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Everything you want to know about the world we live in

HOW IT WORKS Annual

1000s OF AMAZING FACTS INSIDE

SCIENCE ENVIRONMENT TECHNOLOGY TRANSPORT HISTORY SPACE

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HOW IT WORKS Annual

Welcome to the sixth volume of the How It Works Annual, where your burning questions about how the world ticks finally get answers. Feed your mind, indulge your curiosity, get answers to your strangest questions and uncover the truth behind the greatest misconceptions. We delve deep into the mysteries of our world with in-depth and entertaining articles, accompanied by cutaways, illustrations and incredible images to show you exactly what goes on inside. The How It Works Annual explores the universe through six areas of knowledge: technology, transport, the environment, history, science and space. Our subjects run from the smallest of things in the natural world, like the Monarch butterfly, to huge accomplishments of engineering like the International Space Station. We also uncover the things we cannot touch, like the science of how we fall in love, and the causes behind devastating thunderstorms. We go back in time to meet Vikings and Romans, and gaze into our crystal ball to see what the future holds, like 5G technology and super soldiers. Are you ready to learn more about the world around you? Then read on and be amazed.

HOW IT WORKS Annual

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SCIENCE ENVIRONMENT TECHNOLOGY TRANSPORT HISTORY SPACE

CONTENTS

SCIENCE

TECHNOLOGY

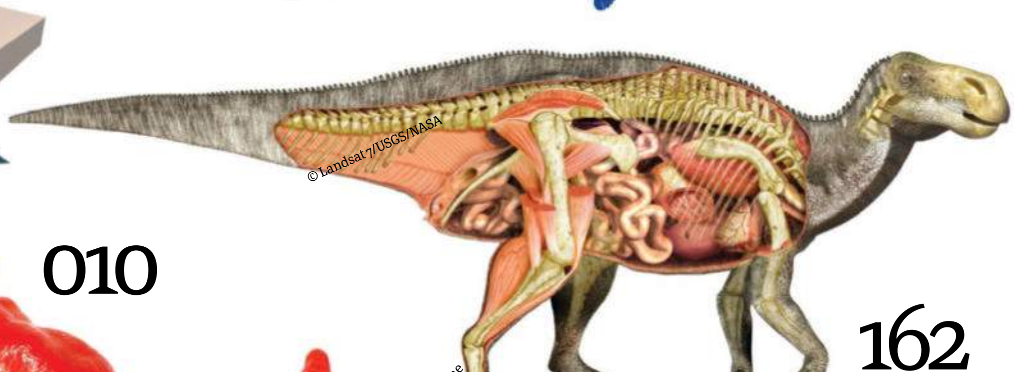
ENVIRONMENT

122

022

070
Weird weather

010



162
Dinosaurs

064

104
Aerobatic displays

092

180

042
Super soldiers

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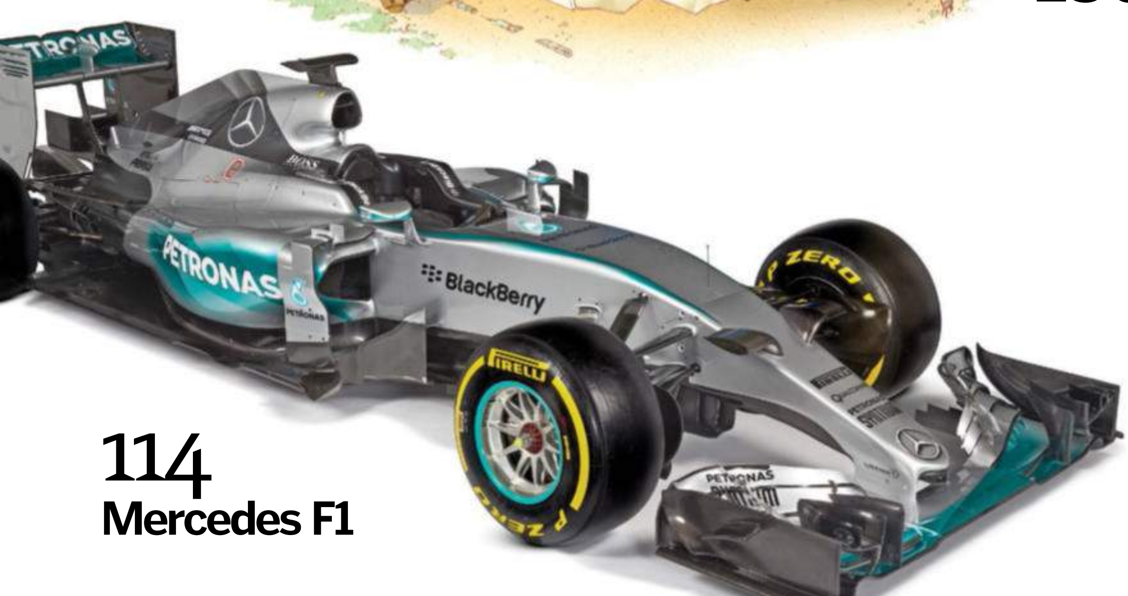


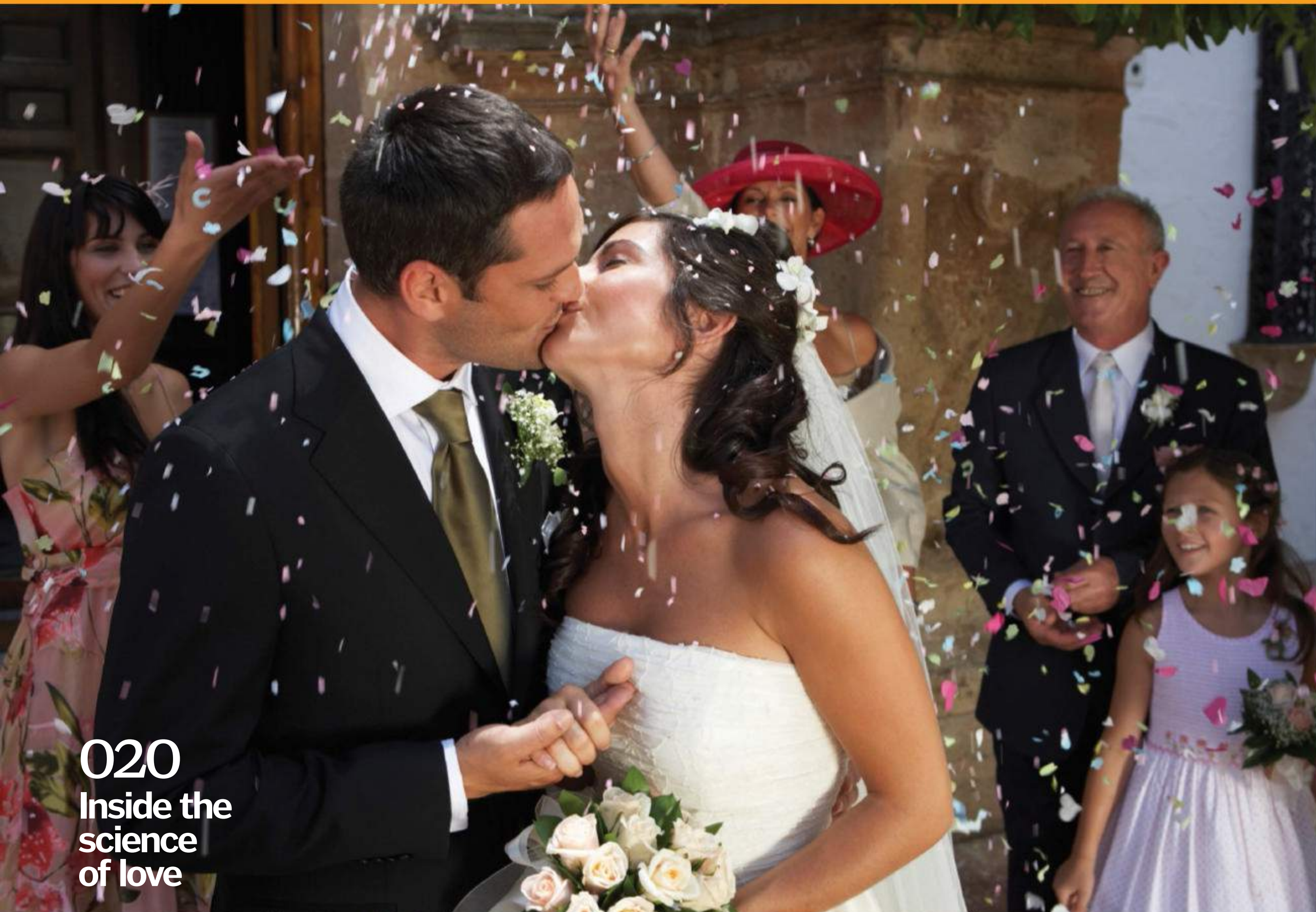
114
Mercedes F1

SCIENCE

032
Cryogenics uncovered

031
Alcohol up close

028
Immune cells



020
Inside the science of love

010
Science myths

030
Iceskating facts

50 SCIENCE MYTHS BUSTED!

Do bumblebees really defy the laws of physics? And will vitamin C actually protect you from the common cold? Discover the truth behind 50 of the world's most common myths

Rain is teardrop-shaped

01 Raindrops are often drawn with a pointed top and rounded bottom, but these simplified pictures are not even close to the truth. Raindrops form high up in the atmosphere when water clings to tiny particles of dust, and as the molecules gather together they form temporary bonds that pull the shape into a sphere. As the raindrops fall through the air, they collide with gas molecules and become distorted, widening and flattening out across the bottom. The top half forms a dome as surface tension struggles to keep the droplet together, but for raindrops over four millimetres (0.16 inches) in diameter, the weak bonds are not strong enough to hold the water together, so the droplets break apart.

1 Spherical drop Raindrops naturally form into spheres because it is the shape with the smallest surface area.

2 Surface tension Water molecules cling to one another with weak hydrogen bonds, creating surface tension.

3 Hamburger-shaped As the drops fall toward the ground, they collide with the air and the pressure flattens out the bottom edge.

4 Parachutes The largest raindrops are unable to hold themselves together and as they drop they start to distort into a parachute shape.

5 Breaking apart Raindrops over 4mm (0.16in) in diameter break up as they fall.

6 Smaller droplets The smallest droplets remain spherical as they tumble toward the ground.

The bull is more interested in the movement of the cape than the colour

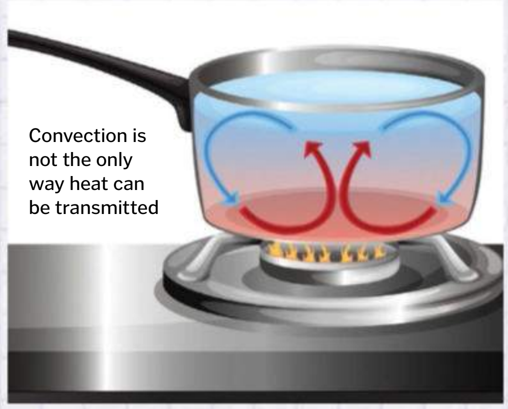
The colour red makes bulls angry

02 Bullfighters are famous for their red capes, but the idea that the colour is a trigger to anger the animals is a myth. While we can see light in red, green and blue wavelengths, bulls, like most other mammals, only have two-coloured vision. They are effectively red-green colour blind, and are more interested in the movement of the cape than its colour.

Cockroaches can withstand radiation because their cells divide less often than our own

Cockroaches can survive a nuclear apocalypse

03 Cockroaches are capable of withstanding much higher levels of radiation than humans and are often listed amongst the animals that will inherit the Earth in the event of a nuclear apocalypse. However, while adult roaches can survive radiation levels equivalent to those released by the Hiroshima nuclear bomb, their fertility is adversely affected by much lower levels of radiation.



Convection is not the only way heat can be transmitted

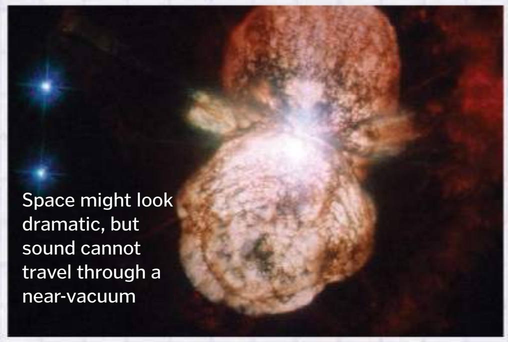
Heat rises

04 This simple myth persists because for many situations it appears to be true. As liquids and gases gain energy, they heat up and expand, which lowers the density compared to cold fluid, causing the hot region to rise. However, heat also transferred by infrared radiation and conduction, both of which can occur in any direction.

There is no link between the MMR vaccine and autism

Vaccinations cause autism

05 This is one of the most dangerous science myths of all and was born out of a combination of fraudulent research and irresponsible media hype. The 'evidence' supporting a link between the MMR vaccine and autism was misreported, and the results were distorted by the media, which spread the idea there was a link between autism and immunisation. Repeated investigations have confirmed the original data was false, but the myth has caused lasting damage and the rate of measles infections in the UK has risen as a result.



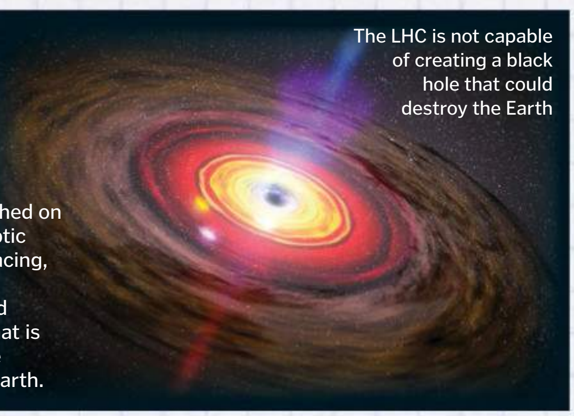
Space might look dramatic, but sound cannot travel through a near-vacuum

A firefight in space would be loud, just like in the movies

07 Sound propagates when vibrations are transferred from one particle to the next, but in outer space there are so few particles, spread so far apart, that the vibrations cannot travel. So despite the popular Hollywood scenes depicting loud explosions, in space nothing makes a sound.

The Large Hadron Collider could create a black hole and destroy the Earth

06 With the upgraded LHC being switched on again at CERN in 2015, the apocalyptic myths about black holes are resurfacing, as people are wondering whether two protons slamming into one another at high speed could produce a black hole. Some physicists think that is possible, but the resulting black hole would be microscopic and would do no damage to the Earth.



The LHC is not capable of creating a black hole that could destroy the Earth

The best thing you can do in a falling lift is to lie on the floor

In a falling lift, you should jump before you hit the floor

08 People often wonder whether they could jump just before a falling lift hits the floor, avoiding the impact of the crash, but unfortunately this tactic will not work. You are falling at the same speed as the lift, and as you push away from the floor in the opposite direction you are only counteracting a fraction of that downward acceleration.

Antibiotics can treat flu

09 Antibiotics are bacteria-busting drugs, so they are no use against flu or the common cold, both of which are caused by viruses. Antibiotics work by blocking the chemical processes bacteria use to survive and reproduce, but viruses hijack our own cells to replicate and are unaffected by these drugs.

Drawing on skin causes ink poisoning

10 Inks used to be made from dangerous chemicals, but today most pens have water or alcohol-based inks and are nontoxic. It takes a large amount of ink to cause poisoning and the most common routes of ingestion are either swallowing or inhaling, not drawing.

Bats are blind

11 Bats are well known for using echolocation to find their way through the darkness, but their mastery of hearing does not mean they are blind. All bats have eyes and can see. Some of the larger fruit-eating species have eyesight even better than our own.

Go out with wet hair and you'll catch a cold

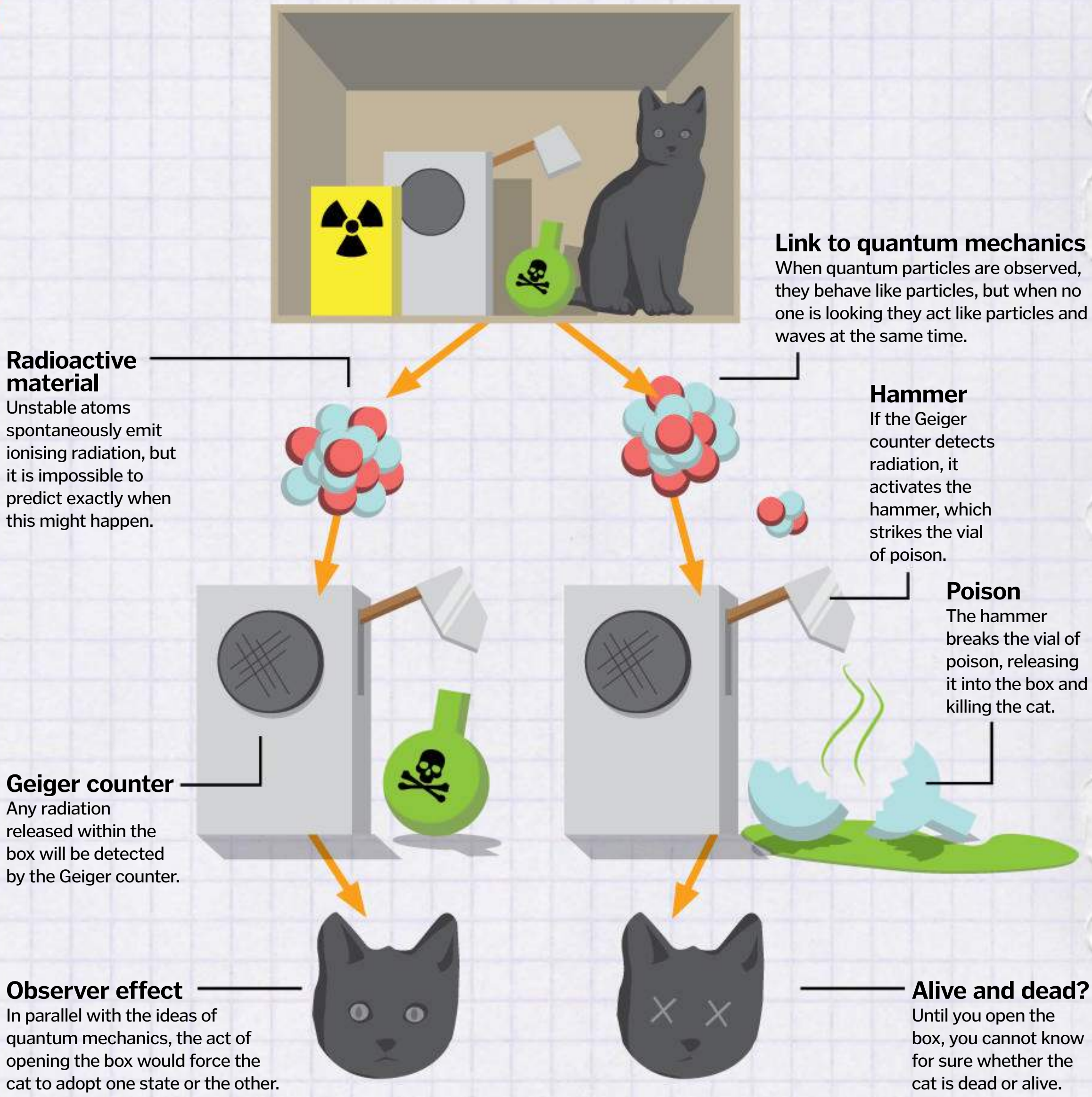
12 There is nothing special about wet hair that will increase your chances of catching the cold virus, but there is actually a grain of truth behind this myth. Getting chilly can increase your likelihood of developing the symptoms of a cold; possibly by decreasing the blood flow to your nose, thus enabling the virus to replicate.

White spots signal calcium deficiency

13 The white marks that appear on fingernails are known as leukonychia, and many people believe they are the result of mineral deficiency. However, the real cause is most often damage to the nails from knocks, bumps and even wearing false nails, all of which can cause abnormal marks to form at the nail plate.

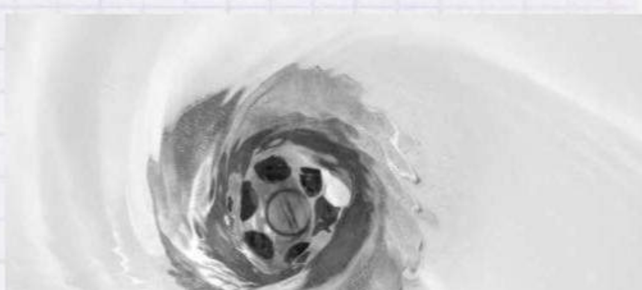
Schrödinger's cat is both dead and alive

14 In 1935, Erwin Schrödinger devised a thought experiment involving a cat locked in a steel box with a Geiger counter, a radioactive substance, a vial of poison and a hammer. If radioactive decay triggers the Geiger counter, the hammer will strike the vial of poison and kill the cat. However, because radioactive decay happens at random, you cannot know whether the cat is dead or alive until you look inside the box. Does this mean that the cat is both dead and alive at the same time? Well no, despite popular belief, Schrödinger was actually trying to point out the absurdity of quantum theory with an impossible example and was not suggesting that a cat could be both dead and alive.



Sinks drain in different directions on either side of the equator

15 It is often claimed that the spin of the Earth affects the way water drains out of the sink, and that to the north of the equator it swirls down the drain in a clockwise direction, while to the south it turns anticlockwise. While the Earth's spin does affect the rotation of hurricanes in what is known as the Coriolis effect, the amount of water in a sink is so small that Earth's spin does not affect the direction it drains, so in reality it is down to way the water is poured into the bowl and whether there are any imperfections in the surface.



The direction the water drains is not decided by the spin of the Earth

Bumblebees shouldn't be able to fly

16 The myth that bumblebee flight is impossible under the laws of physics has been traced back to the first half of the 20th century, when our understanding of flight was much more basic than it is today. According to early calculations, the wings of a bumblebee were too small to generate enough lift, however, using smoke and high-speed cameras, scientists at the University of Oxford watched bumblebees fly. They are not aerodynamic, but they do not break any laws of physics in the air.

Bumblebees don't look very aerodynamic, but their flight does not defy physics

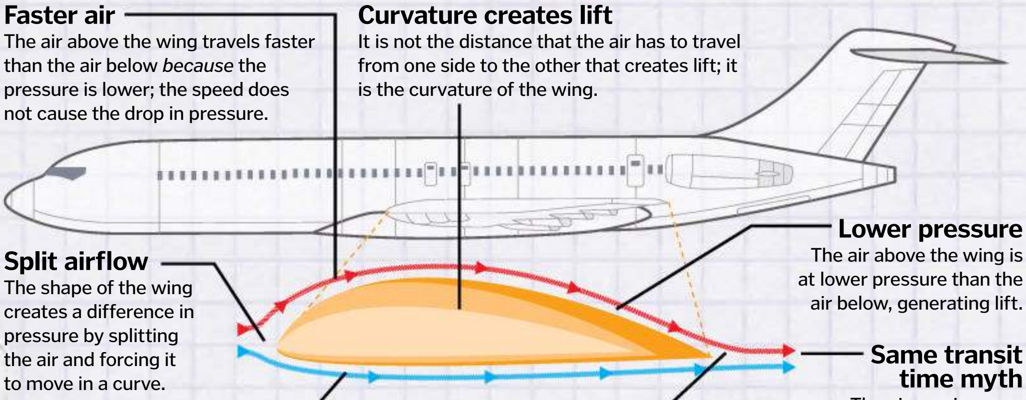
Groups of lemmings deliberately hurl themselves off cliffs

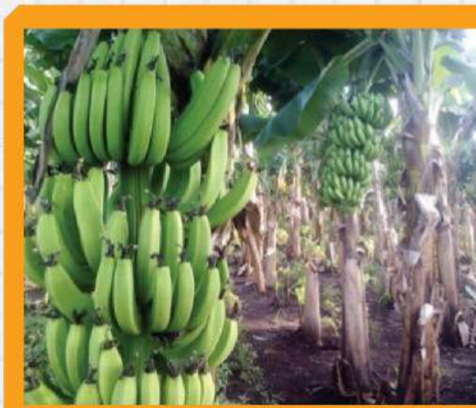
17 A film made by Walt Disney in 1958 called *White Wilderness* showed footage of lemmings leaping into the sea in an apparent mass suicide. However, in 1983 it was found the footage had been staged, using imported animals and tight camera angles to disguise the environment. In reality, the crew had herded the lemmings over the edge. It is true that when lemming populations get too high the animals disperse, gathering in numbers near the edges of rivers before attempting to swim across, but they do not deliberately jump to their deaths.

Lemmings are able to swim, so they jump into the water to disperse, not to die

Air takes the same amount of time to travel over and under an aircraft wing

18 One of the most famous misconceptions about aeroplane flight is that their wings are shaped so that the upper surface is longer than the lower surface, and that this forces the air moving over the top to move faster than the air underneath, which in turn creates a pressure difference and generates lift. However, as NASA points out; if this were true, how could planes fly upside down? If you take aerofoil with upper and lower surfaces of equal length, you generate lift even though the air has to travel the same distance.





Bananas grow on trees, and those trees can walk

19 Banana plants might look like trees, but they are actually herbs with 'trunks' made from tightly wrapped leaves. The bananas themselves are classified as berries. Beneath the ground the plants have a network of sideways-branching roots known as rhizomes, which spread out laterally and creep away under the soil. From these hidden roots, new leaves can spring up far from the original stem, making it appear as though the banana plant has moved.

Special 'superfoods' will do wonders for your health

20 Foods like blueberries and kale top the charts for their claimed health benefits, but the whole concept of 'superfoods' is a fabrication. There is no legal definition of a superfood, and the claimed health benefits are often based on experiments performed in test tubes with abnormally high amounts of the beneficial chemicals. These kinds of marketing myths can be dangerous, and not only is there no evidence to support many superfood claims; some supplements may even be harmful to human health.

The rust on a dirty nail causes tetanus

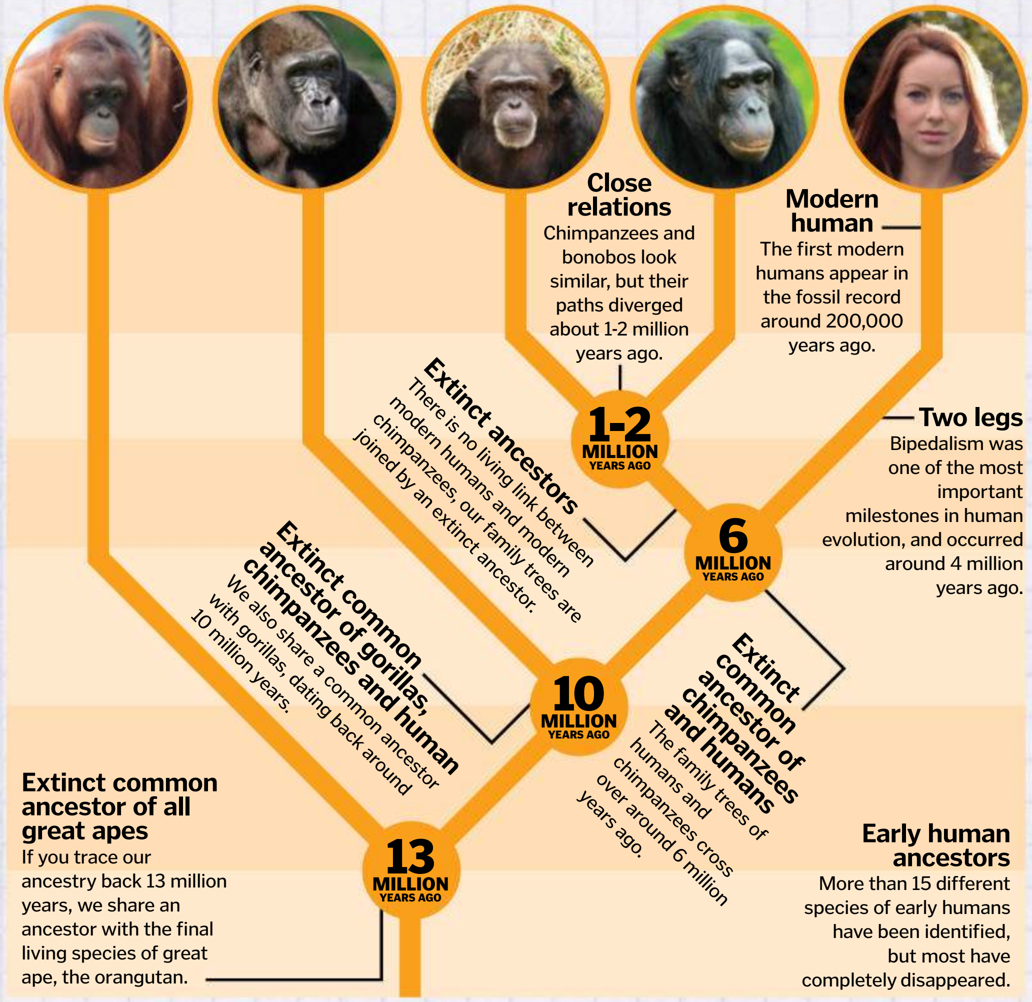
21 It is well known that if you are cut with rusty metal, you should check that your vaccinations are up to date, but it is not the rust itself that causes tetanus. Tetanus is the result of a bacterial infection called Clostridium tetani, which exists as spores in the soil, and can survive for decades at a time. If metal is rusty, it means it has probably been left outside for an extended period, making it more likely to have come into contact with the bacteria.

Swimming after eating gives you cramp

22 It is often claimed that entering the water on a full stomach can lead to deadly cramps, but if this were true, then why would endurance swimmers risk eating during a race? The pressure of a full stomach can cause a stitch, but in the event of this happening in the water, it is very unlikely the pain would be so bad that it would result in drowning.

Humans evolved from chimpanzees

23 One of the most common misinterpretations of the theory of evolution is the idea that we are descended from chimpanzees. We are closely related; we are both primates and share 98.8 per cent of the same DNA, but the African apes are our cousins, not our ancestors. If you traced the family trees of chimpanzees and humans, the two would cross over at a point around 6 million years ago. This common ancestor was neither a human nor a chimpanzee, and the descendants of that now-extinct species went down different evolutionary paths, leading to the modern species we see today.




Some structures are more likely to be hit by lightning than others

Lightning doesn't strike in the same place twice

24 If the Earth were an even sheet, with equal distribution of elements, lightning would have the same probability of striking each area, so the chance of two strikes in the same place would be low. However, our planet is lumpy, and variations like the height of a building, the moisture in the soil and even the positioning of leaves can make lightning more likely to strike in one place repeatedly.


The smell of a human will not prevent birds from returning to their nests

Birds abandon chicks touched by humans

25 Birds have keen eyesight but a poor sense of smell, so there is no evidence that the scent of a human would result in the abandonment of a chick. They are known to abandon their young when they feel threatened, but for most birds it would take more than an approaching human to trigger this behaviour.


Pears contains the toxic preservative formaldehyde

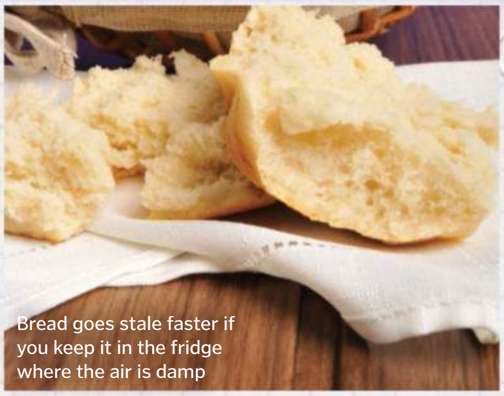
Natural products are safer than man-made

26 There is much scepticism about man-made products and products often advertise themselves as being 'all natural', but there is nothing inherently safe about naturally occurring chemicals. Everything is toxic in a high enough dose, whether man-made or naturally occurring, and how something was made is not as important as what it contains.


Your sense of balance allows you to tell up from down

Humans only have five senses

27 Humans have five main senses: vision, hearing, touch, taste and smell, but the list does not end there. We have many more senses, including equilibrioception, the sense of balance, and nociception, the sense of pain. We also have proprioception, the ability to tell where our bodies are in space, and thermoception, the sense of hot and cold.


Bread goes stale faster if you keep it in the fridge where the air is damp

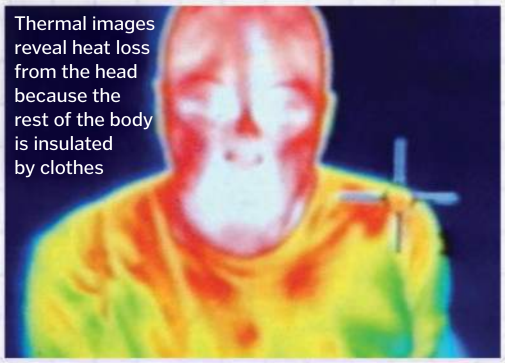
Bread goes stale because it dries out

28 Stale bread feels dry and can be rejuvenated with a splash of water, but it has not dehydrated. Instead, the water has become bound up in hard starch crystals. The process can be slowed down by adding more fat to the bread recipe, or by keeping the bread in a cool, dry place.

Imperfections in old glass windows and bottles were there when the objects were first made

Glass pools at the bottom of windows

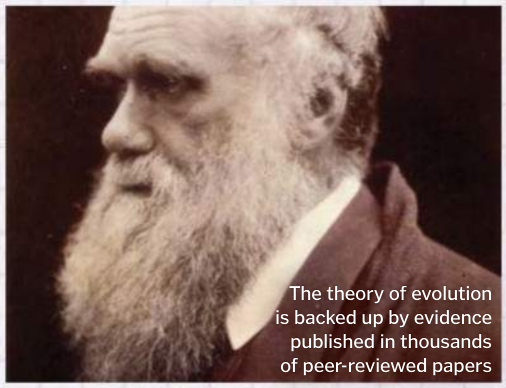
29 Old windows are often thicker at the bottom than they are at the top, and it was once thought that glass was as a slow-moving liquid. However, glass is now classified as an elastic solid, and according to chemists and glass experts, any imperfections in old windows were introduced at the time they were made.



Thermal images reveal heat loss from the head because the rest of the body is insulated by clothes

You lose most of your heat through your head

30 In the winter, people are often advised to put a hat on under the pretext that most of your body heat escapes through your head. In fact, there is nothing particularly special about this body part and it loses heat at around the same rate as any other; it's just that the rest of our bodies are often covered with clothes.



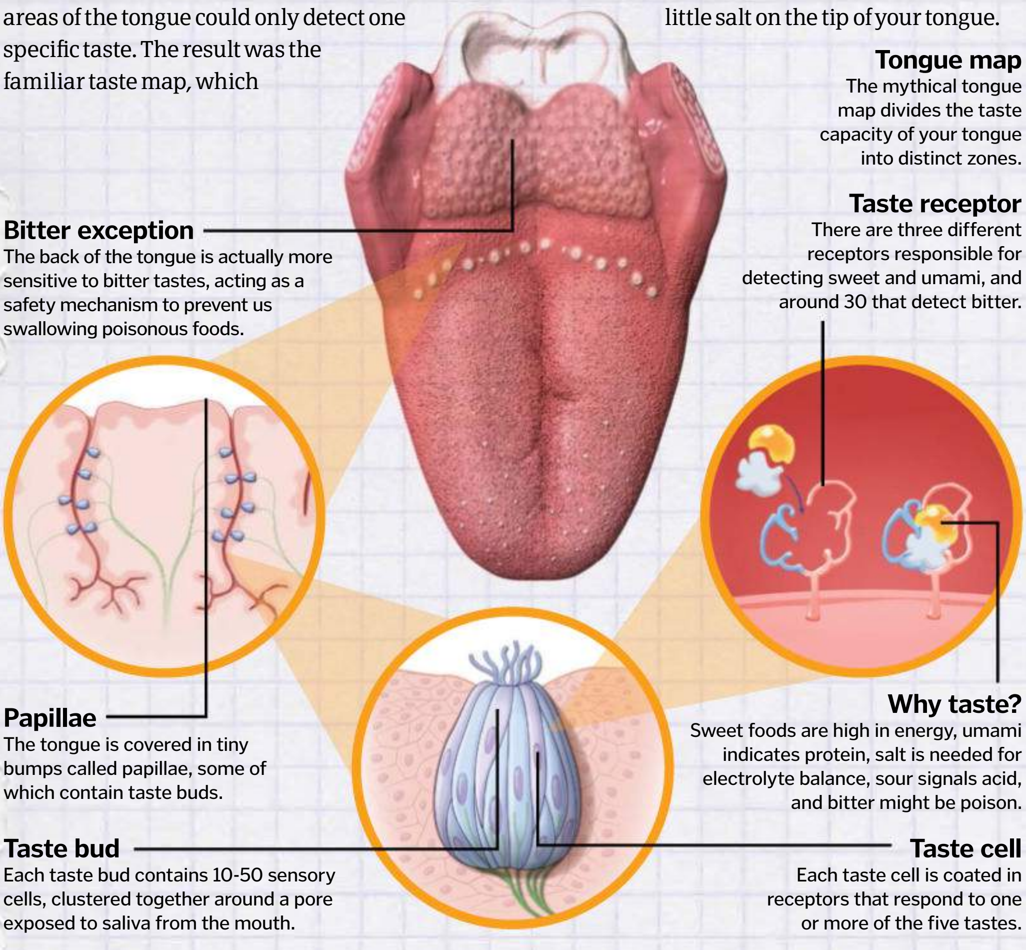
The theory of evolution is backed up by evidence published in thousands of peer-reviewed papers

A theory is just an idea

31 In day-to-day usage, the word 'theory' is often taken to mean the same as 'idea', or 'educated guess', and as a result scientific theories like evolution and the Big Bang are sometimes treated with suspicion. In science, a theory is built using evidence, and is close enough to the 'truth' that it can be used to predict what might happen next.

Different parts of your tongue respond to different tastes

32 This myth was born in 1901 when German scientist DP Hanig tested people's responses to different tastes on different parts of the tongue. His test subjects reported they were able to taste certain things better in different areas, but the research was mistranslated, leading people to believe certain areas of the tongue could only detect one specific taste. The result was the familiar taste map, which arranged the surface of the tongue into different zones; the tip detecting sugar, the front sides salt, the rear sides sour and the back of the tongue bitter. Incredibly, it wasn't until 1974 that scientists challenged the well-established myth, even though you can easily disprove it at home by putting a little salt on the tip of your tongue.



The heat of a chilli is in the seeds

33 Many cooks mistakenly believe the hottest part of a chilli is the seeds, when in fact the heat-producing chemical is concentrated in the white pulp that surrounds them. The chemical is known as capsaicin and it activates nerves that normally transmit signals about temperature. Chilli seeds are destroyed in the mammalian digestive system and scientists think the plants produce capsaicin as a deterrent. Birds are unaffected by the fiery chillies and their digestive systems actually help the seeds to germinate.

Shaving causes hair to grow back thicker

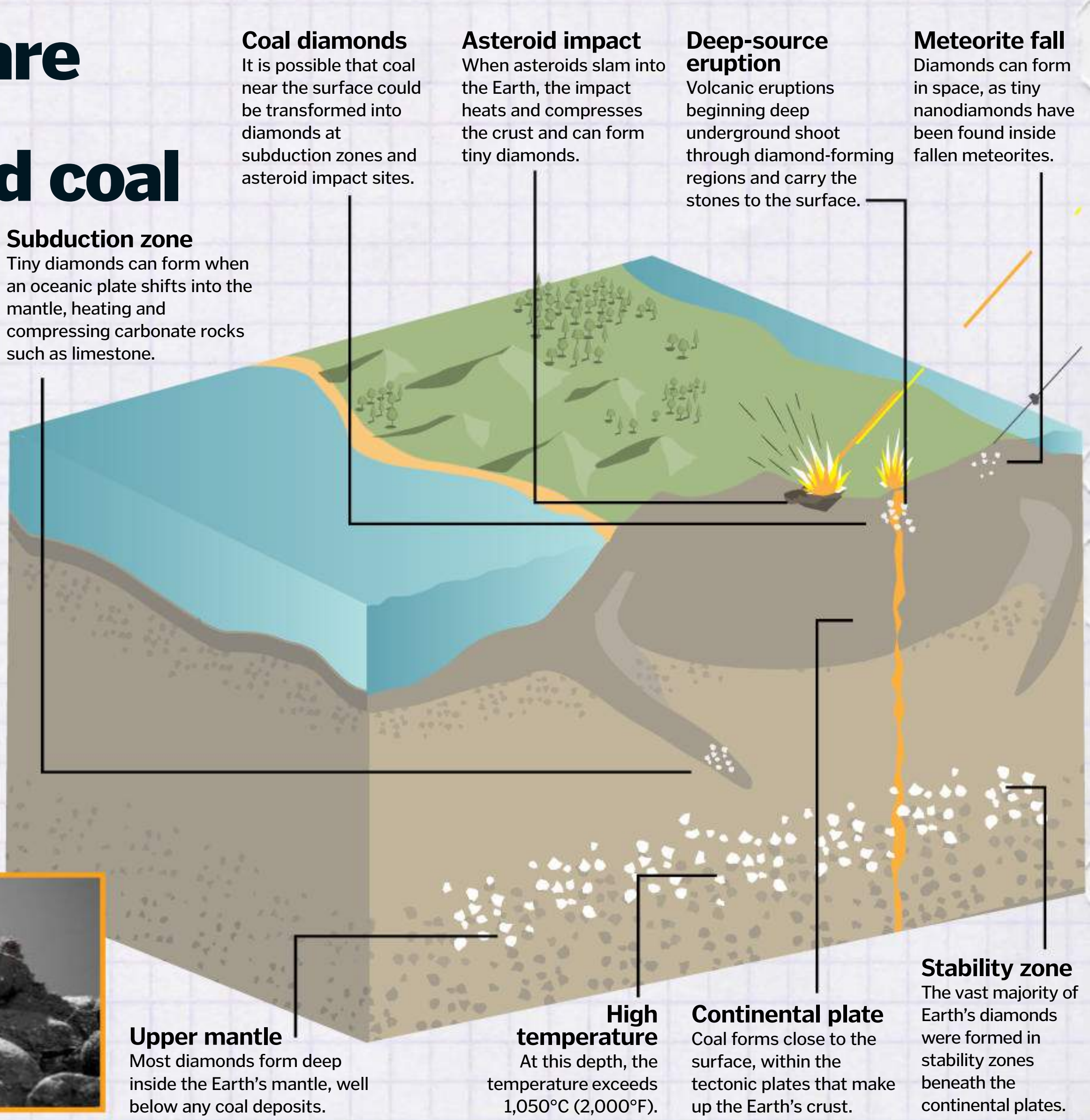
34 Shavers are often convinced that their hairs grow back thicker after they have been razored, but there is no evidence to support this idea. The perceived increase in thickness or coarseness of the hairs is actually to do with their shape. Before hairs are cut they have soft, tapered ends, and they tend to fall or curl under their own weight, but when they are trimmed the hairs end abruptly in a sharp, flat cut, which stands upright against the skin.

During an earthquake, you should hide in the nearest doorway

35 Doorframes used to be one of the last structural features of a house to collapse during an earthquake, but technological advances have changed the way that modern houses are built and it is no longer the safest place to stand. New advice recommends dropping to the floor and curling up, preferably beneath a sturdy piece of furniture like a bed or a table, and protecting your head and neck with your arms.

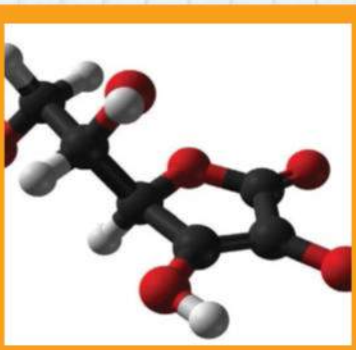
Diamonds are made from compressed coal

36 Diamond and coal are both formed from carbon, but it is not true that one is made from the other. Coal is formed from the remains of prehistoric plants and tends to be found around 3.2 kilometres (two miles) below the surface of the Earth, while most diamonds are formed from carbon-containing minerals found in the upper mantle, around 150 kilometres (90 miles) beneath the ground. The diamonds are delivered to the surface by a rare form of volcanic activity known as a deep-source eruption, which pushes upward through the mantle carrying the diamonds toward the surface and traps them in a pipe of igneous rock.



Close-up TV harms your eyes

37 There is no evidence that sitting too close to the television is bad for your eyesight; however, the myth is not completely unfounded. Although moving closer to watch your favourite programmes does not cause near-sightedness, it could indicate an underlying problem with your eyesight.



Vitamin C protects you from illness

38 Many people choose to load up on vitamin C supplements in the winter in an effort to stave off the common cold, but there is little evidence that it actually works. In a large-scale study of over 11,000 people, scientists found no significant difference between people who took daily supplements and those who did not.

Hens need a rooster to lay eggs

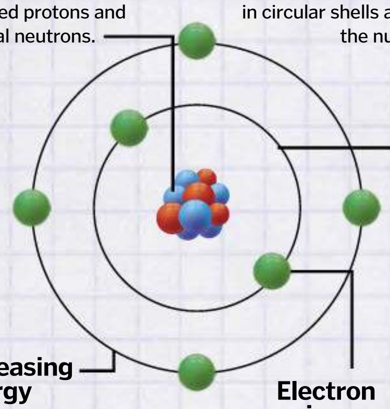
39 It is a common misconception that hens need a rooster in order to lay eggs. Hens are able to store sperm inside their bodies, allowing eggs to be fertilised before they are laid. If there is no sperm available, the eggs are still produced and are laid even though they will not develop into chicks.

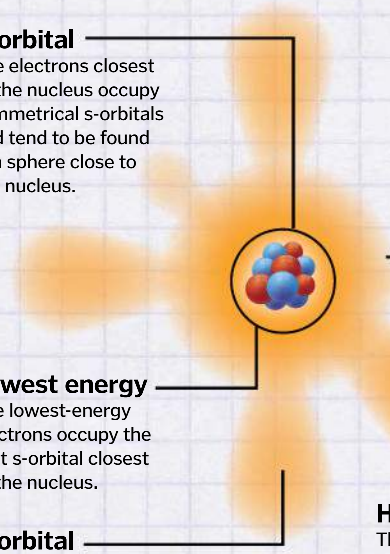
The Sun is burning

40 The Sun might look like a ball of fire in the sky, but it is not really burning. The Sun is a nuclear fusion reactor, and the light and heat that it emits is the result of energy released when hydrogen atoms slam together and fuse to form helium.

Electrons orbit atomic nuclei like planets orbit the Sun

41 Looking at the standard textbook image of the atom, it is easy to imagine that the electrons orbit the nucleus in circles, like planets revolving around the Sun, but the diagrams are misleading. Rather than representing the orbits of the electrons, these images show their energy levels. In reality, we cannot know where an electron is and where it is going at the same time, so it is not possible to map out the path they take around the atomic nucleus. Instead, physicists map three-dimensional regions of space known as orbitals, which predict where each electron is likely to be.





Baking soda absorbs smells

42 Baking soda is a common kitchen ingredient that reacts with acids like vinegar to produce bubbles of carbon dioxide. It is hailed as a deodoriser because it can also neutralise smelly acids, like those found in sweat. However, on non-acidic smells it makes little difference, and as it absorbs water from the air it forms a crust that prevents its acid-neutralising action.

Salt makes water boil quicker

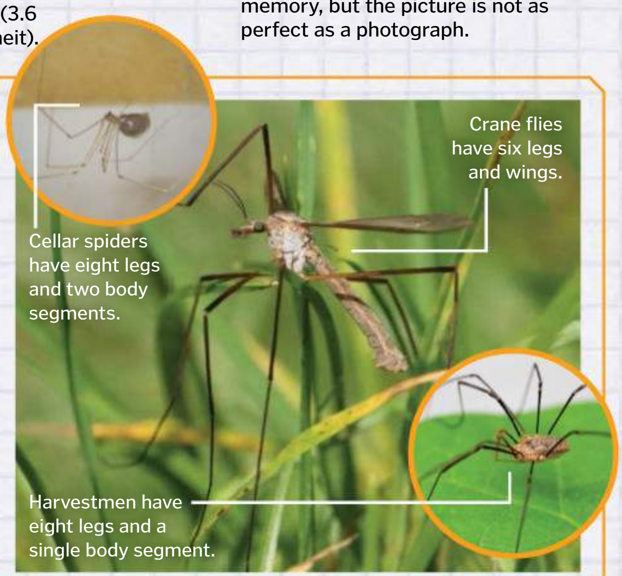
43 People add salt to their cooking water in the hope that it will boil faster, but it actually makes the water boil at a higher temperature. In the kitchen this effect is barely noticeable; it takes about 230 grams (8.1 ounces) of salt to increase the boiling point of one litre (0.26 gallons) of water by just two degrees Celsius (3.6 degrees Fahrenheit).

Some people have photographic memories

44 Many people have claimed to be able to recall an image in perfect detail, but no case has ever been confirmed. Some people are able to hold an image in their mind for a short time after it has been taken away, a phenomenon known as eidetic memory, but the picture is not as perfect as a photograph.

Daddy long legs are the most venomous spiders, but they cannot bite through your skin

45 There are three different invertebrates people commonly know as 'daddy long legs', crane flies, harvestmen and cellar spiders. Cellar spiders are venomous, and their fangs are anatomically similar to those of brown recluse spiders, which are capable of biting people, but there is no evidence that their venom is powerful enough to kill a human. Harvestmen and crane flies are not spiders and have neither fangs nor venom.



The Moon has a dark side

46 The moon is tidally locked to the Earth, meaning we always see the same side of its surface, but the other side is not in permanent shadow. Like the Earth, the Moon turns on its axis and all of its surface experiences both day and night.

Popping candy could burst your stomach

47 Popping candy is made by mixing molten sugar syrup with pressurised carbon dioxide gas. When the candy melts in your mouth, trapped bubbles release their pressure with a pop. The amount of gas released is very small and stories of children dying after eating a combination of popping candy and carbonated drinks are merely urban legend.

Fur and hair are different

48 Despite names and appearances, there is no real difference between the fur and hair. Both are both made from exactly the same material, keratin, and they are both produced by follicles in the skin. In fact, fur and hair are the same as eyelashes, whiskers and even porcupine quills.

Oil is not attracted to water

49 Amazingly, oil molecules are more strongly attracted to water than they are to one another, (which is why an oil droplet will spread out across the surface and does not stay together as a ball). The reason the fluids do not mix is because the water molecules are more strongly attracted to each other than they are to the oil.

Club soda is a miracle stain remover

50 Carbonated water is hailed as a miracle stain remover, but it turns out it is no better than plain water for removing an unwanted mess. Some people claim the bubbles contribute to loosening the stain from the fabric, but in head-to-head cleaning tests both liquids are equally effective.

THE SCIENCE OF SHOPPING

How supermarkets influence how you shop and what you buy

1 Essentials at the back

Essential items such as bread and milk tend to be at the back of supermarkets, as this forces us to walk through the store and may lead us to buy other items. The smell of freshly made bread from the in-store bakery makes us feel hungry as it activates our salivary glands, increasing the chance of us buying additional items.

2 In-store surveillance

The cameras dotted around supermarkets aren't just for theft detection. They also assess the way people choose certain items to see whether they immediately pick up their choice, or linger and consider the options. This lets supermarkets learn the specific areas in which people are open to new products, as well as where people are consistent.

3 Golden zones

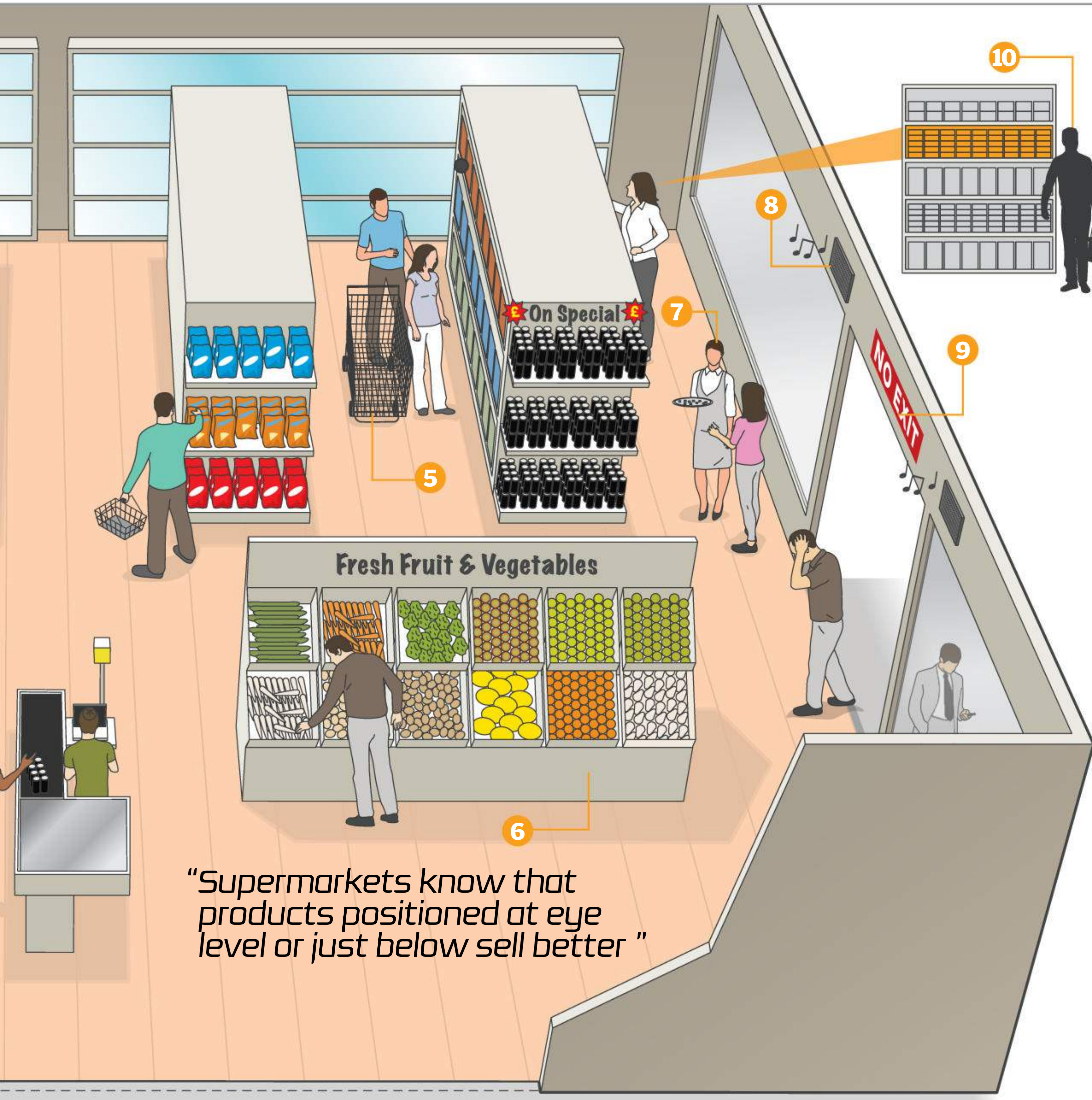
Also known as 'impulse areas', these zones are tactically placed next to checkout queues. They are typically filled with sweets and treats to encourage us to reward ourselves for the task we've just completed. There are often lower shelves as well, to enable children to grab something and ask their parents to buy it for them.

4 Endcaps

We have become accustomed to seeing the short blocks of shelves at the ends of aisles in supermarkets. These tend to include special offers and signage relating to deals. Some stores now put undiscounted items on their endcaps, as this has been found to boost sales, since people are so used to the items in this location being discounted.

5 Larger trolleys

In recent years the average trolley size has increased. The motive for this isn't just to provide us with more space, it's due to the psychological effect this has on us. The larger trolley tricks us into thinking we've got less than we have, encouraging us to keep shopping. A full trolley subconsciously makes us feel that we have finished shopping.



"Supermarkets know that products positioned at eye level or just below sell better"

6 Fresh produce

Fruit and vegetables are at the front of supermarkets for a reason. Seeing the fresh produce as soon as we enter the main store affects us psychologically, making us likely to believe the entire store's food range is fresh and inviting. Some supermarkets even spray their fruit and vegetables with water to give the appearance that it has been freshly picked.

7 Free samples

People are creatures of habit, tending to buy the same things each time they shop. To combat this, supermarkets offer free samples, enabling them to introduce you to new products you wouldn't normally even look at and keep you in store for longer. It may even direct you down a rarely visited aisle.

8 Slow music

Many supermarkets have music playing in their stores, but this is not solely to provide entertainment. Almost all of them play slow music as studies have proven this slows shoppers down, leading to them staying in store for longer and potentially continuing to spend. Classical music encourages shoppers to buy more expensive products, which is why this is played in jewellers.

9 Separate entrance and exit

Many supermarkets now have a separate entrance and exit which forces you to walk through the store even if you only popped in to buy a sandwich, or if you don't end up buying anything. Stores are often designed to be shopped counter clockwise, as studies have found that shoppers spend more when they shop in this direction.

10 Eye level is buy level

The position of products on a shelf is incredibly important to supermarkets. They know that products positioned at eye level or just below sell better, which is why you will tend to find branded, high-priced goods in such a position. These days, supermarkets also take advantage of a child's eye level by putting sugary, colourful treats to catch their attention.

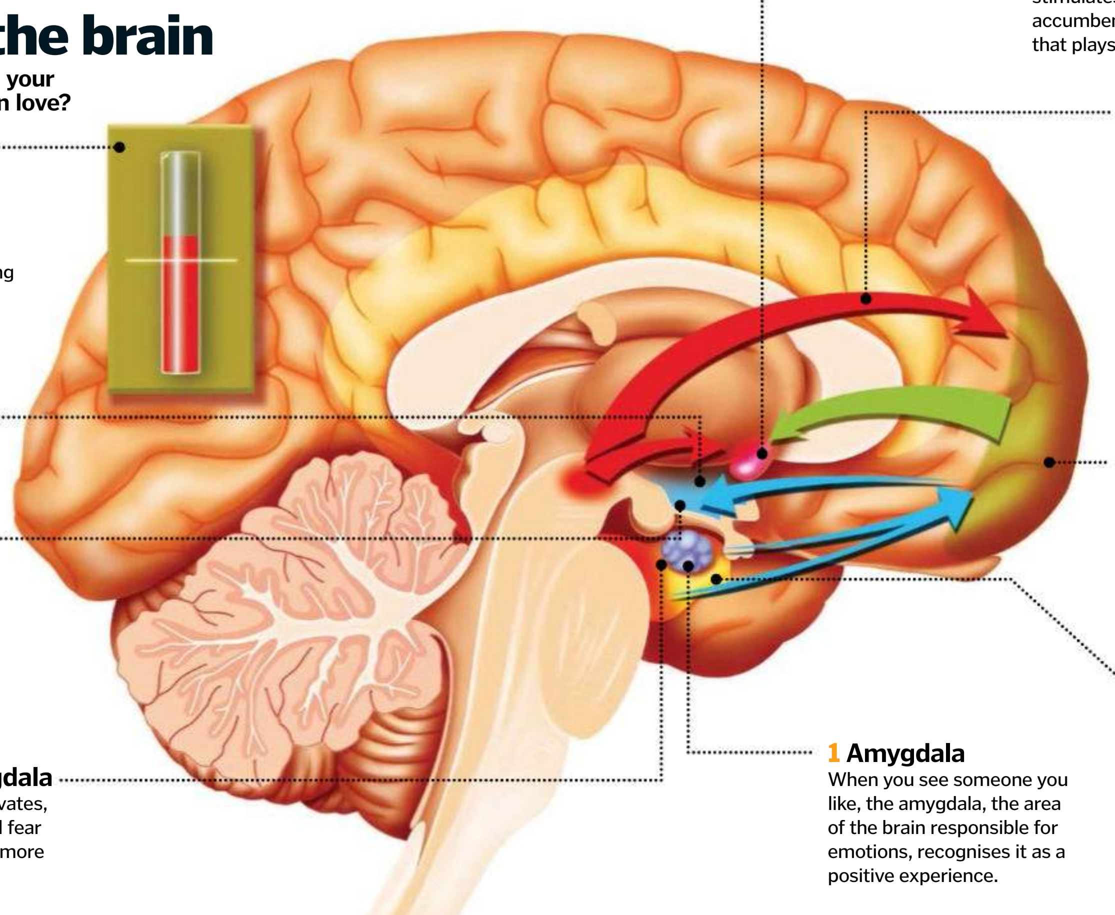
Image by Acute e Graphics

The science of love

The hormones and chemicals that cause us to fall head over heels

Love on the brain

What goes on inside your head when you fall in love?



6 Hormone levels
As dopamine levels increase, levels of serotonin, the hormone responsible for mood and appetite, decrease, causing feelings of obsession.

2 Hippocampus
The hippocampus, the memory forming area of the brain, records this pleasant experience making you want to seek it out again.

5 Norepinephrine
Norepinephrine, another neurotransmitter similar to adrenalin, is also released, which gets your heart racing and causes you to sweat.

9 Deactivate amygdala
The amygdala also deactivates, reducing the ability to feel fear and stress and creating a more happy, carefree attitude.

7 Nucleus accumbens
The secretion of dopamine stimulates the nucleus accumbens, an area of the brain that plays a vital role in addiction.

8 Deactivate prefrontal cortex
The nucleus accumbens then pushes the prefrontal cortex for action, but it deactivates, suspending feelings of criticism and doubt.

3 Prefrontal cortex
Messages are then sent to the prefrontal cortex, the brain's decision-making centre, where it judges if the potential romantic partner is a good match.

1 Amygdala
When you see someone you like, the amygdala, the area of the brain responsible for emotions, recognises it as a positive experience.

4 Hypothalamus
If the attraction is there, the prefrontal cortex stimulates the hypothalamus, which releases the neurotransmitter dopamine, causing feeling of ecstasy.

The three stages of falling in love

Lust

When we reach puberty, testosterone and oestrogen become active in our bodies. These hormones create the desire to experience love, and so we start looking for a mate. Who we lust after is influenced by a number of factors. Looks and personality play a roll, and research has revealed that we tend to be attracted to people who remind us of our parents. We also sniff out potential mates, and studies have found that we tend to prefer the smell of others who have an immune system that is different to our own.

Attraction

When you become attracted to someone, a series of chemicals are released in the brain. Dopamine produces the feeling of bliss, leading to a loss of appetite and sleepless nights. Norepinephrine activates stress responses, causing an increased heart rate and sweating, and a protein called nerve growth factor is produced. Serotonin levels fall, making it difficult to keep the object of your desire out of your thoughts, idealising them and becoming oblivious to their flaws.

Attachment

If a relationship is going to last, a strong bond must form. Two key hormones, oxytocin and vasopressin, are involved in forming this commitment. Oxytocin is released when we hug, kiss and have sex. It helps to establish trust and intimacy. Vasopressin, a hormone responsible for regulating the body's retention of water, is also released during sex and encourages monogamy. Endorphins also play a key role in attachment, suppressing pain and creating a sense of security when released.

DID YOU KNOW? *Some African tribes still use scarification as a rite of passage and to indicate social status*

Types of scars

Scars are made up of the same proteins as normal skin, so why do they look so different?

Scars are a natural part of the healing process, with most of us having some form of them on our body. The reason why scars look different to normal skin stems from their proteins' composition. Normal skin benefits from a weaved protein structure, whereas the proteins in scars are aligned in one direction. This results in a different appearance compared to normal, healthy skin. Scars are smoother due to a lack of sweat glands and hair follicles, so they can often become itchy.

There are a number of different types of scar that can form. The most common is a flat scar – these tend to initially be dark and raised, but will fade and flatten over time as the scar matures. A hypertrophic scar can be identified by its red appearance and elevated nature. This scar type typically forms when the dermis is damaged, and this can become itchy and painful over time.

Keloid scars are by far the most extreme scar type when compared to the others. Unlike most scars, they extend beyond the confines of the original injury and are formed due to excessive scar tissue being produced. Keloid scars are raised above the surrounding skin, and are hard, shiny and hairless. The reason behind why keloids form is poorly understood, but it is known that people with darker skin tones are more likely to form keloids.

Pitted scars are generally formed from acne or chicken pox, and tend to be numerous in areas where these conditions were prevalent. Scar contractures, meanwhile, usually form after a burn, and are caused by the skin shrinking and tightening. The severity of these kinds of scars can depend on their bodily location; if they form around a joint they can lead to movement being restricted.

Clotting
Clotting occurs due to a combination of proteins in the blood, which help a scab to form, protecting the wound from infection.

Epithelial cells
By rapidly multiplying, the epithelial cells fill in over the newly formed granulation tissue.

Newly formed scar
Once the newly formed epithelium thickens, the area contracts and forms a scar on the skin's surface.

