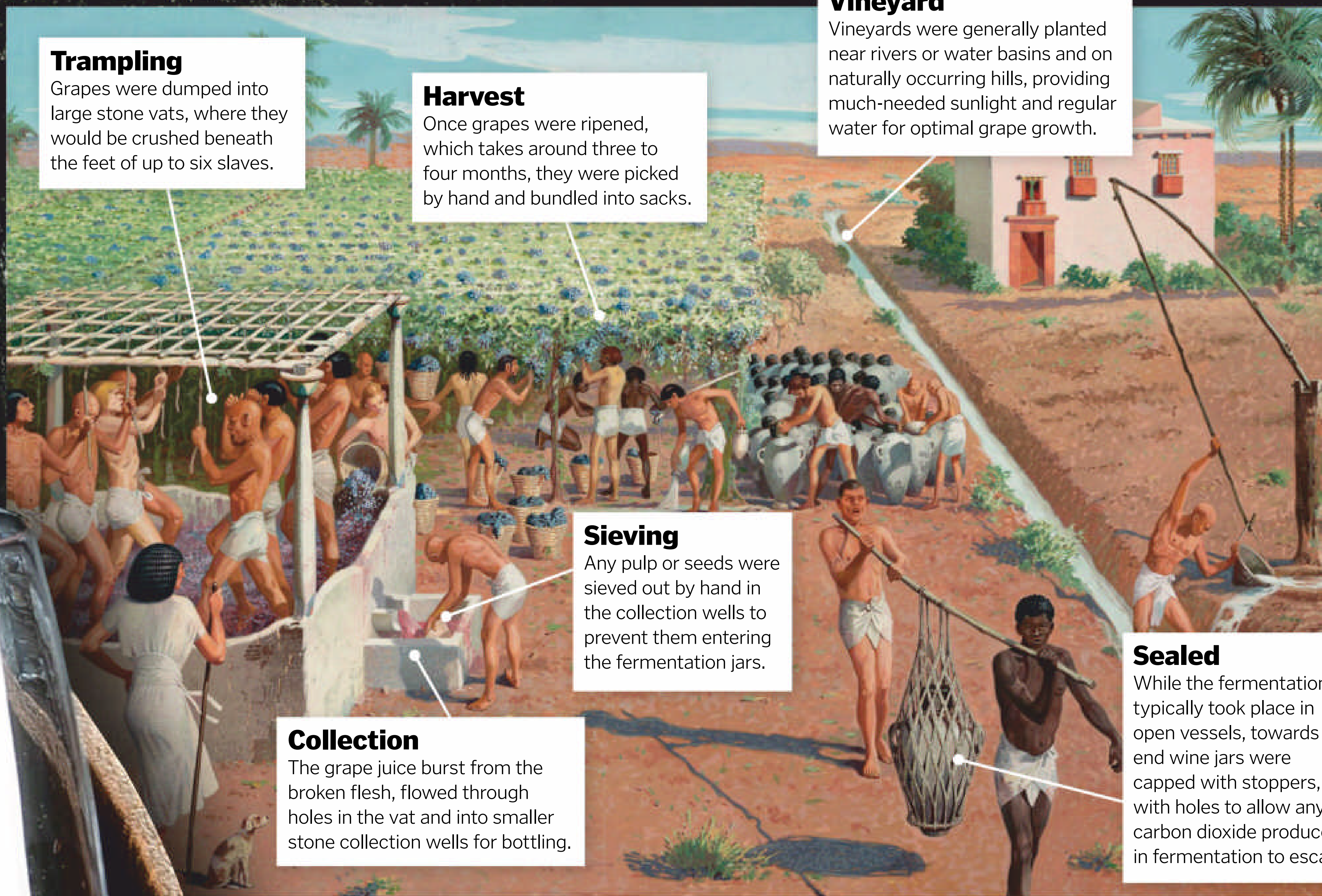
As Roman technology advanced, so did the Romans' ability to make the most of their grapes. Using heavily weighted beams and a corkscrew-style wooden press, Roman wineries such as those found in the vineyards of Juffer-Sonnenuhr, Germany, were used throughout the Roman Empire.

These were the first mechanically aided wine presses, but the mechanical screw and press went on to feature as the predominant method for wine production, booming in the Middle Ages across Europe with the creation of the basket press. As a compact version of the Roman invention, this press used a basket bound with metal or wooden rings and a wooden lid that was screwed down, crushing the grapes within. With each new century that followed, varying designs of the basket press have sprung up.

By the 1830s the industrial revolution was sweeping Europe and the US, bringing with it a new era of winemaking and a mechanical makeover for the basket press. Innovative inventions such as the automatic hydraulic accumulator – with heavy-duty preloaded springs and fluid chambers – made manually screwing down the lid of a basket press a thing of the past for commercial wineries, ultimately paving the way for modern-day winemaking machinery.

Egyptian vineyard

From vine to clay vessel, discover how wine was made 5,000 years ago



Trampling
Grapes were dumped into large stone vats, where they would be crushed beneath the feet of up to six slaves.

Harvest
Once grapes were ripened, which takes around three to four months, they were picked by hand and bundled into sacks.

Vineyard
Vineyards were generally planted near rivers or water basins and on naturally occurring hills, providing much-needed sunlight and regular water for optimal grape growth.

Sieving
Any pulp or seeds were sieved out by hand in the collection wells to prevent them entering the fermentation jars.

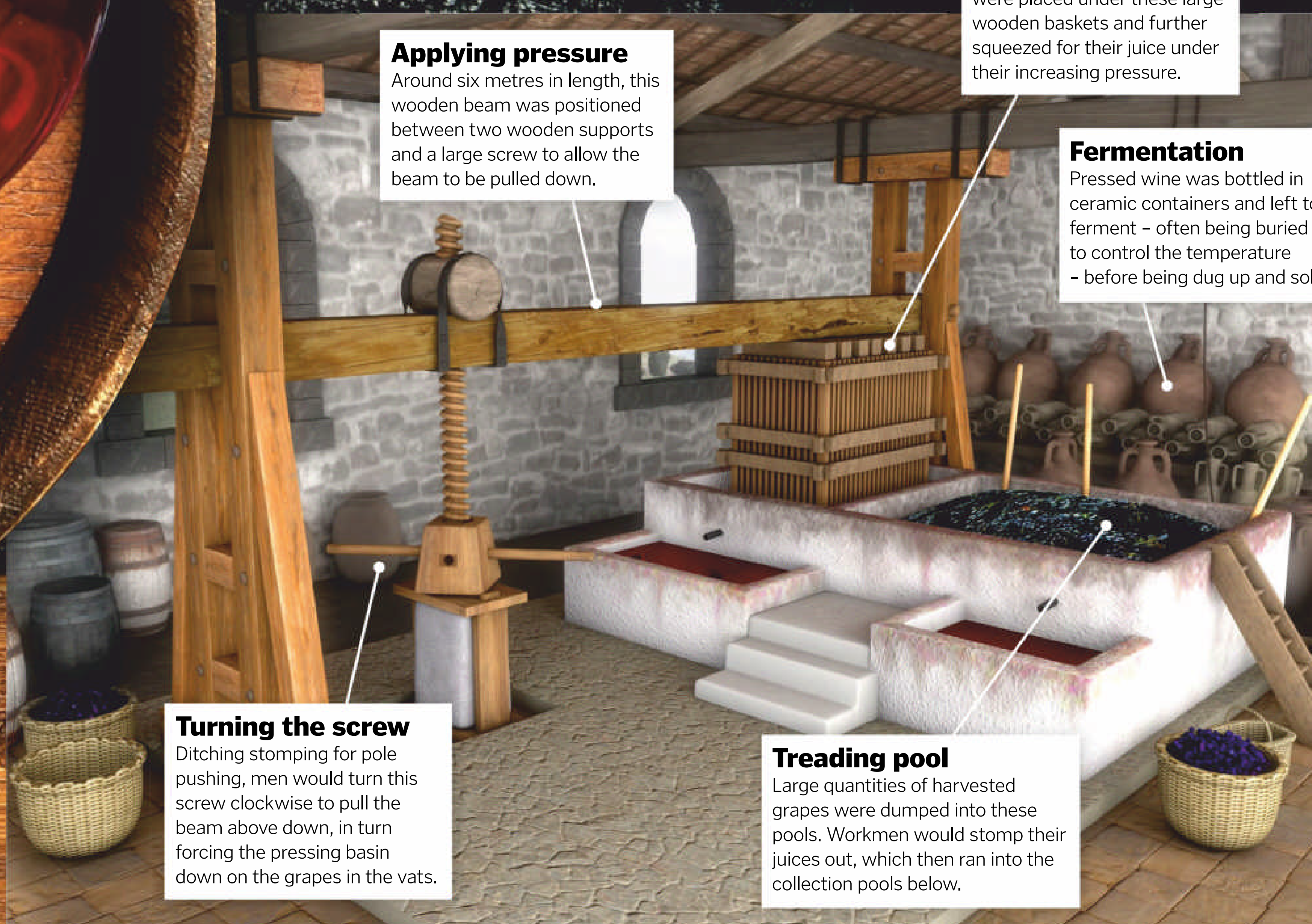
Collection
The grape juice burst from the broken flesh, flowed through holes in the vat and into smaller stone collection wells for bottling.

Sealed
While the fermentation typically took place in open vessels, towards the end wine jars were capped with stoppers, with holes to allow any carbon dioxide produced in fermentation to escape.

© Alamy

Inside the Roman winery

How the Romans squeezed every last drop from their grapes



Pressing basin
Grapes which had already experienced human treading were placed under these large wooden baskets and further squeezed for their juice under their increasing pressure.

Applying pressure
Around six metres in length, this wooden beam was positioned between two wooden supports and a large screw to allow the beam to be pulled down.

Fermentation
Pressed wine was bottled in ceramic containers and left to ferment – often being buried to control the temperature – before being dug up and sold.

Turning the screw
Ditching stomping for pole pushing, men would turn this screw clockwise to pull the beam above down, in turn forcing the pressing basin down on the grapes in the vats.

Treading pool
Large quantities of harvested grapes were dumped into these pools. Workmen would stomp their juices out, which then ran into the collection pools below.

© Adrian Mann

The Eiffel Tower

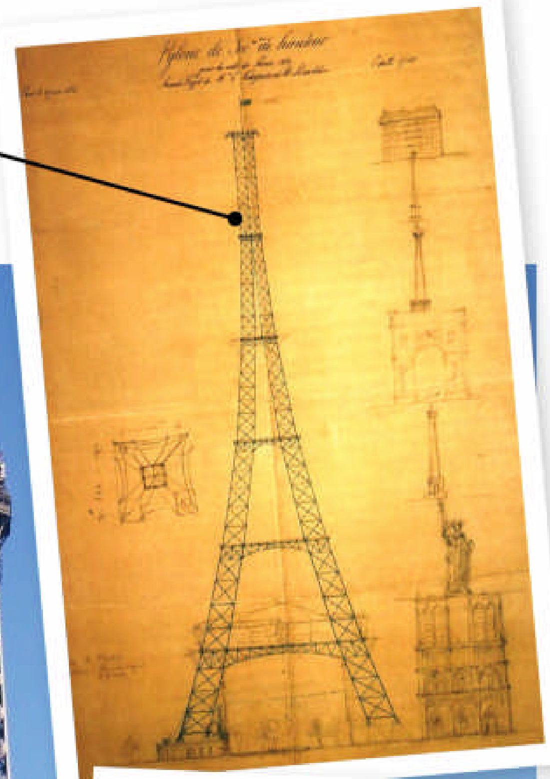
Arguably one of the world's most recognisable landmarks, the Eiffel Tower is a celebration of science, engineering and art in unison

The Eiffel Tower was the brainchild of French structural engineer Alexandre Gustave Eiffel, who proposed a 324-metre tower for the capital's Champ de Mars, costing the city $1.5 million, for its World's Fair. Work began in January 1887 and took two years to complete.

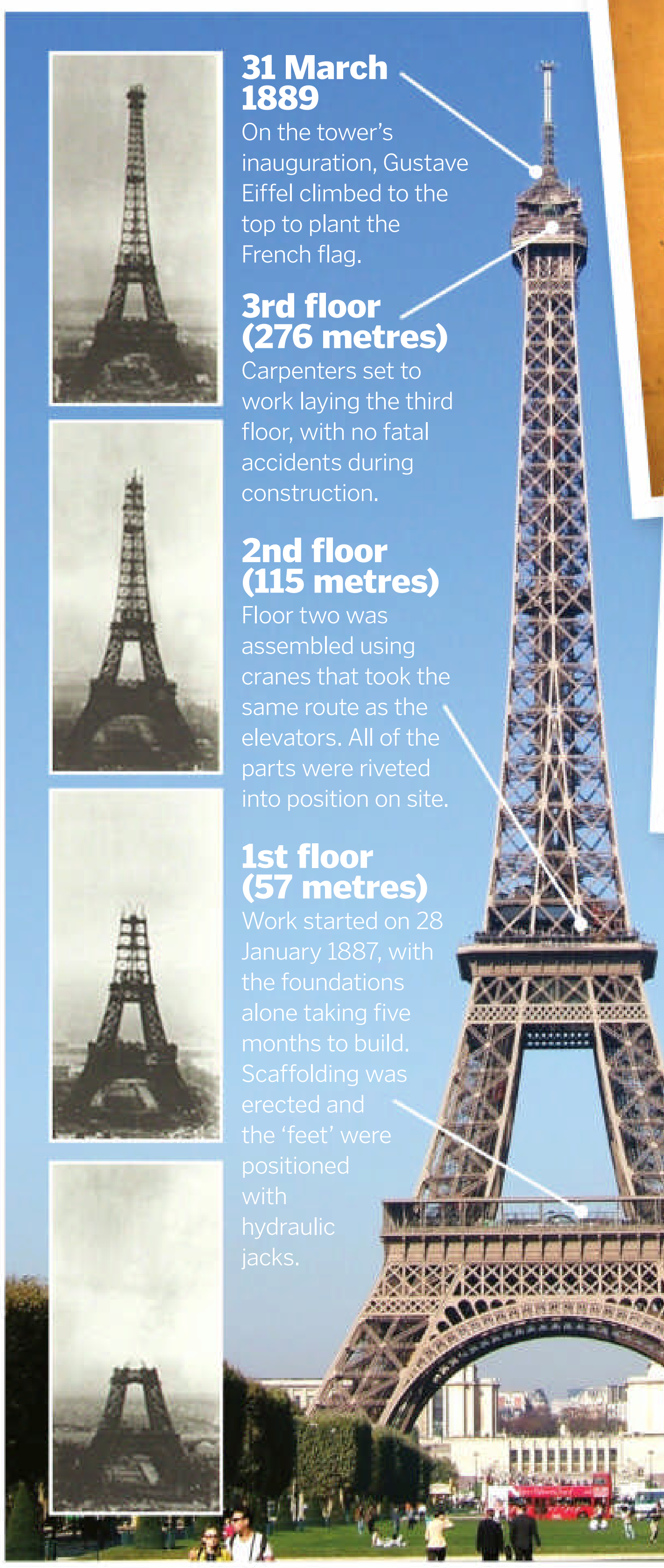
To begin with the framework was assembled in a factory, and in total about 300 workers joined 18,000 pieces of puddle iron to produce parts of the frame. When the parts were ready they were transported to the Champ de Mars, where welders secured each segment in place.

As the tower grew, moveable platforms were propped into place on the intermediary levels, not only to enable the workforce to weld the latticework together, but for their own safety. The tower features exposed latticework and consists of two main parts: a 2.54-acre base which compromises a platform sitting upon four individual legs, known as pylons or bents, and a tower created as the pylons incline towards each other, rising upwards past a second platform, which then merges into one long column.

The shape of the tower was engineered using a mathematical calculation involving wind resistance. Eiffel reasoned that the tower had to counterbalance the wind pressure applied on any point by spreading the tension between the construction elements at that point. Therefore the tower's curvature revealed two exponentials: a lower base section that delivers stronger resistance to wind forces, meaning the tower will only sway at a maximum of six to seven centimetres in the wind.



Original blueprint
This blueprint was drawn up in 1884 by engineer Maurice Koechlin.



© XXXXXXX

Paris job creation
More than 18,000 parts were built in Eiffel workshops in Levallois and assembled on site by 132 workers.

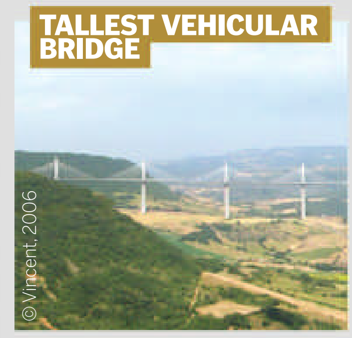
History of the tower

The Eiffel Tower took just two years for 300 workers to complete, and despite working on an open framework – and without the safety of intermediate floors – accidents were low, with only one man dying during construction. This is thought to have been due to the foresight of Gustave Eiffel, who had insisted upon safety precautions in the form of moveable stagings, guard rails and screens.

In 1909, at the end of its 20-year lease, the tower came under criticism as an eyesore, and was almost torn down. It was only saved because of its antenna, which was used for the city's communications.

Head to head
FRENCH CONSTRUCTIONS

TALLEST VEHICULAR BRIDGE



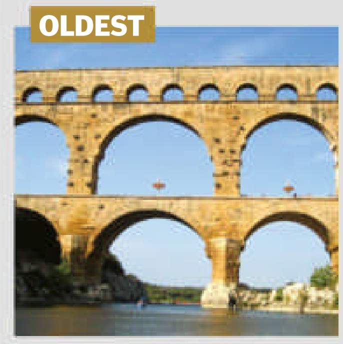
© Vincent, 2006

The Millau Viaduct
Location: Spans the River Tarn near Millau, southern France
Constructed: 2001 to 2004
Architect: Michel Virlogeux and Norman Foster
Use: Four-lane cable-stayed road bridge of the A75
Size: 343 metres high; 2,460 metres long
Fact: With one of the mast summits reaching 343 metres, it's taller than the Eiffel Tower

MOST SYMBOLIC

Statue of Liberty
Location: Liberty Island, New York Harbor
Constructed: 1876 to 1886
Architect: Frédéric-Auguste Bartholdi
Use: A gift to celebrate the independence of America
Size: 46 metres tall
Fact: Christened 'Liberty Enlightening the World', the statue was gifted by the French people to America for the centennial anniversary of the US Declaration of Independence

OLDEST



Pont du Gard
Location: Vers-Pont-du-Gard
Constructed: 19 BCE
Architect: Marcus Vipsanius Agrippa
Use: Aqueduct constructed during the rule of the Roman Empire to carry water from the Fontaines d'Eure springs to the Roman city of Nîmes
Size: 49 metres high; 275 metres long
Fact: Today it is one of France's top-five tourist attractions and was added to UNESCO's list of World Heritage Sites in 1985

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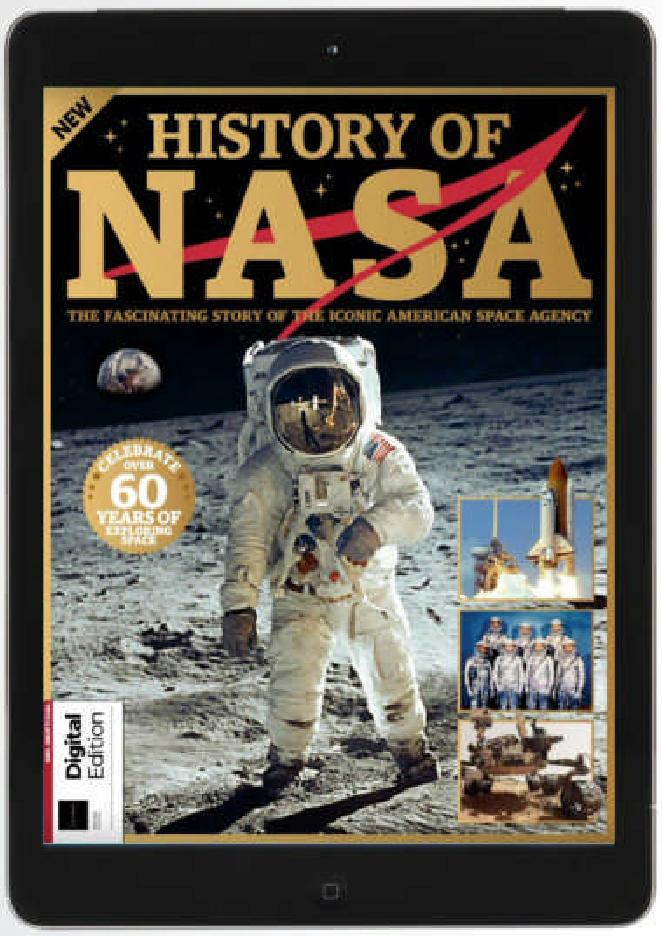

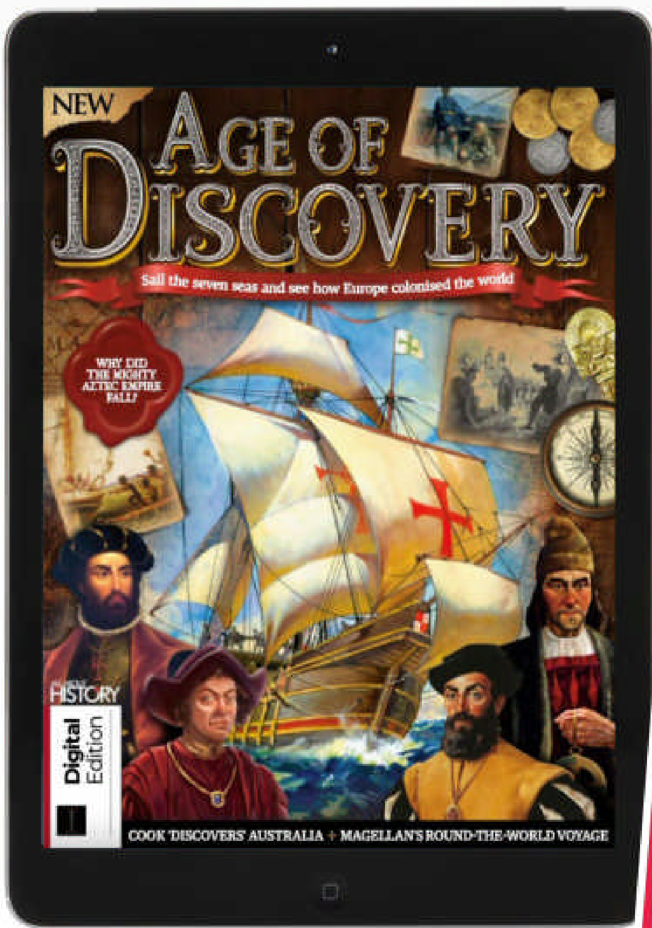

History of NASA

This is the story of how and why NASA was created, its greatest triumphs and darkest days, of the times it exceeded hopes and the times when hope was utterly crushed. It's a story of adventure, heroism, resourcefulness and of the greatest achievements in human history. This is the story of how this iconic agency has consistently and tirelessly devoted itself to its founding principle, that "activities in space should be devoted to peaceful purposes for the benefit of all humankind".

Age of Discovery

Imagine a map where the borders of Europe are detailed and defined, but the fringes of Africa and Asia are barely sketched out. They simply fade into nothingness. The Age of Discovery changed all that. Europeans set out to explore the globe, encountering other advanced civilisations. In **All About History Age of Discovery**, you'll meet the men responsible for colonising the globe and examine the profound consequences of European exploration that still resonate today.

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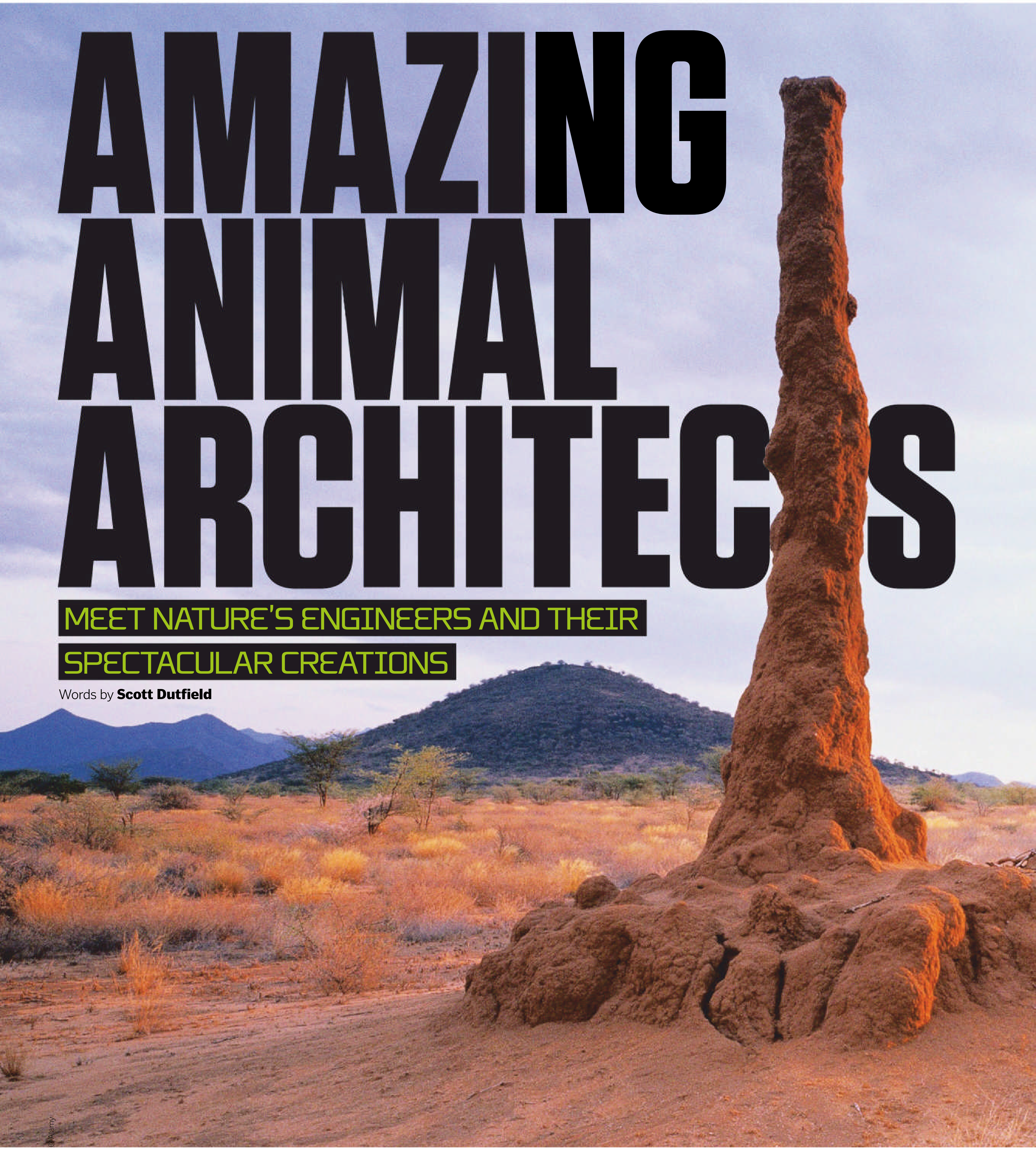
AMAZING ANIMAL ARCHITECTS

MEET NATURE'S ENGINEERS AND THEIR SPECTACULAR CREATIONS

Words by **Scott Dutfield**



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TOWERING TERMITE HILLS

Arguably this is one of the most impressive animal architects on this list. Only a few millimetres in size, when these ant-like insects work as one they can create monuments that reach over five metres tall. Over a year the millions of termites in a single mound can shift around a quarter of a tonne of soil to create their homes. Inside this nest are tunnels and chambers that form an underground insect city. What's interesting about termites is that they cohabit with another organism, a fungus called *Termitomyces*. In this symbiotic relationship the termites feed upon the nutritious waste of the fungus' digested wood. The fungus gets free lodging inside protected underground chambers and the termites get a healthy meal. It's a win-win situation.

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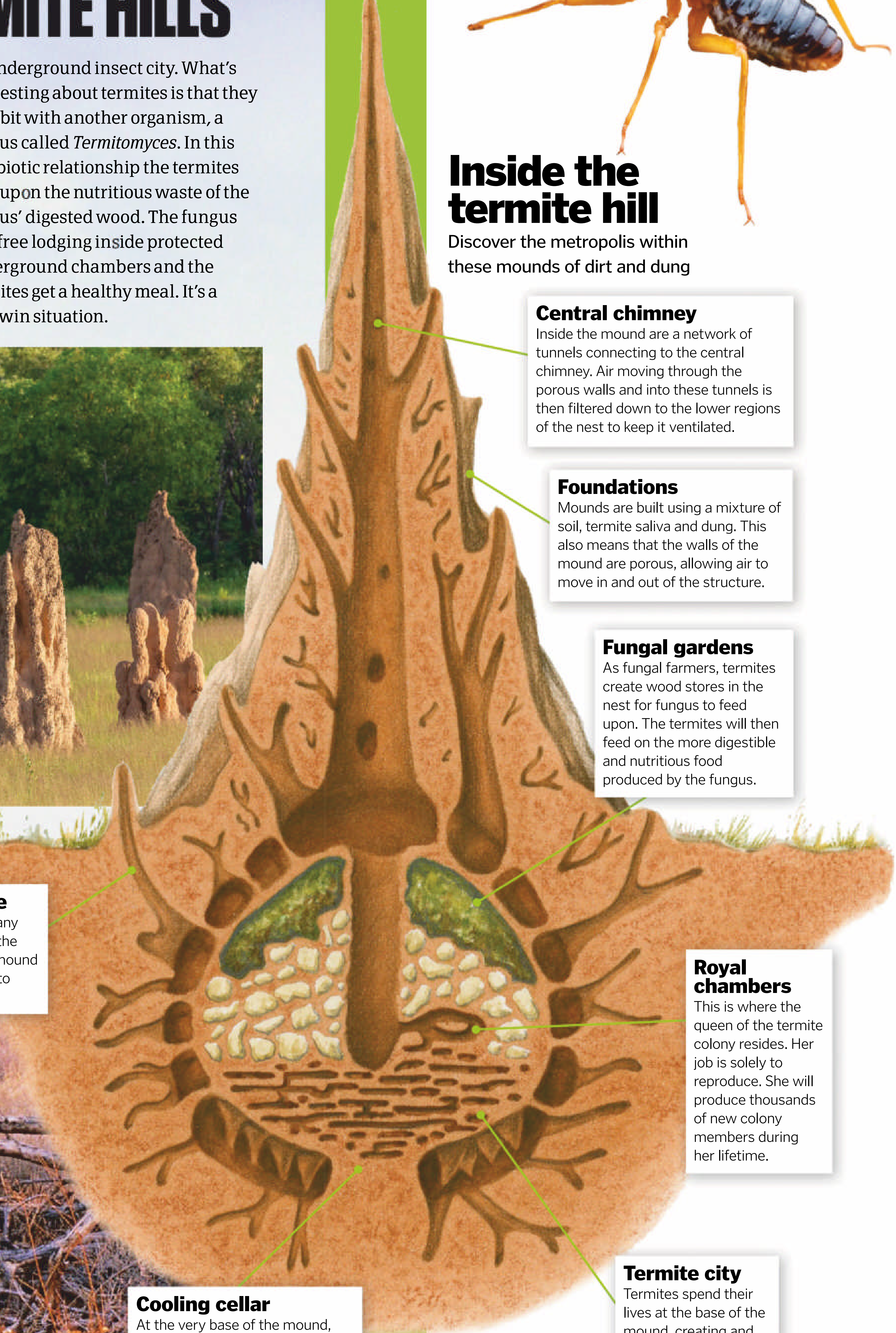
Termites prefer warmer temperatures and can be found across Northern Australia

Inside the termite hill

Discover the metropolis within these mounds of dirt and dung



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Weaver ants are also known as green ants due to the colour of their abdomen


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WEAVER ANT

Found throughout Asia and Australia, weaver ants work hard together to create homes among the leaves. It's very much a team effort when constructing a weaver nest. A single ant will hold onto one edge of a leaf with its back legs and stretch out towards the other side, hoping to grasp it in its mandibles. If the leaf is too wide for the lone ant to reach, then an ant chain begins to form. Ants clamber over one another, holding each other's ankles until the edges of the leaf can be reached and curled over to form the walls of the nest. This is repeated until a cocoon-shaped nest is formed, which can be as large as 70 centimetres in diameter. However, curling leaves over one another is not enough to create a stable nest. They must also be somehow stuck together. As an ant's version of cement, a sticky silk excretion produced by the ant larvae is used to stick the leaves together. While ant chains are holding leaves in place, another ant marches around with larvae between its mandibles and rubs silk around the construction.

COURTSHIP CREATION

Scurrying around the Australian forest floor are a diverse group of feathered architects called bowerbirds. In an attempt to attract a mate, these blue-eyed birds gather twigs and branches to construct a U-shaped 'bower'. Often mistaken for a nest, this platform of twigs is simply a stage for the male bowerbird to perform on. Male bowerbirds will also decorate their stages with berries, shells and pebbles, although this differs between species. Once a female is in the vicinity of the bower, the male will dance and sing to entice her.


© Getty

Satin bowerbirds have been known to steal anything blue for their bowers

It can take ovenbirds two weeks to three months to construct their homes

STONE NESTS

One group of birds has ditched branches for clay. As feathered potters, ovenbirds, like rufous hornero, sculpt their homes from dirt and clay and allow the Sun to bake them dry. As their name suggests, their clay nests resemble a stone oven, but rather than housing a bubbling pizza, it's built to raise ovenbird offspring. The nest consists of two chambers, one at the entrance and the other tucked away around a corner. This design allows three to four chicks to shelter from the elements, out of view from wide-eyed predators. These nests are commonly seen in trees and on other structures such as telephone poles and electrical posts. Ovenbirds will only use their clay homes once, however, so once their offspring have flown the coop, abandoned nests are taken over by any other birds that want a free home.


© Getty

The Sun acts like a clay kiln, baking the mud until it forms a solid structure

Wasps in the family *Vespidae* construct paper nests

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PAPER PALACE

Bees and wasps are known for their exquisite knowledge of geometry, creating perfect hexagons within their wax-filled nests. However, some species, called paper wasps, build their hexagonal homes from paper. These wasps aren't stealing from your stationery cupboard, however. Their bodies are their own paper-producing factories. By chewing up wood fibres from surrounding trees and fences, they produce a pulp that they mix with their saliva. This forms the foundation for around 200 individual honeycomb cells to make up their home. However, these are not forever homes. During winter these nests degrade, and a new nest will have to be rebuilt each spring.

INSIDE A WASP NEST

© Alamy

Cells
Each of the hexagonal cells is home to a developing wasp larva.

Pillars
Each platform is connected via comb pillars to allow worker wasps to move between platforms and feed growing larvae.

Platforms
Inside the wasp nest there are several platforms of hexagonal cells that occupy the main body of the nest.

Temperature control
The paper-like envelope of the nest, along with pockets of trapped air running through its walls, keep the nest at the wasp's preferred 31 degrees Celsius.

CREATIVE CHRYSALIDES

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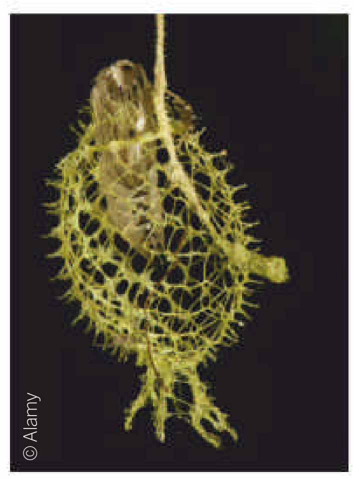
Tigerwing butterfly

Inside this metallic cocoon is a tigerwing butterfly pupae metamorphosing into its adult form. The cocoon is not actually made with metal particles, but instead a shiny substance called chitin.

© Getty

Orange-tip butterfly

The chrysalis of this butterfly mimics the appearance of a leaf, either seen as green or brown, preventing predators from spotting the developing pupating caterpillar inside by blending in perfectly with its surroundings.



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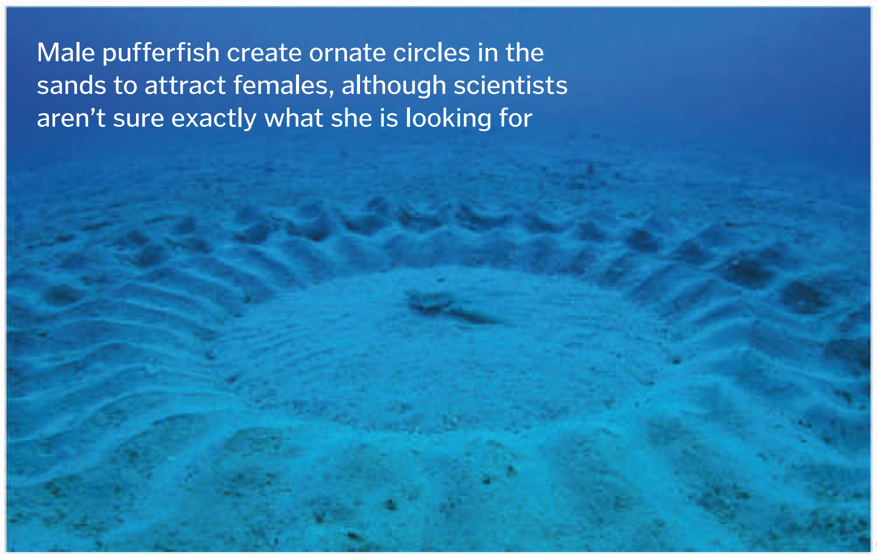
False burnet moth

For a little bit of added protection, moths belonging to the family *Urodidae* not only spin a silk chrysalis but also create an open mesh shield that swings like a pendulum from a leaf.



Male pufferfish create ornate circles in the sands to attract females, although scientists aren't sure exactly what she is looking for

© Nature PL

UNDERWATER CIRCLES

They've been called the crop circles of the sea after divers in Japan first spotted these strange sculptures drawn in the sand back in 1995. It would be 18 years before the underwater architect was revealed. It turns out that these geometric creations are the work of small pufferfish – males to be precise – and are built to attract the attention of females. Flapping their fins furiously, these marine flirts throw up the seafloor sediment to create ridges and valleys in circular patterns. These unusual sand sculptures are around two metres in diameter. If a female likes what she sees, she will lay her eggs in the centre to be fertilised by the male.

THE MYSTERY OF SILKHENGES

Unlike a common spider web, these leaf-bound 'silkhenges' are not made to catch prey, but to protect the eggs within. Typically spiders can produce hundreds of offspring at one time, but the unknown spider that spins this silk structure only produces a single or twin offspring, which emerges from the central spire surrounded by a silk fence. It's presumed that these elaborate constructions are built to protect the infant spiders from predators such as parasitic wasps. No one has ever witnessed a spider construct a silkhenge, though scientist Phil Torres recorded the birth of two spiders last year. DNA comparisons of the infant spiders are yet to match any other species on record.

These 'silkhenges' can be found on Amazonian leaves in Peru and are around 0.5 centimetres in diameter

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Caddisfly larvae attach to rocks using tough silk, blending in seamlessly with their surroundings

© Getty

This scanning electron microscope image reveals the hiding caddisfly

BENTHIC BUILDERS

Flying around the UK, there are almost 200 species of caddisfly, a moth-like insect that dwells around lakes and rivers. Adult caddisflies aren't well versed in natural architecture, but as larvae they are skilled builders. At the start of a caddisfly's life, its larval stage is a soft-bodied insect that lives underwater. To protect themselves from lurking predators, these marine larvae construct full-body casings built from riverbed rocks, wood and sediment. To stitch these materials together, they spin silk secreted from glands at their mouths. Some species of caddisfly will fix their shelters to rock faces using their spun silk, while others stay mobile to hunt for food. Those that remain on rocks or vegetation use their silk to cast silken nets to capture passing food particles. The larvae will remain in these makeshift homes until they are ready to pupate and metamorphose into their final adult form.

Beavers can be found around the world, in the UK, Spain, France, the US and Russia

© Getty

BEAVERS

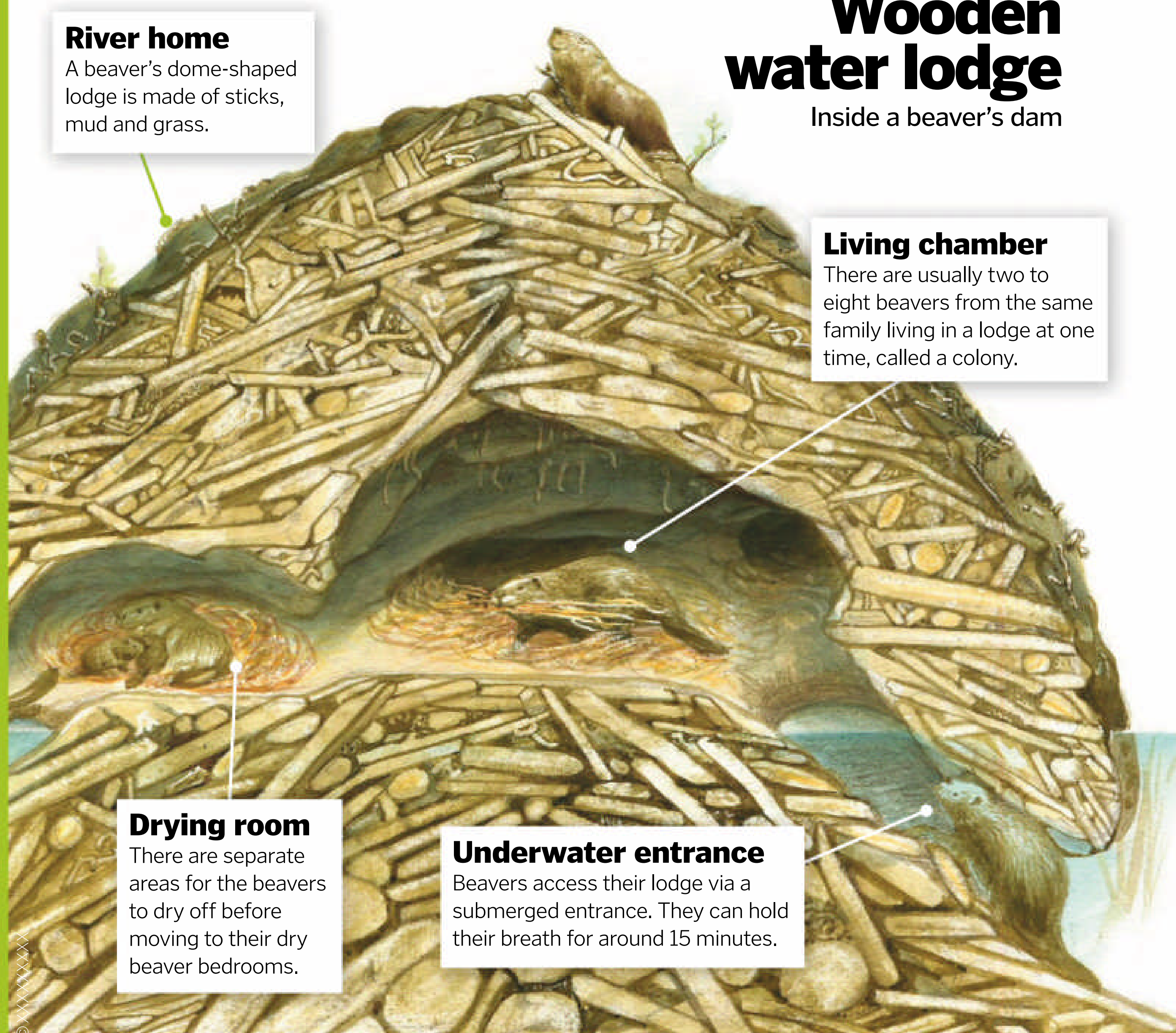
Every animal needs a place to live, and for beavers that place is a wooden lodge that can only be accessed via an underwater entrance from a beaver-made pond. It's an elaborate way to build a home, but for beavers, it works. After piling mud and stones on a river bed, beavers use their bright-orange and razor-sharp front teeth to gnaw through tree trunks and begin building a dam on the river bed. This blockade creates a deeper pond and the foothold for their live-in lodge. A dam can stretch several hundred metres and a couple of metres high. In creating dams, beavers not only serve themselves, but also benefit the surrounding ecosystem. Dams ultimately provide new wetlands, preventing soil erosion and supporting fish and amphibian populations.

© Getty

There can be hundreds of trees involved in creating a single beaver dam

Wooden water lodge

Inside a beaver's dam



River home
A beaver's dome-shaped lodge is made of sticks, mud and grass.

Living chamber
There are usually two to eight beavers from the same family living in a lodge at one time, called a colony.

Drying room
There are separate areas for the beavers to dry off before moving to their dry beaver bedrooms.

Underwater entrance
Beavers access their lodge via a submerged entrance. They can hold their breath for around 15 minutes.

How animals see in the DARK

Under the limited light of the Moon, discover the creatures that thrive in the night

Words by **Ailsa Harvey**

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Seeing after sunset

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Human eyes are built for operation in bright daylight and will struggle to see anything on a night lit solely by moonlight. Some of the animals that are active at night require better sight to stay alive, and their eyes have evolved accordingly. In general, the eyes of a nocturnal animal will be proportionally larger than a human's. They work to let more of the limited light in, with widely dilating pupils.

A human's conscious life is largely dictated by the position of the Sun. We have learned to rise with it and sleep shortly after it dips below the horizon. Why do we do this? It's because our species depends on visible light to navigate through each day.

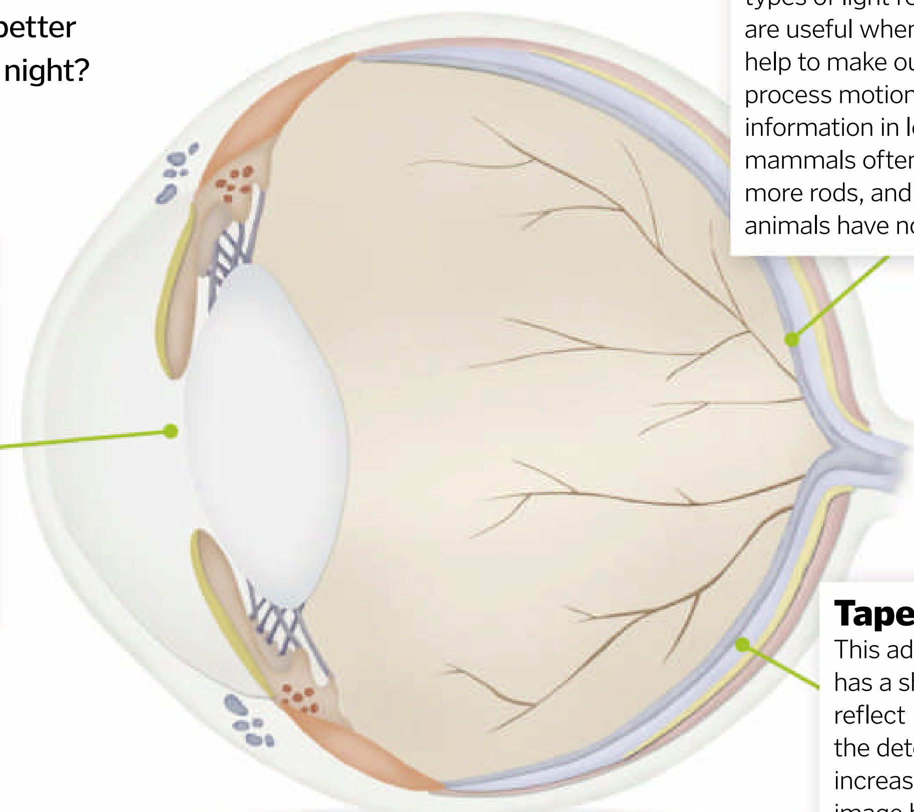
While we are walking to work in the morning sunshine or relaxing in the evening as the light begins to fade, other animals are hidden away in their dens and burrows. They are waiting for darkness to fall. When it does, a new community of creatures comes out to play.

These masters of the night carry adaptations that give them an advantage during the colder and darker hours. If you were to intrude on nocturnal life with the light of a torch, you'd likely see a variety of wide, glossy eyes staring back at you. These big eyes give an advantage to animals by allowing them to utilise every glimmer of light available, to observe the activity of the night.

Some other animals avoid the daytime as the lack of illumination gives them no disadvantage at all. They are blind to light anyway but rely on other, heightened senses. With ways of feeling, smelling and hearing nocturnal homes and neighbours, read on to discover some of these night-navigating superpowers.

Mammal eyes

What makes nocturnal mammals' eyes better equipped for the night?



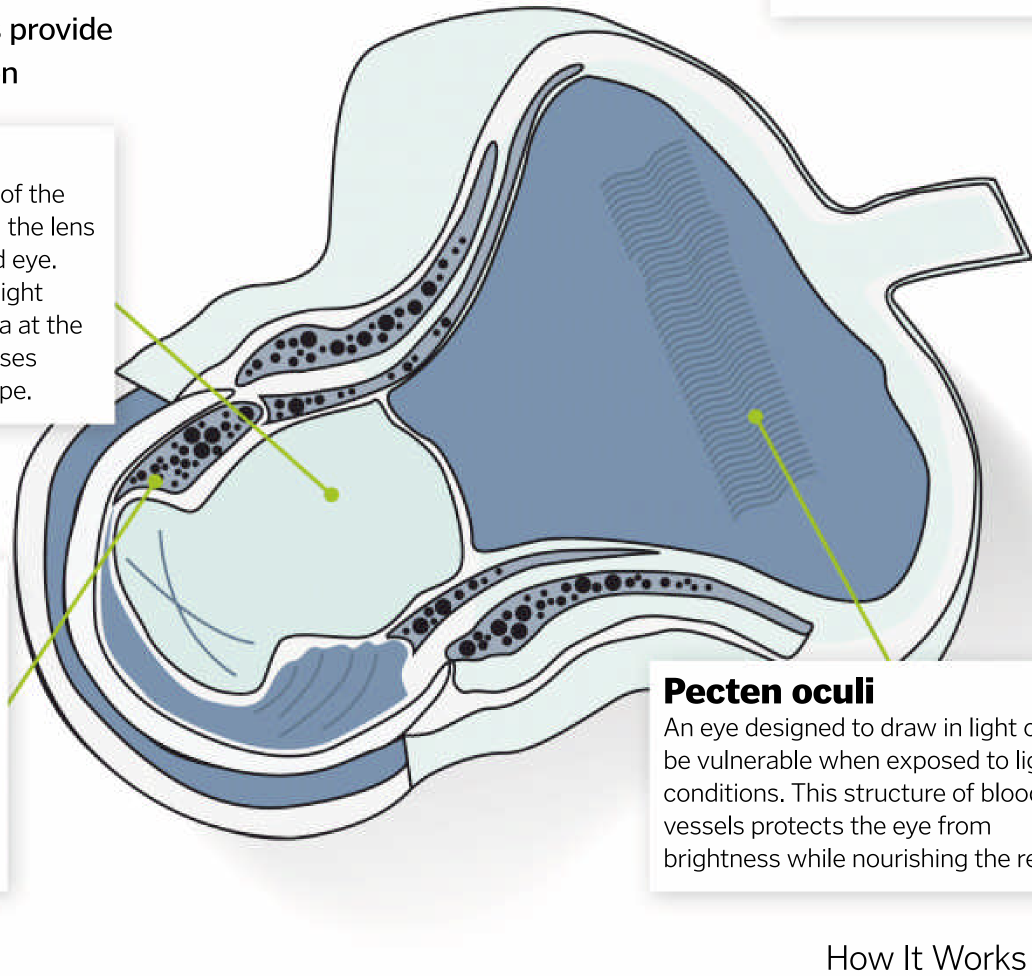
Refined retina
The retina at the back of the eye contains cones and rods, different types of light receptor cells. Cones are useful when light is bright and help to make out details, while rods process motion and other visual information in low light. Nocturnal mammals often have proportionally more rods, and some nocturnal animals have no cones at all.

Wide-eyed
The eye is usually large to provide more room for the pupil to expand. This wideness increases the brightness of the image on the retina.

Tapetum lucidum
This additional layer of cells has a shiny surface and can reflect light back through the detector cells. This increases the chance of an image being detected, providing more than one exposure to the light.

Bird eyes

Tubular-shaped eyes provide owls with night vision



Tubular focus
While the outer surface of the eye covers a larger area, the lens sits inside this elongated eye. This enables it to focus light onto a concentrated area at the back of the eye as it passes through the thinned shape.

Sclerotic ring
These rings of bone help to support the eyes' shape. Holding them firmly in place, the eyes don't move in the socket. Instead the owl rotates its whole head 270 degrees.

Pecten oculi
An eye designed to draw in light can be vulnerable when exposed to lighter conditions. This structure of blood vessels protects the eye from brightness while nourishing the retina.

Thermal vision

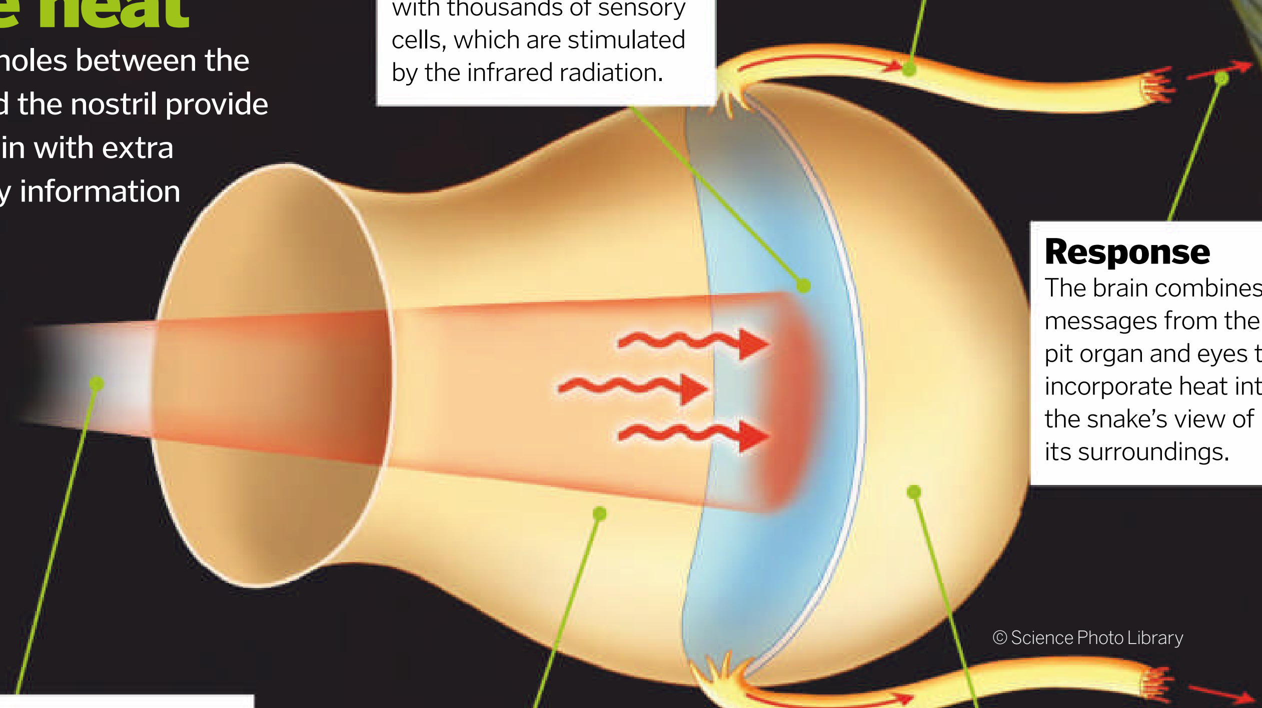
Using infrared alone, snakes have been able to successfully pounce on prey while their eyes are covered

For snakes that hunt during the darkest hours of the night, spotting a tiny, scurrying mouse in the pitch black might sound like an impossible task. In reality, some snakes have an incredibly advantageous signalling system in their heads: they are able to see heat.

Warm-blooded rodents are a large portion of a snake's diet, and with mice only giving off a small amount of body heat, this navigational skill is efficient and quick enough to allow precise and successful hunting at night. By the time the snake pounces, the mouse has minimal chance of spotting their impending death in the dim conditions.

How snakes see heat

These holes between the eye and the nostril provide the brain with extra sensory information



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Messengers

Heat detection information is fired to the brain through the nervous system. The specific part of the brain is the optic tectum.

Sensory membrane

This membrane is packed with thousands of sensory cells, which are stimulated by the infrared radiation.

Response

The brain combines messages from the pit organ and eyes to incorporate heat into the snake's view of its surroundings.

Infrared radiation

The heat detected from the prey enters the pit organ through holes in the snake's face. It then reaches the exposed membrane.

Inner cavity

This cavity insulates the sensitive membrane from the back wall of the pit.

Outer cavity

Because this area is about as wide as it is deep, the images from the membrane can be blurry.

5 FACTS ABOUT NIGHT-VISION ANIMALS

1 Owl
At the back of their eyes, these birds have almost a million rods per square millimetre. In comparison, humans have just 200,000 of these photoreceptors in total.

2 Fruit bat
Said to have the best vision of all flying mammals, fruit bats combine enhanced night vision with their keen sense of smell while hunting for food.

3 Elephant hawk-moth
These moths not only have eyes that can see shapes well at night, but also colour, being able to distinguish between colours in low light.

4 Tarsier
This small primate has adorably large eyes, roughly the same size as its brain. Though they can't see colour too well, their massive eyes mean they can see in extremely dim light.

5 Colossal squid
At 27 centimetres in diameter, these beasts' eyes are the size of footballs, and are the largest on Earth. At the dark depths of over 2,000 metres underwater, they need their expert night vision.

Stargazers

The night sky presents patterns and points of light in the form of stars. In beautiful contrast to the black backdrop, it is no wonder that some species are drawn to their glow. Stars can help to guide animals in different ways: seals can recognise the unique patterns, some birds use a single bright star to find their way and dung beetles follow the path of the Milky Way's spiral arm. Unlike seals, insects are too small to be able to notice each individual star, but the luminous band created by our galaxy's arm is clear enough to provide direction and keep them moving in a straight line.

There are an estimated 100 to 400 billion stars in the Milky Way, each lighting insects' paths

© Getty

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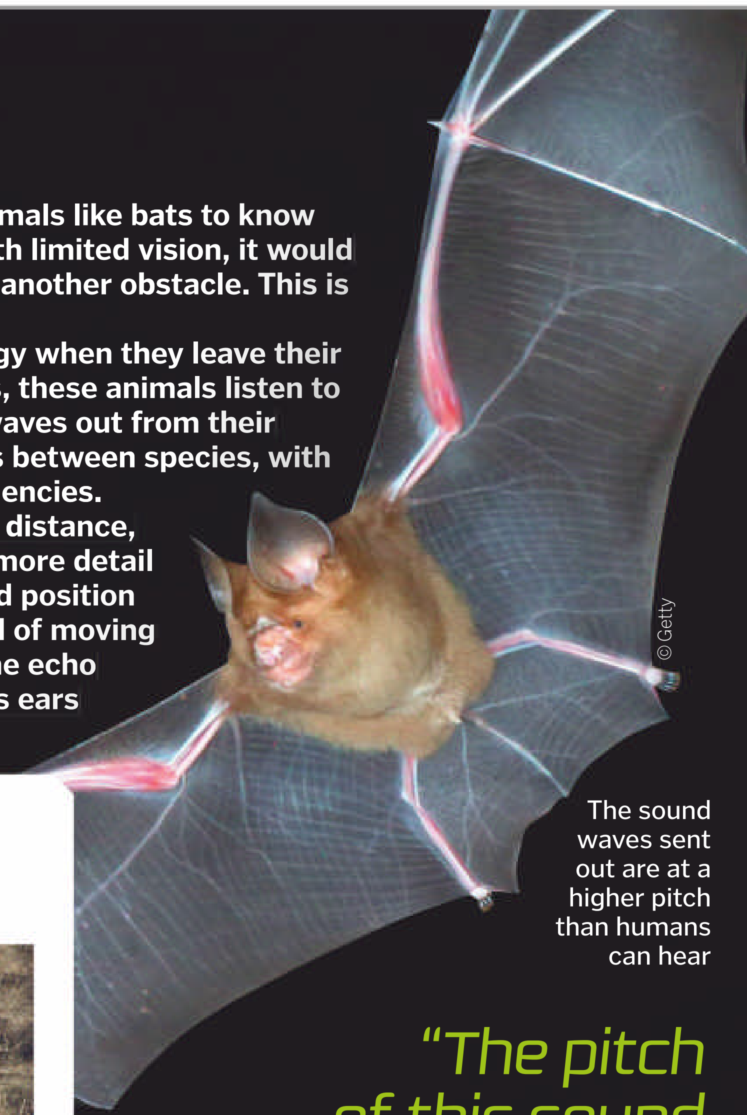
Echolocation

Soaring through the sky, it's essential for animals like bats to know their position in relation to other objects. With limited vision, it would be easy to hurtle at high speed into a tree or another obstacle. This is where echolocation comes in.

The majority of bat species use this strategy when they leave their roosts. Instead of viewing their surroundings, these animals listen to the objects around them by sending sound waves out from their mouth or nose. The pitch of this sound varies between species, with some producing sequences to cover all frequencies. Generally, a low pitch is used for objects at a distance, while high frequencies present the bat with more detail of its surroundings. This includes the size and position of static objects, and the direction and speed of moving objects. When these waves hit something, the echo that is bounced back is picked up by the bat's ears and analysed by its brain.



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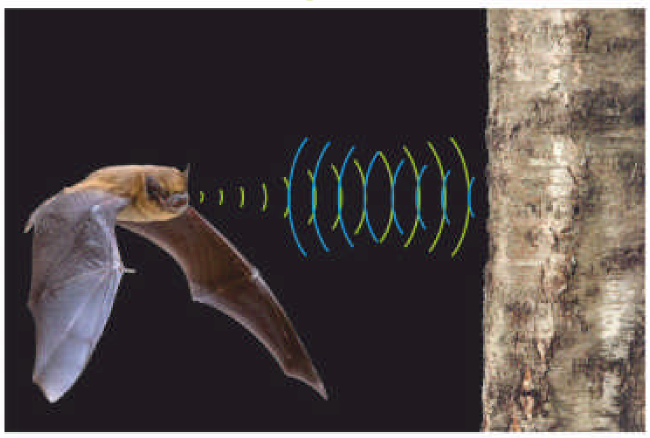
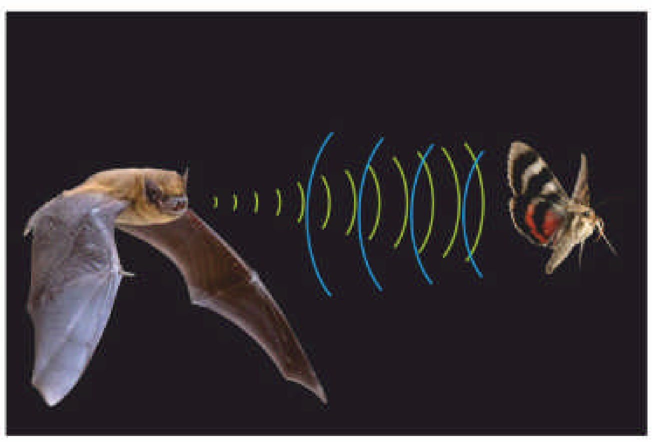
The sound waves sent out are at a higher pitch than humans can hear

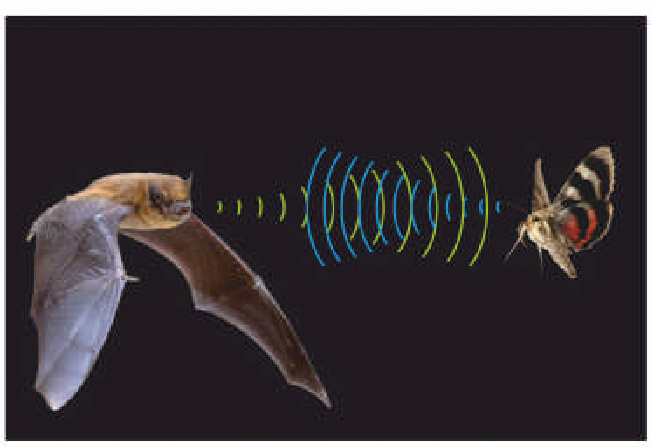
What do the waves say?



Still object
When sound reaches an object, it's deflected in the opposite direction. The time between sending and receiving the sound tells the bat how close something is.



Moving away
When the object detected is moving away from the bat, the returning waves will produce a lower pitch than that sent out.



Moving closer
Objects approaching the bat will return each sound wave closer together, producing a higher pitch than that originally produced.

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"The pitch of this sound varies between species"

Bogong moths look for visual landmarks, as well as analysing the planet's magnetic field

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Hair tactility

If you were stuck in a completely dark room, how would you walk to the door? Chances are you would put your hands out in front of you, feeling out your way to safety. Animals use the same method, but with a more technical and efficient system.

Sensitive whiskers on the snouts of animals such as lemurs, badgers and dormice can aid foraging in the most complex habitats. Spending most nights in the dangerous heights of the trees, hazel dormice need these feelers so that they know where gaps lie between branches. They move their whiskers in a movement called 'whisking'. Brushing backwards and forwards in a cyclic motion, this is one of the fastest movements made by mammals. Special facial muscles found in whiskered animals allow these speedy movements so that the whiskers can constantly brush against surfaces as the animals travel. The uneven surfaces surrounding them are detected by hundreds of motion sensors in these modified hairs.

The largest dormice can jump three metres

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Magnetic mapping

If you've ever opened your window at night to see a moth mindlessly following the light into your room, you may be fooled into thinking that these insects have developed rather limited navigational skills. The truth is that moths are extremely well-evolved to fly at night, using a sense called magnetoreception.

Australia's bogong moths were the first insects discovered to have a built-in compass, allowing them to follow the Earth's magnetic field for migration. Along with nocturnally migrating birds, these creatures are able to find specific locations in the country.

It is believed that these insects have small magnetite crystals within their nervous system which are extremely sensitive to Earth's magnetic field. This signal changes with the moth's direction of flight, allowing them to check their position with Earth's and keep them heading on the right flight path.

BIG CATS

What makes these beautiful creatures such consummate experts in the business of killing?

The big cats aren't a single biological grouping. It's an informal term that includes the lion, tiger, jaguar and leopard (sometimes called the Great Cats), as well as the cheetah, cougar, snow leopard and clouded leopard. (The three kinds of leopard actually belong to three different genera and aren't very closely related, despite looking quite similar.) Big cats are all apex predators that hunt large mammals using their excellent camouflage to keep hidden and powerful muscles to catch and dispatch their prey.

An antelope runs on the very tips of its feet, which allows it to have a much longer stride and means it is very fast. Cats can't do this because they have claws instead of hooves, and they need to retract them to keep them sharp. To catch hoofed animals, the big cats must run with their entire spine flexing to help elongate their effective stride. It's a very energetic technique though and cats can't run fast for long distances. This in turn pushes them to be stealthy in the approach and brutal in the attack. Where a wolf will bite and retreat as it waits for its prey to bleed to death, a cougar will leap onto the back of its prey and crunch straight through the spine with a single bite.

The roar of a big cat is a sound made by the walls of the specially elongated larynx vibrating as the cat exhales, but not all big cats can do it. The cougar, cheetah and snow leopard have no roar, but they do make a variety of other noises, including chirps, screams and growls. All of the big cats are able to climb trees. Leopards are the strongest climbers; indeed, an adult male can haul a young giraffe almost six metres (20 feet) into a tree. This skill enables big cats to protect their kills from hyenas and other pack scavengers that might steal them.

It's easy to think of animals this magnificent in terms of being 'perfectly adapted', but in fact hunting large animals is incredibly difficult and all apex predators hover perpetually close to the brink. If they were anything less than brutally fit, they simply couldn't survive at all.

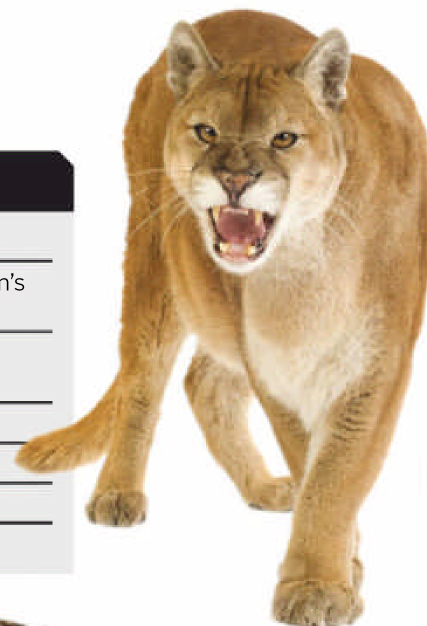
Meet the cats...