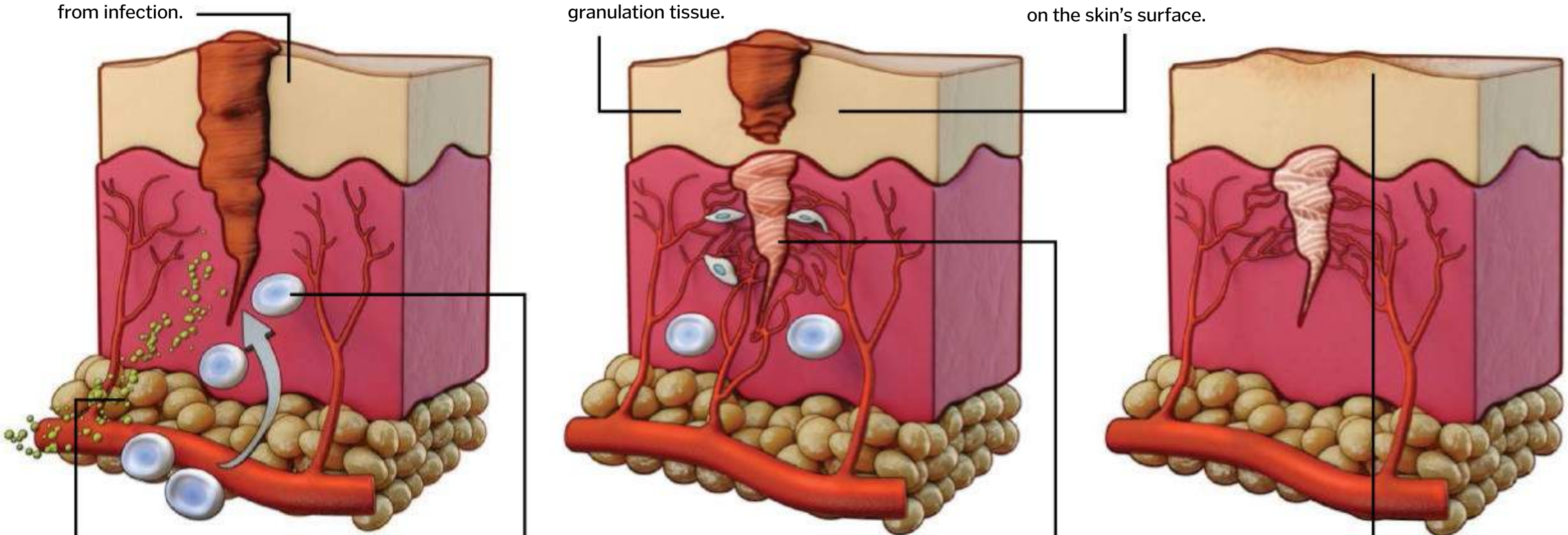


Illustration by Nicholas Forder

Inflammatory chemicals
The body recognises that it has sustained an injury, and white blood cells release inflammatory chemicals to help protect the area.

White blood cells
To help fight off potential infection, white blood cells seep into the area and flock to the wound.

Granulation tissue
The new granulation tissue replaces the clotted blood, and helps restore the blood supply to the damaged area.

Scar tissue
Once fully formed, this tissue is known as scar tissue. Due to excessive collagen production this tissue often lacks in flexibility, which can lead to pain and dysfunction.

Can scars be treated?

Scars cannot be stopped from forming, but there are various treatments available to help reduce their appearance. Silicone gels or sheets have been shown to effectively minimise scar formation and are often used when people have been burnt. These must be applied or worn throughout the scar's maturation phase to maximise their efficacy. Corticosteroid injections can be used to reduce any inflammation (swelling) around the scar and to flatten it as well. A riskier treatment for scars is surgery. This can be used to change the shape of the scar, however it can make scarring worse if unsuccessful.

There are also certain steps that can be taken to help reduce the risk of an unsightly scar forming from an injury. By cleaning dirt and dead tissue away from the wound, you are increasing the chance that the scar will form neatly. It is also vital that you don't pick or scratch the scar, as this will slow down its formation, resulting in a more obvious appearance.

A neat, even scar is the best you can hope for even with today's technology

SERENA WILLIAMS, tennis

Tennis combines aerobic fitness with bursts of power, and players tend to have strong legs, backs, arms and shoulders.

TOM BRADY, American football

American football quarterbacks have to combine and balance the strength of linemen with the speed and agility of running backs.

MICHAEL PHELPS, swimming

Swimmers have strong arms and well-developed core muscles, relying on their upper body for propulsion through the water.

SCIENCE OF SPORT

With training, the human body can be transformed into a truly impressive sporting powerhouse

RICKIE LAMBERT, football

Footballers rely on strong leg muscles to power their kicks, but must be lean in order to manoeuvre quickly across the pitch.

LEWIS HAMILTON, F1 car racing

F1 is intense, so drivers need to be lightweight but strong. Strict weight limits mean that shaving weight off the driver is as important as keeping the car light.

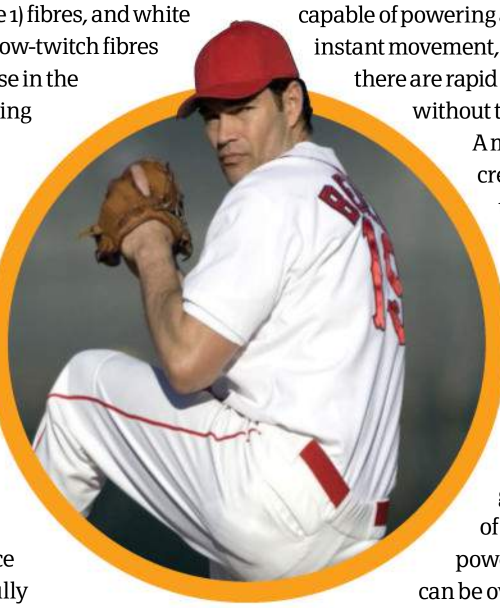
LEBRON JAMES, basketball

Height surely matters in basketball, but agility and power are more important. Players have strong leg muscles for crouching, sprinting and jumping.

Muscles are the driving force behind sporting ability, but there is a trade-off between power and endurance. Like a cheetah, a sprinter is adapted for intense bursts of speed, but tires quickly, and like a wolf, an endurance runner can travel for a sustained period of time, but at a lower speed. With training, human athletes can choose whether to adapt their bodies for power and agility, or for endurance.

All muscles use the same energy currency to perform; a molecule called adenosine triphosphate, or ATP, generated within the muscle cells by the breakdown of glucose. The way this molecule is created and recycled differs depending on muscle type.

Muscles are composed of two types of muscle fibres, red slow-twitch (type 1) fibres, and white fast-twitch (type 2) fibres. Slow-twitch fibres specialise in burning glucose in the presence of oxygen, producing sustained activity, while fast-twitch fibres are adapted for instant power, burning fuel without oxygen for intense output over shorter periods of time.



Endurance athletes, like long-distance runners, swimmers and cross-country skiers rely on slow-twitch fibres for sustained output at lower power. In the presence of oxygen, glucose can be fully burnt, creating lots of ATP and producing carbon dioxide and water as waste. An elite endurance athlete generates over 99 per cent of their energy using oxygen.

They train by stressing their cardiovascular system, increasing the duration of exercise and performing lots of repetitions at lower power output. Training increases the volume of blood in their bodies and causes the heart to grow in size, becoming around 25 per cent larger by volume. This reduces the resting heart rate and increases the amount of blood pumped with each beat, maximising their ability to supply their muscles with oxygen.

Local improvements are also made to the muscles endurance athletes regularly use. The red colour of type 1 muscle comes from a dense capillary network and the muscle fibres themselves are packed with mitochondria, the powerhouses of the cell, which specialise in the end stages of metabolising glucose in the presence of oxygen to produce maximum ATP. Endurance athletes store more glucose in their muscles, locked away in long chains known as glycogen, and are better at diverting it through the aerobic pathway, burning it in the presence of oxygen.

In contrast, power athletes, like boxers, weightlifters and sprinters rely on fast-twitch fibres for rapid, powerful movement. Using repetitive resistance training, power athletes adapt their muscles causing the fast-twitch fibres to grow in diameter, packing more and more contractile proteins in. A good blood supply would waste valuable power-generating space within the muscle, and power muscles have fewer capillaries, hence the paler colour.

Without a constant supply of oxygen, fast-twitch fibres rely on ready-made sources of ATP to perform. Within the muscle, there is a store of ATP capable of powering around three seconds of instant movement, and once this is used up, there are rapid ways to replenish it without the need for oxygen.

A molecule known as creatine phosphate is used to quickly restoring ATP for reuse, supplying an additional eight to ten seconds of activity without oxygen. Glucose can also be burnt anaerobically creating a smaller amount of ATP, and giving around 90 seconds of breathing-free muscle power. A men's 100-metre race can be over and done with in under ten seconds for top performers, and some athletes do not even breathe at all during this time.

This type of respiration produces a high power output, but it comes at a cost, and as time goes on, waste products build up in the muscle, rapidly leading to fatigue and pain. Oxygen is ultimately required to replenish the stocks of ATP within the muscles, and power athletes are forced to stop and breathe before they continue exercising.

There is an upper limit to the sporting ability of the human body, but it seems this is yet to be reached, and science continues to improve performance. Our understanding of biology is helping to develop training and nutrition plans for athletes, while chemistry and physics are used to improve the physiology of sport, and to develop equipment used to enhance performance. World records continue to be broken, and as incredible athletes appear, their abilities are driving others to improve their game. In the year Usain Bolt smashed the world record for the men's 100 metres, the average performance of the other top sprinters improved as well, a phenomenon now known as the 'Usain Bolt Effect.'

Pitch perfect

The maximum speed a human can throw a baseball is around 160 kilometres (100 miles) per hour. This speed limit is capped by basic human anatomy. A pitcher moves his or her shoulder at incredible speeds, putting an estimated 100 Newton-metres (74 pound-feet) of torque on the arm. Beyond this, the ligament that holds the elbow together would snap.

1 Coiled spring

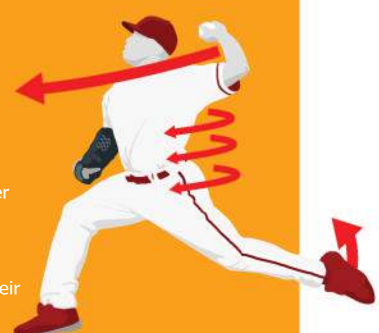
As a pitcher prepares to throw, they coil up like a spring, drawing in their throwing arm, twisting backward, and raising one leg. This prepares the entire body to put maximum force into the coming throw.

2 Acceleration

The foot comes down and the pelvis turns, followed by the torso. The arm is the last thing to move, and as the momentum is transferred from the chest into the shoulder it rotates forward similar to a slingshot.

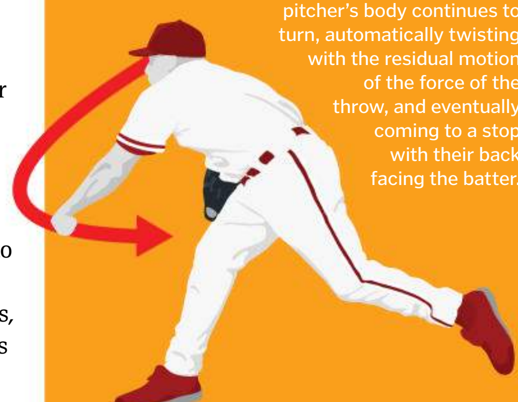
3 Release

The back leg moves away from the floor as the pitcher's arm comes forward. The elbow is straight and the tendons are stretched. The pitcher prepares to release, throwing their hand forward, using the momentum of their entire body to power the throw.



4 Follow-through

As the ball is released, the pitcher's body continues to turn, automatically twisting with the residual motion of the force of the throw, and eventually coming to a stop with their back facing the batter.



MECHANICS OF MOVEMENT

Discover how your heart and lungs keep your power-hungry muscles moving

At rest, the skeletal muscles receive around 20 per cent of the blood pumped with every heartbeat, but during exercise, their oxygen requirement rockets. They are given priority over almost all other tissues, and up to 80 per cent of the cardiac output is diverted to supply their increasing demands. Adrenaline from the adrenal glands above the kidneys and noradrenaline released from nerve endings increases the heart rate, and causes the arteries to constrict, diverting blood flow away from other areas of the body, like the digestive organs.

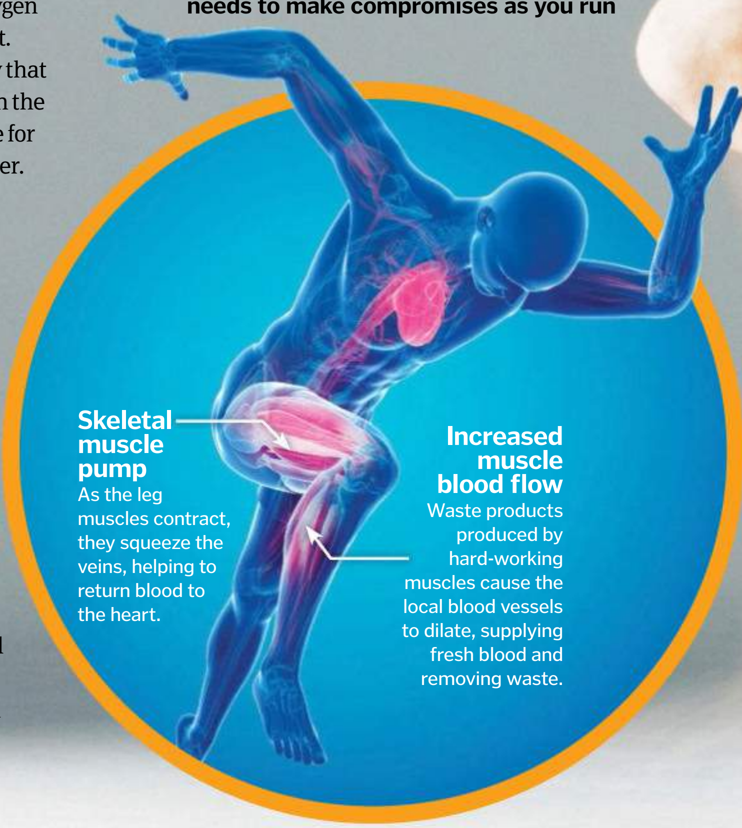
As the muscles work, waste products like carbon dioxide, potassium and acids start to build up, and the tissue becomes hypoxic as the oxygen is used up. These strong signals override the constriction of blood vessels, causing the local blood vessels within the working muscles to dilate. At the same time, the acidic by-products change the shape of the pigment haemoglobin, and as the red blood cells pass they drop their oxygen in the place where it is needed most.

The heart is pumping so quickly that the blood spends much less time in the capillaries of the lungs, so the time for gas exchange to take place is shorter. However, when increased carbon dioxide in the blood reaches the brain, the rate and depth of breathing increases, and raised blood pressure forces extra alveoli and capillaries open, creating an even greater surface area for gas exchange, and ensuring that carbon dioxide is swapped for oxygen as the blood passes.

As the muscles continue to contract and relax, they squeeze the veins in the legs and arms, helping to force blood back toward the heart. This in turn maximises the amount of blood pumped with each beat.

Biomechanics of running

To keep your muscles moving, the body needs to make compromises as you run



SPORTS INJURIES

The most common sporting injuries affect the muscles, bones, ligaments, tendons and joints, and can be caused by a number of things, from physical accident to overtraining and poor technique. The first line of treatment is to stop exercising and give the tissue time to repair and recover.

If the damage is severe, involving a broken bone or a tear, medical intervention is necessary to ensure proper healing, but for most routine injuries, at-home medical remedies are sufficient.

The acronym RICE – for rest, ice, compression and elevation – is often used to remind people of the procedure in case of an injury. Rest to avoid further damage to the area, ice for pain relief, and compression and elevation to limit blood flow and bring down swelling.

Non-steroidal anti-inflammatory drugs, like ibuprofen, can also help to reduce swelling and relieve pain, and physiotherapy can aid in restoring muscles and joints to normal function after the injury has healed. Gentle exercise is still very important in order to stretch and strengthen the area of the body after the initial healing process.

Digestion halted
The blood vessels constrict, diverting blood flow away from nonessential organs like the stomach, intestines, and kidneys.

Mythbusters!

1 Sports drinks improve your performance

Many sports drinks claim to replace minerals lost through sweating, but the concentrations of ions in the drinks are so low that they make little difference. You can make an isotonic drink at home using 800ml (28fl oz) of water, 200ml (7fl oz) of sugary squash and a pinch of salt, but eating a healthy snack, such as pretzels or a banana, before or after exercising is more effective.

2 Caffeine boosts endurance

In laboratory tests on elite athletes, caffeine equivalent to around one mug of coffee has been shown to improve athletic performance, but these results have not been repeated in the field, and the mechanism is unknown. The effects have not been tested on the general population because muscle fatigue kicks in before the benefits would be seen.

3 Special running shoes prevent injury

Many shops offer services to monitor your gait and prescribe shoes that support the foot and ankle depending on how your feet move as you run, but recent studies show that these specialist shoes make no difference to injury rates. Technique is much more important, and experts recommend that you choose comfortable, well-fitting shoes for exercise.

Post-exercise pain

What happens to the muscles after exercise stops?

MUSCLE RECOVERY

When exercise ends, the muscles need time to rest and repair

During intense and prolonged exercise, your muscles demand more oxygen than your heart and lungs can supply, and they start to burn. This familiar sensation is often blamed on lactate.

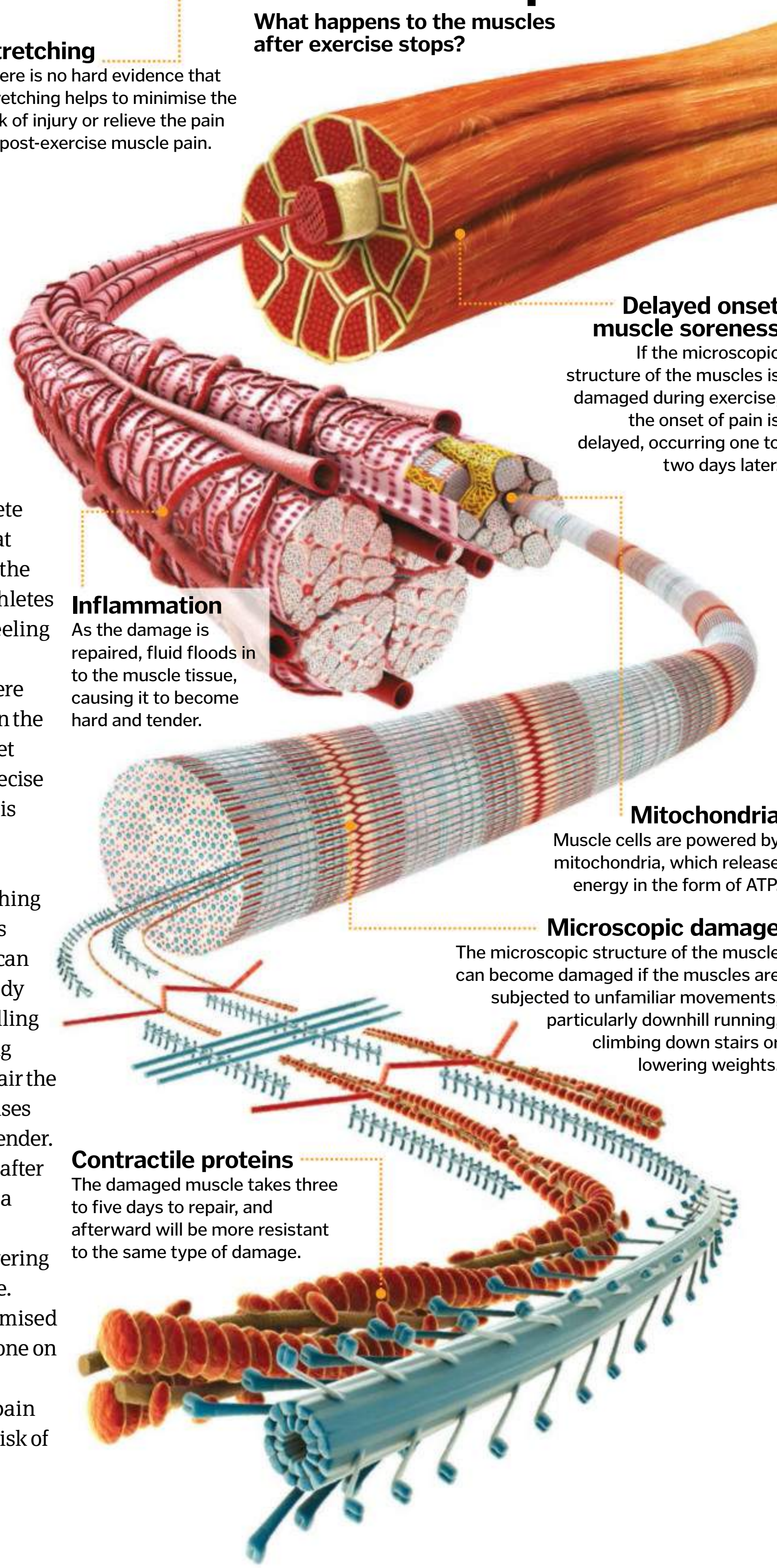
Lactate has a bad reputation and is widely criticised for being the cause of lactic acidosis; a painful build-up of acid within the muscles leading to fatigue and muscle soreness, but in reality this idea is a myth. The acid that causes muscles to burn is not caused by lactate, but is a normal side effect of energy use. Lactate actually acts to neutralise the acid, not to create it.

During intense exercise, muscles demand huge quantities of the energy molecule ATP; each time a molecule is split, a hydrogen ion (H+) is released. If the muscle is receiving enough oxygen, this acid is used as part of the normal metabolic processes of the cell, but if not, this acid starts to build up, causing the muscles to burn. As glucose is broken down to create more ATP, two molecules of pyruvate are generated. This pyruvate can hold on to two H+ molecules, mopping up the acid to become lactate, which itself can then be broken down to produce more vital energy.

The more an endurance athlete trains, the better they become at using up the H+ and the slower the lactate builds, meaning elite athletes can exercise for longer before feeling the burn.

Several days after exercise there may be a different kind of pain in the muscles, known as delayed onset muscle soreness (DOMS). The precise mechanism is not known, but it is thought that during strenuous exercise, particularly involving movements that combine stretching with muscle contraction (such as running downhill) micro-tears can occur within the muscle. The body responds with inflammation, filling the muscle with fluid, and taking immune cells with it to help repair the damage. This inflammation causes the muscle to become stiff and tender. The pain only occurs a few days after exercise and disappears within a week as the muscle tissue is strengthened and repaired, lowering the likelihood of similar damage.

Interestingly, very few randomised controlled studies have been done on stretching, but those that have suggest that it neither reduces pain after exercise, nor reduces the risk of injury during exercise.



DIFFERENT STROKES

Swimming success is all about balancing forward propulsion through the water while minimising drag

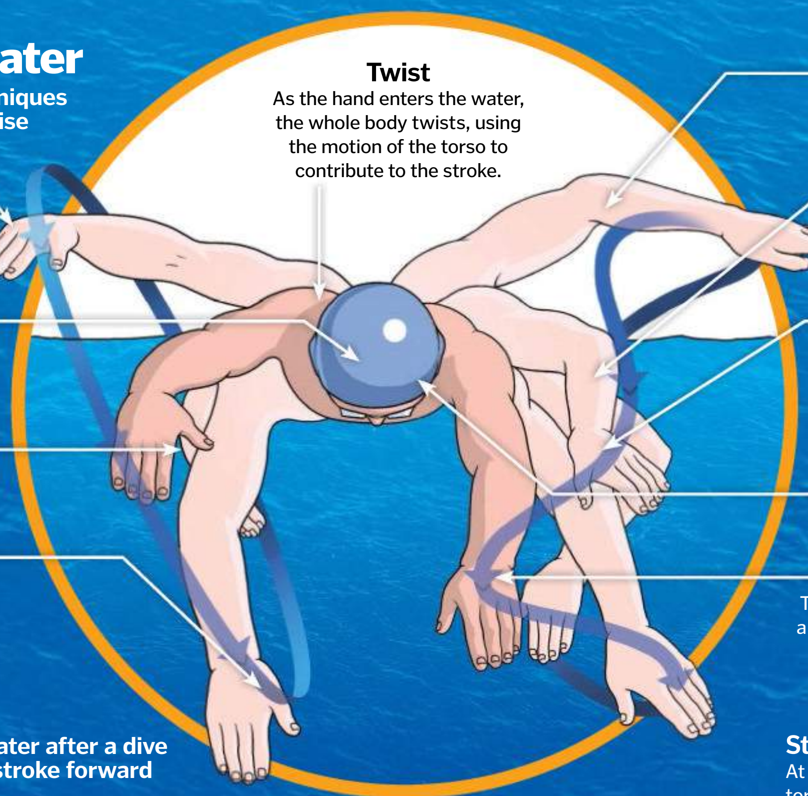
Freestyle – also known as the front crawl – is the fastest type of swimming stroke, combining powerful arm movements with a flutter kick, which keeps the legs up and minimises the frontal surface area exposed to the oncoming water. Swimmers use their hands and forearms as paddles to pull themselves through the water, keeping their head in line with the straight body and facing down toward the floor of the pool.

With each stroke, freestyle swimmers rotate from side to side, using the core muscles in their backs and shoulders to contribute to each movement. This allows them to efficiently slice through the water, and also enables them to reach farther with each arm movement, pulling more water back with their hands.

The technique of the swimmer is only part of the story, and the achievements of elite athletes are aided by technology in their clothes, and in the pool itself. Pools are designed to minimise waves as the swimmers move, and the lane markers help to prevent turbulence spreading from one swimmer to the next. The water level is kept as high as possible to prevent waves reflecting off the edges. High-tech materials in swimwear help to decrease drag, and full-body suits compress the body into a cylinder, preventing wobbling and improving the hydrodynamic profile of the athletes, allowing their bodies to move more easily through the water. These led to many world records being broken in 2008 and 2009, but the suits are now banned in competitive swimming, helping to ensure achievements are based purely on athletic skill.

Gliding through water

See how two different stroke techniques – deep catch and skulling – maximise water caught and minimise drag



Reach
The swimmer reaches forward, maximising the amount of water that can be pushed back with each stroke.

Side breaths
When the swimmer needs to breathe, they turn their head to the side, keeping the body balanced and streamlined.

Fingers first
The fingertips enter the water first, slicing through the water.

Deep catch
In this stroke, the hand is pushed deep into the water, maximising the amount of fluid caught and producing more thrust.

Twist
As the hand enters the water, the whole body twists, using the motion of the torso to contribute to the stroke.

Elbow up
As the arm comes out of the water, the elbow comes out first minimising drag.

S-shape
The sculling stroke reduces both lift and drag, but can allow endurance swimmers to go for longer without tiring.

Sculling
With a sculling stroke, the elbow is bent and the arm moves in an S-shape through the water.

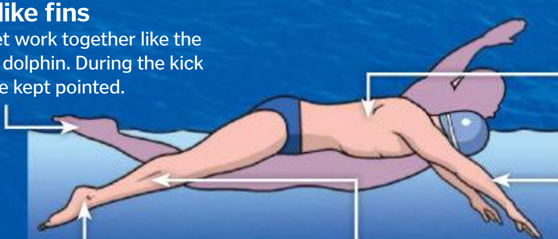
Head straight and down
The head, legs and body are held in a straight line, keeping the swimmer streamlined and minimising drag.

Paddle
The hand and forearm are used together as a paddle to pull the body through the water.

Dolphin kick

This powerful kick is used underwater after a dive or turn, and to drive the butterfly stroke forward

Feet like fins
The feet work together like the fin of a dolphin. During the kick they are kept pointed.



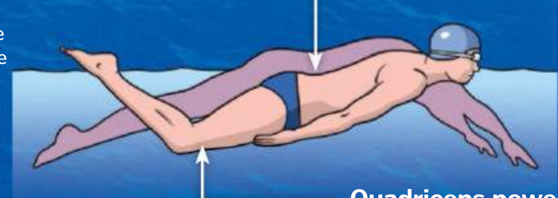
Stiff core
The upper body is tense and the hips are controlled – most of the movement is in the legs.

Forward thrust
As the legs straighten, water is forced down and back by the feet, pushing the swimmer forward and upward.

Like kicking a ball
The power comes from the hips and knees, which whip the lower legs forward.

Power from the arms
There are two kicks per butterfly stroke, helping the momentum as the arms enter the water, and again as they leave.

Streamlined shape
At the end of the stroke, the arms and torso of the swimmer form a straight line, and the head is tucked in.



Quadriceps power
The power of the kick comes from the muscles in the thighs, which snap the legs straight.

Immune cells

Your white blood cells are the specialised army troops that defend your body against infection

Your immune system is made up of a combination of cells, each with a specific job. Macrophages are large cells that patrol the tissues of your body, vacuuming up dead cells and debris, and searching for anything that seems out of the ordinary. If they encounter an infection, they release chemical messengers encouraging other white blood cells to leave the bloodstream and join the fight.

In the early stages of infection, macrophages are assisted by two major cell types; neutrophils and natural killer (NK) cells. Neutrophils are able to swallow and digest bacteria and fungi, while NK cells inject granules into unhealthy cells, causing them to self-destruct and killing any viruses hiding inside.

These cells are quick to respond to infection and can be on the scene within minutes, but they are not very specialised. In order to target an invading pathogen more effectively, the immune system needs to train cells to attack the bacteria or virus directly; this is where the lymphocytes come in.

Lymphocytes come in two major types, T-cells and B-cells, and every single one is specifically trained to attack a different pathogen, delivering a highly targeted assault. T-cells help to coordinate the immune response, can kill virally infected cells, or help to stop the immune response getting out of hand. Meanwhile, B-cells make antibodies that stick to the surface of pathogens, immobilising them and flagging them up for destruction by other cells.

Dendritic cells chop up invading pathogens and stick the pieces on the surface of their membranes. When a T or B-cell sees its matching fragment displayed it becomes activated, and divides thousands of times to produce an army. This response takes several days to develop, but when the infection is cleared, a few lymphocytes stick around, and if the same pathogen tries to infect again, these memory cells will be ready to divide and defend immediately.

A macrophage white blood cell (purple) engulfing a tuberculosis (Mycobacterium tuberculosis) bacterium (pink) by the process of phagocytosis

DID YOU KNOW? *Your bone marrow releases around a trillion infection-fighting neutrophils into your bloodstream every day*

How do white blood cells know what to attack?

Bacteria, viruses and other pathogens make products the body does not recognise. White blood cells like macrophages and dendritic cells have a group of proteins called Toll-like receptors (TLR), which detect these danger signals, putting the immune system on immediate alert and triggering the first stages of the immune response. These danger signals can tell the immune system in general terms what kind of invader it is fighting, whether it is a bacterium, virus, or something else.

In order to activate a more specific immune response, the immune system needs to know exactly what it is up against. Macrophages and dendritic cells are known as antigen-presenting cells, and can take the pathogens they ingest, break them into pieces, and stick those pieces out on their membranes for inspection by other cells. T-cells and B-cells are trained to respond to a different pathogen; if they spot their matching fragment, they are activated and begin a specific attack.

Red and white blood cells in the bloodstream

The physics of figure skating

Find out how science helps a figure skater execute fearless flying stunts

Figure skaters appear to glide effortlessly across the ice, performing breath-taking moves and spins, often at unimaginable speeds. At their core, these impressive performances rely on simple scientific principles, including friction, momentum and Newton's third law – every action has an equal and opposite reaction.

It's actually a lack of friction and the physical properties of the ice that enable a skater to glide, turn, speed up and stay in motion during a routine. Friction is a resisting force that occurs when two objects slide against one another, dissipating their energy of motion. A figure skater performing on smooth ice with sharpened skates will therefore encounter very little resistance. Some friction is still required for skating, though, as it enables skaters to start a stroke and come to a complete stop.

Newton's third law helps to explain how a figure skater is able to move and execute jumps on the ice. To put it simply, a skater will apply force down onto the surface of the ice; the ice then generates an upward force, which pushes back and helps to propel the skater into the air.

Figure skating routines that feature dramatic spins also rely on angular momentum. The amount of momentum depends on the skater's weight, speed and the distribution of mass from the centre of the body. Because of this, skaters will often tuck their arms in during a spin to reduce their radius, which in turn enables them to pick up more speed as they spin.

Science of spinning

Find out how a skater can pick up speed on ice

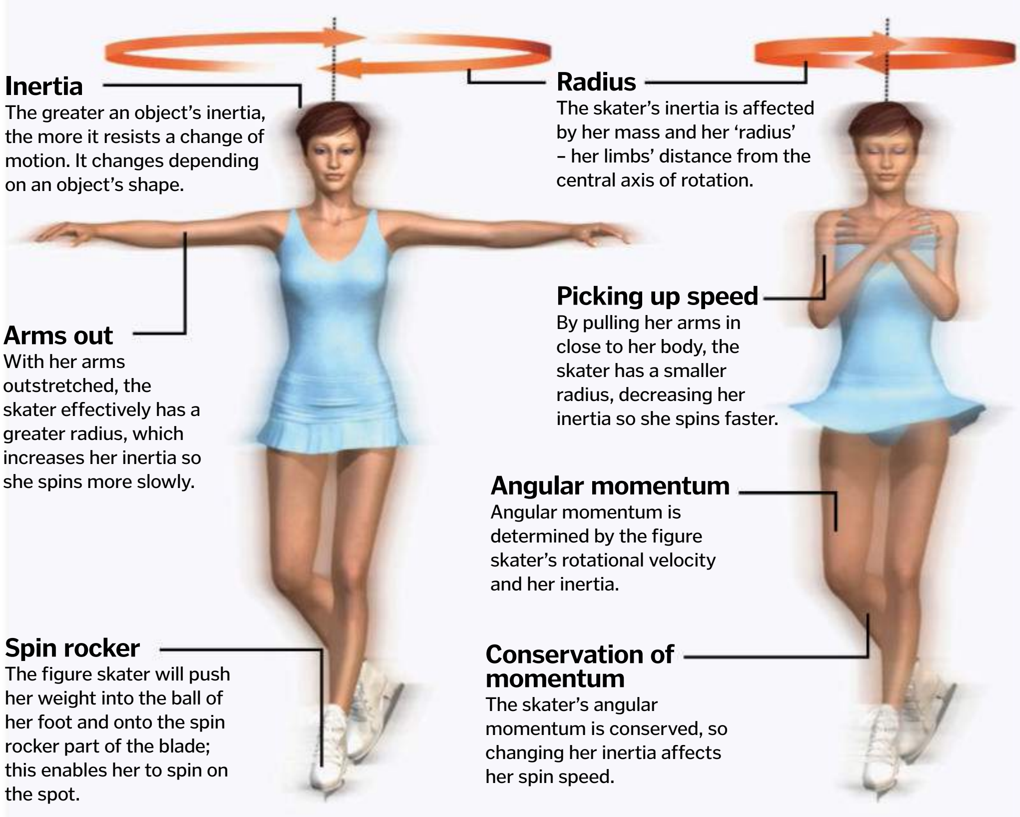


Figure skate design

Figure skates' unique design helps to ensure the athlete is able to glide and complete complex manoeuvres on the ice. The prominent metal blade, which is attached to the bottom of the boot, has a slight inward curve added when it is sharpened. This is known as the rock and offers two edges to skate upon, the inside and outside edge. Skaters will use the edges to move across the ice and pick up speed. It's also possible to skate on both edges, which is known as skating on flat.

The sweet spot, which is just below the ball of the foot, is known as the spin rocker and is the area on the blade that the skater will use to spin. The spikes at the tip are called toe picks and are used primarily for fancy footwork and jumping.

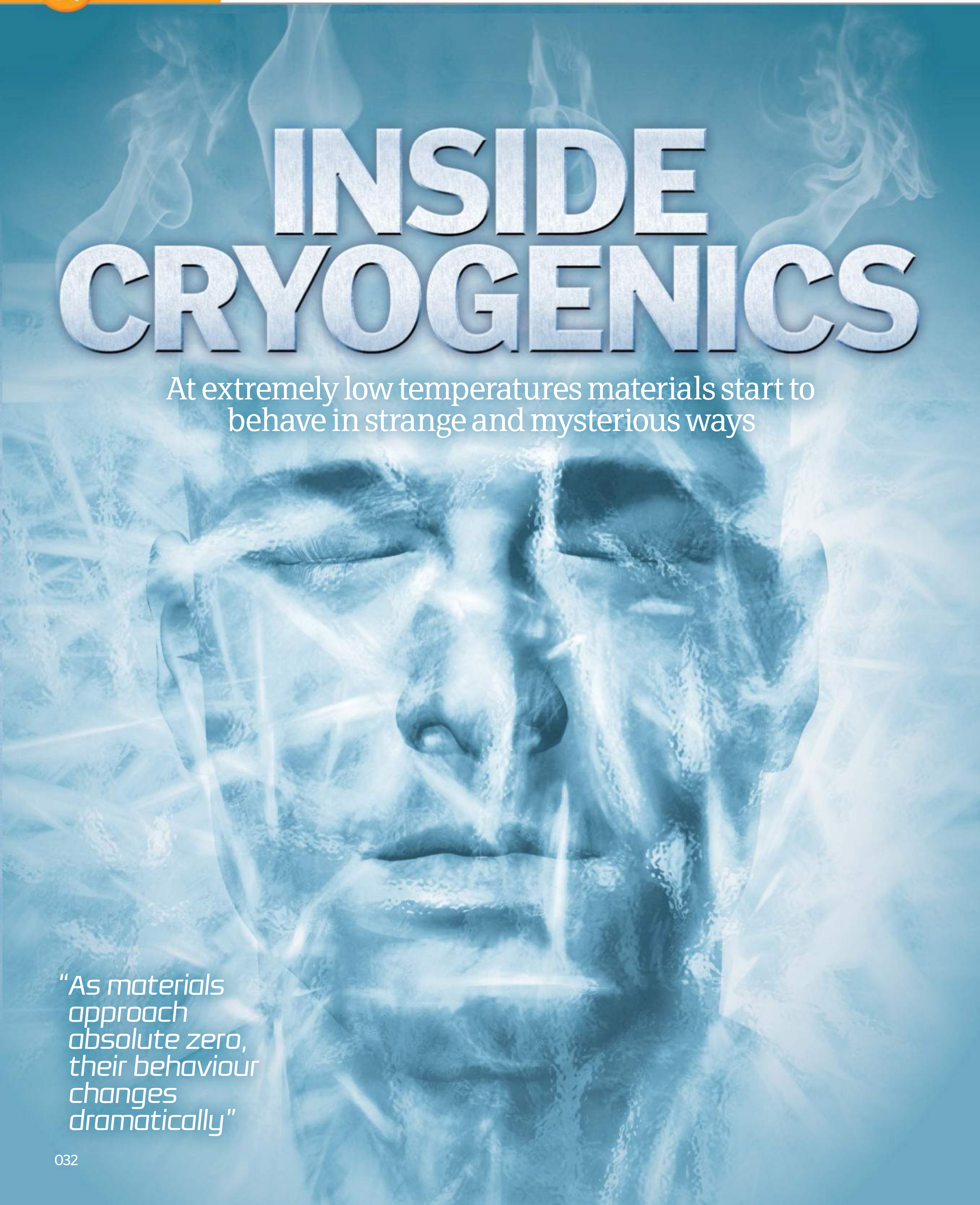
Crystallised alcohol

The hidden beauty of our favourite alcoholic drinks

If you leave a drop of an alcoholic beverage, to dry out, the water and alcohol will eventually evaporate to leave behind crystallised sugar. If you then look at this sugar through a polarising microscope, you will see a pattern of bright colours as light refracts through the crystals. The effect is created using two polarising filters, one between the crystals and the light underneath them, and another positioned at a 90-degree angle from it, between the crystals and the microscope lens above them. As these filters force light waves to oscillate in one direction, rather than all different directions as they would normally, the two polarising filters should block the light completely. But when the light passes through the crystals, it refracts, allowing it to pass through the filters at different angles so we see lots of vibrant colours. Geologists use the same technique to study the structure and composition of rocks.

INSIDE CRYOGENICS

At extremely low temperatures materials start to behave in strange and mysterious ways



"As materials approach absolute zero, their behaviour changes dramatically"

ICY DEAD PEOPLE

Cryogenics versus cryonics

When people talk about cryogenics, one of the first things that comes to mind is frozen bodies waiting patiently in tanks for reanimation. This idea was popularised by science fiction, and is performed in specialist facilities in the U.S., but the scientific evidence is severely lacking.

Scientists are careful to separate the real science of cryogenics from the practice of freezing human bodies, and the field has its own name – cryonics. After a cryonics patient is pronounced dead, their blood is removed and replaced with a cocktail of chemicals that aim to protect the delicate cells from the freezing process.

Once this procedure is complete, the body is frozen using liquid nitrogen and stored in a holding tank. There is no requirement for cryonics companies to be scientifically or medically certified, and some of the work is carried out by volunteers. Despite the undeniably exciting concept, there is still no evidence that whole-body freezing procedures are effective.

Cryonics is the practice of freezing human remains in the hope that one day they might be brought back to life

Cryogenics is the science of extreme cold. Research in this field aims to understand how to produce and maintain temperatures below 123 degrees Kelvin, or minus-150 degrees Celsius (minus-238 degrees Fahrenheit), and to study the effects of these freezing environments on various different physical, chemical and biological processes.

Heat is generated by the random movement of molecules, and as the temperature drops they start to slow down. According to the laws of thermodynamics this cannot continue indefinitely – there must be a bottom, a point at which molecular motion stops completely. This point, the coldest possible temperature, is known as absolute zero, or zero degrees Kelvin (minus-273.15 degrees Celsius / minus-459.67 degrees Fahrenheit).

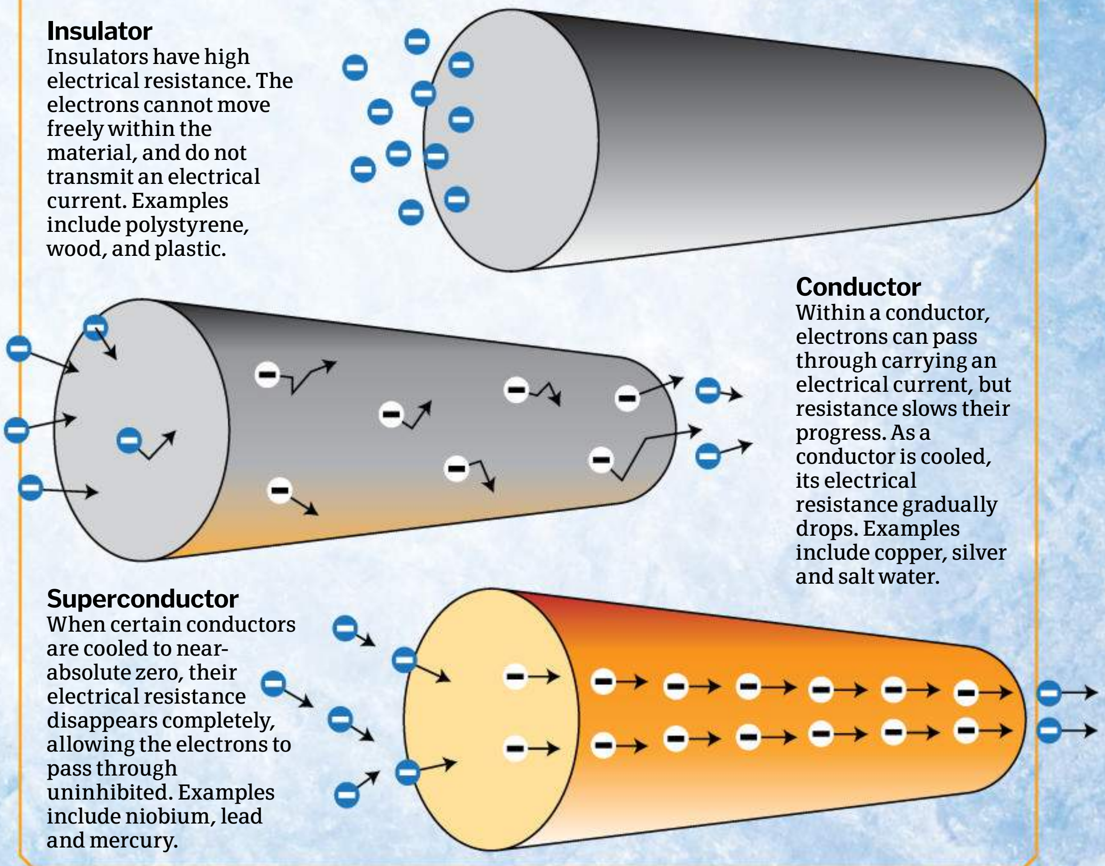
As materials' temperature approaches absolute zero, their behaviour changes dramatically. When permanent gases such as nitrogen and oxygen reach temperatures in the tens of Kelvins, they can be turned into liquids, which can be used as fuel for spacecraft, to rapidly cool food for preservation, or even for the surgical removal of damaged cells in the body. When niobium alloys drop close to absolute zero, they completely lose their electrical resistance, and become superconductors, capable of producing powerful electromagnets that can accelerate subatomic particles to almost the speed of light. And when the temperature reaches 2.19 degrees Kelvin or lower, helium loses its viscosity and becomes a superfluid that can, amazingly enough, crawl up the sides of glass beakers.

Join us as we investigate some of the ways cryogenics is pushing the frontiers of science as we know it.

KEEPING CERN COOL WITH CRYOELECTRONICS

The flow of electrical current through a conductor is opposed by material resistance, but as the temperature of certain metals falls, this resistance drops away. In some cases, at these super-low cryogenic temperatures, electrical resistance suddenly drops to zero, creating a superconductor.

The main magnets that guide particle beams around the Large Hadron Collider at CERN are cooled with liquid helium to a temperature of 1.9 degrees Kelvin (-271.3 degrees Celsius / -456.3 degrees Fahrenheit) – that's colder than in outer space. Their resistance completely disappears, preventing energy being lost as heat.



Insulator
Insulators have high electrical resistance. The electrons cannot move freely within the material, and do not transmit an electrical current. Examples include polystyrene, wood, and plastic.

Conductor
Within a conductor, electrons can pass through carrying an electrical current, but resistance slows their progress. As a conductor is cooled, its electrical resistance gradually drops. Examples include copper, silver and salt water.

Superconductor
When certain conductors are cooled to near-absolute zero, their electrical resistance disappears completely, allowing the electrons to pass through uninhibited. Examples include niobium, lead and mercury.

Fuelling rockets

One of the major applications of cryogenics is in space travel; the first cryogenically fuelled rocket was NASA's Centaur upper stage, first successfully launched in 1963.

The most commonly used cryogenic pairing is liquid hydrogen fuel (LH_2), burnt using liquid oxygen (LO_2 or LOX). Hydrogen is a light gas that burns cleanly in the presence of oxygen, and by cooling both gases to extremely low temperatures, more fuel can be crammed into each tank.

The tanks are exposed to a number of different heat sources during space flight, from the engine's exhaust to friction as the craft travels through the atmosphere, and the heat from the Sun. To keep the fuels liquid, the tanks must not only be well insulated, but also able to withstand the extremely low temperatures of the cryogenic fluids inside.

The fuels are traditionally contained in heavy metal tanks, but NASA and Boeing are working on a revolutionary composite fuel tank, 30 per cent lighter than standard cryogenic tanks. In the future, these tanks will allow more fuel to be carried, taking cargo farther into space than ever before.

The core stage of NASA's new Space Launch System (SLS) will be powered by four RS-25 liquid-fuel engines

MAKING METALS STRONGER

As metal cools from a liquid to a solid, it forms a crystal structure, with the individual atoms arranged into a regular lattice, but there are often imperfections to this. Traditionally, these are minimised using heat treatment, allowing the metal to become liquid again to relieve stress and fill in the gaps, but the process is incomplete. Using cryogenic technology, the imperfections and stresses in heat-treated metal can be removed.

Following heat treatment, the metal is slowly cooled to near-absolute zero. The process allows certain elements within the structure to move, filling in the microscopic defects and making the structure more uniform. This relieves stress and results in a denser, more resilient metal. Cold-treated metals are used in sport to create golf clubs and baseball bats with less vibration, so more energy can be transferred to the balls.

BEFORE

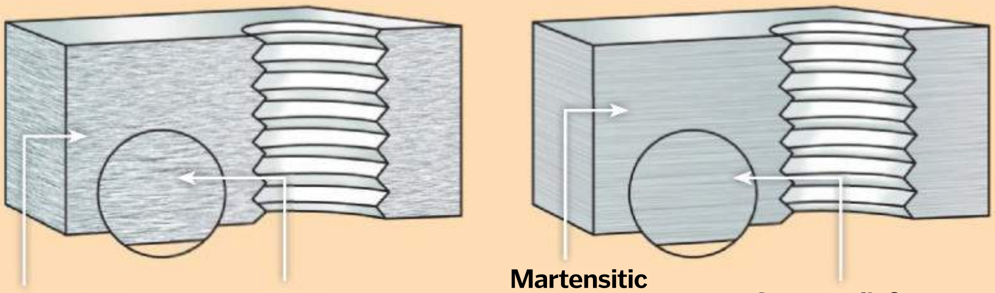
Heat-treated steel

Steel is traditionally heat-treated to improve its strength. At high temperatures, the imperfect internal structure melts and can reform evenly.

AFTER

Cryogenic treatment

After heat-treating, the temperature of the metal is gradually lowered toward absolute zero.



Quenching

Heat-treated steel is cooled slowly, allowing 60-80 per cent of the molecules to settle into a tight, regular structure.

Stress

The cooling process introduces stresses as the outside contracts before the red-hot centre has had time to cool.

Martensitic structure

As the metal cools and contracts, the structure is forced into line, transforming into a uniform structure.

Stress relief

Cryogenic treatment allows the molecules within the metal to redistribute gradually, relieving stresses introduced by heat treatment.

TREATING SPORTS INJURIES

Not all cryogenic techniques are well established, and in the sporting world, there is an emerging field in whole-body cryotherapy (WBC). Traditionally, ice and cold-water immersion have been used to treat sports injuries, but this new approach, based on research originally pioneered in Japan in the 1970s, aims to relieve the symptoms of athletic injury, muscle and joint pain, and arthritis by cooling the entire body in a cryogenic chamber. Air is a poor conductor compared to water, so there is a much lower chance of the core body temperature being affected than with traditional techniques.

Entering the nitrogen-cooled chamber, people are exposed to temperatures lower than minus-100 degrees Celsius (minus-148 degrees Fahrenheit) for a period of around three minutes. Their extremities are protected with clothing, gloves, socks, facemasks and underwear, but other than that, their skin is exposed to extreme temperatures. The body's natural response is to cut off the blood supply to the skin, redirecting it to the core in order to minimise heat loss and maintain a healthy internal body temperature. A by-product of this is the release of natural painkillers known as endorphins, which can induce feelings of well-being and euphoria.

ENTERING THE CRYOCHAMBER

Patients spend up to three minutes in these superchilled rooms

Insulated walls
The walls of the chamber are insulated to ensure the temperature inside remains as cold as possible.

Air diffuser
Normal air enters the chamber through vents near the ceiling.

Main chamber
The air in the main treatment chamber is maintained at temperatures between -123 and -162°C (-190 and -260°F).

Monitoring cameras
The patients are monitored throughout the procedure using a combination of cameras and viewing windows.

Liquid nitrogen
Liquid nitrogen vapour can cause suffocation, and does not enter the chamber – it cools the air from the outside.

Intercom
There is a two-way intercom to allow the patients and technicians to communicate.

Magnetic doors
The doors are closed using magnets, allowing the patients to leave easily if they need to.

Pre-chamber
Patients acclimatise to the cold in the first chamber, kept at a slightly warmer -40 to -62°C (-40 to -80°F).

Treating arthritis

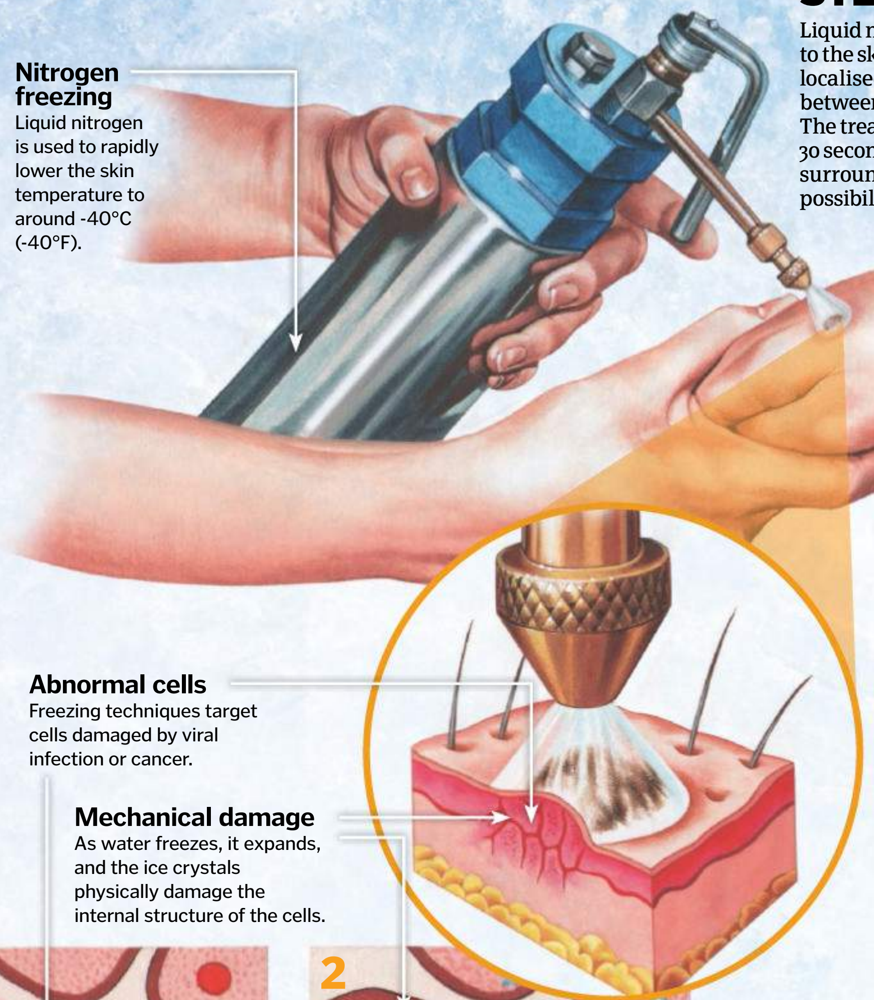
Cryotherapy is being researched for its use in treating illnesses such as arthritis. Exposure to low temperatures slows down nerve conduction, helping to reduce muscle spasm by decreasing the rate of firing of the muscle spindles. This effect is easy to see in your own body – just try undoing the buttons on your coat with frozen fingertips after you come in from the cold.

Cold temperatures are also thought to decrease the activity of damaging enzymes present within arthritic joints, known as collagenases, which break down the protective collagen cartilage that covers the bones.

Studies in patients with a variety of joint disorders have shown that these techniques can temporarily reduce pain for periods of around 90 minutes, allowing patients to undergo physiotherapy and other interventions, which might otherwise have been too uncomfortable. So although it does not have a long-term effect, when used in conjunction with other therapies, there is the potential for significant medical benefit.

CRYOSURGERY

The damaging effects of cryogenic temperatures have been harnessed for use in medical treatment. The extreme chill of liquid nitrogen is routinely used to destroy abnormal cells, from warts to cancers. The technique varies slightly depending on the specific condition, but generally involves applying the liquid nitrogen directly to the affected area, using a cotton bud, a spray gun, or a hollow tube known as a cryoprobe. This rapidly freezes the damaged tissue and destroys the abnormal cells. It is much more specific than drug treatment, causes little pain and is less traumatic to the surrounding tissue than surgery.



STEP 1

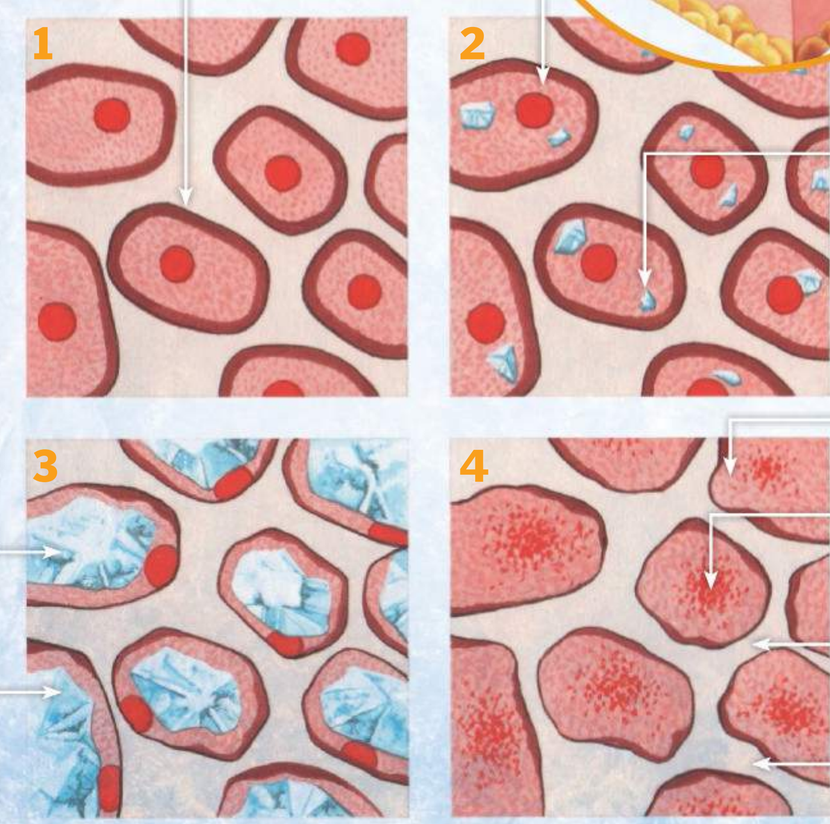
Liquid nitrogen is sprayed directly on to the skin, rapidly cooling a small, localised region to temperatures between -25 and -40°C (-13 and -40°F). The treatment is finished in less than 30 seconds, preventing damage to the surrounding tissue and limiting the possibility of scarring.

STEP 2

The treatment is applied until a ball of ice appears over the lesion, freezing the abnormal cells beneath. This takes just a few seconds and the surrounding tissue is unaffected. Local anaesthetics can be used to numb the pain, but the procedure is much less invasive than surgery.

STEP 3

As water freezes, it expands, forming jagged crystals, which burst through the membranes of the cells, causing irreparable damage. The cells become dehydrated, and by the time the ice thaws, the abnormal cells are already damaged beyond repair, and are cleared away by the body.



DID YOU KNOW? *Cryogenics as a field began in 1877, when Louis-Paul Cailletet and Raoul Pictet liquefied oxygen for the first time*

CRYOPRESERVATION

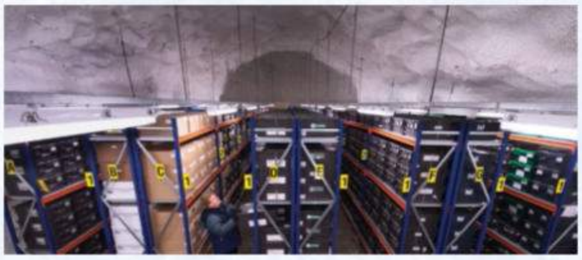
At very low temperatures, biological processes come almost to a complete stop. Without heat energy, enzyme activity slows down and living cells can be preserved almost indefinitely. However, preparing living cells for cryopreservation is far from simple. The delicate microscopic structures of cells can be torn to shreds as water freezes, and as the pure water forms ice, dissolved ions, salts and other molecules become concentrated, upsetting the delicate chemical balance inside the cells.

To prevent this, cells are prepared with chemicals known as cryoprotectants. Glycerol, dimethyl sulphoxide (DMSO), or sugars are introduced to replace the water, helping to stop the formation of ice crystals, or to alter their shape and size. Liquid nitrogen is then used to rapidly cool the cells past a point known as the glass transition temperature; at this point, water freezes to form a solid more like glass than ice. The cells can then be stored safely in liquid nitrogen vapour.

Cryopreservation can be used to preserve plants, seeds and even cells

Seeds

Many plants' seeds can withstand the winter cold and, if air-dried, can remain dormant for decades at temperatures of around -18°C (-0.4°F). Cryopreservation is used for long-term storage and protection of valuable or endangered species for preservation. The seeds are soaked in glycerol and sucrose for protection against ice and then rapidly frozen in liquid nitrogen.



At the Svalbard Global Seed Vault, precious seeds are stored in man-made caves inside the Arctic permafrost

Blood

Red blood cells have a short life span and in order to supply transfusion demands, whole blood and blood products are cryogenically stored. They are cryopreserved with glycerol and either frozen slowly at -80°C (-112°F), or snap frozen in liquid nitrogen. If they are stored correctly, frozen red blood cells can last for at least ten years.

Donated blood can be kept fresh for years in cryogenic storage

Plants

Many plant tissues can be stored at extremely low temperatures. Plants face the same ice-related dangers as animal cells, and must be prepared before freezing. Many plants already have mechanisms to resist the frost, and preparation techniques vary, including air-drying to remove moisture and submersion in cryoprotectants.

Many plants can withstand freezing temperatures, but for cryogenic storage they need a bit of extra help

Cells

Single cells, from bacteria to human sperm, are now routinely frozen for long-term storage in liquid nitrogen. Cryoprotectants are used to prevent damage from the near-absolute cold, but the chemicals used are sometimes toxic, so a careful balance must be achieved to ensure that the cells can be thawed successfully for use later.

Sperm is stored in liquid nitrogen for use in assisted reproduction and IVF

Is it possible to freeze whole organs?

Cryogenic techniques could prolong organ survival time for transplants

Scientists are now able to reliably freeze and thaw single cells, replacing the water with cryoprotectants to prevent the damaging formation of ice, but freezing entire organs is not so simple. The cells within an organ are so closely packed together that it is much more difficult to protect them all, leaving many vulnerable to ice crystals. During the freezing process, ice forms in blood vessels, damaging their structure, and it creeps between cells, prising them apart and leading to micro-fractures.

In 2002, Greg Fahy and his team at 21st Century Medicine in California achieved something unusual. They cooled a rabbit kidney to -130 degrees Celsius (-202 degrees Fahrenheit) for 20 minutes, thawed it and successfully transplanted it into a living rabbit.

They used a solution known as M22, which helps water turn to a glass-like solid at low temperatures. They pumped the liquid through the blood vessels in the kidney, allowing it 25 minutes to reach all the cells, and then rapidly froze it using nitrogen vapour. They then gradually warmed the kidney back to normal temperature, using even more of the protective fluid as it thawed.

This finding was a one-off and has not since been repeated, but it shows the idea of preserving organs by freezing is potentially a viable one.

Today, researchers continue to work on the problem, taking inspiration from antifreeze proteins made by animals resistant to the extreme temperatures of polar ice, and using cutting-edge technology to watch how water behaves inside organs they freeze.

Preserving entire organs is a complex challenge, and although it is still a distant dream at the moment, cryogenic techniques could significantly extend the life of organs destined for transplant in the future.

The science of singing

How do some people manage to hit all the right notes?

From belting out ballads like Mariah Carey to crooning along to Frank Sinatra, singing is an ability we all possess. We may not all be talented enough to reach the top of the charts, but we can all produce some sort of tune, which all stems from a clever little organ in the neck.

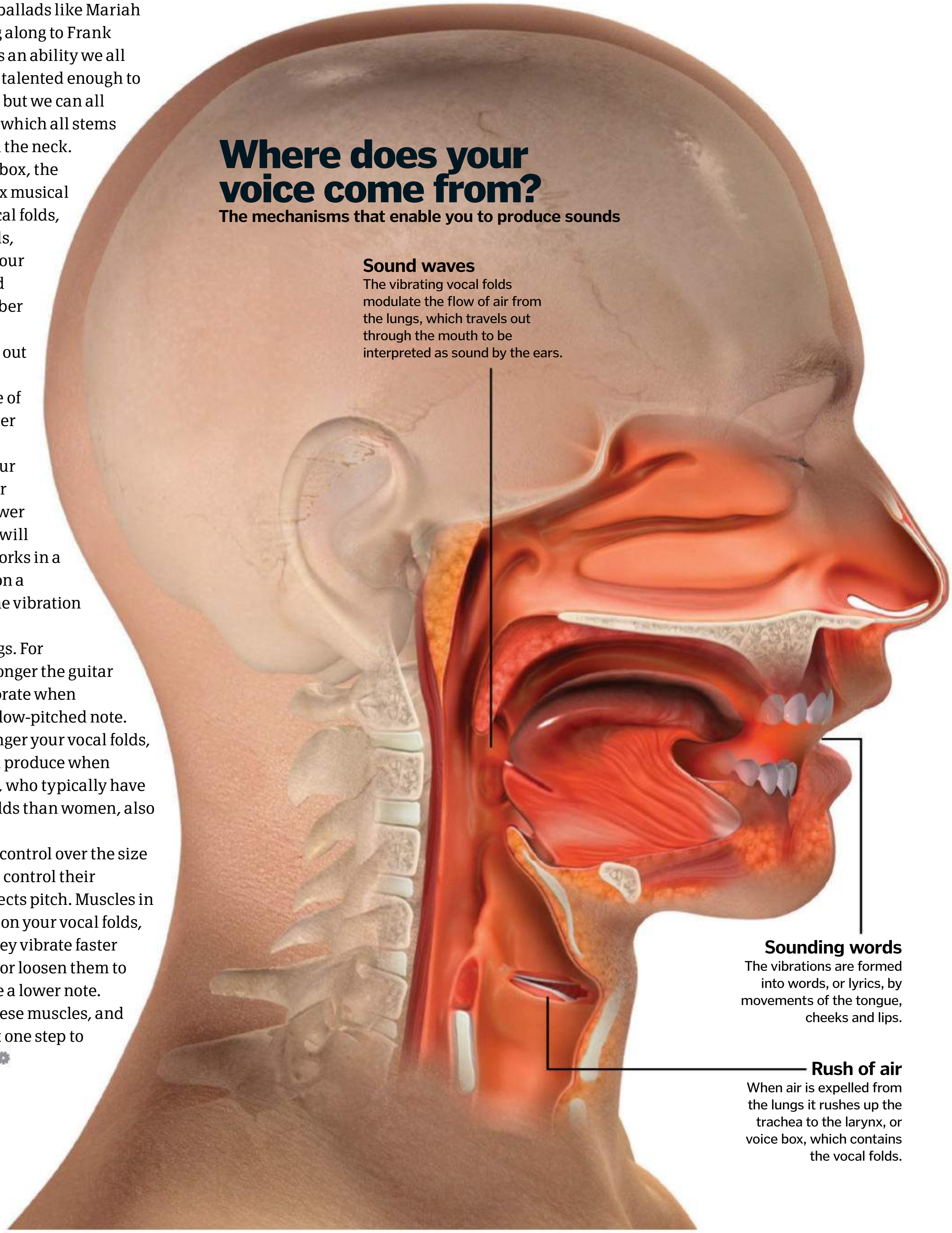
Also known as the voice box, the larynx is your own complex musical instrument. It contains vocal folds, better known as vocal cords, which vibrate to produce your voice, but the type of sound created depends on a number of factors.

The amount of air forced out of the lungs controls the volume, so a greater exhale of breath will generate a louder sound, while the pitch is determined by how fast your vocal folds vibrate. A slower vibration will produce a lower note and a faster vibration will produce a higher note. It works in a similar way to the strings on a guitar, with the speed of the vibration influenced by the physical characteristics of the strings. For example, the thicker and longer the guitar strings, the slower they vibrate when plucked, thus producing a low-pitched note. Similarly, the thicker or longer your vocal folds, the lower the sound they'll produce when vibrating. This is why men, who typically have thicker and longer vocal folds than women, also have deeper voices.

While you may not have control over the size of your vocal folds, you can control their tightness, and this also affects pitch. Muscles in your larynx create tension on your vocal folds, and can tighten them so they vibrate faster and produce a higher note or loosen them to vibrate slower and produce a lower note. Learning how to control these muscles, and therefore your pitch, is just one step to becoming a better singer.

Where does your voice come from?

The mechanisms that enable you to produce sounds



Sound waves
The vibrating vocal folds modulate the flow of air from the lungs, which travels out through the mouth to be interpreted as sound by the ears.

Sounding words
The vibrations are formed into words, or lyrics, by movements of the tongue, cheeks and lips.

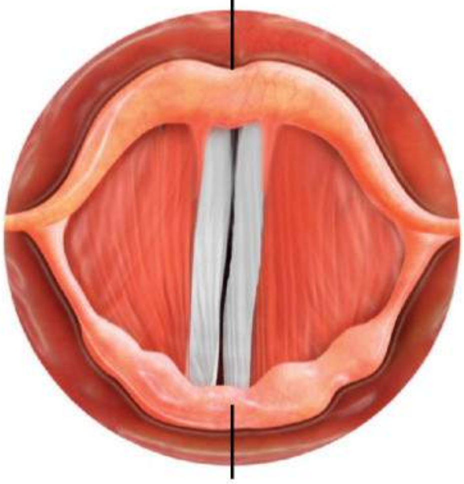
Rush of air
When air is expelled from the lungs it rushes up the trachea to the larynx, or voice box, which contains the vocal folds.

Why are some people naturally good at singing?

No matter how much practice you have or how good your vocal coach is, there's no guarantee that you'll be able to win *Eurovision*. The fact is some people are just born with a naturally great singing voice. The shape and size of their vocal folds plays a part in this, but so does the measurements of their mouth, throat and nasal cavities. These are the body's natural resonators, meaning they can help enhance the tone and intensity of the voice. This is what creates the distinctive nasal tone of some country music stars and the more breathy voice of Marilyn Monroe, for example. You may not be able to control the natural tone of your voice, but you can adjust the style by making use of particular resonance chambers in your body. For example, if you want your voice to have an airy quality, try directing the vibrations toward the back of your mouth.

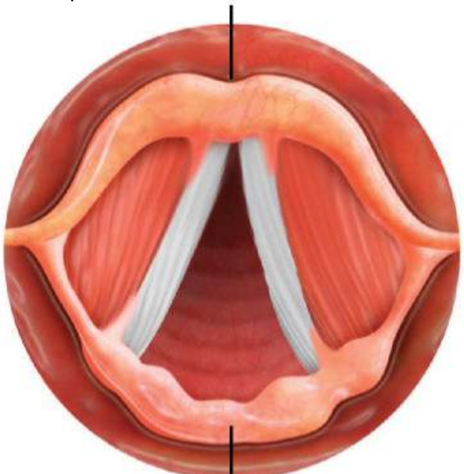

Sometimes a great singing voice is all down to genetics

Speaking and singing
When you speak or sing, the muscles in your larynx cause the vocal folds to close.

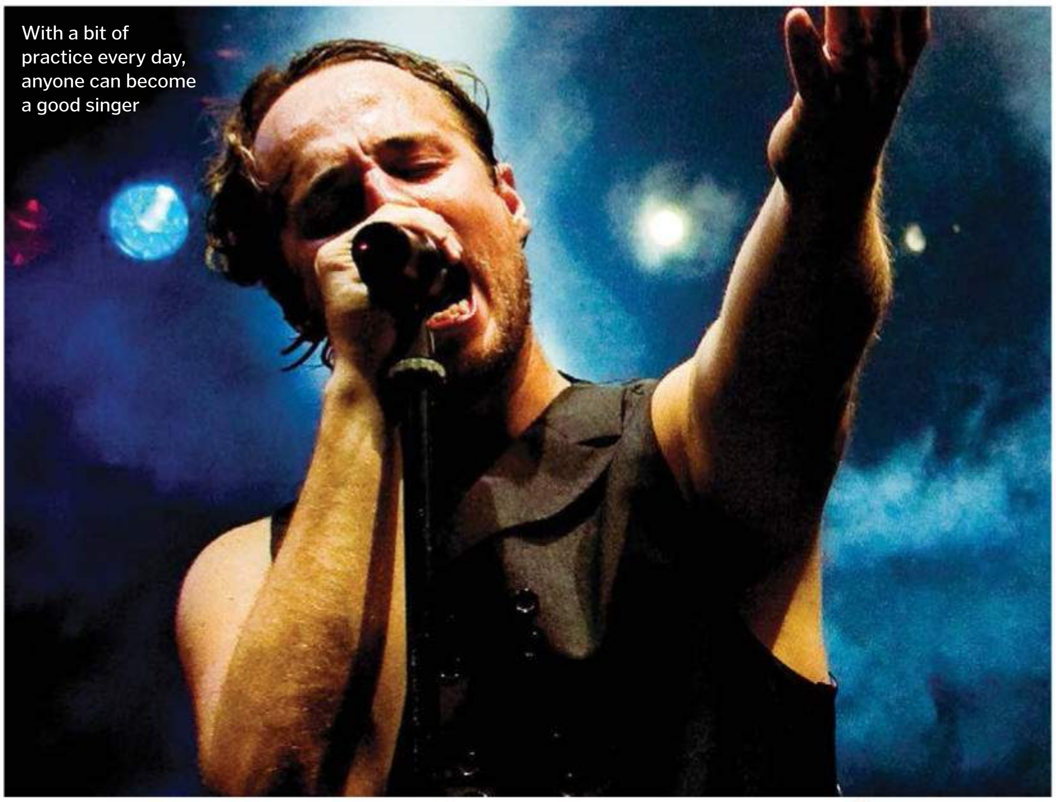


Vocal folds
When a burst of air forces the vocal folds open, the pressure behind them decreases, causing them to close again.

Breathing
When you breathe, the vocal folds open up to let the air in and out unobstructed.



Air pressure
As the air pressure builds up again behind the folds, they reopen. This process repeats several times a second to vibrate the vocal folds.


With a bit of practice every day, anyone can become a good singer

How can I become a better singer?

Anyone can become a better singer with the right training and enough practice. The problem for most bad singers is the inability to imitate the correct notes. Perceiving the notes isn't the problem, because this is how they recognise tunes in the first place, but when it comes to controlling the tension of the vocal cords to match the same pitch, they often struggle. This is simply a case of poor wiring in the brain, but with plenty of practice the brain can be reprogrammed to give the larynx muscles the correct instructions to produce the right sounds. For many people, inefficient breathing can also hinder their ability to carry a tune. However, by training themselves to breathe by moving their diaphragm – not their chest and shoulders – they can prevent their vocal folds from tightening when they inhale and air from being forced out too quickly when they exhale, thus having better control over their voice.

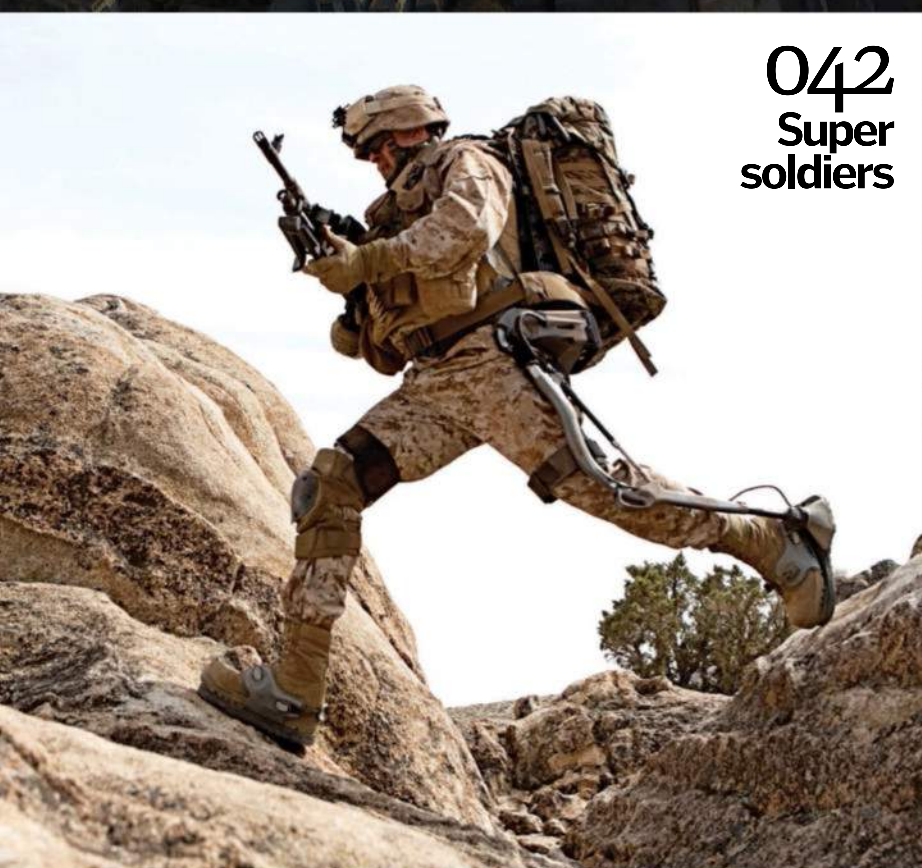
TECHNOLOGY

052
Real CSI science

050
Meet the bionic ants

063
Extreme sports tech


066
Future 5G technology


042
Super soldiers


058
Inside planetariums

SUPER SOLDIERS

HOW TECH IS TRANSFORMING THE FUTURE OF WARFARE

Armies are getting smaller, but soldiers are growing more powerful than ever thanks to amazing new technology

War has been one of the greatest spurs to science in history. Developments as diverse and far-reaching as space travel, superglue, duct tape and microwaves owe their origins beneath camouflage netting and behind sandbags.

A century on from the start of World War I's disastrous Gallipoli Campaign and 70 years on from the end of the World War II and the dropping of the atomic bombs, the catastrophic loss of life looms far larger in the memory than the technologies these conflicts helped to inspire.

Today's military innovations, though, are focused not just on getting the job done and winning the fight, but doing so as quickly as possible and bringing the men and women in the boots home to their families in one piece.

"There's obviously a trend toward trying to increase personal protection as far as possible given that training is ever more extensive and armies are getting smaller and smaller," explains Justin Bronk, military sciences analyst at The Royal United Services Institute for Defence and Security Studies, a think-tank founded in the 19th century to advise the British government.

"I think the basic picture of a soldier probably won't change too much – [like] body armour which is scalable depending on the threat expected. Until you see full exoskeletons there'll still be a trade-off between how much a threat and therefore how protected you want to be versus how much you want to move, so you'll still have your pelvic body armour, helmet and various kinds of advanced night vision scopes."

Armour could be significantly strengthened by a number of means beyond the current protection that's offered to infantry. There are ongoing experiments in liquid armour, which would harden on impact but remain flexible enough to allow the soldier free movement, and nanotechnology, which enables materials to be manipulated on an atomic, molecular and supramolecular scale.

"If you are engineering something to a nanoscale you can then create vastly more resistant and strong materials because they don't have any imperfections," explains Bronk. "You can design a lattice structure instead of having to either kiln something or cast something. You can effectively build up, for example, carbon fibre-infused ceramics at a nanoscale if you were doing it like that. You can build it so it's a perfect lattice structure and you get fantastic integration between the materials so it's more stronger pound-for-pound than something that's made in the more traditional way."

Innovations like superstrong exoskeletons and bulletproof carbon-fibre body armour are one option, but Bronk believes that better intelligence – not just from commanders on the other end of the radio, but right there in the field – also has a big part to play.

"The main focus for standard infantry is going to be a mix of sensors," he says. "So for example we're already seeing trials of a combination of thermal and infrared vision aids for seeing at night. At the moment soldiers tend to use infrared, your standard green *Predator*-style night vision to see and move around, but when they're actually engaging targets at night, they use thermal. Obviously this involves more equipment and thermal scopes are traditionally rather large, but they give much better definition. One way of increasing efficiency is to use an integrated binocular/monocular attached to the helmet so that you don't have to carry two things, you can carry one power pack for both and switch between them quickly."

These sort of neat fixes in existing technology might not sound like much, but they can make a huge difference to both the weight a soldier carries and the convenience of not having to fumble around with a variety of equipment.

"There are things like the Fighting Load Carrier vest which uses a small amount of power to distribute the load from the shoulders toward the hips and make sure the load is even," offers Bronk as an example. "It also gives an exact GPS fix of the soldier to within an axis of about five to ten metres [16.5 to 32.9 feet] and it also integrates a radio, so you're there looking at addressing one major problem and then seeing 'What could I add in there that would also make the overall equipment package more efficient and lighter?'

"There's also going to be a huge focus on engaging communications and networks. We're basically still using satellite communications and radios. I think there'll be continuing heavy reliance on digital technology, but at the same time we'll be much more aware by that point of the dangers of relying on a guaranteed supply of information in a contested environment because I just don't think that's going to be possible. We'll have to fall back a lot more on command intent [decisions on the ground] as opposed to minute-by-minute instructions.

"Also, I think there'll be a lot more micro-drones and other machines. In the end though, soldiers will still be there. There'll still be people with guns and body armour."

Virtual reality training

Simulations may already have a place in air-force training, but now soldiers have a chance to put their skills to the test in virtual-reality combat zones.

Wearing head-mounted displays (HMD) or VR glasses such as Oculus Rift, soldiers can explore a variety of scenarios, such as the challenges of administering first aid to a wounded comrade while under enemy fire. This is all realised in a 360-degree 3D environment that changes the image with the movement of the head and the body, via an in-built tracking system.

Some battlefield simulation programs are even more realistic still. Polish troops train with integrated feedback that administers a small electric shock when the soldier gets 'shot', while the US Department of Defense is so committed to the idea that they want every soldier to have a virtual avatar that can be customised to reflect their individual skills and weaknesses.

US Army soldiers training with the Dismounted Soldier Training System (DSTS)

SOLDIERS OF TOMORROW

How the Future Soldier project plans to change the face of warfare

Exoskeletons are only the beginning when it comes to preparing for tomorrow's conflicts. The greater carrying power being developed by the likes of Lockheed Martin will let soldiers field a whole new package of weapons and armour that will turn a single soldier into a one-man war machine capable of dealing with any situation.

"There's obviously a trend toward trying to increase person protection as far as possible given that training is ever more extensive and armies are getting smaller and smaller," explains Bronk.

A continuation of the Future Soldier project launched by the US and its allies in the Nineties, this new generation of super soldier programmes such as the US Army's Future Soldier 2030 Initiative will bring together similar combinations of next-generation military technology. This ranges from heavy carbon-fibre body armour to more sophisticated sensors that monitor the soldier's health and software to instantaneously decipher speech and weigh up threats.

US Army Rangers conduct a training exercise in Land Warrior gear

Head-up display
The soldier's HUD provides facial recognition and threat assessment, and a 180-degree field of vision.

Recoilless rifle
Firing caseless rounds rather than bullets, the rifle will have lethal and nonlethal settings.

AI wingman
An AI 'buddy' constantly monitors the soldier's health and suggests solutions based on the data.

Electronic textiles
Textiles transmit the data and power around the suit without cables or wires.

Nano-ceramic armour
Existing ceramic plates are strong enough to stop a rifle bullet, those engineered by nanotechnology would be far stronger.

Wrist display
Wrist-mounted display will be able to show anything normally visible through the HUD.

Norwegian naval commandos practice antiterrorism operations in the NORMANS Future Soldier system

LAND WARRIOR

While we wait for armoured exoskeletons and integrated firearms, the US's Land Warrior (since superceded by the Nett Warrior) and similar systems such as the UK's FIST (Future Infantry Soldier Technology) and France's FELIN (Fantassin à Équipements et Liaisons Intégrés/Integrated Infantryman Equipment and Communications) – represent a package of cutting-edge military technology that we don't have to wait 15 years to see. In fact, it's in use right now.

Networked for battle
The antenna can receive video and data as well as voice communications.

Monocular sight
As well as showing what the rifle's camera sees, the monocular sight has both night vision and infrared.

Camera sight
A camera mounted on the rifle allows the soldier to shoot from cover without exposing their head.

Power supply
Lithium batteries power the whole system, including a Fighting Load Carrier vest which takes some of the weight from the soldier's back.

Smart gun
The rifle's crosshair is shown on the HUD and it can be fired by voice command or electronic trigger.

Environmental protection
As well as providing full NBC (Nuclear, Biological, Chemical) protection, the suit will be climate controlled for extremes of temperature.

Exoskeleton
A smart exoskeleton increases the soldier's strength and speed to reflect his or her movements.

Power
Chargeable lithium-ion batteries provide four to five hours of power. These can be replaced when they run down.

An Australian soldier trials a new grenade launcher attachment during the development of their Future Soldier system, Land 125.

ARMY EXOSKELETONS

Soldiers carry more gear than ever before, could this supersmart exoskeleton take the strain?

Soldiers clunking across battlefields in powered exoskeletons may have long been a staple of many a science fiction writer's wildest wishlist, but they're starting to become reality.

Taken from the Greek word meaning 'outer skeleton', exoskeletons are inspired by the hardened shells of the insect world. They involve a frame of hydraulics which magnify the leg and arm movements of the wearer, enabling them to take more effortless strides while carrying even greater weights.

Military exoskeletons trialled as far back as the Sixties – such as General Electric's Hardiman – were able to increase the magnitude by a factor of 25, making lifting an 11-kilogram (24 pound) load as easy for the wearer as lifting 0.5 kilograms (one pound). They even had force feedback – similar to an Xbox or PlayStation controller – so that the operator could get an idea of the resistance that he or she was experiencing. These projects were ultimately unsuccessful as the early exoskeletons reacted unpredictably (and sometimes violently) to anything less than gentle movements. Sadly, for General Electric, gentle wars are few and far between.

While many current exoskeleton projects have medical uses in mind – enabling those who are unable to walk to do so without crutches – XOS and XOS 2 (developed for the US Army by Raytheon-Sarcos), Hercule (developed for the French Army by RB3D), and Human Universal Load Carrier, better known by its intimidating acronym of HULC, are primarily military endeavours. Developed by Ekso Bionics and Lockheed Martin, HULC is a lower extremity exoskeleton powered by a lithium-ion battery that works to redistribute the weight across the hips and legs – this will enable its operator to comfortably carry 91 kilograms (201 pounds) with far less effort.

The increasing weight of a soldier's gear – including standard weapons, ammunition, rations, water, first-aid kits, basic tools, satellite phone, GPS, helmet and body armour, and depending on the scenario, anything else from snowshoes and camping stoves to night vision goggles and micro-drones – is a growing worry for commanders. Indeed, the consequences of lugging around a weight of anywhere between 36 and 54 kilograms (79 and 119 pounds) can be severe – perhaps even deadly.

The incredible HULC

Inside the tech that will give tomorrow's soldiers super strength

Weapons mount
A swing mount is available which hangs over the chest to take the weight of a weapon away from the soldier.

Smart tech
A microprocessor linked to sensors detects the wearer's movements and then calculates movements in the exoskeleton to match them.

Massive weight
The average soldier could be carrying up to 54kg (119lb) of kit. HULC can enable them to comfortably carry up to 91kg (201lb).

Power
Chargeable lithium-ion batteries provide four to five hours of power. These can be replaced when they run down.

Motor
An electronic motor, discretely mounted at the rear, drives the exoskeleton's hydraulics.

Legs like pistons
Hydraulics in the joints provide the motion, enabling the soldier to walk, run, bend, crawl or jump without any loss of agility.

Titanium frame
HULC's titanium frame is lightweight enough to keep it from hindering movement, but strong enough to take the weight of a soldier's kit.

"Distributing and managing a soldier's load can give enormous benefits in terms of combat endurance and efficiency," explains Bronk. "People ended up toting around up to 40 kilos [88 pounds] of stuff which means if they've been on patrol for a couple of hours and they go prone (lie face down) when they start taking fire, often they just can't get back up again!"

Far more flexible than earlier exoskeletons, sensors mounted throughout HULC's titanium frame and linked to an onboard microcomputer spur electric motors into action, enabling the limbs to match the operator's movements instantly. Lockheed's ambition is that the system will allow troops to be able to easily carry otherwise back-breakingly heavy gear, as well as bulkier armour – since the HULC offers no physical protection – which would normally be impractical for a soldier on foot to carry.

According to Bronk, what is currently holding them back from a roll out across battlefields is simple: energy.

"The basic problem with exoskeletons is that you need about ten kilowatts of power to run a typical load-bearing, armour-protected suit," he explains. "And you need to be able to run it for ten hours or so to make it mission-capable. Otherwise, if the power runs out, an exoskeleton becomes a massive impediment to the soldier's ability rather than a bonus."

Lockheed is currently investigating electrochemical and solid oxide fuel cells to solve exactly this problem, and the plan is for a 'long-range HULC' with a 72-hour battery life capable of powering bursts of speed up to 16 kilometres (10 miles) per hour.

Until the power issue is cracked, the type of exoskeletons most likely to hit the battlefield may be more difficult to spot than Lockheed's piston-powered HULC.

DARPA – the US government's Defense Advanced Research Projects Agency – is currently testing Warrior Web, a wetsuit-like 'soft exosuit' designed to be worn under the soldier's uniform to provide leg and joint support on only 100 watts of power. Instead of a titanium frame covered with battery-sapping hydraulics, Warrior Web uses computer-controlled textiles and wires that offer conventional orthopaedic support, as well as powered robotic systems in the legs to reduce strain on muscles and tendons.

It may not be the sleek armoured exoskeleton of videogames and action movies, but these sophisticated exosuits will take some of the strain from a soldier's bulging backpack and protect their muscles and joints from the effects of hours of patrols across rugged terrain.

Ultimately, whatever keeps a soldier in good shape will keep them alive.

Exosuits like Warrior Web are designed not just to carry more weight, but to protect muscles and tendons

Exoskeletons such as the French Army's Hercule can be fitted with 'arms' to enhance carrying strength

The HULC exoskeleton enables soldiers to comfortably carry up to 91kg (201lb)

THE FUTURE BATTLEFIELD

From drones to data, technology will be a soldier's true ally

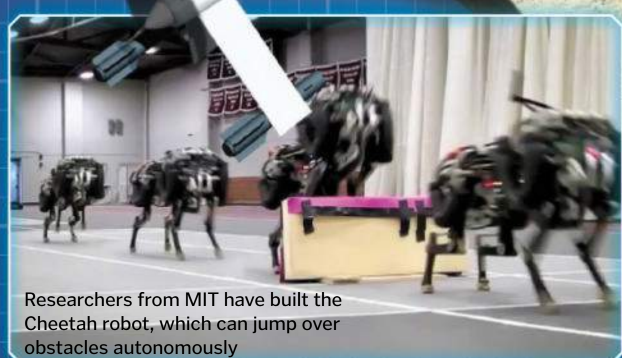
As professional armies grow smaller and technology grows more advanced, soldiers may have to rely on machines for backup.

"You'll start to see more things like a micro-drone called the Switchblade, which can be carried in a backpack," explains Bronk. "It comes in a sort of tube, you launch this and you use a set of first-person-view goggles to see what it sees. That can be launched from behind cover, you throw it up and it flies around, and once you've seen who's shooting at you, you can guide it towards them and it's got a roughly grenade-sized warhead in it. That sort of smart micro-drone technology should soon be hugely influential."

The potential disruption caused by hacking and jamming technology will also ensure that while a soldier's ability to scan, transmit and receive more detailed information on what's round the next corner will increase, so will information on a potential foe's means to block it.

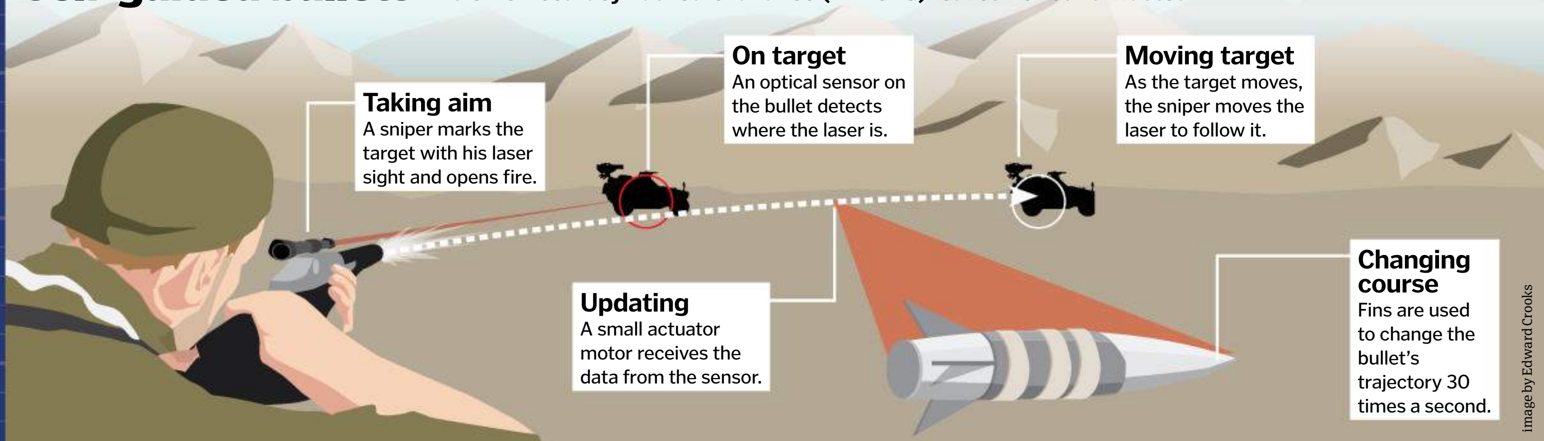
"In the land environment you'll start seeing greater capability for soldiers to connect with a network, to link up with, for example, helicopters that are coming to give them support, or fast jets or vehicles in order to increase the situational awareness and therefore effectiveness," confirms Bronk.

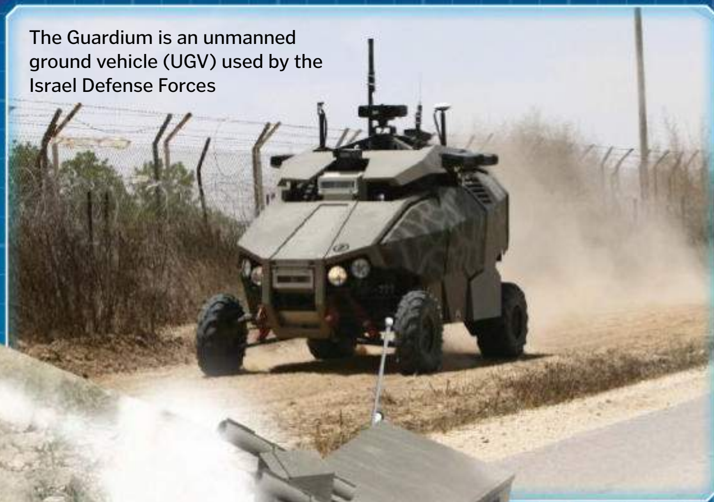
"That's got to be played off against the fact that you can't rely on electronics, particularly networked electronics against a serious opponent who really knows what they're doing because the first thing they'll do is jam it."


Researchers from MIT have built the Cheetah robot, which can jump over obstacles autonomously

Self-guided bullets

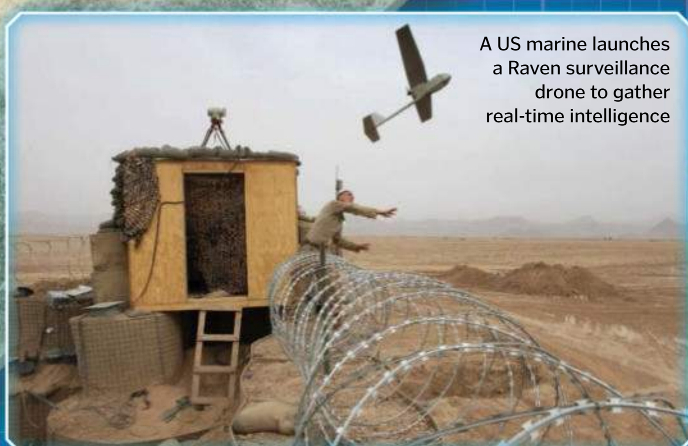
Extreme Accuracy Tasked Ordnance (EXACTO) leaves no round wasted





The Guardium is an unmanned ground vehicle (UGV) used by the Israel Defense Forces

Unmanned ground vehicles
Tracked or wheeled UGVs can patrol camps or scout ahead, while more heavily armed designs can join the fight.



A US marine launches a Raven surveillance drone to gather real-time intelligence

Medics on the move

Warfare has always led to huge advances in medicine, but despite progress, one of the biggest killers in the field is one of the most preventable – blood loss.

Fabrics like PolySTAT will be used in dressings to help the fibrin strands in the body cement a blood clot and stop bleeding, while more dramatic results will be provided by the XStat Rapid Hemostasis System – a syringe which fills the wound with a hardening polyurethane foam – or nanoparticles, which can be also be injected to speed up clotting in cases of internal bleeding.

Head-up display

Increasingly sophisticated HUDs such as Urban Leader Tactical Response, Awareness and Visualization (ULTRA-Vis) will give soldiers all the information they need in one place, more accurately and intuitively than ever before.

The holographic augmented reality display will appear in the eyepiece mounted on a soldier's helmet and will show waypoints, information about the terrain and targets, and enable soldiers to add their own 'notes' to the landscape to share with their teammates.

Fixed markers pinpoint targets or waypoints and remain in place, even if the user looks away

Special forces scope

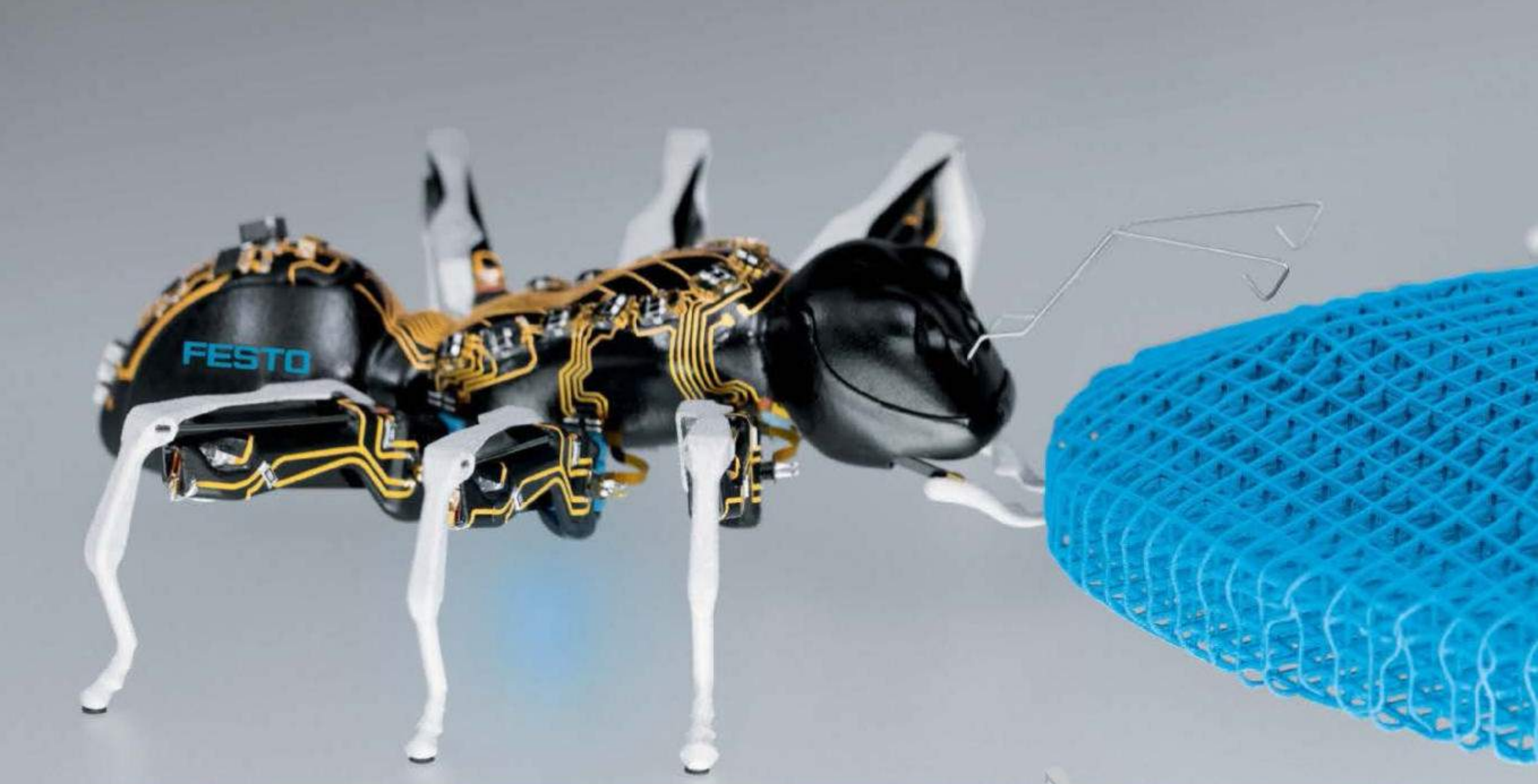
Rather than physically switching between green-tinged night vision and heavy heat-sensing thermal scopes in the dark, both of which require their own power sources, BAE Systems' ENVG III/FWS-I is just one of a new breed of scope which incorporates both in a single set of goggles

A wireless video link to the gun's sight also enables the ENVG III/FWS-I to aim without the need for a laser sight, which would easily give the game away in covert operations.

Army ants

The army of robots inspired by nature's hardest workers

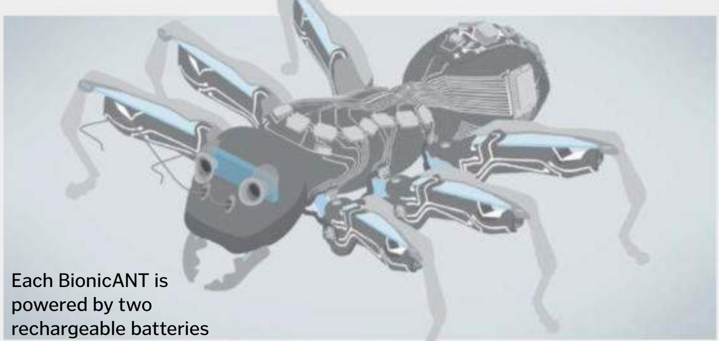
You might think humans would be the natural inspiration for an army of robots, but German engineering company Festo has a much smaller role model. Its BionicANTs not only look like their insect counterparts, but also behave like them, as they mimic ants' ability to communicate and coordinate with each other to complete complex tasks. A group of BionicANTs, which are about the size of a human hand, can make autonomous decisions and work together to move an object much larger than they are. Festo hopes that this approach could help improve the factories of tomorrow with a network of machines that can adjust and coordinate themselves for different production scenarios. It's not just ants that the company is interested in, though, as it has also developed a fleet of eMotionButterflies too.



BionicANTs are made of polyamide powder, which is melted layer by layer with a laser

Energy-efficient insects

Each BionicANT weighs just 105 grams (3.7 ounces) and has a 3D-printed plastic body. Its six ceramic legs and jaw, which it uses to grip onto objects, are powered by piezo technology. When the ant lifts a leg, pressure is applied to the bending transducer in its thigh. This forces the charge of its atoms out of balance, so when the pressure is relieved, an electric charge flows between them. This electricity powers the motors that keep the robot moving, meaning it requires very little energy and therefore has a relatively impressive 40-minute battery life. However, when it does need to recharge, the robot simply has to connect its antenna to a charging station. The BionicANTs also have a camera and sensors, which they use to determine their position and navigate their environment, and can communicate with each other via radio signal.



Each BionicANT is powered by two rechargeable batteries

The ANT in the name actually stands for Autonomous Networking Technologies

FORENSIC SCIENCE UNCOVERED

REVEALED: THE INCREDIBLE TECH THAT SOLVES CRIMES AND CONVICTS CRIMINALS

Forensic science has never been under more scrutiny than right now. Since the dissolution of the UK's government-owned Forensic Science Service and the use of private contractors became the norm, every court in the country is on the lookout for mistakes and poor practice; the defence will try to discredit forensic experts to save clients from prosecution.

The huge popularity of TV shows relating to forensics has not helped either. The general public's expectations have been raised; they expect 100 per cent accuracy and rapid results, both of which are misrepresented in many crime dramas. In some instances, this has led to miscarriages of justice, through the wrongful representation of various theories as undisputed fact. The public struggles to appreciate this; forensic science has long been thought of as a tool to expose wrongful convictions, rather than cause them. The popularity of forensics in the entertainment world has also aided criminals. They now tend to have greater awareness of many of the techniques used by forensic scientists, enabling them to avoid detection with greater success.

However, the technology used in forensics has developed hugely in the last century. Toxicologists no longer have to taste stomach contents to check for poisons, which was an unsavoury part of their job description during Victorian times. Instead, they can now use precise analytical techniques, such as mass spectrometry and high-performance liquid chromatography, to determine the exact quantity of compounds present in any test sample. DNA technology has breathed life into cases that have been left untouched for decades, and continues to be refined for greater accuracy.

Forensic technology has undeniably improved the police's ability to solve crime, but improvements are still needed. Experts are constantly trying to reduce the length of time analysis takes, as waiting weeks for a DNA result can have a detrimental effect on police investigations, allowing more time for criminals to evade detection. The amount of evidence that needs analysing has created a huge backlog, which means evidence has to be prioritised by what is most likely to reveal probative evidence.

It will be fascinating to see how forensic technology develops over the coming years and whether the new techniques we've featured speed up investigations and lead to convictions.

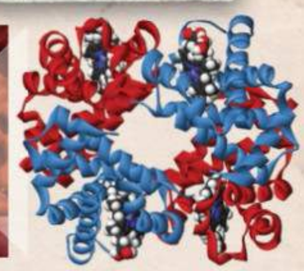
MATCHING GLASS TO SUSPECTS

Using a clever type of mass spectrometry involving lasers, it is now possible for even the tiniest fragments of glass to be matched from an individual to crime-scene samples.

DATING BLOOD SAMPLES

A revolutionary camera that can scan the visible spectrum of haemoglobin could make it possible to date blood stains to within a day, potentially even within an hour. This hyperspectral imaging device could enable police to immediately establish time of death, which currently takes days to achieve. It's thought that this technology could be adapted to confirm the presence of other fluids, such as saliva and sweat.

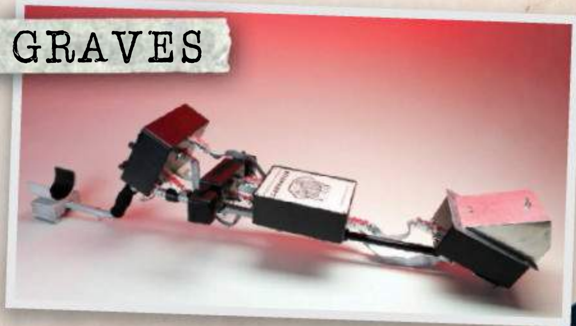
HAEMOGLOBIN



Haemoglobin is a protein made up of four polypeptide chains, each joined to an iron-containing haeme group

SNIFFING OUT HIDDEN GRAVES

Locating hidden graves is both timely and costly, impacting law enforcement and military operations globally. The lightweight analyser for buried remains and decomposition odour recognition device – LABRADOR for short – claims to help find hidden graves. As our bodies decay, over 400 chemicals are released, producing a unique chemical signature that this device identifies. Its potential applications are vast, and include detecting narcotics, accelerants and even explosives.



CRIME-SCENE PHOTOGRAPHY

When photographing a crime scene, it is imperative the photographer does not delete a single image, as this would be deemed as tampering with evidence.

AREA OF CONVERGENCE

When bloodstain pattern analysts arrive at a crime scene, they will examine the distribution, size, shape and location of the bloodstains, to determine what has happened. Using the stringing method, the analyst will record the location of each spatter by employing the coordinate system. By determining both the angle and direction of each spatter, the starting point of the bloodshed and the victim's location are established.

CRYSTAL PATTERN MAPPING

In order to make the identification of stolen goods harder, criminals will remove any form of serial number. By using electron backscatter diffraction (EBSD), it is possible to map the deformations in the metal's crystal structure, revealing the removed information. This technique could prove useful for reconstructing vehicle identification numbers, or even the imprints left on ammunition casings.

Blood pattern analysis

Cast-off

Cast-off stains are often formed when a bloodied weapon is swung through the air, casting blood onto a nearby surface.

Shadowing or ghosting

A gap in an otherwise consistent spatter typically indicates that an object was present at the time of the incident.

Swipes and wipes

Wipes are seen when blood on a surface is smeared, whereas swipes occur when an object covered in blood brushes a separate surface.

Expiratory blood

Blood exhaled by a person creates a unique pattern. This is typically misty, somewhat resembling high-velocity spatter.

Transfer

Transfer patterns form when a bloody object is pressed against a clean surface. This is often seen with bloody footprints.

VIRTUAL AUTOPSY

CAN CAUSE OF DEATH BE ESTABLISHED WITHOUT DISSECTING A CORPSE?

Autopsies are a messy business in more ways than one. They can take hours to perform, and further analytical results can take months to produce. This not only delays forensic investigation; it can also add to the grief the deceased person's relatives experience. On top of this, researchers believe more than ten per cent of post-mortems are not completed to a satisfactory standard, meaning many suspicious deaths are never correctly identified.

The new virtual autopsy, or 'virtopsy', aims to speed up the entire process and achieve faster results. They offer the advantage of preserving a virtual form of the body, which can be continually reviewed and analysed. This will greatly increase accuracy, as multiple experts will be able to simultaneously examine the corpse, which is impossible to do during traditional post-mortems. The ability to gather nondestructive findings is a huge benefit of a 'virtopsy'; many families would rather their loved ones' bodies weren't subjected to the rigours of a traditional post-mortem. By using the virtopsy software, precise areas of interest can be chosen for further investigation, allowing pathologists to reduce the time they spend physically looking for clues in the body. Although unlikely to completely replace the traditional autopsy, the virtopsy has huge potential to speed up the process and greatly reduce the chance of missing vital evidence.

VIRTOPSY TECH

How is a virtual autopsy carried out, and what equipment is needed?

3D scanning

By combining MRI and CT-scanning technology, it's possible to create a 3D scan of the body. This scan can be used to examine the body with more clarity than a standard autopsy.

Heart-lung machine

During a virtual autopsy, this machine will circulate contrast solutions around the body, allowing clear visualisation of any circulatory problems that may have contributed to death.

How traditional autopsies are performed

1 The Y-incision
The pathologist will perform a Y-shaped incision by cutting from each shoulder to the sternum, then down to the abdomen. This allows access to the major organs.

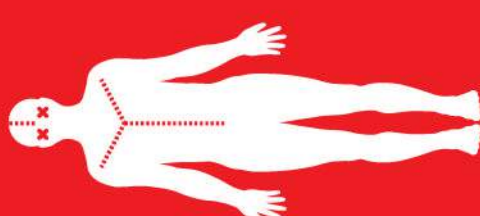
2 Organ removal
All of the body's major organs are removed and weighed for comparison. Blood and DNA samples are obtained and the heart is examined for signs of poisoning.

3 Stomach contents
The stomach contents reveal the deceased's last meal. Time of death can also be calculated by analysing the amount of digestion that has taken place.

"The ability to gather nondestructive findings is a huge benefit of a virtopsy"

High-resolution surface scanner
During an autopsy it's easy to miss a tiny fibre. This machine accurately scans the entire body, providing a detailed picture of what's on the skin's surface.

Computer-supported biopsy
This machine works to choose the best tissue and fluid samples for analysis, which it can then help to analyse once they are collected.



4 Brain examination

The brain is thoroughly examined for signs of injury or abnormality. Often it will be preserved in formalin, which will harden the brain, allowing it to be dissected with greater accuracy.

5 Replacement

After all of the previous procedures have been conducted, the organs will be placed back inside the body cavity and the Y-incision will be sewed up. Samples may be further analysed.

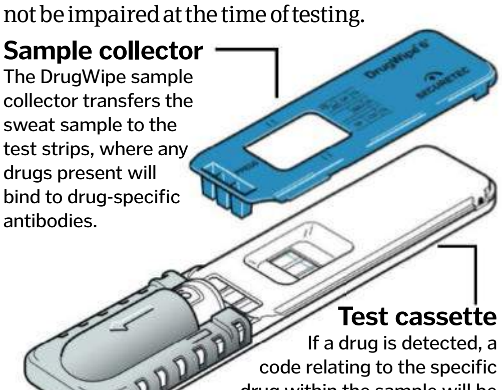
Roadside drug testing

Drugs have the ability to slow reactions, increase risk taking and alter judgement, all of which are detrimental to a person's ability to drive safely. It's important to remember that not only illegal drugs cause problems; people on prescription medication can be just as dangerous if they fail to follow their doctor's guidance.

Drug driving is a frequent problem across the globe. Due to the overall lack of a definitive roadside test for drugs, many users believe they can get away with driving under the influence and tend to be more worried about being caught in possession. The UK and US have relied heavily on a set of impairment tests to detect drug intoxication, but these are unreliable and don't tell you the identity of the ingested drug.

The Securetec DrugWipe can detect up to five substances, including cocaine and cannabis, in a single test using a person's sweat. Results are available after three to ten minutes, making it feasible for police to use the device at the roadside. By using highly specific antibodies, it is able to guarantee reliable drug detection.

A range of other forms of DrugWipe are available depending on what you want to test for. This includes a test for ketamine, which is currently the fourth most popular recreational drug in the UK. Using sweat is a more reliable test of impairment compared to many oral tests. This is because drug deposits can form in the mouth, providing a positive test even though the drug may have been taken days before, meaning the individual would not be impaired at the time of testing.



Sample collector
The DrugWipe sample collector transfers the sweat sample to the test strips, where any drugs present will bind to drug-specific antibodies.

Test cassette
If a drug is detected, a code relating to the specific drug within the sample will be displayed. For example, in the case of cannabis, "CA" would be shown.

FORENSIC HOLODECK RECREATES CRIMES IN 3D

NEW VR TECH WILL HELP JURY MEMBERS VISUALISE CRIME SCENES

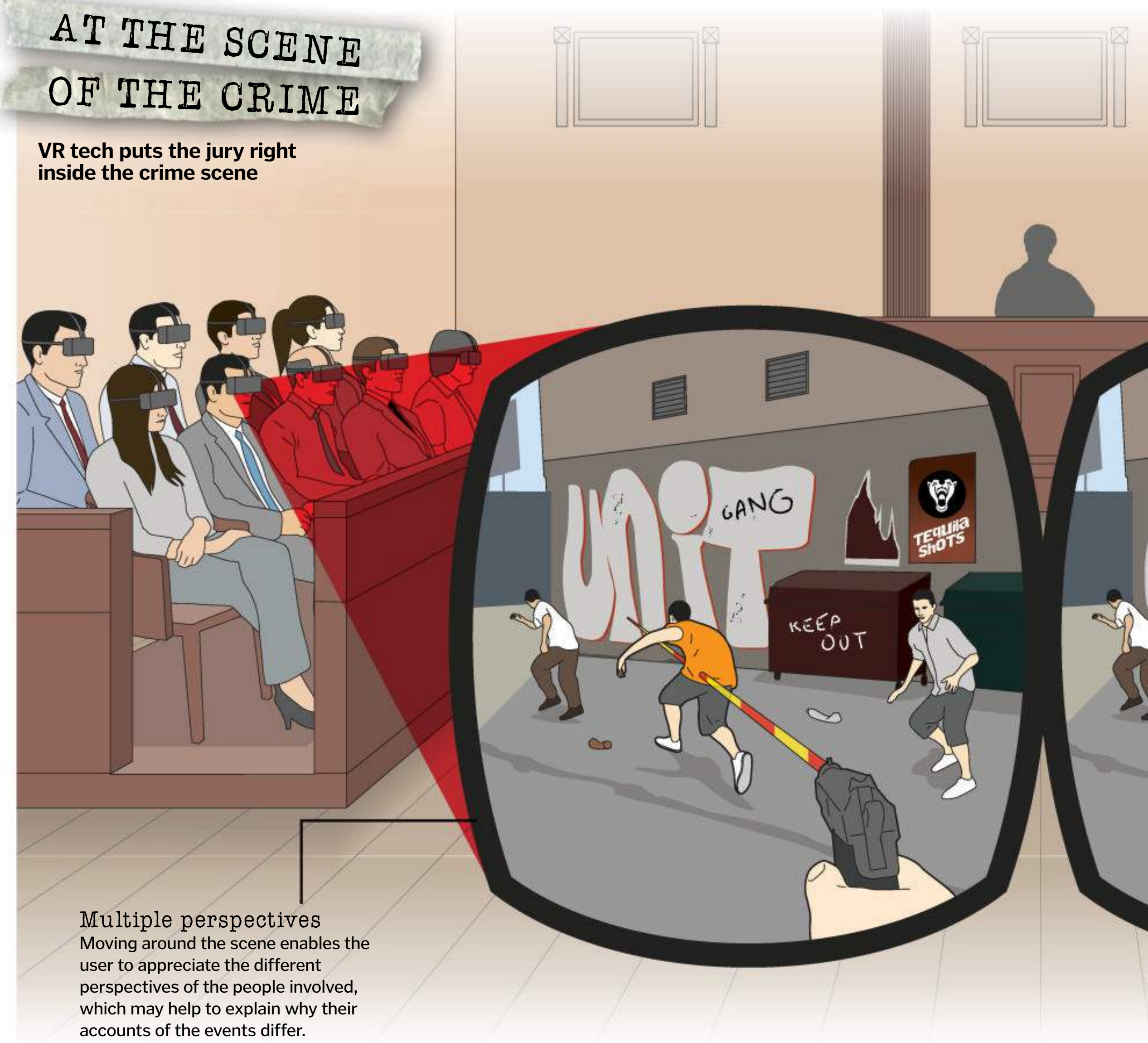
Reconstructing a crime scene is one of the toughest jobs for any forensic scientist. This is particularly apparent when they give evidence in court. It's vital that both the judge and jury are able to develop detailed knowledge of any crime scene, in order to figure out what happened as well as the precise order of events. Without live footage of the scene, this has been incredibly difficult to achieve; photos of the scene and other types of evidence presented to the jury often leave much to the imagination.

By combining MRI, CT, laser-scanning technology, camera footage, eyewitness statements and the virtual reality headset, Oculus Rift, the forensic holodeck has been created. Using this new technology, all members of a courtroom may soon be able to walk through the crime scene in high-resolution 3D. Named after the simulated-reality device featured in *Star Trek*, an advantage of the forensic holodeck is that it can simplify a scene. This can help show exactly the evidence in question, or make particularly violent scenes less traumatic for the jury. Being able to appreciate a particular individual's line of sight is another significant benefit, as this can show whether someone is telling the truth about what they saw, or whether a suspect could be seen by certain individuals.

The Oculus Rift is able to measure the user's orientation in real-time, which allows crime scenes to be viewed with the correct perspective. Originally designed for use in the world of videogames, the Oculus Rift has been modified so that it can measure the user's position with the help of an optical tracker.

AT THE SCENE OF THE CRIME

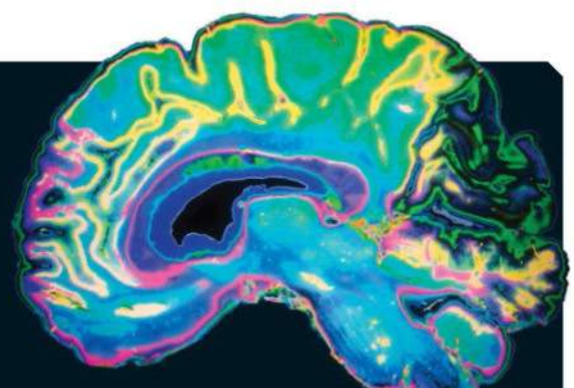
VR tech puts the jury right inside the crime scene



Multiple perspectives
Moving around the scene enables the user to appreciate the different perspectives of the people involved, which may help to explain why their accounts of the events differ.

How lies can be 'seen' in the brain

Researchers claim to have found the gold standard in lie detection, by monitoring the brain with functional magnetic resonance imaging (fMRI). Research has shown that telling lies increases blood flow to the brain, which in turn increases oxygen levels. This increased oxygen level causes the brain to brighten in the fMRI image. Scientists believe this method is much harder to cheat than a traditional polygraph, as the fMRI continually tracks changes in the brain. Polygraphs only measure typical stress responses and link them to the chance of a subject answering untruthfully.



The fMRI will highlight specific areas in the brain to show increased blood flow

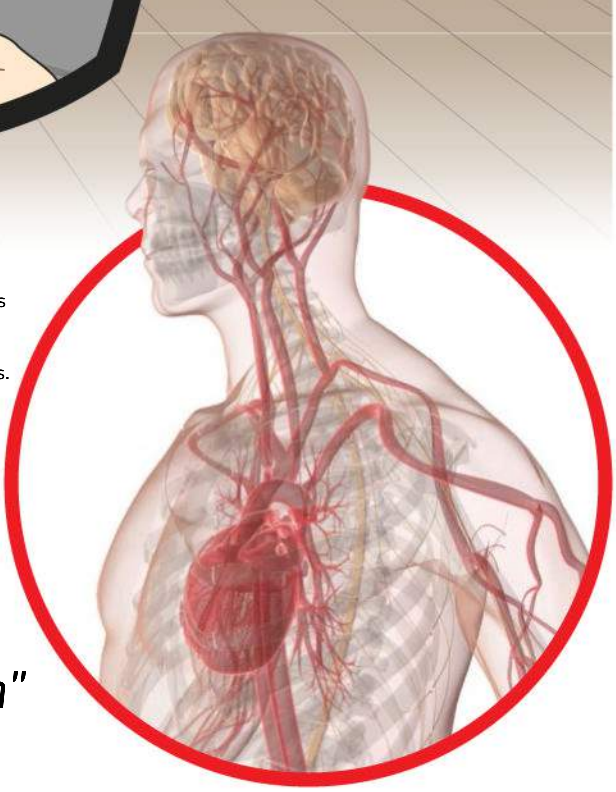
Polygraphs debunked

Polygraphs detect lies by measuring physiological changes, such as blood pressure and sweating. The key to beating them is to answer the control changes strangely. Your control answers are what the polygraph bases your test answers on, therefore by changing your blood pressure, respiratory rate and sweat levels when telling the truth, the polygraph won't be able to detect lies during the test.

Polygraph tests aren't standardised and therefore they lack scientific validity

Bullet trajectories
The red and yellow line shows clearly the bullet's trajectory, revealing how close certain people were to being shot.

Victim location
By moving around the scene, it's possible to appreciate the exact locations of the various suspects, victims and witnesses.



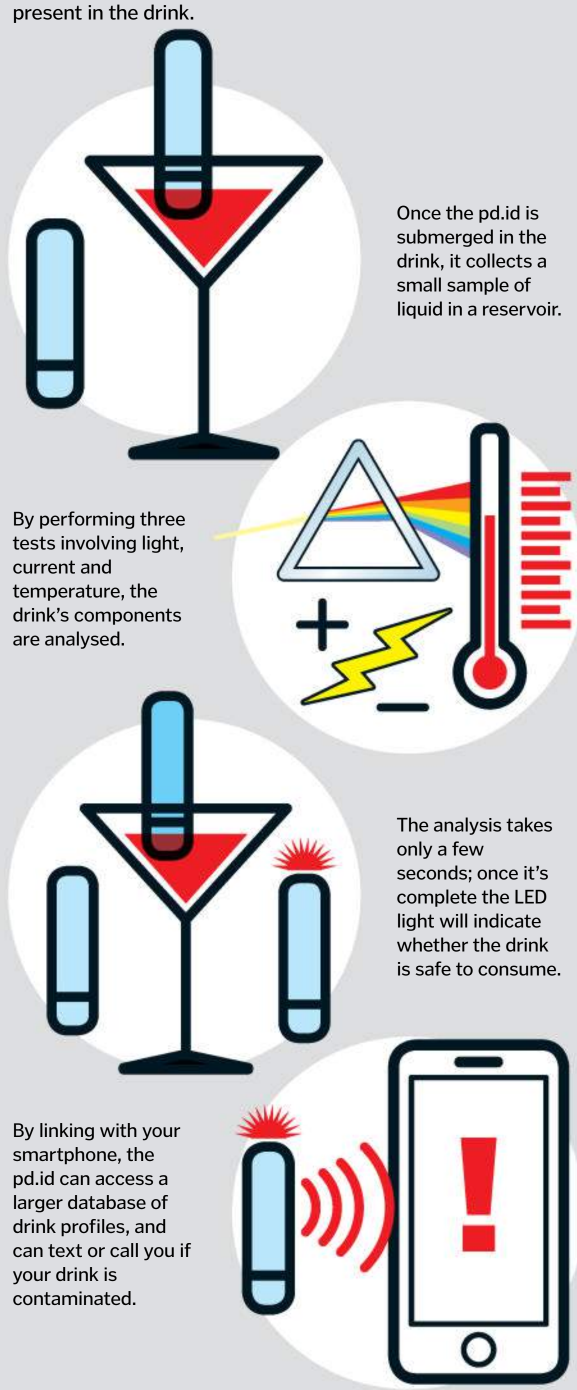
"Telling lies increases blood flow to the brain"

DIY spiking test

How to perform your own forensic analysis to see if your drink has been spiked

Proving someone has had their drink spiked is notoriously hard to do. For many years, claims of being spiked have been met with scepticism, and any symptoms reported by the individual put down to alcohol intoxication. The problem lies in the fact that very little evidence is ever preserved; the drug is often completely metabolised by the time the victim reports the crime and the glass has usually been cleaned or lost.

Similar in shape and size to a USB stick, the Personal Drink Identification Device, or pd.id, aims to let users test their own drink to see whether it contains a common date-rape drug. Operated simply by dipping it into a drink, it can identify whether your drink has been modified in some way, by examining the drink's components. It then compares them to a preloaded database of known substances and drink characteristics, to see whether or not there are any anomalies present in the drink.



Once the pd.id is submerged in the drink, it collects a small sample of liquid in a reservoir.

By performing three tests involving light, current and temperature, the drink's components are analysed.

The analysis takes only a few seconds; once it's complete the LED light will indicate whether the drink is safe to consume.

By linking with your smartphone, the pd.id can access a larger database of drink profiles, and can text or call you if your drink is contaminated.

Planetariums

The incredible theatres where you can explore the night sky and beyond

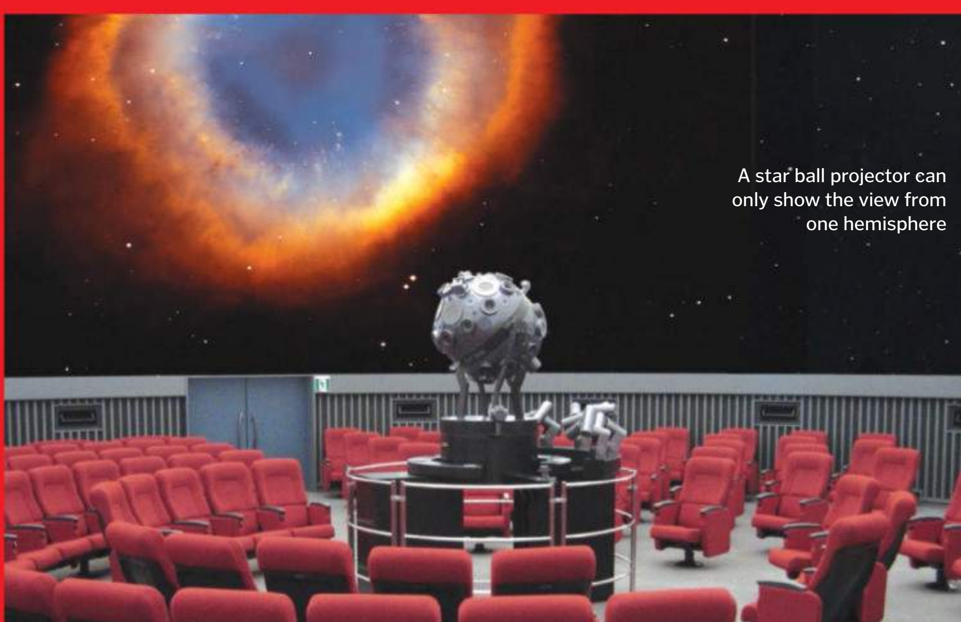
You no longer need to train for several years as an astronaut to explore space, as planetariums can give you an amazing virtual tour of the universe while you keep your feet firmly on the ground. Instead of a big cinema screen at the front of the room, images are projected onto a domed ceiling to create a more immersive experience.

"There's no edge to the screen so it's like you're actually there," says Jenny Shipway, Head of the Winchester Planetarium in the UK. "During a show you shouldn't be aware of the dome at all, the dome should be invisible so your brain can imagine you are actually in this three-dimensional virtual universe."

Early planetariums simply had paintings of the night sky on the inside of the dome to give people a clear view of all the constellations. However, when projectors were developed they could depict moving celestial objects as well as fixed stars, and represent views from different points on the Earth's surface too. Traditional planetariums use mechanical star ball projectors, but they are limited to showing the stars and planets that can be seen from Earth.

The most modern planetariums now use digital projectors hooked up to computers instead, and can project any image onto the dome to show incredible views from anywhere in the universe. Combining data from space agencies, spacecraft and telescopes all over the world, realistic graphical representations of entire galaxies can be projected onto the dome.

"We use software called Uniview and it has a virtual model of the known universe in it", says Shipway. "We use it as a flight simulator. It's literally like playing a computer game; just using a computer mouse you can fly anywhere. You can do a seamless zoom all the way out from Earth right to the edge of the visible universe."



A star ball projector can only show the view from one hemisphere

Star-ball projectors

Some planetariums still use traditional analogue projectors known as star balls. These metal spheres sit in the middle of the audience and have a bright electric lamp inside that shines light through several small lenses surrounding it. The lenses are used to represent stars, focusing light onto the planetarium dome to recreate the night sky as it can be seen from Earth. Single star balls are often fixed at one end so can only show the view from one hemisphere. However, many projectors feature two star balls attached together in a dumbbell-shaped structure so that they can represent the view from anywhere on Earth. Additional moving projectors can also be attached to show moons, planets and other moving celestial objects. The main limitation of star-ball projectors is that they can only show the view from Earth, while digital planetariums let you explore the far reaches of the universe too.

Inside a modern planetarium

How several projectors work together to create one seamless image

Seamless screen
The perforated aluminium panels are very thin, making the joins almost invisible.

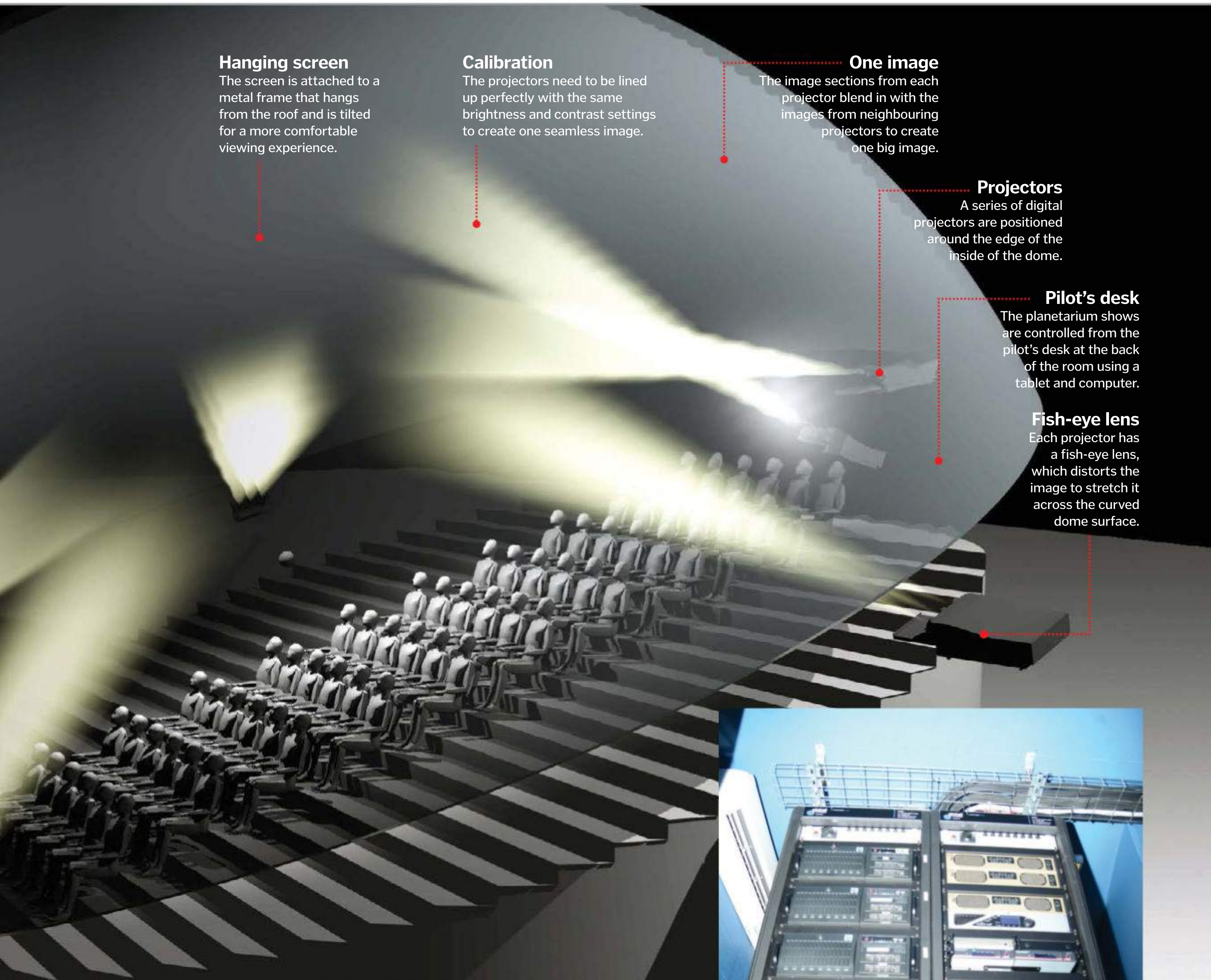
No echoes
The screen panels are made from aluminium perforated with tiny holes to let sound pass through, instead of bouncing around the dome.