Tiger

Type: Mammal
Diet: Carnivore (eg wild boar, water buffalo)
Life span in the wild: 20-26 years
Weight: 240kg (530lb)
Height: 1m (3.2ft)
Length: 3m (9.6ft)
Able to roar?: Yes

Leopard

Type: Mammal
Diet: Carnivore (eg Thomson's gazelle, monkeys)
Life span in the wild: 18-20 years
Weight: 60kg (132lb)
Height: 0.65m (2.1ft)
Length: 2.1m (6.8ft)
Able to roar?: Yes



Cougar

Type: Mammal
Diet: Carnivore (eg deer, elk)
Life span in the wild: 8-10 years
Weight: 80kg (176lb)
Height: 0.75m (2.5ft)
Length: 2.4m (7.9ft)
Able to roar?: No

Clouded leopard

Type: Mammal
Diet: Carnivore (eg hog deer, brush-tailed porcupine)
Life span in the wild: 7-10 years
Weight: 18kg (40lb)
Height: 0.33m (1ft)
Length: 1.8m (5.9ft)
Able to roar?: Partially

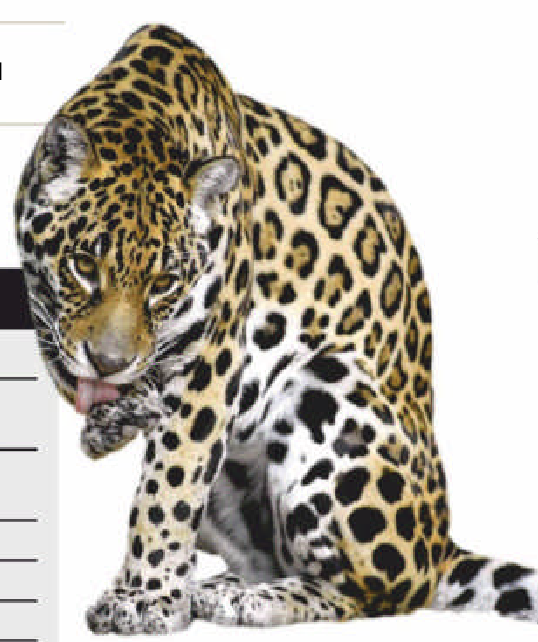
ON THE MAP

How the big cats are globally distributed

Lions: Sub-Saharan Africa, and a single population in the Gir Forest, northwest India (yellow)
Tigers: India, southeast Asia, southeast Siberia (orange)
Cheetahs: Sub-Saharan Africa, plus a small population in Iran (light blue)
Cougars: West Canada, central and west USA, plus most of Central America and South America (red)
Jaguars: Central/South America (dark blue)
Leopards: East/central Africa, pockets of the Indian subcontinent, southeast Asia, China (green)
Snow leopards: Hindu Kush, Himalayas, Altai Mountains and Khangai Mountains (purple)
Clouded leopards: Southeast Asia, Nepal (blue)

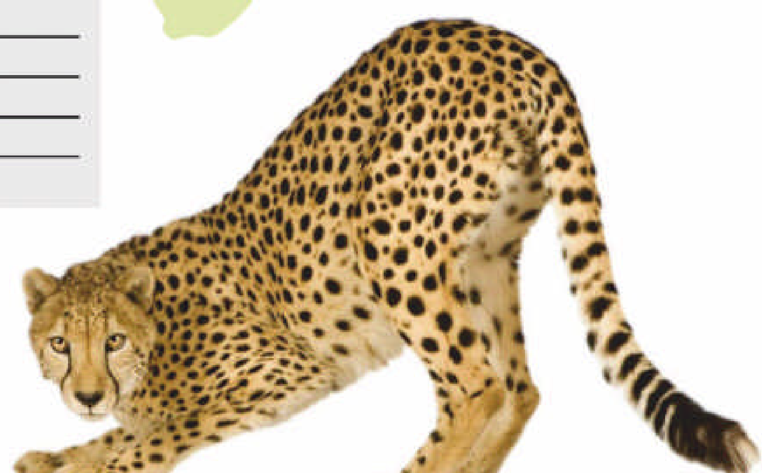
Snow leopard

Type: Mammal
Diet: Carnivore (eg goats, ibex)
Life span in the wild: 15-18 years
Weight: 41kg (90lb)
Height: 0.6m (2ft)
Length: 1.9m (6.2ft)
Able to roar?: No



Jaguar

Type: Mammal
Diet: Carnivore (eg caimans, capybaras)
Life span in the wild: 12-15 years
Weight: 75kg (165lb)
Height: 0.7m (2.2ft)
Length: 2.2m (7.2ft)
Able to roar?: Yes



Cheetah

Type: Mammal
Diet: Carnivore (eg Thomson's gazelle, impala)
Life span in the wild: 12-14 years
Weight: 55kg (120lb)
Height: 0.8m (2.6ft)
Length: 1.3m (4.3ft)
Able to roar?: No

Lion

Type: Mammal
Diet: Carnivore (eg wildebeest, zebra)
Life span in the wild: 10-14 years
Weight: 200kg (440lb)
Height: 1.2m (3.9ft)
Length: 2.2m (7.2ft)
Able to roar?: Yes

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Purr-fect predators

Want to kill something three times your size? Here's what you need…

© Dreamstime

Feuding families

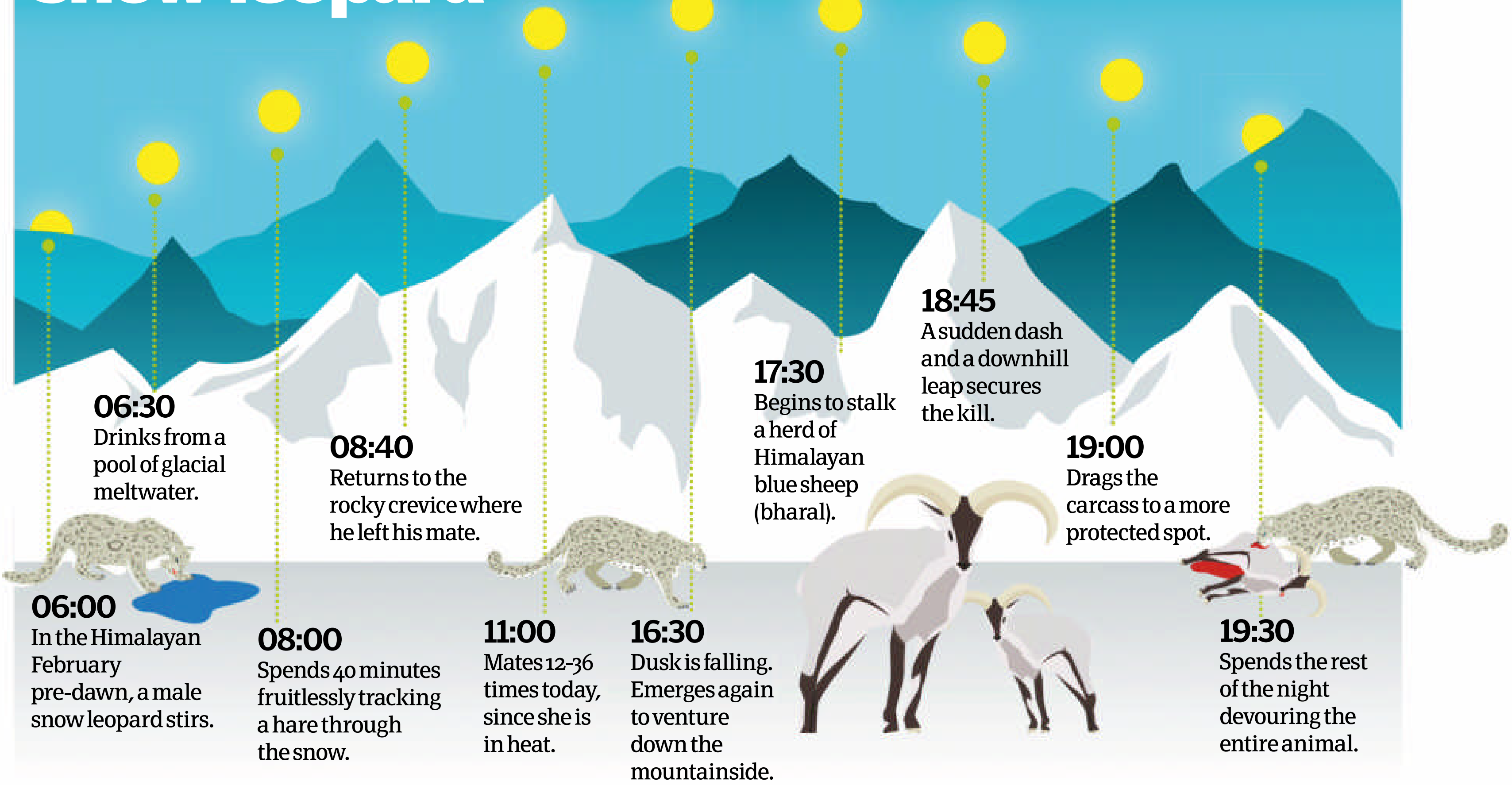
Most big cats are solitary creatures. Female tigers, cougars, jaguars and leopards will maintain a territory of roughly 15-25 square kilometres (5.8-9.7 square miles) and raise their cubs alone. The male has a much larger territory – indeed, cougars have been reported with territories as extensive as 1,300 square kilometres (500 square miles) – but this is to control access to females, not food.

In the big cat kingdom, lions are unusually social because they hunt in the open and need to co-operate to have any chance of success. A typical pride consists of five or six females and one or two males, along with several cubs. Females do most of the hunting; males overheat too easily with their large manes. Males that join a pride will normally start by killing all the cubs. Females are very promiscuous and mate 20-40 times a day when in heat; this makes it harder for males to tell which cubs are theirs and so reduces the rate of infanticide.

Threats to the big cats

Top carnivores are inherently vulnerable species. They require large home ranges and reproduce relatively slowly. Lions, leopards and cheetahs all suffer high infant mortality from other predators – indeed, up to 90 per cent of cheetah cubs are lost. Cheetahs also have very low genetic variability, possibly due to an extreme population bottleneck thousands of years ago, leading to birth defects as a result of inbreeding; captive breeding schemes have had very limited success. The biggest threats to big cats, though, are habitat loss due to human expansion and poaching. Although most cats have a wide geographic distribution, human development has fragmented these ranges into pockets, each of which may be too small for them to flourish in the long term.

A day in the life of a snow leopard



Hunting techniques

Big cats generally hunt between sunset and dawn. They are ambush predators that move silently through dense undergrowth using their excellent vision and hearing to spot their prey before their prey spots them. Although they are all incredible sprinters, big cats lack stamina. A cheetah may exhaust itself so badly in a 60-second dash that it needs half an hour to recover and most cats will give up if they cannot run down their quarry in 30 seconds. Accordingly, they always attack from a position of advantage, leaping from cover or a tree branch, etc. Tigers will even launch attacks from the riverbank into the water and are strong enough swimmers to take on crocodiles.

What's on the menu?

Hunting big game is an erratic profession. Cheetahs can generally manage a 50 per cent success rate but a tiger may only kill its prey one time in every 20 attempts. Consequently, they need to be able to make the most of each kill. Lions will eat 30 kilograms (66 pounds) of meat in one sitting, while jaguars can eat 25 kilograms (55 pounds) – a third of their body weight; that is the equivalent of you eating over a hundred Big Macs in one sitting! After a meal like that, lions, tigers, cougars and snow leopards can go for up to two weeks without eating again. Big cats are all quite opportunistic hunters. As well as their favoured prey of medium to large herd animals, they will eat monkeys, rodents, lizards, porcupines and birds' eggs. Many cats – especially the forest dwellers – will also eat insects and a small amount of fruit and vegetation.

Strangulation

The most common attack technique, used by all big cats, is to lunge at the neck and clamp down on the windpipe with powerful jaws. This cuts off the air supply and prey that is already out of breath from the chase quickly loses consciousness.

© Dreamstime

Asphyxiation

Another way to achieve the same result is to take a wide bite and clamp over the victim's mouth and nostrils, so it can't breathe. Lions and occasionally leopards will use this technique on antelope, but it isn't suitable for larger prey like zebra.

Neck breaking

The largest cats can leap on the back of an animal and bite right through its neck, severing the spine. This paralyses the victim instantly and ends the struggle, but it requires tremendous bite force. Lions, tigers and cougars all use this method.

Artery slicing

In the chaos of the final lunge, a cat may miss the windpipe of its prey and instead slice open the carotid artery. This is a slightly slower kill but it still gets the job done, as the victim will bleed to death.

The paw swipe

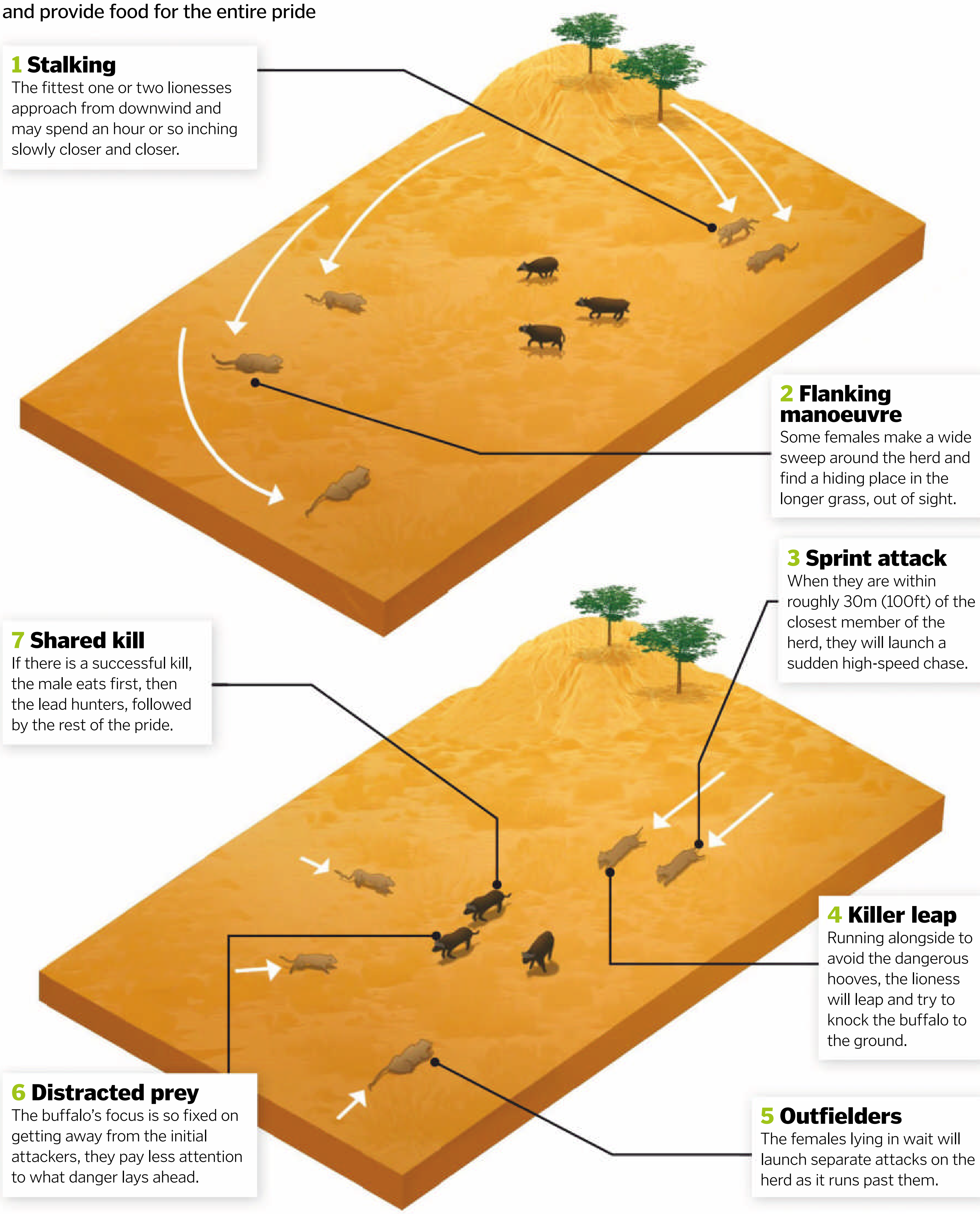
Lions and tigers are so strong that they can kill merely with a swipe of their paws. Tigers in particular have been witnessed swiping at adult domestic cattle with enough force to shatter the skull.

Skull piercing

The jaguar has the strongest bite of any cat – twice as powerful as the much larger lion. This may have evolved to enable them to bite through the shells of turtles, but jaguars also use it for a unique finishing move: their canine teeth can puncture an animal's skull and pierce the brain.

How lions hunt

Lionesses work as a team to efficiently bring down large prey on the savannah and provide food for the entire pride



1 Stalking
The fittest one or two lionesses approach from downwind and may spend an hour or so inching slowly closer and closer.

2 Flanking manoeuvre
Some females make a wide sweep around the herd and find a hiding place in the longer grass, out of sight.

3 Sprint attack
When they are within roughly 30m (100ft) of the closest member of the herd, they will launch a sudden high-speed chase.

4 Killer leap
Running alongside to avoid the dangerous hooves, the lioness will leap and try to knock the buffalo to the ground.

5 Outfielders
The females lying in wait will launch separate attacks on the herd as it runs past them.

6 Distracted prey
The buffalo's focus is so fixed on getting away from the initial attackers, they pay less attention to what danger lays ahead.

7 Shared kill
If there is a successful kill, the male eats first, then the lead hunters, followed by the rest of the pride.

Why is fracking bad?

Controversial but effective, hydraulic fracturing enables us to tap into shale gas reserves trapped deep underground, but how does this mining process work?

As we exhaust more easily accessible natural gas reserves, countries across the globe are increasingly turning to shale gas. But how do you release gas that's imprisoned in millions of tiny pores inside shale rock, deep beneath Earth's surface? The answer is hydraulic fracturing, or fracking.

Fracking involves drilling deep into rock and pumping a highly pressurised jet of water, sand and chemicals down the wellbore. This forces a network of tiny cracks to open up and spread through the impermeable rock, allowing pockets of gas within the rock to seep out.

The main ingredient that makes up fracking fluid is water. Since water is incompressible, it can pass on the extreme pressures needed from the pump to the shale rock over 2,000 metres below. Sand or ceramic beads act as 'proppants', holding the cracks open after the pressure drops and while the gas is collected.

Finally, a cocktail of different chemicals is added. Their uses range from averting microorganism growth to preventing corrosion of metal pipes, maintaining fluid viscosity and reducing friction during extraction.

Hydraulic fracturing was first used in the 1940s, but is far more efficient today. The advent of horizontal drilling in the 1990s, for instance, made wells far more productive, making the operation economically viable.

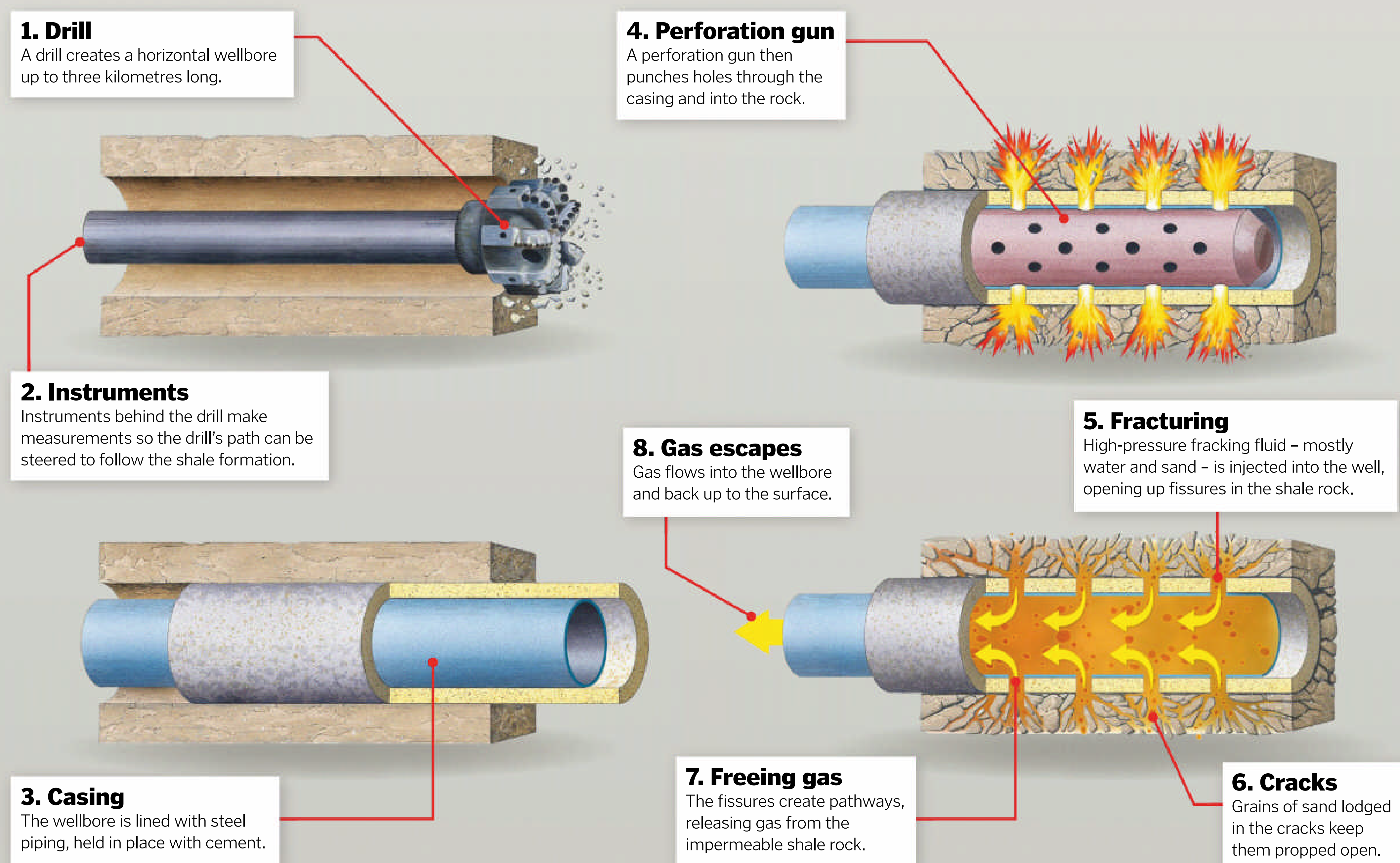
While fracking has allowed governments to unlock previously unreachable and abundant shale gas resources, it has sparked concerns among some geologists and conservationists.

A fracking well uses millions of litres of water per frack, putting pressure on local water resources. Around half of the fracking fluid remains in the rock, and although much deeper than groundwater, some fear it could, over time, contaminate drinking supplies. The fluid recovered at the surface also needs to be disposed of safely. Finally, geologists must ensure fracking sites are far away from fault lines, since they can increase the likelihood of earthquakes and tremors in at-risk areas.

"A fracking well uses millions of litres of water per frack, putting pressure on local water resources"

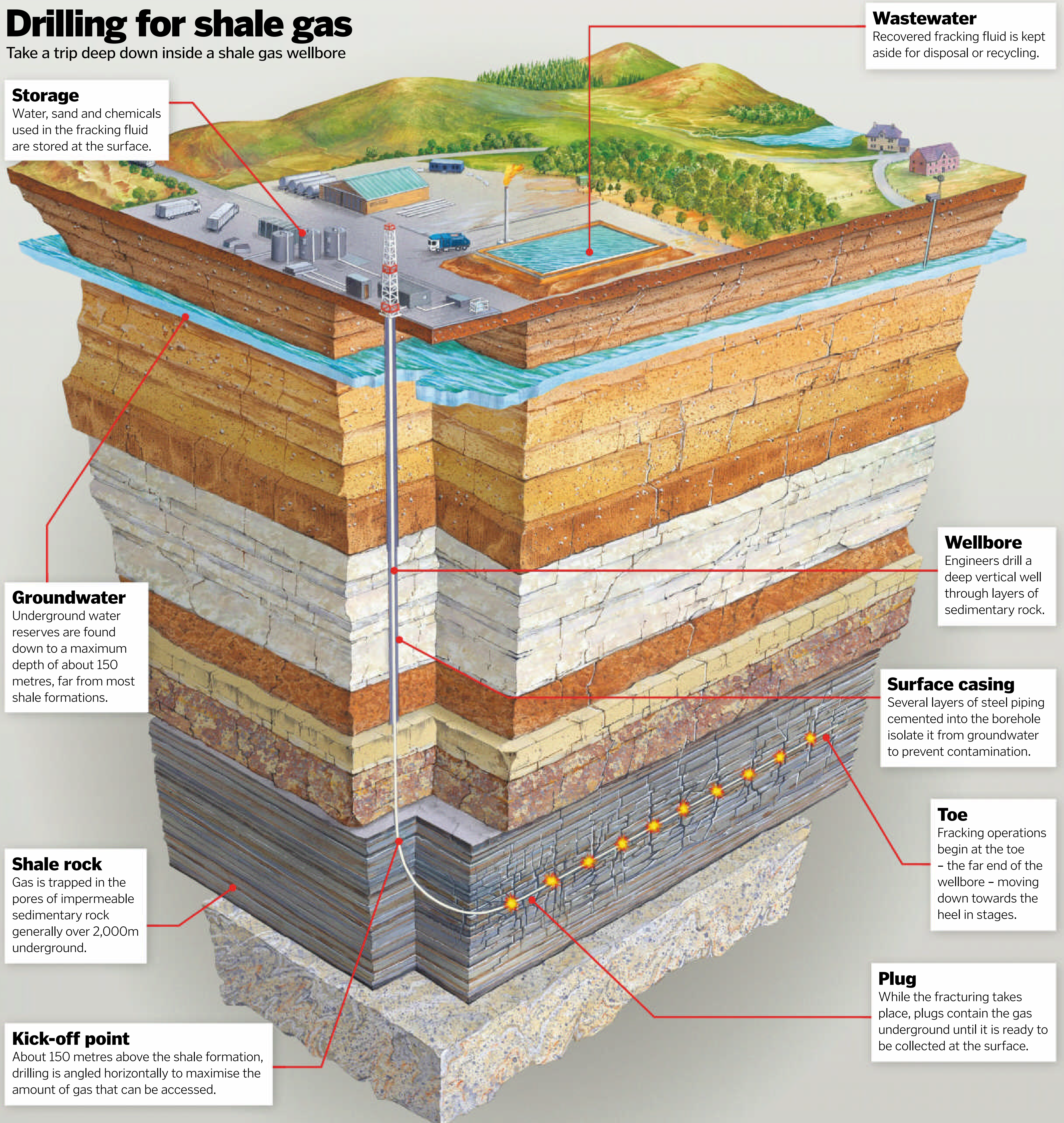
Fracking in action

Take a closer look at how fracking releases shale gas from rock



Drilling for shale gas

Take a trip deep down inside a shale gas wellbore



A focus on natural gas

Natural gas is a mixture of four naturally occurring gases. It's mostly methane, with smaller amounts of ethane, propane and butane. Highly flammable, it fuels stoves, water heaters and many other appliances in our homes, but is also used for industrial manufacturing and generating electricity.

Like oil and coal, gas is a fossil fuel which was produced underground millions of years ago as plant and animal matter was crushed under layers of sediment. While permeable rocks allow gas to rise through and collect in a large pool, impermeable shale rock traps the gas in tiny bubbles.

As with any fossil fuel, there is a limited supply of gas on Earth. Much of our remaining reserves are locked away in shale formations, so governments are increasingly turning to hydraulic fracturing in order to extract it, despite the risks and impact on the environment.

© SPL

RECYCLING

What kind of machinery do we use to take our everyday waste and make new products out of it?

Take a look around you. Practically everything that you see which is human-made can be recycled. Everything from this copy of **How It Works** you're holding, the wooden table you're sitting at, the fabric of the clothes you're wearing, the battery in your mobile phone, the components of your computer and even the materials that make up the building around you… But not everything is recycled – why is that?

What can and can't be recycled is quite an expansive question, but for domestic purposes, it depends very much on the recycling facilities available to your local authorities. Materials like paper and plastics – as long as they aren't too contaminated – can be processed and baled into a raw material ready for reuse. Metals – especially more valuable ones like lead, copper and aluminium – are highly sought after. All these materials have unique recycling processes that have been an established part of manufacturing for over a century, with scrap metal merchants and salvage yards forming a significant industry all of their own.

Many scrap electronics can be stripped down to make new products too. Car parts can be salvaged and gold can even be extracted from computer chips. For some materials, such as mercury, heavy metals like lithium and electrolytes in batteries, recycling might not make financial sense, but because of their toxic nature, recycling them is a legal requirement.

In this feature, we check out the specialised machinery and processes that take our daily refuse and turn it back into products that we can use again and again.

> *"Aluminium and copper are recovered with a magnetic field that repulses non-ferrous metals"*

Aluminium recycling

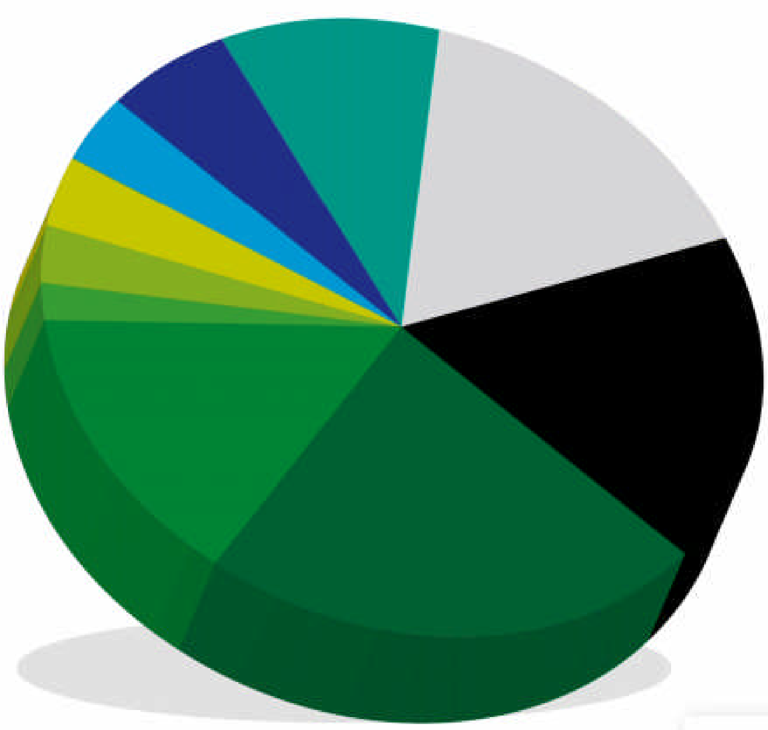
Aluminium in particular is highly sought after as a scrap metal. Because it is both lightweight and strong, it's used everywhere from drinks cans to aeroplanes. Extracting aluminium from its ore, bauxite, is relatively expensive, but salvaging it from scrap uses just five per cent of the energy needed to make new aluminium.

Like plastic bottles, a large percentage of recycled aluminium comes from beverage containers. The process is similar to plastics too. Once collected, they're separated from the other metals by an eddy current separator that splits the non-ferrous aluminium with a powerful magnet. The aluminium is shredded into pieces of uniform size, mechanically cleaned and then pressed into blocks to minimise oxidation. The blocks are loaded into a furnace and heated to around 750 degrees Celsius, at which point it becomes molten. The melted-down aluminium produces a surface scum known in the industry as dross, which is removed before high-purity aluminium is added to bring the molten aluminium up to the required grade. The furnace is then rolled onto its side and the liquid aluminium poured out. The end product is either atomised aluminium powder or ingots. Because aluminium isn't transmuted by this process, it's just as good as the new stuff and can be recycled indefinitely.

Once old aluminium has been processed, it can be melted down to make new products time and again

UK refuse breakdown

HIW reveals the various materials which make up annual household waste in Britain

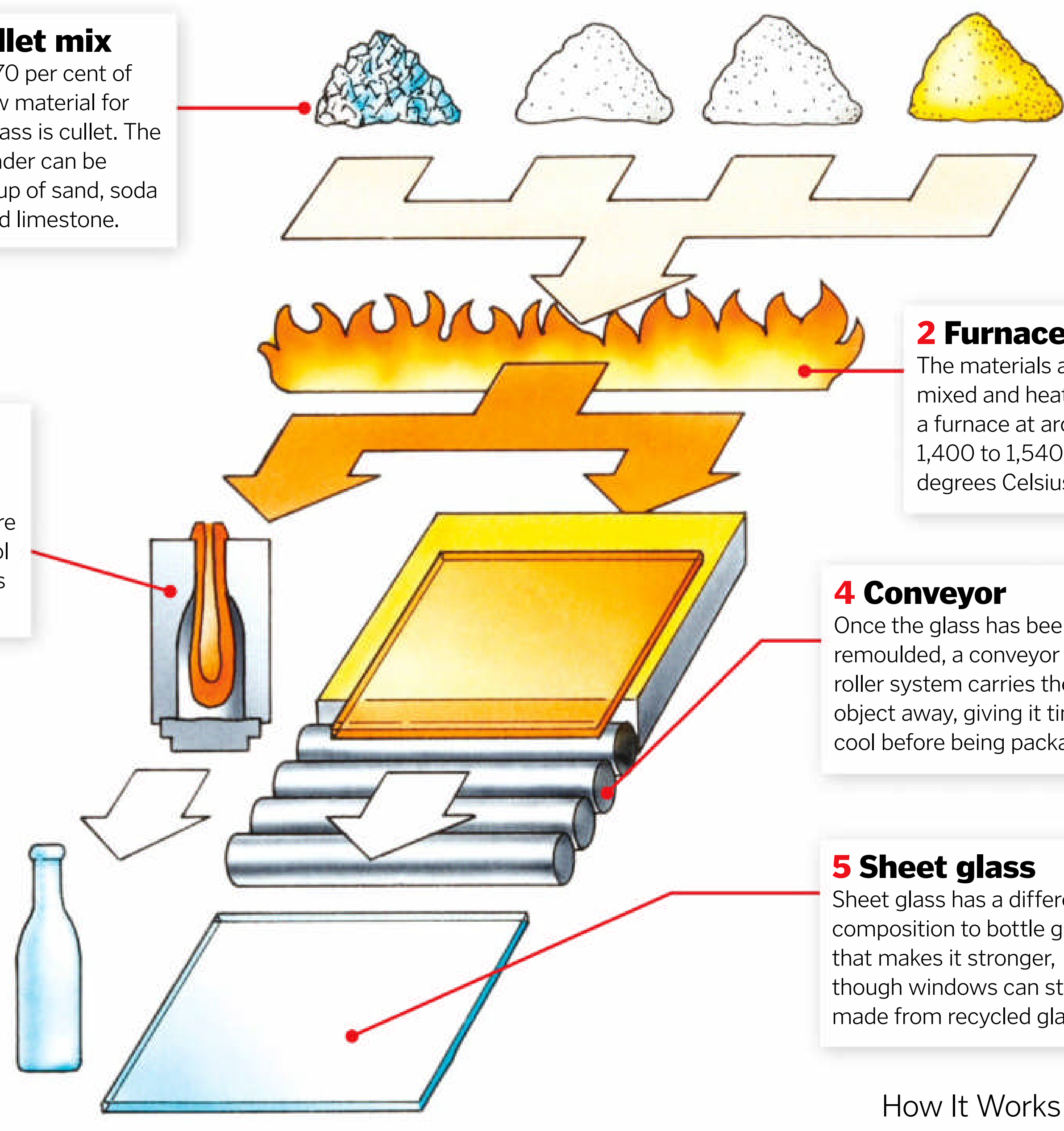


- Waste electricals: **2%**
- Textiles: **3%**
- Wood: **4%**
- Metals: **4%**
- Glass: **6%**
- Plastics: **10%**
- Garden and organics: **16%**
- Food: **18%**
- Paper and card: **23%**
- Other: **14%**

Source: Defra (2006-7)

Glass recycling

Glass recycling is an old industry that has evolved over decades. A large proportion of glass still makes up household and industrial waste, most of it bottles and glassware. Glass from bottle banks and household recycling is collected and taken to a cullet processing plant. Manual sorting separates metal and plastic contaminants as well as the various glass colours: chemicals used for different coloured glass can't be removed. The glass is washed and often passed through a ferrous metal removal machine to capture any metal contaminants that could damage machinery and taint the quality of the final product. The glass is next passed through a belt crusher that pulverises it to a uniform grade. The material is now known as cullet and is ready to be made into new products.



1 Cullet mix
Up to 70 per cent of the raw material for new glass is cullet. The remainder can be made up of sand, soda ash and limestone.

2 Furnace
The materials are mixed and heated in a furnace at around 1,400 to 1,540 degrees Celsius.

3 Mould
Melt glass for bottles is poured into a mould, where it is allowed to cool and solidify into its new form.

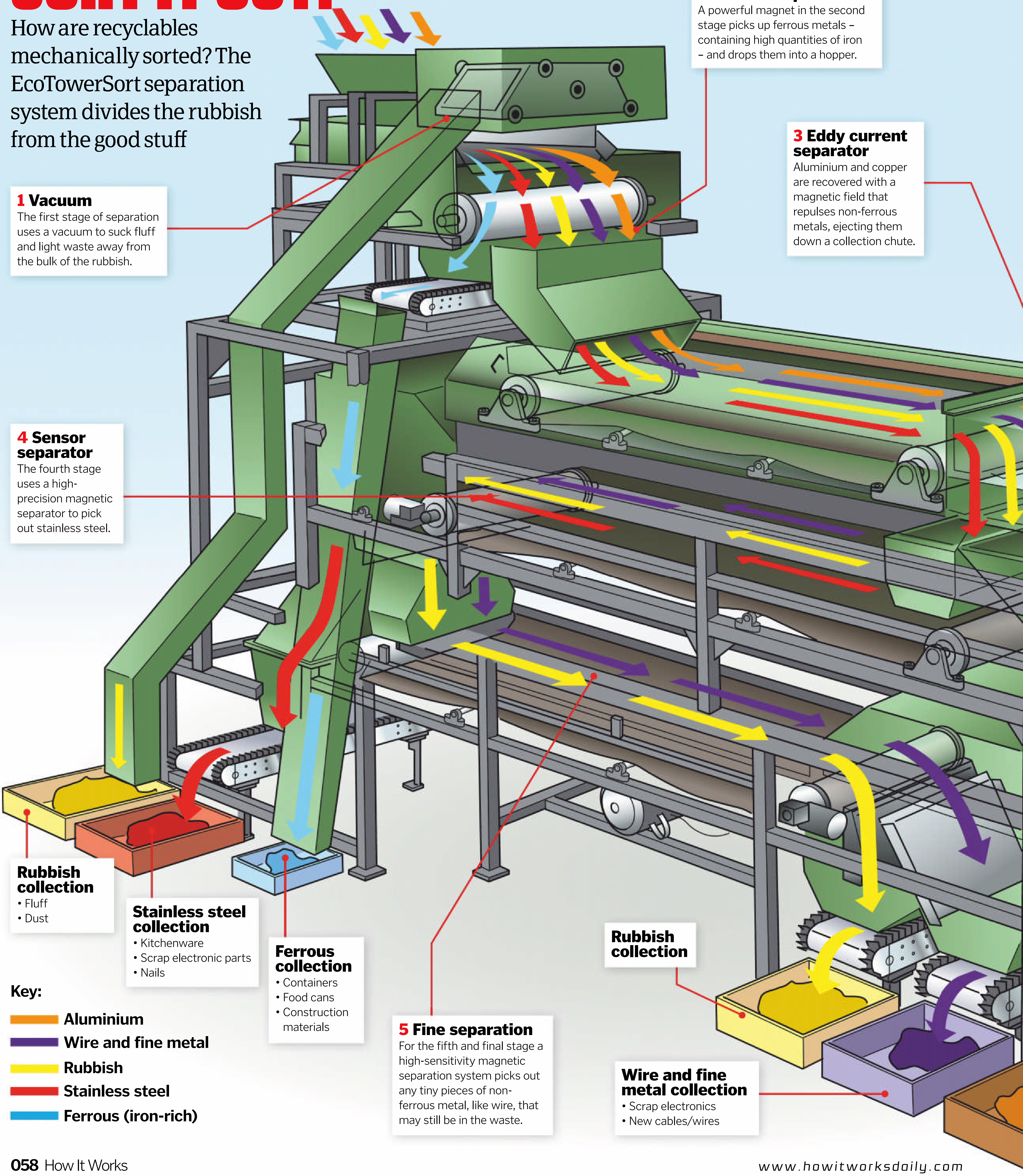
4 Conveyor
Once the glass has been remoulded, a conveyor or roller system carries the object away, giving it time to cool before being packaged.

5 Sheet glass
Sheet glass has a different composition to bottle glass that makes it stronger, though windows can still be made from recycled glass.

© Thinkstock

SORT IT OUT!

How are recyclables mechanically sorted? The EcoTowerSort separation system divides the rubbish from the good stuff



1 Vacuum
The first stage of separation uses a vacuum to suck fluff and light waste away from the bulk of the rubbish.

2 Ferrous separation
A powerful magnet in the second stage picks up ferrous metals – containing high quantities of iron – and drops them into a hopper.

3 Eddy current separator
Aluminium and copper are recovered with a magnetic field that repulses non-ferrous metals, ejecting them down a collection chute.

4 Sensor separator
The fourth stage uses a high-precision magnetic separator to pick out stainless steel.

5 Fine separation
For the fifth and final stage a high-sensitivity magnetic separation system picks out any tiny pieces of non-ferrous metal, like wire, that may still be in the waste.

Rubbish collection
- Fluff
- Dust

Stainless steel collection
- Kitchenware
- Scrap electronic parts
- Nails

Ferrous collection
- Containers
- Food cans
- Construction materials

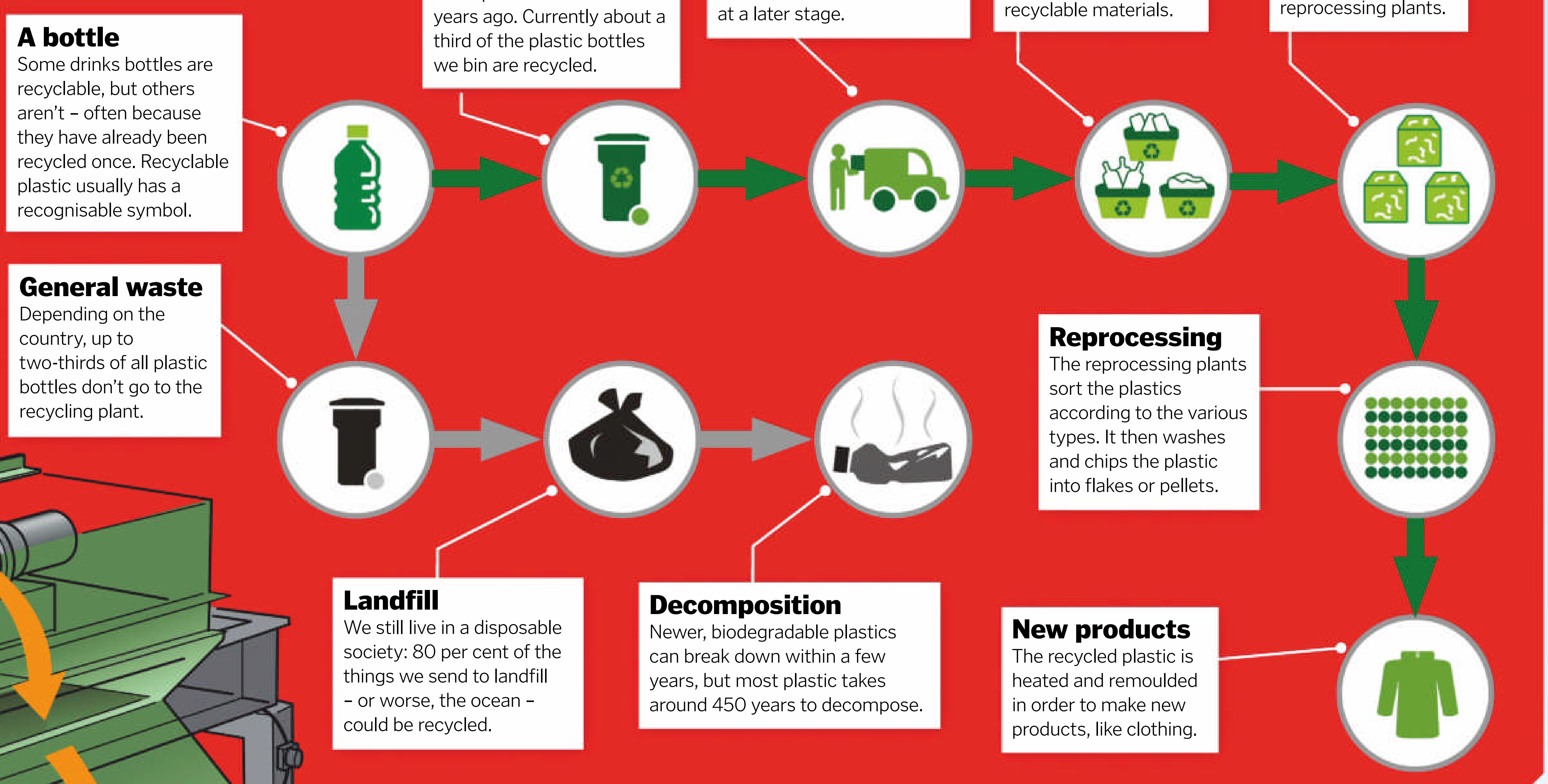
Rubbish collection

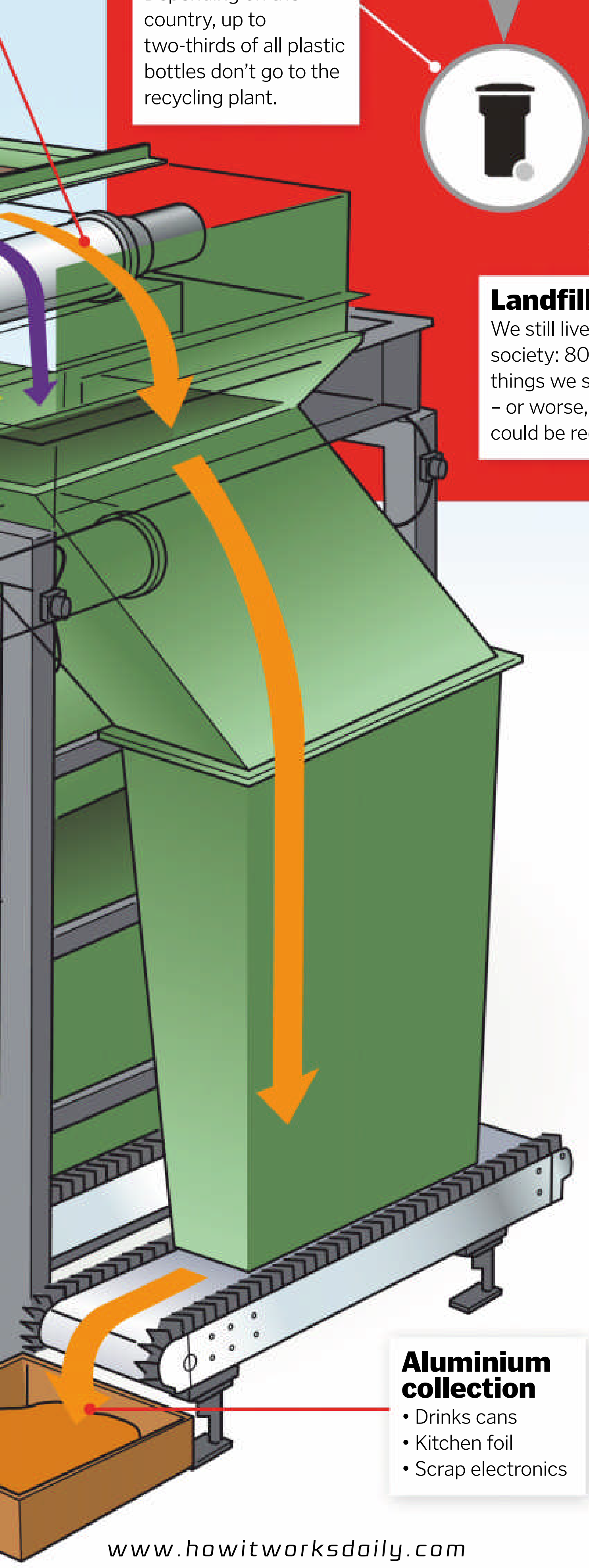
Wire and fine metal collection
- Scrap electronics
- New cables/wires

Key:
- Aluminium
- Wire and fine metal
- Rubbish
- Stainless steel
- Ferrous (iron-rich)

What happens to my drinks bottle?

Take a look at the two potential life cycles of a plastic bottle





Recycling in numbers

40KG
Plastic wasted by a family annually

£36m
Cost of aluminium thrown away per year

50%
The amount of glass that is recycled in the UK

250 million
trees saved if all US newspapers were recycled

24 trees to make one tonne of paper

25
recycled PET bottles can be used to make an adult's fleece jacket

500 years
How long it takes for a nappy to decompose

© Peters & Zabransky

The father of GPS

Bradford Parkinson is the engineer behind the navigation system that we rely on daily

© Queen Elizabeth Prize for Engineering

Parkinson served 21 years in the US Air Force

© USAF

Air Force Colonel Bradford Parkinson was lead architect for the Global Positioning System (GPS) program. In 1973 he convinced the US Air Force of the value of a new satellite-based navigation system. By building satellites and experimenting to improve them, Parkinson and his team provided the world with accurate positioning, navigation and timing services. The first GPS satellite was launched into space just 44 months after the team's program was approved. Parkinson went on to become a professor at Stanford University in 1984, the same university that he graduated from with a PhD in guidance control navigation. There he continued to explore the multitude of applications his team's satellite service could achieve, including robotic tractors. From the maps on our phones to real-time aircraft positioning for pilots, Parkinson's lead role in this groundbreaking technology has resulted in some declaring him the 'father of GPS'.

How did you get into engineering?
I don't think I ever thought of myself as anything other than an engineer. It was not a serious question to me. When I was young, I made electronic amplifiers from scratch. This was back in the era of vacuum tubes, and they were all discrete components. I went to the US Naval Academy in Annapolis and education there was principally engineering, so I felt right at home. I graduated and went out in the Air Force as an engineering officer, and there I was trained in aircraft avionics.

Whose idea was it to create GPS?
There had been a previous satellite navigation system called Transit. It was, by our standards, quite crude, but it was worldwide. GPS can provide 24/7, 365 days a year coverage to the whole Earth, and Transit couldn't do that. It would give you a relatively crude fix once every two or three hours. It was good enough for some Navy ships, but it wasn't good enough to land aeroplanes. A study was done, and 12 techniques were highlighted as ways to navigate using space satellites. We selected the hardest, which provided four dimensions: latitude, longitude, altitude and very precise time.

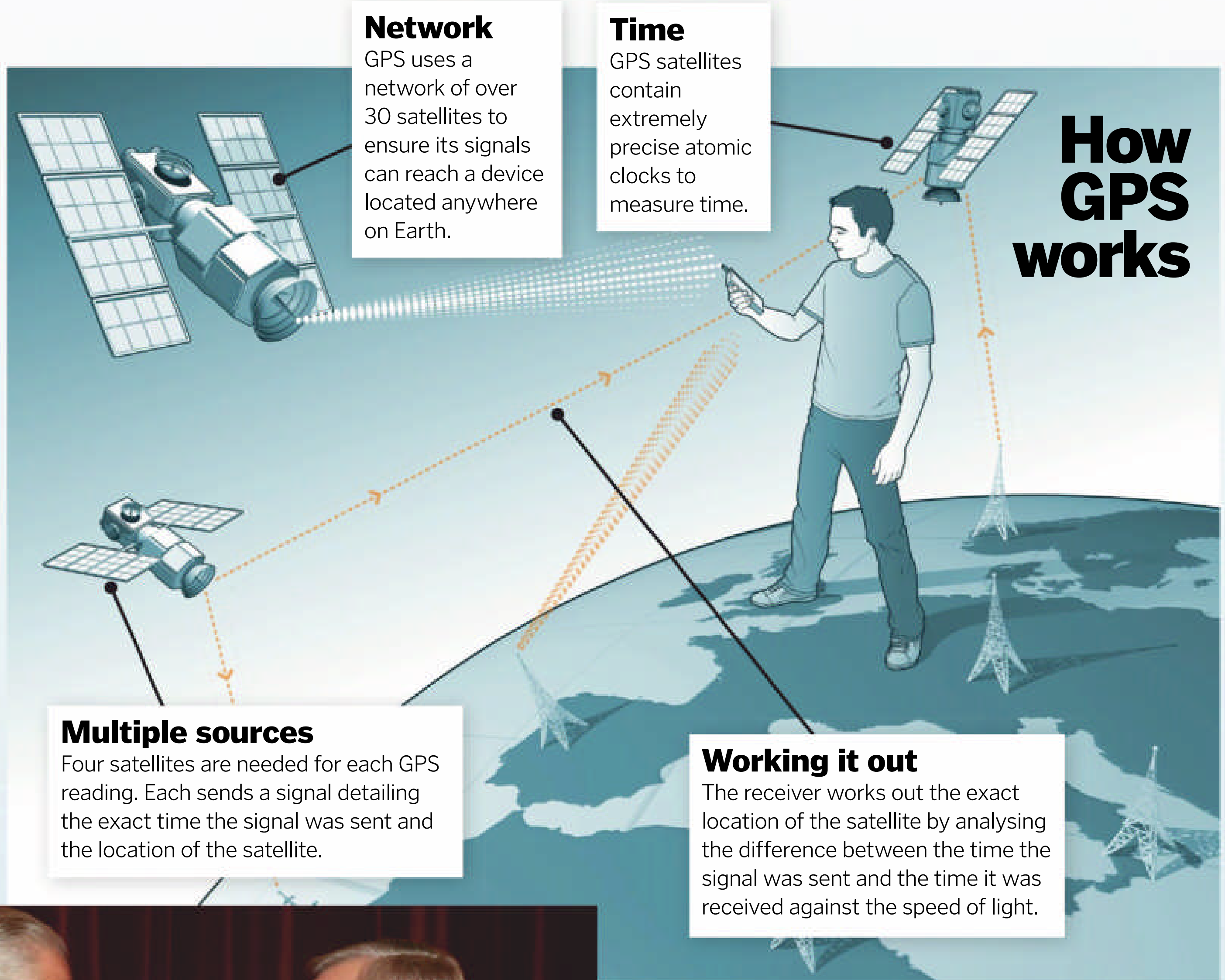
Two important breakthroughs had to occur. First we had to come up with a signal that was very unique. Back then we were experimenting with a new signal that was so quiet that if you looked at the radio spectrum you wouldn't see it at all. Now everyone accepts it as a GPS signal, but there was great scepticism that it could be good enough to navigate. Today we navigate to a millimetre with it.

Secondly, we wanted the satellites to go around the Earth, be autonomous and have clocks with stability better than one second in 300,000 years. We were trying to measure time to a fraction of a billionth of a second.

How did the Air Force respond?
The Air Force did not want this system; they fought it tooth and nail. I got in a lot of trouble in the Pentagon. I remember the two-star general taking his finger and sticking it in my chest and saying: "Parkinson, if you keep advocating this your career is going to go down in flames."

Why didn't they want it?
They wanted aeroplanes, not satellites. It cost a lot of money, and they couldn't envision what precision would do for them. Even after we ran the tests and met every single one, the Air Force still tried to cancel the whole thing. Now the Air Force fully embraces it. The reason the signal is so reliable – and it is very reliable at 99.98 per cent on any given satellite, and for the whole system even better

© Getty



– is because it is operated by young Air Force sergeants and lieutenants. Everyone says that's not a good idea, but these are great people, really good people. I'm proud of them.

How did the Air Force come to accept it?
They were forced to accept it. It turned out Dr Mal Currie, who was in charge of all the development for the whole Department of Defense, had come to our offices. He was a bright guy with a PhD in physics. I spent three hours with him – it was just me, a very young colonel and group captain, and the Defense Department's development leader. And at the end of that time, he emerged and became a champion of us.

Who was on your team?
Within my office there were 50 or 60 Air Force officer engineers that I had hand-picked. In almost all cases, they were officer engineers who worked with real hardware. They typically had master's degrees from MIT, Stanford, Michigan – the big engineering schools. Six of us had PhDs. This was an extremely competent group of people. When asked if a lot of people worked for me, I like to say they were working with me. They were working for me, but these were the kind of people you admire, and I trusted them. It was sort of like combat.


Parkinson received a Queen Elizabeth Prize for Engineering in 2019 for his contributions to GPS

© Getty

What other challenges did you face?
Early on I realised I was getting really stressed leading this, but I had a solution. At noon I wouldn't eat lunch. I would go and run. I'd been in the office from seven to noon, and by that time the problems had gotten pretty thick. Running was sort of a zen thing. I would contemplate the problems, and by the time I came back to the office I knew what to do. It was important.

Usually I'd run alone, but because my schedule was full, my guys knew that if they couldn't get in to see me, they could run with me and talk about anything they wanted. On Fridays we'd all start running as a big band of 10 or 12 of us, and I was a pretty fast runner back then. We were doing these big two mile loops, and I would hold it at eight-minute miles. The guys that had something to talk about would run the first two miles, and those who could would run the next two, until there was just one lieutenant. Boy, was he fast. As soon as everyone else left, we'd pick up the pace and finish off the ten miles. I got into marathoning, and I would say at least a dozen of my officers became marathoners. They did have a saying: 'Run for your career'.

Before GPS launched, what did you think the most beneficial application would be?
I knew that the Air Force in World War II had to do, in essence, carpet bombing. What was called 'precision weapon delivery' was if they dropped a bomb within a quarter mile of the target. And I was saying: "Let's do that within 30 feet [nine metres]." Precision was the number-one purpose in my mind, so that when the military decides it has to take out a target, that it was that target, and not a mosque, or a school or a hospital. I called it a weapon system for humanity. That sounds strange, but to me that's what it was.

I also recognised that there were civilian applications. From the get-go I declared that there was going to be a civil signal available. We weren't going to guarantee accuracy, but it was going to be available. Within 24 hours of turning that satellite on, the students under Peter Daly at the University of Leeds, UK, became the first civil set to use the very first satellite we launched.

Are there any current GPS applications you didn't expect?
There's all kinds of them. I knew we could position to a metre or two, and I knew there was a technique to get down to millimetres, but it involves a signal-processing technique that I didn't think was robust. Engineers proved me wrong. If you can do that, you can use it for automatic landing of aeroplanes. In your cell phone there is a little chip that costs about $2 [£1.50]. It has roughly 10,000 times the capability of the receivers that we built for a quarter million dollars. If you have accuracy, and it's cheap and affordable, all of a sudden the whole world opens up. It's a tribute to engineers who keep building on the previous generation and making things bigger, better and cheaper. I didn't expect these applications. I envisioned some things, but at the time I envisioned them it demanded both that the accuracy would be improved and that the cost had to go down.

Design the next QEPrize trophy

The Queen Elizabeth Prize for Engineering is a global prize that celebrates the successes of modern engineering. If you are aged 14 to 24 with a talent for 3D design, the next trophy could be designed by you. Scan the QR code for details on how to enter the 'Create the Trophy' competition. Closing date for entries is 21 December 2020.

Inside the Apple Watch Series 6

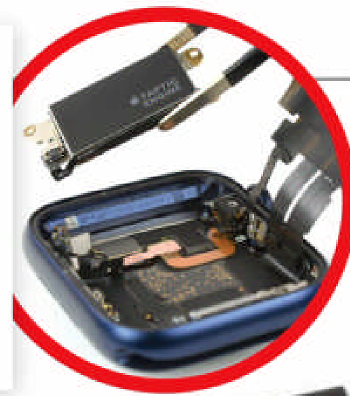
How It Works peeks inside the latest wearable fitness tracker

Smart watches enable wearers to manage and track their fitness, message and call contacts, consult a voice assistant and more – all from a single wrist accessory. Working as a portable and accessible extension of your mobile phone, Apple's watches have become the highest selling wearable tech products in the world. The latest addition to Apple's smart watch series was released in September 2020.

But what can this watch do? Thinner than its predecessor, the Series 6 monitors your health during both the day and night. Tracking the wearer's movements, it comes with a built-in altimeter, constantly providing you with your elevation in real-time. This comes in handy with the compass application, adding an extra element to its potential as a navigational tool.

Many Apple Watch wearers use the device to monitor their workouts, and this model has made changes to improve this function. While there are few major changes to the design from the Series 5, one is a longer lasting battery to limit the likelihood of battery drainage cutting short any fitness analysis.

The watch's sleek design and the ability to navigate personal applications at the touch of a finger work seamlessly – the tech gets to know your own body better than you do. We've deconstructed the device to assess its discrete components and discover what makes this watch tick.



© iFixit

Taptic Engine
Made using recycled rare-earth metals, the Taptic Engine detects your fingers' taps at different pressures as well as creating vibration notifications. It is bigger than that in the previous series.

Magnetic core
The dense rectangular magnet helps to centre the watch during charging, and is surrounded by LEDs and sensors.

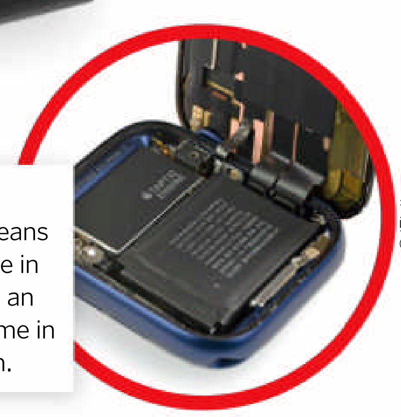
Rubbery material
To reduce impact, the backplate and bezel found around the display is rubber-like.

Bright display
Previous Apple Watches are dimly lit, brightening when the user raises their wrist, but the always-on default mode of this series means it is two-and-a-half-times brighter when the wearer's wrist is down.

© iFixit

Water resistance
This is the first Apple Watch to use liquid-crystal polymers and is water resistant up to 50 metres.

Better battery
Fully charging in 1.5 hours means the S6's battery is an upgrade in speed, while still maintaining an 18-hour battery life. They come in two sizes: 40mm and 44mm.



© iFixit

Timepiece teardown

What tech keeps Apple's new watch ticking beneath its touchscreen?

© iFixit

Rear sensor
Red, green and infrared light can detect biometrics through skin, such as how much oxygen is in the wearer's blood. The photodiode senses how this light is received when it bounces back to the device.

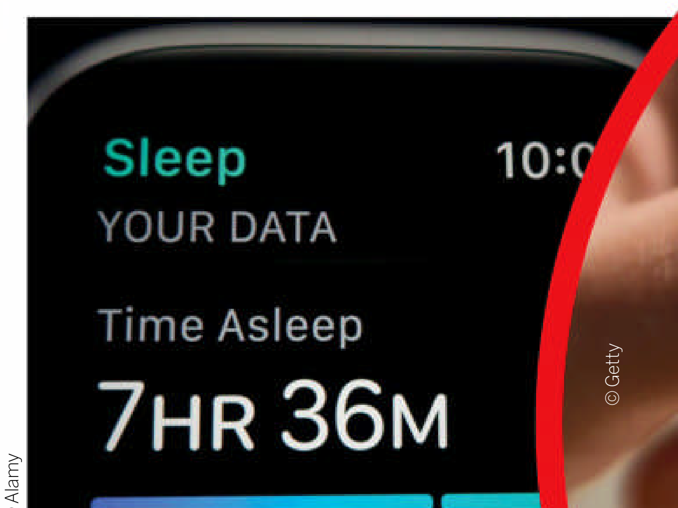
© iFixit

S6 package
20 per cent faster than the S5's, the brain of this watch is covered in a protective hardened resin.

© iFixit

Blood oxygen sensing

New to the Series 6 Apple Watch, one of the biggest updates from the Series 5 is its ability to track the saturation of oxygen in your blood. At a time when blood oxygen levels are useful early indicators of viruses such as the coronavirus, this function allows wearers to get a more rounded picture of their general wellness. The sensor is able to calculate the colour of the blood using updated algorithms. Brighter red indicates that more oxygen is present in the blood, while dark red blood contains less oxygen. The wearer is presented with a blood oxygen percentage within 15 seconds of a reading.



© Alamy

The watch can display your sleep activity during the night

© Getty

The watch takes background readings throughout the day, but these can be displayed on demand at any time

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ELECTRICITY EXPLAINED

Learn some shocking facts behind the everyday energy we take for granted

Many people think of electricity as something you buy from the power companies, but as well as coming out of the wall socket, electricity is one of the many ingredients that make up the universe.

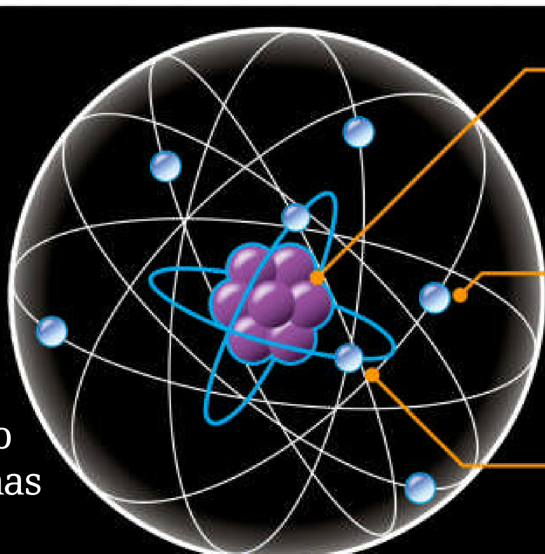
Everything in the universe is made of minuscule atoms, and these atoms consist of a nucleus orbited by one or more electrons. These electrons carry a negative charge, while the nucleus is positively charged.

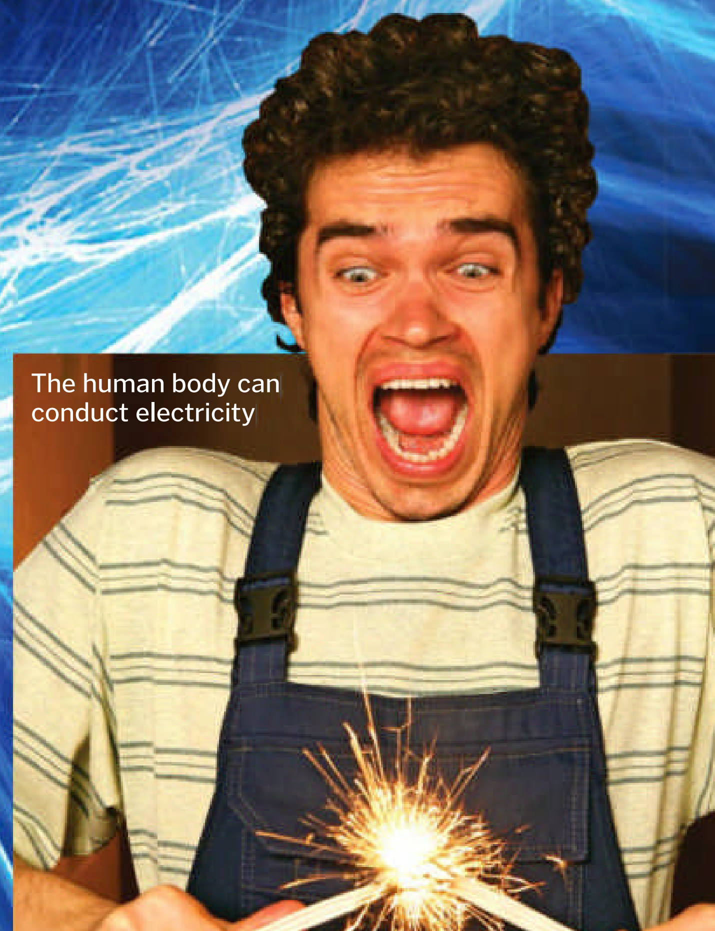
We're all familiar with the effects of static electricity. We are not often aware of electricity around us as the positive and negative charges usually balance. When certain objects touch, electrons can jump between them. For instance, when you rub a balloon on your hair, electrons will jump across to the balloon, giving the balloon stationary negative charge, or static electricity. Static electricity relies on electrons not being able to move around easily. Materials like wood, glass, ceramics and cotton all have electrons that like to stick with their atoms, and because the electrons don't move the materials can't conduct electricity very well.

In most metals, electrons can move freely to form an electric current. When charges move, current electricity is formed, and this is the power that drives much of the contemporary world. Current can be measured by the amount of charge passing a fixed point each second.

Inside an atom

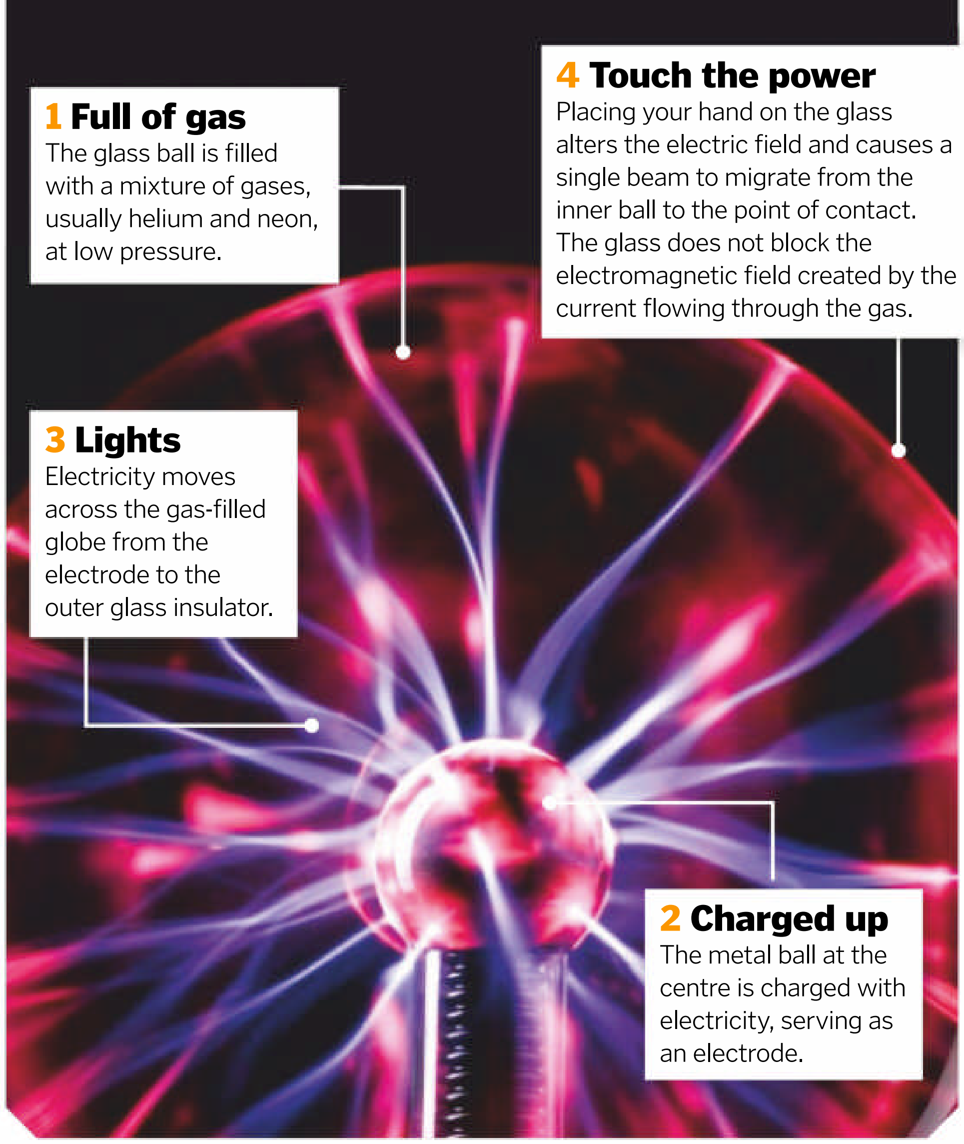
Atoms are held together by electricity. The positive nucleus attracts negative electrons. The two cancel each other out so the atom has no electric charge




The human body can conduct electricity

Plasma balls: static incarnate

They went out of fashion in the 1980s, but still demonstrate electricity really well



1 Full of gas
The glass ball is filled with a mixture of gases, usually helium and neon, at low pressure.

2 Charged up
The metal ball at the centre is charged with electricity, serving as an electrode.

3 Lights
Electricity moves across the gas-filled globe from the electrode to the outer glass insulator.

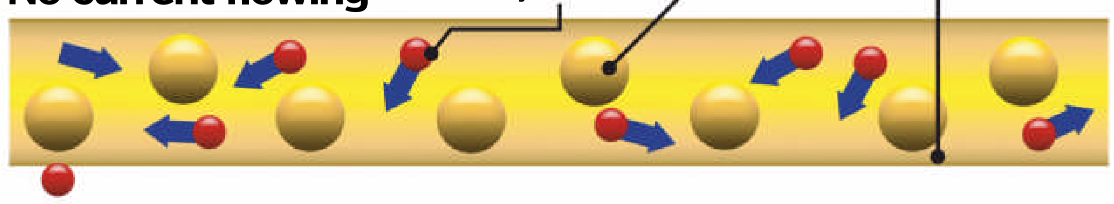
4 Touch the power
Placing your hand on the glass alters the electric field and causes a single beam to migrate from the inner ball to the point of contact. The glass does not block the electromagnetic field created by the current flowing through the gas.

Conductors

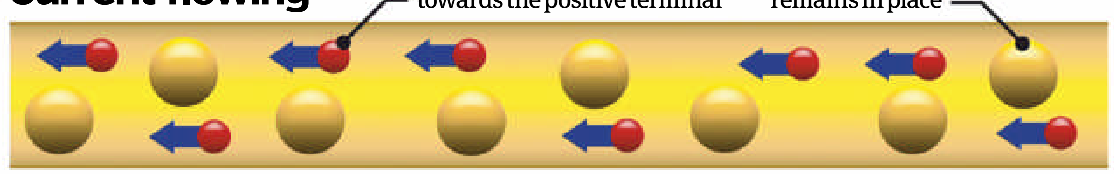
Very simply, a conductor is a material that allows electric charge to pass along it as a current. As stated, metals make good conductors as the electrons of their atoms are loosely bound and free to move through the material. For instance, in copper the electrons are essentially free and strongly repel each other. Any external influence that moves one of them will be replicated through the material.

A superconductor is a material that has no resistance at all to the flow of current when kept below a certain temperature. For most superconducting materials, the critical temperature is below about 30 Kelvin, 30 degrees Celsius above absolute zero.

No current flowing

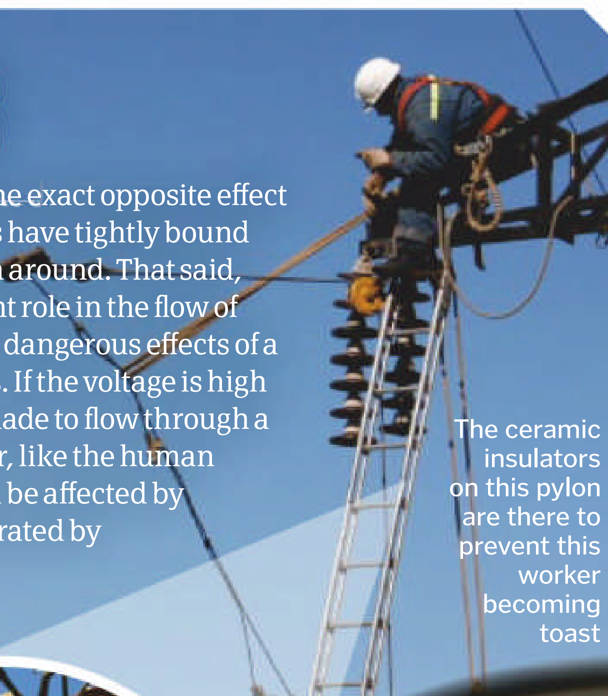


Current flowing



Insulators

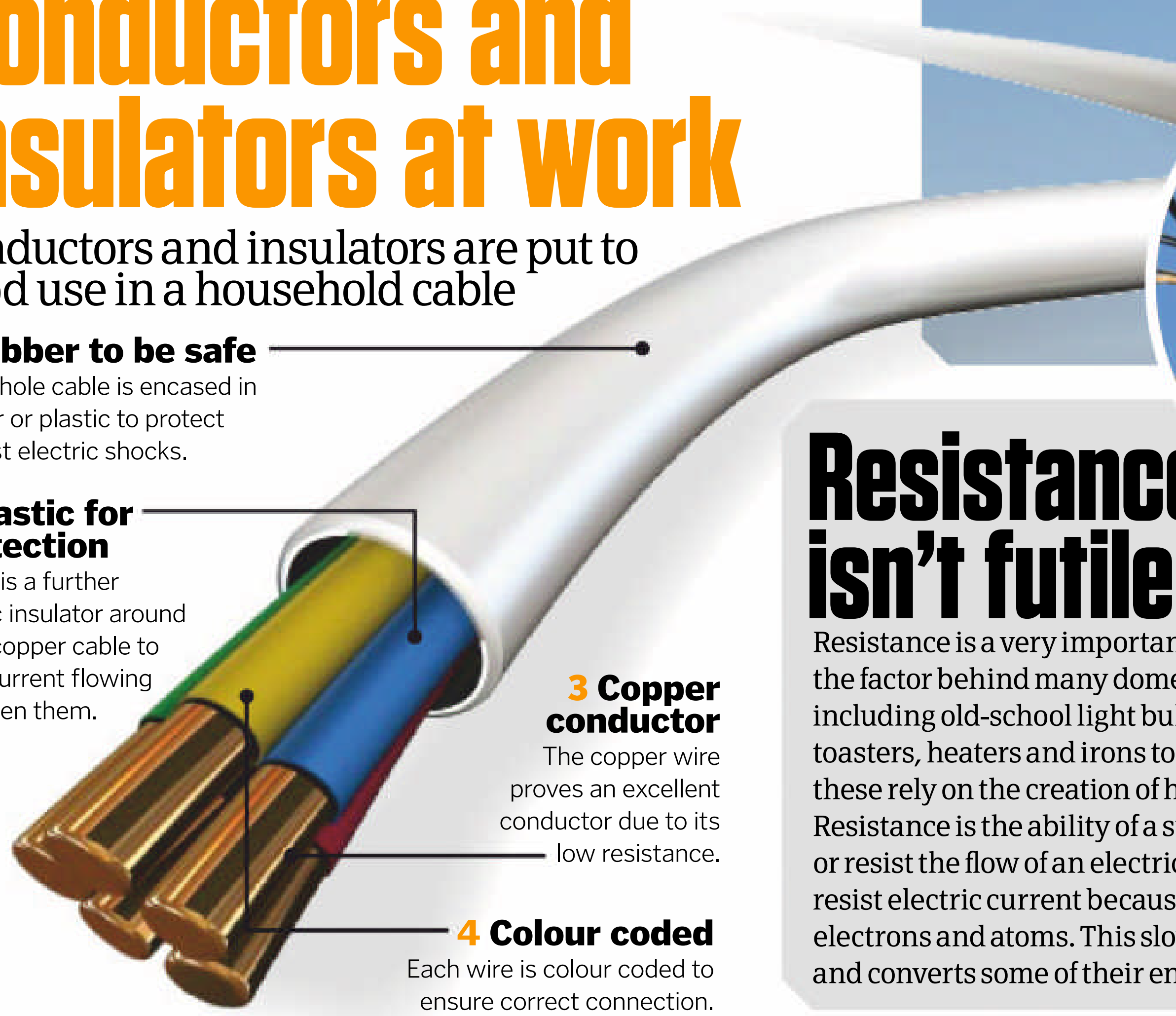
Insulators are materials that have the exact opposite effect on the flow of electrons. Their atoms have tightly bound electrons which are not free to roam around. That said, insulators can still play an important role in the flow of electricity by protecting us from the dangerous effects of a current flowing through conductors. If the voltage is high enough an electric current can be made to flow through a material that is not a good conductor, like the human body. The function of our hearts can be affected by an electric shock, and the heat generated by the current can cause burns.