Anti-reflective
The screen is painted grey to reduce reflections from the bright lights of the projectors.

Mechanical curtains
Each projector only shows a section of each frame, using mechanical curtains to block out the rest.

Learn more

Download the free **How It Works: Great Days Out** app onto your iPhone or iPad to find a planetarium near you, as well as many other fun and educational places to visit.



Hanging screen
The screen is attached to a metal frame that hangs from the roof and is tilted for a more comfortable viewing experience.

Calibration
The projectors need to be lined up perfectly with the same brightness and contrast settings to create one seamless image.

One image
The image sections from each projector blend in with the images from neighbouring projectors to create one big image.

Projectors
A series of digital projectors are positioned around the edge of the inside of the dome.

Pilot's desk
The planetarium shows are controlled from the pilot's desk at the back of the room using a tablet and computer.

Fish-eye lens
Each projector has a fish-eye lens, which distorts the image to stretch it across the curved dome surface.

Reclining seats make it much more comfortable to view the action overhead

A main server controls the footage displayed by the projectors

Plugs from around the world

Learn why we are unlikely to see a universal plug any time soon

If you ever plan on charging your laptop abroad, be sure to check before you travel – many countries don't have a national standard of electrical outlets so you could find yourself grappling with as many as six different plugs and sockets!

As travelling became affordable to the masses, the problem of using the correct plug for our electrical devices from home started to grow. In an age where technological advancements continue to amaze, it seems bizarre that we cannot introduce a plug we can use globally.

Why so many countries have different plugs is mainly down to the fact they prefer to develop their own standards. Harvey Hubbell designed a "Separable Attachment-Plug", which allowed non-lighting devices to use a light socket for power. This was adapted and refined to create a three-pronged plug which included the addition of a grounding wire to provide protection from electric shocks.

Throughout the early-1900s, inventors around the world were creating their own version of this pioneering plug. During this period, international plug compatibility was not of concern, as electronics hadn't reached many parts of the world. With every country having different historical circumstances, the plug came in at different times where different technologies were available. Even as recently as the 1950s, the UK was developing a plug with no consideration for the rest of the world.

The question on any frequent traveller's lips is, "when will we see a universal plug?" At the moment, the consensus is never. Although it would make sense, the motivation for countries to pay for a universal plug is very low, considering they have all invested heavily in their own systems. Moreover, there would be an inevitable interim period where multiple plug standards would exist within one country, which we know from experience to be dangerous. Even if countries decided to adopt a standard plug system, at least two standards would have to exist – a 110-volt flat plug along with a 240-volt round plug. However, two would be a vast improvement on over a dozen types globetrotters currently have to deal with.

Type K

Found in Denmark and Greenland, the type K has an unusual, U-shaped earth pin. It is thought the type K will soon be a thing of the past because Danes regularly import appliances from the rest of Europe that are fitted with the more widely used type F plugs.

Type A & B

The type A is fairly standard across most of North America. The two blades are of different width and the plug is not grounded. Type B has a third, rounded prong for grounding. Most North American sockets are now compatible with both types.

Type L

The usage of type L plugs is rather sporadic; these plugs only crop up in Italy, Chile and North Africa. The type L is atypical as it is a symmetrical three-pronged plug. It is possible to insert it in either direction, as it is unpolarised.

Type N

The type N, found in Brazil, is the plug suggested by the International Electrotechnical Commission (IEC) to be used around the world as a universal plug. Until the type N arrived, Brazil was using an incredible ten different types of plug.

DID YOU KNOW? *The copper shortage after WWII forced Britain into designing a new plug, which is still in use today*

Type G

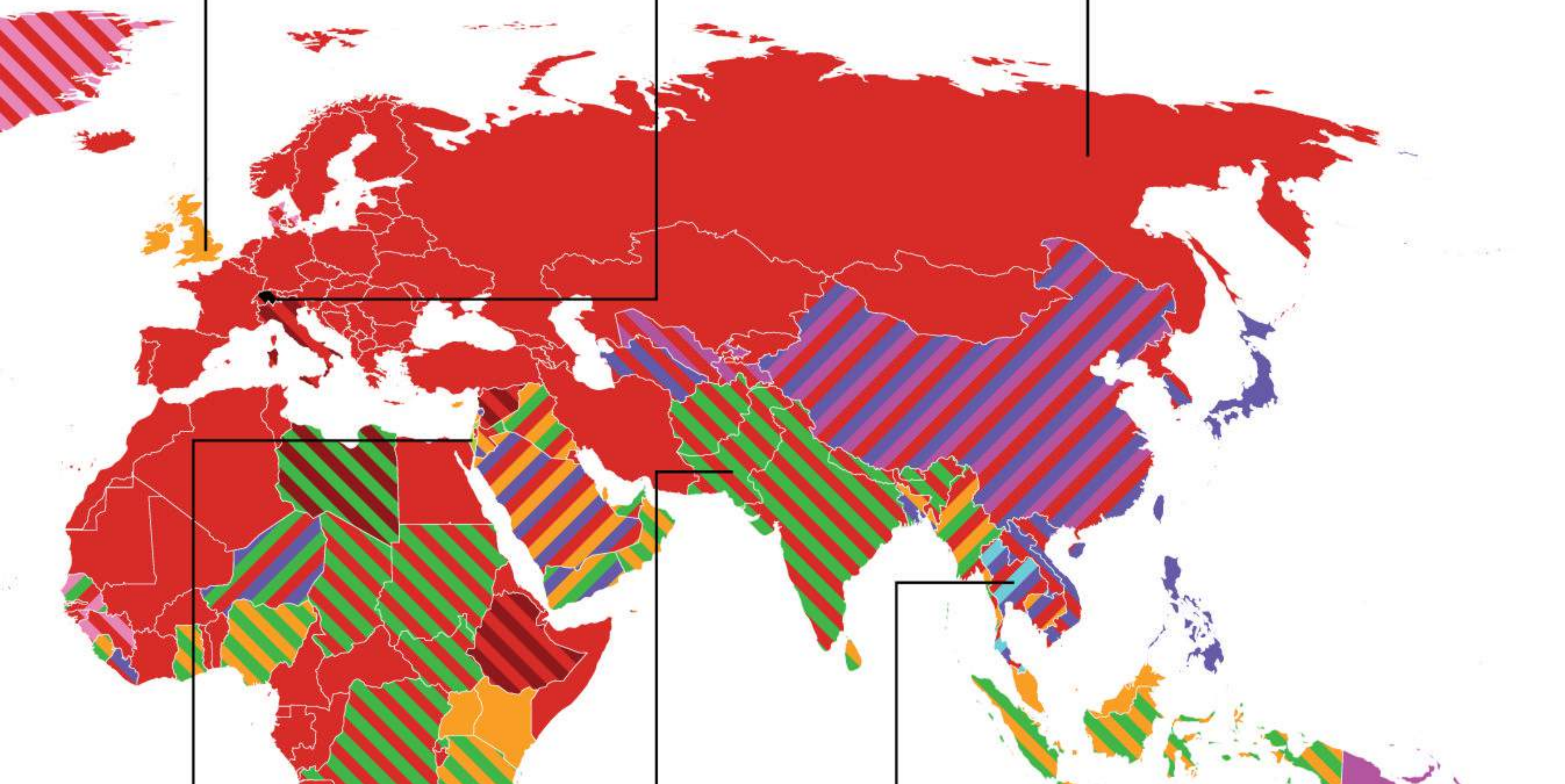
Type G plugs are synonymous with the United Kingdom, but are also found in other countries such as Singapore. This has three rectangular prongs. The type G is one of the safest kinds of plug in the world, but has the downside of being bulky.

Type J

This plug type is found in Switzerland and Liechtenstein, although Switzerland has their own standard, the SEC 1011. It's structurally similar to type C, other than its additional grounding pin. A type J socket will accept a type C plug perfectly.

Type C, E and F

All three of these plugs operate in the 220 to 240-volt range. Type C is credited with being the most widely used international plug. Type E is found in France and Belgium. Type F is found across Europe, and was designed in Germany after WWI.



Type O

The type O was created in Thailand in 2006, and is still being phased in. Why Thailand decided to design and implement a new type of plug when multiple alternatives already exist is a mystery, and highlights the difficulties of adopting a new standard.

Type H

The type H is unusual as it is used solely in Israel. Originally, it was three flat prongs in a V-shape, but since 1989 this design has been phased out in favour of three circular pins. The Type H socket will also accept type C plugs.

Type D & M

The type D is mainly used in India but is compatible with type C sockets. This plug was the standard in Great Britain before 1947. Type M is found in South Africa and is a three-pin, grounded plug. It requires 220 to 240 volts and looks like a type D with larger pins.

Type I

The type I is found in Australia and New Zealand, and is available in a two or three-pronged option. This type was favoured over the UK's type G because Australian manufacturers could produce flat pins more easily than round ones.

Faster 3D printing

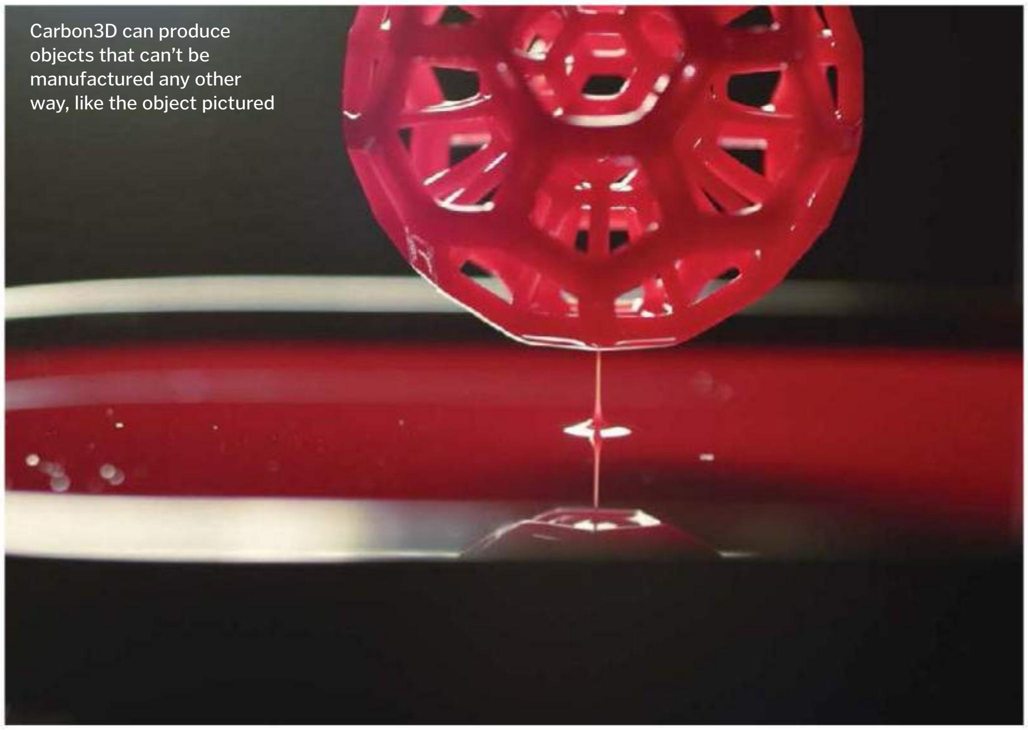
Inspired by *Terminator 2: Judgement Day*, the creators of Carbon3D aim to revolutionise 3D printing

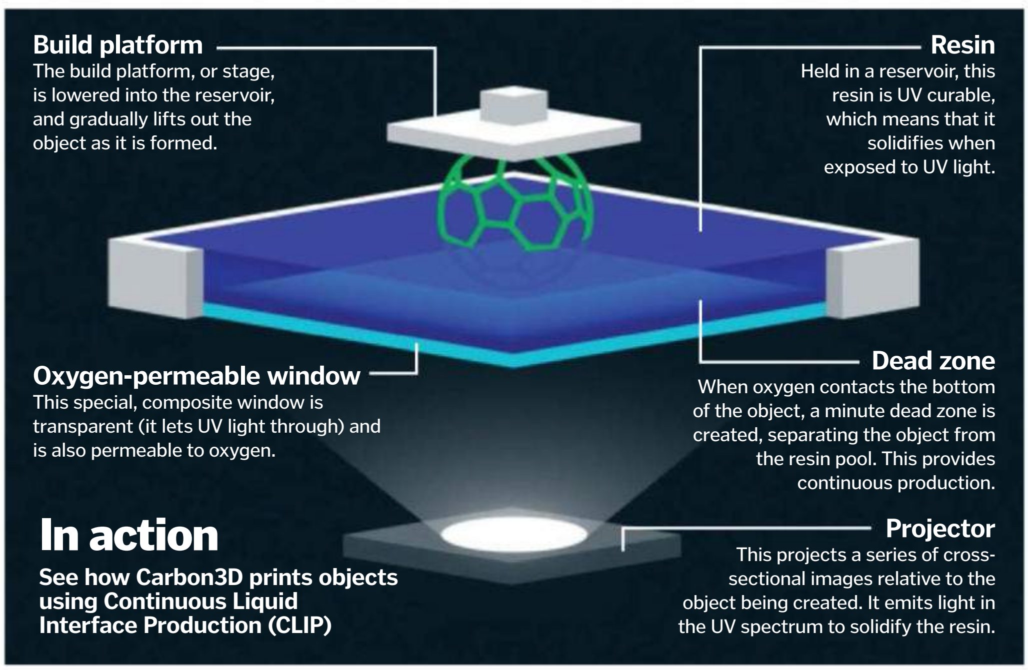
The inventors of Carbon3D argue that traditional 3D printing is a misnomer. This process is actually just repeated 2D printing, which creates a 3D object as the layers build up. Traditional 3D printing also has a number of limitations. It is a lengthy process, often taking hours to produce a single object. The materials you can use are extremely limited, and the objects produced are often mechanically weak. These problems are the reason 3D printing is yet to be widely employed in mass production.

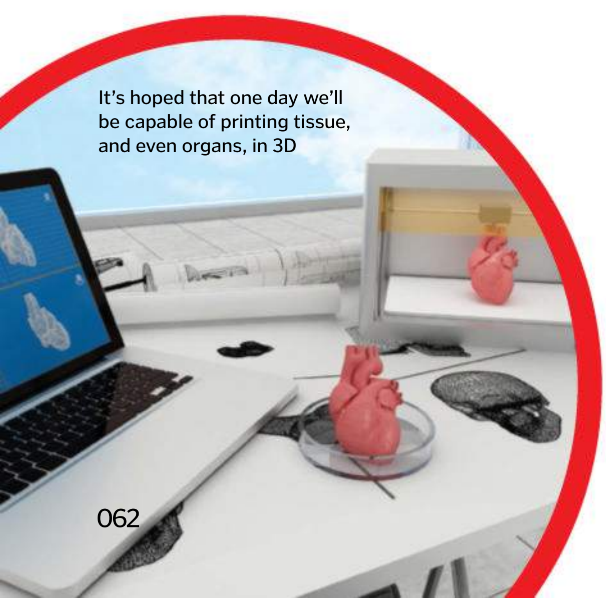
Carbon3D's creators believe their technology will change 3D printing forever. It's capable of producing objects between 25 and 100 times faster than traditional techniques, working in minutes rather than hours. Carbon3D utilises the properties of light and oxygen to 'grow' parts from a liquid resin. Light and oxygen, in this case, work as polar opposites. Light converts the liquid resin into a solid, whereas oxygen stops the resin from solidifying.

By harnessing these properties, the mechanical steps and layers seen in traditional 3D printing are eliminated, producing a smooth, structurally sound object. The real innovation lies in the 'window', which enables the oxygen flux to be controlled, creating a layer between the window and the object called a 'dead zone'. This area enables the object to be continuously grown from the resin.

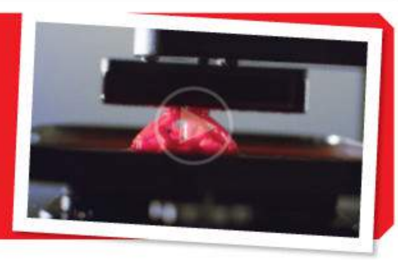
With continued research and refinement, the creators of Carbon3D hope to see their technique used to mass-produce objects. They also believe that they will be able to offer personalised medicine by producing parts designed to work for individuals, such as small tubes used for widening arteries known as stents.


Carbon3D can produce objects that can't be manufactured any other way, like the object pictured




It's hoped that one day we'll be capable of printing tissue, and even organs, in 3D

AMAZING VIDEO!
Watch this amazing video to see how Carbon3D printing works
www.howitworksdaily.com



© Dreamstime

New BMX technology

How tech taken from drones is helping BMX riders log their best times

Riders can immediately assess their performance after completing a lap of the track

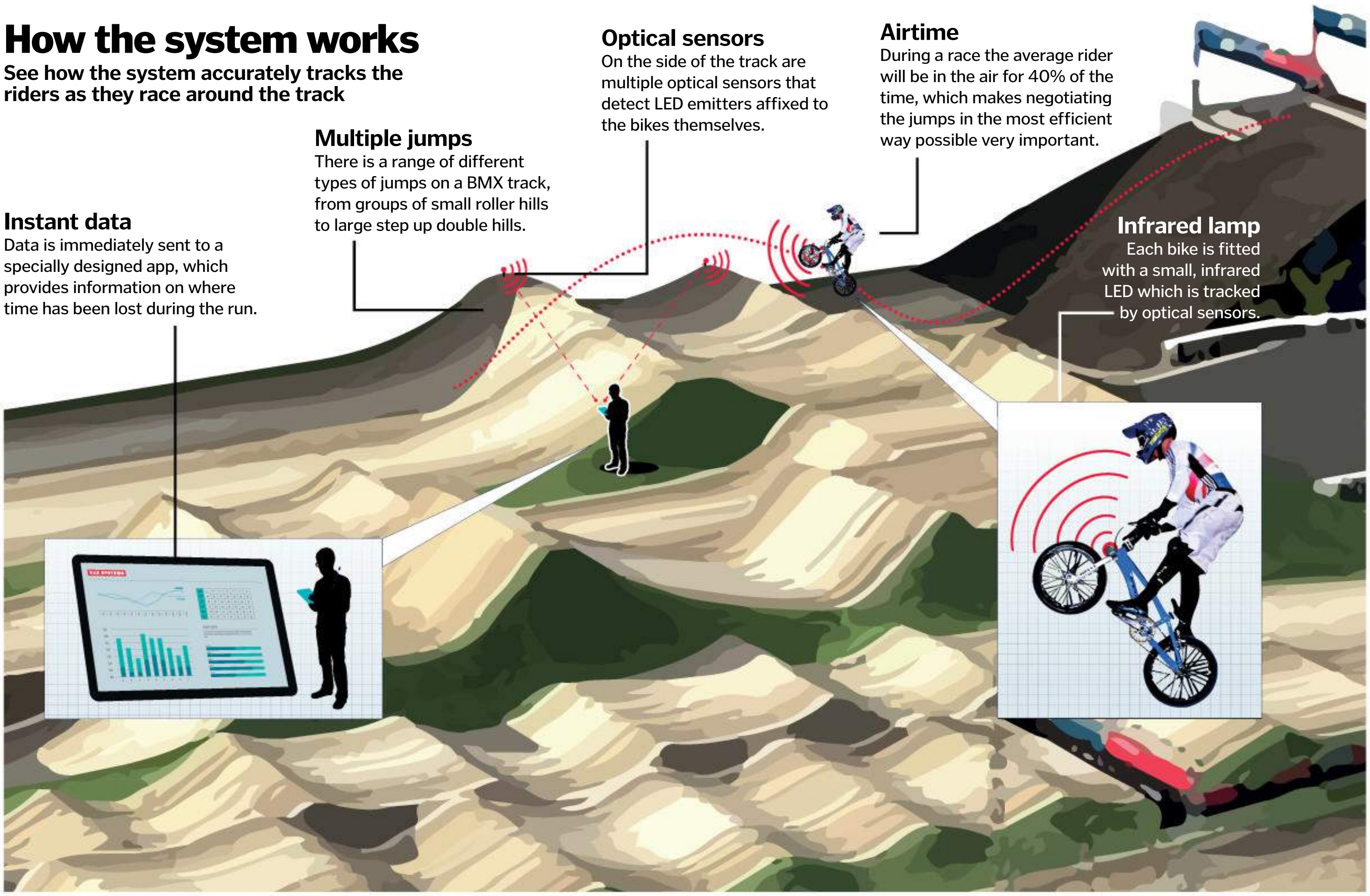
Ahead of the Olympics in Rio next year, Great Britain's BMX team are tirelessly training to give themselves the best chance of medalling. Every millisecond counts in events such as this, which has led the team to seek help from BAE Systems to see if their advanced tech can help them beat their personal best times.

BAE Systems offered a drone from their "sense and avoidance" system, which has been trialled as part of the Autonomous Systems Technology Related Airborne Evaluation & Assessment (ASTRAEA) programme, focusing on tracking objects in the sky. They adapted this technology to provide real-time data of a BMX rider's speed and trajectory, with more accuracy than had been possible before. The riders travel at high speeds during the race, in the region of 40 kilometres (25 miles) per hour. Maintaining these high speeds for as long as possible is vital; it's hoped that the precision of this technology will enable the riders and coaches to see exactly where time and speed is being lost.

The data collated during each run can be used to compare different riders with one another, which can identify what each rider does well and where they could make marginal gains. Prior to the use of this technology, only the overall time of the run was used. Now, the riders are able to review how their speed fluctuates during the run, especially over the multiple jumps.

How the system works

See how the system accurately tracks the riders as they race around the track



Smartwatch

Discover how the latest must-have gadget has been developed over the last 75 years

The smartwatch might seem like a brand new invention, but it has actually been around in some form or another for decades. The inspiration for a wrist-based device that could do more than just tell the time is often credited to fictional detective Dick Tracy. A two-way wrist radio first featured in the comic strip in 1946, but by this time the first real-life multi-functional wearable device had already appeared on the scene. Early smartwatches were typically timepieces that doubled as calculators, but as technology developed, more features were added to provide for data storage and wireless connectivity to a phone or PC. Modern smartwatches, such as Samsung's Galaxy Gear and the Apple Watch, can now host apps, monitor your heart rate and even pay for your shopping. Over 373 million smartwatches are expected to have been shipped all over the world by 2020, but we can only speculate about the sort of features these high-tech timepieces will have as we enter the next decade.

27 million smartwatches are expected to be shipped in 2015

Measuring your heart rate

Talk about wearing your heart on your sleeve; the Apple Watch can measure your heart rate continuously during a workout. It then uses this information to estimate how many calories you have burned and stores all this information in the Health app. The watch uses green LED lights paired with light-sensitive photodiodes to sense the amount of blood flowing through your wrist. It works because blood reflects red light and absorbs green, so when your heart beats, the green light absorption is greater than in between beats. The LED lights are flashed hundreds of times per second, so the watch can work out exactly how many times your heart beats each minute.

1941 Calculate

The first watch to do something other than tell the time was the Mimo Loga. This slide-rule watch had moveable logarithmic tables that enabled the wearer to make basic calculations when on the go.

1972 LED display

The Hamilton Watch Company made the first electronic digital watch, the Pulsar, with an LED display and 18-carat gold body. In 1975, they also released the first electronic calculator watch.

1980s Storage

The first watches that could store information included the Seiko D409 with 112- bytes of memory and Casio's Databank series of watches that featured tiny keyboards.

1995 Synced up

The Timex Data Link was the first watch to be able to wirelessly sync with your computer. Special software on your PC flashed in a particular pattern that the watch could translate into data.

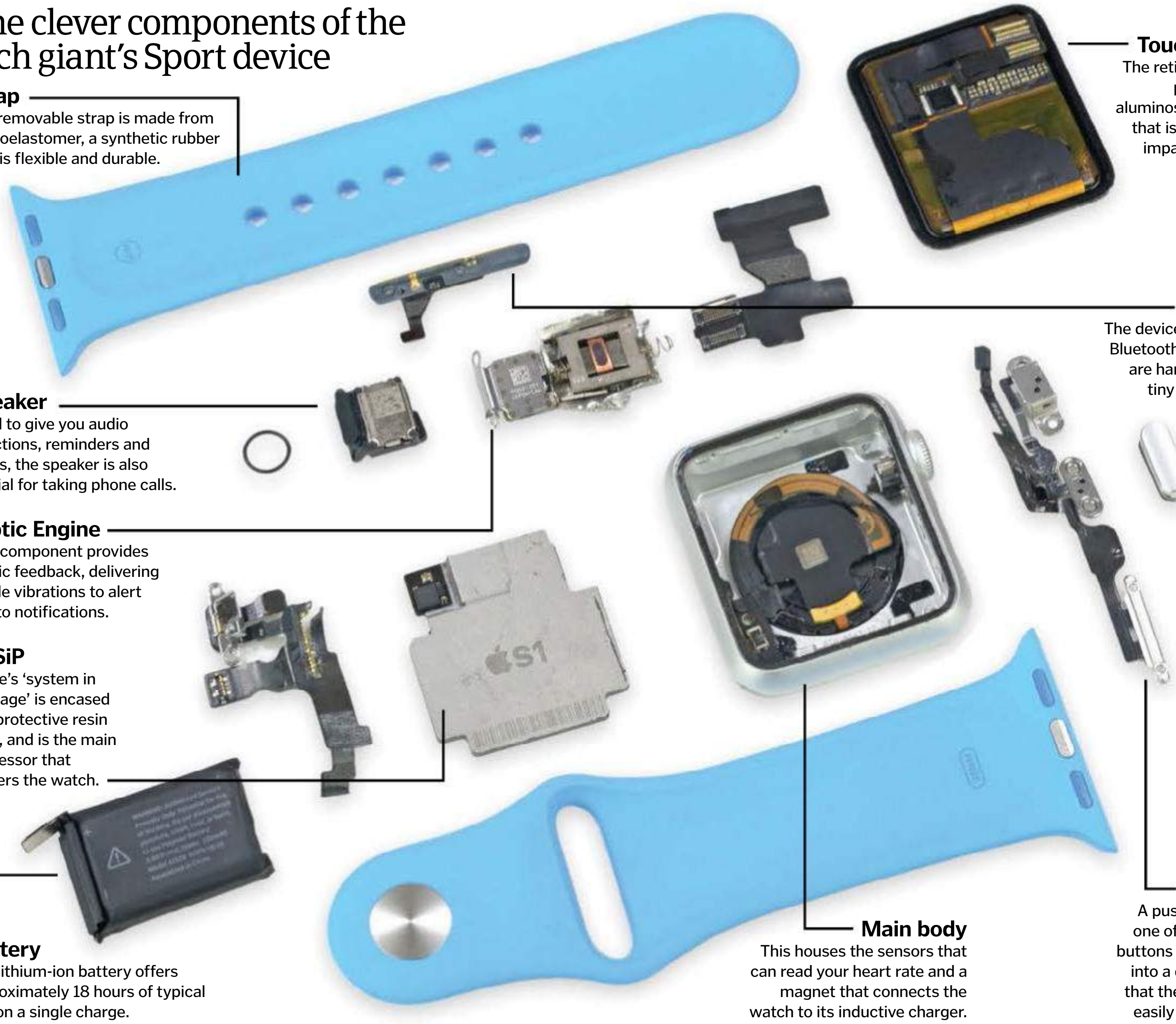
1940s | 1970s | 1980s | 1990s

SMART WATCH TIMELINE

Explore the evolution of the technology that you thought was brand new

Inside the Apple Watch

The clever components of the tech giant's Sport device



Strap
The removable strap is made from fluoroelastomer, a synthetic rubber that is flexible and durable.

Touchscreen
The retina display is protected by aluminosilicate glass that is scratch and impact resistant.

Antenna
The device's Wi-Fi and Bluetooth capabilities are handled by this tiny component.

Speaker
Used to give you audio directions, reminders and alerts, the speaker is also crucial for taking phone calls.

Taptic Engine
This component provides haptic feedback, delivering subtle vibrations to alert you to notifications.

S1 SiP
Apple's 'system in package' is encased in a protective resin shell, and is the main processor that powers the watch.

Battery
The lithium-ion battery offers approximately 18 hours of typical use on a single charge.

Main body
This houses the sensors that can read your heart rate and a magnet that connects the watch to its inductive charger.

Encoder
A push or twist of one of the watch's buttons is converted into a digital signal that the S1 chip can easily understand.

2000
Run Linux
The IBM Linux Watch and WatchPad 1.5 were the first devices to run the Linux operating system. The latter also featured a touchscreen, a fingerprint scanner and Bluetooth.

2004
FM signals
Microsoft's Smart Personal Object Technology (SPOT) watches were released. They received FM radio broadcast signals to display news and weather updates.

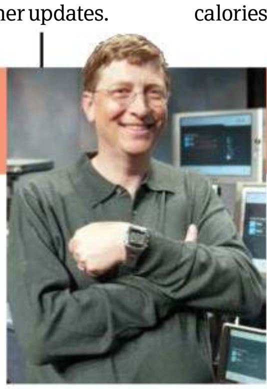
2006
Keep fit
The first sports watch/wearable fitness tracker was Garmin's Forerunner with built-in GPS and the ability to track speed, distance, pace and also calories burned.

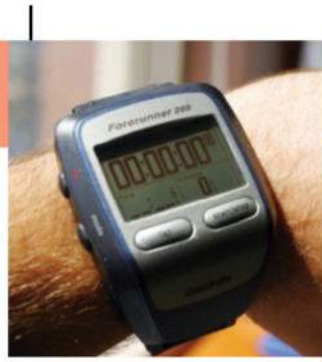
2009
Added SIM
Samsung's S9110 watchphone featured a SIM card so could be used to make calls and texts, and play music. It was also the slimmest device of its kind on the market at just 11.98mm (0.47in) thick.

2013
The Pebble
After a successful Kickstarter campaign that raised over £6.5 million ($10 million), the Pebble Watch was released. It has an e-paper display and is compatible with both iOS and Android smartphones too.

2015
Apple Watch
Following the release of various Android smartwatches, such as the Samsung Galaxy Gear, Apple's highly anticipated smartwatch went on sale with 38 different versions available for sale.

2000s





2010s>

What is 5G?

How the next generation of mobile communication could help to connect us, our homes and our cars

Many of us don't even have access to the 4G mobile network yet, but already the race is on to develop 5G. With demand for mobile data doubling each year, this fifth-generation technology will soon be required to satisfy our ever-increasing need to browse the web and stream online content on our mobile devices. It will also be needed to connect the technology of the future, such as driverless cars, smart cities and the 'Internet of Things' – a network of everyday objects that communicate with each other.

Although some parts of the world are expected to have 5G as early as 2018, the technology behind it hasn't actually been fully figured out yet. Some companies are looking to build on existing technologies, simply making 4G radio frequencies faster. Others believe the entire radio network will need to be restructured. For example, one promising concept for 5G involves using high-frequency millimetre-waves and a series of base stations connected to buildings and lampposts.

What we do know is that 5G will be incredibly fast. It's expected to be about 100 times faster than 4G, allowing you to download an entire film in under a second. Latency – the time it takes for data to start transferring – will be greatly reduced, meaning the video you want to stream will start instantly when you press play. 5G will also have a much larger capacity, enabling more users to access the network at once and potentially bringing an end to those restrictive data limits imposed my mobile operators.

> "It's expected to be approximately 100 times faster than 4G"

Of course, your current mobile phone is unlikely to work with any future 5G network, as it will probably need new hardware and software to support it. However, by the time 5G becomes available, you will probably have upgraded your handset anyway and manufacturers are guaranteed to kit out their newer models with the most up-to-date technology.

How 5G could work

Transmitting data from lampposts and cars in the towns and cities of the future

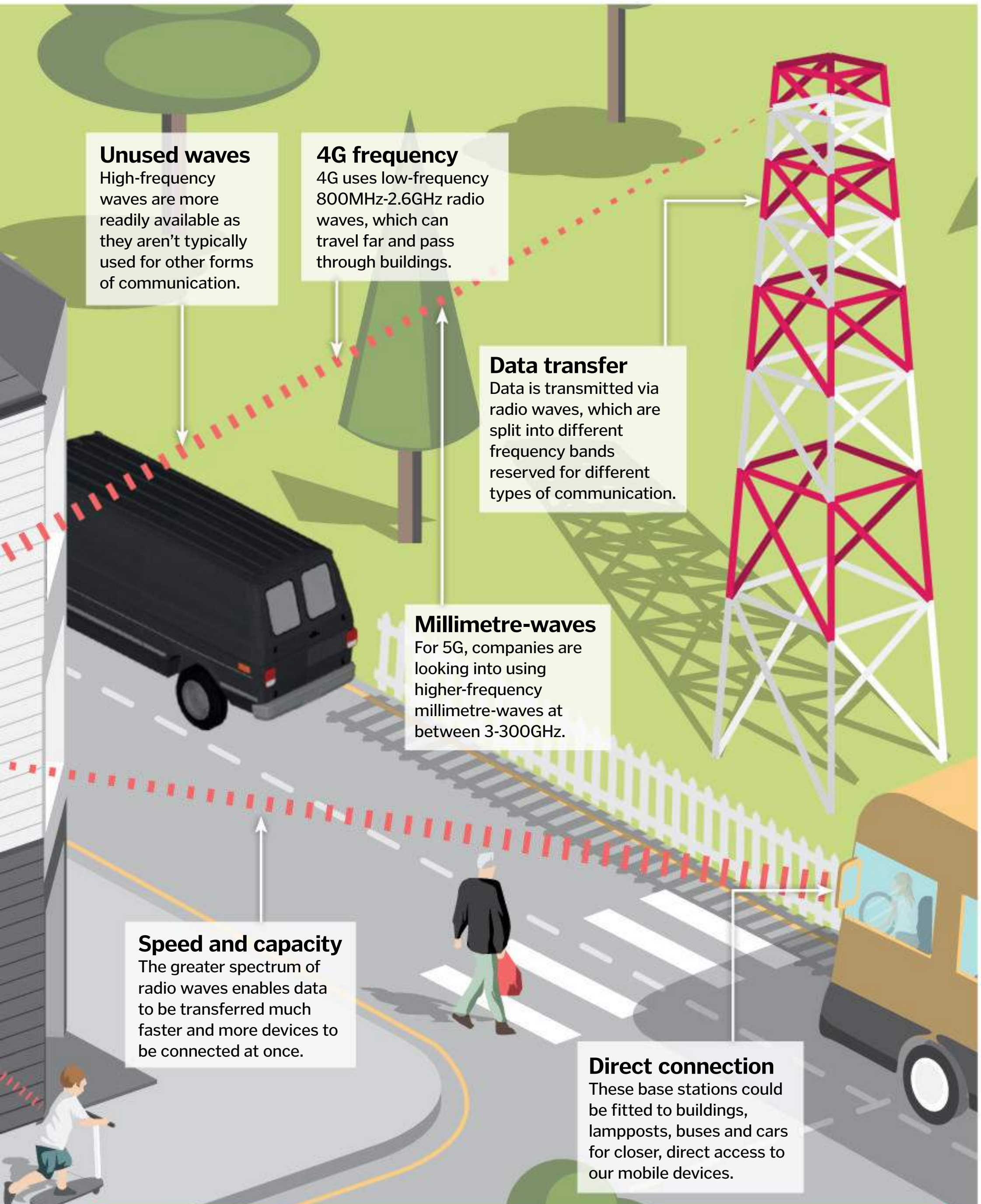
Small base stations
To overcome the short range of the signals, lots of small base stations will be needed to pass on the radio waves of larger masts and dodge buildings.

Personal connection
Each base station would contain hundreds of antennas packed together, potentially one for each nearby mobile device.

Supply and demand
The base stations could also share data between themselves, working out how much each user needs and distributing it accordingly.

Shorter reach
Higher-frequency waves don't travel as far and struggle to pass through buildings, causing a signal drop.

Learn more
To keep up to date with the latest developments in 5G mobile communication, visit **www.5g.co.uk**. The website will be updated with news, guides and events as new information on the tech becomes available.



Tokyo's 5G stadium


Tokyo's futuristic-looking Olympic Stadium could host its own 5G network

In the race to develop 5G, it seems most companies are setting global sporting events as their finish line. Samsung hopes to launch a temporary 5G network in time for the 2018 Winter Olympic Games in South Korea, while Huawei is aiming to trial 5G at the 2018 FIFA World Cup in Moscow. However, it's Japan that's hoping to play host to the world's first commercial 5G network, just in time for the 2020 Olympic Games in Tokyo. The Japanese government has invested in several local companies to develop the next generation of mobile technology, and plans to implement it into its Olympic Stadium. It is hoped the planned 80,000-seat venue will feature several small base stations, providing each spectator with a whopping one gigabit per second of data-transfer speed. This will make it possible for everyone to share their opinions, photos and videos from the games in real-time.

5G plans

Professor Rahim Tafazolli from the 5G Innovation Centre (5GIC) explains the current outlook for the next generation of mobile networks.

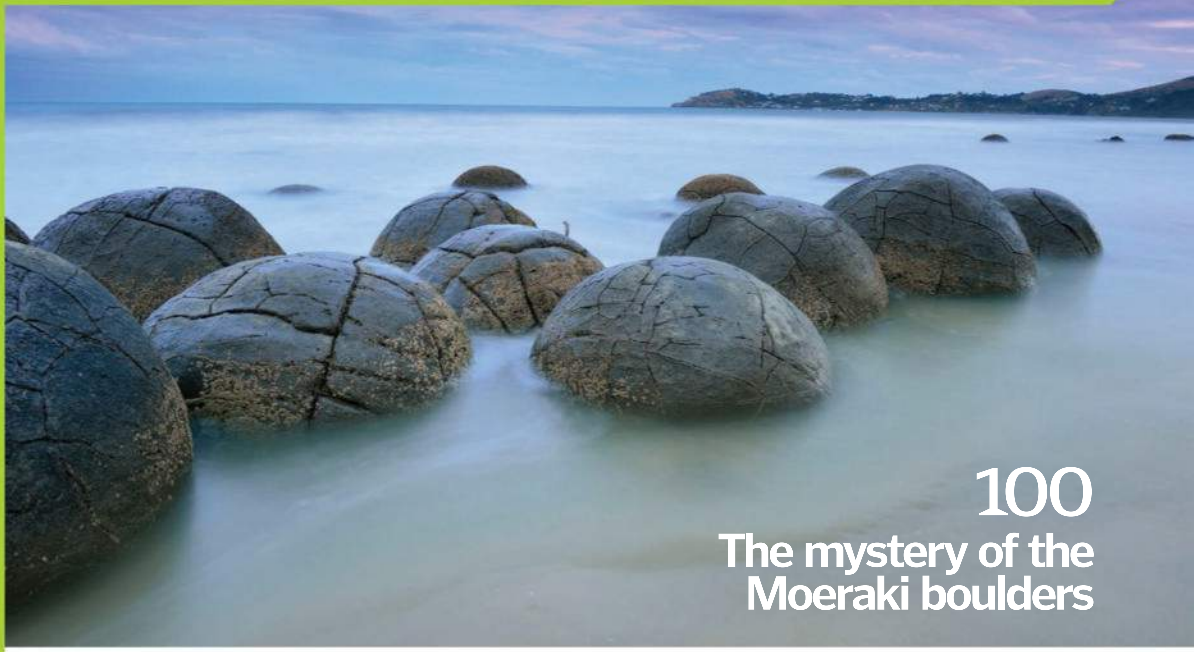
Why is there a need for 5G?
5G will be fully focused on users and their needs, unlike previous mobile communication networks. The aim will be to give the user the impression of infinite capacity and availability while juggling available resources. Two ways of achieving this will be to predict user demand better so that applications perform bandwidth-heavy tasks when the network is least loaded – optimising network response times where needed using a measure known as 'latency' – and to make better use of all available wireless networks.

What problems need to be overcome in developing 5G?
In developing the 5G network there will be a pressing need to reduce end-user costs: given that data requirements may grow up to a hundred-fold, monthly bills cannot increase by the same amount if emerging technologies are to be accessible for mainstream use. Reducing energy consumption will be another key focus, both in order to lessen emissions and to improve end-user benefits such as enabling longer battery life and providing innovative energy solutions for wearable devices.
One result will be that in the future, there will be a wide range of business models – for example, as well as paying operators to provide us with coverage, we may be able to charge others for the coverage we provide with our Wi-Fi routers or femtocell home-base stations.

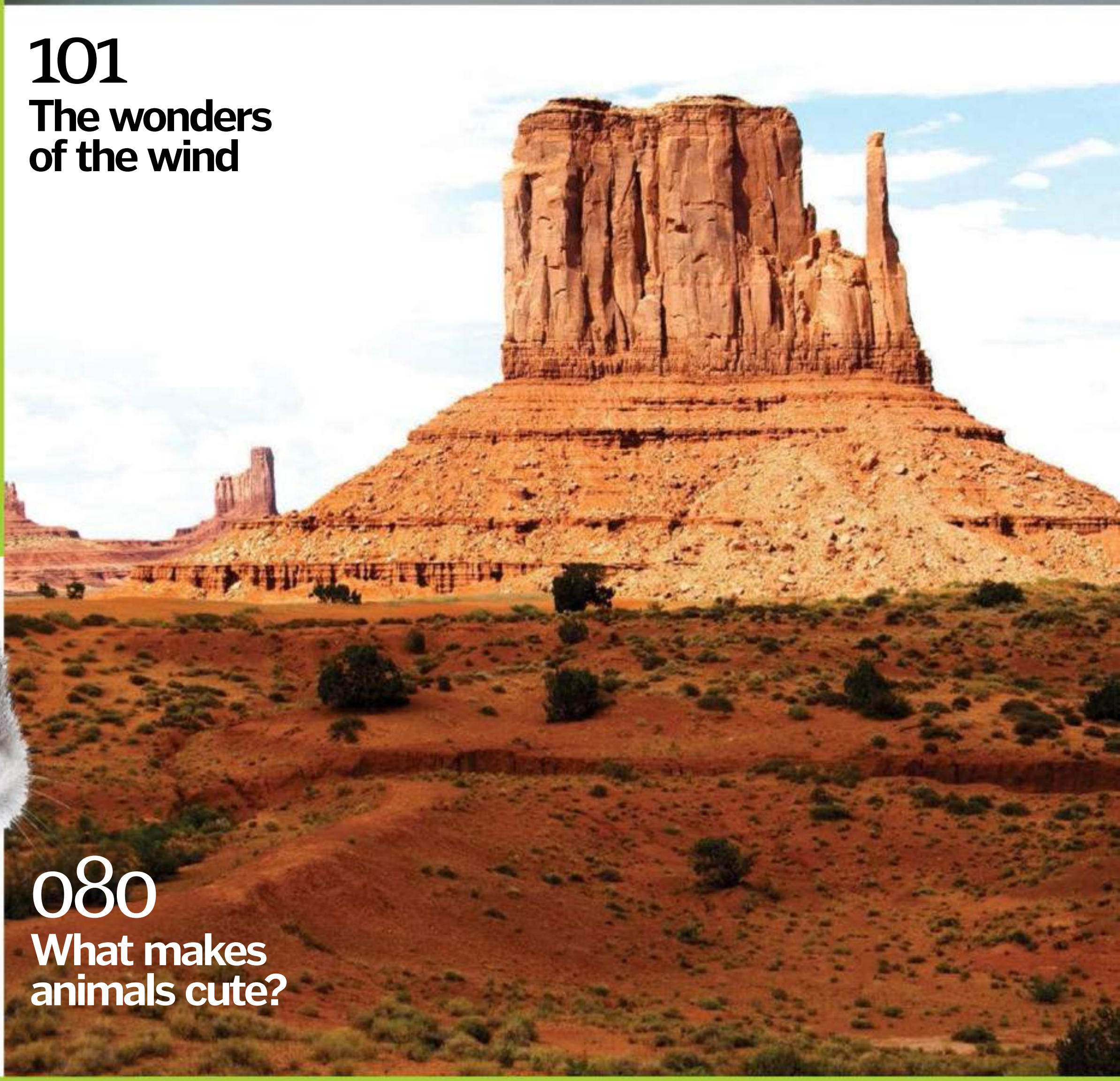
What will be the main benefits of 5G?
5G won't be simply a new network like 2G, 3G and 4G were. It will be a heterogeneous network (HetNeT) that will provide wireless coverage in an environment with a wide variety of wireless zones, ranging from an open outdoor environment to office buildings, homes and underground areas. In particular, the network and devices will decide how to use the access networks available in that location (2G, 3G, variations of 4G, Wi-Fi, small cells, wide-area mobile etc) and different frequency bands in order to deliver sufficient capacity to all active users so that they have the impression that the capacity is always sufficient.


5GIC at the University of Surrey is the UK's centre for 5G research and development

ENVIRONMENT

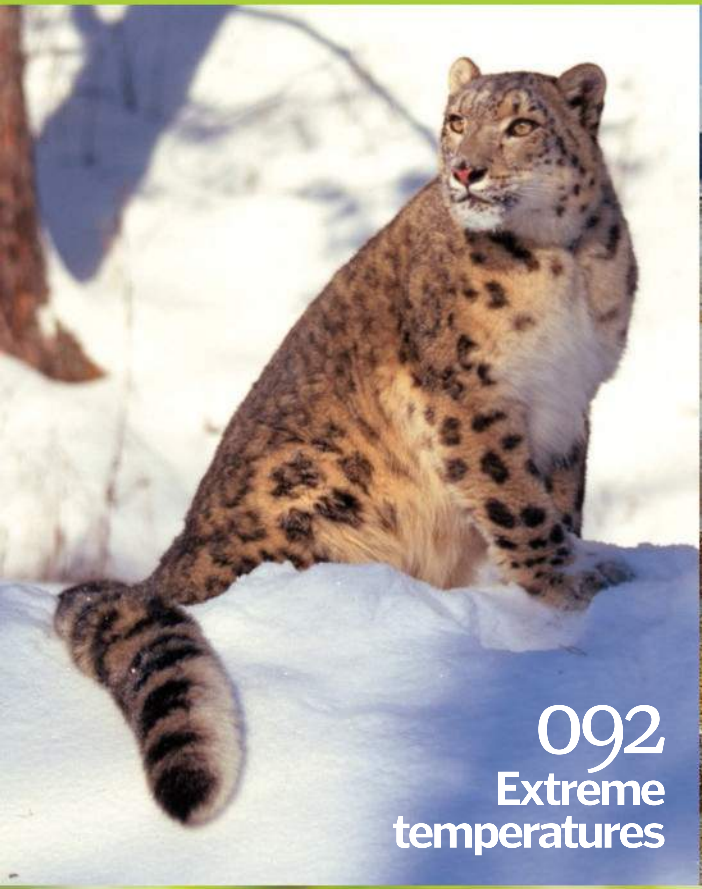


100
The mystery of the Moeraki boulders



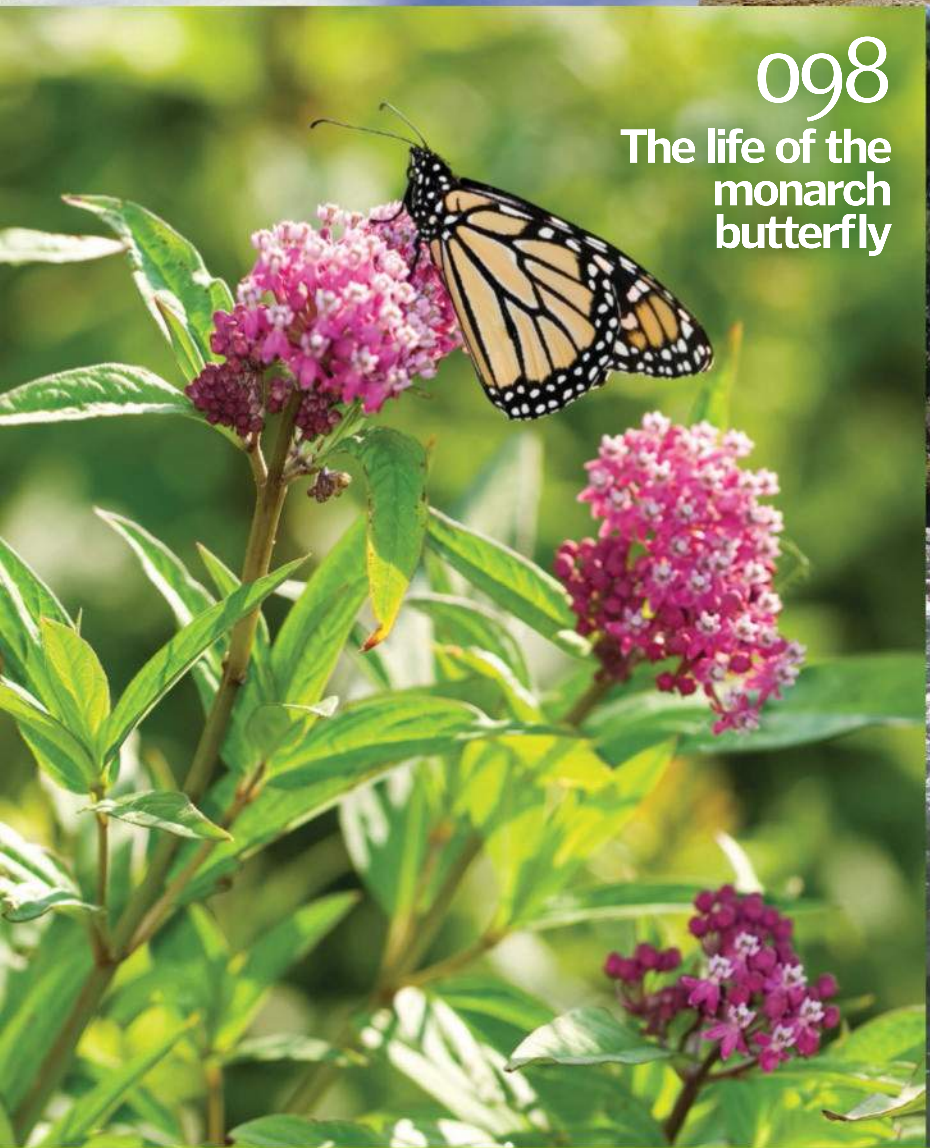
101
The wonders of the wind

080
What makes animals cute?

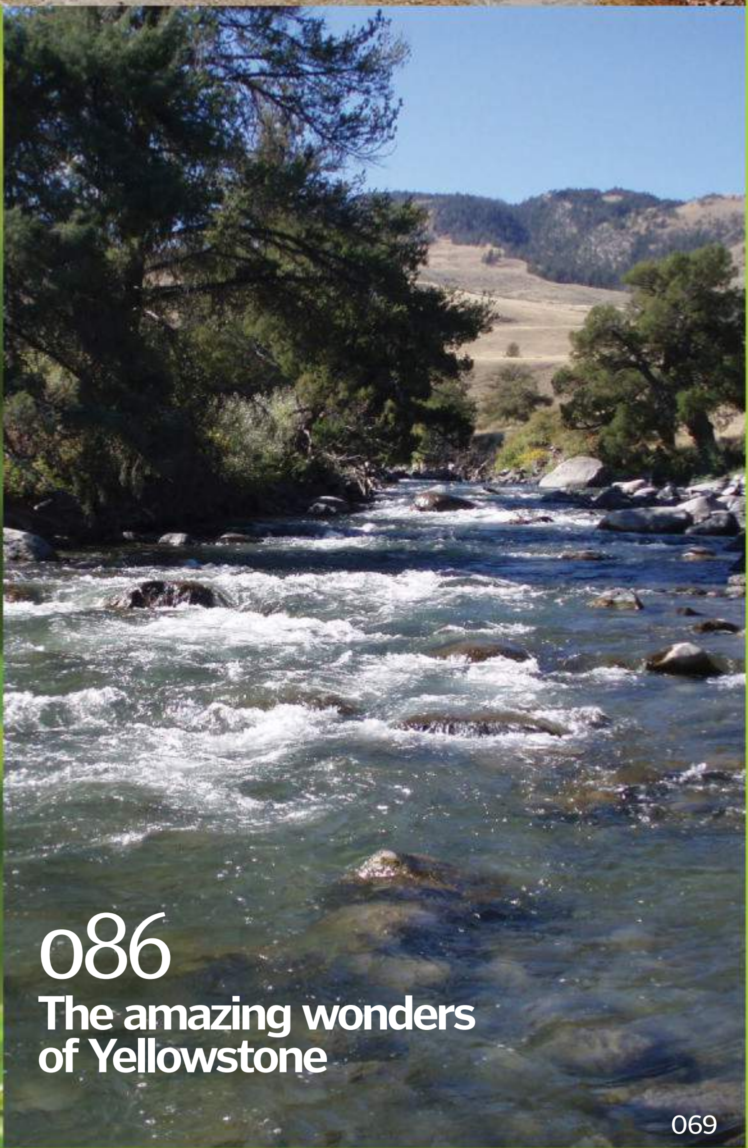


092
Extreme temperatures

070
The world's weirdest weather

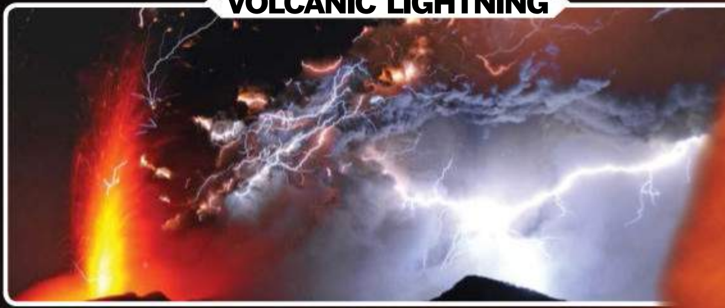


098
The life of the monarch butterfly



086
The amazing wonders of Yellowstone

VOLCANIC LIGHTNING



FIRE RAINBOW

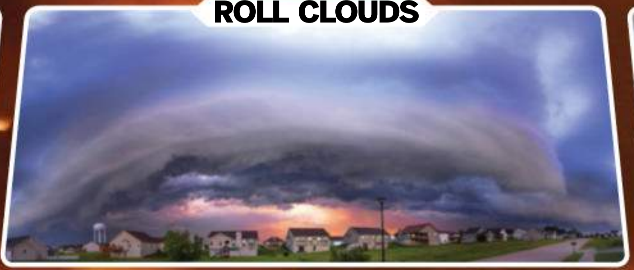
WORLD'S WEIRDEST WEATHER

The science behind our planet's most spectacular, dangerous and downright bizarre weather phenomena

Weather key: Cloud, Wind, Sun, Heat, Cold, Rain, Lightning, Hail

FALLSTREAK HOLE

ROLL CLOUDS



DUST STORMS

Have you ever seen a swirling tornado of fire, or heard a sand dune sing? Perhaps you've witnessed balls of lightning floating in the sky or even been caught in a downpour of frogs. Even if you haven't, someone elsewhere in the world definitely has.

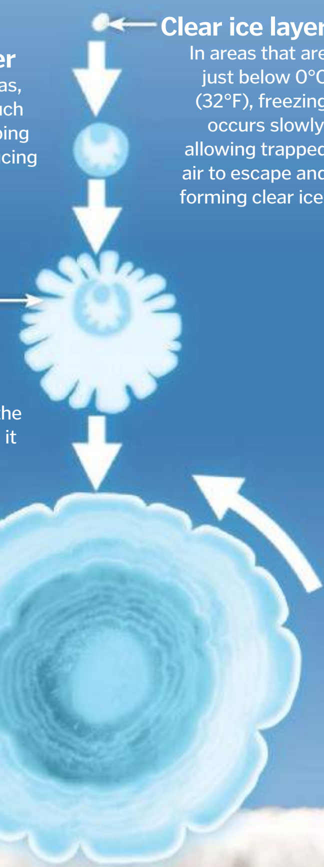
Although most of the weather we encounter on a day-to-day basis isn't particularly exciting, it can occasionally deliver some incredibly strange surprises. From enormous hailstones the size of tennis balls to towering clouds of dust that engulf entire cities, weather has the potential to be breathtaking, destructive and even explosive.

The basis for most weather is wind, water and temperature. Thunderstorms are the perfect example, as they involve all three at once. As the Sun heats the Earth, moisture in the air rises up into the cooler regions of the atmosphere via a strong updraft. When it gets high enough, the moisture condenses into water droplets, forming clouds and eventually precipitation. Colder air also sinks in strong downdrafts that create powerful horizontal winds. Thunderstorms are often the main catalyst for some of the world's most extreme weather, spawning lightning, hail and even tornadoes. However, wind, water and temperature can sometimes work in even more unusual ways to create bizarre weather phenomena that scientists are still trying to understand. Most weather, though, no matter how rare and unusual, can be explained by relatively simple science, and over the next couple of pages we will explore the most fascinating processes that cause some of our planet's oddest examples.

HUGE HAIL

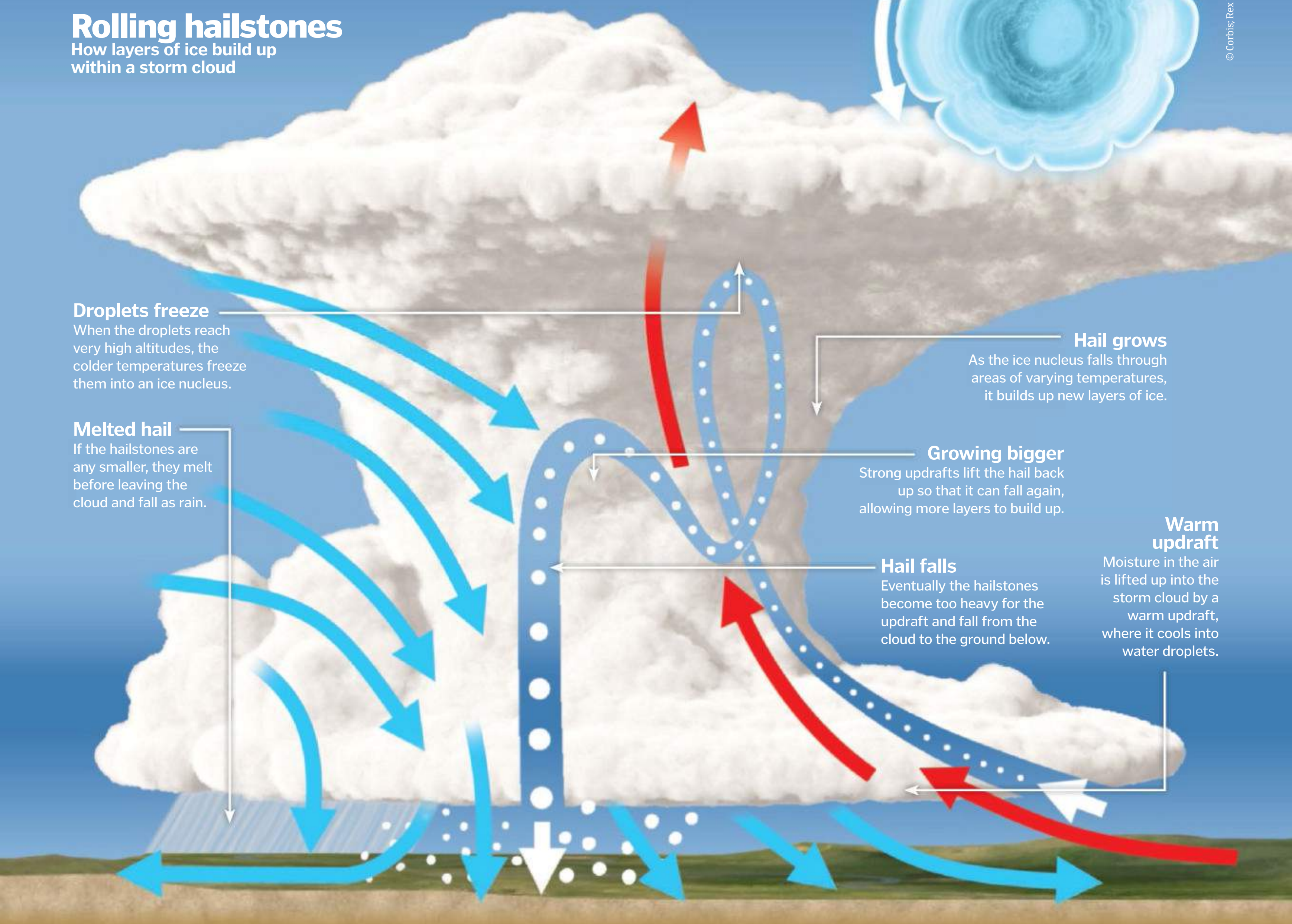
The enormous balls of ice that fall from the sky

Rather than just being solid lumps of ice, hailstones actually consist of several layers, much like an onion. This makes them incredibly tough and allows them to grow to large sizes, creating hail that is extremely destructive. Hail is often confused with ice pellets, frozen raindrops that consist of one layer and are much weaker.



Rolling hailstones

How layers of ice build up within a storm cloud



VOLCANIC LIGHTNING

The big eruptions that really light up the sky

A volcanic eruption is spectacular and violent enough as it is, but sometimes it is accompanied by big flashes of lightning too. However, this lightning doesn't descend from storm clouds in the sky. It is generated within the ash cloud spewing from the volcano, in a process called charge separation.

New discoveries
Volcanic lightning was a relatively understudied area of science until 2000, and its cause is still merely speculated.

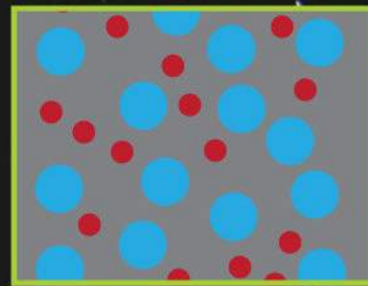
Ice crystals form
As temperatures are cooler at higher altitudes, the vapour cools and eventually turns into ice crystals, which collide to create lightning.

Difficult to study
Volcanic lightning typically occurs during the beginning stages of an eruption, making it very difficult to record and study.

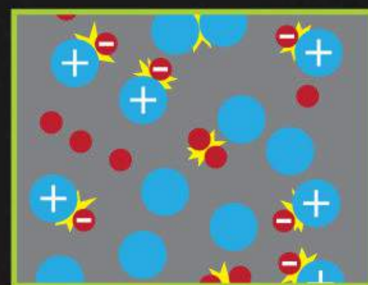
Water-laden magma
These ice particles form when water dissolved in the magma becomes vapour and rises out of the volcano during an eruption.

Initial sparks
The first sparks of lightning during an eruption are believed to be caused by ash particles colliding as they are ejected.

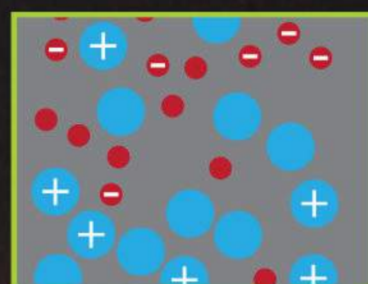
What is charge separation?



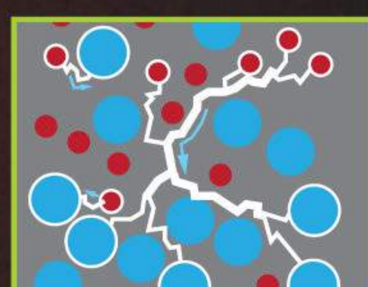
1 The particles within the cloud start out neutral, with an equal number of electrons and protons, meaning that they have neither a positive or negative charge to them.



2 As particles heat up, they collide and transfer electrons in a process known as charge separation. This causes some to become positively charged, and others negatively charged.



3 A difference in the aerodynamics of the positive and negative particles causes them to separate, so some parts of the cloud become more positive, and others become more negative.



4 The electrons flow back towards the positively charged particles when the charge separation gets too great. This forms sparks of electricity and neutralises the particles again.