The ceramic insulators on this pylon are there to prevent this worker becoming toast

Conductors and insulators at work

Conductors and insulators are put to good use in a household cable



1 Rubber to be safe
The whole cable is encased in rubber or plastic to protect against electric shocks.

2 Plastic for protection
There is a further plastic insulator around each copper cable to stop current flowing between them.

3 Copper conductor
The copper wire proves an excellent conductor due to its low resistance.

4 Colour coded
Each wire is colour coded to ensure correct connection.

An electric current passes through a thin filament, heating it so that it produces light

Resistance isn't futile

Resistance is a very important property; it's the factor behind many domestic appliances including old-school light bulbs, kettles, toasters, heaters and irons to name a few. All of these rely on the creation of heat energy.

Resistance is the ability of a substance to prevent or resist the flow of an electrical current. Materials resist electric current because of a collision between electrons and atoms. This slows the electrons down and converts some of their energy to heat energy.

Circuits

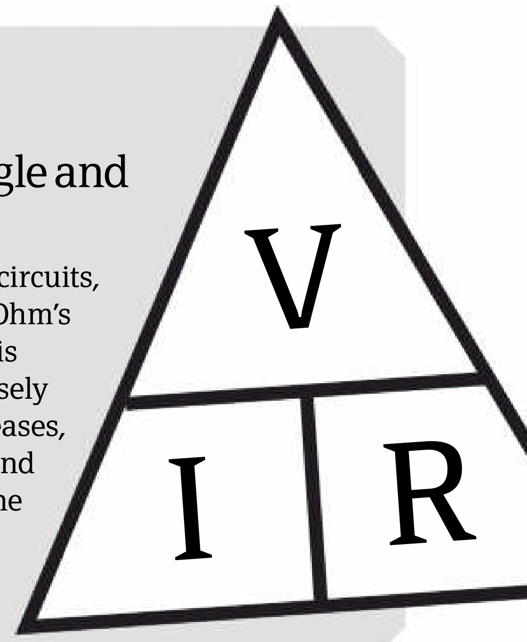
Putting electricity to work all over the world

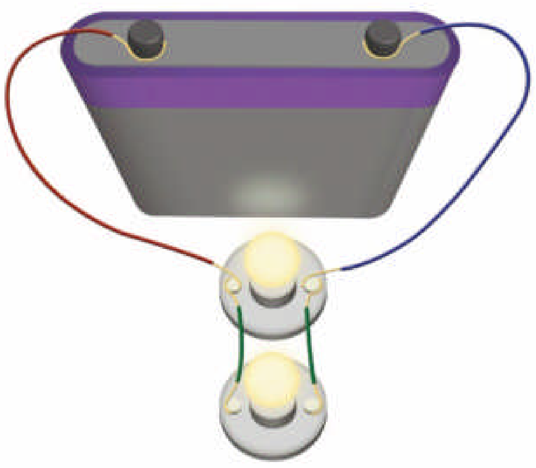
Now that we've explained where electricity comes from, it's time to look at some of the work it can do for us. Electricity can't do much work without circuits as these provide a path for the electricity to flow around. Circuits include devices such as resistors, which control the flow of voltage, or difference in electrical charge, and capacitors, which store electrical charge and come in one of two types: series and parallel.

Laws of circuits

An explanation of Ohm's triangle and why it is important

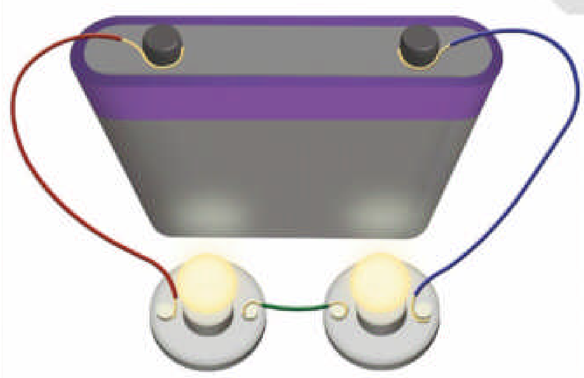
There are many laws that apply to electrical circuits, but Ohm's law is one of the most important. Ohm's law states that an electrical circuit's current is directly proportional to its voltage and inversely proportional to its resistance. If voltage increases, for example, the current will also increase, and if resistance increases, current decreases. The formula for Ohm's law is V = I x R, where V = voltage in volts, I = current in amperes and R = resistance in ohms.





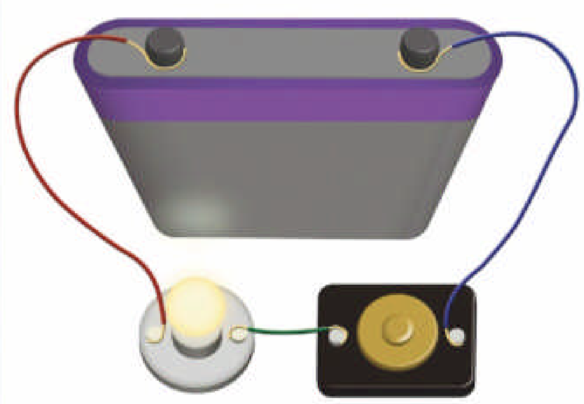
Parallel circuits

In a parallel circuit there is more than one pathway between its beginning and end. Since the electricity has more than one route to take, the circuit can still function should one component fail. This means that parallel circuits are much less prone to failure than the series variety. For this reason parallel circuits are the kind you will find in most everyday applications such as domestic appliances and household wiring.



Series circuits

A series circuit has more than one resistor and only has one path for the charges to move along. A resistor is anything that uses electricity to do work – in this case, light up bulbs – and the electric charge must move in series from one resistor to the next. If one of the components in the circuit is broken then no charge can move through it. An example of a series circuit is old-style Christmas lights – if one bulb breaks the whole string goes out.



Circuit control

The simplest electrical control is a switch. This simply breaks the circuit to stop the current flowing, and this is most notably seen in domestic light switches. They may seem simple, but the most complex computers are made from millions of electronically controlled switches.

CIRCUIT JARGON

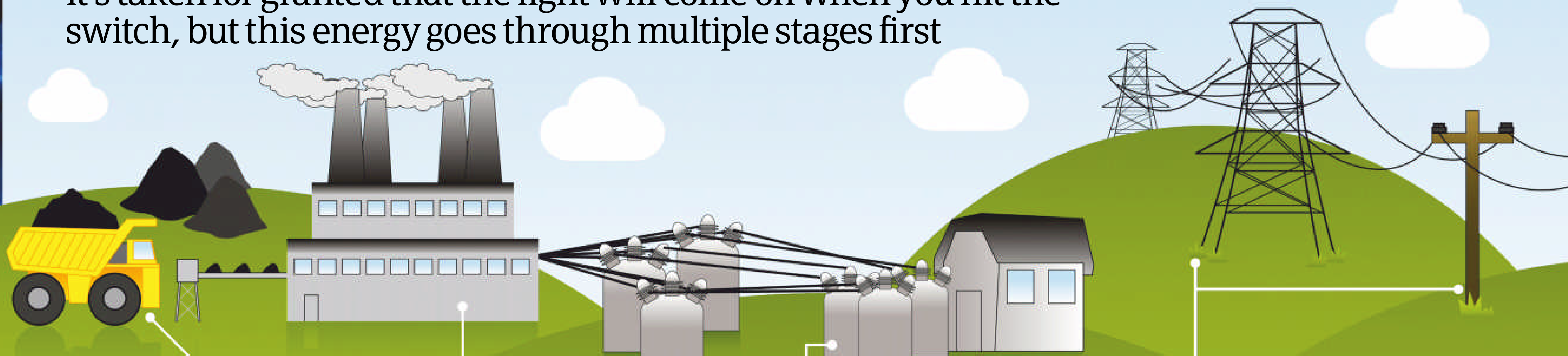
Current
The flow of an electric charge. Unit: Ampere; Symbol: A.

Voltage
Electrical potential difference, the force that drives the current in one direction. Unit: Volt; Symbol: V.

Resistance
The opposition of an object to having current pass through it. Unit: Ohm; Symbol: Ω.

How electricity reaches your home

It's taken for granted that the light will come on when you hit the switch, but this energy goes through multiple stages first



1. Coal or nuclear
Coal is burnt at the electricity plant to generate steam. Nuclear power stations use a different method, and so do hydroelectric plants, wind farms and solar panels.

2. Generation
Be it nuclear, coal-fired or hydro, a turbine spins a huge magnet inside a copper wire. Heat energy converts to mechanical energy, which then converts to electrical energy in the generator.

3. Danger: high voltage!
The electricity then flows though heavily insulated wires to a step-up transformer. This raises the voltage so it can travel long distances over the grid. It's raised as high as 756,000 volts.

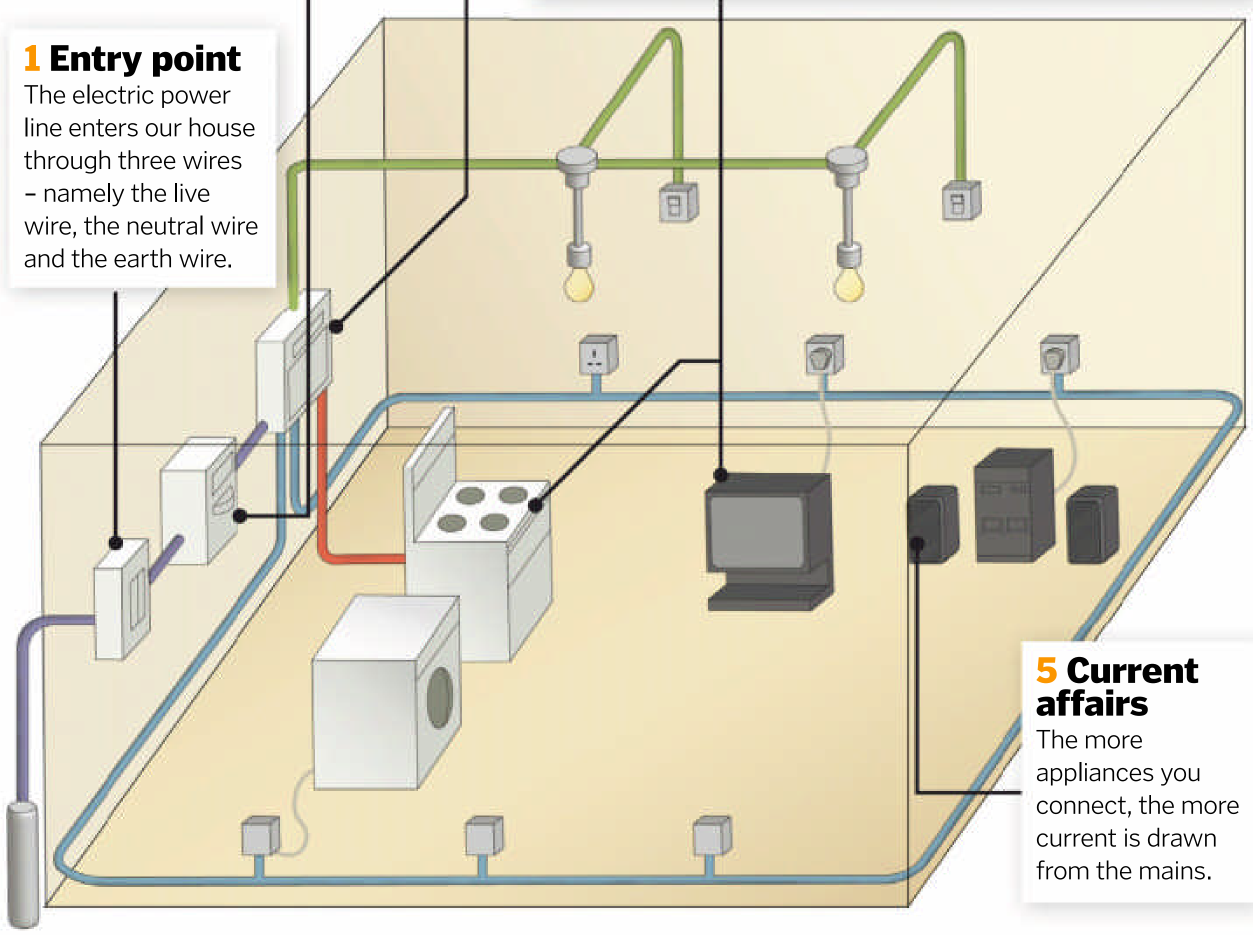
4. Transform it
The electricity then runs along the power lines until it reaches a substation. This lowers the voltage to around 2,000 to 13,000 volts.

5. Pylons
The current continues along the lines to another transformer, either a pole transformer or an underground box, and voltage is lowered again to between 120 and 240 volts.

6. Service with a spark
The next stop is the service box at your home. Here your meter will measure how much power you use. Wires then take the electricity around your home, powering your lights and everything else.

Electricity in your home

Once electricity reaches your home, how does it get around?



2 Electricity meter
Electricity meters are typically calibrated in billing units, the most common one being the kilowatt hour. Periodic readings of electric meters establish billing cycles and track the energy used during a cycle.

3 Distribution box
This contains the main switch and fuses for each circuit.

4 Appliances of science
Domestic appliances are connected in parallel. In a parallel circuit, even if there is a fault or short-circuiting in any one line, the corresponding fuse blows off, leaving the other circuits and appliances intact. This prevents damage to the entire house.

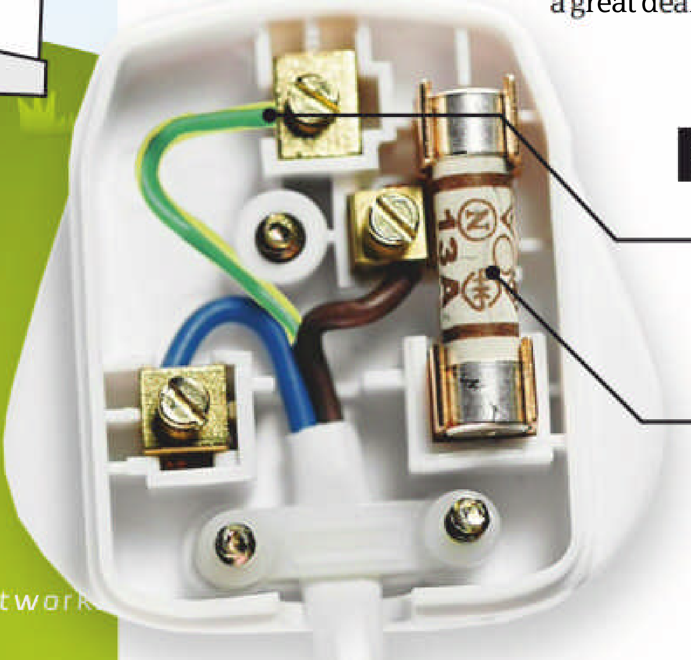
1 Entry point
The electric power line enters our house through three wires – namely the live wire, the neutral wire and the earth wire.

5 Current affairs
The more appliances you connect, the more current is drawn from the mains.

Why are British plugs so big?

We owe our plugs to World War II

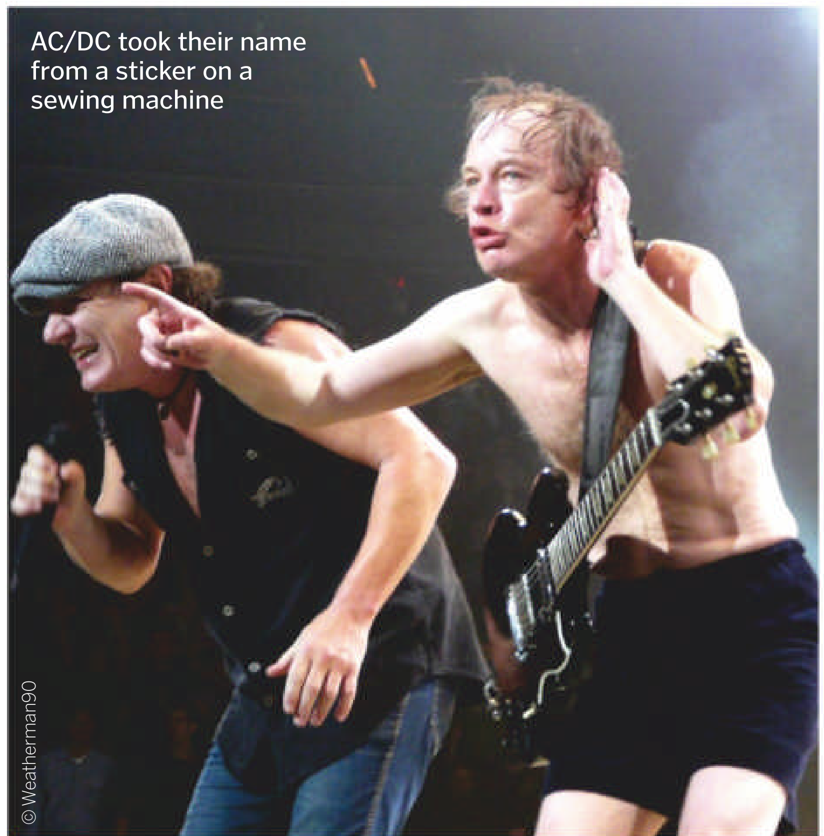
Visitors to and natives of the British Isles get to use one of the weirdest plugs in the world; unlike many other plugs it has a fuse built in. After being bombed heavily by the Germans during WWII, much of the country had to be rebuilt. Building supplies were short, so rather than wiring each socket to a fuse board they were linked together on one wire and the fuses put in each plug, saving a great deal of copper in the process.



Inside a British plug

1 Ground to earth
The earth wire is there to prevent electric shocks and is secured by a screw terminal.

2 Fused
The fuse is designed to blow and break the circuit if the appliance gets too much current.



AC/DC took their name from a sticker on a sewing machine

© Weatherman90

All about AC/DC

As we've learnt, the word electricity is derived from the fact that current is electrons moving along a conductor that have been harnessed for energy. The difference between alternating current (AC) and direct current (DC) is related to the direction in which the electrons flow. In DC the electrons flow steadily in a single 'forward' direction. In AC electrons keep switching directions. The power supplied by electricity companies is AC because it's much easier to transport across long distances. It can easily be stepped up to a higher voltage with a transformer. It's also more efficient to send along power lines before being stepped down by another transformer at the customer's end.

Why do all countries have different plugs?

Why you might need an adapter when travelling abroad

Even more than baggage handling and passport control, one of the biggest problems faced by the frequent traveller is the fact that every country in the world has different plugs. In the US, shortly after the AC/DC battle had been resolved – AC won – a man named Harvey Hubbell invented the two-pin plug "so that electrical power in buildings may be utilised by persons having no electrical knowledge or skill". This was later developed into a three-pin plug by Philip Labre in 1928, with a third pin for grounding. At the same time developments like this were occurring all around the world with absolutely no global standardisation. There was some effort made by the International Electrotechnical Commission shortly before World War II occurred, which put a hold on the plans.

Two pin or three pin? It depends where you are!

Aluminium

It's the most abundant metal in Earth's crust, yet it entirely escaped our notice until 1825

You might say it was hidden in plain sight. Aluminium is a highly reactive metal, meaning it readily undergoes chemical reactions with other elements and compounds to form different substances. As a result, nearly all of the naturally occurring aluminium atoms on Earth ended up tucked away in the molecules of more than 270 different minerals, including gemstones like emeralds and rubies. While it's actually 8.2 per cent of the Earth's crust, making it the most common metal and third-most common element, behind oxygen and silicon, you would never know it's there without investigating on a chemical level.

The search was on in the mid-1700s, when chemists began experimenting with alum, a class of abundant chemical compounds. Alum compounds, such as potassium aluminium sulphate, were well known, going back at least to the ancient Greeks and Romans, who used them as an astringent to close wounds and a mordant to bind dye to cloth. Early chemical investigation of alum suggested that the compound included an unknown metal.

The trouble was that 18th-century chemists had no way to separate the mystery element from the rest of the atoms in the compound. In 1825 the Danish chemist Hans Christian Ørsted finally devised a chemical reaction that could extract it, but his process could only yield minuscule amounts at a time, making thorough experimentation difficult. Following up on

The statistics

Aluminium

Protons: 13

Neutrons: 14

Electrons: 13

Melting point: 660.3 degrees Celsius

Boiling point: 2,519 degrees Celsius

Superconduction temperature: -271.975 degrees Celsius

Density of solid: $2.7g/cm^3$

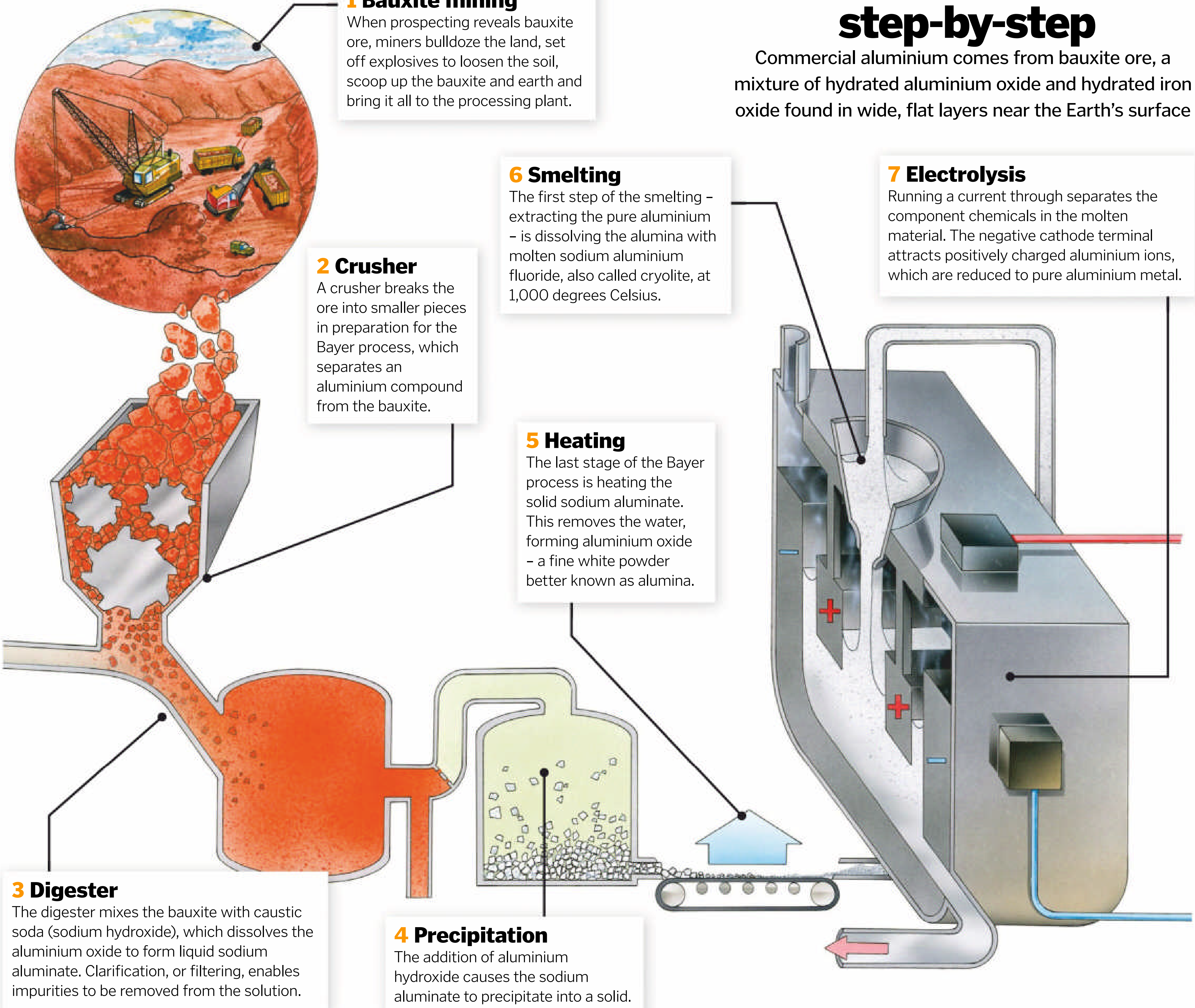
Atomic mass: 26.981539 atomic mass units

Reflectivity: 71 per cent

Atomic radius: 118 picometres

Aluminium extraction step-by-step

Commercial aluminium comes from bauxite ore, a mixture of hydrated aluminium oxide and hydrated iron oxide found in wide, flat layers near the Earth's surface



1 Bauxite mining
When prospecting reveals bauxite ore, miners bulldoze the land, set off explosives to loosen the soil, scoop up the bauxite and earth and bring it all to the processing plant.

2 Crusher
A crusher breaks the ore into smaller pieces in preparation for the Bayer process, which separates an aluminium compound from the bauxite.

3 Digester
The digester mixes the bauxite with caustic soda (sodium hydroxide), which dissolves the aluminium oxide to form liquid sodium aluminate. Clarification, or filtering, enables impurities to be removed from the solution.

4 Precipitation
The addition of aluminium hydroxide causes the sodium aluminate to precipitate into a solid.

5 Heating
The last stage of the Bayer process is heating the solid sodium aluminate. This removes the water, forming aluminium oxide – a fine white powder better known as alumina.

6 Smelting
The first step of the smelting – extracting the pure aluminium – is dissolving the alumina with molten sodium aluminium fluoride, also called cryolite, at 1,000 degrees Celsius.

7 Electrolysis
Running a current through separates the component chemicals in the molten material. The negative cathode terminal attracts positively charged aluminium ions, which are reduced to pure aluminium metal.

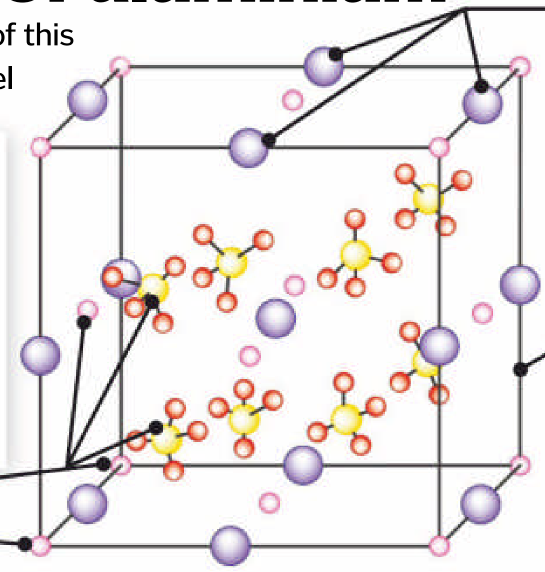
Ørsted's discovery, the German chemist Friedrich Wöhler developed a more effective process, and by 1845 he had produced enough aluminium to demonstrate its basic properties. However, Wöhler's method of extraction was still far too troublesome and slow to support wide-scale production.

In 1856 the French chemist Henri Étienne Sainte-Claire Deville refined the process further, reducing the price of aluminium from $1,200 per kilogram to $40, which was a huge drop, but still very expensive. That all changed in the 1880s, thanks to two key technological leaps.

In 1886, American chemist Charles Martin Hall and French chemist Paul LT Héroult both independently invented a process for extracting aluminium from aluminium oxide. The Hall-

Anatomy of aluminium

A look at the make-up of this metal on an atomic level



Aluminium atom
Each aluminium atom consists of a nucleus (yellow) orbited by 13 electrons, including three electrons in the outermost energy level. These valence electrons (red) can be used for chemical bonding.

Chemical bonds
The individual aluminium atoms bond with one another by sharing valence electrons. In addition to the three it already has, each atom borrows extra electrons from other atoms.

Face-centred cube
The bonded atoms form a cubic structure. Together, many cubes form a crystal lattice that makes up solid aluminium material.

© Thinkstock; Zonk43; P.Loos; David Sim

Héroult process relies on electrolysis, a means of breaking down chemical compounds into their component elements using an electric current. The basic idea is to conduct electricity from a positive terminal – an anode – to a negative terminal – a cathode – via liquid or molten material. Each terminal attracts and repels charged atoms (ions). The positively charged anode attracts negative ions and repels positive ions, and the cathode does the opposite.

Scientists had tried to produce aluminium through electrolysis since the 1800s, but had no luck. Hall and Héroult's breakthrough was first dissolving aluminium oxide in molten cryolite – sodium aluminium fluoride. Applying an electric current to this material draws the positive aluminium ions to the cathode, which is typically the vat itself, made from iron lined with graphite.

Hot on their heels in 1888, Austrian chemist Karl Josef Bayer found a way to extract aluminium oxide from bauxite, a naturally occurring ore found in abundance in layers just below the Earth's surface. Geologists drill core samples in likely areas, and on locating bauxite they clear the ground above with bulldozers so that they can collect the ore beneath. Australia leads global bauxite mining, producing roughly one-third of the total ore.

Together the Hall-Héroult process and the Bayer process, both still in use, ushered in what could be called the 'Aluminium Age'. The metal's properties made it an instant hit. It's lightweight – about a third the weight of steel – but still strong. It's also very ductile, meaning it's easy to draw into a wire or flatten into a sheet, and it's malleable, making it relatively simple to bang it into just about any shape.

Add to that exceptional conduction of heat and electricity and you've got an incredibly versatile metal. But aluminium's greatest trick may be its resistance to corrosion. Like iron, aluminium is highly reactive to oxygen in the air, but the result of the oxidation reaction is very different. Oxygen and iron react to produce a flaky layer of rust, which falls away, revealing a lower layer of iron, which then oxidises to form yet more rust. In contrast, when aluminium encounters oxygen, the oxidation reaction produces an incredibly hard transparent oxide compound that essentially surrounds the aluminium with a shield that protects it from oxygen and other elements. And best of all, if this protective layer happens to get damaged, it will very quickly reform, reconstructing the shield.

Most aluminium products are actually made from an aluminium alloy – a combination of two metals. The combinations accentuate and amplify certain properties. For example, alloying aluminium with copper improves strength, while an alloy of aluminium and manganese improves resistance to corrosion.

You can turn aluminium into an infinite variety of products through a number of different manufacturing processes. You can cast it into any shape that you want by pouring it into a mould and then letting it cool. You can roll it into malleable sheets up to a minuscule 0.15 millimetres thick, commonly used in the kitchen. You can forge it to make it super-strong. You can machine it – cutting away material – to produce screws, bolts and other hardware. Finally, you can force it through a die to extrude it into a particular shape, including thin wire.

Aluminium also boasts another major superpower over many other metals: its recyclability. Recycling programs use old aluminium cans to make new ones at about 30 per cent the cost of making them from scratch. They shred old cans into pieces, melt them in a furnace, form rectangular blocks called ingots and then roll out the ingots into thin sheets from which new cans are cut. Believe it or not, this whole process can take just 60 days. Old car parts can undergo a similar process. Thanks to recycling, about 75 per cent of the aluminium ever produced is still in use today.

Aluminium consumption by market

Building and construction	25%
Transport	27%
Consumer goods	5%
Electrical	13%
Machinery and equipment	9%
Foil and packaging	16%
Other	5%

Source: UC RUSAL (2014)

Rocket fuel

While you might not be surprised to hear that NASA's Space Shuttles were made mainly from aluminium, what you may not have realised is that they were also powered by aluminium inside the solid rocket boosters. When burned with oxygen, atomised aluminium powder makes for a great fuel. Aluminium powder accounts for about 16 per cent of solid rocket booster fuel.

World of aluminium

It's durable, light and you can mould it into any shape you want. Little wonder it's everywhere...

ASM Space Lattice

Aluminium's high strength-to-weight ratio makes it an excellent dome material. Geodesic dome inventor Buckminster Fuller designed this 76-metre-diameter, 80-tonne aluminium structure for the American Society for Metals' (ASM) headquarters in Ohio.

Airstream trailers

The quintessential camping trailer took its design from 1920s aeroplane fuselages. Inventor Wally Byam opted for malleable aluminium, which he could shape into a fuel-efficient, aerodynamic form.

Ravensbourne University London

Aluminium's weather resistance and sculptural flexibility make it a popular material for building façades. Ravensbourne's building on London's Greenwich peninsula is covered in 28,000 aluminium tiles.

Top of the Washington Monument

When the monument was approaching completion in 1884, the lead engineer selected the novel, relatively rare aluminium for its 23 centimetre lightning rod pyramid.

Wider world

ISS
The US Destiny laboratory module is a major component of the International Space Station. The 8.5-metre pressurised unit is made from aluminium and represents the heart of the space station. Aluminium forms part of the outer debris shield too, which is tough enough to vaporise small particles of space junk.

Airbus A380
Aluminium has become the most important material in aerospace history. The world's largest commercial aircraft is 61 per cent aluminium alloy.

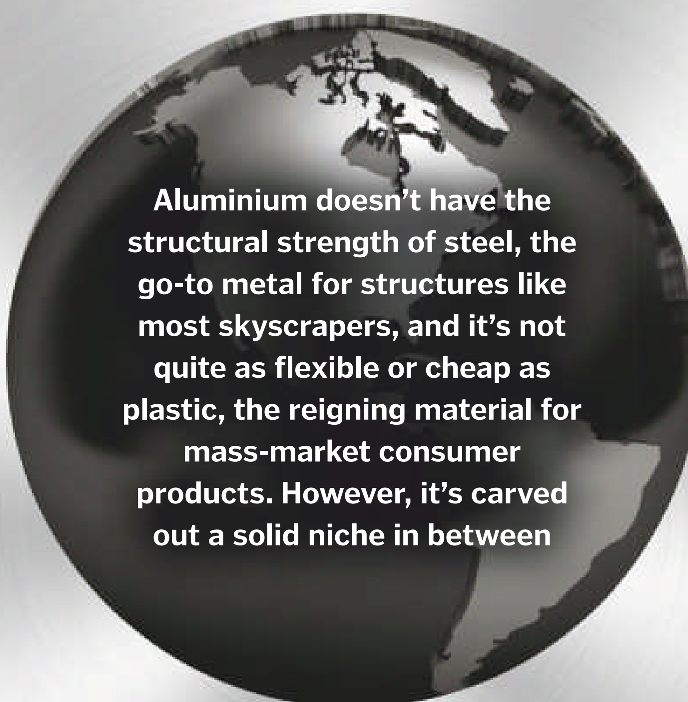
Burj Khalifa
The world's tallest human-made structure is also the highest installation whose architectural cladding consists of an aluminium and glazed façade. The total weight of the aluminium used is the same as five Airbus A380s, and the surface area of the curtain wall is 132,190 square metres.

Everyday world

Morning coffee
Nespresso's airtight coffee capsules are made of aluminium to keep the product fresh, away from air, light and humidity.

Pots and pans
Much modern cookware includes aluminium, which boasts excellent thermal conductivity, but possible links to neurodegenerative diseases have made it somewhat controversial.

Automobiles
Aluminium keeps this all-electric car lightweight, while still strong and rigid. Each car begins life as a 9,072-kilogram aluminium coil, which is then stamped into sections.



Aluminium doesn't have the structural strength of steel, the go-to metal for structures like most skyscrapers, and it's not quite as flexible or cheap as plastic, the reigning material for mass-market consumer products. However, it's carved out a solid niche in between

Phone lines
Aluminium is a great electrical conductor, like copper but much lighter. Its low weight makes it an ideal choice for elevated power and phone lines.

Computers
Many of Apple's devices are made of anodised aluminium, which not only polishes and toughens a product, but also provides a way of adding colour via the process of oxidation.

Kitchen foil
As a natural barrier to light, oxygen, moisture and just about anything airborne – including bacteria – flexible aluminium sheets are great food protectors.

Drinks cans
On top of being light and cheap, the king of aluminium products is 100 per cent recyclable. Around 113,200 cans are recycled every minute.

© NASA; Thinkstock; Alex Beltyukov; Tesla Motors; Tom Morris; Dave 7; Nespresso

What are the noble gases?

This select bunch of elements have a variety of useful properties

There are six naturally occurring noble gases found around our world and beyond. These are helium (He), neon (Ne), argon (Ar), krypton (Kr), xenon (Xe) and radon (Rn). Together they form Group 18 of the periodic table and are characterised by their lack of colour, smell, taste and their low flammability in their natural state.

Despite being historically referred to as rare and inert, noble gases – which were designated 'noble' due to their apparent reluctance to undergo a chemical reaction – are nothing of the sort. In fact, all of these gases are found in Earth's atmosphere, and each is capable of being chemically active and producing compounds.

The majority of the noble gases – such as argon, krypton, neon and xenon – are formed via liquefaction and fractional distillation techniques. However, helium is attained by separating it from natural gas and radon by isolating it from the radioactive decay of radium compounds.

As noble gases show extremely low chemical reactivity, while they are not inert, only a few hundred noble gas compounds have been formed to date, with xenon varieties making up the bulk. In theory, though, radon is more reactive than xenon, so should form chemical bonds more readily. However, its high radioactivity and short half-life are the key factors which prevent this.

There are many applications for noble gases. The most obvious and visible of these are illuminated signs, light bulbs and lamps, with xenon, argon and neon commonly used due to their lack of chemical reactivity. Using these gases helps to preserve filaments in light bulbs and grants distinctive colours when used in gas-discharge lamps – as demonstrated by the main image shown here.

Where are noble gases used?

Arc lamps

A specialised type of gas-discharge lamp, arc lights pass electricity through a bulb full of ionised gas, such as xenon or argon. They're used in IMAX cinemas among other places.

Blimps

Today most blimps are filled with helium due to its lightness and incombustibility. Hydrogen was used originally, but was phased out due to its high flammability.

MRI scanners

One of the most advanced pieces of medical equipment, magnetic resonance imaging scanners use liquid helium to cool the superconducting magnets inside.

"As noble gases show extremely low reactivity, only a few hundred noble gas compounds have been formed"

Illuminated signs

Many illuminated signs and billboards utilise noble gases due to their ability to generate vibrant colours when ionised – neon lights being a prime example.

Refrigerants

Due to their incredibly low boiling points – for instance, argon boils at -186 degrees Celsius and neon at -246 degrees Celsius – the Group 18 gases are often used in cryogenics.

Radiotherapy

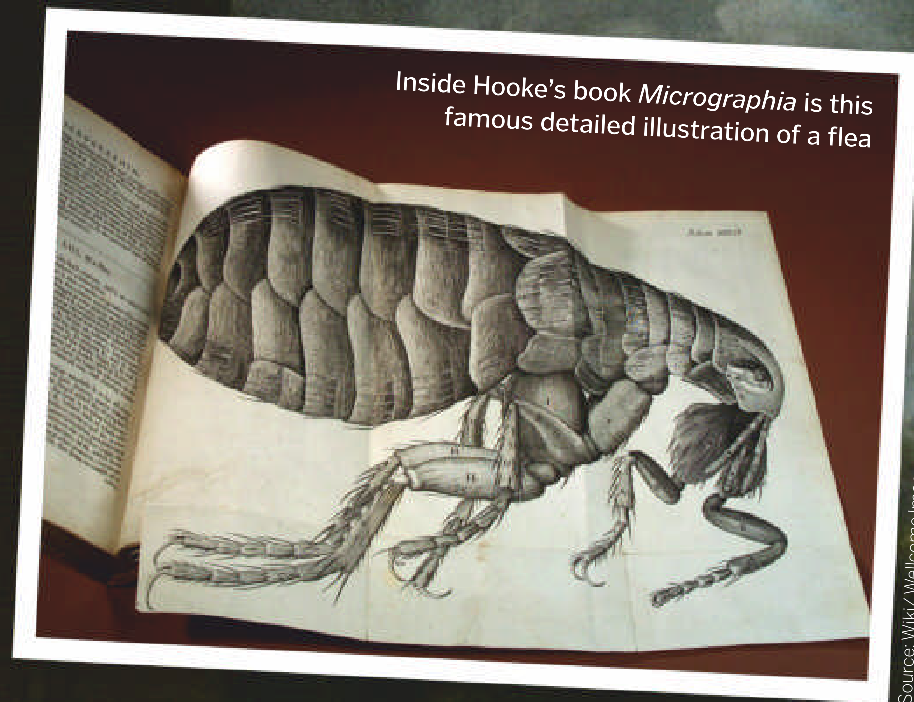
Despite the noble gas radon being highly radioactive and able to cause cancer, it can also be used as part of radiotherapy treatments to control or kill malignant cells.

© Atlant; Getty; Thinkstock

HEROES OF... SCIENCE

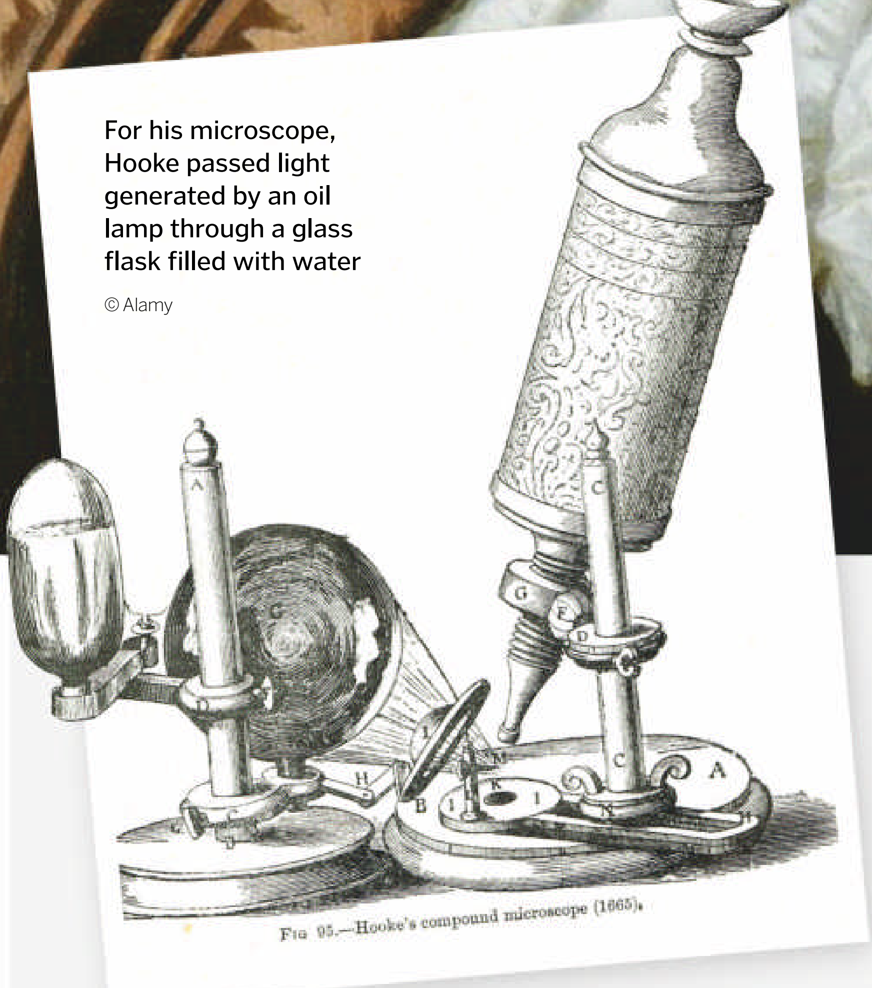
No contemporary portrait of Hooke was preserved, but this painting is believed to be him

Source: arthistoryproject.com



Inside Hooke's book *Micrographia* is this famous detailed illustration of a flea

Source: Wiki/ Wellcome Images



For his microscope, Hooke passed light generated by an oil lamp through a glass flask filled with water

© Alamy

A life's work

The life of the versatile scientist

1635
On 28 July, Robert Hooke was born in Freshwater, Isle of Wight.

1648
13-year-old Hooke moved to London for an apprenticeship, but he leaves to study at the reputable Westminster School.

1653
Enrolling at Oxford's Christ Church College, he studied a range of science subjects, including chemistry and astronomy.

Robert Hooke

Meet the English polymath who discovered the building blocks of all life

Not confining himself to one field, this 17th-century scientist was responsible for contributing to our knowledge of everything from mathematics and mechanics to biology and astronomy. Born on the Isle of Wight, off the south coast of England, Hooke began his series of interests as a keen artist.

He lived with his parents until the age of 13, and due to being a sickly child was a latecomer to education. Instead of attending school, he spent much of his childhood drawing from his bedroom. But his lack of an early education didn't stop Hooke realising his genius. It was his later enrolment at Westminster School in London that would take him down a scientific path. Here he discovered that his talents lay beyond painting, particularly in mathematics, mechanics and languages.

Many people are aware of Hooke's work in microscopy, but in 1653, at the age of 18, Hooke attended Christ Church College at Oxford, where he spent much of his time building telescopes. Shortly after in 1660, he discovered a physical law that would later be named after him: Hooke's law. It states that the force needed to extend or compress a spring is proportional to the distance it is stretched.

In 1662, two years after the Royal Society was founded, Robert Hooke was named a curator of the society. Today this is the oldest independent scientific academy, and Hooke's broad scientific interests helped set the society in motion during its early years. During his time with the society he carried out experiments and made further discoveries alongside its other members. In 1663 his interests in meteorology and seafaring saw him contribute to the invention or improvement of the five main meteorological instruments: the barometer, thermometer, hydroscope, rain gauge and wind gauge.

Hooke is certainly best known for discovering and observing the living cell, but this came with multiple lesser known findings along his journey in microscopy. As he researched down to the extent of what the available microscopes could see, he discovered spores in mould, he became the first to examine different fossil types with a microscope and he uncovered how mosquitoes and lice suck blood.

To further his areas of expertise, following the disastrous Great Fire of London in 1666, Hooke was given the opportunity to try his hand at architecture. Alongside Sir Christopher Wren, he designed a monument to commemorate the fire. With the lead architects both being scientists, they decided to add some practicality to the aesthetic. Underneath this 60-metre-tall structure, Hooke built an underground laboratory where he could conduct many of his science experiments, while the central passage was built to house a large telescope.

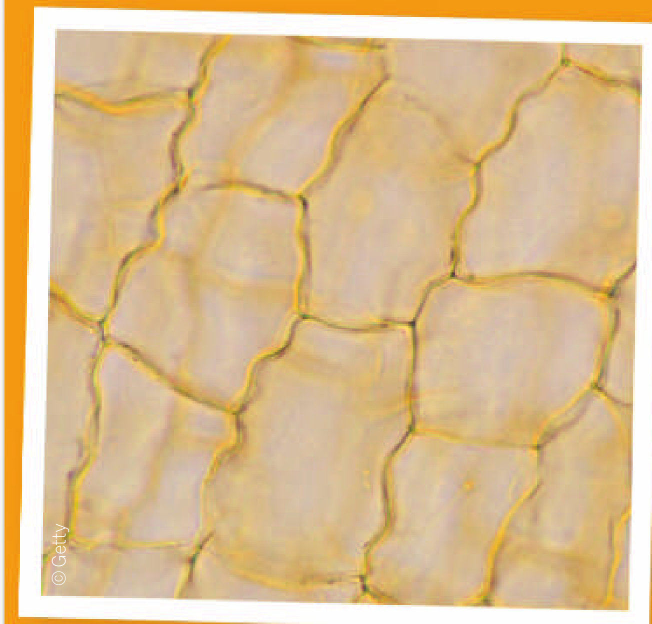
There are few areas of science which Hooke didn't venture into. Since his death in 1703, scientists continue to be inspired by and benefit from Hooke's findings as they delve further into the microscopic world he opened up. As he quotes in his book *Micrographia*: "By the means of telescopes, there is nothing so far distant but may be represented to our view; and by the help of microscopes, there is nothing so small as to escape our inquiry."

THE BIG IDEA

Cells' first witness

Every living thing is made up of cells, and the study of these structures enables biologists to understand how all organisms live, as well as develop new medical science. Before 1665, however, these cells had never been seen. With a keen drive to explore what lay beyond the visible world, Hooke reinvented his compound microscope to allow him to observe finer details.

Using three lenses and a stage light, he was able to increase the size of what he was viewing, with the light adding even more clarity. As he placed a piece of cork underneath his improved microscope, he was presented with its hidden structure. The cork looked like it was covered in pores, with packed shapes that reminded Hooke of the small cell rooms in a monastery. It was then that he named these structures 'cells'.



Cork cells were the first cells to be observed

FIVE THINGS TO KNOW ABOUT… ROBERT HOOKE

1 ceiiinosssttuv
Hooke first published the law of elasticity as an anagram to stop others claiming his discovery while he developed it. The anagram was for 'ut tensio, sic vis', meaning 'as the extension, so the force' in Latin.

2 Long service
Being a curator of the Royal Society, Hooke's roles involved producing exciting, new experiments each week at the society's frequent meetings.

3 Space discoveries
Hooke wasn't limited to discoveries on Earth. He discovered one of the stars in the constellation Orion, as well as being the first to suggest that gas giant Jupiter rotates on its axis.

4 Memory model
When taking a lecture, Hooke described a scientific model of human memory. This was the first of its kind, but was overlooked until 200 years later, when another scientist released a similar theory.

5 Artistic science
As a child, Hooke took an interest in drawing. Using his chemistry skills, he made his own art supplies using iron ore, chalk and coal. He would later illustrate some of his own scientific works.

1657
Hooke invented the anchor escapement, a component which would improve the pendulum clock. This cog stopped the clock running down.

1660
Hooke's law, stating that the extension of a spring is proportional to the applied force, was discovered, though it wasn't announced until 1676.

1663
A year after becoming curator of experiments, Hooke was elected a Fellow of the Royal Society.

1664-1665
During these years, Hooke closely studied comets. This work was published in 1666 and entitled *Cometa*.

1665
Following his discovery of cells, Robert Hooke published *Micrographia*, detailing the specimens he observed under the microscope.

1703
On 3 March, Hooke died in London at age 67.

As the pilot increases the speed, the propellers move quicker to lift the drone in a forward direction

Royal Navy Puma drone

Why this remote-controlled aircraft has become the Navy's new eyes in the sky

The Royal Navy works to patrol and protect the UK out at sea. This task involves monitoring large sections of coast using ships, planes and a recent addition to the fleet. These new remote-controlled air systems provide Navy crew members with easier access to their surroundings. Working like a drone, this miniature uncrewed aircraft can be thrown by hand off the deck of a ship and subtly survey activity at sea. They are currently being tested by the 700X Naval Air Squadron in Cornwall, UK.

Using these Puma drones, pilots can navigate the area, substituting weapons for powerful cameras and other intelligence tools to pinpoint a target's location. Pilots are able to remain at a safe distance, remotely controlling the device up to 20 kilometres away on the deck of their base ship. This means they aren't placed close to potentially hostile vehicles like they would be if they operated from inside an aircraft or sailed their ship in closer proximity. Keeping distanced, they can analyse the images received in real-time on a computer. With this information the vehicle can be steered and the viewpoint manipulated using a remote console. This becomes especially useful to the Navy when conducting reconnaissance tasks, such as assessing battle damage and initiating search-and-rescue missions, over land and sea.

The unmanned vehicle is able to remain in the air for two hours at a time. While there is nobody on board the aircraft, it requires three people to operate each flight: a vehicle operator who controls the camera during flight, a mission operator who pilots the flight and a flight commander to ensure safe flying among other surrounding aircraft.

This new technology aims to combine small, lightweight vehicles that are quick and easy to launch with surveillance tools for when Navy ships are threatened. Moving at top speeds of 50 miles per hour, the drones can easily catch up with and monitor suspicious ships on the water from above. Maintaining distance, these systems remain unheard and unseen until intervention is necessary.

"Pilots are able to remain at a safe distance"

Q&A

Meet a Puma pilot

Jon Neal serves as a petty officer air engineering technician. He leads the squadron's research team, evaluating the Puma remote air systems.

What's it like to fly and control the Puma?
It's very easy. They fly themselves until you put in an input to do something, like change altitude. You can fly them manually with the controller or autonomously.

What advantages do remotely piloted air systems provide?
It depends on the operation. We went out with a fishery protection vessel. If you have a big boat coming, you can see it a long way off, but you can't see this Puma. It's very difficult to see from the ground because of its colour and size, and few people think to look up anyway. Above 90 metres, you can't hear it either. The ship would detect a trawler on its radar and we would send out the Puma to get identification.

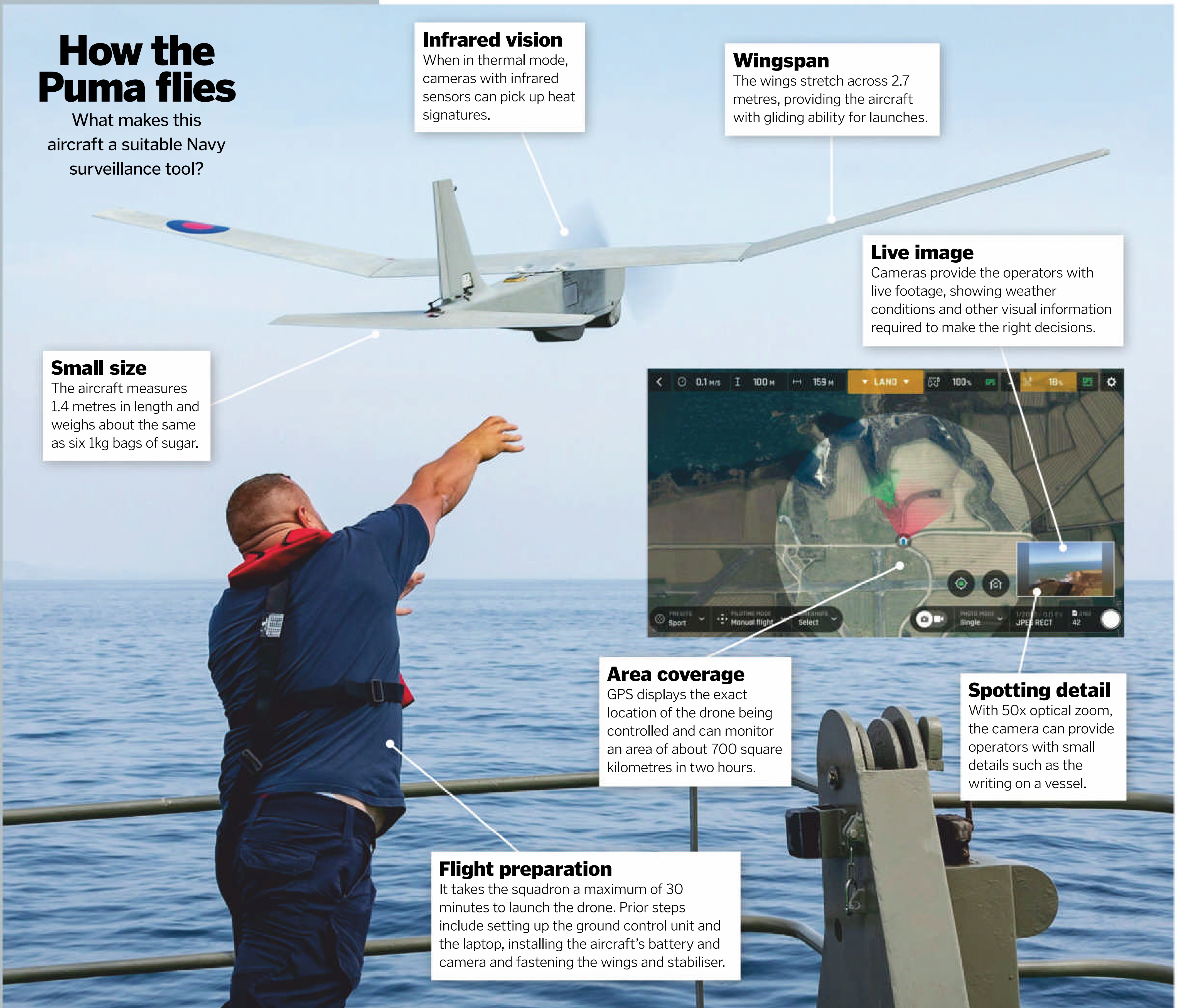
What happens in the event of a crash, and how likely is that?
Any system can crash from a pilot error or if there's a significant mechanical failure, but that's really unlikely. With the Puma there is in-built resilience. If we lose the data link, it will fly back on its own, or if we lose the GPS we can easily work out a return bearing. If it suffers a non-critical failure it will land itself, even at sea – and because it floats we can easily recover it.

How do you think this new technology will evolve to further benefit the Navy?
At the moment we can put a remote video terminal on the ship's bridge, but it would be brilliant to integrate the air system into the ship's own systems. This has never been done before. We're currently working on those procedures to understand how it all works together.

We have selected Puma for now, but the technology is moving forward all the time, and my job is to understand that emerging technology and its capabilities for the Navy. This is just the start for the Royal Navy. As we move forward, we're going to truly see what this technology is capable of, realise that capability with better systems and integrate those systems into the platforms permanently. This is the future.

How the Puma flies

What makes this aircraft a suitable Navy surveillance tool?



Infrared vision
When in thermal mode, cameras with infrared sensors can pick up heat signatures.

Wingspan
The wings stretch across 2.7 metres, providing the aircraft with gliding ability for launches.

Live image
Cameras provide the operators with live footage, showing weather conditions and other visual information required to make the right decisions.

Small size
The aircraft measures 1.4 metres in length and weighs about the same as six 1kg bags of sugar.

Area coverage
GPS displays the exact location of the drone being controlled and can monitor an area of about 700 square kilometres in two hours.

Spotting detail
With 50x optical zoom, the camera can provide operators with small details such as the writing on a vessel.

Flight preparation
It takes the squadron a maximum of 30 minutes to launch the drone. Prior steps include setting up the ground control unit and the laptop, installing the aircraft's battery and camera and fastening the wings and stabiliser.

Launch
Being lightweight, buoyant and waterproof, the unmanned system can be thrown over the side of the ship by a single sailor, without the launchpad needed for a typical aircraft.

Royal Navy operators were trained on aircraft assembly, flight and airspace safety

All images © Royal Navy

HYDROGEN-PO

Discover how hydrogen cars produce zero emissions with less dependence upon foreign fossil fuels

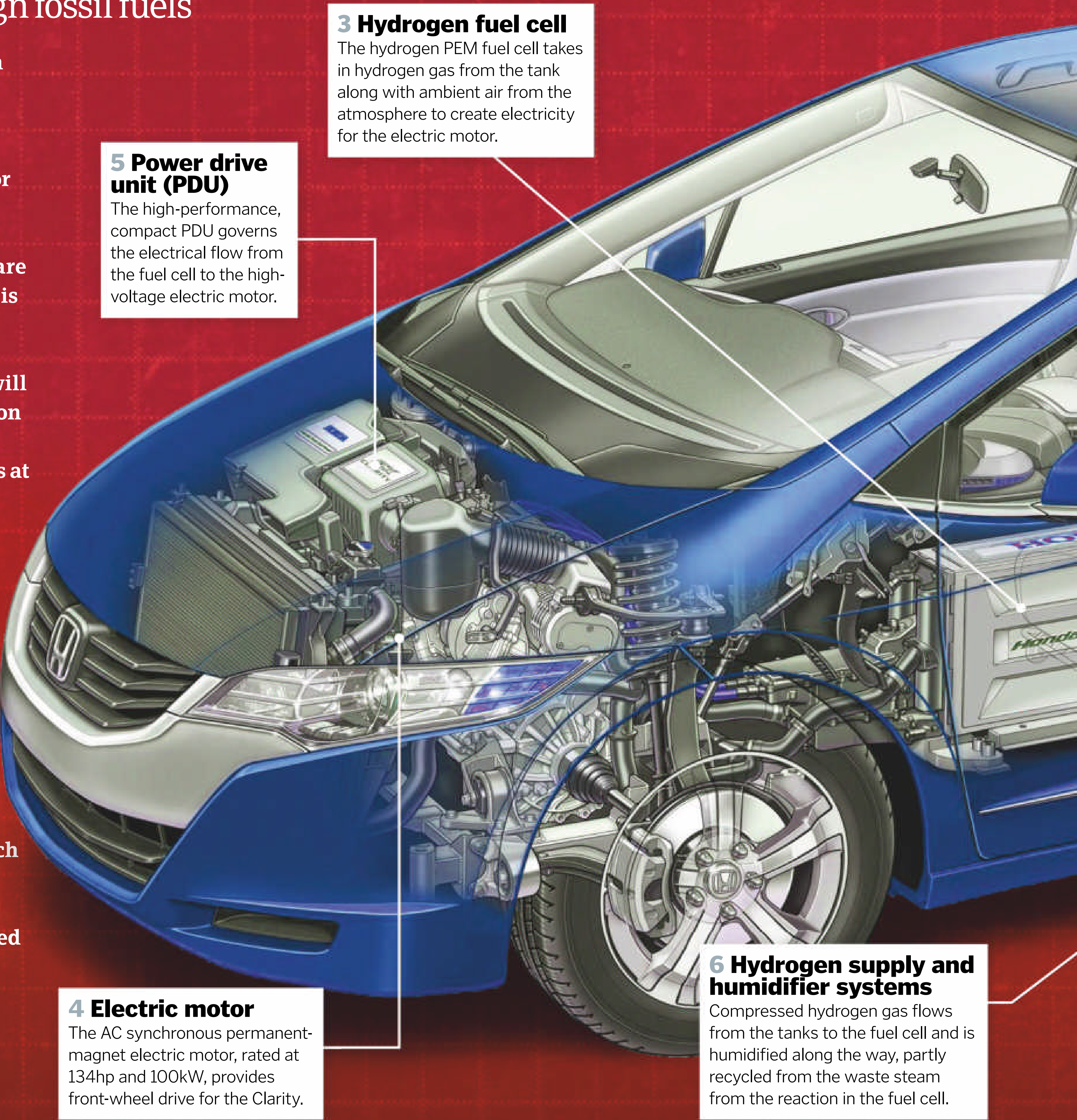
There are two basic types of hydrogen cars: those that run on PEM (proton exchange membrane) fuel cells and those which burn hydrogen (H_2) inside an internal combustion engine (ICE). All major car manufacturers have developed one or both of these types of vehicles.

The most popular of these two varieties are those that run on hydrogen fuel cells. This is because these are seen as zero-emission vehicles that will not contribute to greenhouse gases in the atmosphere and will help towards breaking the dependence upon foreign fossil fuels.

The fuel cell car works as follows: drivers at a refuelling station will pump compressed hydrogen gas into the car's tank. Once the driver starts the vehicle, the compressed hydrogen, along with oxygen from the air, will flow into the fuel cell.

The positive and negative ions of hydrogen molecules will split around the fuel cell, creating an electrical charge. On the backside of the fuel cell, the hydrogen ions join with the oxygen to form water vapour, which flows out the tailpipe of the vehicle. The electrical current created by the fuel cell flows to an electric motor, which powers the wheels of the car.

The hydrogen ICE vehicles are a bit more simplistic in that they use either compressed or liquid hydrogen and burn it inside the cylinders of the engine. Near-zero tailpipe emissions are created when burning hydrogen in this fashion. ICE vehicles are currently cheaper to build or retrofit than fuel-cell vehicles.



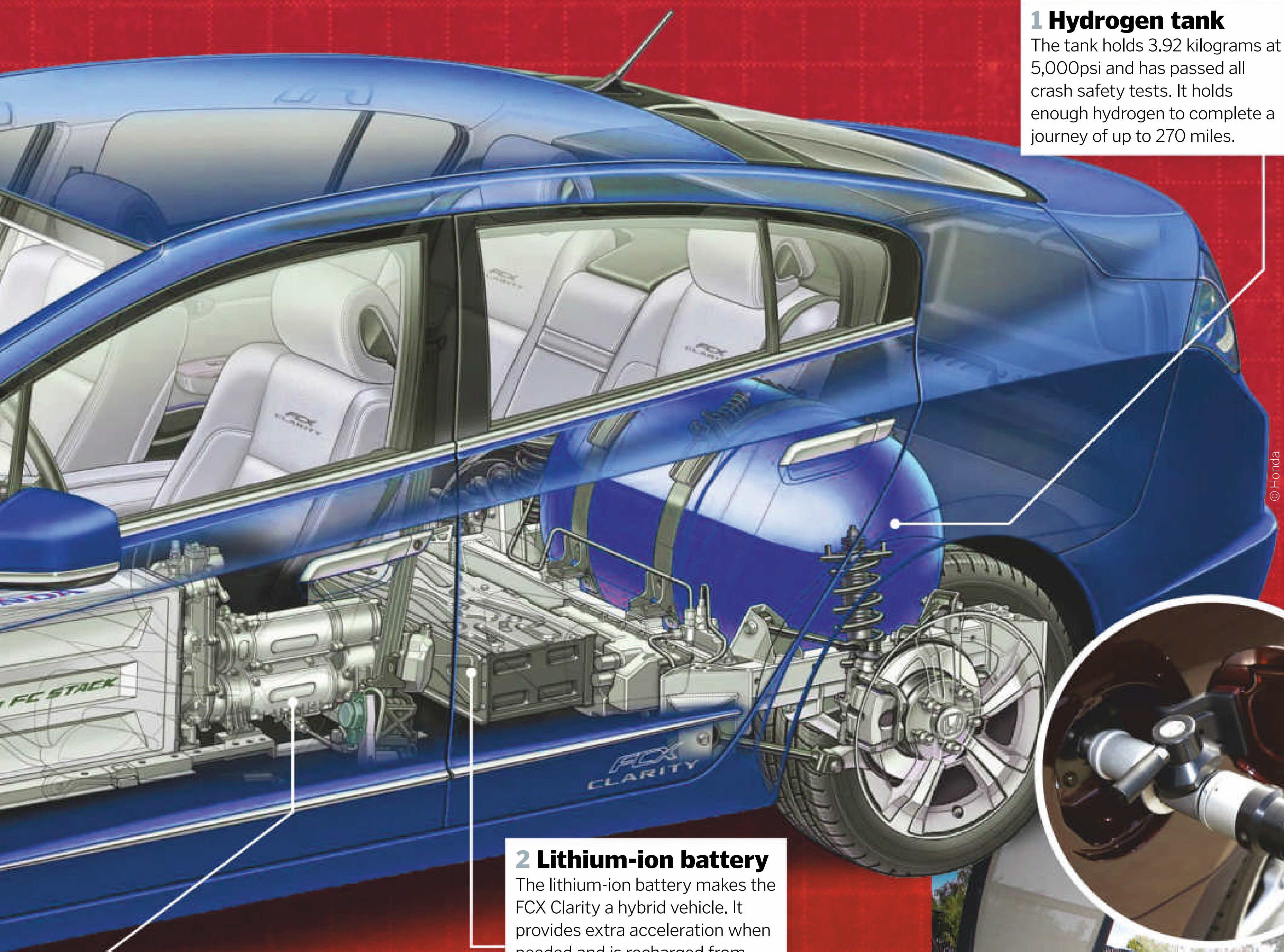
Hydrogen cars Important moments in hydrogen car development

1807
François Isaac de Rivaz built the very first automobile which burnt hydrogen inside an internal combustion engine.

1860
Étienne Lenoir built the Hippomobile, which was later fuelled by electrolysing water and using the hydrogen in a one-cylinder engine.

1941
During World War II, Boris Shelishch converted a GAZ-AA truck to run off hydrogen after Nazi's had cut off Russian oil supplies.

OWERED CARS



© Honda

1 Hydrogen tank
The tank holds 3.92 kilograms at 5,000psi and has passed all crash safety tests. It holds enough hydrogen to complete a journey of up to 270 miles.

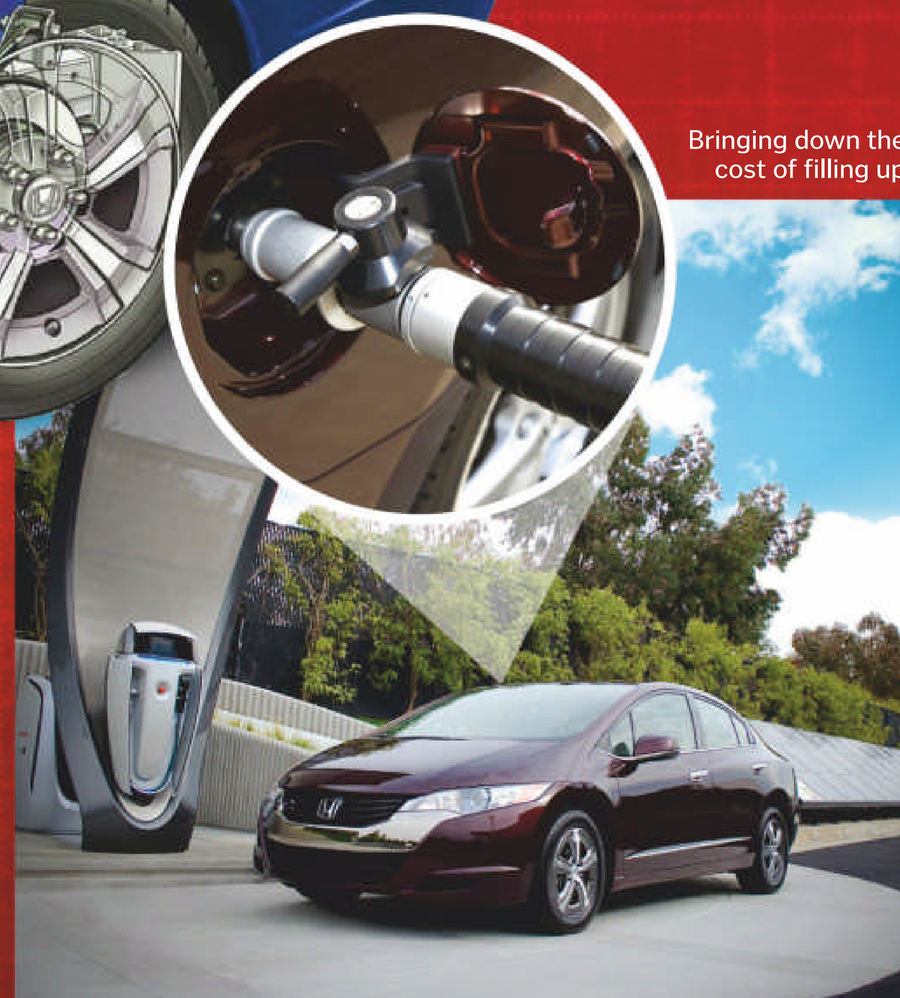
2 Lithium-ion battery
The lithium-ion battery makes the FCX Clarity a hybrid vehicle. It provides extra acceleration when needed and is recharged from regenerative braking.

The statistics

Honda FCX Clarity

© Honda

Manufacturer: Honda
Dimensions: Length: 4.83 metres; width: 1.85 metres; height: 1.47 metres
Driving range: 270 miles
Required fuel: Compressed hydrogen gas at 5,000psi
Carbon emissions rating: Zero emission



Bringing down the cost of filling up

© Honda

Hydrogen fuel cells

The hydrogen PEM fuel cell vehicle works by taking hydrogen from the compressed hydrogen tank and then running it along with oxygen taken from the air through a fuel cell. Hydrogen gas is channelled to the anode of the fuel cell while the oxygen is channelled to the cathode.

On the anode side, a catalyst such as platinum splits the hydrogen atom into protons (positively charged) and electrons (negatively charged). The PEM allows only the protons to pass through it to the cathode. The electrons must pass along an external circuit, which is how electricity is created.