ROLL CLOUDS

The odd-shaped clouds that roll across the sky

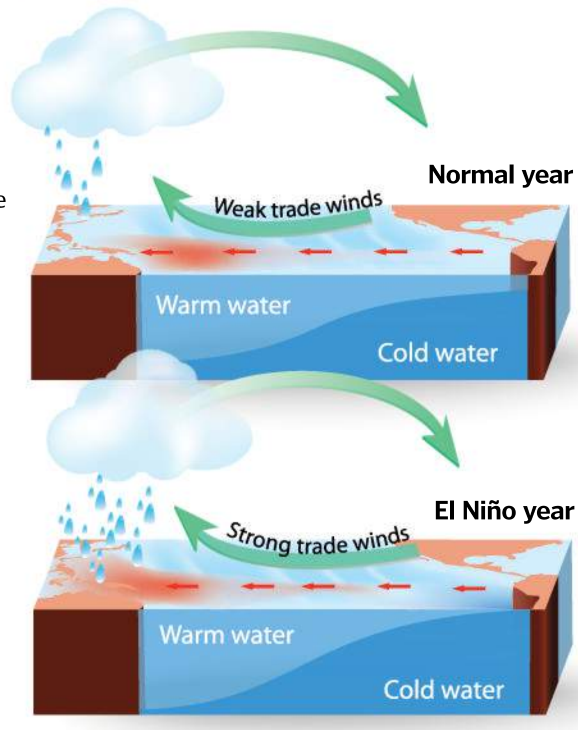
Although they look like horizontal tornadoes, roll clouds are actually completely harmless. Along with shelf clouds, which are more wedged-shaped, they are a type of low horizontal cloud formation, known as an arcus cloud. The difference is that shelf clouds are only created by thunderstorms and remain attached to the main storm cloud, while roll clouds can be formed by a number of different weather systems and are often independent from any other surrounding clouds.

They are the result of a mass of cold air meeting a mass of warm air, so can be formed by thunderstorms, cold fronts or sea breezes.

EL NIÑO

The cyclical weather change that causes unusually high ocean temperatures

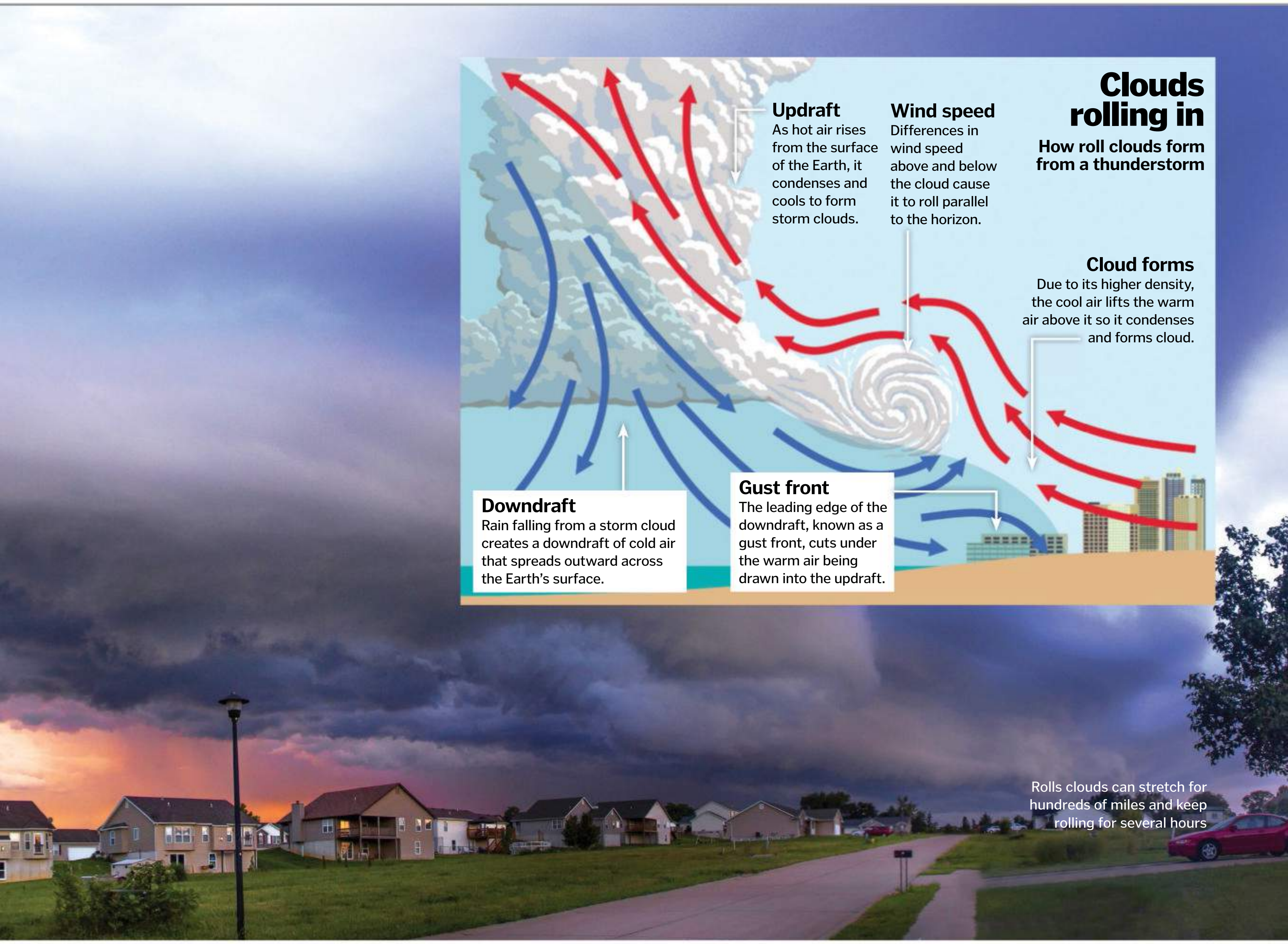
Every few years, the trade winds that blow towards the west across the Pacific dwindle, causing a pool of warm water to form along the equator. As this warm water travels eastward, it triggers severe weather, such as increased rainfall and flooding in North and South America, and extreme drought in the West Pacific. South American fishermen named the phenomenon El Niño, Spanish for "The Christ Child," because it usually arrives around Christmas time.



RAINING ANIMALS

The very real threat of amphibious rain

Although there are no accounts of it actually raining cats and dogs, other animals, such and fish and frogs, have been seen to fall from the sky in some parts of the world. This occurs when waterspouts – small tornadoes that form over water – suck up low-weight items, such as small creatures, with their low-pressure core. When these waterspouts hit land, they lose some of their energy and slow down, releasing whatever it is that they are carrying. Their spinning winds can reach up to 480 km/h (300mph), helping them to suck up objects from up to 1m (3ft) below the surface.

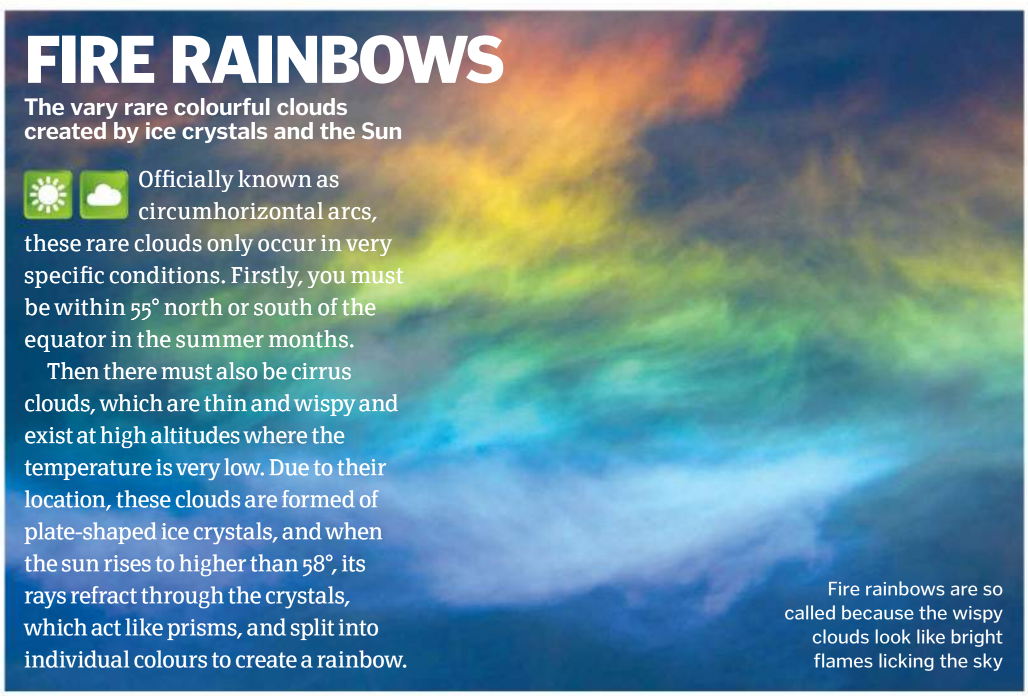


Rolls clouds can stretch for hundreds of miles and keep rolling for several hours

ST ELMO'S FIRE

The flames and sparks that climb ship masts and church steeples

Named after St Erasmus, the patron saint of sailors, St Elmo's Fire is the glow of blue flames often observed at the top of tall structures, such as ship masts, in a thunderstorm. It occurs due to charge separation, just like lightning. However, it involves a difference in charge between the air and an object, rather than the air and the ground. It is most common on pointed objects as they discharge electrical energy at a lower voltage level.



FIRE RAINBOWS

The vary rare colourful clouds created by ice crystals and the Sun

Officially known as circumhorizontal arcs, these rare clouds only occur in very specific conditions. Firstly, you must be within 55° north or south of the equator in the summer months.

Then there must also be cirrus clouds, which are thin and wispy and exist at high altitudes where the temperature is very low. Due to their location, these clouds are formed of plate-shaped ice crystals, and when the sun rises to higher than 58°, its rays refract through the crystals, which act like prisms, and split into individual colours to create a rainbow.

Fire rainbows are so called because the wispy clouds look like bright flames licking the sky

FIRENADOES

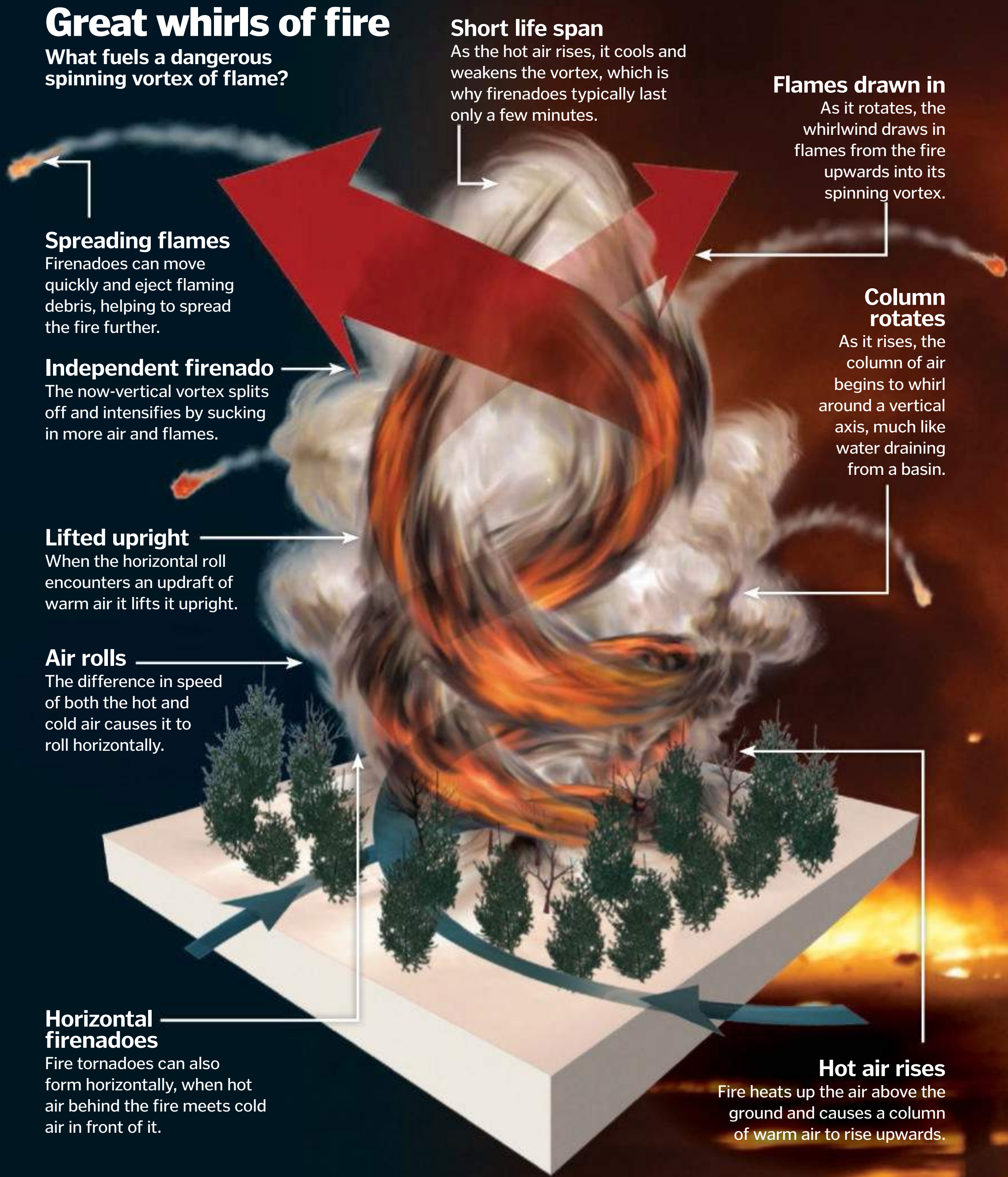
The deadly tornadoes with added fire

Firenadoes are actually more closely related to whirlwinds and dust devils than tornadoes, which is why they are also known as fire whirls and fire devils. They usually grow from wildfires, but have been spotted at the scene of house fires too, and can vary greatly in size.

Firenadoes are usually small, but some have grown to be 122m (400ft) tall and 15m (50ft) wide

Great whirls of fire

What fuels a dangerous spinning vortex of flame?



DUST STORMS

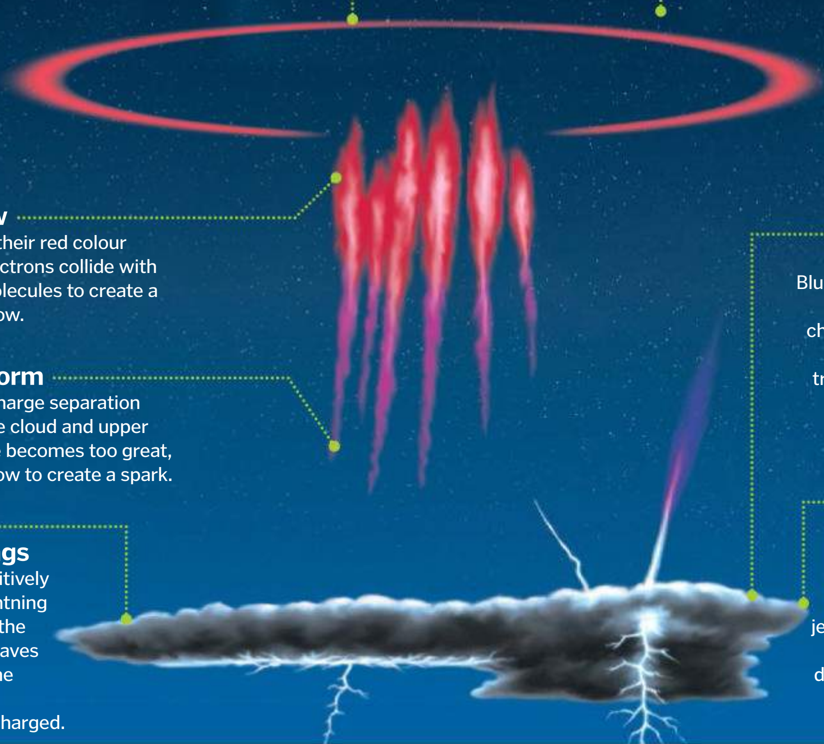
The blizzards of dirt that black out the sky

Dust storms are started by gust fronts, the downdrafts of cold air from thunderstorms that hit the ground and spread outward. As the wind passes over the ground, it moves the dust particles and starts a process called saltation. When the particles bounce along to the surface, they start a chain reaction, hitting other particles and causing them to bounce too. As these particles hit each other and the ground, they acquire a negative charge that repels them from the positively charged surface. This lifts them higher, where they get picked up by the wind and blown further.

Dust storms originate in arid or semi-arid regions where the soil is dry and loosely held on the surface

Elusive light show

What causes transient luminous events?



Electromagnetic pulse
Elves are caused by the abrupt, rapid acceleration of electrons, known as an electromagnetic pulse (EMP), in a lightning strike.

Colourful halo
As this energy passes upward through the base of the ionosphere and spreads outward, it causes gases to glow red.

Red glow
Sprites get their red colour because electrons collide with nitrogen molecules to create a colourful glow.

Sparks form
When the charge separation between the cloud and upper atmosphere becomes too great, electrons flow to create a spark.

Sprite beginnings
When a positively charged lightning bolt strikes the ground, it leaves the top of the storm cloud negatively charged.

Upwards lightning
Blue jets occur when a large positive charge at the top of a storm cloud triggers an upward lightning strike.

Tall storm clouds
The higher the storm cloud, the more likely a blue jet is to appear, but they are not directly associated with cloud-to-ground lightning.

SPRITES, ELVES AND BLUE JETS

The flashes of light that occur high above storm clouds

As well as the regular lightning that we experience in the troposphere, the lowest layer of the Earth's atmosphere, thunderstorms can also generate further activity much higher up. Transient luminous events (TLEs) are colourful flashes of light that occur in the middle and upper atmosphere and take the form of sprites, elves or jets. As they are very rare and last for just a fraction of a second, these phenomena are usually impossible to see with the naked eye and very difficult to capture on camera and study. Very little is known about them, but high-sensitivity cameras and observations from space are helping scientists to learn more.

The colours in secondary rainbows are reversed, with blue on the top and red on the bottom

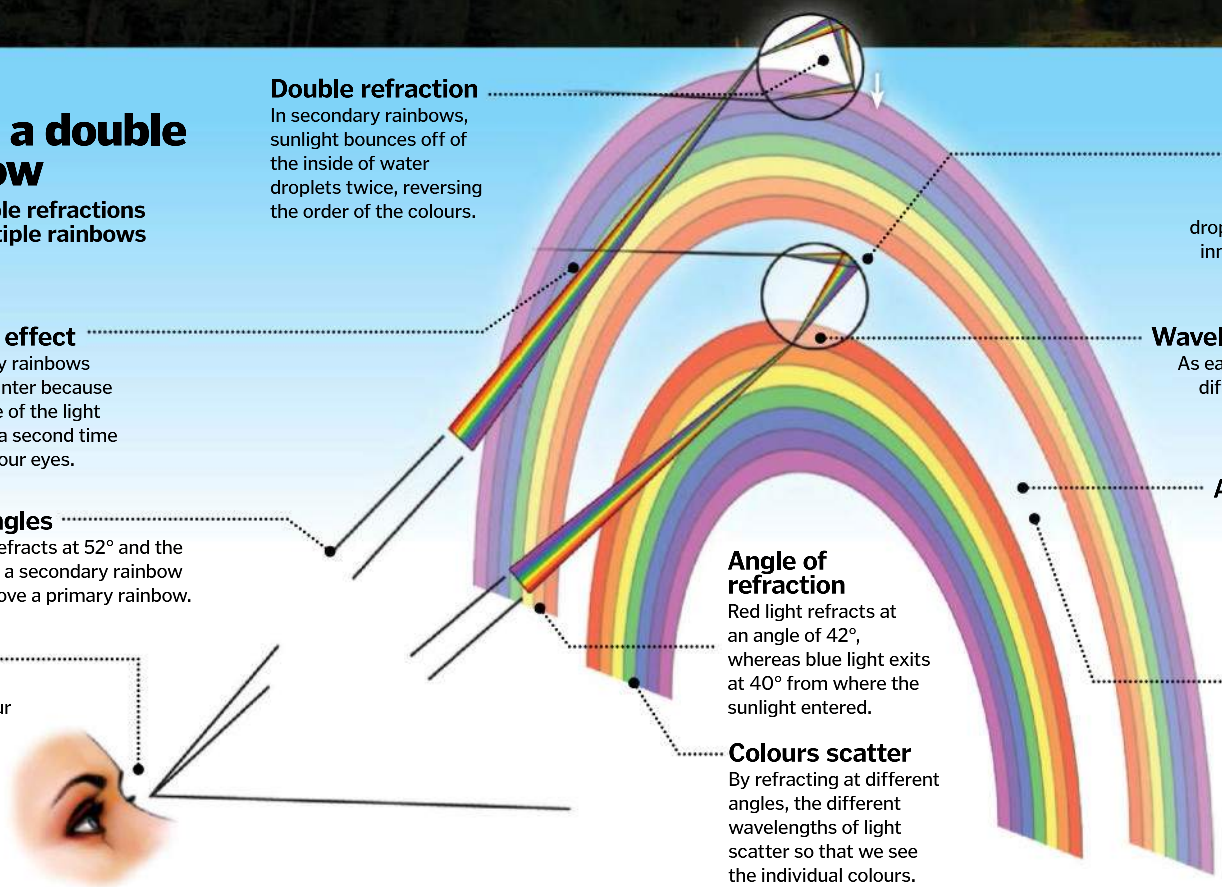
MULTIPLE RAINBOWS

The awe-inspiring double, tertiary and quaternary rainbows

Rainbows form when sunlight bounces off of the inside of water droplets suspended in the air. To create one rainbow, the light must bounce once inside the droplet. However, if the light bounces multiple times, more rainbows form. It is thought that larger water droplets that have been flattened by the surrounding air are needed to form double rainbows. These so-called 'burgeroid' droplets have a larger surface area for reflecting light more than once. If the light bounces three or four times, tertiary or quaternary rainbows form, but they are usually too faint for the naked eye to see.

Inside a double rainbow

How multiple refractions create multiple rainbows



Double refraction
In secondary rainbows, sunlight bounces off of the inside of water droplets twice, reversing the order of the colours.

Refraction
In primary rainbows, sunlight enters a water droplet and bounces off its inner surface in a process known as refraction.

Fainter effect
Secondary rainbows appear fainter because only some of the light reflected a second time reaches your eyes.

Wavelengths separate
As each colour of light has a different wavelength, it is refracted at a slightly different angle.

Greater angles
The red light refracts at 52° and the blue at 54°, so a secondary rainbow appears 9° above a primary rainbow.

Alexander's Band
The area between the two rainbows is known as Alexander's Band, named after Alexander of Aphrodisias who first noticed it.

Rainbow effect
Only one colour from each droplet will refract at the exact angle necessary to directly reach your eye.

Angle of refraction
Red light refracts at an angle of 42°, whereas blue light exits at 40° from where the sunlight entered.

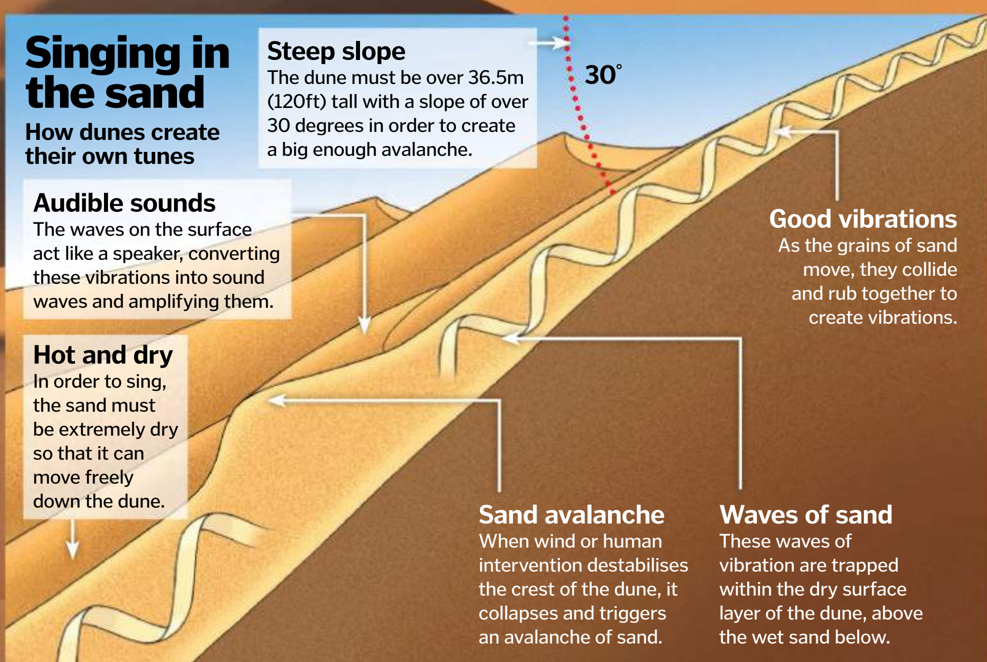
Colours scatter
By refracting at different angles, the different wavelengths of light scatter so that we see the individual colours.

Darker in-between
Alexander's Band appears to be extra dark because the droplets within it are refracting light at angles that don't reach your eyes.

SINGING SAND DUNES

The mountains of sand that can hit the low notes

In several of the world's driest climates, sand dunes regularly emit a strange low-pitched rumbling noise that can be heard from up to ten kilometres (six miles) away. These singing or booming sand dunes baffled scientists for decades, but it is now believed that the sound comes from sand vibrating within the top layer of the dune. This produces a single musical note, typically G, E or F. The thicker the top layer of sand, the lower the note it creates.




Ball lightning only lasts for a few seconds, as it disappears once the silicon oxide has burned out

BALL LIGHTNING

Mysterious orbs of light that float across the sky

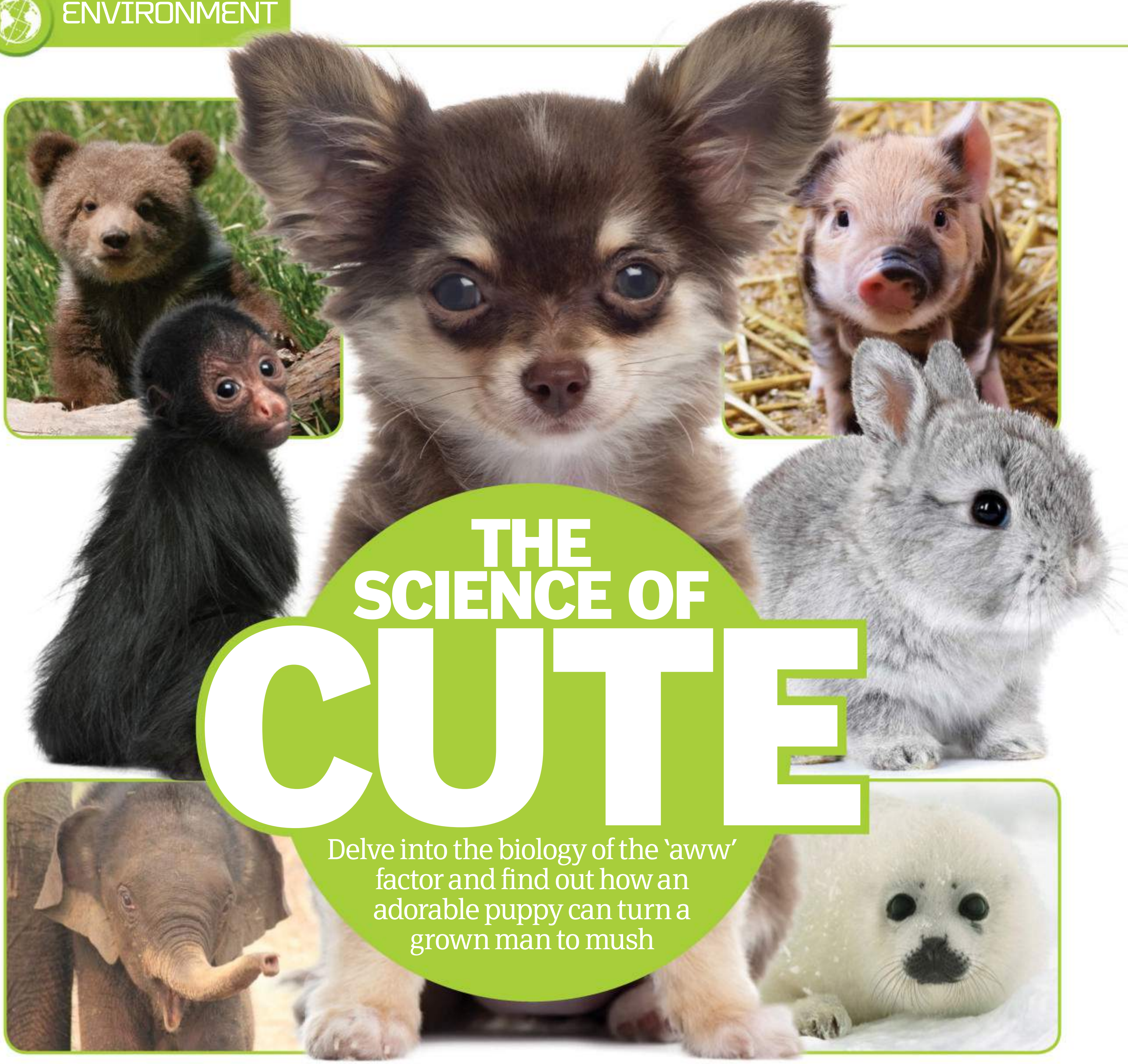
When lightning strikes the ground, it vaporises silicon oxide in the dirt. If the soil also contains carbon, perhaps from dead leaves, it will steal oxygen from the silicon oxide, turning it into pure silicon vapour. As the silicon recombines with oxygen in the air, the reaction creates an orb of light.


These so called 'hole-punch clouds' are the result of extremely localised snowfall

FALLSTREAK HOLE

The phenomenon that punches a hole in the clouds

Cirrocumulus and altocumulus clouds are composed of 'supercooled' water droplets that are below freezing temperature, but can't freeze because they don't have any particles around which ice crystals can form. When an aeroplane passes through the cloud, it triggers an expansion of air that causes the surrounding temperature to drop below -40°C (-40°F). This is cold enough to freeze the droplets, which fall as snow and leave behind a hole in the cloud.



THE SCIENCE OF CUTE

Delve into the biology of the 'aww' factor and find out how an adorable puppy can turn a grown man to mush

Cute baby creatures are adorable; lambs gambolling in a field, fluffy ducklings or kittens playing with a ball of wool can make even the hardest soul melt. But what makes the 'oohs' and 'aahs' escape us with cute creatures, but not when we're faced with a swarm of bees, for example?

The science behind the cutesy faces is simple: we like baby animals because we are biologically programmed to like human babies, and we need to like our human bambinos so that we take care of them, ensuring the human race lives on.

There are certain features that a lot of baby mammals have in common and these are the triggers that make us go gooey on the inside. Among others, big eyes and fuzzy, podgy bodies push our buttons. Babies have these traits, as do puppies, along with many other things that you might not even notice. Ever wandered past a car and thought it looked cute? Not a coincidence. The manufacturers of the Mini Cooper have thought ahead and made the headlights large, rounded and forward-facing to mimic a pair of large baby peepers and send our cute receptors firing all over the place.

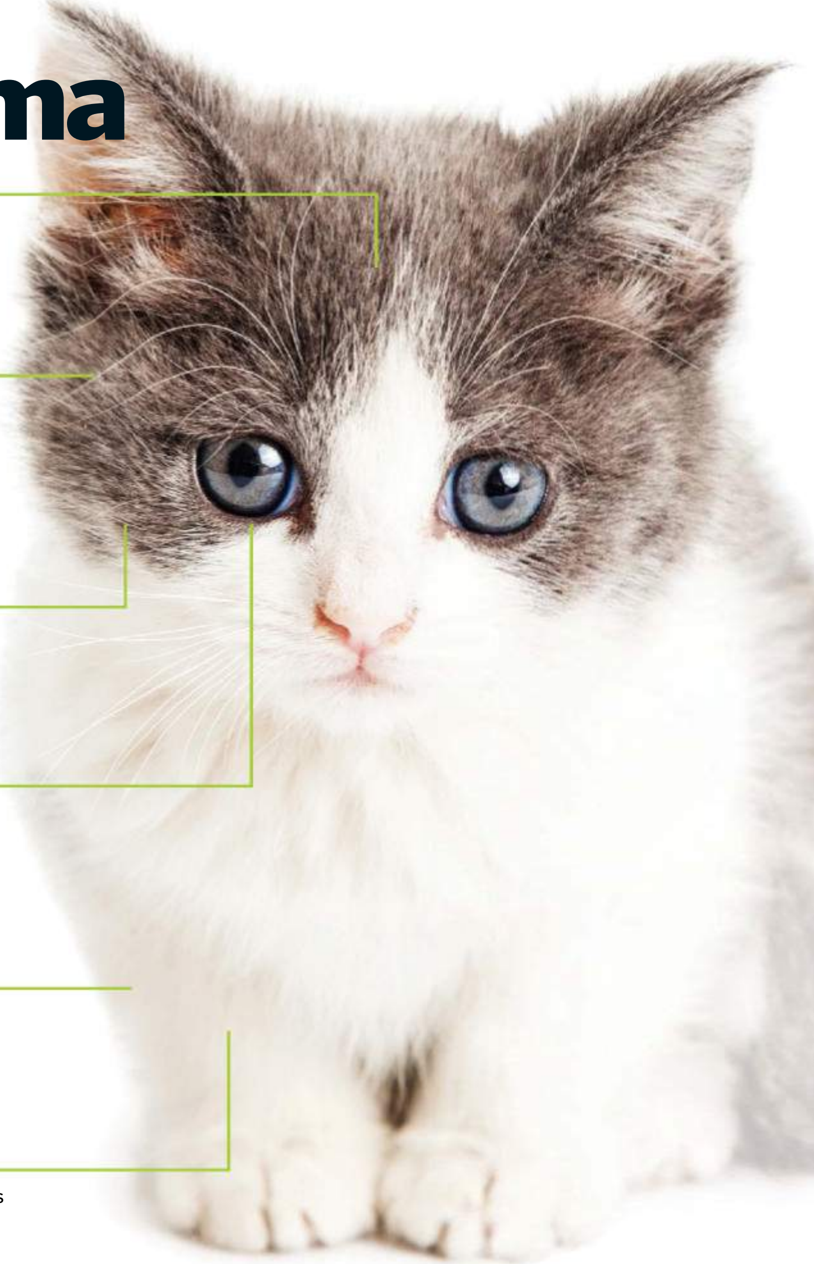
The reason why we love cute things is because they flood our brains with feel-good chemicals. If you're having a bad day, just do a swift internet search for a baby llama and you'll feel better in no time. Interestingly, many people will look at that llama and think it's just so incredibly adorable they could smoosh it up and eat it. This is called cuteness aggression and, although it sounds a bit weird, it's perfectly normal. Your brain senses the cute, but then tries to overcompensate for it! As long as you don't actually take a bite out of the little guy, you're fine.

But why are we so cute? It's because we walk on two legs. Due to our bipedalism, our pelvises shifted, meaning that women can't give birth to anything larger than a baby's head. Our human brains are already disproportionately large, which is why a baby's head is so big and round at birth. This sends our cute response into overdrive and we can't help but want to take care of the mini person forever.

The baby schema

This is a tried-and-tested set of physical characteristics that are almost guaranteed to induce an audible 'aww'. Documented by scientists, these features are based upon the things that we most find adorable on a human baby – the things that provoke our innate desire to take care of something.

Baby schema features also appear on many other animals, most often baby mammals. When we see these visually cute clues, which include big heads, round bodies, large eyes and soft textures, they often elicit the same response – making us want to pick them up, give them a big cuddle and look after them.



Big forehead
Babies heads are large which gives them a big forehead, replicated by the young of other species.

Bobble head
Human brains are disproportionately large and babies' brains are fairly advanced at birth – they have large heads to accommodate this.

Chubby cheeks
A podgy little body and a rounded head give rise to chubby little cheeks that human's can't resist.

Large eyes
A baby's eyes are about 75 per cent the size of an adult's, which is the same as the peepers of countless baby animals.

Soft textures
Baby-soft skin is very cute indeed. So is the soft, fluffy texture of fur or the downiness of feathers.

Round body
A roly-poly body of a kitten is cute to us because human babies are usually chubby.

Kids prefer cute
Even toddlers can recognise 'cuter' faces, according to a study by the University of Lincoln, which manipulated images of faces and analysed the response of children aged 3-6. (*These photos are a representation and weren't used in the actual study.*)

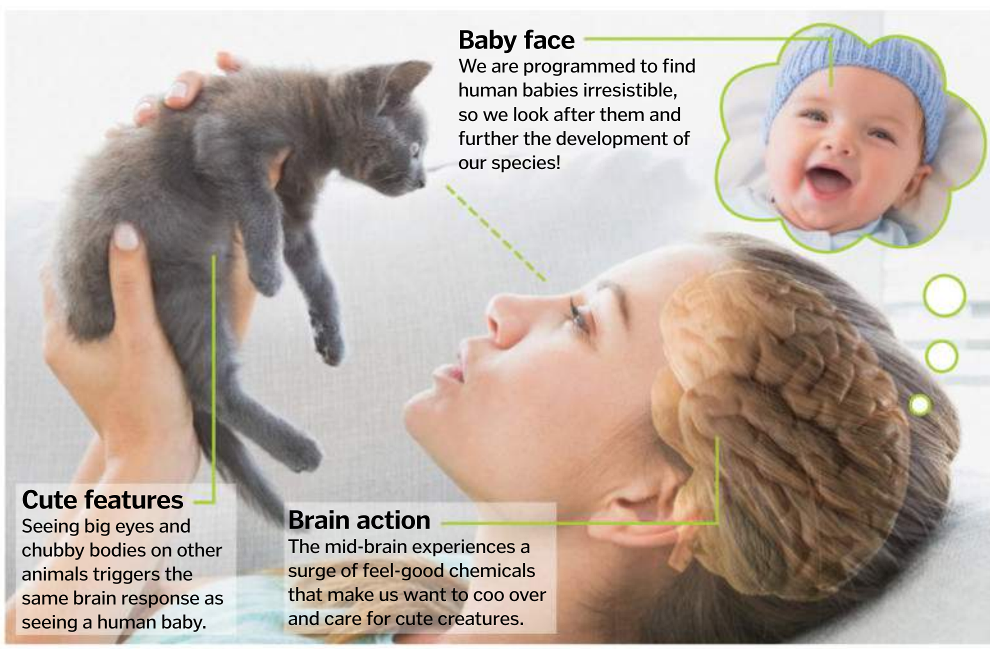
Original Image

Less Cute

More Cute

What cute does to the brain

When we see something that's totally adorable, it captures our attention, brings a smile to our faces and we will more than likely feel compelled to rush up and touch it. This is because it stimulates an area in our mid-brains known as the mesocorticolimbic system. This is the part of the brain that is associated with the processes of motivation and reward. When we look at a sweet bouncing baby, our brains recognise the features that make us relate to our own young (as outlined by the baby schema). This causes a surge of the neurotransmitter dopamine (one that's involved when we fall in love) and makes us feel all warm and fuzzy, which is an enjoyable feeling. Our brains commit that rewarding feeling to memory, letting us know to do it again. The emotional response triggered by the cuteness also stimulates the motivation to care for the animal, hence the urge to pick it up and give it a big old cuddle. This reaction is so ingrained in our human brains that it can be triggered by other things, such as cute little creatures or even inanimate objects with certain features that trigger our 'cute' response!



Evolutionary advantage

Why having adorable babies is essential for some species' survival

In the animal kingdom there are some animals that, once born, charge headfirst into the big wide world without a second look at the parent from whence they came. For example, most insects, reptiles and fish follow this gung-ho approach to infancy. Generally, these types of creatures are notoriously 'not cute'. Although they may have some redeeming features, what the baby schema denotes as 'classically adorable' is largely missing from their profiles. Many other species have an entirely different childhood where they need nurturing and protecting while they grow big and strong – much like our own parental care. It is absolutely no coincidence then that we consider these creatures as much cuter than their more headstrong classmates.

The nature of mammals means that animals are born with plenty of growing left to do. Their features are rounder, noses and snouts are stubbier and there's often a thick layer of baby fat to help cut an even more rotund silhouette. As they slowly grow up, these features elongate and exaggerate and their 'cuteness' fades.

The evolutionary advantage to gradual growth and development is thought to be a sort of trade-off. Where a baby horse can stand up within minutes of being born, it takes a human baby months to even hold itself up. Scientists think that the downside to humans being able to achieve such incredible things in adult life is that it takes us around eighteen years to fully mature – which is a very long time in comparison to our animal friends.

This is why our kids need to be cute and why we need to find them cute! The same is true for the animal kingdom – both humans and animals need to care for their offspring in order to prolong the existence of their species.

In humans, as the cute response is triggered by looking at newborn bundles of joy (or the fluffy animal variety), the neurotransmitters dopamine and oxytocin are released. Associated with the 'reward' pathway in our brains, they also play a key part in social interaction and intimacy – how we bond with other humans. The bond that a mother shares with her baby needs to be strong so that the mother will protect her offspring no matter what. This kind of empathy also enables us to form attachments to our pets!

The cutesy features of an adorable polar bear cub turn most humans to mush

The scaly skin, fearsome teeth and knobbly body of a baby crocodile doesn't push our cute buttons

All grown up

The physical changes as little cuties grow into perfectly adapted adults

A dog's life
Small dog breeds reach adult size at around one year old. Their heads and snouts extend significantly – an adaptation for housing their spectacular sense of smell and optimally placing their canine teeth.

Hare development
Baby hares (known as leverets) grow quickly. Their rounded faces develop into elongated snouts with large nostrils for sniffing food and big ears for acute hearing.

Boy to man
A baby's eyes are almost the same size that they'll be in adulthood! As a child grows, the skull gradually matures and lengthens – the forehead becomes less pronounced and the face elongates.

Growing birdbrains
Young birds mature quickly. Like other baby-to-adult transformations, their heads and beaks elongate. A longer beak is essential for pecking food.

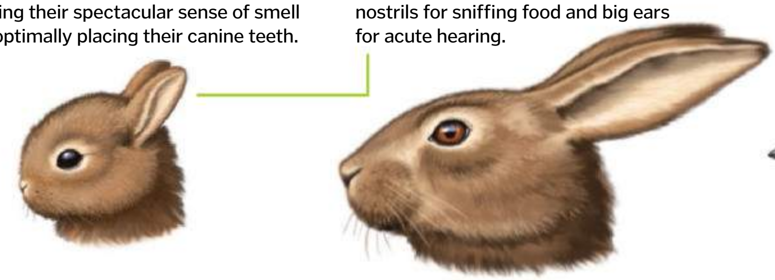


Illustration by Tom Connell/Art Agency

Instinct and empathy

The urge to care for our young is the result of biological programming

As mammals, we have an innate desire to care for our babies. Yet the primal instinct to care isn't always expressed through having our own children. Keeping pets is a good example of this – we empathise with these animals, triggered by the cute response in the brain, and feel the need to care for and nurture them, sometimes as if they were our own children.

Other animals also exhibit this kind of behaviour. There are many stories of unlikely animal companions that have come together, usually when a mother takes on the care of a more helpless creature. YouTube is replete with videos featuring monkeys looking after puppies and kittens. There have even been reported cases of inter-species primate adoption in the wild. For example, a tiny marmoset was witnessed living with a group of larger capuchin monkeys.

There are some species for which the maternal instinct means that if they lose their own baby, the will adopt another. This has been seen in marine mammals such as seals; the mothering instinct can also be so strong that females that have never given birth will foster the young of another individual and care for them, known as 'allomothering.'

Bonds can form between the most unlikely of species. Non-human primates are a good example of innate maternal behaviour

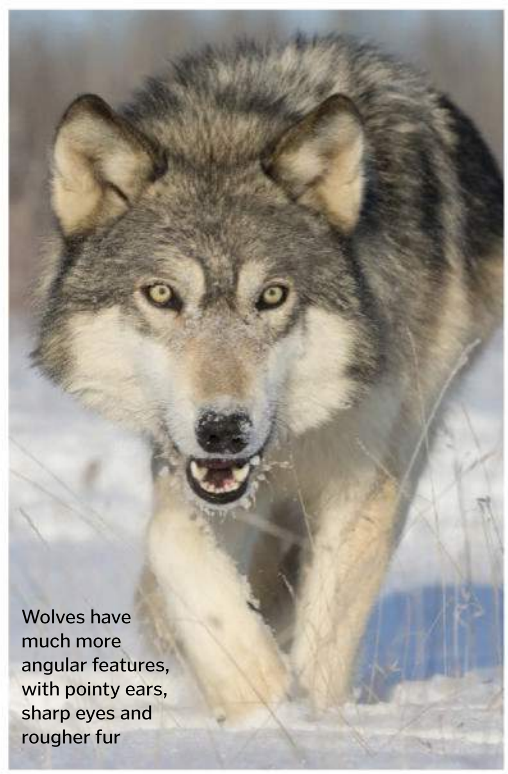
Mother orangutans carry their babies with them for up to five years

Did dogs evolve to be cuter?

Man's best friend evolved alongside us to be the adorable companions we know and love

Anyone who owns a pet dog will be no stranger to 'puppy dog eyes' – the look our pooches give us that we just can't resist. We know that domestic dogs are descended from wolves and it's also very clear to anyone who's ever set eyes on a labrador, that there are features domestic dogs have that make them far cuter to us. An aggressive wolf approaching a group of early humans with teeth bared is far less likely to be tolerated than a friendly wolf that gives the classic puppy dog eyes. So, it may be that this doe-eyed expression that sends us reaching for the treat jar may have developed as dogs have exploited human preferences. This manipulation tactic may even work so well that it ensures rescue dogs find a new home: scientists studied dogs in shelters and those that pulled certain facial expressions that we find to be cute were more likely to be adopted!

Domesticated dogs are big softies, with floppy ears, silky fur and friendly faces



Wolves have much more angular features, with pointy ears, sharp eyes and rougher fur

The ever-changing Plitvice Lakes

How incredible geology has formed Croatia's waterfall paradise

The spectacular Plitvice Lakes are actually part of one large river flowing between the Mala Kapela and Licka Plješivica mountains in central Croatia. The river has divided into this series of interconnected lakes and waterfalls because of a geological phenomenon known as a karst landscape, where rock, water and organisms all work together to create new features.

The Plitvice river basin is made of limestone and dolomite, and as the water passes through it dissolves these rocks and becomes saturated with calcium carbonate. This chemical compound then sticks to the mucus secreted by the microscopic bacteria and algae that grow on moss plants in the water. The plants gradually become encrusted with the calcium carbonate and it slowly builds up at a rate of about one centimetre (0.4 inches) per year to form barriers of travertine rock. Some of these barriers, which have been growing since the Upper Triassic period, are around 4,000 meters (13,123 feet) thick and act as natural dams that split the river into lakes. As more water travels down from the mountains, it flows over these barriers to create waterfalls that cascade down the river basin.

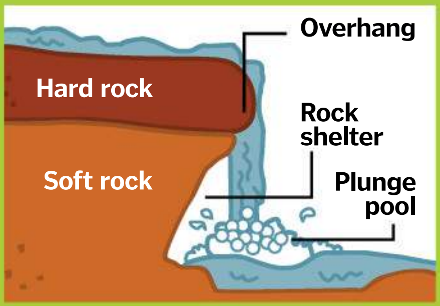
Just as quickly as the flowing water erodes the travertine, more is formed when the calcium carbonate-saturated water pools at the base of the waterfalls. This means that the Plitvice Lakes are constantly changing size and shape as old waterfalls run dry and new ones form.

This clever geology is also responsible for giving the Plitvice Lakes their distinctive blue-green colour. When the white calcium carbonate coats the bottom of the lakes it reflects sunlight and the sky to create vivid colours that change depending on how the Sun's rays hit the water and how many organisms and minerals are present.

"The Plitvice Lakes are constantly changing size and shape"

How does a waterfall form?

Usually, waterfalls form when a river flows over areas of soft and hard rock. The flowing water erodes the soft rock more quickly than the hard rock, undercutting it to leave an overhang. This forms a basic waterfall, and as the water flows over this ledge, it often takes some rocks with it. These rocks crash into the riverbed below, so more erosion occurs to form a plunge pool. The soft rock behind the waterfall is also eroded as water splashes at the bottom, cutting into the rock to form a cave-like structure called a rock shelter. Eventually the water erodes the overhang of hard rock too, causing the waterfall to recede upstream. This process is slightly different to that which occurs at the Plitvice Lakes, as instead of carving existing rock into an overhang, the mineral-rich water there helps to create new ledges that the water can flow over.



The tallest Plitvice waterfall is over 70 metres (230 feet) high, the equivalent of almost 16 double-decker buses stacked on top of each other

Wonders of YELLOWSTONE

Jackson Lake

Grand Teton

Heart Lake

Yellowstone Lake

Grand Canyon of the Yellowstone

Lewis Lake

PARK

Wild beasts, 30-metre high geysers and a supervolcano that could destroy America

Shoshone Lake

'Old Faithful' Geyser

Grand Prismatic Spring

Mammoth Hot Springs

Welcome to Yellowstone Park – America's, and the world's, very first national park. Its vast swath of 9,000 square kilometres (3,500 square miles) of protected land, which spans the borders of Wyoming, Montana and Idaho, could house all five boroughs of New York City ten times over, and attracts over 3 million visitors each year.

Its world-renowned scenery includes soaring peaks, plunging canyons, lush forests, rushing rivers, brilliant lakes, rolling meadows, thundering waterfalls, shimmering hot springs and gushing geysers. Amid all this visual poetry lives a rich assortment of wildlife, including wolves, bears, bison and elk.

Yellowstone National Park was established by US Congress in 1872, soon after the first Europeans arrived in the American West, but archaeological records show that people have been in Yellowstone for over 11,000 years. Many tribes have lived on and passed through the land now occupied by the park, including the famous Native American Sheepeaters.

The park lies at the heart of the Greater Yellowstone Ecosystem, which at over 80,000 square kilometres (30,000 square miles) is one of the largest nearly intact temperate-zone ecosystems on Earth. It preserves a staggering variety of terrestrial, aquatic and microbial life, making it a truly invaluable resource for scientists who are conducting various studies, ranging from landscape-level changes right down to some of the tiniest microscopic organisms imaginable.

Yellowstone was set aside as the world's first national park primarily because of its extraordinary geology and hydrothermal wonders. The park contains around half of all the hydrothermal features on Earth – over 10,000 of them – including hot springs, mud pots, fumaroles and the world's greatest concentration of geysers. The most famous of these, Old Faithful, is a perennial crowd pleaser that reliably erupts almost once every hour.

Yellowstone's hydrothermal features are fuelled by volcanic activity deep within the Earth. Just a few miles underneath the park, partially molten rock churns and seethes. The area has seen three gargantuan volcanic eruptions and at least 30 smaller ones over the last two million years, and the park and its immediate surroundings typically experience between 1,000 and 3,000 earthquakes each year, with several large enough to be felt by visitors.

Visitors, wildlife, and the park's pristine landscapes are managed and protected by a team of rangers – 780 work during the peak summer season and a core 355 are permanent year-round employees. As you might expect, competition to become a park ranger at Yellowstone is fierce. Can you imagine a better "office" to go to each day?

Animals of Yellowstone

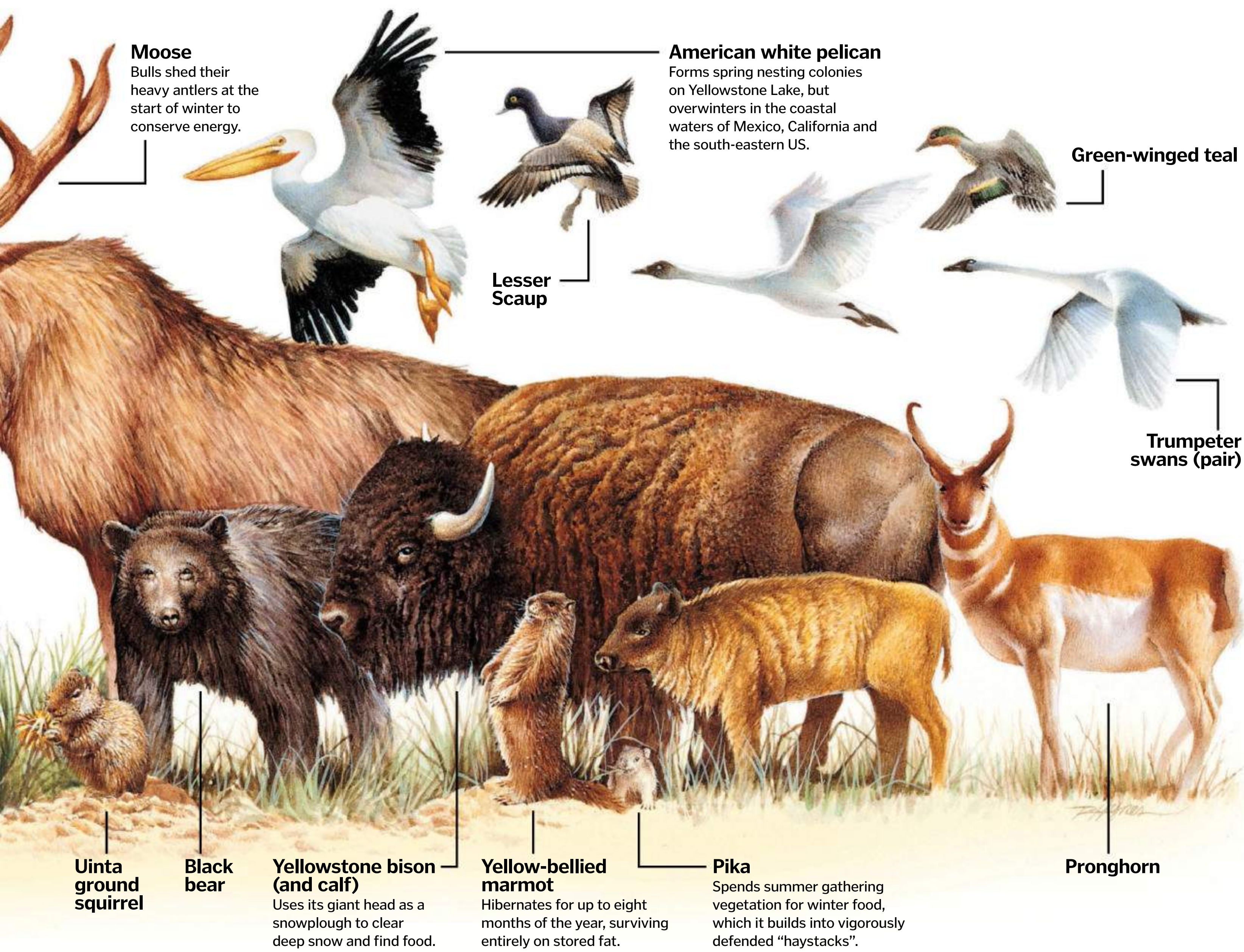
As well as breathtaking scenery, Yellowstone is home to a staggering diversity of wildlife. The region sustains one of the largest communities of free roaming large animals seen anywhere on Earth, and contains the most powerful mega fauna in the contiguous US. Following the re-introduction of grey wolves in 1995, today's Yellowstone boasts almost the full complement of animal species that inhabited the park when it was first explored over a century ago.

As well as wolves, some of the major attractions for park visitors are the two types of bears – grizzlies and black bears – bison, wild horses and America's national bird, the bald eagle. Among the animal species are 67 mammals, nearly 300 birds, 16 fish, four amphibians and six reptiles, which can be found within the park's boundaries. The variety and abundance of wildlife is due, in part, to the collection of specialist habitats it encompasses. The animals are also protected by law; only park rangers may fire guns, although visitors can obtain fishing permits.

But that isn't to say that life in Yellowstone is a walk in the park for its inhabitants. They must endure cold harsh winters, with temperatures at or below freezing from November through to March and snowfall heavy enough to cause the main roads to be closed for months on end. Each species has its own way of coping – from the moose's specially hinged joints, which they can swing over the snow rather than having to plough through it, to the bison's tendency to graze and find warmth near hydrothermal areas.

The entire Yellowstone ecosystem exists as a delicate balance between predators, prey, and their habitat – itself governed by climate fluctuations, forest fires, invasive species and volcanic activity. The way the park is managed today reflects shifting attitudes and new understanding about this balance. For example, wolves, once considered too great a threat to other species, are now recognised as linchpins in the health and stability of the overall ecosystem. Forest fires were once viewed purely in terms of the death and destruction they cause, but today controlled burns are recognised as a critical step in the natural cycle of regeneration and renewal.


Yellowstone is the only place in the contiguous US where bison have roamed continuously since prehistoric times



How wolves balance the Yellowstone ecosystem

An icon of the wilderness, the grey wolf once thrived in Yellowstone before it became systematically shot, trapped and poisoned until it was finally eradicated from the park in 1926. But without the wolves the entire ecosystem went into free-fall; the deer population exploded and grazed almost all the vegetation bare, causing a cascade of knock-on effects.

In 1995, 14 wolves were reintroduced to the park. Where the deer avoided the wolves, woody vegetation flourished and beavers – whose dens are important to otters, fish, reptiles and amphibians – were bolstered. Wolves kept the coyote population in check, which boosted numbers of small mammals. Bears thrived on wolves' discarded carcasses and the new proliferation of berries. Even rivers were affected with their banks strengthened by improved plant growth, erosion slowed and they meandered less.

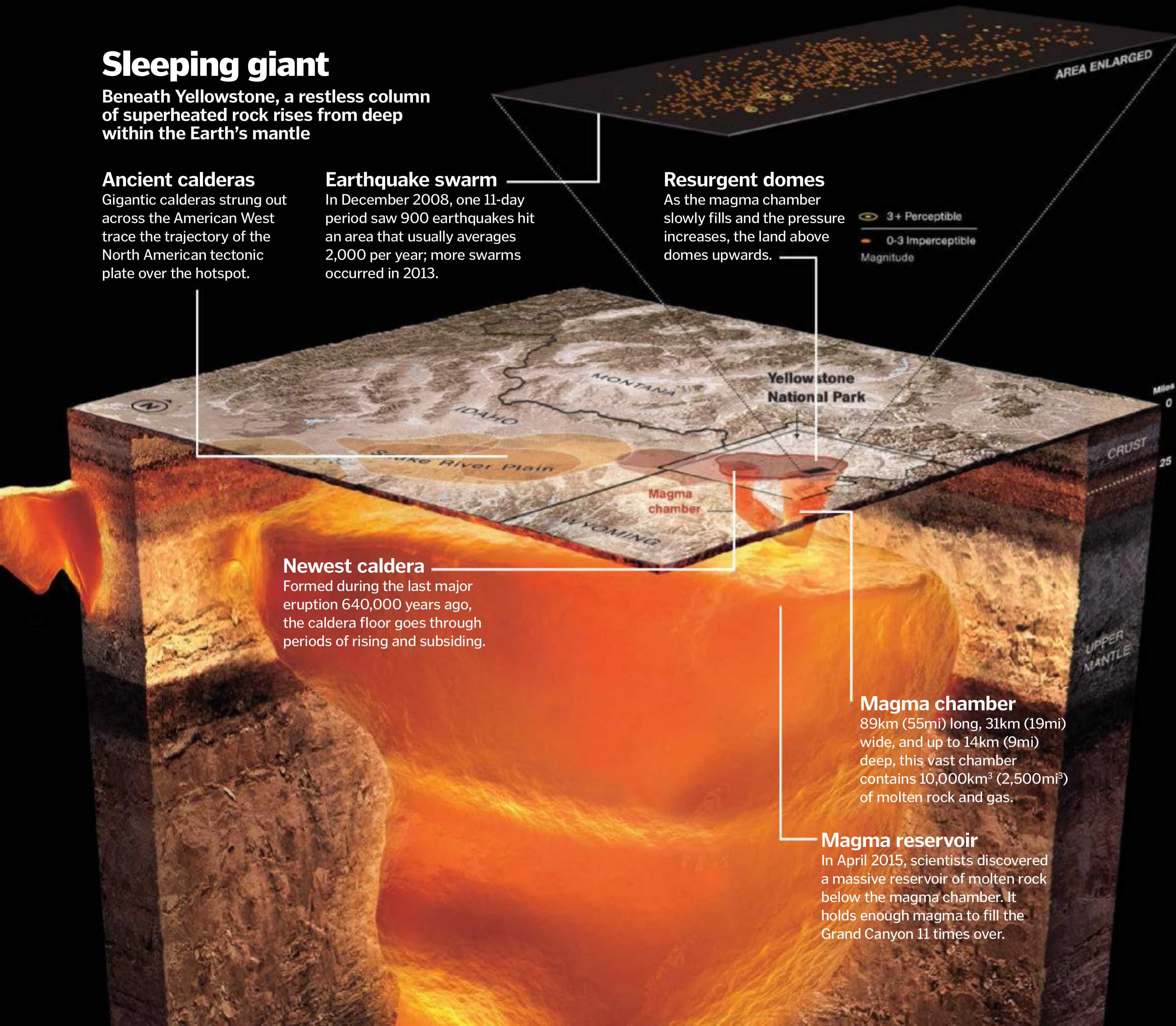
What lies beneath...?

Yellowstone's natural serenity belies its violent volcanic underbelly. In fact, one third of the park's area lies within the gigantic caldera of a colossal supervolcano. These types of volcanoes are defined by their ability to eject more than 1,000 cubic kilometres (240 cubic miles) of material – making them at least a thousand times larger than the 1980 Mount Saint Helens eruption, the deadliest and most destructive volcanic eruption ever recorded in US history.

Yellowstone's super volcano is powered by an immense geological hotspot, which fuels a growing magma chamber directly underneath the park. Three massive eruptions have occurred within Yellowstone – 2.1 million, 1.3 million, and 640,000 years ago respectively – a regular pattern that leads many experts to believe a globally catastrophic eruption is long overdue.

Sleeping giant

Beneath Yellowstone, a restless column of superheated rock rises from deep within the Earth's mantle



Ancient calderas
Gigantic calderas strung out across the American West trace the trajectory of the North American tectonic plate over the hotspot.

Earthquake swarm
In December 2008, one 11-day period saw 900 earthquakes hit an area that usually averages 2,000 per year; more swarms occurred in 2013.

Resurgent domes
As the magma chamber slowly fills and the pressure increases, the land above domes upwards.

Newest caldera
Formed during the last major eruption 640,000 years ago, the caldera floor goes through periods of rising and subsiding.

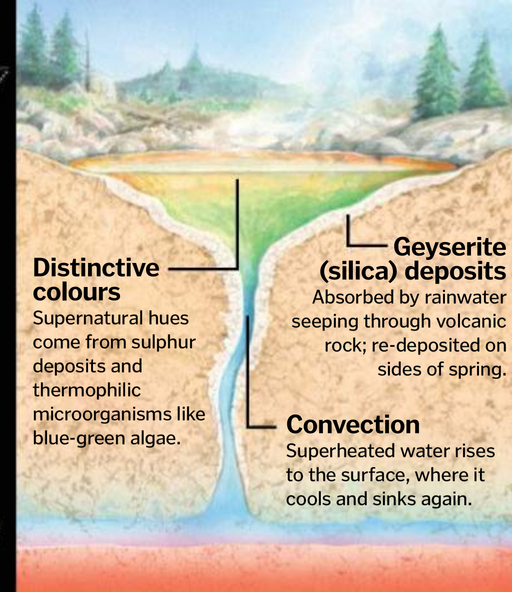
Magma chamber
89km (55mi) long, 31km (19mi) wide, and up to 14km (9mi) deep, this vast chamber contains 10,000km³ (2,500mi³) of molten rock and gas.

Magma reservoir
In April 2015, scientists discovered a massive reservoir of molten rock below the magma chamber. It holds enough magma to fill the Grand Canyon 11 times over.

Guide to Yellowstone's hydrothermal features

Hot springs

The most common type of thermal feature in Yellowstone, formed when rain and snow seeps through the underlying bedrock and becomes superheated from the energy radiated by partially molten rock that lie a few miles below the surface.



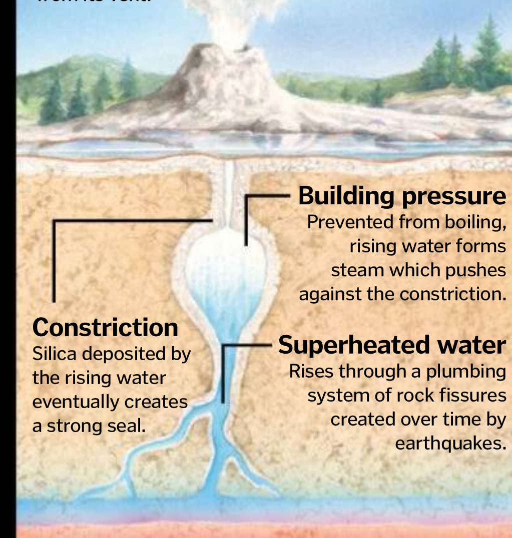
Distinctive colours
Supernatural hues come from sulphur deposits and thermophilic microorganisms like blue-green algae.

Geyserite (silica) deposits
Absorbed by rainwater seeping through volcanic rock; re-deposited on sides of spring.

Convection
Superheated water rises to the surface, where it cools and sinks again.