1959
Harry Karl Ihrig created the first fuel cell vehicle (FCV), an Allis-Chalmers farm tractor, which used over 1,000 individual cells.

1966
General Motors researchers created the Electrovan, the first hydrogen fuel cell car on record which resembles the FCVs of today.

1979
The BMW 520h prototype was built, which had an internal combustion engine that could run on either hydrogen or gasoline.

1999
The Honda FCX-V1 prototype is created, using a Ballard fuel cell for power and a 49kW electric motor.

H_2ICE

Under the hood of a hydrogen internal combustion engine

Hydrogen internal combustion engines (H_2ICE) work in a similar fashion to gasoline engines. Mazda uses a Wankel rotary engine and BMW, Ford and others use a piston engine, but the concept is the same.

A mixture of hydrogen gas and ambient air is drawn into the engine, where a spark ignites the H_2. Hydrogen has a higher flame speed than gasoline, burning more quickly, so timing adjustments need to be made. Also, since H_2 is the smallest atom, it is prone to leaks, so couplings and fittings also need to be adjusted.

Specialist tanks are needed to transport the fuel

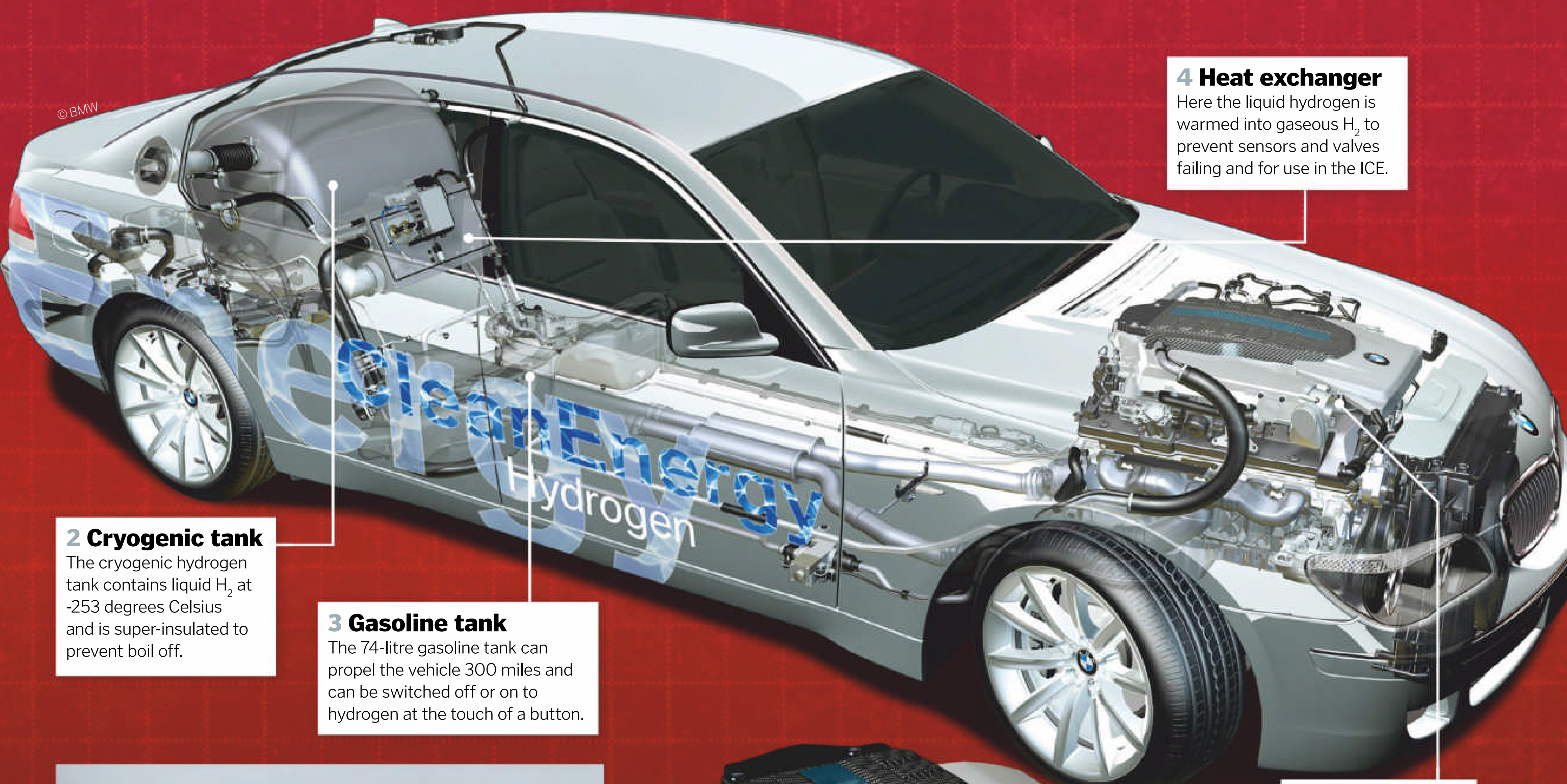
© BMW

The statistics

BMW Hydrogen 7

© BMW

Manufacturer: BMW
Dimensions: Length: 5.2 metres; width: 1.9 metres; height: 1.48 metres
Driving range: 125 miles on hydrogen and an additional 300 miles on gasoline
Required fuel: Hydrogen or gasoline
Carbon emissions rating: Near-zero emissions when using hydrogen
Status: Limited series production luxury vehicle



© BMW

4 Heat exchanger
Here the liquid hydrogen is warmed into gaseous H_2 to prevent sensors and valves failing and for use in the ICE.

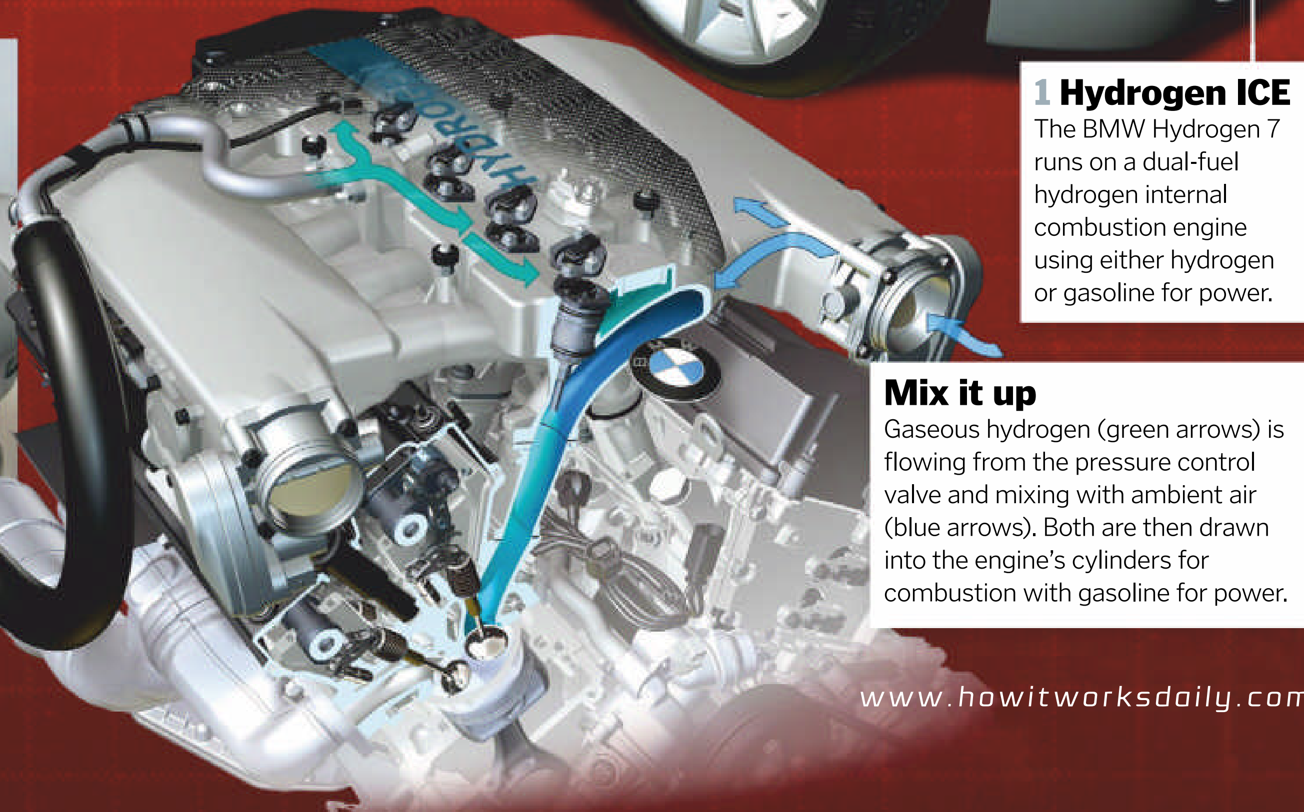
2 Cryogenic tank
The cryogenic hydrogen tank contains liquid H_2 at -253 degrees Celsius and is super-insulated to prevent boil off.

3 Gasoline tank
The 74-litre gasoline tank can propel the vehicle 300 miles and can be switched off or on to hydrogen at the touch of a button.

1 Hydrogen ICE
The BMW Hydrogen 7 runs on a dual-fuel hydrogen internal combustion engine using either hydrogen or gasoline for power.

Not a car you'll see on your local forecourt

© BMW



Mix it up
Gaseous hydrogen (green arrows) is flowing from the pressure control valve and mixing with ambient air (blue arrows). Both are then drawn into the engine's cylinders for combustion with gasoline for power.

© Air Liquide

HYDROGEN REFUELLING STATIONS

A vision of the petrol station forecourts of the future

© Air Liquide

Looking similar to gas stations already in use, hydrogen refuelling stations may dispense compressed hydrogen gas, cryogenic liquid hydrogen or possibly even both. Those that dispense compressed H_2 do so at two different pressures: 5,000psi or 10,000psi.

The advantage of dispensing hydrogen at 10,000psi is that the hydrogen cars can travel approximately twice the distance than at the lower pressure. Most hydrogen produced today for refuelling stations is made by high-temperature steam reforming of natural gas.

Hydrogen molecules from both the steam and natural gas are separated from the other molecules, including carbon dioxide (CO_2). In recent years more renewable, sustainable hydrogen is being created using wind or solar energy to electrolyse water (H_2O), producing hydrogen (H_2) and oxygen (O_2) gas. Another type of H_2 refuelling station that is currently being developed is one for the home so that car owners can refuel in the privacy of their own garages.

Canadian hydrogen energy expert Air Liquide supplied fuel for the hydrogen fuel station that served a fleet of 20 zero-emission buses that carried visitors to and from the 2010 Winter Games


© Air Liquide

THE FUTURE OF MOTORING?

We compare some of the best hydrogen cars from motoring's biggest names

The statistics
B-Class F-CELL

Manufacturer: Mercedes-Benz
Dimensions: Length: 3.8 metres; width: 1.77 metres; height: 1.6 metres
Driving range: 250 miles
Required fuel: Compressed hydrogen gas
Carbon emissions rating: Zero emissions
Status: Limited production

© Mercedes-Benz

The statistics
RX-8 Hydrogen RE

Manufacturer: Mazda
Dimensions: Length: 4.4 metres; width: 1.77 metres; height: 1.34 metres
Driving range: 62 miles in hydrogen mode, 341 miles in gasoline mode
Required fuel: Compressed hydrogen (dual fuel car)
Carbon emissions rating: In hydrogen mode there are near-zero emissions
Status: Limited production leasing as a fleet vehicle in Japan


© Mazda

The statistics
Chevy Equinox Fuel Cell

Manufacturer: General Motors
Dimensions: Length: 4.8 metres; width: 1.81 metres; height: 1.76 metres
Driving range: 250 miles
Required fuel: Compressed hydrogen gas
Carbon emissions rating: Zero emissions
Status: Limited production SUV


© Toyota

The statistics
FCHV-adv

Manufacturer: Toyota
Dimensions: Length: 4.7 metres; width: 1.8 metres; height: 1.7 metres
Driving range: 470 miles
Required fuel: Compressed hydrogen gas
Carbon emissions rating: Zero emissions
Status: Previously available in very limited numbers as a lease vehicle

© GM

AR ZONE!

All aboard the deep-sea driller

Meet the Japanese research vessel crossing the ocean in search of earthquake-makers

Words by **Scott Dutfield**

Power production
There are several generators on board Chikyu: the main six generators can produce 5,000 kilowatts and the two secondary auxiliary generators produce 2,500 kilowatts. That's enough to power a town of 1,000 homes.

Derrick
This over 70-metre-tall metal crane can hold 1,250 tonnes of drill piping before it's lowered beneath the water.

Living area
Surrounded by the laboratory and the control bridge, the living quarters are for the crew of 95. However, the ship can house another 105 passengers.

Laboratory
Core samples collected from the drill are analysed on the ship using a vast array of equipment such as X-rays, CT scanners and mass spectrometers to discover the cores' chemical composition.

Mud circulation
Mud is pumped through the riser and drill pipe through this circulation station to counter geological pressure and stabilise the pipeline.

Thrusters
Chikyu is equipped with several azimuth propeller thrusters and a bow thruster, but they can only send the ship sailing at 22 kilometres per hour, not much quicker than an average bicycle.

Between the decks

How does Chikyu function while collecting samples from below the seafloor?

AR ZONE! SCAN HERE


The deep-sea-drilling vessel Chikyu of the Japan Agency for Marine-Earth Science and Technology, anchored in Shimizu, Japan

© Getty

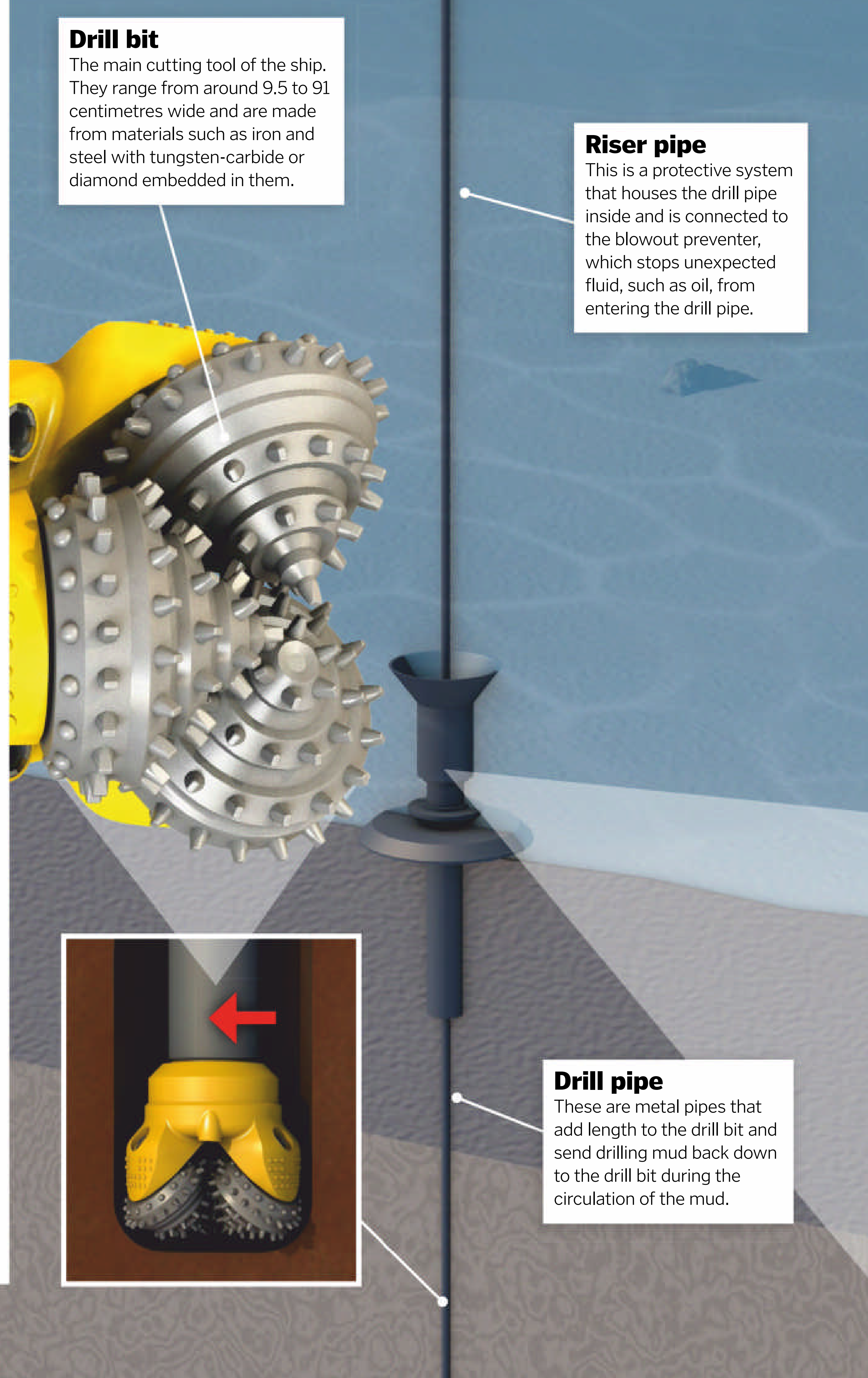

Seismologists aboard Chikyu study cores from below the seafloor to learn the origins of earthquakes

© Getty

Chikyu, meaning 'the Earth' in Japanese, is one of the world's deepest-drilling vessels. Construction on the ship was completed back in 2005, and it took four years to build. This behemoth boat stretches 210 metres long, equivalent to about eight bullet-train cars. It was built to operate in water depths of around 2,500 metres and is capable of drilling down around 7,500 metres below the seafloor. However, the speed at which it can burrow depends on how soft the muddy seabed is. If the material is soft enough the drill can dig down 300 metres in a single day, but when it reaches the dense earth below the seabed the rate of penetration can decrease to as slow as 50 metres in a day.

Drilling to depths of 7,500 metres should take between five and six months to achieve. The ship is kept well stocked with the help of supply boats that provide food and fuel to its 200 crew members. It's also equipped with a helipad to ferry supplies and any maintenance equipment that might be needed to support the drill. For drilling to occur, Chikyu has to remain still while floating for months on end in the open ocean without an anchor long enough to reach the deep ocean floor. So what prevents it from drifting away? The ship is equipped with a dynamic positioning system (DPS) that works like a self-correcting version of the GPS device in your car or on your phone. This automatic navigation system will calculate the ship's location and adjust its position, with the help of Chikyu's azimuth thrusters, should the ship stray away from the drill site.

The reason Chikyu needs to stay still is to collect rock core samples from Earth's mantle, a 2,900-metre-thick layer of rock beneath our planet's crust. These cores offer an insight to seismologists about the origins of the tectonic plates and the earthquakes caused by their movements. This type of research can help to predict earthquakes and tsunamis for areas of the world most at risk, such as Japan, which experiences 1,500 earthquakes each year. Cores retrieved from deep beneath the ocean floor can also give scientists clues to the origins of life by exposing trapped microbes found in coal buried for millions of years.



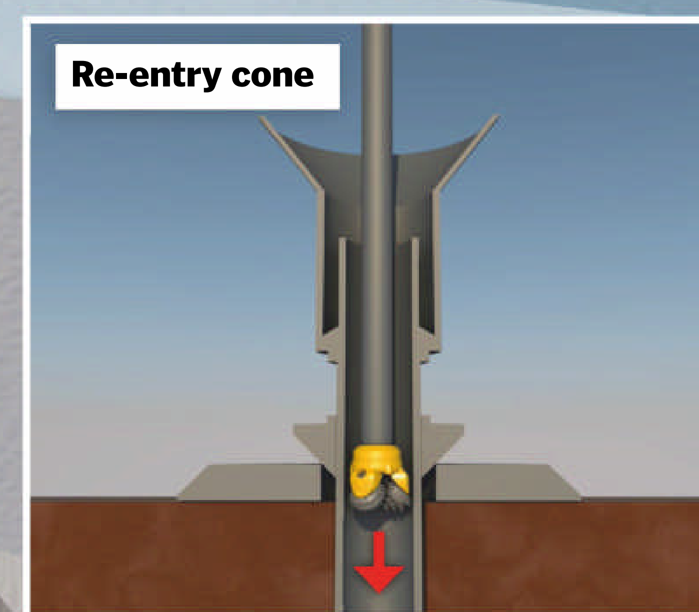
© Illustration by Adrian Mann

Not deep enough

Over the years Chikyu has sailed out on several missions, such as a 2009 two-month-long expedition to the Nankai Trough, reaching 1,600 metres beneath the seafloor. However, the full capabilities of Chikyu have yet to be achieved. With the ultimate goal of burrowing over 7,000 metres below the seafloor, to date the most the ship has managed to dig is around 3,250 metres during an attempt to reach depths of over 5,000 metres last year. The continual collapse of the borehole prevented the drill from reaching its goal. Drilling that deep took six months, and the mission cost around $55 million (approx. £42 million) to operate. It's unclear as to when Chikyu will next set sail, but hopefully one day it will reach its goal of breaking through the crust and into Earth's mantle.


© Getty

This grinding drill bit can bore through 7,500 metres of rock and mud below the ocean floor



BRAIN DUMP

Because enquiring minds need to know...

The Large Hadron Collider, a 27-kilometre particle accelerator at CERN

© CERN

DID YOU KNOW?

The compass was invented in China over 2,000 years ago

SCIENCE

Where would antimatter go on the periodic table?

Aidan Walker

Antimatter doesn't appear on the standard periodic table of elements because it has an anti-periodic table of its own. Scientists at the European Organization for Nuclear Research (CERN) created antihydrogen in 1995, which was the world's first human-made antiatom. **BB**

WANT ANSWERS? Send your questions to... How It Works magazine @HowItWorksmag @howitworks@futurenet.com

© Getty/Arterra

This is an entrance to one of the well-preserved chambers of the Cairn of Barnenez

HISTORY

What is the oldest building in the world?

Dulovan Crawford

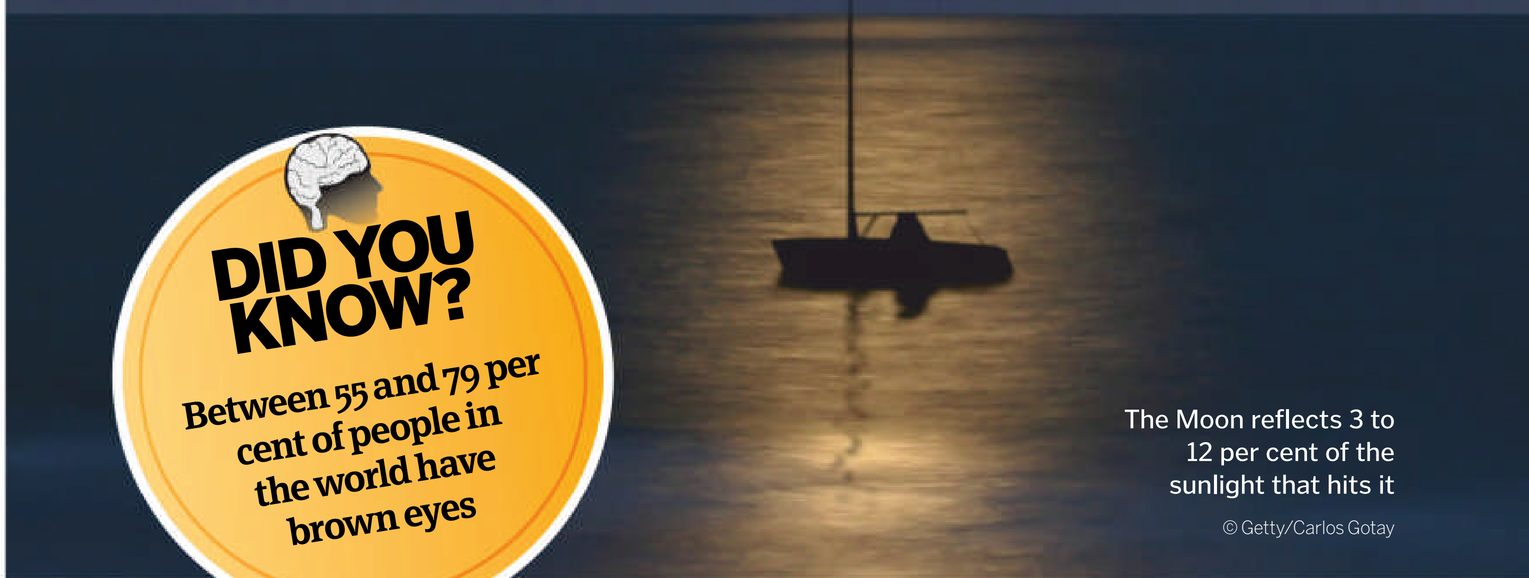
This question can never be answered with complete certainty, as the oldest building might not have been discovered yet. The oldest known human-made structure still standing to this day is the Cairn of Barnenez in Brittany, France. This building dates back to 4850 BCE. Containing nine defined chambers and interlinking passageways, the walls stretch across an area 72 metres in length and are 25 metres wide. Situated atop a hill, the nine-metre-tall construction was built in the Neolithic period, when humans began farming. **AH**

SPACE

What would happen if the Moon disappeared?

Jason Oxley

The gravitational pull of the Moon slows down Earth's rotation, so without it a day would only be about 6 to 12 hours long. This would mean having over 1,000 days in a single year. The angle of Earth would no longer be constant, with the potential for more extreme weather. Tides would change in size, making them one-third of the size they are now. Many animals that rely on tides, like starfish and mussels, might be lost, while the nocturnal animals that rely on moonlight would struggle to hunt. **AH**



The Moon reflects 3 to 12 per cent of the sunlight that hits it

© Getty/Carlos Gotay

DID YOU KNOW?

Between 55 and 79 per cent of people in the world have brown eyes

© Getty

SCIENCE

Why do some runners get diarrhoea in the middle of a marathon?

Mared Hartley

Doctors aren't completely sure why long-distance runners get the runs. However, some believe the continual jostling of internal organs and decreased blood flow to the intestines may be the cause. **BB**

SCIENCE

Why do we have exactly five fingers on one hand?

Monica Bielik

During development in the womb, human embryos grow five rods of cartilage before the cells that surround them die away, leaving four separate fingers and a thumb. It's a physical characteristic that has been passed from generation to generation over millions of years of evolution. The ancestors of modern-day mammals, reptiles and birds, called tetrapods, which evolved between 420 and 360 million years ago, also had five digits at the end of their limbs. **SD**

Our hands begin to open after around three months of pregnancy

© Getty

BRAIN DUMP

Small amounts of the pigment eumelanin scatter light to the front of the eye, converting it to shorter, blue wavelengths

© Getty

SCIENCE

Where do we get our eye colour from?

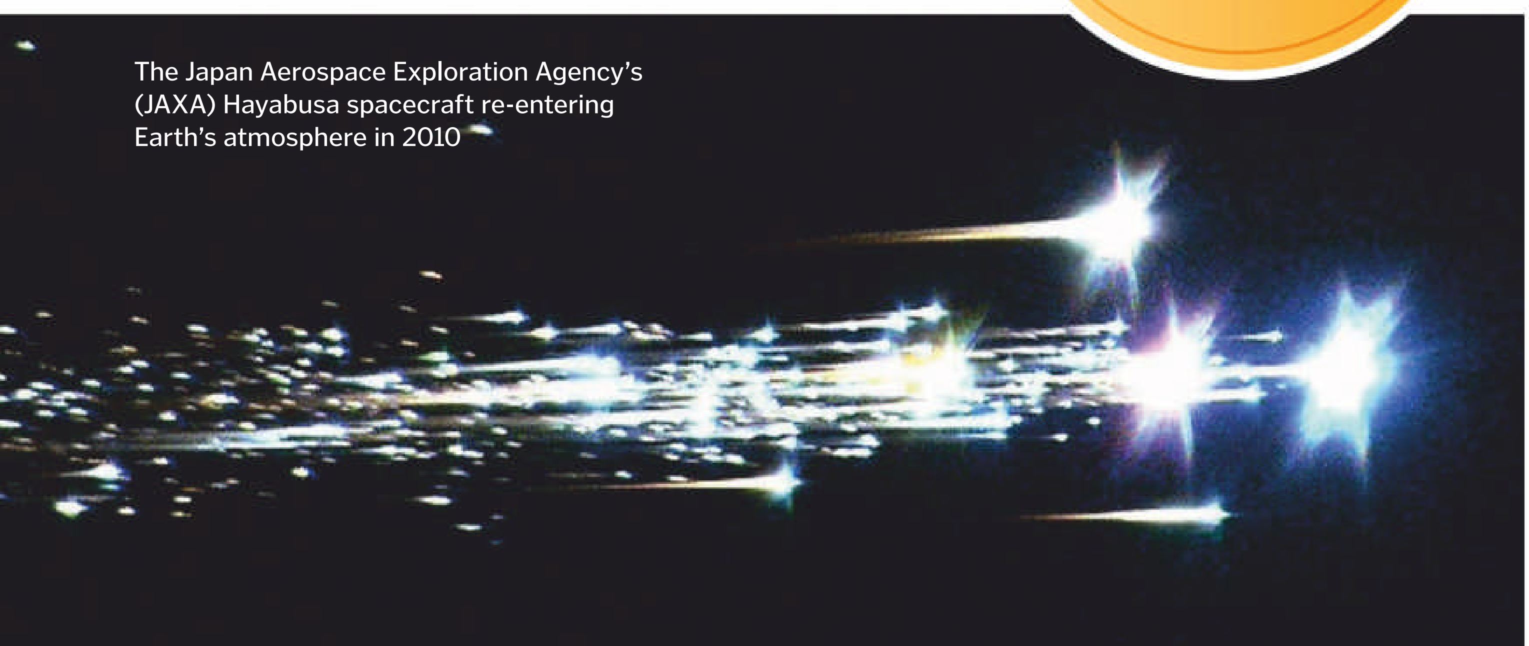
Rachel Culley

Our eye colour comes from melanin, a pigment that also determines the shade of our skin. As most of the light that enters our eyes goes into the retina, a small amount is reflected back, which is perceived as colour. The exact colour is down to the melanin concentration.

Eumelanin produces brown eyes, unless there is relatively little, which then produces a blue shade. Meanwhile pheomelanin creates green, hazel or amber eyes. Red eyes are a sign of no melanin, with the colour coming from the blood vessels themselves. **AH**

DID YOU KNOW?

Up to 71 per cent of long-distance runners experience 'runner's trots'



The Japan Aerospace Exploration Agency's (JAXA) Hayabusa spacecraft re-entering Earth's atmosphere in 2010

© NASA Ames / Jesse Carpenter / Greg Merkes

SPACE

Why does a spacecraft burn so hot during re-entry?

Cameron Harvey

Upon re-entry, atmospheric particles are compressed and rub together, creating friction and generating heat. During descent spacecraft also generate a pressure wave, ionising air molecules and creating superheated plasma. A craft travelling at 7.8 kilometres per second reaches over 7,500 degrees Celsius on re-entry. To protect against overheating, the base of craft are lined with silica tiles. These tiles hold the heat at their centre, preventing it from spreading. **SD**

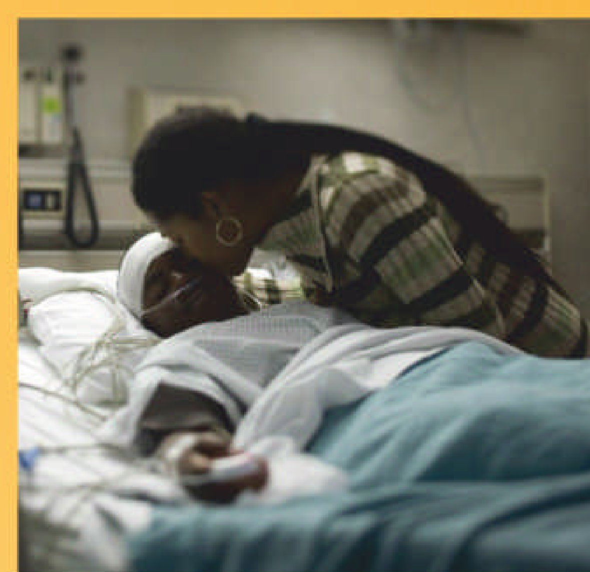
© Getty

TRANSPORT

Could you put car petrol in a jet?

Stefan Caroll

You could, but big jet engines wouldn't tolerate it very well, as car petrol boils off at relatively low temperatures. Jet A-1 fuel is made from kerosene and is similar to diesel fuel. It could work in a car with a diesel engine – though it would damage the car – and diesel fuel could work in a jet engine. However, at the very low temperatures encountered at high altitudes the car diesel would turn into a jelly-like substance and stall the jet engines. **BB**



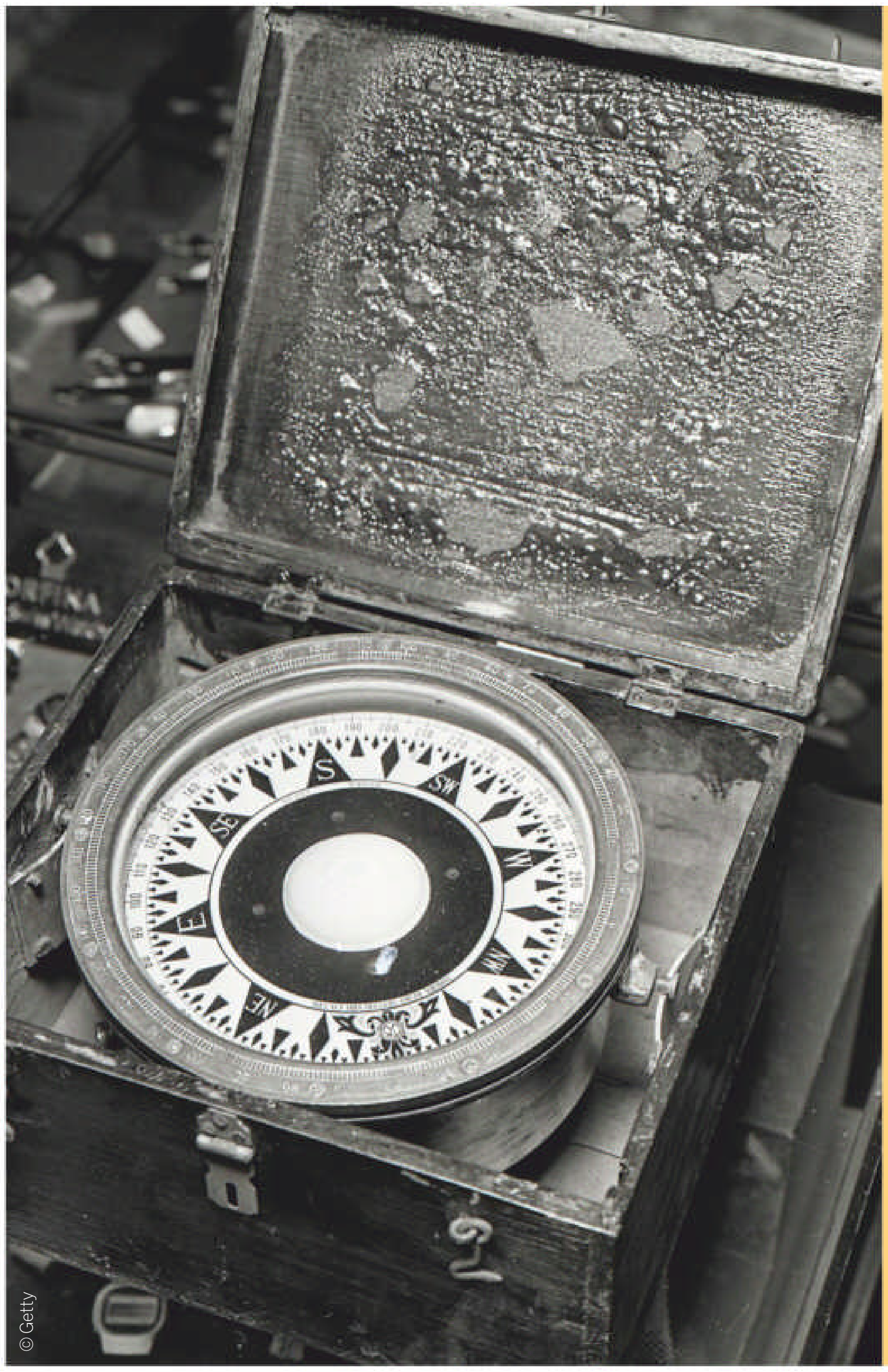
© Getty

SCIENCE

If someone has to spend a long time in a medically induced coma, does that cause long-term brain damage?