Geysers

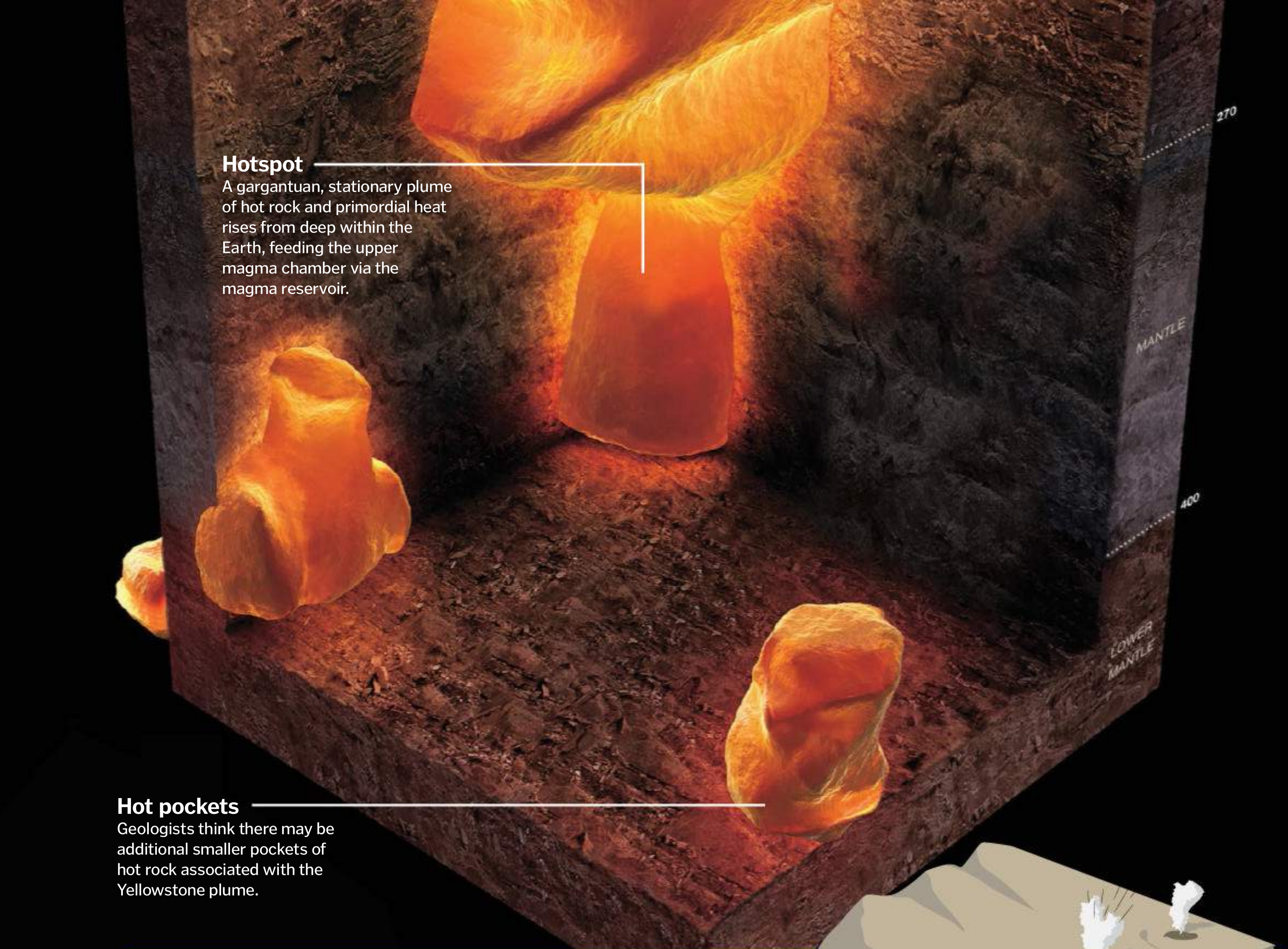
A rare kind of hot spring that forms when a plumbing constriction prevents superheated water from circulating freely. Pressure builds as rising water is prevented from boiling, until eventually the geyser blows, spewing huge volumes of steam and water from its vent.



Building pressure
Prevented from boiling, rising water forms steam which pushes against the constriction.

Constriction
Silica deposited by the rising water eventually creates a strong seal.

Superheated water
Rises through a plumbing system of rock fissures created over time by earthquakes.



© Corbis

What if Yellowstone blows?

Geologists have never witnessed a supervolcanic eruption, but by looking at remnants of previous cataclysms, mapping the underground bodies of magma and using computer models, they can glean horrifying details about what might happen if Yellowstone blows.

Gas-filled magma would explode from the volcano, raining rocky debris and hot, dense ash – a mix of splintered rock and glass capable of killing people and animals in a most gruesome fashion as they inhale it – across tens of thousands of square kilometres. A high-altitude umbrella cloud would spread out in all directions, blanketing the Rocky Mountains with metres of ash and sending particles across the entire country.

The cloud would temporarily shut down air travel and interfere with electronic communications across North America. Roofs would collapse under the weight of ash; roads, sewers and water supplies would become clogged and unusable, and crops would be smothered. The states of Wyoming, Montana, Idaho, Colorado and Utah would be devastated, perhaps unliveable for several years, and the entire globe would cool by a couple of degrees as gas from the cloud blocks out the Sun, causing climatic effects that could threaten many species with extinction.

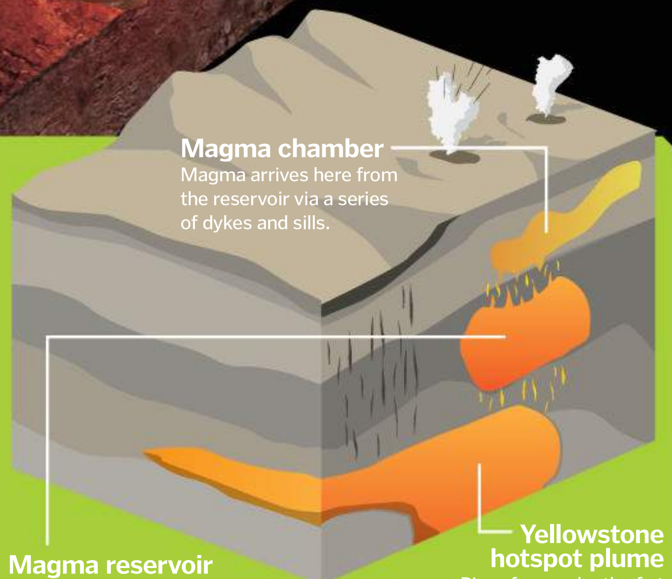
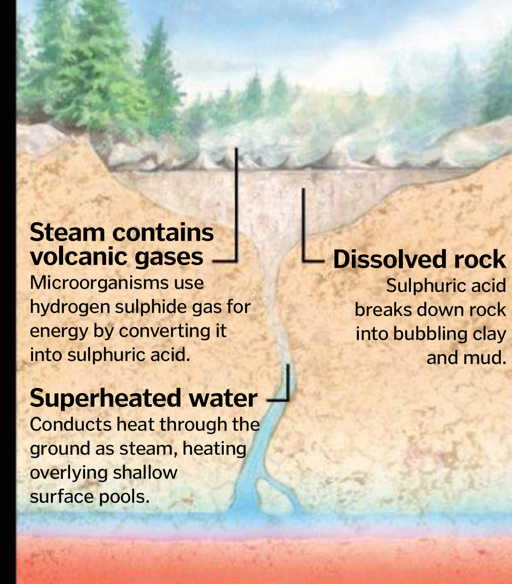


Image by Ed Crooks

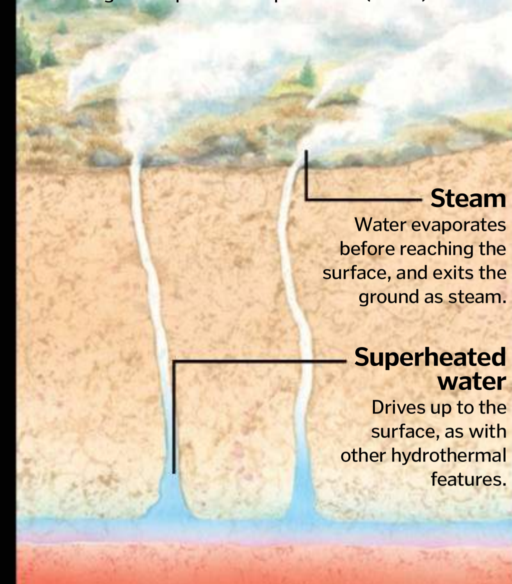
Mud pots

Steaming vents of hydrogen sulphide acidify shallow, heated pools of surface water which turns the underlying rock into bubbling blue-grey clay. Minerals in the clay interact with the acids resulting in a shimmering rainbow of coloured deposits.



Fumaroles

Also called a steam vent, these are hydrothermal features with such limited water supplies that it all boils away before reaching the surface. Steam and other gasses emerge from the vent hissing and whistling at temperatures up to 114°C (237°F).



Images by Peter Scott/Art Agency

SURVIVING THE BIG FREEZE

Discover how animals take on the extremes and win

The adaptive techniques that animals use to survive the temperature changes in their environment are nothing short of extraordinary. Some creatures such as Arctic ground squirrels or brown bears choose to while away winter in a deep slumber, while others like caribou or Arctic terns embark upon epic migrations to warmer climes the moment things start to get really chilly. Then there are the hardcore stay-putters, the animals that have evolved some truly wonderful – and some downright weird – ways to weather the storm. Take the Arctic tundra's musk oxen, for example; this grumpy beast has a shaggy coat made of hollow hair for warmth that hangs so low to the ground that it traps a layer of warm air beneath the animal. Couple this with a whole herd of huddling musk oxen and things get very toasty indeed.

Physical adaptation is a key weapon against the cold. Animals such as many rodent species will bulk up during the summer months in order to have sufficient fat reserves to see them through the harsh winter. Other animals, like Arctic foxes or hares, have developed a thick coat of fur that actually changes colour with the seasons to provide both warmth and camouflaged protection.

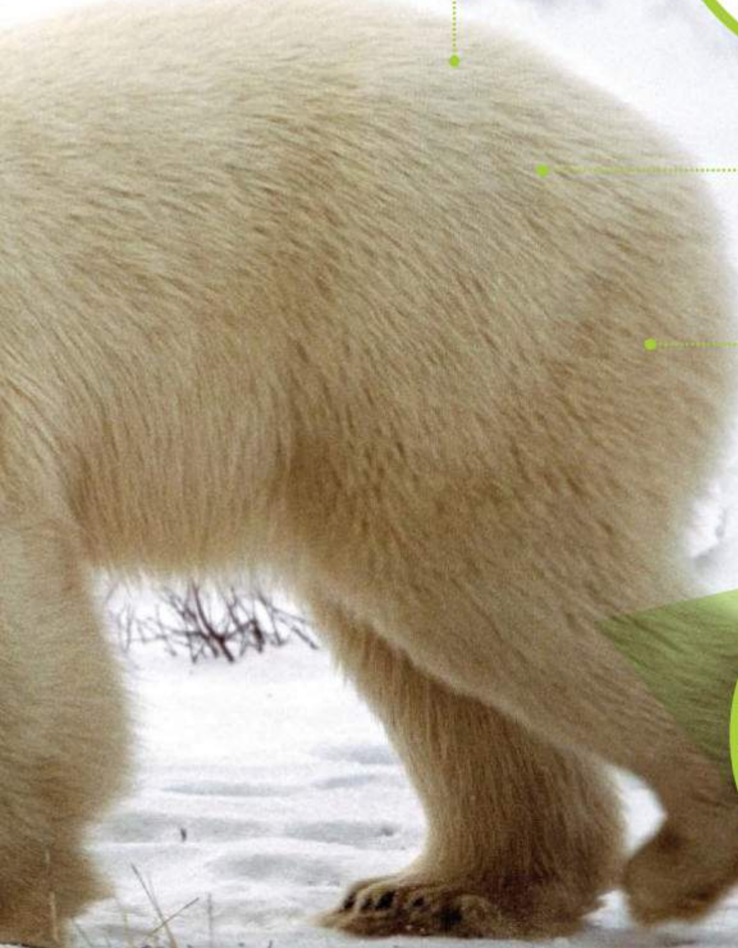
Metabolic changes allow survival against all odds, as well as amazing chemical adaptations, like the icefish, which has antifreeze literally running through its veins.

However, surviving the chill isn't all about adapting to seasonal changes. There are some animals in ecosystems such as the deserts that have to survive the daily extremes of day-to-night temperature fluctuations, and have developed incredible methods of coping with both extremes.

Furry defences

During the summer when the Arctic's snow has receded, the Arctic fox's coat is a brownish hue. This camouflages the animal against the tundra and scrubland and allows it to blend in seamlessly with its surroundings. When the snow starts to fall, the fox's coat moves with the seasons and transforms into a perfect icy white. These foxes have big, bushy tails to curl up under for warmth, thick, insulating fur to keep out Arctic chills, small eyes and snouts to minimise heat loss, and even furry soles on their paws to provide grip in their wintery home.

The fox's legs are short – keeping low to the ground avoids icy Arctic winds



Polar defences

The polar bear is perfectly adapted for life deep inside the Arctic Circle

Bountiful blubber

A layer of blubber up to 11cm (4.3in) thick sits beneath the bear's skin and keeps it warm during long swims.

Life habits

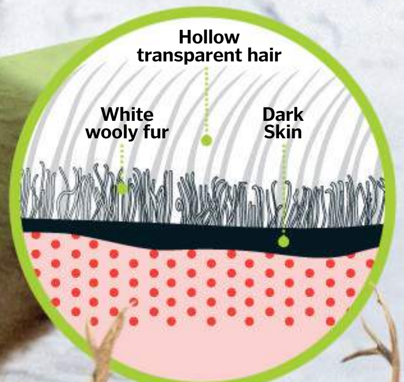
Pregnant female bears will dig a snow den to escape the harsh winters and give birth to cubs.

Downy undercoat

The polar bear's undercoat is so efficient at keeping in warmth that adult bears often overheat when running!

Specialised skin

Although they appear snowy white, a polar bear's skin is actually very dark – this helps to maximise the absorption of warmth from the Sun. The hairs comprising their outer layer of fur are also hollow, trapping air for extra warmth.



Migration tactics

Caribou, more often known as reindeer, roam the Arctic tundra in large herds. Although they migrate long distances to avoid the worst of the winter, they still have a remarkable set of adaptations to keep them snug in the cold. Two very different layers of fur keep the reindeer's body warm, and their hooves are a unique shape to provide excellent balance on wintery ground. The caribou's muzzle is covered in tiny hairs, as are its nostrils, which help to warm the freezing air before it reaches the lungs. This is especially important, as the reindeer relies on its sense of smell to sniff out a meal.

Caribou have complex digestive systems, allowing them to survive on lichens, their main winter food

Hot versus cold

What are the benefits or being warm or cold blooded when it comes to weathering the winter?

Polar bear

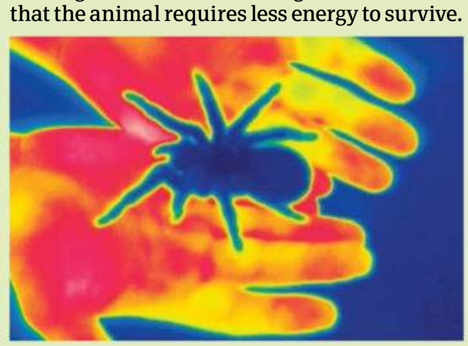
This thermogram shows the temperature of heat emitted from a warm-blooded polar bear. The bear's thick fur provides such good insulation that not much heat is lost. The most heat escapes through the bear's eyes, nose and ears, which is why they have such small facial features!

Elephant

Elephants are also warm blooded, and this thermogram shows that the elephant's body (and pile of manure) is much warmer than the environment around it. The animal is emitting more heat than the polar bear – this is because it doesn't need such extreme amounts of thermal protection for life in warmer climates.

Tarantula

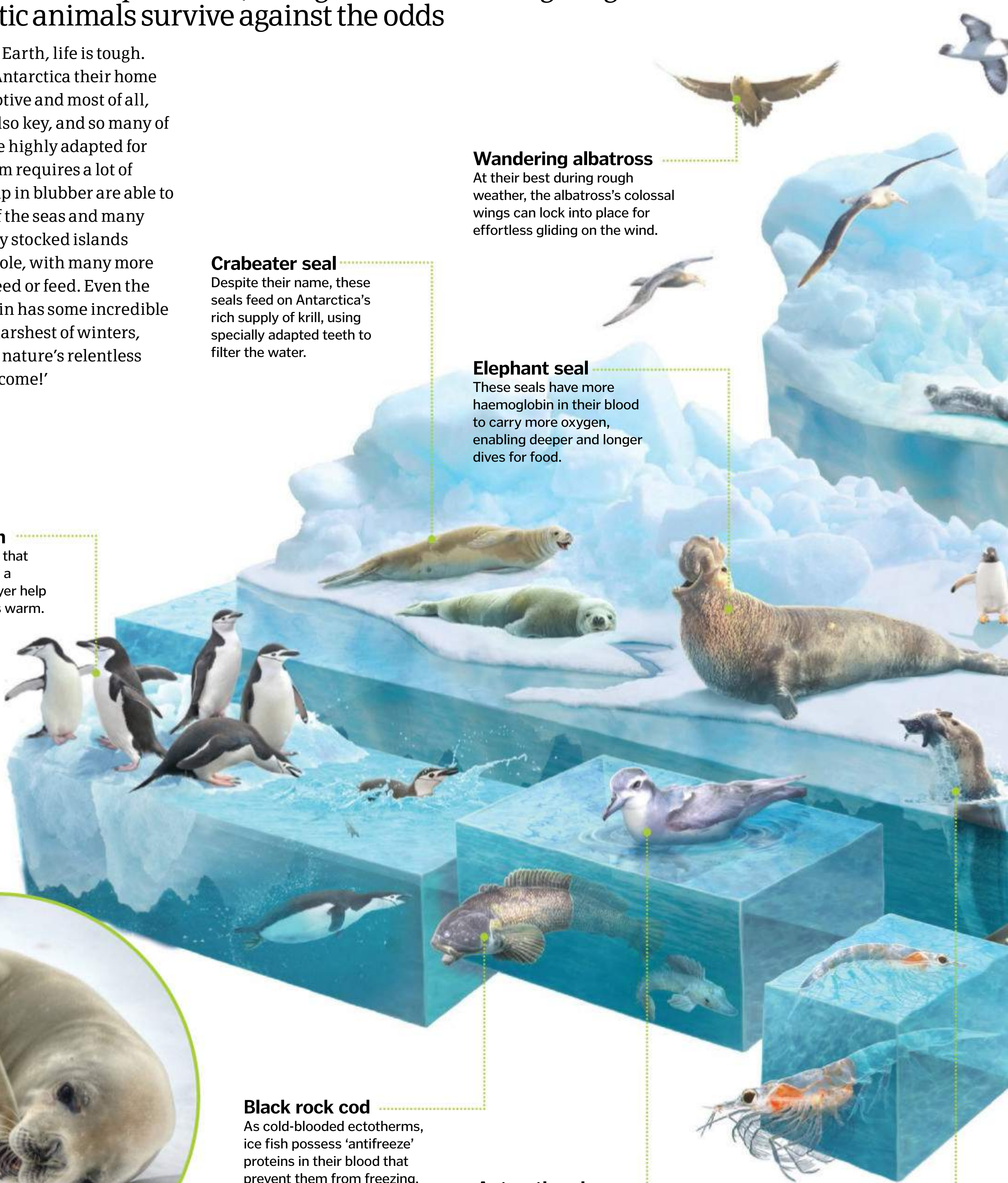
Unlike mammals, spiders are cold blooded. They are ectotherms, which means they use the external environment to regulate their temperature. The spider appears blue on this thermogram, much colder than the hands holding it. The benefit of being cold blooded is that the animal requires less energy to survive.



Animals of the Antarctic

Despite the sub-zero temperatures, biting winds and unforgiving terrain, Antarctic animals survive against the odds

At the very bottom of the Earth, life is tough. The animals that make Antarctica their home have to be resilient, adaptive and most of all, well insulated! Food is also key, and so many of Antarctica's residents are highly adapted for hunting, as keeping warm requires a lot of energy! Seals wrapped up in blubber are able to withstand the icy chill of the seas and many seabirds live on the richly stocked islands surrounding the South Pole, with many more visiting seasonally to breed or feed. Even the majestic emperor penguin has some incredible means of surviving the harshest of winters, serving as living proof of nature's relentless policy of 'adapt and overcome!'



Wandering albatross
At their best during rough weather, the albatross's colossal wings can lock into place for effortless gliding on the wind.

Crabeater seal
Despite their name, these seals feed on Antarctica's rich supply of krill, using specially adapted teeth to filter the water.

Elephant seal
These seals have more haemoglobin in their blood to carry more oxygen, enabling deeper and longer dives for food.

Chinstrap penguin
Densely packed feathers that insulate and also provide a protective waterproof layer help to keep these small birds warm.

Black rock cod
As cold-blooded ectotherms, ice fish possess 'antifreeze' proteins in their blood that prevent them from freezing.

Antarctic prion
Antarctica's islands support many breeding colonies of this bird, which feeds on the rich supply of fish, squid and crustaceans.

Leopard seal
A streamlined super-speedy swimmer, this seal keeps warm though rapid motion and a diet of warm-blooded critters.

Killer whale
A thick layer of blubber sits beneath the whale's skin to insulate and provide energy when food is scarce.

Sperm whale
These leviathans can hold their breath for up to 90 minutes on deep dives hunting for giant squid.

Minke whale
Minke whales leave the icy waters of Antarctica and head to the tropics to breed.

Gentoo penguin
Penguins are perfectly streamlined in the water, enabling them to be excellent fish hunters for sustaining energy reserves.

Emperor penguin
Four layers of specialised feathers, a plump body and plenty of huddling are just some of Antarctica's emperors' adaptations.

Mountain survivors

Up in the hills, it takes more than just a thick coat of fur to survive in this harsh ecosystem

High mountains provide a unique ecosystem, and with that comes a set of unique challenges for the animals that live there.

When winter falls, inhabitants have a few choices – one option is to wait out the worst of this energy expensive season and hibernate, like the marmot, which sleeps from October into April. The marmot's body temperature and heart rate drop, as the little critter conserves precious energy until the weather warms.

Other animals that stay awake through the winter will adapt their appearance. Some creatures, such as the rock ptarmigan, a chicken-sized bird found in rocky mountains of North America and Europe, changes colour for camouflage. Other animals, such as some deer species, will turn a darker colour. Although it stands out against the snow, the benefit is that darker colours retain more heat.

When it comes to staying warm, energy is everything and size really matters. Small animals need to eat much more in order to stay warm as they lose heat fast. The mountain shrew must consume its own weight in food every day just to survive the chill.

The snow cat

Snow leopards are perfectly suited to life in a mountainous wilderness

Nose
The nose is wide with an enlarged nasal cavity to heat cold air before it reaches the lungs.

Fur
A camouflaged coat of long fur with a thick, woolly undercoat keeps the cat snug in the snow.

Legs
Front legs are short and back legs are long and strong to power the leopard's colossal leap.

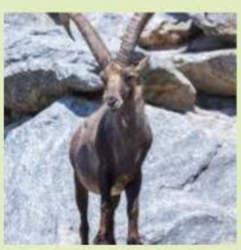
Tail
A long, thick tail helps it balance when traversing its rocky, mountainous home area.

Paws
Huge, wide paws act like snowshoes, distributing its weight as it stalks over the snow.

Animal mountaineers

Alpine ibex

Thick fur and nimble sure-footedness are the things that allow the ibex to thrive in the hills. Its specialised hooves help to grip the rock as it leaps across the terrain in search of vegetation to eat.



Elk

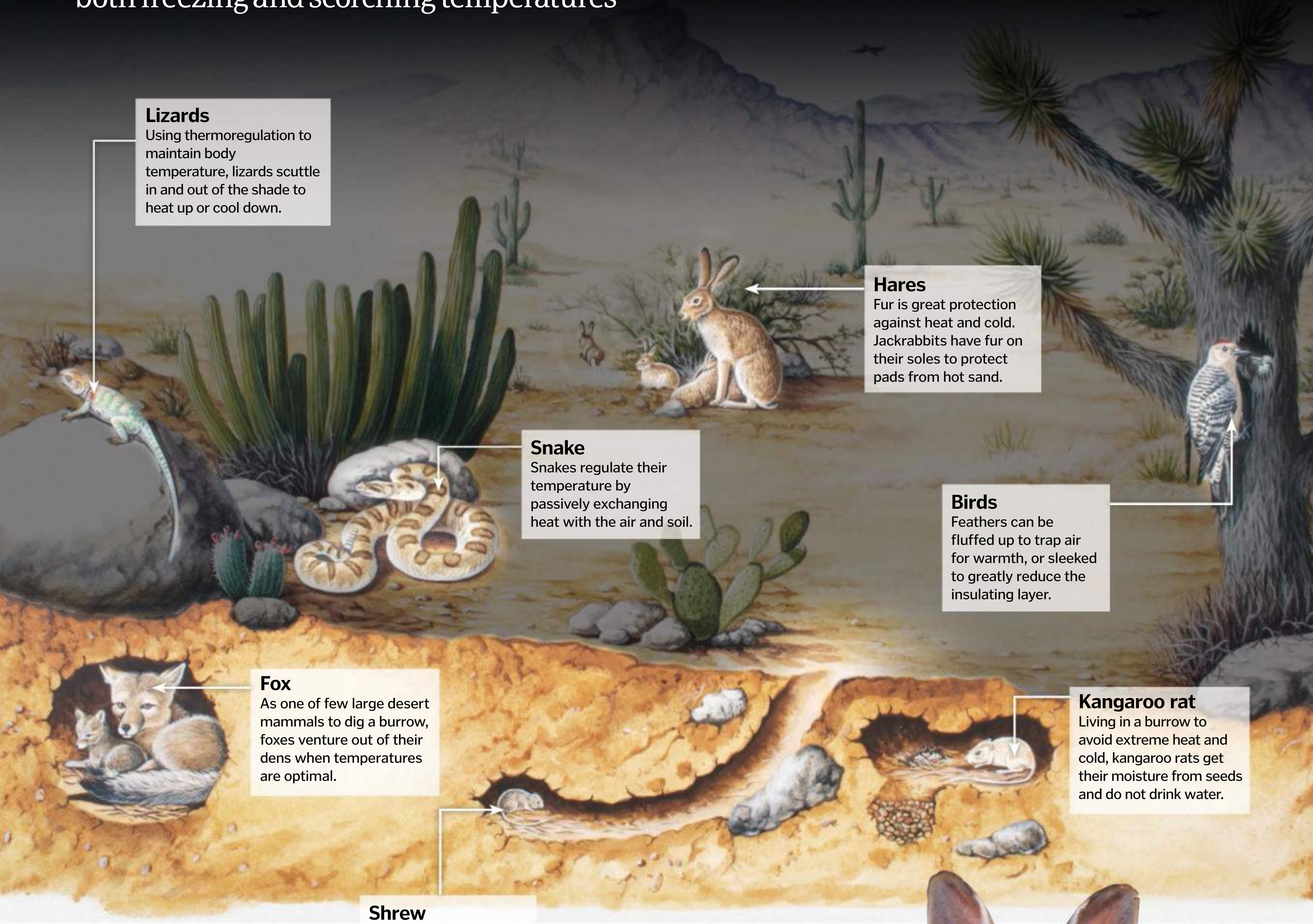
In summer, large herds of elk migrate to the mountains to graze in western USA. When the seasons turn, they head back down the hillside into they valleys where the weather changes are much less severe.

Yak

As one of the highest-living domesticated animals, yak have thick, shaggy coats to keep them warm. They also have much larger lungs and hearts, which help them deal with living at high altitudes.

Desert dwellers

In a world of sandy extremes, desert animals have to withstand both freezing and scorching temperatures



The desert is well known for its hot, dry and dusty expanses of burning sand. Animals that live here have to deal with scorching temperatures of up to 50 degrees Celsius (122 degrees Fahrenheit) and deal with less than 250 millimetres (9.8 inches) of rainfall per year. However, the clear, cloudless conditions that heat the desert to such soaring temperatures during the day also mean that during the night, temperatures regularly drop below freezing. These extreme conditions make it a constant challenge for animals to maintain a safe body temperature and survive.

One of the best strategies to escape both the heat and the cold is simply avoidance. Many small mammals will dig burrows in the sand to create a more manageable microclimate for themselves, while cold-blooded creatures will seek out sheltered spots in crevices or shadows of cliffs. Animals that are active during the day will be out and about at dawn, when the temperatures are at their coolest, but not in the frozen grip of night.

Larger animals don't dig burrows, but having a large body is actually beneficial in the desert – it takes longer to heat up. This makes it possible to stay cool for long enough until the sun starts to set. After this, fur can be fluffed up to insulate against the chill.

Life of a monarch butterfly

The butterfly king makes a spectacular migration, guided by instinct and an internal compass

The monarch is one of the most recognisable and beloved butterflies in the world. It is also one of the most remarkable. Each year, anywhere between 60 million and 1 billion of them undertake an incredible winter migration from the chilly regions of southern Canada and northern USA to southern California and the forests of western central Mexico – a distance of up to 4,828 kilometres (3,000 miles).

Monarchs have a wingspan of about 10.4 centimetres (four inches), and are identified by their striking black, white and orange colouring. Males and females are almost identical apart from a dark spot on the hind wing of the male – a scent gland that produces chemicals to attract females. As well as being undeniably beautiful, their bright colouring warns predators that they are foul tasting and poisonous.

The butterflies actually develop their poisonous quality as caterpillars. Female monarchs lay their eggs on the toxic milkweed plant, and the caterpillars feed exclusively on this. Its glycoside toxins are harmless to the monarch, but poisonous to the monarch's predators. By munching milkweed, the caterpillars develop a reservoir of toxins in their bodies, which persist in their system beyond metamorphosis and make them an ill-advised meal.

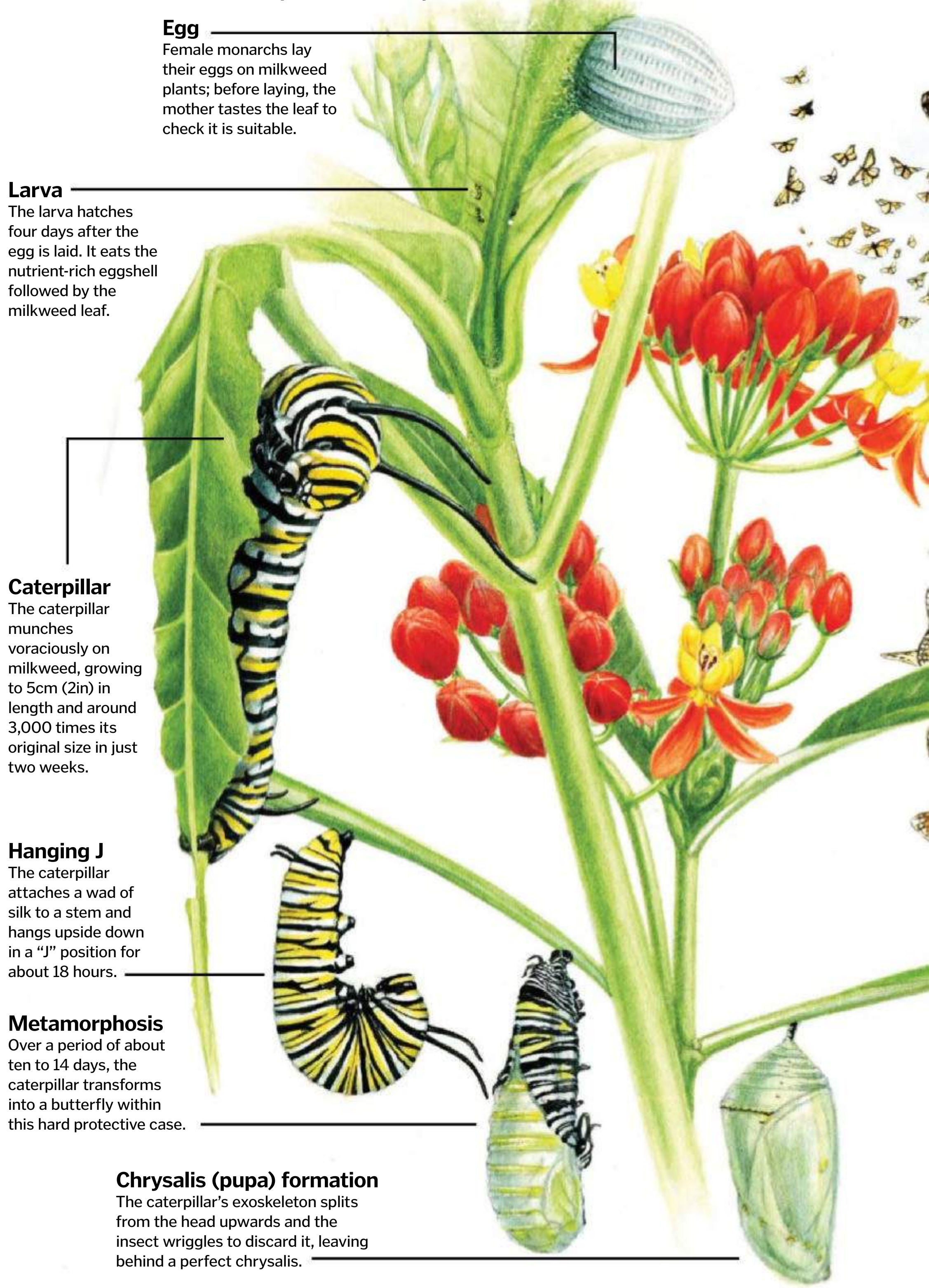
Most monarchs don't live longer than about five weeks. About three to five generations are born between early spring and the end of summer, but the generation that emerges from their chrysalises at the start of autumn is different. This is the "over-wintering" generation, and it's their job to fly south, away from the freezing North American winters, and ensure the survival of the species.

The migration is astounding, not only in terms of the distances the butterflies cover, but also for the fact that they instinctively know the route, despite never having made the journey before. Their arrival in Mexico usually coincides with Día de Muertos (Day of the Dead), one of Mexico's most important holidays. According to local legend, the arriving monarchs are believed to be the souls of the deceased returning to Earth.

Over-wintering monarchs live for up to eight months. They embark on the northward journey in early spring, mating on the wing and laying their eggs on milkweed plants in the southern United States. Their offspring will complete the journey north, before the whole cycle begins again.

Metamorphosis

The transformation from caterpillar to butterfly



"Between 60 million and 1 billion monarchs undertake an incredible winter migration"

Take off!
The monarch finally spreads its wings and takes flight, ready to begin the cycle all over again.

Flight preparation
A newly emerged butterfly waits about an hour for its wings to dry completely and become fully airworthy.

Emergence
The adult monarch pushes its way out, grabbing on to the exoskeleton; within minutes, its tiny folded wings grow to full size.

Final stages
The green pupa becomes transparent one day before the adult is ready to emerge.

Fluttering on the brink

Revered or not, the monarch is under threat. Populations have fallen drastically since the Nineties due to environmental degradation and human agricultural practices.

In Mexico, habitat loss from illegal logging, plus a string of natural disasters have reduced the availability of suitable overwintering grounds. In the US, herbicides used by farmers have decimated the monarchs' vital host milkweed plants.

Experts are also concerned about how global warming will affect rainfall patterns and alter the timing of the migration. Monarchs can't fly unless their body temperature is at least 30 degrees Celsius (86 degrees Fahrenheit), so cold snaps in Mexico – one of the predicted effects of climate change – could spell disaster for the species. According to the US Fish and Wildlife Service: "Unless we act now to help the monarch, this amazing animal could disappear in our lifetime."

Milkweed plants are essential to the monarch's survival

The mysterious Moeraki boulders

There are only around 50 boulders left on the beach today, after many were taken during the 19th century

Learn the origins of these legendary boulders located on New Zealand's Koekohe Beach

Maori legend states the Moeraki boulders are eel baskets, washed up after a large canoe was sunk. Their actual origins couldn't be more different; they formed roughly 60 million years ago. These boulders, which can weigh up to 7,000 kg (15,432 lbs) and measure up to three metres (9.8 feet) across, are actually calcite concretions.

The process that formed them is similar to that which forms oyster pearls, where layers of material repeatedly cover a core. For the boulders, this core would likely have been a bone fragment, wood or a fossilised shell. Over time, lime minerals in the sea accumulated around the central nucleus, growing into perfect, spherical boulders. This process could have taken up to around 5 million years. These boulders would have resided in the cliffs, as this was where the original seabed would have been. Erosion over time has worn away the cliffs, releasing them onto the beach. The Moeraki boulders now have legal protection, so it is an offence to damage, graffiti or remove them from the location.

The geology of rubies

Find out why scientists are struggling to prove the precise mechanism that forms these precious gemstones

Rubies are actually a type of rare mineral called corundum. Corundum is made up of densely packed aluminium and oxygen atoms, which are colourless on their own. However, when chromium ions replace some of the aluminium, bright red hues appear in the gemstone. Burmese warriors believed that placing rubies under their skin made them invincible in battle. Although this was not the case, rubies do have a hardness of 9.0 on the Mohs scale, beaten only by diamond among minerals.

How rubies are formed is still debated by scientists, but there are leading theories. It is widely accepted that plate tectonics are involved, specifically where the continents of India and Asia collide to form the Himalayas. What has baffled scientists is why rubies occur only erratically within this area's marble. Geologists need access to Burma's Mogok mine to prove or disprove any theory they put forward. Due to the delicate political situation in this country, this is not currently an option.

Ruby formation theories

Some researchers believe the key to ruby formation is salt's presence within the limestone. This salt would have mixed with the detritus (dead organic material) and helped form the limestone that produced rubies. Once the limestone became heated, the salt lowered the melting point of the mixture (a flux), allowing the aluminium to have enough mobility to mix with the chromium. Crystals of salt have been found within the ruby-containing marble, which aids this theory's likelihood of becoming widely accepted. Other geologists believe the process requires a liquid to transport silica away before rubies can develop. Silica will actually stop corundum formation, so there would be no chance of rubies forming in areas with high levels of this compound.

How wind erosion works

Learn about how the sheer power of the wind can shape and sculpt whole landscapes

Ever wondered how desert stacks get to where they are, how huge archways appear out of the rock and how colourful stripes stretch along rocky ledges in the desert? All of these are formed by wind erosion – the fancy term for which is Aeolian processes.

In the wide-open expanses of deserts, the sheer force of the wind can eat into softer types of rock, such as sandstone. Particles of rock are removed and lifted up by the wind (this is known as deflation) and then, as the wind blusters its way through the arid landscape, its path governed by the rock formations that dominate the terrain, these particles act almost like sandpaper on the rocks and gradually transform them into the streamlined shapes that follow the wind's path – a process known as abrasion. Over time, this gradual erosion produces the incredible landforms we associate with the desert, which are known as 'yardangs'.

The type of rock in an area greatly affects how the wind shapes it. Softer rock is easily eroded, while harder rock is far more resistant and is likely to be polished by the ferocity of the wind, resulting in smooth, buffed formations. Softer rock is carved out by the wind, producing much more pronounced effects, while a mixture of both hard and soft rock types can produce incredible formations such as buttes and arches.

Other types of desert erosion

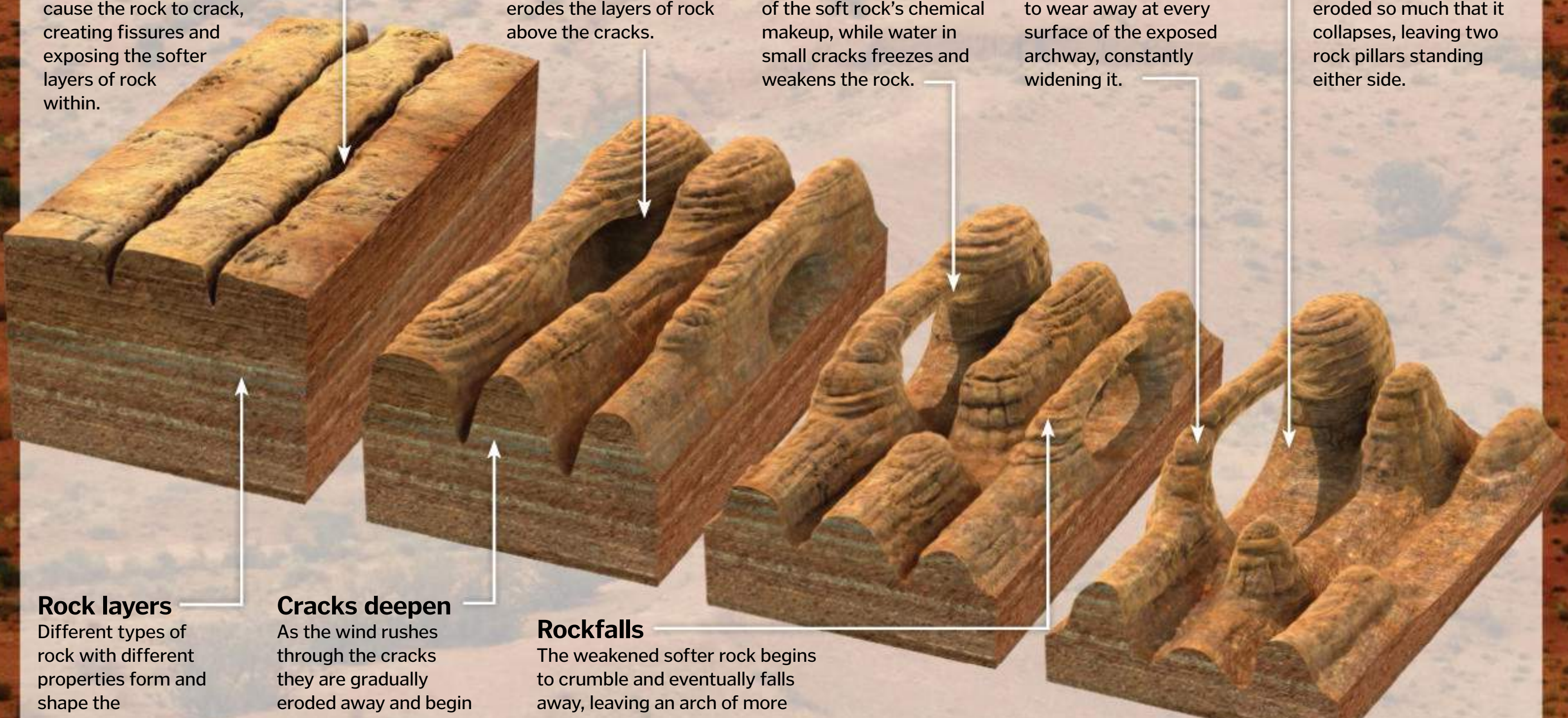
Although the deserts are known for having very little rainfall, the landscape can also be shaped heavily by water action. Rare flash floods are caused by thunderstorms and cloudbursts. The resulting rainwater picks up debris from the desert floor and charges its way through the landscape. The force and action of the water can carve its way through rock, and this is helped by the water's sediment load that, similar to the wind, eats away at the rock in its path. The steep slopes and lack of vegetation in the desert environment means there is little in the way to stop these flash floods tearing through the landscape and making their mark on the desert terrain, carving out canyons and gullies and buffering rocks as they go.

Water flowing through a desert landscape can shape the environment as much as wind erosion

Monument Valley in Utah, USA is a famous example of extreme wind erosion

How rock archways are formed

Over time, erosion by the wind helps to hollow out these incredible natural structures



Cracking
Geological processes can cause the rock to crack, creating fissures and exposing the softer layers of rock within.

Overlying rock
The wind gradually erodes the layers of rock above the cracks.

Rain and ice
Rainwater dissolves some of the soft rock's chemical makeup, while water in small cracks freezes and weakens the rock.

Archways widen
Wind erosion continues to wear away at every surface of the exposed archway, constantly widening it.

Collapse
Eventually, the arch is eroded so much that it collapses, leaving two rock pillars standing either side.

Rock layers
Different types of rock with different properties form and shape the landscape in layers.

Cracks deepen
As the wind rushes through the cracks they are gradually eroded away and begin to widen and deepen.

Rockfalls
The weakened softer rock begins to crumble and eventually falls away, leaving an arch of more resistant rock.

TRANSPORT

116
The most expensive cars

126 **Meet the VTOL drones**

114
The hybrid Mercedes F1

104
Airshow displays

"A 'full' or 'high' show will be performed in clear weather, when the cloud base is over 1,372 metres high"

AEROBATIC DISPLAYS

THE AMAZING TECH BEHIND THE DEATH-DEFYING DISPLAYS

Anyone who's seen the Red Arrows or the Blue Angels perform will know why many consider these pilots to be the world's best. They execute death-defying stunts at breakneck speeds; flying low to the ground and experiencing g-forces that makes their heads feel like 20-kilogram (44-pound) balls. They manage not only to control the aircraft, but also work in a team, pushing themselves and their aircraft to the limit.

The Blue Angels – the US Navy's flight demonstration squadron – and Red Arrows – the UK's Royal Air Force Aerobatic Team – have very interesting origins. After World War II ended, the US chief of naval operations, Admiral Chester Nimitz, was keen to maintain the high level of public interest in naval aviation. He feared that he would lose significant amounts of funding to other areas of the US Army; therefore, he devised a plan to create a flight exhibition team. Throughout the following decades, the Blue Angels flew a number of different planes, including the F6 Hellcat, the F-4 Phantom and the A-4 Skyhawk. They finally settled on the Boeing F/A-18 Hornet in 1986, the 40th anniversary of their conception, which they still use today. The Blue Angels now perform all over America, with air shows taking place between March and November.

The Red Arrows take their name from two aerobatic display teams that preceded them, the Red Pelicans and the Black Arrows. The first Red Arrow display team was formed in 1964 after concerns that aerobatic display pilots were neglecting their combat training, as they preferred to practice their stunts. The first official Red Arrows flew the Folland Gnat which had been used by the Yellowjacks in previous years. The original team flew with seven aircraft, until 1968 when they decided to adopt their now trademarked 'Diamond Nine' formation. In 1979, the BAE Systems Hawk – a modified version of the Royal Air Force's fast jet trainer – was chosen to replace the Gnat. The Red Arrows have now performed nearly 5,000 shows and celebrated their 50th season in 2014.

Death-defying displays

Find out how display pilots pull off their incredible manoeuvres with precision and coordination

Both the Red Arrows and the Blue Angels update their show routine each year, which typically lasts between 20 and 30 minutes. They prepare three different displays and choose which one to perform by examining the weather conditions. A 'full' or 'high' show will be performed in clear weather, when the cloud base is over 1,372 metres (4,500 feet) high. This allows a full, looping display to be carried out and means that even at the top of each loop, the planes will remain visible.

If the cloud base is lower than this and conditions are overcast, a 'rolling' or 'low' display is performed. When the weather is particularly bad and the cloud base is below 762 metres (2,500 feet), a 'flat' show is performed. This will include mainly flypasts and steep turns, as these are the only manoeuvres that remain visible in such conditions.

The first five Red Arrow planes (Reds 1 to 5) are the front part of the overall formation, known as 'Enid.' The remaining three planes, Reds 6 to 9, make up the rear section and are known as 'Gypo.' Reds 6 and 7 are the 'Synchro Pair,' and will perform opposition manoeuvres during the second half of the show. The Blue Angels also have a similar pair – the Blue 5 and 6.

Blue Angel 5 pilot Mark Tedrow spoke about the most challenging manoeuvre that he performs: "It's called the inverted tuck over roll which is where I'm trying to hide my plane behind Blue 6, so the crowd only see one aircraft. Last year we performed this upright, but this year we decided to make things harder and perform it inverted."

Being disciplined during a manoeuvre is vital for all display pilots. Hours of practice enable the Red Arrows to move nine aircraft as one. Red 2 pilot Mike Bowden, revealed how the Red Arrows achieve this visual feat: "There's a perfect position to be in during all manoeuvres and to achieve this we aim to triangulate a position on the Team Leader's aircraft," he explains. "We use two reference points to put us in the right part of the sky, which helps us to ensure that we don't get too close. Six feet [1.8 metres] apart is close enough when you've got nine aircraft in one vicinity."

Dye in the sky

Both the Blue Angels and the Red Arrows use smoke as a visual aid for spectators, enabling them to follow a traceable path from each plane during the display. The Red Arrows are famous for their white, red and blue smoke, while the Blue Angels stick to using just white smoke during their performances.

Adding small quantities of diesel into the jet exhaust pipe produces the vapour trails. As soon as this diesel meets the high temperatures found in the exhaust pipe it instantly vapourises, creating a strong, visible, white smoke. The Red Arrow pilots change the smoke's colour by adding red or blue dye, which they do through switches on their control column.

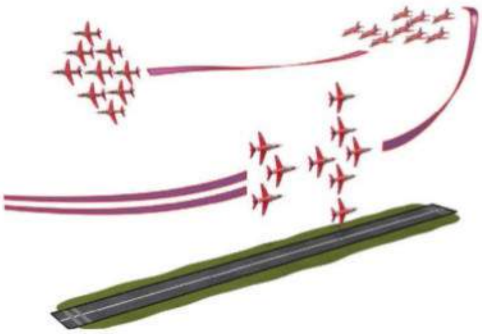
Although they do add something extra to the display visually, these vapour trails have a more important function. They enable pilots to judge wind speed and direction, and also make it possible for the Team Leader and the Synchro Leader to see each other even when separated by large distances. In this way, they are an essential part of flight safety.

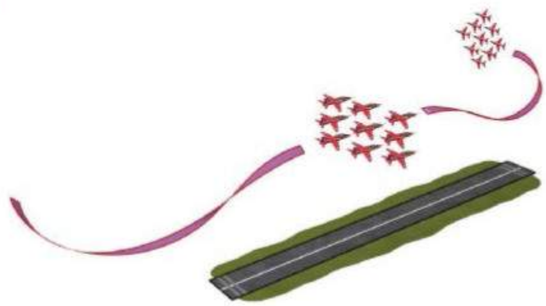
The Red Arrows can produce a vapour trail for seven minutes during a 30-minute display

"The first five Red Arrows planes (Reds 1 to 5) are the front part of the overall formation, known as 'Enid'"

DISPLAY MANOEUVRES

See the display manoeuvres that will be performed this year



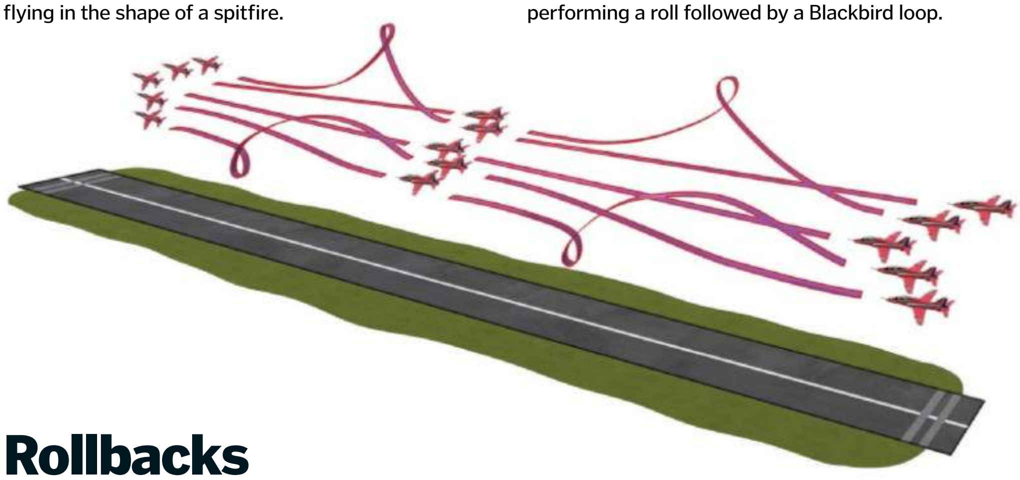


Spitfire Reversal

In recognition of the 75th anniversary of the Battle of Britain, the 2015 Red Arrows display will feature them flying in the shape of a spitfire.

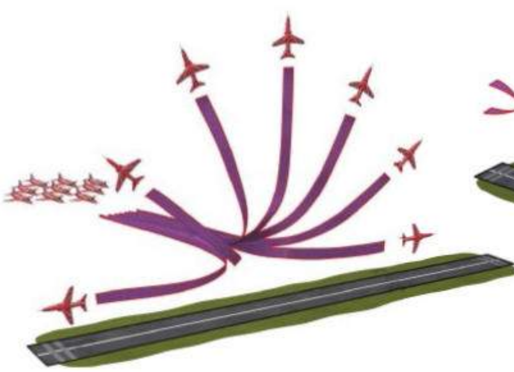
Whirlwind

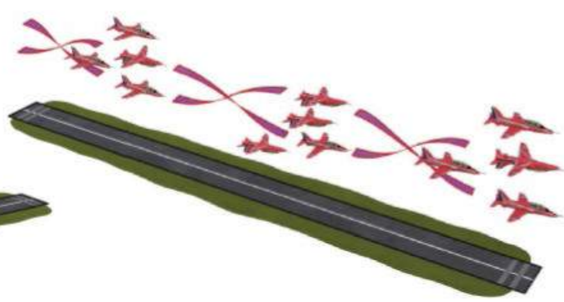
The Whirlwind is a brand new manoeuvre for the 2015 Red Arrow displays and features all nine jets performing a roll followed by a Blackbird loop.



Rollbacks

Red 2 will pull out of the Diamond Nine formation and perform a full 360-degree roll around Red 4 and then himself outside of Red 4. At the same time, Red 3 will perform an identical manoeuvre around Red 5. The difficulty here is to keep the roll as tight as possible, and to time the rolls so that they are the same speed and look the same to the crowd.





Vixen Break

All planes fly directly towards the crowd, before breaking in different directions up and away from the crowd, pulling up to 7g. This is often a crowd favourite, but is one of the simplest manoeuvres to perform.

Mirror Roll

Throughout their 2015 displays, the Red Arrows will be reviving the Mirror Roll which involves Red 6 performing an inverted barrel roll at -2.5g, while Reds 7, 8 and 9 remain in formation.

Inside the moves

Explore what makes the awe-inspiring manoeuvres work

All of the manoeuvres performed by the Blue Angels are difficult in their own way, but some of the stunts that look the hardest are actually the easiest. An example of this is the high speed-crossing manoeuvre, which is actually much easier to do than rolling into formation. This may look graceful, but it requires much more skill to perfect.

33 YEARS OLD
AVERAGE AGE OF A BLUE ANGEL PILOT

68 NUMBER OF SHOWS SCHEDULED FOR 2015

Fat Albert

Every show requires a huge behind-the-scenes effort. The Blue Angels use a C-130 Hercules to carry spare parts and support the many personnel that make their displays possible. Affectionately known as "Fat Albert", it has a range of 3,862 kilometres (2,400 miles) and can carry a colossal 20,412-kilogram (45,000-pound) payload.

1200 GALLONS (4,542 LITRES) JET FUEL BURNT PER HOUR

Double Farvel

This manoeuvre involves the first four Blue Angels. They perform a flypast in a very tight diamond formation while two of the planes, Blue Angels 1 and 4, are inverted.

Knife Edge Pass

To perform this manoeuvre, two planes fly towards the same point at high speed, before suddenly altering their position so they pass each other. This can be performed as low as 15.24 metres (50 feet).

Section High Alpha Pass

This is the slowest manoeuvre the Blue Angels perform, and involves two of the jets slowing to 193km/h (120mph) as they pitch the noses of their planes up to an angle of 45 degrees.

"The high speed-crossing manoeuvre is actually much easier to do than rolling into formation"

11 MILLION

SPECTATORS PER YEAR
(ABOUT THE SAME AS THE POPULATION OF GREECE)

© US Navy

Blue Angels versus Red Arrows

Blue Angel: F/A-18 Hornet

Find out about the Blue Angel F/A-18's most important features

"Efficient and reliable communications are important for the Blue Angels," says Kyetta Penn, aviation electronics technician for the Blue Angels. "It is vital that they are able to talk to each other during a display and also to the ground staff so we know what's happening and can troubleshoot problems."

GPS is also absolutely vital so that their location can be pinpointed, while radar enables the pilots to see exactly what is going on around them. "They can make sure they are clear to carry out their display and that there are no other aircraft in their airspace," Penn adds.

Although every effort is made to ensure the pilot's safety, things can go wrong. Recently, part of Mark Tedrow's F/A-18 became detached mid-flight, calling into question the lifespan of these ageing fighter jets. He explains exactly what happened: "I was in a high-g rendezvous with the diamond to execute a manoeuvre called 'the line of our swoop' which is when part of my wing became detached," he recalls. "This is why we take seven planes to each show; I was able to land my F/A-18, jump into the spare and complete the performance." The show must go on!

LOWEST MANOEUVRE
15.24m (50ft)

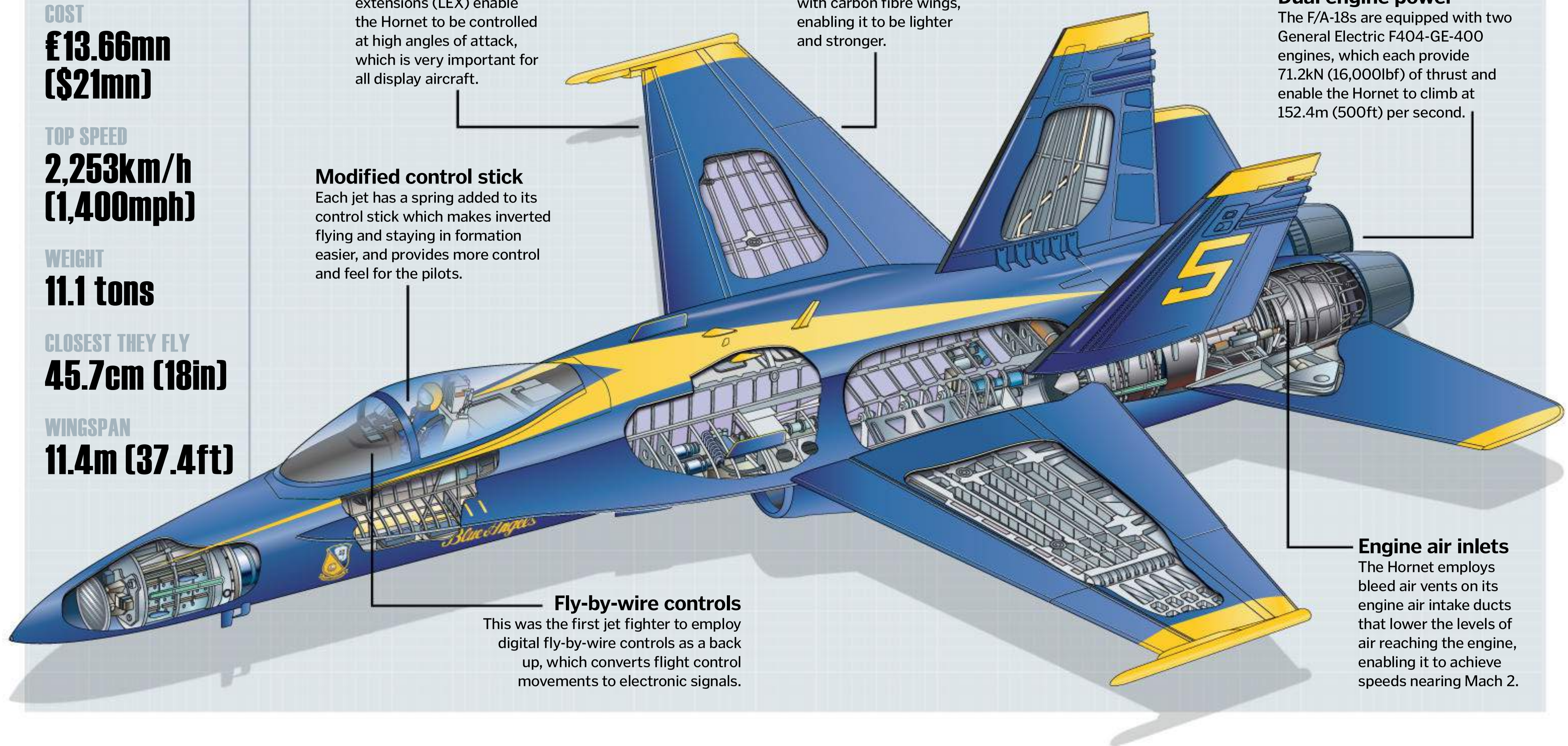
COST
£13.66mn ($21mn)

TOP SPEED
2,253km/h (1,400mph)

WEIGHT
11.1 tons

CLOSEST THEY FLY
45.7cm (18in)

WINGSPAN
11.4m (37.4ft)



Outstanding manoeuvrability
The leading-edge extensions (LEX) enable the Hornet to be controlled at high angles of attack, which is very important for all display aircraft.

Carbon fibre wings
The F/A-18 Hornet was the first aircraft to be fitted with carbon fibre wings, enabling it to be lighter and stronger.

Dual engine power
The F/A-18s are equipped with two General Electric F404-GE-400 engines, which each provide 71.2kN (16,000lbf) of thrust and enable the Hornet to climb at 152.4m (500ft) per second.

Modified control stick
Each jet has a spring added to its control stick which makes inverted flying and staying in formation easier, and provides more control and feel for the pilots.

Engine air inlets
The Hornet employs bleed air vents on its engine air intake ducts that lower the levels of air reaching the engine, enabling it to achieve speeds nearing Mach 2.

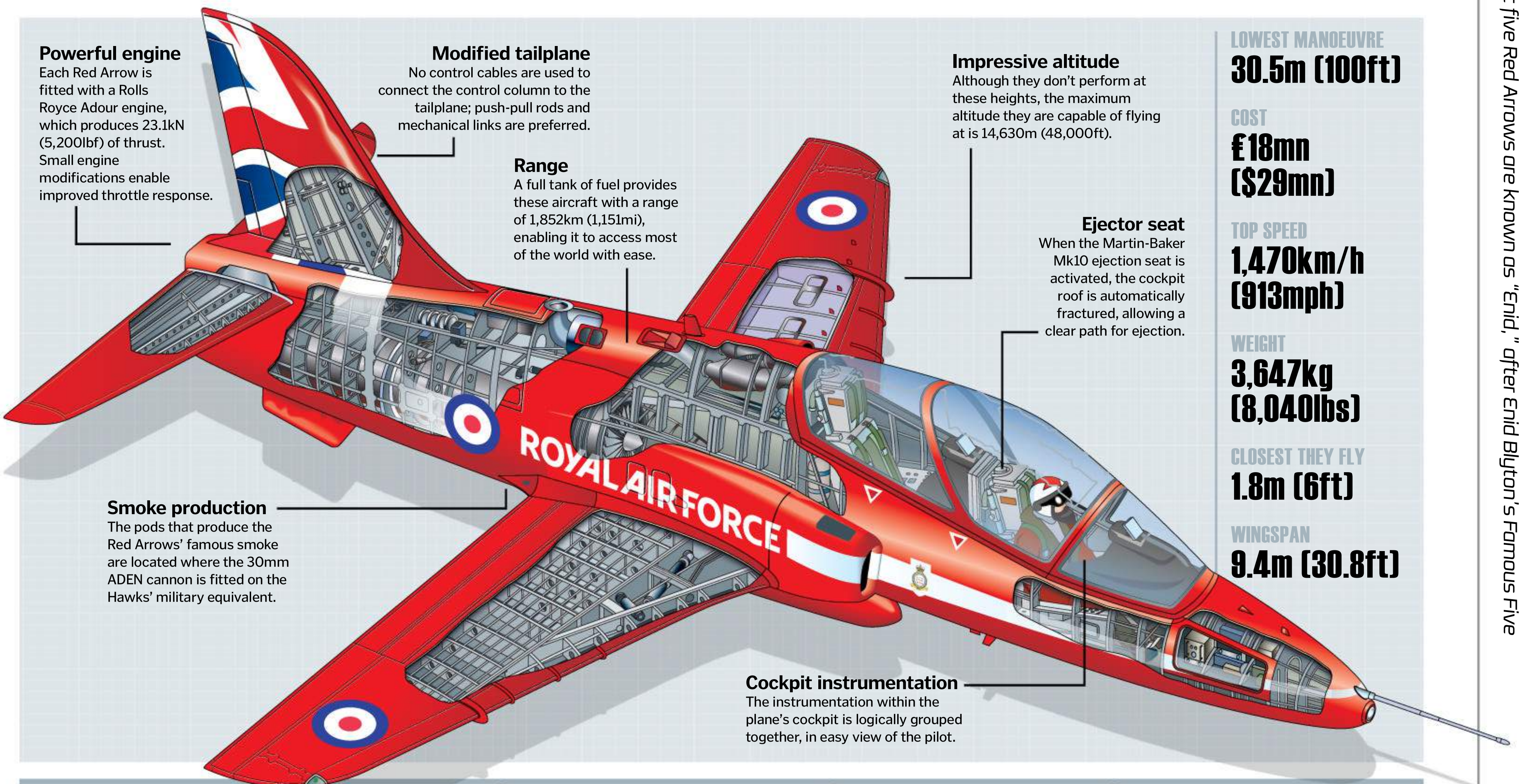
Fly-by-wire controls
This was the first jet fighter to employ digital fly-by-wire controls as a back up, which converts flight control movements to electronic signals.

Red Arrow: Hawk T1

Why the Hawk is still the best choice for displays

The Hawk T1 has been used by the Red Arrows since 1979 and Red 2 pilot Flt Lt Mike Bowden tells us why: "The Hawk is used by the military to train their pilots and the Red Arrows. Hawk is ultimately the same aircraft bar a few modifications," he says. "Although it is somewhat dated, the Hawk is absolutely perfect for what we do. It handles well, especially well in formation, and doesn't have any fancy gadgetry that could go wrong and cause unnecessary problems, which is very important considering how many shows we perform and the precision flying we need to execute."

The Hawk was designed to be easily fixed with the majority of its physical parts interchangeable for convenience – ideal for the Red Arrows who often perform on consecutive days. Maintenance is performed under very strict controls and all procedures are thoroughly supervised and checked to ensure the jets are safe to fly. In addition, the Hawk has backup systems that can be used if the primary system fails.



Powerful engine
Each Red Arrow is fitted with a Rolls Royce Adour engine, which produces 23.1kN (5,200lbf) of thrust. Small engine modifications enable improved throttle response.

Modified tailplane
No control cables are used to connect the control column to the tailplane; push-pull rods and mechanical links are preferred.

Range
A full tank of fuel provides these aircraft with a range of 1,852km (1,151mi), enabling it to access most of the world with ease.

Impressive altitude
Although they don't perform at these heights, the maximum altitude they are capable of flying at is 14,630m (48,000ft).

Ejector seat
When the Martin-Baker Mk10 ejection seat is activated, the cockpit roof is automatically fractured, allowing a clear path for ejection.

Smoke production
The pods that produce the Red Arrows' famous smoke are located where the 30mm ADEN cannon is fitted on the Hawks' military equivalent.

Cockpit instrumentation
The instrumentation within the plane's cockpit is logically grouped together, in easy view of the pilot.

LOWEST MANOEUVRE
30.5m (100ft)

COST
£18mn ($29mn)

TOP SPEED
1,470km/h (913mph)

WEIGHT
3,647kg (8,040lbs)

CLOSEST THEY FLY
1.8m (6ft)

WINGSPAN
9.4m (30.8ft)

GROUND CREW:

Aircraft engineers
Responsible for all the upkeep and maintenance on the jets, these engineers are present at all displays, ensuring that everything is functioning properly.

Flight operations
This team is responsible for all aviation planning and coordination, ensuring that the daily schedule can be carried out without delay.

Team manager
Head of the administration team, the team manager oversees all aspects of organising the team; from booking accommodation to organising leave passes.

images by Ian Moore

STAYING SAFE IN THE SKY

A number of steps are taken to keep aerobatic display pilots in one piece

The purpose of the Red Arrows and the Blue Angels is to thrill millions of spectators every year, but they never compromise on pilot safety. Due to the nature of their flying and the high number of shows they perform, accidents do happen, although they are less regular than they were when the aerobatic teams first performed. By studying both the pilots and the planes themselves, both teams are now aware of exactly how far man and machine can be pushed. Both the Blue Angel and the Red Arrow pilots wear specific safety equipment which enables them to perform their amazing displays with the minimum amount of danger.

Flying helmet
Although it primarily functions to protect the pilot's head, the helmet houses the communications equipment as well.

Oxygen mask
The Red Arrow pilots all wear oxygen masks fitted with a microphone, but their Blue Angel counterparts do not, as they typically don't fly above 4,572m (15,000ft).

Display flying suit
The Red Arrows and the Blue Angels have their own display suits accordingly coloured to suit their name. These are not worn during training.

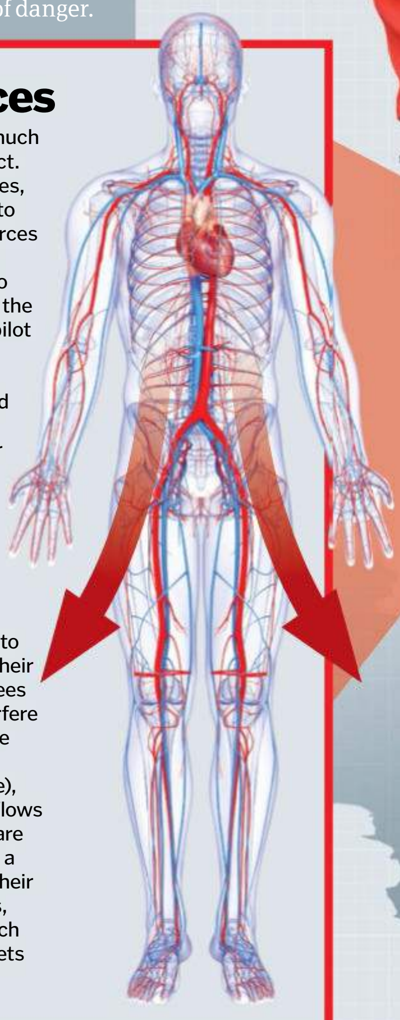
Life preserver
The life preserver is equipped with vital survival aids, such as a locator beacon and mini flares.

Personal equipment connector
Red Arrow pilots use this to connect to their aircraft. It provides oxygen and also inflates their 'g' trousers.

Anti-g trousers
Unlike the Blue Angels, the Red Arrows wear anti-g trousers to prevent blood from rushing to their legs during manoeuvres involving strong g-forces.

The Blue Angels are famous for their yellow flight helmet but do not wear an oxygen mask during performances

Combating g-forces



We measure gravity in terms of how much acceleration a force applies to an object. During some of their daring manoeuvres, aerobatic pilots will often be exposed to extreme gravitational forces. These forces direct their blood away from the brain towards their feet, causing the heart to stop pumping sufficient blood back to the brain which will eventually cause the pilot to totally blackout.

There are two ways that aerobatic pilots can counteract this problem. Red Arrow pilots wear a g-suit which employs a compressed air and bladder system. This compresses the legs and abdomen, reducing the likelihood of a blackout by reducing the amount of blood able to flow away from the brain.

Blue Angel pilots undergo specific training to enable them to fly without g-suits. This is because it is impossible to wear them when they fly, as they rest their forearms on their legs and use their knees as a fulcrum which the suits could interfere with if worn. Instead, they learn to tense their lower body muscles and exhale sharply (known as the 'hick' manoeuvre), that slows the rate at which the blood flows away from the brain. Blue Angel pilots are mandated to exercise at least six times a week, which keeps them fit and helps their bodies cope with g-force. On top of this, they train in a centrifuge each year which exposes them to extreme g-force and lets them practice dealing with its effects.

What it takes to be a display pilot

Learn about the rigorous interview and training that future pilots have to face

As you would expect, the interview process for selecting a new member of a display team is incredibly thorough. In the case of the Blue Angels, there has to be a completely unanimous (16-0) vote in favour of a candidate in order for them to join.

The Red Arrows will shortlist nine potential pilots via a pre-selection board, who are then invited for the seven-day interview. During this time, the candidates will undertake a flying test, meet the current team, accompany a Red Arrow pilot during a display practice and be formally interviewed. Once this has been completed, the current team will meet to decide which applicants have been successful.

Flight lieutenant Mike Bowden, who pilots Red 2, explains how first-timers learn to fly in unison: "When you fly in formation on the front line, you wait for the aircraft around you to move and copy what they do," he says. "If we were to do this in the Red Arrows it would make the overall formation look very broken, which is why we learn to follow voice commands from the 'Boss' Team Leader). We aim to perfect formation flying before moving onto the complex manoeuvres."

After meeting the initial criteria, Blue Angel applicants, or 'rushees' as they're fondly referred to, shadow the current pilots for numerous displays, typically from April until June. They watch everything the existing team do, attend team briefs and go to social engagements. Candidates are then whittled down, with the remaining potential pilots put forward for a daunting one versus 16 interview, where all current Blue Angel pilots and officers ask the candidate a question.

After this, the current team sits down and decides which candidates will be joining the following year's team. We spoke to LCDR Mark Tedrow, the lead solo pilot for the Blue Angels, who revealed how they train: "The Blue Angels are so unique and the flying we do is very different to anything you do in the military – it really does feel like learning to fly all over again," he says. "Between the end of one season and the start of the next, we aim to accumulate 120 training flights. This means that we are usually flying 15 times per week, which is a fairly gruelling schedule, but that means we can perform our manoeuvres practically from muscle memory."

Blue Angels recruits have to complete a variety of survival challenges before earning their qualifications to fly with the team

The experience you'll need to qualify

With only three spots available each year, gaining a place in a display team needs a very specific set of skills

RED ARROWS

Education

Many pilots are educated to degree level, but this isn't a requirement.

Experience

- ☑ Completed a frontline tour of duty.
- ☑ Assessed as being above average in their flying role.
- ☑ An exceptional flying record that includes reports on operational flights.

Flying Hours

A MINIMUM OF

HOURS IS EXPECTED.

Becoming Team Leader

To apply to become Team Leader, or the 'Boss', a pilot must have completed a three-year tour with the Red Arrows earlier in their career, which makes the number of people that can apply for this role limited. The Royal Air Force personnel department will select the officer they believe is best suited to carry out the wide range of duties expected of a Team Leader.

BLUE ANGEL'S

Education

Many pilots are educated to degree level, but this isn't a requirement

Experience

- ☑ Experience in an F/A-18.
- ☑ Carrier-qualified, active-duty Navy or Marine Corps tactical jet pilot.
- ☑ Combat experience, usually in landing on and taking off from aircraft carriers.

Flying Hours

A MINIMUM OF

FLYING HOURS IS EXPECTED.

Becoming 'The Boss'

The Chief of Naval Air Training selects the 'Boss', the Blue Angels commanding officer. The Boss must have at least 3,000 tactical jet flight-hours and have also commanded a tactical jet squadron. The Commanding Officer flies the Number 1 jet and leads all of the formations.

Mercedes 2015 is not the only fast part of the team; they have also been achieving the fastest pit stops with an average of 23.6 seconds

Mercedes F1 W06 hybrid

Find out why many consider Mercedes' 2015 entry to be the greatest hybrid Formula One has ever seen

Lewis Hamilton has had incredible success with Mercedes' 2015 F1 car, finishing on the podium in the first nine Grand Prixs

In 2014, the governing body of Formula One decided that it was time to introduce hybrid engines. This changed F1 forever; the 2.4-litre V8 gas-guzzling monsters were replaced with the much more economical 1.6-litre V6. This was hugely challenging for all the teams in F1, but none have dealt with the change as successfully as Mercedes. Their 2014 concoction dominated F1, but rather than resting on their laurels they set about making improvements immediately at the conclusion of the season.

Upgrades were implemented in almost every part of the car, including the mechanics, structure, aerodynamic properties and weight-saving technology. They have looked to squeeze every possible ounce of performance out of the design, which has clearly paid dividends if 2015's race results are anything to go by. The two drivers, Lewis Hamilton and Nico Rosberg, lost only 65 points out of a possible 516 in the first 12 races of the season. They took ten wins, 12 pole positions and eight fastest laps, not to forget seven one-two finishes.

At the time of writing it seems very unlikely that another team will be able to catch up to Mercedes. Another F1 driver / manufacturer double beckons for the German giants.

DID YOU KNOW? *As of 2015, F1 celebrates 65 years since its very first race, during which King George VI attended*

Mercedes' hybrid technology

As the age of the hybrid engine continues, Mercedes are constantly researching new ways to boost power and performance while remaining within Formula One's limits. The current engine produces the same power output as its V8 predecessors, but incredibly uses only two thirds of the fuel. It boasts a 40 per cent thermal efficiency compared to the 29 per cent achieved in Mercedes' previous models, which has led some to class this engine as the most efficient gasoline powertrain ever built.

STATS

WEIGHT: **702kg**

HEIGHT: **0.95m**

WIDTH: **1.8m**

LENGTH: **5m**

Hybrid engine
The PU106 Hybrid Turbo is a 1.6 litre V6, capable of producing 15,000 RPM in its mid-mounted, rear-wheel drive format.

Prioritised safety features
The cockpit is fitted with a survival cell that features built-in, impact-resistant construction with sturdy penetration panels, as well as front and rear roll structures to protect the driver in a crash.

Immense cost
In material costs alone, the average F1 car is worth a staggering £1.7 million ($2.6 million). The steering wheel is worth more than your average family car, around £50,000 ($77,000).

Tyres
Formula 1 has used Pirelli tyres exclusively since 2011. There are six different depending on race conditions, ranging from the slick super softs to treaded wets, which sit on magnesium forged Advanti wheels.

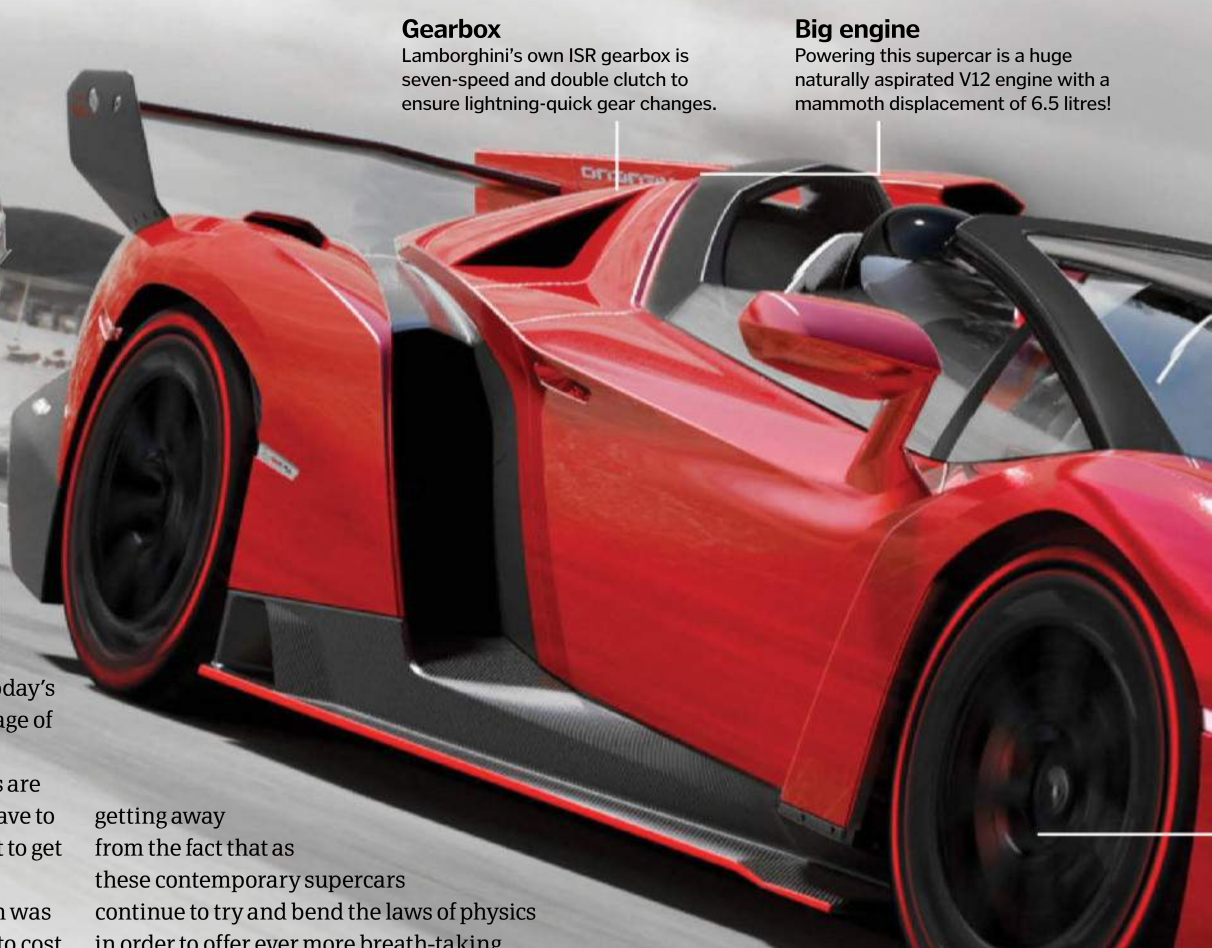
Chassis
The car's bodywork is made mostly of a carbon fibre composite, which is used for the engine cover, sidepods and the front and rear wings.

Front nose
One of the most noticeable changes from Mercedes' 2014 model is in the front nose. It is now shorter and stiffer than ever before, which helps protect the driver in a collision.

Hi-tech suspension
Both the rear and front suspension are fitted with carbon fibre wishbone and pushrod activated torsion springs and rockers, providing the most efficient and smoothest ride possible for the driver.

MULTI-DOLLAR

They cost more than three times the average house, so just what's behind the price tag of a modern supercar?



Among the hustle and bustle of today's busy public roads, there's a new age of motoring exotica roaring into prominence. These high-octane hypercars are making headlines chiefly because you'll have to pay the best part of one million dollars just to get one on your drive.

It started with the Bugatti Veyron, which was perhaps the most widely known supercar to cost around the £1 million mark (over $1.5mn) when it was launched in 2005. However, that has opened the floodgates to many more since, with today's hypercars including the LaFerrari, McLaren P1, Porsche 918, Koenigsegg One:1 and Aston Martin One-77 all commanding a seven-figure asking price.

Of course, there's a school of thought that this prominent rise in multi-million-dollar motors is simply down to the principles of supply and demand: the number of billionaires walking the planet has doubled since the 2008 financial crisis, and so luxury manufacturers may well take this into account when finalising the price points of their motoring exotica. While there may be an element of truth here, there's no getting away from the fact that as these contemporary supercars continue to try and bend the laws of physics in order to offer ever more breath-taking performance, the cost of parts, technology and even tooling required to produce the car from its outset has increased. The levy for this is passed onto the customer in order to protect a vehicle manufacturer's profits.

For example, lightweight titanium exhausts are often found at the rear of supercars, but titanium itself is an expensive material due to its durability at high temperatures and feather-light nature in comparison to more conventional materials such as steel. Similarly, carbon ceramic brakes take 20 days to produce but have a proven ability to improve braking performance (and not warp!) under extreme heat, which makes them essential for stopping a supercar capable of accelerating to great speeds. Though they perform better than steel items, the process of making ceramic brakes is a complicated one, inflating their cost significantly.

The premiums for these contemporary road rockets may be extremely high, then, but for your money you're guaranteed an exquisite supercar that boasts nothing but the zenith in craftsmanship, exclusivity and, of course, blistering performance. This has proved an attractive and ultimately popular venture for millionaires obsessed with the latest tech – and there's perhaps no better example than that of the luxury carmaker Rolls-Royce, whose sales have quadrupled since 2009.

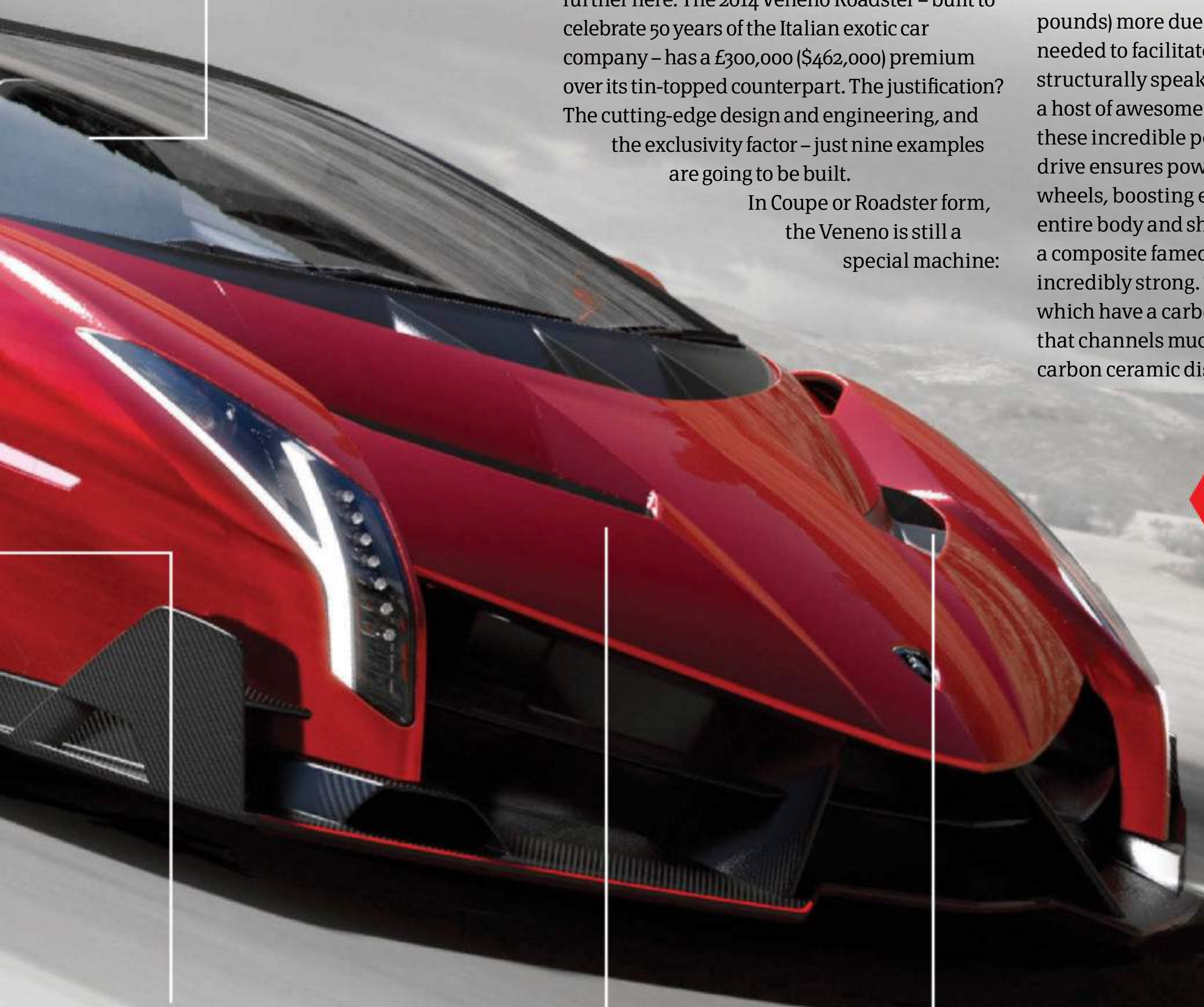
-MILLION MOTORS

LAMBORGHINI VENENO ROADSTER

It may not have a roof, yet the Veneno Roadster is still £300k more than its Coupe brethren

It's well known in motoring circles that German giant Porsche has mastered the art of charging customers more for less thanks to their veritable RS models, yet Lamborghini have gone one further here. The 2014 Veneno Roadster – built to celebrate 50 years of the Italian exotic car company – has a £300,000 ($462,000) premium over its tin-topped counterpart. The justification? The cutting-edge design and engineering, and the exclusivity factor – just nine examples are going to be built.

In Coupe or Roadster form, the Veneno is still a special machine: both iterations accelerate to 100 kilometres (62 miles) per hour in a mind-boggling three seconds before blasting on to a staggering top speed of 355 kilometres (221 miles) per hour. While the Roadster weighs 40 kilograms (88 pounds) more due to the chassis strengthening needed to facilitate the absence of a roof (which structurally speaking is an integral part of a car), a host of awesome tech is utilised to maintain these incredible performance figures. All-wheel-drive ensures power from the engine goes to all wheels, boosting efficiency, while nearly the entire body and shell is made from carbon fibre, a composite famed for being lightweight and incredibly strong. Then there are the wheels, which have a carbon fibre ring around the edge that channels much-needed cool air to the carbon ceramic discs.



Lightweight seats
The seats are made from Lamborghini's patented Forged Composite technology, which uses a resin to bind bundles of carbon fibre together.

Specially crafted wheels
Spokes on the wheels are specially designed to draw in air, cooling the brakes.

Carbon body
The entire body of the Veneno is made from the lightweight material carbon fibre, reducing overall mass.

Extra downforce
Vents in the bonnet enable air to flow up from under the car, aiding downforce by sucking the car to the floor.

£2.9 MILLION
$4.5 MILLION

POWER: 750bhp

TORQUE: 690Nm

0-100km/h: 2.9s

TOP SPEED: 355km/h

NUMBERS MADE: Nine

SPECIAL BECAUSE: Street-legal race car built to celebrate 50 years of Lamborghini.

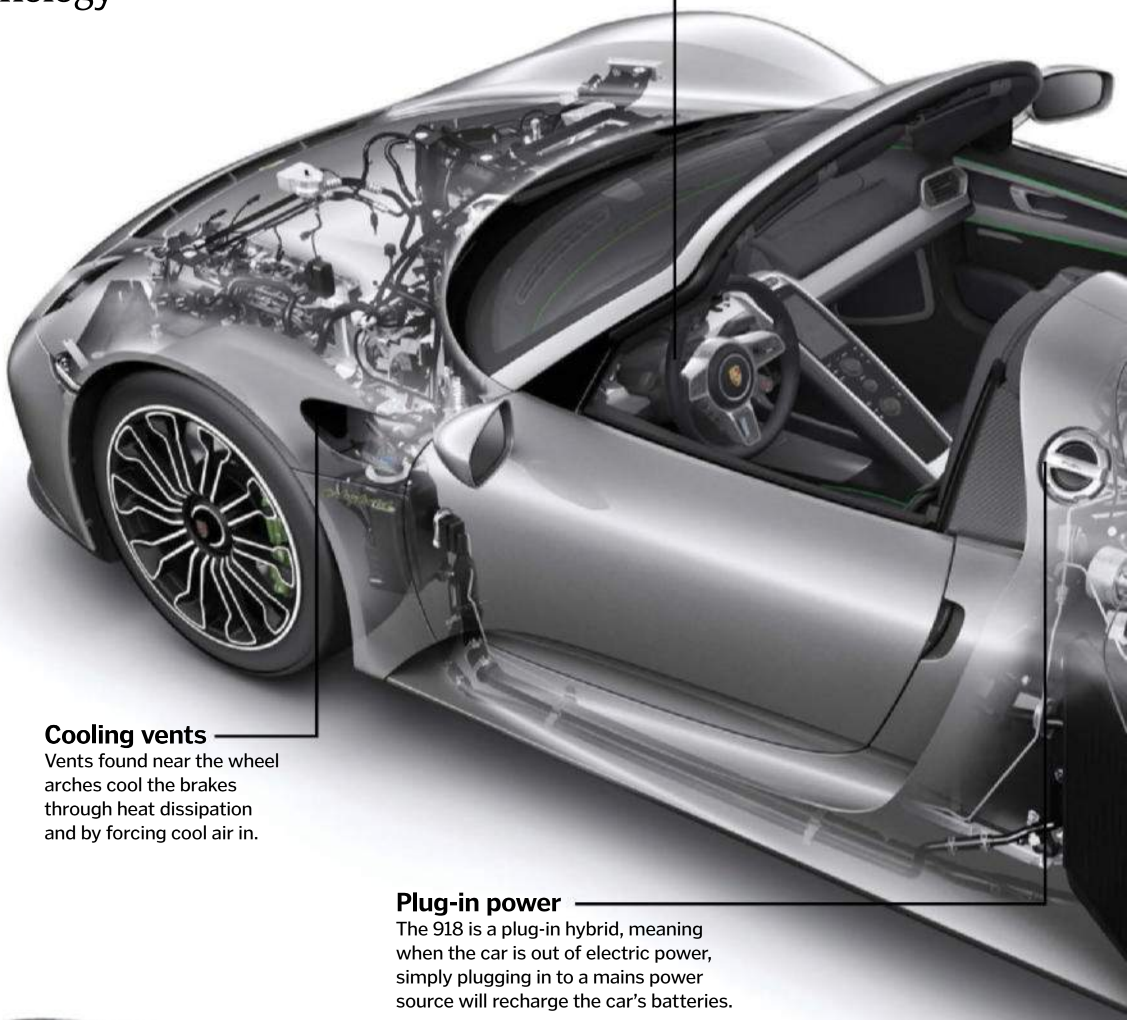
PORSCHE 918 SPYDER

Porsche's supercar of a generation melds insatiable performance with hybrid technology

The genius behind Porsche's latest hypercar lies not only in the fact that it can use its 4.6-litre V8 engine to race around the Nürburgring in just six minutes and 57 seconds (the fastest ever time for a road-legal race car). When the race track is long disposed of, the 918 can then utilise full electric mode and cruise into the heart of London and fall comfortably under the city's strict emissions regulations.

Indeed, Porsche's hypercar is a hybrid, meaning it is not only one of the fastest cars on the planet, but it is also one of the cleanest. The initial £550,000 ($845,000) fee may well make this car seem like great value compared to the Lamborghini Roadster, but optional extras on the 918 ensure the price soon rises: just take in the 'liquid metal' paint shade for some £41,000 ($63,000) – which is made up of nine super-thin layers to provide ultimate protection from stone chips without being detrimental to weight – while a clever front axle lift system helps raise the low-slung car in the event of a speed bump, all for the princely sum of £6,800 ($10,500).

Many parts of the Porsche 918 are handmade. Just one person assembles the entire V8 engine over hundreds of hours, and even the stitching around one sun visor takes a Porsche production line worker 45 minutes to do by hand, such is the high craftsmanship of Zuffenhausen's marquee supercar.



Mode selection
Switching between full race mode for the track or full hybrid mode for the city is easy; the driver merely flicks a toggle mounted on the steering wheel.

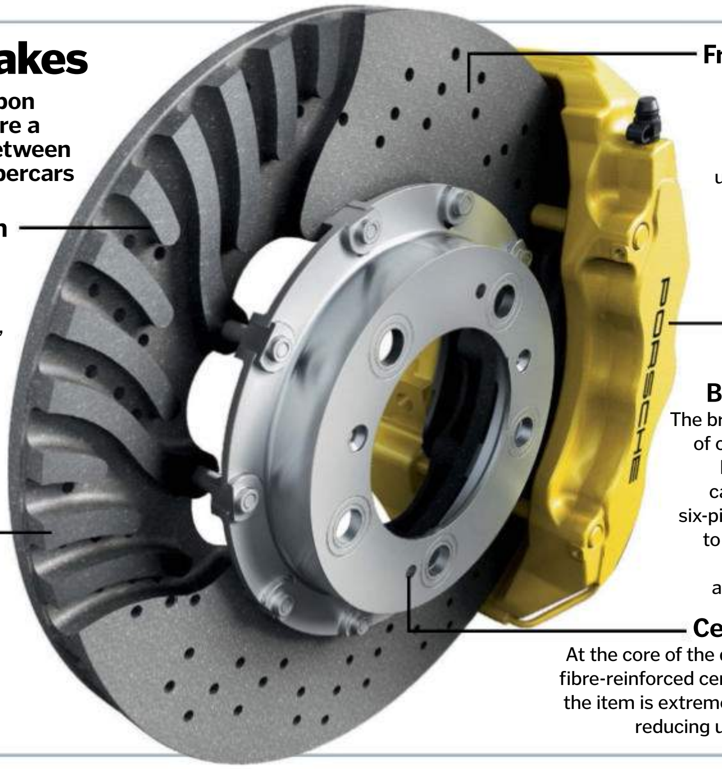
Cooling vents
Vents found near the wheel arches cool the brakes through heat dissipation and by forcing cool air in.

Plug-in power
The 918 is a plug-in hybrid, meaning when the car is out of electric power, simply plugging in to a mains power source will recharge the car's batteries.

Rear steering
Like on more sporty 911s, the rear wheels of the 918 Spyder steer with the front, aiding high-speed stability on turn-in to a corner.

Super brakes

Find out why carbon ceramic brakes are a common sight between the wheels of supercars



Heat dissipation
Various grooves and holes are drilled in to the discs to dissipate heat under heavy use, increasing efficiency.

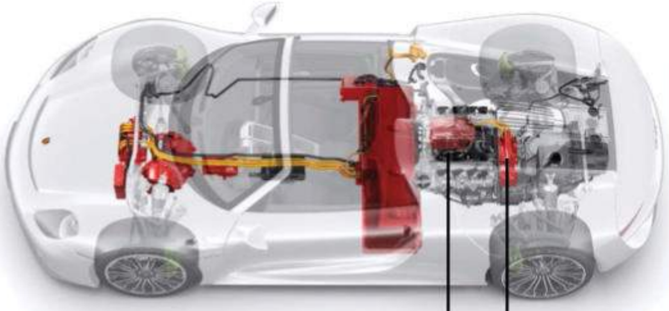
No brake fade
Carbon ceramic brakes don't produce dust under heavy use, meaning cars with ceramic brakes will have cleaner wheels than those with steel.

Friction coat
The discs are covered in an extra ceramic friction layer, useful when the callipers clamp hard on to the rotating disc.

Big callipers
The braking potential of ceramic discs is huge, so bigger callipers (usually six-piston) are fitted to help clamp the brake pad hard against the disc.

Ceramic core
At the core of the disc is a carbon fibre-reinforced ceramic, ensuring the item is extremely lightweight, reducing unsprung mass.

Want to switch between race mode and hybrid mode? Just flick a toggle on the steering wheel



Top-mounted exhaust
For the same reasons as the engine placement, the exhausts are mounted on top of the car, rather than underneath like on conventional cars.

Internal combustion engine
This is cleverly placed above the electric batteries, ensuring the heat given off rises immediately up and out the car.

Electric motor
These heavy items are mounted at the bottom of the car, lowering its centre of gravity and improving handling.

Adjustable rear wing
The 918's rear wing adjusts automatically in height and angle of attack according to the speed of the car.

SPYDER EXTRAS

1	'Liquid metal' special edition paint	$63,000
2	Front axle lift system	$10,500
3	'Weissach Pack' weight reduction package	$84,000
4	Electric comfort heating	$6,000
5	Seat trim, authentic leather	$26,000
6	Painted platinum wheels	$5,800
	TOTAL	$195,300

£0.7 MILLION
$1.08 MILLION

POWER: 887bhp

TORQUE: 540Nm

0-100km/h: 2.5s

TOP SPEED: 344km/h

NUMBERS MADE: 918

SPECIAL BECAUSE: One of the fastest cars in the world – and capable of producing zero emissions!

Porsche 918 VS McLaren P1

WEIGHT
PORSCHE 918: 1,675kg (3,692lb)
MCLAREN P1: 1,395kg (3,075lb)

TOP SPEED
PORSCHE 918: 344km/h (214mph)
MCLAREN P1: 350km/h (217mph)

ACCELERATION (0-100km/h)
0 40 80 100
PORSCHE 918: 2.5s
MCLAREN P1: 2.8s

POWER (OF WHICH ELECTRIC)
PORSCHE 918: 887bhp (285bhp)
MCLAREN P1: 903bhp (176bhp)

POWER TO WEIGHT
PORSCHE 918: 4.16lbs/hp
MCLAREN P1: 4.3lbs/hp

DRAG COEFFICIENT (Cd)
PORSCHE 918: 0.36
MCLAREN P1: 0.34

LENGTH
PORSCHE 918: 4,646mm / 182.9in
MCLAREN P1: 4,588mm / 181in

WIDTH
PORSCHE 918: 1,941 mm / 76.4in
MCLAREN P1: 2,134mm / 84in

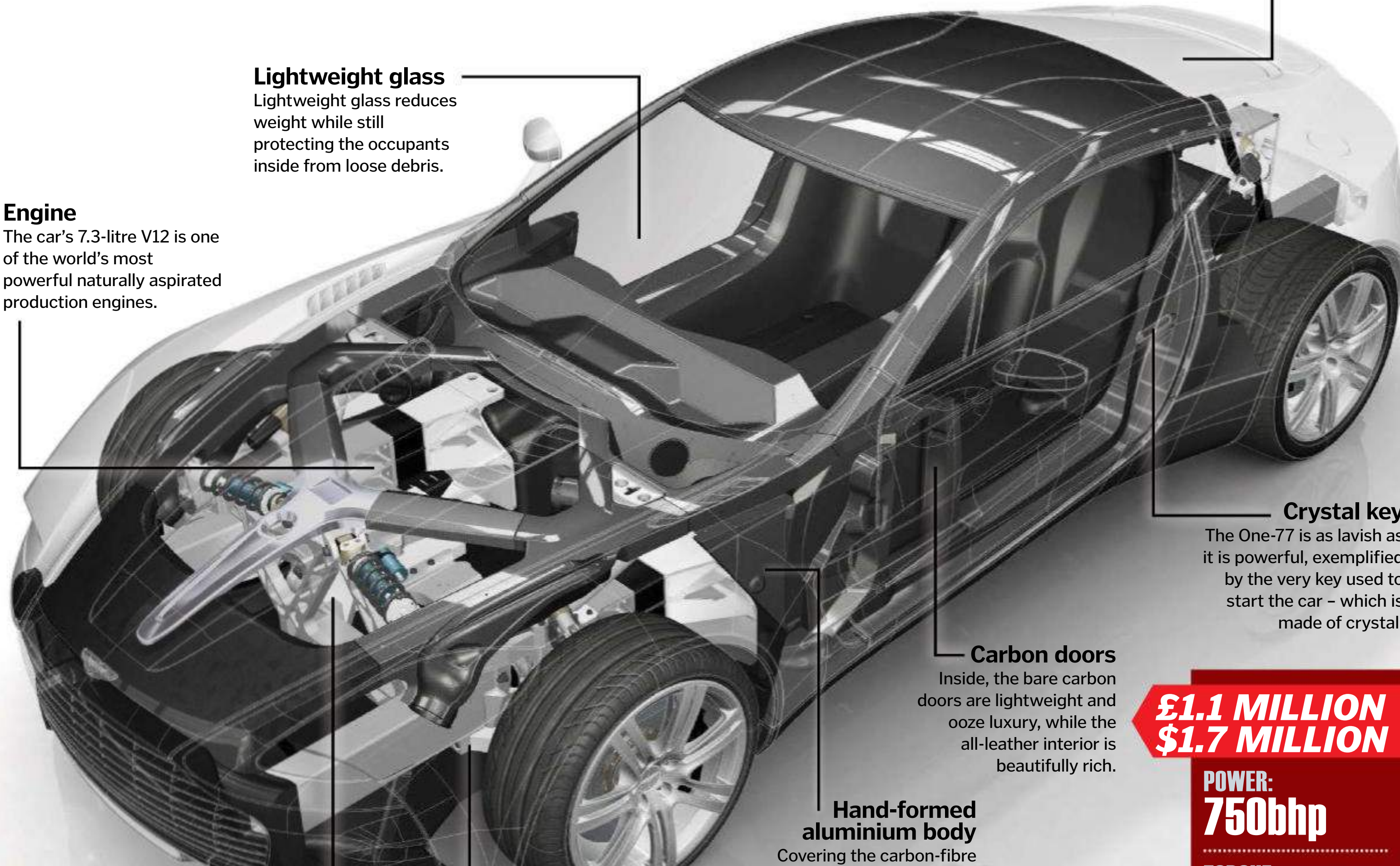
HEIGHT
PORSCHE 918: 1,167mm / 46in
MCLAREN P1: 1,188mm / 47in

ASTON MARTIN ONE-77

Britain's only million-pound supercar has performance, craftsmanship and rarity in abundance

Self-billed as 'the ultimate Aston Martin', performance is assured from the monstrous V12 engine, which produces a hefty 750bhp and propels the car well past 320 kilometres (200 miles) per hour mark. Superior craftsmanship comes in the form of a body handcrafted from lightweight aluminium – a practice unheard of on modern times of mass production.

And what of its rarity? Predictably just 77 examples of the One-77 are to be produced, meaning it's unlikely that you'll ever see one on the road. Shame.



Vehicle dynamics
The One-77 is shorter than the Aston Martin DB9, lower than the Vantage and the engine is mounted low too, ensuring an exquisite driving dynamic for the One-77.

Lightweight glass
Lightweight glass reduces weight while still protecting the occupants inside from loose debris.

Engine
The car's 7.3-litre V12 is one of the world's most powerful naturally aspirated production engines.

Crystal key
The One-77 is as lavish as it is powerful, exemplified by the very key used to start the car – which is made of crystal.

Carbon doors
Inside, the bare carbon doors are lightweight and ooze luxury, while the all-leather interior is beautifully rich.

Hand-formed aluminium body
Covering the carbon-fibre monocoque shell is a lightweight aluminium body that is entirely hand-crafted.

Clutch
The race clutch is specially designed to handle the sheer power generated from the engine, ensuring smooth gear changes even at high speed.

Ceramic brakes
Like its peers, ceramics are deployed on the Aston Martin as they won't warp under the extreme heat garnered during harsh braking of the 354km/h (220mph) car.

£1.1 MILLION
$1.7 MILLION

POWER: 750bhp

TORQUE: 750Nm

0-100km/h: 3.7s

TOP SPEED: 354km/h

NUMBERS MADE: 77

SPECIAL BECAUSE: One of the most powerful naturally aspirated engines in the world is mated to the most exclusive-ever Aston Martin.

Five of the most expensive cars from the movies

Aston Martin DB5
£2.9 million/$4.4 million
Goldfinger

Batmobile
£3 million/ $4.62 million
Batman (TV series)

1965 Shelby Cobra Daytona Coupe
£5 million/$7.7 million
Red Line 7000

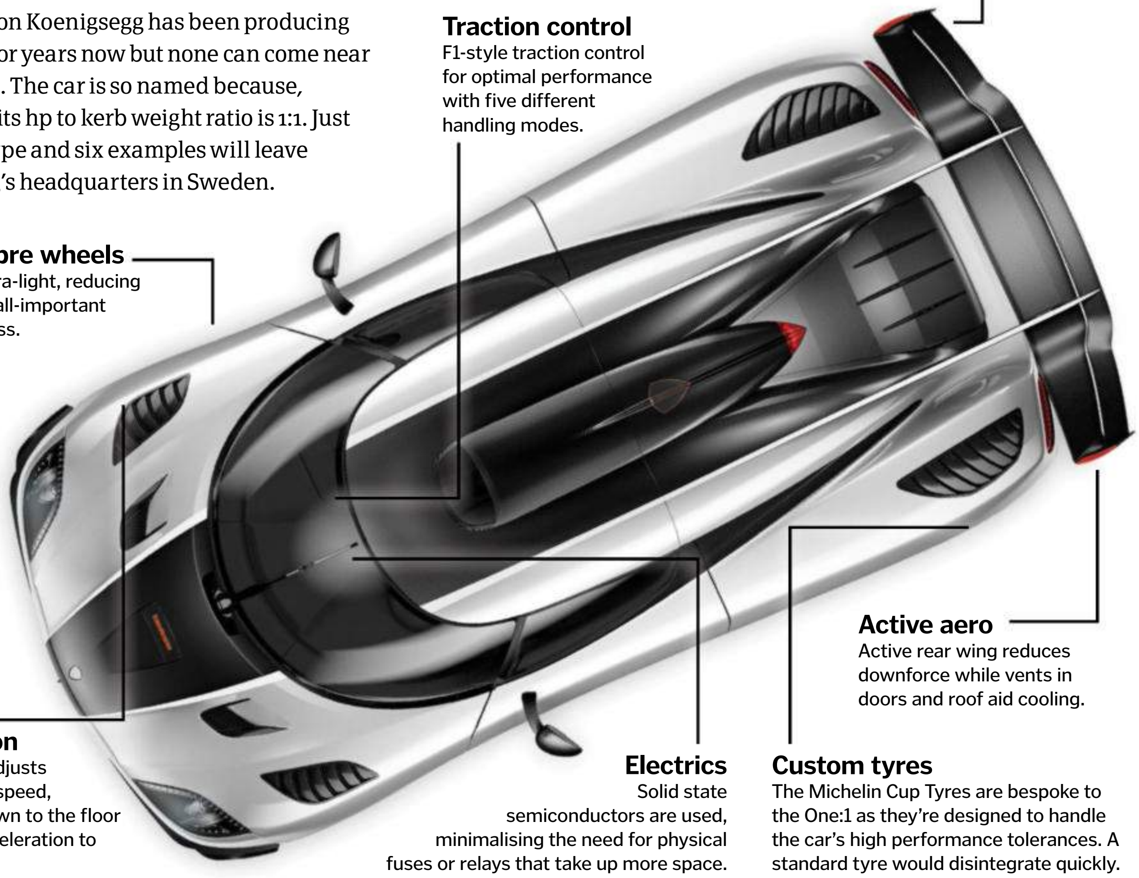
1961 Ferrari 250 GT
£7.1 million/$10.9 million
Ferris Bueller's Day Off

1968 Ford Gulf GT40
£7.2 million/$11 million
Le Mans

KOENIGSEGG ONE:1

Dubbed as the world's first 'megacar', it's the first production car with one megawatt of power

Christian Von Koenigsegg has been producing crazy cars for years now but none can come near to the One:1. The car is so named because, incredibly, its hp to kerb weight ratio is 1:1. Just one prototype and six examples will leave Koenigsegg's headquarters in Sweden.



Traction control
F1-style traction control for optimal performance with five different handling modes.

Underside aero
Under the chassis is perfectly flat, with venturi tunnels at the front and rear of the vehicle, producing a large 'ground effect'.

Carbon fibre wheels
These are ultra-light, reducing the vehicle's all-important unsprung mass.

Active aero
Active rear wing reduces downforce while vents in doors and roof aid cooling.

Active suspension
Ride height adjusts according to speed, hunkering down to the floor under big acceleration to reduce drag.

Electrics
Solid state semiconductors are used, minimalising the need for physical fuses or relays that take up more space.

Custom tyres
The Michelin Cup Tyres are bespoke to the One:1 as they're designed to handle the car's high performance tolerances. A standard tyre would disintegrate quickly.

£1.8 MILLION
$2.85 MILLION

POWER: 1,341bhp

TORQUE: 1,371Nm

0-100km/h: 2.8s

TOP SPEED: 439km/h

NUMBERS MADE: Seven

SPECIAL BECAUSE: Boasting an unrivalled power-to-weight ratio of 1:1.

LaFERRARI

Ferrari's first hypercar is also its first to utilise hybrid power

Ferrari needs no introduction as one of the most prestigious manufacturers of exotic cars in the world, but the LaFerrari is extra special because, for the first time, Ferrari has turned to electric assistance to help boost power of its famous internal combustion engine. Unlike the P1 or 918, which can run on electric mode only, the LaFerrari makes use of its Formula One-oriented KERS system (which recovers a vehicle's moving energy under braking) at the rear axle to add to the power of its 6.3-litre V12 engine to produce a jaw-dropping 950bhp. This is part of an array of technology the hypercar hijacks from Ferrari's successful Formula One racing team.

£1.15 MILLION
$1.76 MILLION

POWER: 950bhp

TORQUE: 900Nm

0-100km/h: 2.4s

TOP SPEED: >350km/h

NUMBERS MADE: 499

SPECIAL BECAUSE: Quite simply the most technologically advanced road-going Ferrari ever made.

How a car is made

We travel to Germany to witness cars being born on the European production line

It's 8.30am on a cold September morning in Cologne as we shuffle our way into the European headquarters of the international motoring giant Ford. Along with a select few from the media, we are the first-ever members of the press to have been invited for a sneak peak behind the factory gates. The statistics say a new Ford Fiesta rolls off the production line every 86 seconds, so let's begin the tour to see how.

It starts at the body shop where a robot will attach the car door to the vehicle. Laser lines are used to ensure a precise fit. The body of the car is then cleaned in the body washer to prepare for the paint job. More robot arms then coat the car in its new colour and the body then goes into the wax oven before heading to the assembly plant. Next comes the 'marriage' – the most important part of automobile production. This is where the engine is united with the body and the wheels are fixed.

Speaking of engines, 26 million of them have been made at the factory since it opened its doors on 12 February 1962. Our tour leader and Plant Quality Manager Axel Jaedicke explained that this was enough to make a line from Los Angeles and back! It was fascinating to see how an engine is carefully made from scratch, but most impressive of all was the skill in which it was put together so expertly and efficiently.

The vast hangar ran like clockwork and the whole process to build an entire engine takes a very speedy four hours and 12 minutes. To maintain the high quality levels expected, one in every 5,000 engines enters into a "teardown audit" where engineers analyse and measure the completed machine.

Ford also considers the efficiency of the production process as well as the engine itself. It

The three stages of assembly

How the production line is divided up

1 Trim line The first line attaches the smaller parts of the car such as the pedals, horn, seat belts, electrical switches, wipers and shock absorbers.

2 Chassis line As the name suggests, this line deals with larger bits of kit such as axles, fuel pipes, exhausts, tyres and bumpers.

3 Final assembly line The last few essential parts are brought on board on this line, like glove boxes, sun visors, parking brakes and the license plate lamp.

Engine timeline

The cylinder blocks queue up to be automatically machined in the state-of-the-art CNC machining centres.

A close-up view of a finished crankshaft being inspected for any visual flaws.

The cylinder block is bolted to a fixture on the assembly platen. The engine can now be rotated providing access to all sides of as it moves through the line.

The front view of a fully assembled engine, prior to its shipment to the vehicle assembly plant.

A side-elevation view of the intake side of the fully built and assembled engine.

uses a technique called Minimum Quantity Lubrication (MQL), which drastically reduces the amount of coolant and lubricant required to keep the factory's cutting tools working properly, saving both resources and power.

The EcoBoost has the lowest fuel consumption levels in its class and the majority of its main rivals use four-cylinder versions. Happily for petrolheads, Ford claims there is no loss of sound quality despite having one less cylinder than many other cars in its power range. Overall it's a pretty nifty piece of kit, but what's an engine without a car to put it in?

Before the car is born, between 60 and 80 potential designs are sketched and eight clay models are made to fine-tune the final product. At the beginning of the line, the car is an empty, hollow grey shell, a far cry from the sleek supermini it will end up being. A concrete jungle of welding machines, hydraulic robot arms and conveyer belts, the

Testing the Fiesta

The rigorous testing the supermini is put through

Power run

A test driver positions the Fiesta on a rolling road and will try to max out the car's power as it is held in place but allowed to accelerate. This test measures the torque of the wheels and the power of the flywheel to see if they are reaching the required level.

Water immersion

After the power is tested, the structural integrity of the vehicle must be assessed. Water is sprayed powerfully from every direction so any gap will be exposed. **HIW** sat shotgun during the test, hoping the car was leak free!

Bumpy road

The last test **HIW** witnessed was to decide whether the suspension was up to scratch. Traversing over all manner of rough and uneven roads, the Fiesta was put through its paces to make sure it could handle all surfaces.

Writer Jack Griffiths (second from left) on tour at the Ford factory

A fully assembled and ready-to-drive Ford Fiesta, fresh off the production line

The future of the assembly line

It seems as if all the new technology in the world today goes through Google in some way and now assembly lines can be added to that list. In partnership with international robotics company Foxconn, the focus is on increased automation and robotic use within the factories, taking the strain off manual labour. Tesla is another firm inventing new assembly robots. However, Tesla's stance is that less is more as it is creating robots suited to more than one function, for example able to put on wheels as well as attaching a door. This will hopefully have the dual effect of lowering costs while increasing efficiency at the same time.

Focus on quality

Interview with Harald Stehling, the head of the factory's quality control

What is the role of Ford Cologne in Ford's global and European operations?
Cologne is the lead global Ford Fiesta Plant.

What products does the factory produce and what is its 'flagship' product?
At the Cologne plant the 1.0-litre EcoBoost engine and the Ford Fiesta are produced. These are also the 'flagship' products.

Is a whole car created here or just part of the process?
At the Cologne plant it is stamping, body, paint, trim and final assembly, and the supplier park is connected to the production line as well. Most parts of the vehicle are created in Cologne.

What parts of the car are handmade and what is machine made? Why is this?
Parts are machine made, assembly mostly handmade. The reason for this is the high volume and cost for parts. The assembly is difficult to automate (such as wheel automation).

Does the Cologne plant have any competition with other factories?
Yes, in all metrics you can imagine, like safety, quality, volume and harbour report.

building is a hive of activity. On each vehicle 310 panels are welded together along with 1.2 kilometres (0.75 miles) of wiring. This is done at temperatures of up to 1,400 degrees Celsius (2,552 degrees Fahrenheit) so it was lucky we were behind protective glass when we got close!

Although the process looks like it never alters, 11,400 variations of the Fiesta are made between the three-door, five-door, ST and van models. The Fiesta's assembly is completed by a full immersion into an electro-coat fluid to add a corrosion-resistant layer, and the addition of waterproofing and vibration reducing sealer. But this is not the end of the journey; last but not least are Ford's rigorous testing procedures.

Each model will undergo 40 real-world crash tests, experience temperatures from -40 degrees Celsius (-40 degrees Fahrenheit) to 82 degrees Celsius (180 degrees Fahrenheit) and 130 hours of wind-tunnel testing at speeds of 130 kilometres (81 miles) per hour. HIW had a go at the water test – where torrential rainfall was imitated – and the suspension test, where some bumpy surfaces had to be navigated.

The Fiesta passed both with flying colours as the interior was left completely dry and little discomfort was felt on the rocky road. In addition to the physical exam, Ford employees utilise the power of the 3D Cave Automatic Virtual Environment (CAVE) to perform 5,000 virtual crash simulations. This system allows intricate details to be tested and improved upon without the need for more twisted metal and fuel consumption.

From the original concept ideas to the final touches on the assembly line, the life of a car is an extensive one even before it hits the showroom. It's fascinating how years in the making boils down to 86 seconds on the production line.

VTOL drones

From the humble helicopters of yesterday, to the robotic drones of tomorrow: vertical lift technology is on the rise

Almost as far back as humans have been dreaming of inventions for flight, they have been envisioning craft capable of vertical takeoff and landing (VTOL). Leonardo da Vinci is responsible for some of the earliest designs for today's most common VTOL aircraft – the helicopter. It may have only been an untested imagining of a flying machine that never got off the ground, but this so-called 'aerial screw' harnessed the essential principles of lift through air compression – utilising a corkscrew design.

Though scores of inventors and pioneers attempted to take to the skies in their own prototypes, over the following five hundred years not much further progress in VTOL flight was made. However, though the gyrocopter design was left well behind, the Italian genius's principles of flight in essence remained much the same.

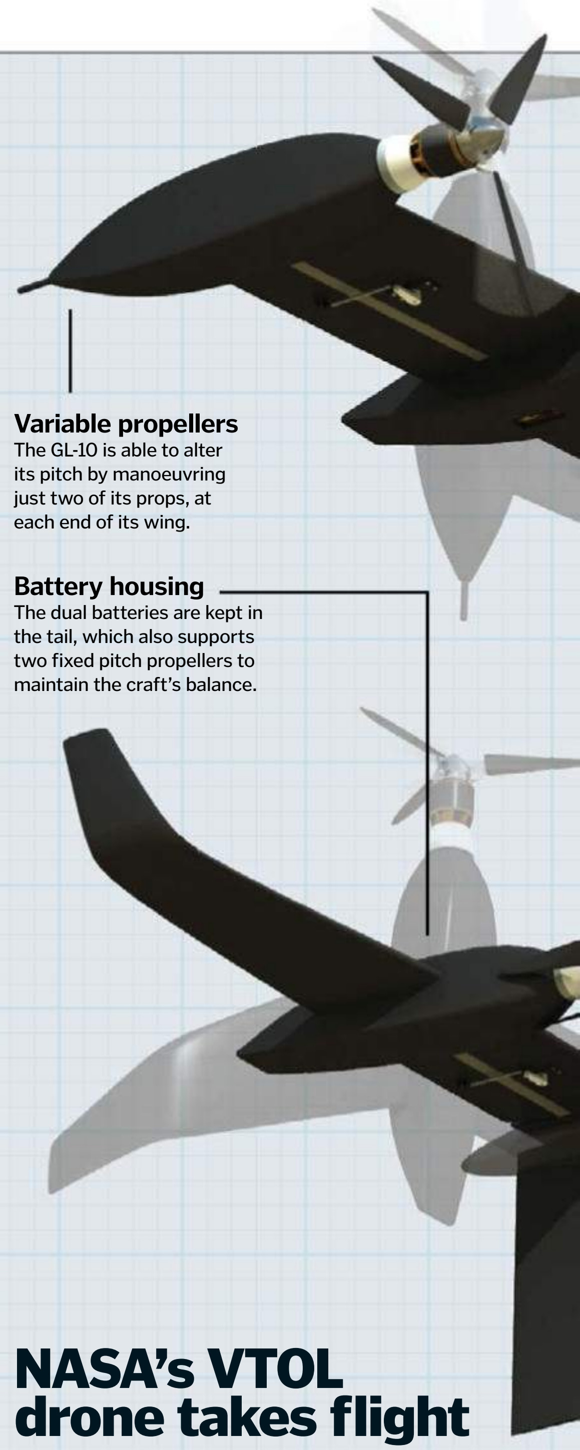
The beginning of the 20th century saw the age of flight dawn, and by 1907 some of the first-ever successful VTOL tests took place in France. Aviation pioneers Jacques and Louis Breguet, as well as Paul Cornu, had developed VTOL craft capable of hovering some feet off the ground for a short length of time – the first baby steps of vertical flight.

The following decades saw aviation technology race skyward, with designs popping up all over the globe. Though the Great War saw a huge demand for newer, faster and more-efficient aircraft to fight the enemy, helicopter designs were largely ignored until the 1940s and the Second World War. Nazi Germany used some early helicopters for reconnaissance, transportation and medical evacuation, but it wasn't until 1944 that the first mass-produced helicopter was revealed.

Hundreds of engineer Igor Sikorsky's R-4, R-5 and R-6 helicopter models were built during the final year of WWII to aid the Allies, and by the end of the war the VTOL craft was quickly gaining acclaim. Unlike da Vinci's gyrocopter design, this modern helicopter used rotor-blades to rapidly compress air downwards to create the necessary lift, and a tail rotor-blade to prevent the aircraft spinning.

As the world cooled into the threatening Cold War, it was the opinion of many that VTOL craft ▶


The GL-10 on its maiden test flight in 2014, tethered by a safety cable

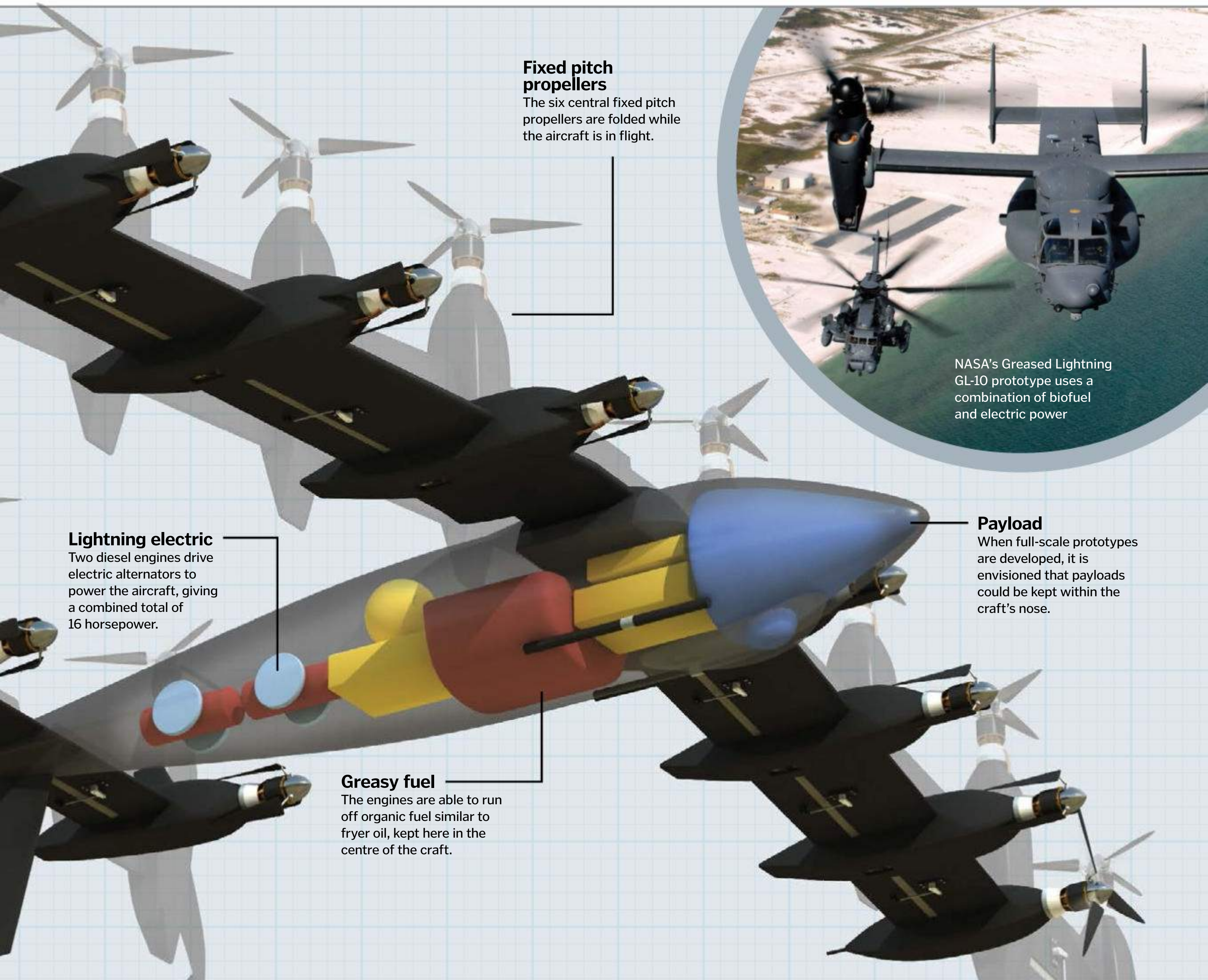


NASA's VTOL drone takes flight

NASA's hybrid-electric craft, dubbed Greased Lightning GL-10, may only have a three-metre (ten-foot) wingspan, but it has already shown promise for stretching VTOL technology much further. Its ten distinctive propellers provide maximum lift efficiency while travelling vertically, before both wing and tail panels tilt to transfer GL-10 to horizontal flight. Only two propellers do all the work at this point, to save energy, while the rest fold back aerodynamically.

It's the combination of biofuel and electric power that gives the craft its nickname – the grease of the fuel and the lightning of the batteries. The hybrid design of the engine means it's far less cumbersome than a standard jet or combustion engine, enabling not only a sleeker design but also far less wasted energy.

While the GL-10 prototype is obviously far too small for transporting any significant payload, NASA has revealed its GL-10 represents a 'scale-free' design, meaning the weights and measures of Greased Lightning could work in much larger sizes. This means that craft similar to GL-10 may become more and more common if further tests are successful.



NASA's Greased Lightning GL-10 prototype uses a combination of biofuel and electric power

The most famous VTOL aircraft

V-22 Osprey
Developed by US manufacturers Bell and Boeing, the Osprey's two unique tilt-rotor propellers provide its VTOL ability. They also enable the craft to reach speeds of up to 500km/h (311mph).

BAE Sea Harrier
Developed during the 1970s, the Harrier Jump Jet utilises four separate vector nozzles to direct its engine thrust. In this way it is able to transition from vertical to horizontal flight, and even hover.

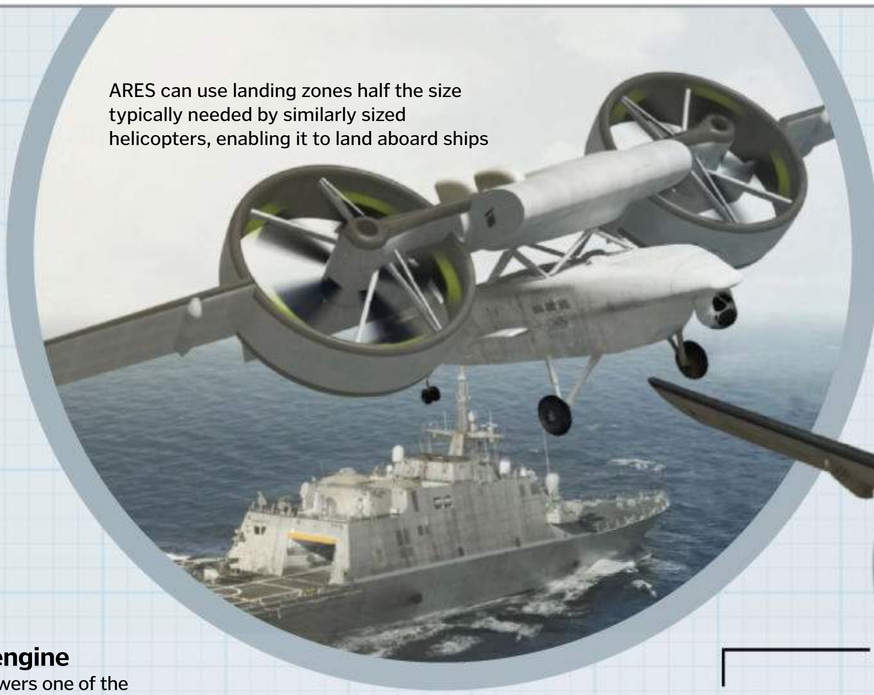
Boeing CH-47 Chinook
Considered one of the great workhorses of modern militaries all over the globe, the Chinook's twin-rotor design enables it to transport hefty payloads of up to 10,886 kilograms (24,000 pounds).

Unmanned VTOL goes to war

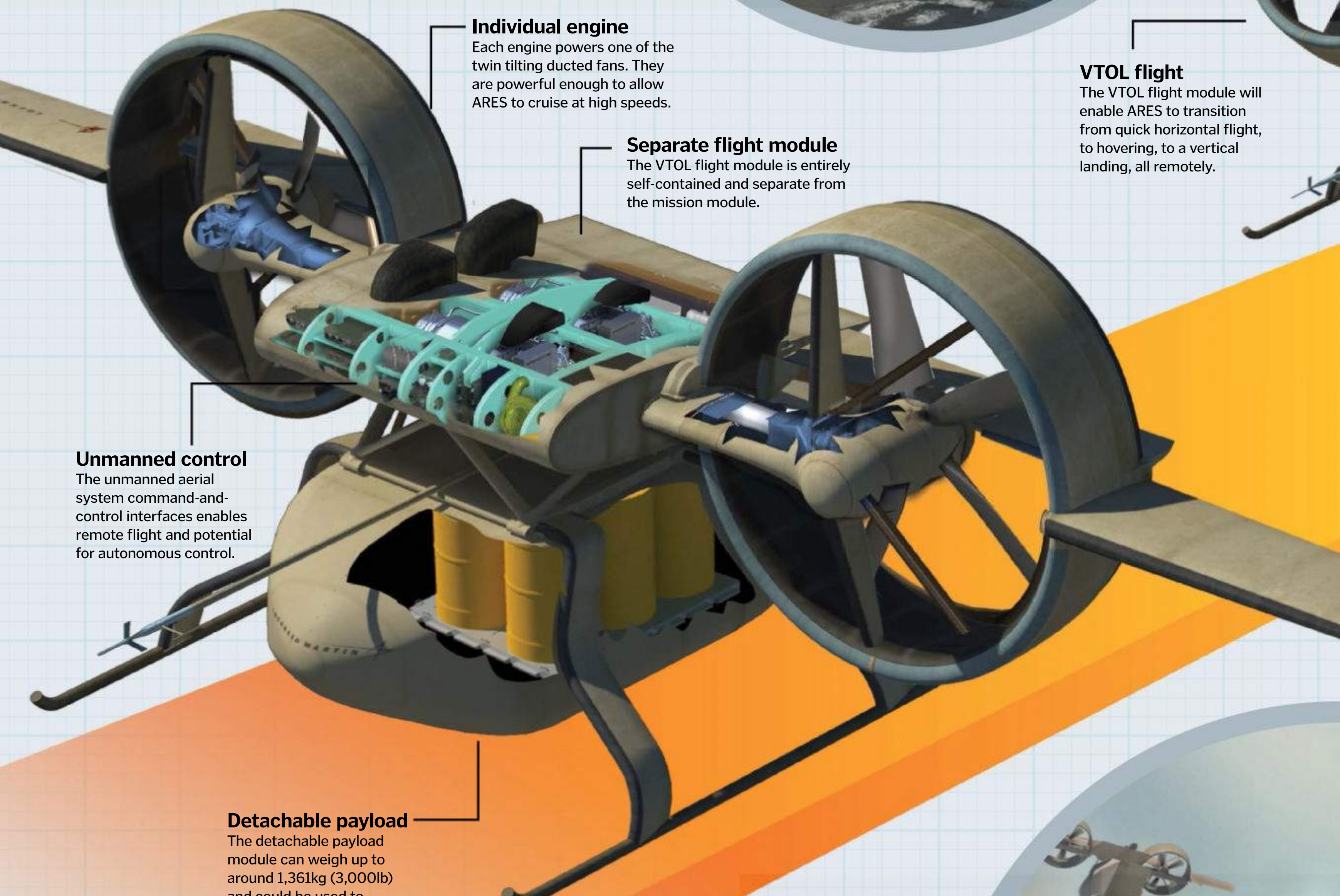
How DARPA's Aerial Reconfigurable Embedded System (ARES) could change the face of frontline combat

In a bid to overcome the problem of transporting supplies across difficult and often dangerous battlefield terrains, DARPA has turned to unmanned VTOL drones. The ARES design is capable of carrying a range of payloads; from supplies, to reconnaissance equipment, to evacuated casualties.