Stephen Conn

A short-term medically induced coma is usually anything less than 72 hours and has few side-effects, if any. Longer than a week in the coma can lead to a variety of complications when the patient wakes up, including nausea, confusion, delirium, muscle wasting and weakness and addiction to the sedatives used to induce the coma. The severity of these side-effects depends on factors such as the age and the general health of the patient. **BB**



© Getty

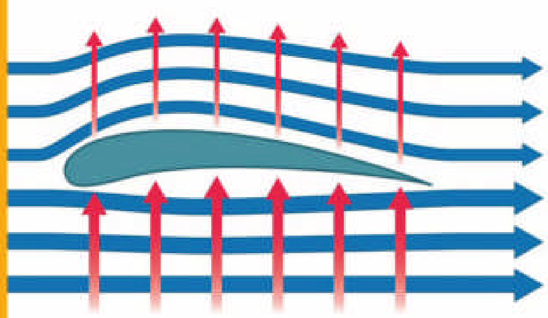
ENVIRONMENT

Why do compasses show only north even in the Southern Hemisphere?

Panos

Compasses align with the magnetic field lines that point into Earth at the North and South Poles. There are compasses designed for use in the Northern and Southern Hemispheres, each of which have an end that points north and is painted red. In the Northern Hemisphere the north end of the needle is pulled downwards, so the south end of the needle has a counterweight that balances the needle. It's the other way around in the Southern Hemisphere, where the south end of the needle is pulled downwards, so the north end is counterweighted. If you took a Northern Hemisphere compass to Australia, the counterweighted south end of the needle would be pulled down by the magnetic south pole, and will drag along the bottom of the compass. **BB**

European sailors began to use magnetic compasses around the 13th century



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SCIENCE

How is lift generated and what is the principle behind it?

Abhi S

Bernoulli's principle describes how the shape of an aircraft's wings generate lift. With a curved top and flat underneath, air has further to travel over the top, flowing faster. Fast-moving air exerts less pressure than the slow air underneath, pushing a craft upwards. **AH**

SCIENCE

How does one-way glass work?

Jeff Jacobs

A reflective coating is applied to glass, called a half-silvered surface, to create a one-way mirror. The molecules that make up the coating are sparsely spread out over the glass, allowing only half the light to pass through it and the other half to be reflected by the silver surface. This means that depending on which side of the glass you're standing, you can either see the light passing through the glass, making it seem transparent, or the glass appearing as a mirror when light is reflected by the silvered surface. **SD**

Skyscrapers around the world use half-silvered windows, allowing those inside to look out but stopping people outside from looking in

© Getty

DID YOU KNOW?

Theoretically, antimatter should have annihilated the universe after the Big Bang

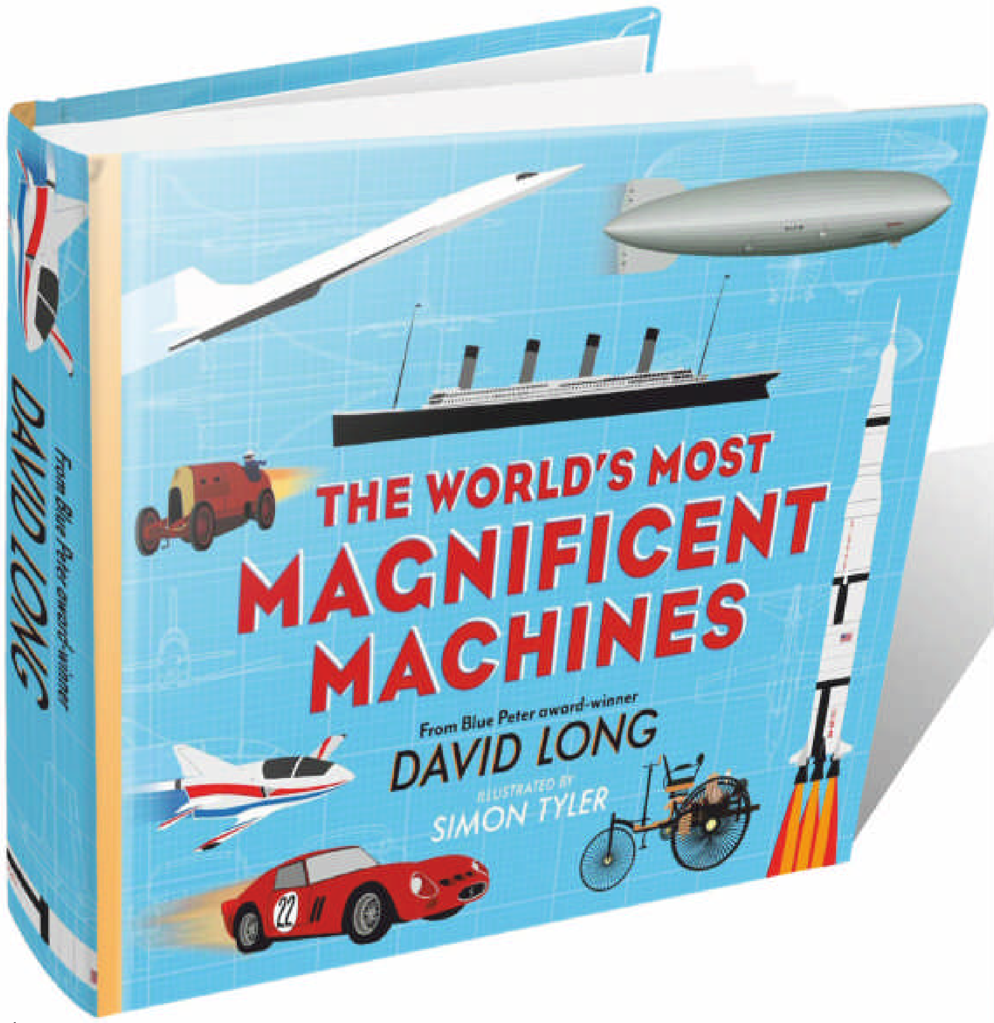
BOOK REVIEWS

The latest releases for curious minds

The World's Most Magnificent Machines

From the first automobile to rocket trains, drilling machines and more

- Author: **David Long**
- Illustrator: **Simon Tyler**
- Publisher: **Faber & Faber**
- Price: **£20 / $26**
- Release: **Out now**



It's crazy to think that just 150 years ago there were no planes or cars, trains were yet to be widely adopted across the world and most ships were still made of wood. While steam power dominated heavy industry, machines that did the same job of many workers were strange and awe-inspiring beasts. We have come an incredibly long way in a relatively short time to change the way we live, and that can be largely credited to the machines that assist us with a multitude of tasks, which in some cases would be impossible for us to achieve otherwise.

Blue Peter award-winning author David Long has compiled the biggest, fastest, most expensive, most powerful, the weirdest and of course, the most magnificent machines in modern history into one attractive hardback book. It's a list of land, sea, air, space and even underground contraptions, of which some we guarantee will surprise and delight you, even if you're a bit of an engineering boffin.

His compilation is peppered with some choice vehicles, including the supersonic Bloodhound LSR, the rocket-launching Stratolaunch aircraft, the 'unsinkable' RMS Titanic and the first modern car – the Benz Patent Motorwagen. But there are also a lot of seriously fun entries that look like something from Hanna-Barbera's *Wacky Races*, like the unwieldy and impractical eight-wheeled car, the Octoauto, or the Motoruota Monowheel, a motorbike with a single wheel that housed both the engine and the driver!

Each pithy entry is fact-packed and accessible, prefaced with three bullet points that won't fail to engage the reader, and coupled with Simon Tyler's simple yet effective vector-style illustrations. Every page highlights the missions achieved, lessons learned and stories of perseverance. The hardback edition is both an engrossing coffee table read and a great gift for younger school children, who will be blown away by the fantastic machines of yesteryear and the incredible technology of today.

★★★★☆

Highlights missions achieved, lessons learned and stories of perseverance

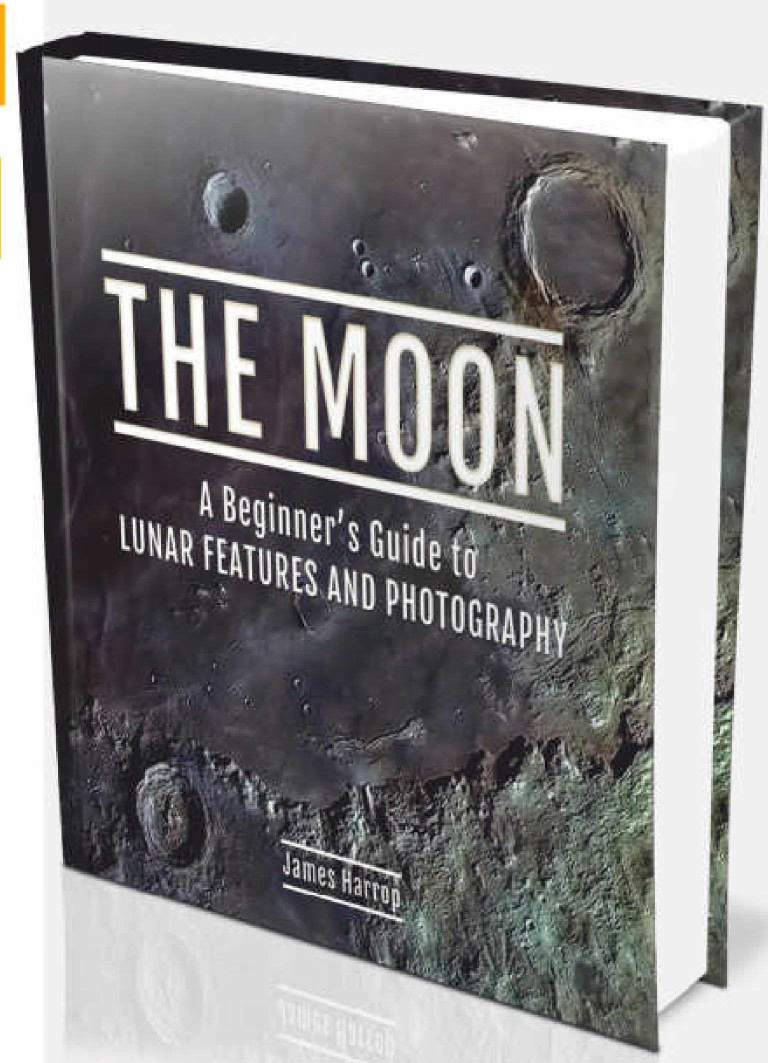
The Moon

A beginner's guide to lunar features and photography

- Author: **James Harrop**
- Publisher: **White Owl**
- Price: **£25 / $42.95**
- Release: **Out now**

General photography is a complex skill in itself, but when you're pointing the lens into the night sky, it becomes increasingly difficult – that is, unless you have this excellent beginner's guide to astrophotography. From getting to grips with a DSLR camera to mastering the full potential of your mobile phone, Harrop takes the reader through the array of techniques you can use to capture the perfect shot of the Moon. Although this book uses the Moon as a starting point, the wisdom it imparts can be applied to many different areas of astrophotography, including how to use planetary imaging preprocessing for crystal-clear images. Whether you've never picked up a camera before or you're looking to get a few tips and tricks, this book is a great addition to your photography library.

★★★★★

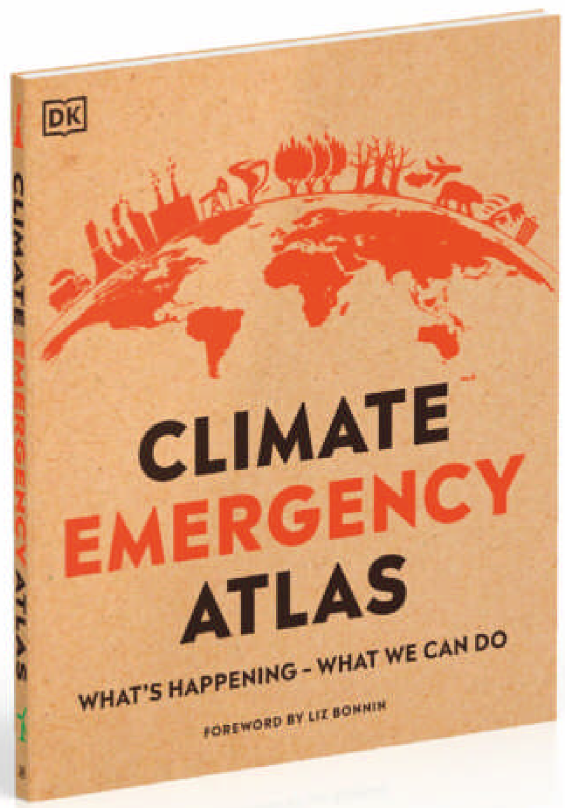


Climate Emergency Atlas

What's happening and what we can do

- Author: **Dan Hooke**
- Publisher: **DK Children**
- Price: **£12.99 / $19.99**
- Release: **Out now**

Trying to wrap your head around the many issues involved in Earth's climate crisis can sometimes be overwhelming. However, this visual guide to our planet's problems is a great way to get informed. Clear and concise, DK has produced a book jam-packed with environmental facts and stats, including disappearing forests, the growth in fossil fuel consumption and farming. However, it's not a book filled with doom and gloom, highlighting the positive global work that's being done to fight the crisis, such as the growth in wind farms and reforesting. This is a great book to help explain what's happening in the world to a younger audience, but it also reveals some stark and surprising information we should all take note of. ★★★★★



Jam-packed with environmental facts and stats

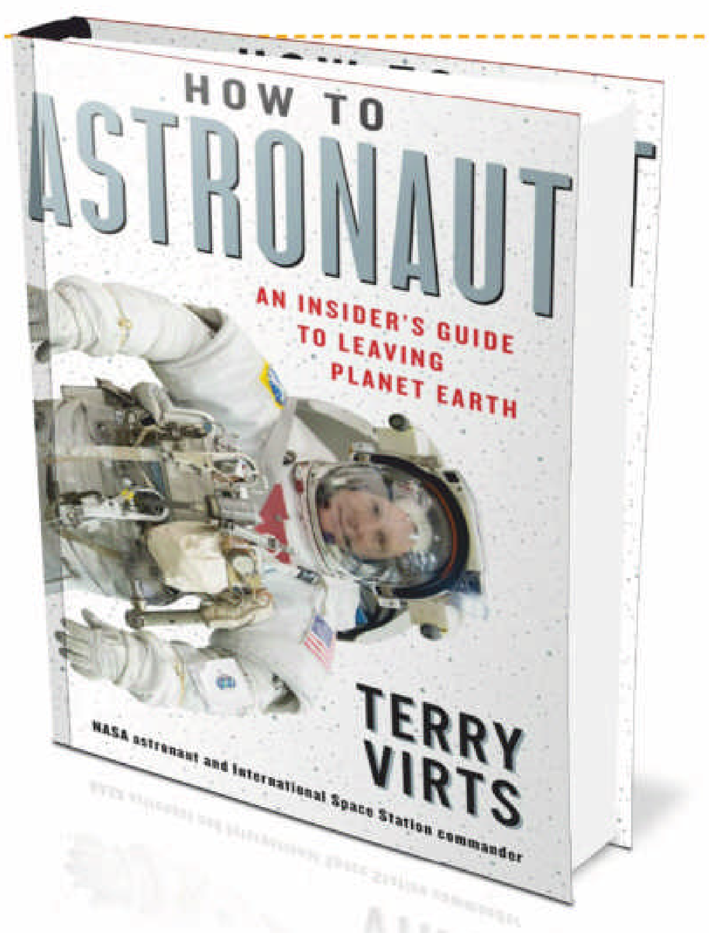
How to Astronaut

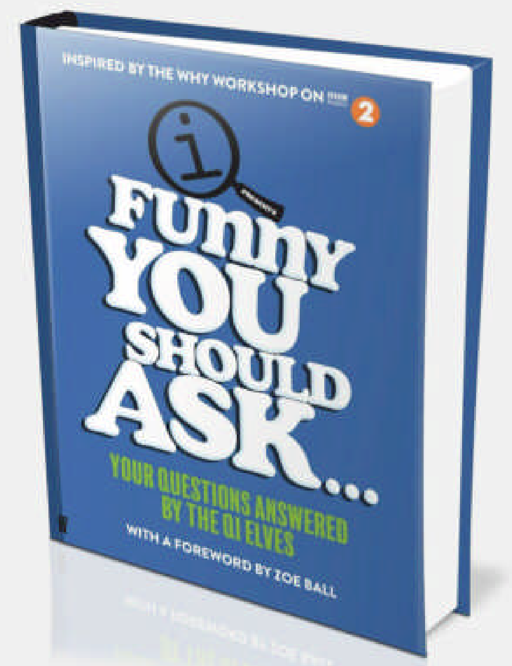
An insider's guide to leaving planet Earth

- Author: **Terry Virts**
- Publisher: **Workman Publishing**
- Price: **£21.99 / $27.95**
- Release: **Out now**

Whether you're space-obsessed, plan to utilise space tourism or are simply curious, this book is guaranteed to leave you dreaming of a trip to the stars. What do you pack for many months in space? What's it like to float to sleep? Not many truly know the answers to these questions, with rocket trips being undertaken by so few humans so far. But this book is here to answer them all, along with those you may not even think to ask. The short chapters are full of valuable first-hand accounts to give you an accurate feel for life in this environment and what it takes to prepare.

Former astronaut Terry Virts draws on his 200-day experience on the International Space Station, sharing humorous, terrifying and inspiring accounts. You'll find out that it's not all glamour being an astronaut, as this book reveals the difficulties of using a space bathroom – with no details spared. With almost every action, movement or chore becoming a totally new challenge in the limited gravity of a space station, this book covers a broad selection of insights, engagingly written to place you into an astronaut's shoes – or space boots. ★★★★★





Funny You Should Ask...

The kind of crazy questions kids might ask you

- Author: **BBC QI Elves**
- Publisher: **Faber & Faber**
- Price: **£12.99 / $16.95**
- Release: **Out now**

The folk who answer the curious questions for TV quiz show *QI* and Radio 2's *The Zoe Ball Breakfast Show* have now compiled them into a book. Known as the 'QI Elves', these 12 clever people broach topics from across the spectrum of general knowledge, and some of the questions people have asked are seriously thought-provoking, such as how much water does it take to put out the Sun? – the answer to this might surprise you! – to the more mundane yet just as fascinating why do men go bald – and always in the same way? Or the philosophical have I read this page before?

Even if the question sounds like it's going to be underwhelming, the answer always over-delivers with bonus facts, snippets of wisdom and sometimes a simple diagram – because a picture can do the job of a thousand words. And if none of the answers to these questions – of which there are around 100 –blow your mind, then you're either incredibly knowledgeable and you're showing off to your friends, or you're one of the QI Elves. *Funny You Should Ask...* is perfect for breaking out and entertaining the family after Christmas dinner or during the long lockdown evenings. ★★★★★

BRAIN GYM

GIVE YOUR BRAIN A PUZZLE WORKOUT

QUICKFIRE QUESTIONS

Q1 How do scientists think the Moon formed?
- It was captured by Earth's gravity
- It was created after another rocky body impacted Earth
- Lizard people made it
- Earth divided during the early Solar System

Q2 Which of the original seven ancient wonders remains?
- Colossus of Rhodes
- Lighthouse of Alexandria
- Pyramids of Giza
- Statue of Zeus

Q3 Which creature has ears on its legs?
- Tiger
- Shark
- Centipede
- Cricket

Q4 When was the first iPhone launched?
- 1999
- 2004
- 2007
- 2011

Q5 Which of these is not a noble gas?
- Krypton
- Hydrogen
- Radon
- Neon

Q6 About how thick is Antarctica's ice cap?
- 20 to 50 metres
- 200 to 500 metres
- 2 to 5 kilometres
- 20 to 50 kilometres

Spot the difference

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

Sudoku

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

EASY

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

DIFFICULT

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

What is it?

Hint: How long is a piece of this?

A ....

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

Wordsearch

FIND THE FOLLOWING WORDS...

NOBLE
ASTRONAUT
MOON
NIGHT
EYES
WINE
WATCH
EGYPT
HYPERNOVA
EIFFEL
FRACKING
GLOBAL

Check your answers

Find the solutions to last issue's puzzle pages

SPOT THE DIFFERENCE

QUICKFIRE QUESTIONS

Q1 Red meat
Q2 Magnetic
Q3 Okra
Q4 1979
Q5 1944
Q6 Supermassive black hole

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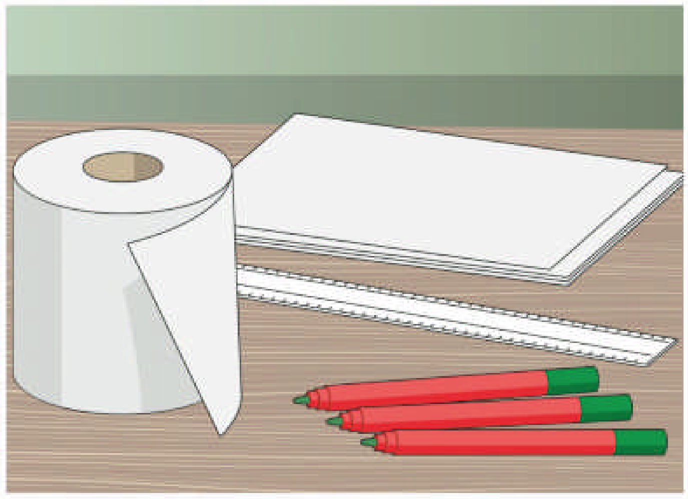
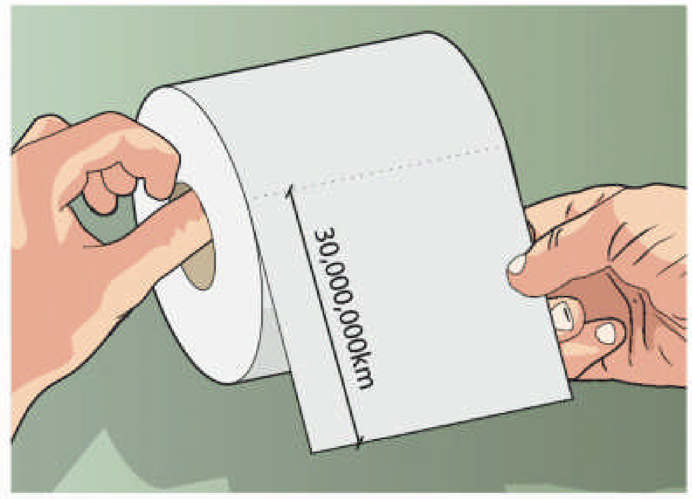
How to make a toilet roll Solar System

Visualise our vast planetary neighbourhood, one sheet at a time

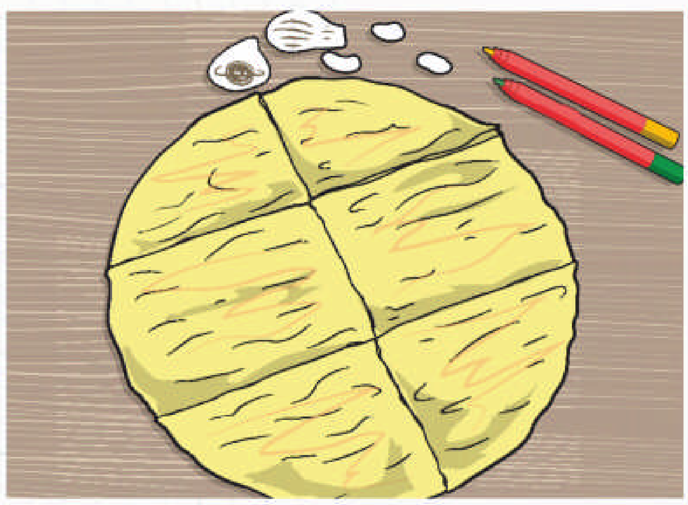


1 Gather your equipment
You'll need a roll of toilet paper with at least 150 sheets and a list of planet sizes and distances. To create the planets, find some felt tip pens or colouring pencils, a ruler and six sheets of A4.

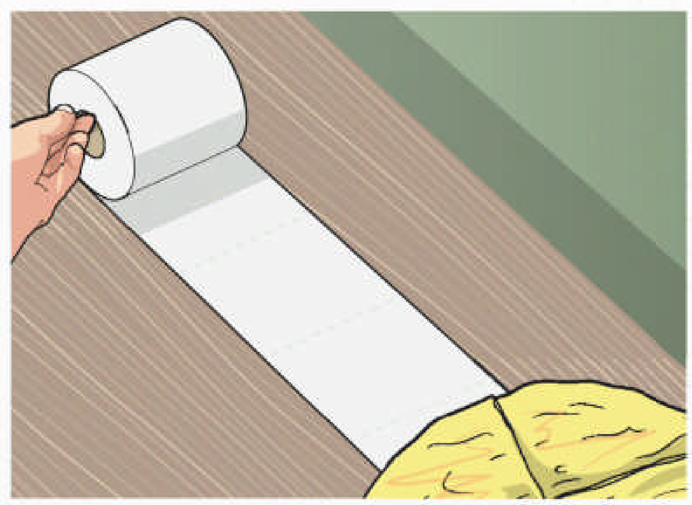


2 Know the scale
Our Solar System is so extensive that it can be difficult to visualise. To make it fit onto one roll of toilet paper, each individual sheet will represent 30 million kilometres.

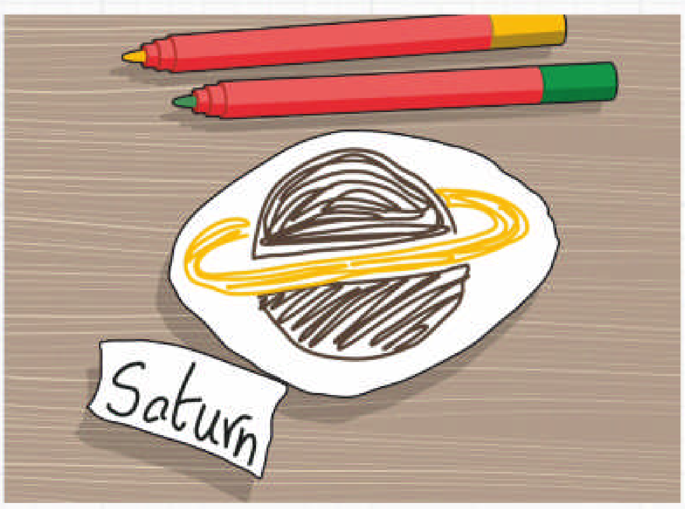
3 Design the planets
While the distance between the planets will be to scale, the planets themselves will need to be designed 100-times bigger than they really would be – otherwise they would be too small to see on the toilet roll.



4 Start with the Sun
Use six sheets of paper to draw the Sun and use the spare paper to draw and label each planet. Place the Sun down at the beginning of your toilet roll line. This represents the centre of the Solar System.



5 Plot the planets
Plotting Mercury first, which will be two sheets from the Sun, begin to calculate the correct distances in 30 million kilometre increments. You may need a calculator, or see our summary. Make sure to place the planets in the correct order.



6 Space unravelled
You might be surprised at just how much distance you need to cover to reach the outer planets. When you get to Uranus and Neptune you might need to take your Solar System upstairs or place the toilet roll trail into a zigzag pattern.

7 Safely store
Once you have admired your Solar System, you can pack it away until you next want to visualise our cosmic home. Make sure to stick down each planet into its position to make this easier next time.

SUMMARY
The toilet roll Solar System compacts millions of kilometres into one sheet. However, it will still take up a huge amount of your home's floor space. Here are the planets' distances in sheets:

Mercury: 2.0 sheets from the Sun
Venus: 1.5 sheets from Mercury
Earth: 1.5 sheets from Venus
Mars: 2.5 sheets from Earth
Jupiter: 18.5 sheets from Mars
Saturn: 21.5 sheets from Jupiter
Uranus: 47.5 sheets from Saturn
Neptune: 54 sheets from Uranus

NEXT ISSUE… Make fake glass for home movies

© Illustrations by Ed Crooks

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INBOX

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WIN! A HAYNES MANUAL

From cars, to skyscrapers, to galaxies and even the Millennium Falcon: Haynes guides take all sorts of things apart, show the reader exactly how they work, and how to repair and maintain them.

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© Javier Zayas Photography/Getty Images

If these vaccines prove effective, they will provide long-lasting immunity

Virus vaccine

Dear **HIW,**

With all this talk about the need for a COVID vaccine, I wondered how the COVID-19 vaccine itself works.

Marie Hardy

There are currently many vaccines undergoing trials around the world, and some are making very promising advancements.

While some of these vaccines have slightly different approaches, the core goals are the same. The virus is covered in spike proteins, which teams are aiming to inject safely into the body to trigger an immune response. Usually upon entering the body, all of the virus' genes are copied and multiplied, but the COVID vaccines will only carry part of this DNA. This ensures that only the outer proteins are copied, and not the more dangerous parts.

Once the body has already encountered this part of the virus, if it comes into contact with COVID again the body will be able to attack the virus before symptoms become severe.

Letter of the month

Women in STEM

Dear **HIW,**

What advice would you give to girls about going into science careers?

Sunny Elvy

As a science-orientated team of both men and women, we would say go for it! If you enjoy science and want a job in which you can research, build or discover something that excites you and will make a difference, there are a broad range of careers to suit you. Just make sure you seek experience in all possible fields that you are interested in to see which career is right for you.

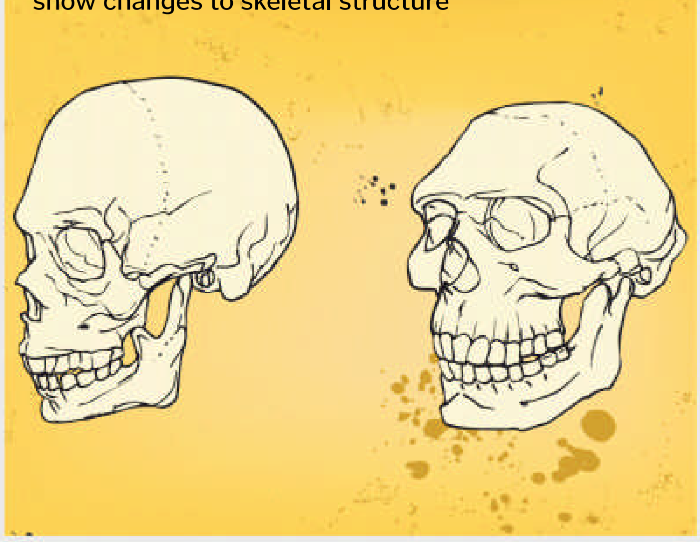
The top minds are a mix of male and female, and the world needs the brightest to enter these careers. You shouldn't be put off by the stats associating STEM careers with males, but instead make a difference in showing what you have to offer.

The number of women in science is rising: just seven per cent of all STEM workers were female in 1970, compared to 26 per cent in 2011. STEM professions are more equal and diverse than they once were, but further increasing the number of female scientists will help to broaden research. The issues that science decides to solve have a lot to do with the scientists behind the products or experiments, so having diverse teams of gender and ethnicity helps to broaden ideas. Stepping into a career in science is a great way to increase the work that matters to you and those you represent.

Get inspired by female scientists and role models. As gender inequality begins to fade in some sectors, scientists are a great example of a community demonstrating the work that can be done when people of any gender, race or other social category come together.

Women now represent over 40 per cent of science professionals

© Getty/ Morsa Images



A human skull (left) and Neanderthal skull (right) show changes to skeletal structure

© Getty

History of the human body

Dear **HIW,**

Do mesomorphs have more Neanderthal DNA than endomorphs and ectomorphs, as they tend to be shorter and stronger?

Theo Schmidt

A mesomorph is a muscular, built-up body, while an ectomorph is a leaner and longer body type. Endomorphs have a higher tendency to store fat. Many aspects of these body types are more a result of environmental factors than genetic, which could have occurred over the course of thousands of years of changes to a genetic line. While it is possible that someone may be short due to having some Neanderthal DNA, there are too many other factors, and this won't be the case for most.

One feature which holds a stronger link is skull shape. Studies have shown that those with more oblong-shaped brains and skulls are more likely to have a closer relation to the Neanderthals.

Prize-winning science

Dear HIW,

What are the implications of the recent Nobel Prize-winning work on CRISPR-Cas9?

Louis Tyndall

The CRISPR-Cas9 discovery was published in 2011

This year's Nobel Prize in Chemistry was awarded to Jennifer Doudna and Emmanuelle Charpentier for the discovery of the CRISPR-Cas9 genome-editing technique. Many of the implications will have come when their work was initially released, but this award for their achievements will raise awareness of the applications of scientists' ability to rewrite genetics with this technique.

The scientists who developed 'genetic scissors' – a method to allow these changes to be made with greater precision – open doors to new applications, such as removing genetic illnesses from individuals. The prize highlighted the beneficial current uses of the technology, such as growing crops that accumulate lower levels of heavy metals.

Sleepy mornings

Dear HIW,

Why do we still feel tired when we wake up?

Monika Bielik

Thank you for your question, Monika. I think many of us can relate to this feeling. Although we are able to enter a conscious state quickly when our alarm goes off in the morning, our brains can sometimes take a while to catch up with us. This is called sleep inertia, and can last between a few minutes to over an hour. Before your brain reaches full alertness, your motor and cognitive abilities are slowed. The best ways to prevent this feeling are to make sure you're getting enough sleep, avoid waking up suddenly and keep to a routine so that your body can get used to it.

© Getty

Sleep inertia most commonly lasts between five and 30 minutes

What's happening on... social media?

This month on Instagram we asked you: 'If you could be the first person to explore part of space, where would you want to go?'

@louistyndall
The Crab Nebula, just because of how beautiful it looks

@definitely.notmax
I would visit Uranus, or a nearby galaxy, as who knows what will be there!

@jonesy_rhys06
I would go to a planet where all organic matter is based on an element that isn't carbon

@jamesf_2005
Mars, a habitable planet

@cameron1harvey
Ross 128 b. A potentially Earth-like planet 11 light years away with ten-day years-that's a lot of birthdays

@cathode149
A nebula somewhere far from Earth where there are no people

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FAST FACTS

Amazing trivia to blow your mind

500

HUNDREDS OF GAMMA-RAY BURSTS ARE VISIBLE FROM EARTH EVERY DAY

0.0018%

NEON GAS MAKES UP A TINY PART OF EARTH'S ATMOSPHERE

4.51 BILLION YEARS

THE MOON IS THOUGHT TO HAVE FORMED SHORTLY AFTER EARTH

$558,000

THE WORLD'S MOST EXPENSIVE BOTTLE OF WINE WAS SOLD AT AUCTION IN 2018

2000 BCE

THE FIRST MOUNDS OF A BRAZILIAN TERMITE 'METROPOLIS' AS BIG AS BRITAIN WERE BUILT 4,000 YEARS AGO

THE TIMEX DATALINK WAS THE FIRST WATCH TO DOWNLOAD DATA FROM A PC WHEN IT LAUNCHED 26 YEARS AGO

A MAGMA OCEAN 100 KILOMETRES DEEP ONCE COVERED THE MOON

2.7 MILLION YEARS

THE OLDEST ANTARCTIC ICE CORE DISCOVERED DATES TO THE BEGINNING OF THE MOST RECENT ICE AGE

1891

NIKOLA TESLA INVENTED THE LIGHTNING-DISCHARGING TESLA COIL OVER 100 YEARS AGO

3100 BCE

ANCIENT EGYPT WAS ESTABLISHED OVER 5,000 YEARS AGO

MANTIS SHRIMP HAVE THE MOST COMPLEX EYES IN THE ANIMAL KINGDOM

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1	m 14.12	m 9.25
m² 22.60	kg 7,123	km/h 1,065
B km A 3,256	m/s 74.8	1.1

1 × Rolls-Royce Pegasus Mk. 105 vectored thrust turbofan

1	m 15.96	m 10.95
m² 51.20	kg 11,15	km/h 2,475
B km A 2,900	m/s 315	1.15

2 x Eurojet EJ200 Afterburning Turbofan

J6002 Typhoon

J6009 Harrier

Aviation Royalty

AMAZING AIRCRAFT OF THE RAF

The Harrier is a jet-powered attack aircraft capable of vertical/short take off and landing operations. Named after a bird of prey, it was originally developed by British manufacturer Hawker Siddeley in the 1960s and emerged as the only truly successful V/STOL design of the many attempted during that era. It was conceived to operate from improvised bases, such as car parks or forest clearings, without requiring large and vulnerable air bases. Later, the design was adapted for use from aircraft carriers.

The Eurofighter Typhoon is a twin-engine, canard–delta wing, multi-role fighter. It was designed originally as an air superiority fighter and is manufactured by a consortium of Airbus, BAE Systems and Leonardo. One of the world's most capable fighter aircraft, it possesses all the attributes that made the Spitfire so successful in combat and is the most effective air defence fighter to ever serve with the RAF.

You can you create your very own fighters of the RAF at home with an Airfix QuickBuild kit. QuickBuild kits allow you to recreate a wide variety of iconic aircraft, tanks and cars into brilliant scale models. No paint or glue is required, the push together brick system results in a realistic, scale model that is compatible with other plastic brick brands.

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