An onboard computer will be capable of selecting optimal routes from its home base to the troops in the field. It will even be able to select a landing zone completely by itself, providing quick and invaluable support to troops on the ground.



ARES can use landing zones half the size typically needed by similarly sized helicopters, enabling it to land aboard ships



Individual engine
Each engine powers one of the twin tilting ducted fans. They are powerful enough to allow ARES to cruise at high speeds.

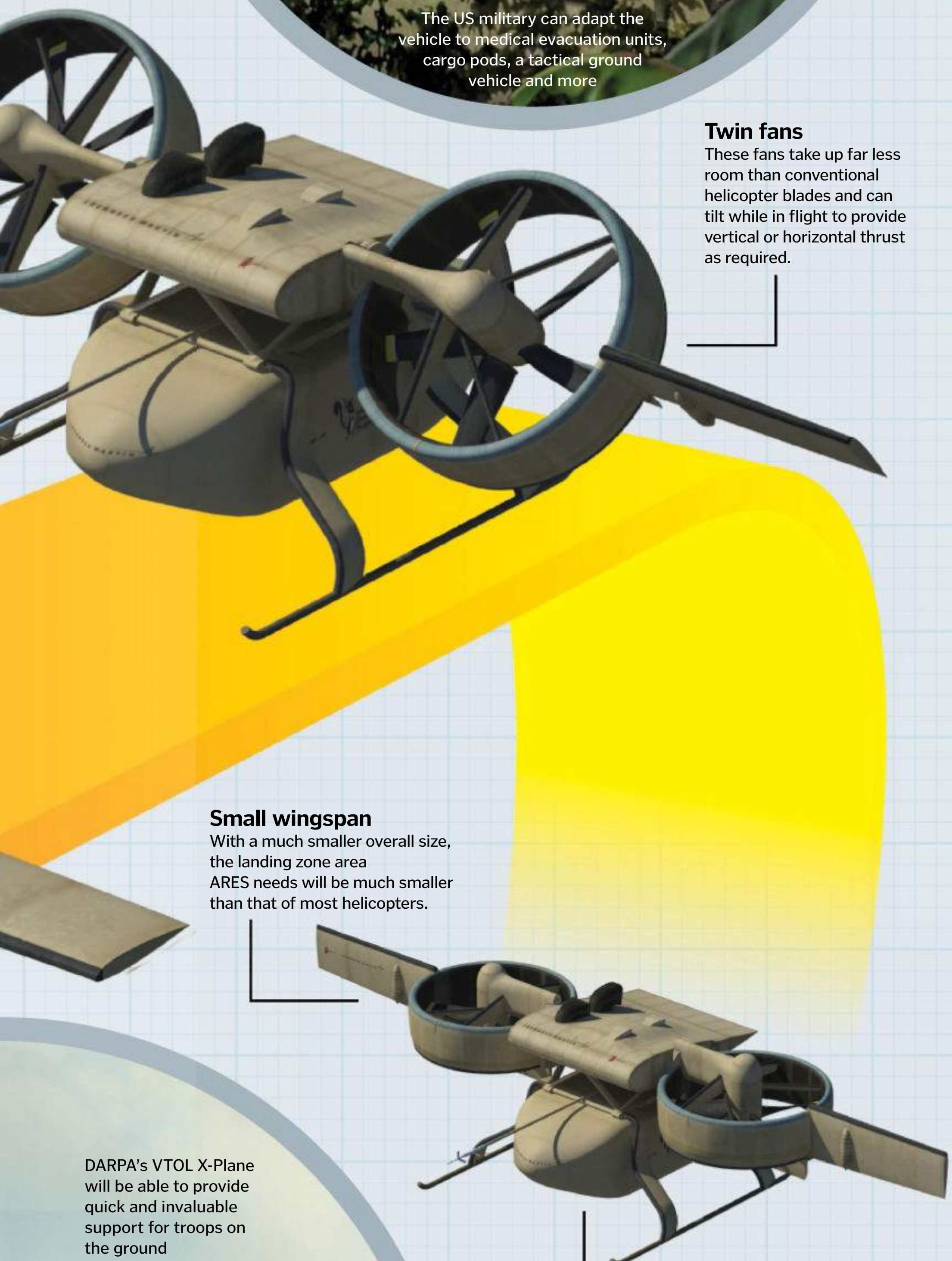
VTOL flight
The VTOL flight module will enable ARES to transition from quick horizontal flight, to hovering, to a vertical landing, all remotely.

Separate flight module
The VTOL flight module is entirely self-contained and separate from the mission module.

Unmanned control
The unmanned aerial system command-and-control interfaces enables remote flight and potential for autonomous control.

Detachable payload
The detachable payload module can weigh up to around 1,361kg (3,000lb) and could be used to transport supplies, house reconnaissance equipment or even evacuate troops.

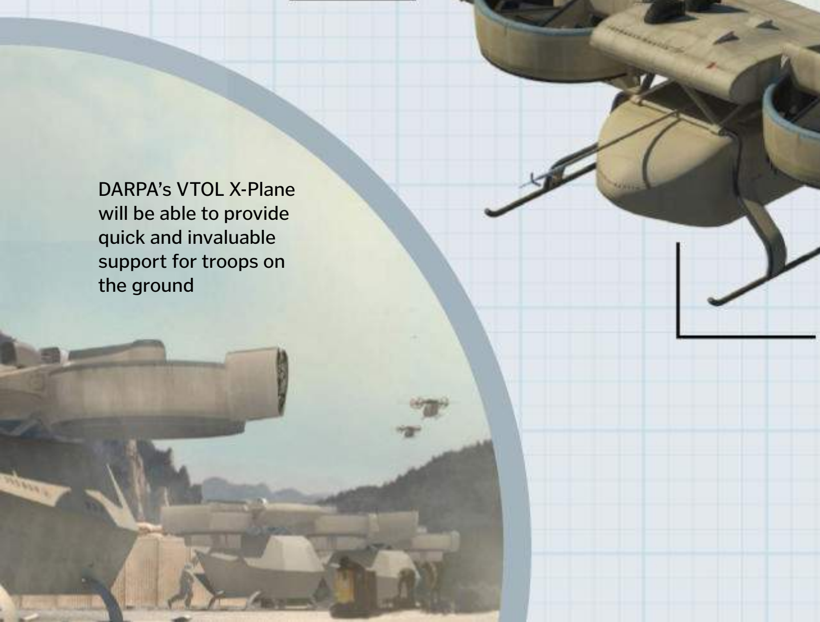
The US military can adapt the vehicle to medical evacuation units, cargo pods, a tactical ground vehicle and more



Twin fans
These fans take up far less room than conventional helicopter blades and can tilt while in flight to provide vertical or horizontal thrust as required.

Small wingspan
With a much smaller overall size, the landing zone area ARES needs will be much smaller than that of most helicopters.

Autonomous flight
With further development it's hoped that ARES will be able to fly and land all by itself, using sensors to select optimal routes and landing locations.



DARPA's VTOL X-Plane will be able to provide quick and invaluable support for troops on the ground

would be the future. In a world potentially ravaged by nuclear blasts, obliterating any obliging runways, it was thought a craft with the ability to take off and land anywhere would rule the skies. In time, bizarre VTOL aircraft such as the Lockheed XFV Salmon – an experimental fighter – and even the flying saucer-inspired Avrocar were tested by the US military, but most failed and were discontinued. Among the only VTOL aircraft to make it out of the Cold War with flying colours was the BAE Sea Harrier.

Also known as the Harrier Jump Jet, this plane was the first successful VTOL jet aircraft. Four vectoring nozzles direct the jet's engine thrust anywhere within a 90-degree radius, enabling the plane to fly across vertical and horizontal paths, transitioning in mid-air and even hovering.

The Harrier's VTOL ability was ideal for working on aircraft carriers – the floating fortresses of the waves. Its Rolls-Royce turbo fan engine, coupled with unparalleled flexibility and the latest weapons arsenal, made the jet a formidable opponent.

One other vehicle to emerge from the Cold War was the V-22 Osprey. Developed by Bell and Boeing, this vertical-lift transport aircraft is packed with twin tilting rotors capable of both hovering and landing like any helicopter, or transitioning to fly like a turboprop airplane.

With a range of over 400 nautical miles (740 kilometres/460 miles) and the ability to rapidly transport over 30 troops, the Osprey serves the US Marine Corps in key insertion and extraction missions. It even has the ability to fold its 25-metre (82-foot) wingspan away, condensing down to just its 5.6-metre (18-foot) -wide fuselage. This makes it invaluable for storage on aircraft carriers.

With each new generation come fresh challenges for engineers to overcome. Today's military minds face the problems of producing aircraft that are not only cost-effective and incredibly flexible, but also smart. Into the future, contractors and state defence ministries are increasingly turning towards VTOL technology for use with military drones.

While the computer power behind these machines may be cutting-edge, the physics lifting them into the air and setting them safely back on the ground remain the same.

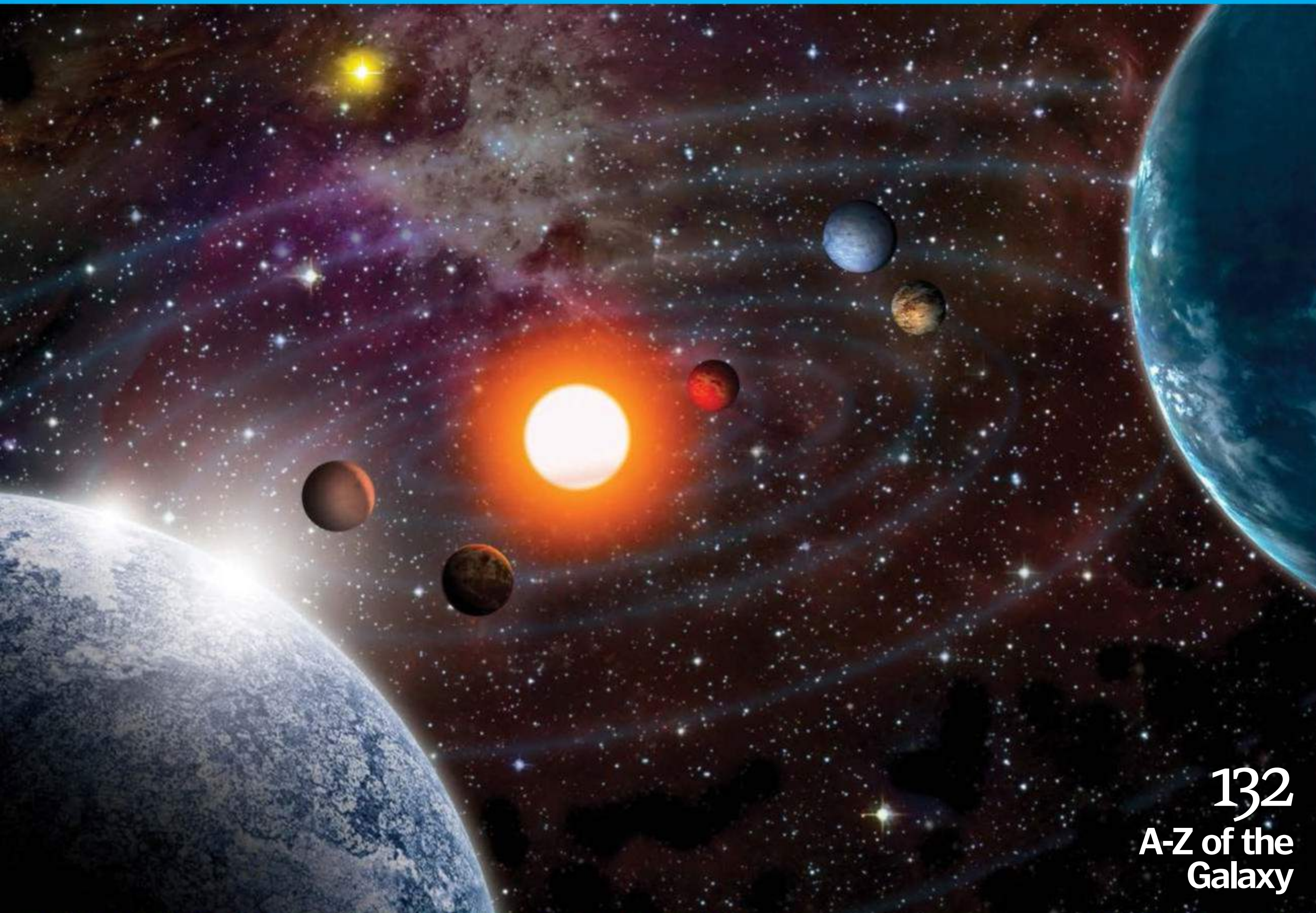
Either by remote operation or autonomous flight, VTOL drones will be capable of performing a range of transport, reconnaissance, or even offensive missions. We've shown you a few exciting visions – from the best and brightest in the aviation industry – set to launch VTOL technology into the next generation.

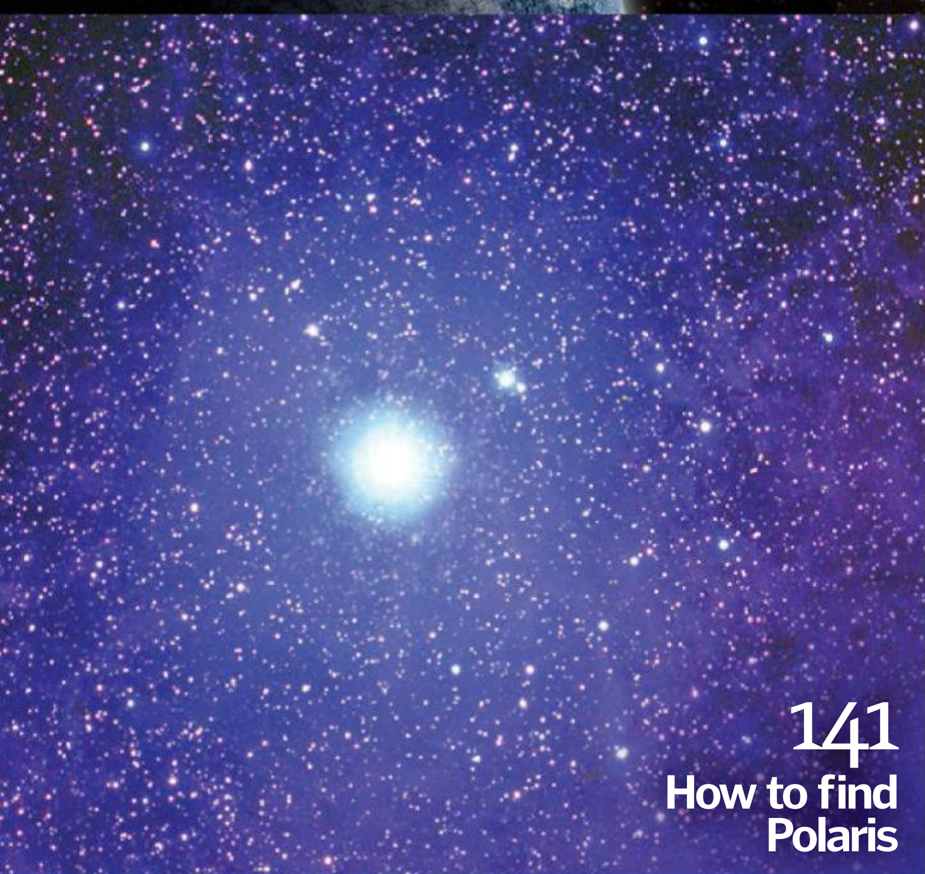
SPACE

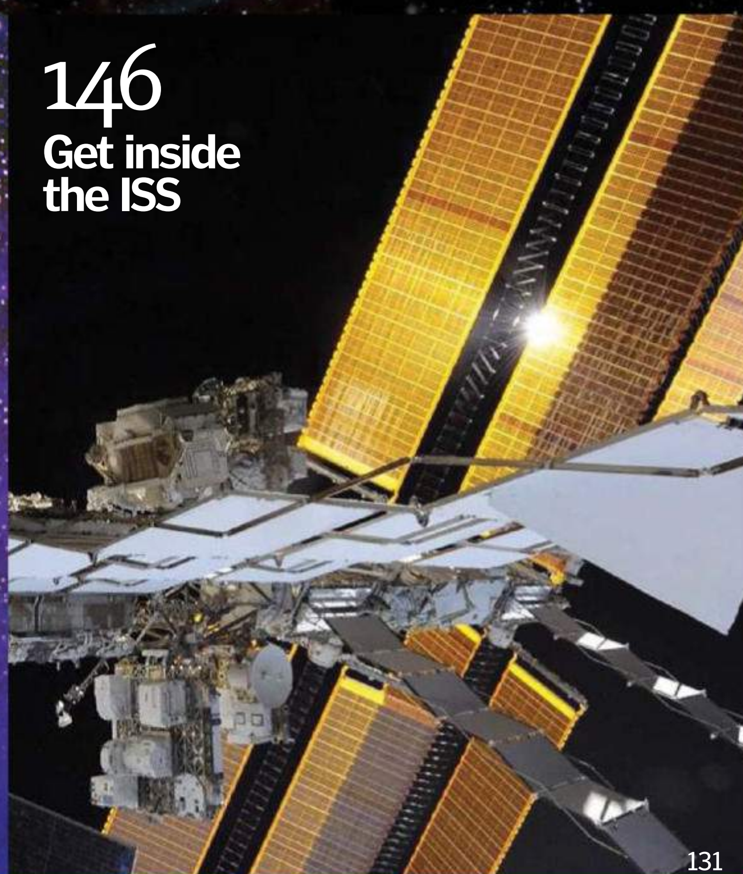
140
Landsat sattelites

142
The end of the sun

148
What are eclipses?







A TO Z OF THE GALAXY

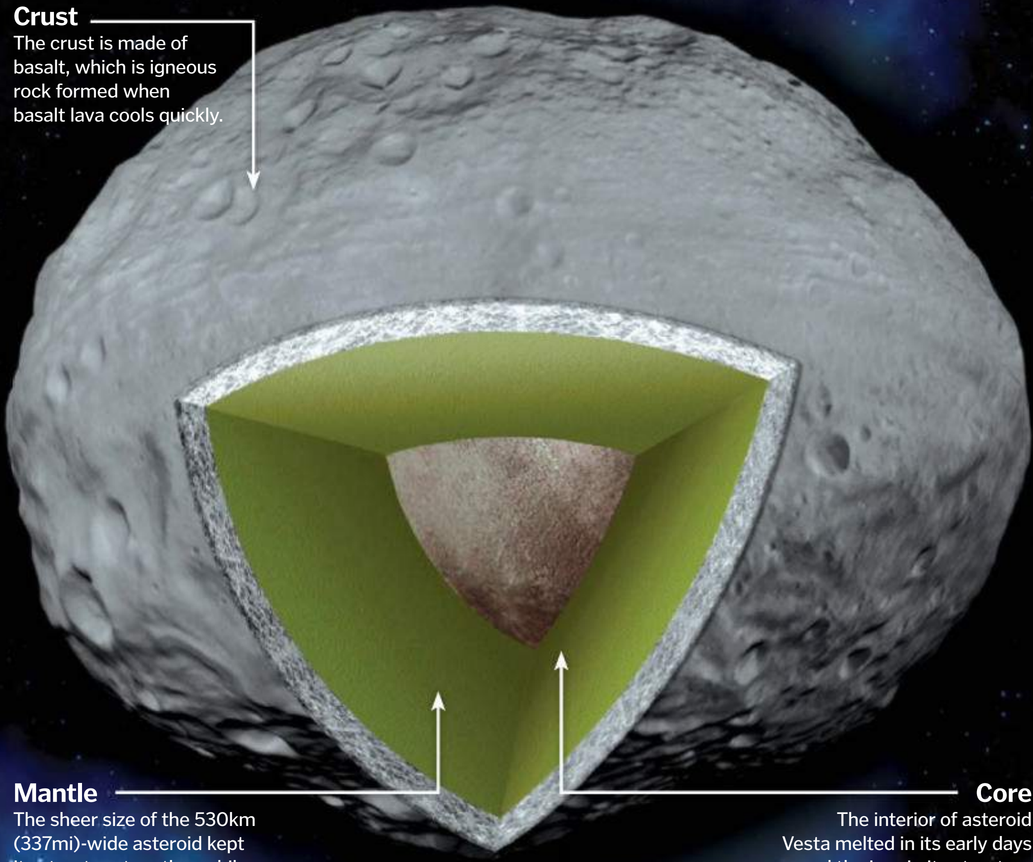
Come on a journey through the cosmos

Asteroids

There are millions of asteroids in our galaxy, ranging in size from less than a kilometre (0.6 miles) across to 950 kilometres (590 miles). The ones in our Solar System are mainly found in the Asteroid Belt between Mars and Jupiter and are made mostly of solid rock. However, they have been known to leave the belt. Asteroid groups called Atens, Amors and Apollos cross close by the Earth's orbit and can occasionally hit Earth. An asteroid would have to be at least 25 metres (82 feet) across for it to survive the journey through the Earth's atmosphere without burning up. NASA estimates that a car-sized asteroid makes it through the atmosphere every year, but will usually disintegrate before hitting the Earth. Back in 2001, NASA orbiter NEAR Shoemaker landed on the surface of near-Earth asteroid 433 Eros. Despite not being part of the original plan, Shoemaker became the first manmade object to land on an asteroid.

Inside an asteroid

What makes up an asteroid?



Barred spiral galaxy

Barred spiral galaxies are made up of an incredibly dense bar of stars, dust and gas surrounded by a number of spirals made up of less densely packed stars and dust. The Milky Way is a barred spiral galaxy and our Solar System sits on the Orion spur, a breakaway of Perseus, the western spiral arm of the galaxy.

The Milky Way contains more than 200 billion stars

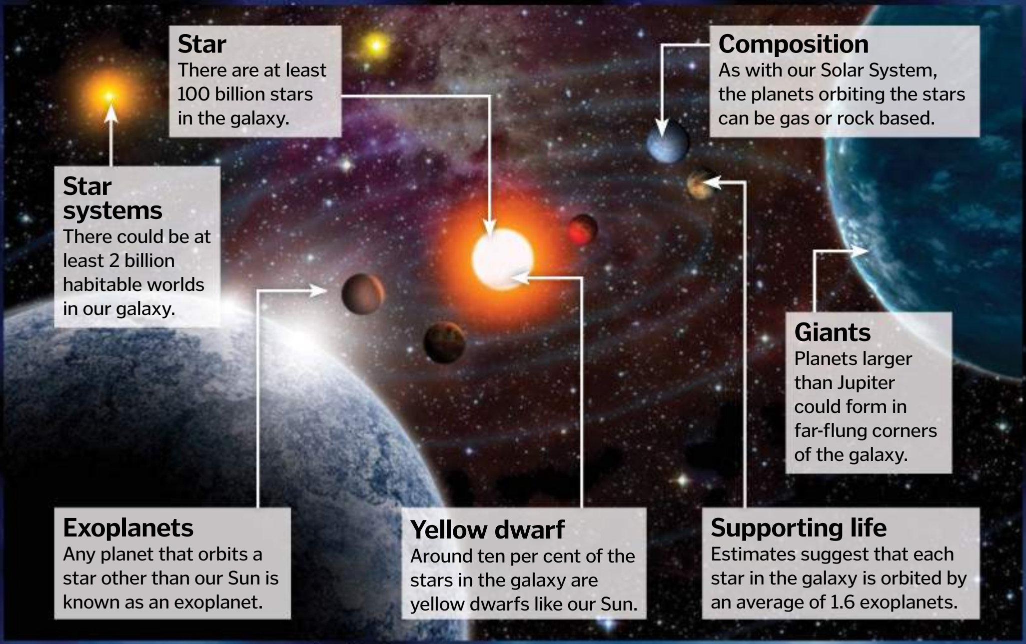
Dark matter

The existence of dark matter is currently theoretical based on the way visible matter behaves. As it doesn't reflect, give out or absorb light, scientists are still unable to detect it. Dark matter is estimated to make up around 26 per cent of the mass of the galaxy, which is over six times greater than the mass of visible matter. Scientists at CERN hope to create dark matter particles in the Large Hadron Collider, but even then they could only know of their existence due to the loss of energy inside the machine.

Dark matter around a galactic cluster is represented here in blue

Exoplanets

An exoplanet is a planet in a solar system other than our own. One of the closest, Gliese 581g, is only 20 light-years away. Over 1,700 such planets have already been discovered, but scientists believe that there could be at least 160 billion in our galaxy alone. According to estimates, around 2 billion of these could potentially be capable of supporting life.



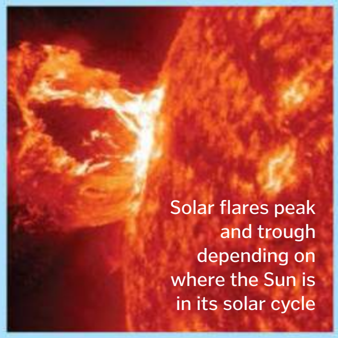
Comet

Despite looking rocky, comets are balls of ice, dust and gas. It is believed they contain remnants from the Big Bang, which is why the Rosetta mission to land on a comet was so important. Comets give off a coma of gas that looks like a tail. They usually stay in the Oort Cloud at the edge of the Solar System.

An illustration of the comet Churyumov-Gerasimenko

Flares

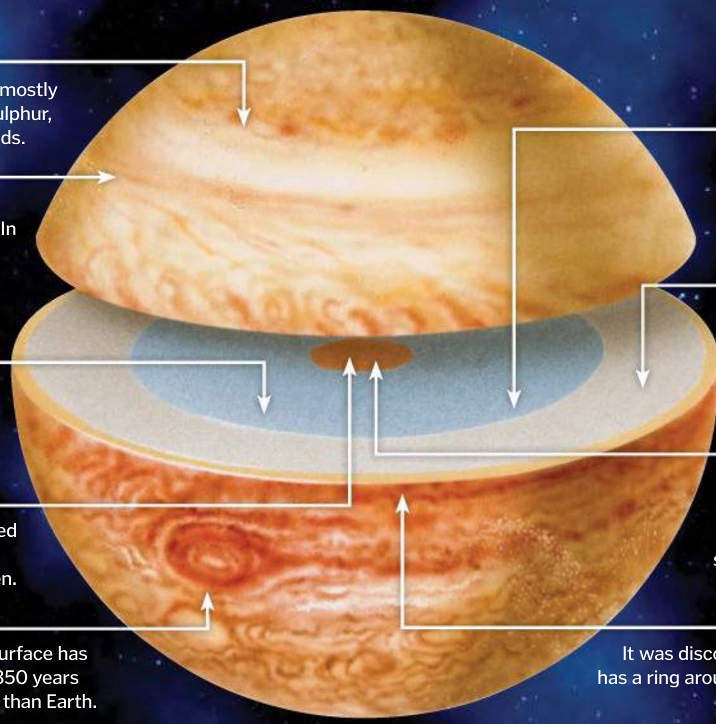
Flares occur when magnetic energy on the Sun (or other stars) builds up, and is suddenly released, heating the surrounding plasma to temperatures of up to 100 million degrees Celsius (180 million degrees Fahrenheit). The three stages of a solar flare are the precursor stage, where the energy starts to build up; the impulsive stage, where the particles begin to accelerate and are emitted; and finally the decay stage, where the flare subsides. Earth is protected from the radiation emitted in flares by its magnetic field, but high solar-flare activity is capable of knocking out our radio signals because the X-rays emitted disrupt the ionosphere.



Solar flares peak and trough depending on where the Sun is in its solar cycle

Gas giants

Gas giants like Jupiter and Saturn are found in star systems across the galaxy. Some are known as "hot Jupiters" because although they resemble our neighbourhood's largest planet, they orbit much closer to their parent stars. All gas giants have thick atmospheres of hydrogen and helium, surrounding either rocky or metallic cores.



Surface
The surface of Jupiter is mostly ammonia crystals and sulphur, which form swirling clouds.

Orbit
Jupiter orbits the Sun at 780mn km (485mn mi). In other star systems, gas giants can orbit even closer to their stars than Mercury does.

Body
Jupiter is built up of layers. The closer to the core it gets, the denser the layers are.

Core
Jupiter's core is composed of rock surrounded by a layer of metallic hydrogen.

Great Red Spot
This storm on Jupiter's surface has been raging for at least 350 years and is three times larger than Earth.

Gravity
The mass of Jupiter's core means the gravity on the planet is 2.4 times that of Earth.

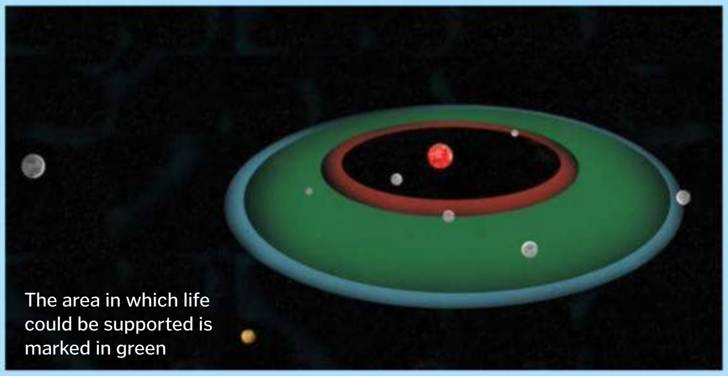
Temperature
The core of Jupiter measures an incredibly hot 35,000°C (63,000°F), six times the temperature of Earth's core.

Composition
90 per cent of Jupiter is hydrogen, ten per cent helium and there is a tiny smattering of other gases.

Ring
It was discovered in 1979 that Jupiter has a ring around it like Saturn, however Jupiter's is much fainter.

Habitable zone

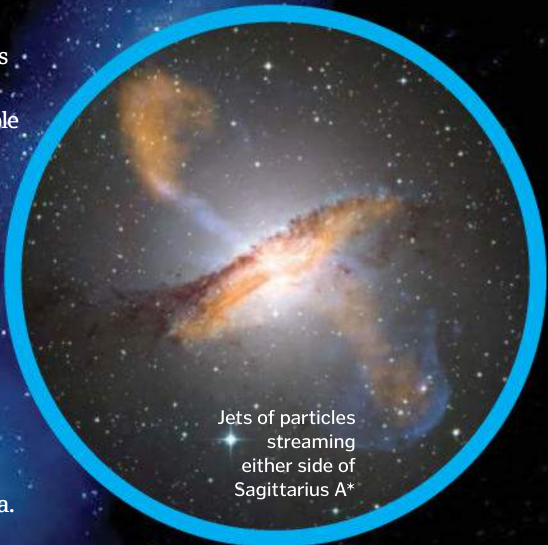
Also known as the Goldilocks zone, the habitable zone is an area around a star that could sustain life. Like in Earth's case, it needs to be close enough to the star to provide heat to its inhabitants but not so close it boils water on the planet. The exoplanet system around star Gliese 667C is thought to have three planets orbiting in its habitable zone.



The area in which life could be supported is marked in green

Jets

Jets are streams of particles emitted by black holes. Sagittarius A*, the black hole at the centre of our galaxy, fires a jet into the galaxy once a day. It is thought they are the result of objects such as asteroids falling into the black hole and being expelled. The jets run into gas around the black hole and produce X-rays, so we are able to detect them using telescopes such as Chandra.



Jets of particles streaming either side of Sagittarius A*

Interstellar medium

The area between stars is the interstellar medium, found in regions where the solar wind streaming from a star is countered by the interstellar wind. The gas is about 75 per cent hydrogen, 25 per cent helium and is found in the form of cold hydrogen clouds or hot ionised hydrogen. Having been launched in 1977, NASA announced that their Voyager 1 probe had reached the interstellar medium in August 2012.

The interstellar medium begins when a star's solar wind drops at the termination shock boundary

Kepler's laws

Johannes Kepler's laws of planetary motion describe how planets orbit stars. The first law explains why the orbit of the planets in our Solar System are elliptical, while the second and third laws provide the model for astrophysicists to map where planets will be at any one time. Despite being formulated from data collected by his mentor Tycho Brahe in the early-17th century, the laws still hold up today.

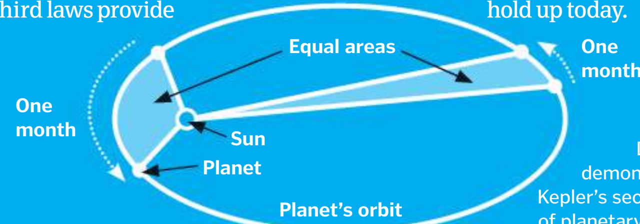


Diagram demonstrating Kepler's second law of planetary motion

Local Group

Our galaxy is part of a group of at least 30 galaxies that are known as the Local Group. Around 20 of these are bright galaxies, the brightest of which are the Milky Way and Andromeda, our nearest neighbour. The Local Group is spread over 10 million light years, but this will inevitably change as it is projected to get drawn into the Virgo Cluster at some point in the future.

The Triangulum galaxy (M33) is the third-largest in our Local Group after the Milky Way and Andromeda

Multiple-star system

We may think planets with two suns are only found in *Star Wars*, but they do exist in our galaxy. Planets that orbit more than one star are rare as the stars' combined heat makes it much harder for planets to form. Therefore they tend to form further out than normal and then move closer toward the stars. Studies suggest that planets in binary star systems are common.

Kepler-35b orbits its two host stars once every 131 days

Nebulae

Nebulae are among the most striking images in the galaxy. Incredible visions such as the Horsehead nebula or the Rosette nebula form when the interstellar medium (see 'I' for further information) collapses. This causes the interstellar dust, hydrogen and helium to draw together due to gravitational attraction. As the nebula forms, its gravitational attraction increases, which draws even more gas and dust toward it. The core of the nebula begins to heat up and nuclear fusion takes place. That reaction sends radiation outward to the edge of the nebula, which ionises the gas and turns it into plasma. These are the ingredients needed for a protostar to become a star. Therefore, the study of nebulae is key for scientists hoping to discover how our Solar System was formed. The dark clouds of a nebula can be quite hard to see, but scientists can sometimes get lucky, as in the case of the Horsehead nebula, which is backlit by the star Sigma Orionis. Nebulae also form at the other end of the scale. When a Sun such as ours dies it turns into a red giant star, which eventually burns the last of its fuel and becomes a planetary nebula.

The Horsehead nebula is part of the Orion constellation

Open clusters

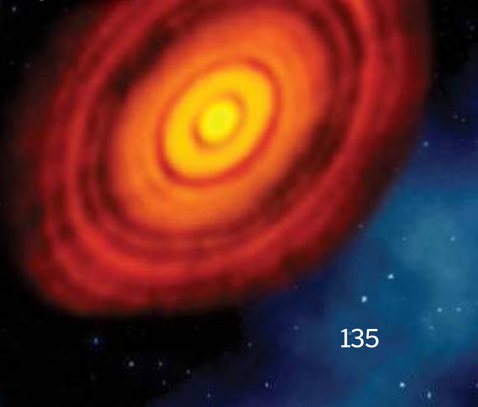
This is a loosely bound group of young, hot stars is called an open cluster. They form inside a molecular cloud, which is a collection of hydrogen molecules and is where every star in the galaxy begins to form. They tend to stay inside their molecular cloud until the radiation they give off dissipates it. As they are so loosely bound together, open clusters are prone to losing members to other systems.

The Pleiades open cluster is bright enough to be seen by the naked eye from Earth

Protoplanetary disks

It is thought that our Solar System, as well as most others in the galaxy, formed thanks to a protoplanetary disk. These start out as a protostar, which is a body that has the potential to become a star but is not yet hot enough, surrounded by a molecular cloud. Gravitational forces cause the cloud to collapse and start spinning, causing material to clump together and form planets and asteroids.

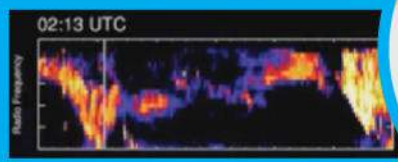
The gaps in between the disk's rings are where planets begin to form

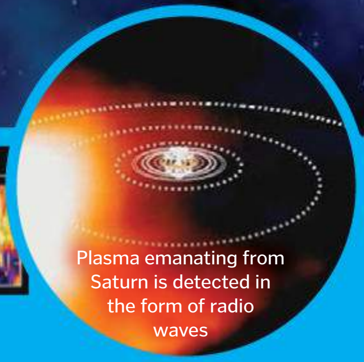


Quasar

Quasars are the brightest objects in the universe, composed of streams of particles emitted by supermassive black holes. These particles exit the black hole at near the speed of light and have more energy than all the stars in their galaxy combined, releasing this as light energy. Although our galaxy doesn't contain a quasar, it's possible that it used to and could again when the Milky Way collides with Andromeda galaxy.

A stunning representation of a quasar, one of the brightest objects in the universe





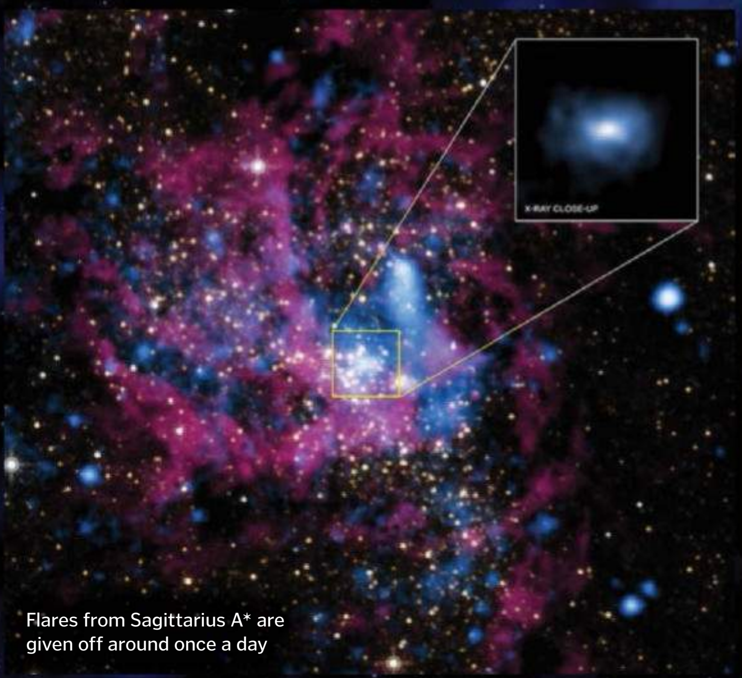
Plasma emanating from Saturn is detected in the form of radio waves

Radio waves

Stars such as our Sun emit electromagnetic radiation in the form of radio waves, which have the longest wavelength of any wave in the electromagnetic spectrum. This allows us to pick up the long-range signals, amplify them using huge dishes and learn more about objects in our galaxy. By viewing the galaxy through radio telescopes we can see further than ever before and detect far-flung pulsars and quasars.

Sagittarius A*

No A-Z of the galaxy would be complete without the mysterious object that sits at its very heart. Sagittarius A* is a supermassive black hole around which the entire galaxy revolves. Its mass is 4 million times greater than the Sun's and sits 26,000 light years from Earth. It is likely to have formed when a star collapsed in on itself, retaining all its mass but dramatically reducing in size. It will have become a supermassive black hole either by steadily acquiring matter or colliding with another black hole and combining. Almost every galaxy has a supermassive black hole at its centre, keeping all the various bodies orbiting around it thanks to its astonishingly powerful gravitational pull. Black holes are impossible to actually see as they suck in everything around them, including light. However, they can be spotted by the high-energy light produced by stars and gases in their vicinity. Having said that, some things do manage to escape from Sagittarius A*. Images from the Chandra and XMM-Newton observatories have shown incredible X-rays, gamma rays and flares being given off from the black hole. It can also be detected by observing the effects of its immense gravity on the surrounding area.



Flares from Sagittarius A* are given off around once a day

The Hubble telescope was launched in 1990 and has carried out nearly 4,000 observation programmes

Telescopes

Telescopes come in many forms, helping us study the galaxy. There is the Very Large Telescope (VLT) array, which combines its four 8.2-metre (26.9-foot)-wide mirrors to see 25 times farther than one alone. The Atacama Large Millimeter/submillimeter Array (ALMA) consists of 66 radio antennas that receive signals emitted billions of years ago, and we can't forget Hubble, currently orbiting Earth at 28,160 kilometres (17,500 miles) per hour.

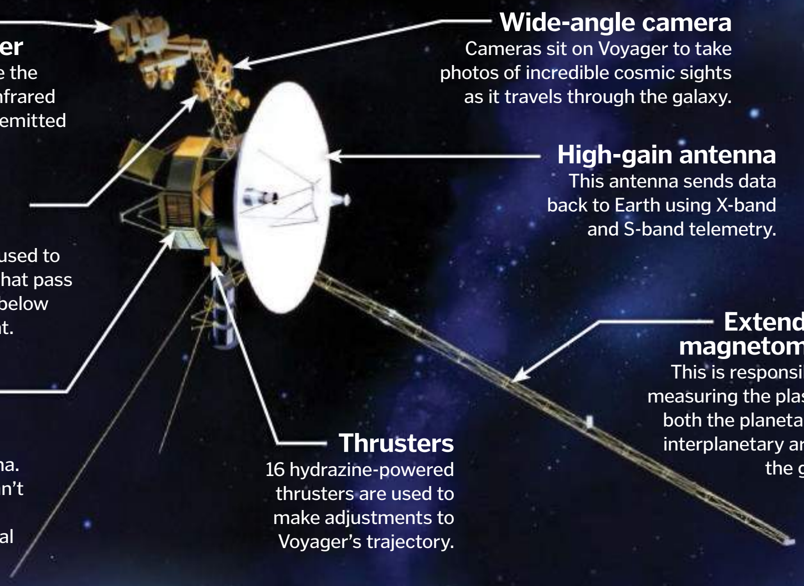
Ultraviolet radiation

If you've ever had sunburn, you are the victim of UV radiation from the Sun. Ultraviolet radiation is on the lower end of the electromagnetic spectrum, meaning that its wavelengths vibrate rapidly and can mess with our DNA. Our atmosphere mostly blocks UV radiation, however. When stars turn into white dwarfs they emit huge amounts of UV radiation that heat up the gaseous layers around them.

The Helix nebula is spewing UV radiation from its core as it dies

Voyager

Voyagers 1 and 2 were launched in 1977 with the brief of exploring Jupiter and Saturn. The two spacecraft returned amazing images of volcanoes on Jupiter's moon Io and Saturn's rings. Once they had mapped the two closest gas giants their mission was extended to travel farther than any manmade object had ventured before. Voyager 1 reached Uranus in January 1986 and Neptune in 1989. It then entered interstellar space in August 2012 and is transmitting data back to Earth about the unknown region between solar systems in our galaxy. Using technology developed nearly 40 years ago, Voyagers 1 are 2 are still successfully exploring the galaxy and providing data via the Deep Space Network, which is an array of radio antennas that allow data to be sent from incredible distances.



Wolf-Rayet star

When a star that is at least 20 times the size of our Sun burns out, it transforms into a red supergiant. If heavy elements manage to push their way out to the surface and cause winds to shoot gas out at incredible speeds, the supergiant becomes a Wolf-Rayet star. Only around 230 Wolf-Rayet stars that haven't detonated into supernova stage have been catalogued in our galaxy.

X-rays

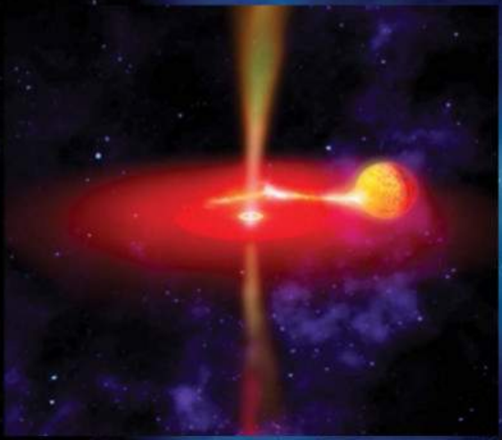
X-rays are emitted from all kinds of galactic bodies, from stars to black holes. As virtually no X-rays are able to penetrate the Earth's atmosphere, NASA has had to send telescopes into space to detect them. They are especially useful to astronomers as they can be detected even when there is nothing visible for other telescopes to pick up. X-rays are the main type of radiation emitted from black holes.

Yellow dwarf

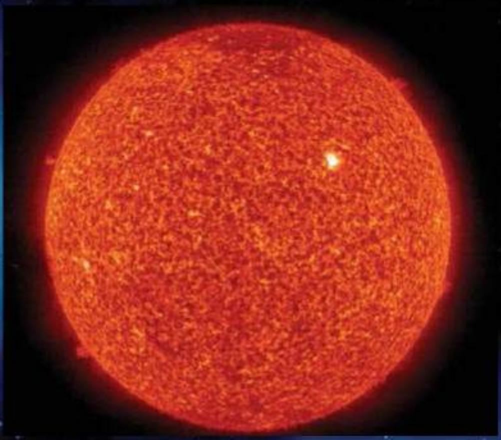
Our Sun is an example of a yellow dwarf, one of several classifications of star. These stars have a temperature range of 5,030 and 5,730 degrees Celsius (9,080 and 10,340 degrees Fahrenheit) and tend to live for around 10 billion years or so. At this point they turn into a red giant star and then collapse into a white dwarf. Our Sun has approximately 5 billion years before it turns into a red giant star.

Z

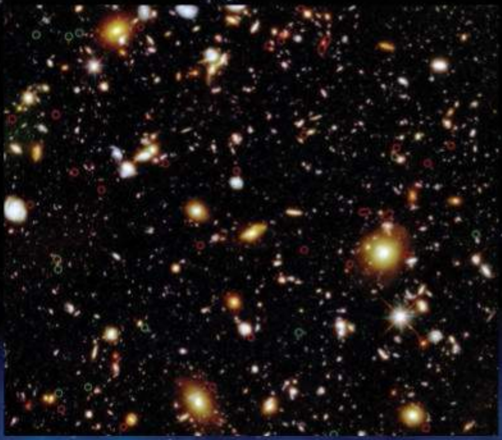
The letter 'z' is the notation for redshift and blueshift. As wavelengths of the light spectrum change, subsequintly so do the colours. If a star is moving away from us, the wavelength of its light is stretched out and becomes redder. If it is moving towards us, it appears bluer as the wavelengths get shorter. When z is positive the light is shifted toward the red and if z is negative it has blueshifted.



Telescopes can pick up X-rays that give information on the location of black holes

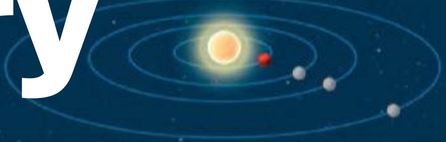


Our Sun is one of the biggest known yellow dwarfs in the Milky Way galaxy



We discover how far away stars are by the amount of redshift and blueshift they exhibit

Explore Mercury

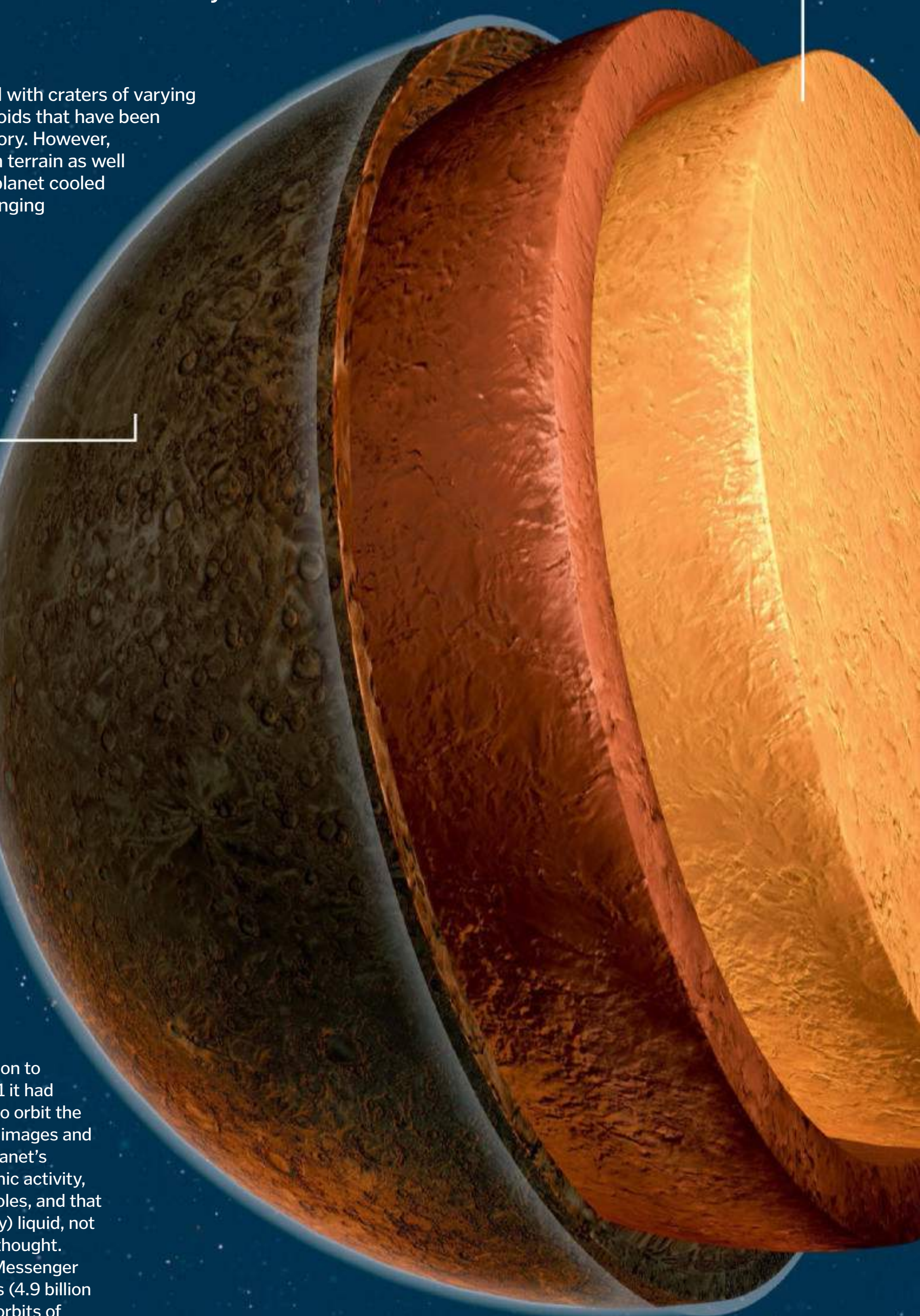


Learn about the planet of ice and fire

As the nearest planet to the Sun, Mercury is one of the most difficult objects in our Solar System to study. Although you can see it from Earth without a telescope, it is usually lost within the Sun's blinding glare and can therefore only be directly observed at dawn or dusk. However, thanks to NASA's Mariner 10 and Messenger spacecrafts, we now know more about this mysterious planet than ever before. For example, despite its scorching average surface temperature of 167 degrees Celsius (333 degrees Fahrenheit), the planet does in fact have ice at its north and south poles.

Inside Mercury

Mercury's Earth-like layers revealed

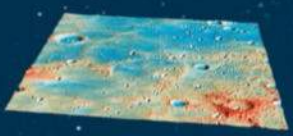


Scarred surface

The surface of Mercury looks a lot like that of our Moon as it is covered with craters of varying sizes. These craters are the result of impacts from comets and meteoroids that have been able to penetrate the planet's very thin atmosphere throughout its history. However, unlike the Moon, Mercury's surface also features large areas of smooth terrain as well as tall cliffs called scarps. It is thought that these were created as the planet cooled and contracted when it first formed, leaving wrinkles on the surface ranging from 100 metres (328 feet) to over 1.5 kilometres (0.9 miles) in height.

The Caloris Basin was formed when a 100km (60mi)-wide asteroid hit the planet about 4 billion years ago. It also sent seismic waves across the surface to form hills and mountains on the opposite side of the planet.

The largest impact crater on Mercury is called the Caloris Basin. It is approximately 1,550km (960mi) in diameter, larger than the US state of Texas.



NASA's Messenger spacecraft crashed near Mercury's 400-kilometre (250-mile)-wide Shakespeare impact basin, forming its own crater thought to be 16 metres (52 feet) in diameter.

Missions to Mercury

Mariner 10

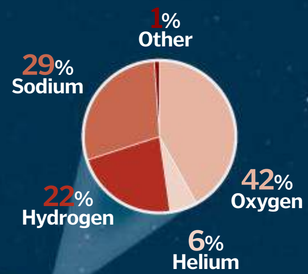
The first spacecraft sent to study Mercury was launched by NASA in 1973. During its mission, Mariner 10 photographed half of the planet's surface, helped scientists discover its magnetic field and revealed its temperature. It was also the first craft to visit more than one planet, as it did a flyby of Venus on the way; the first to use another planet's gravity to alter its speed and trajectory, as its visit to Venus gave it a boost; and the first to make multiple flybys of a planet, as it passed Mercury three times between 1974 and 1975.

Messenger

NASA launched its next mission to Mercury in 2004, and by 2011 it had become the first spacecraft to orbit the planet. Messenger sent back images and data that revealed how the planet's surface was shaped by volcanic activity, large amounts of ice at the poles, and that the core was (at least partially) liquid, not solid as had been previously thought. During its ten-year mission, Messenger travelled 7.9 billion kilometres (4.9 billion miles) and completed 3,308 orbits of Mercury, before finally crashing in 2015.

Absent atmosphere

Mercury's atmosphere is incredibly thin and almost nonexistent. Due to the planet's close proximity to the Sun, strong solar winds blow much of the atmosphere away. However, the planet's magnetic field is able to deflect some of the solar winds away, while its weak gravitational pull holds on to some of the remaining atmosphere.



Extreme temperatures

Being so close to the Sun, temperatures on Mercury can climb to a scorching 430 degrees Celsius (806 degrees Fahrenheit). However, at night they can also plummet to -170 degrees Celsius (-274 degrees Fahrenheit) as the thin atmosphere can't trap much heat in. Temperatures are also extremely cold within the eternally shaded craters at the planet's north and south poles, causing any water present to freeze. It is thought the water could have come from falling comets or vapour from the planet's interior.

During the day, the Sun directly heats the rock.

During the night, the heat of Mercury's rocks is lost rapidly, and the planet's temperature drops.

-183°C (-297°F) **473°C (883 °F)**

Crust
Mercury's crust is ten times thicker than Earth's and is made of silicate rocks.

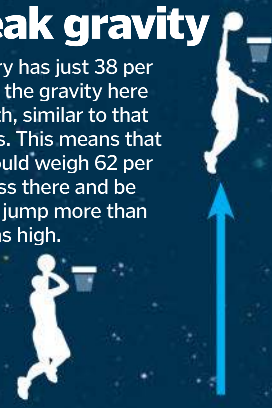
Magnetic field
Mercury's iron core gives it a magnetic field 100 times weaker than that of Earth.

Mantle
The thin mantle is one-fifth the thickness of Earth's and made of silica-based rocks.

Solid layer
Unlike Earth, Mercury's crust is not divided into tectonic plates because its interior is not hot enough to deform the layer.

Weak gravity

Mercury has just 38 per cent of the gravity here on Earth, similar to that of Mars. This means that you would weigh 62 per cent less there and be able to jump more than twice as high.

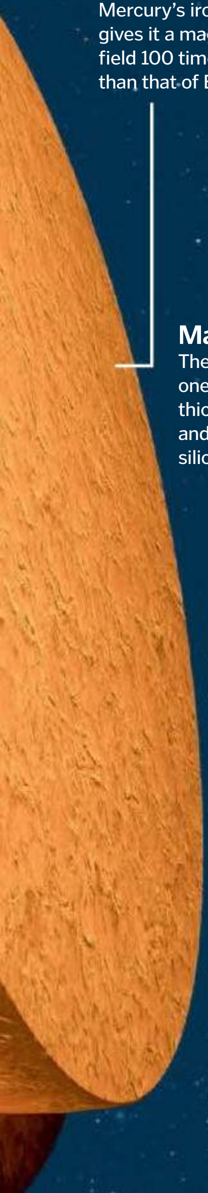


Earth
3m (9.8ft) dunk

Mercury
7.8m (25.5ft) dunk

A slamdunk would be much easier for basketball players on Mercury

Axis inclination
0.1°
One rotation lasts 59 days



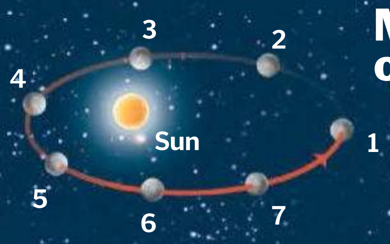
Strange orbit

Mercury's orbit of the Sun takes the shape of an elongated oval as opposed to the more circular orbit of Earth. This means that the planet's distance from the Sun and its speed varies greatly during each orbit. One orbit takes 88 Earth days, but the planet also takes 59 Earth days to spin on its axis. Therefore, someone watching the sunrise on Mercury would have to wait until the planet made two orbits of the Sun, and three rotations on its axis before they could see another one. As a result, one day on Mercury lasts the equivalent of 176 days on Earth, and is actually twice as long as a Mercurian year.

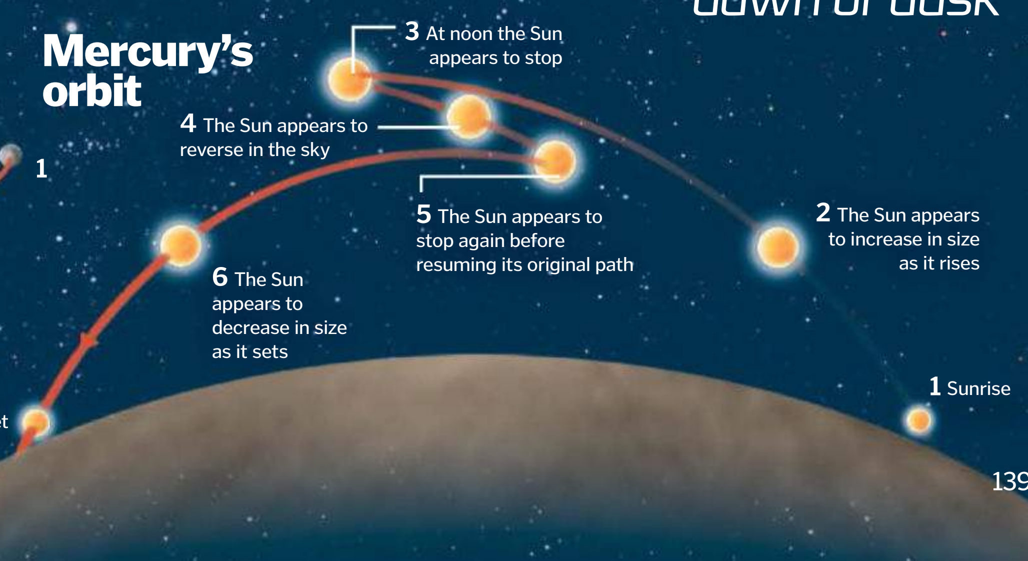
The Sun's motion in the sky would also appear odd if you were on Mercury. The spin of the planet makes the Sun appear to move from east to west in the sky, but its orbit would make it appear to move in the opposite direction. The spin usually wins out, but when the planet is closer to the Sun it moves faster in its orbit, making the Sun appear to briefly reverse in the sky before continuing on its path.

> *"Mercury can only be directly observed at dawn or dusk"*

Mercury's orbit

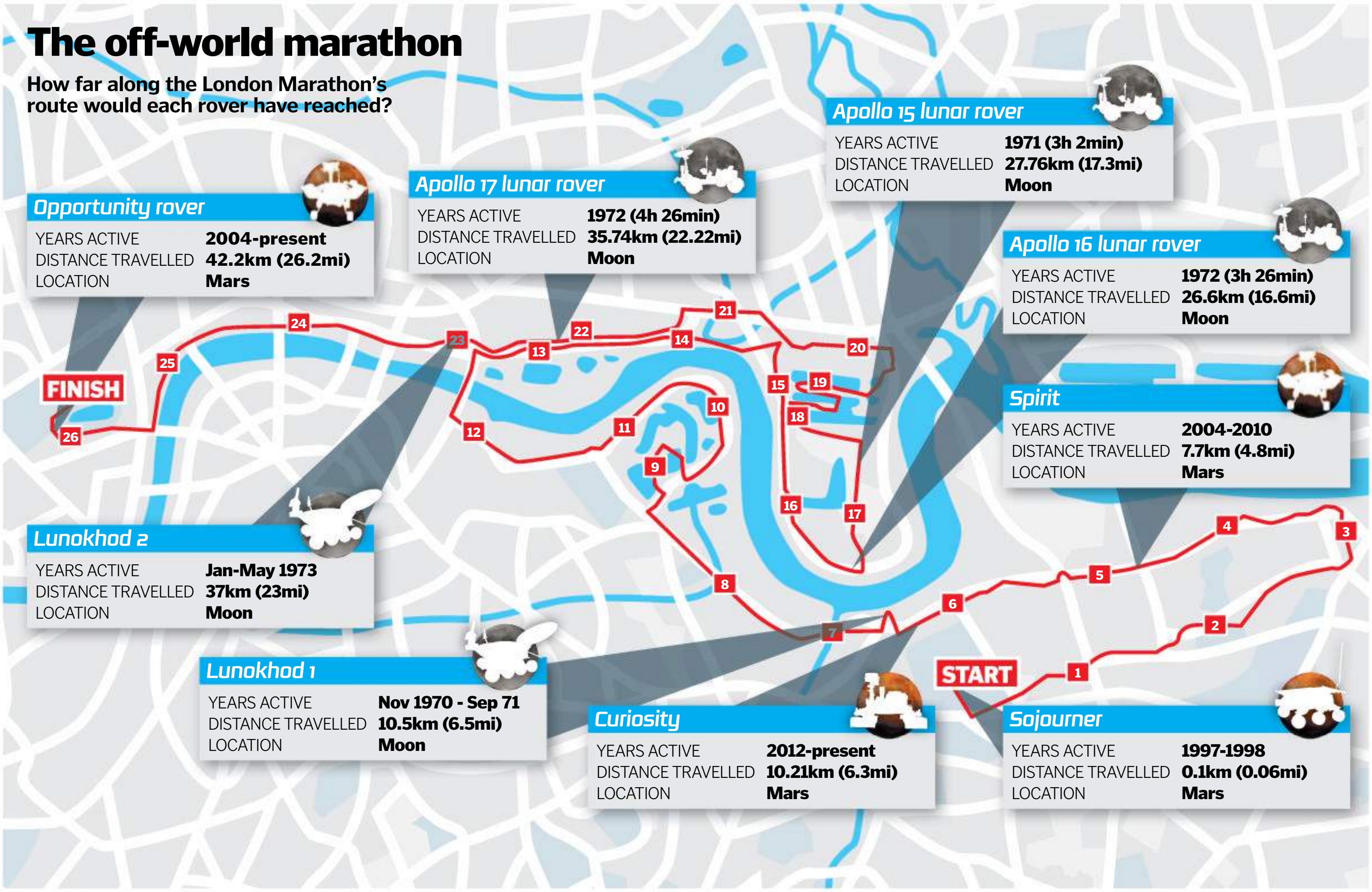


Each number corresponds to a position of the Sun in the sky as seen from Mercury.



How far have we travelled on other worlds?

Our rovers have been busy breaking distance records on the Moon and Mars



How do Landsat satellites work?

Discover how and why this orbital space programme is taking photos of our home planet

In 1972, the very first in what would become a series of Earth-orbiting satellites in the Landsat programme was launched. Inspired by Apollo 17's famous 'Blue Marble' picture of Earth from space, Landsat's mission was simply to photograph the planet and create an archive of hi-resolution, aerial images that would prove a useful resource to people working in many different fields, including agriculture, forestry, geology, education, mapping, conservation and emergency response.

Landsat measures light reflected by Earth from the Sun. As different surfaces reflect various amounts of light, this tells us a lot about our planet's surface. The most recent satellite, Landsat 8, is capable of collecting images in multiple bands of visible and infrared light. It is tailored with two new spectral bands that can make specific observations of coastal regions and of high-altitude cirrus clouds, allowing scientists to take measurements of air and water quality. Landsat 8 takes 400 images a day and returns them to the United States Geological Survey (USGS).

The Landsat programme has recorded how the Earth has changed over the last 40 years from its lofty orbit

How to find Polaris

This star has been used as a navigation aid for centuries

Since the 5th century, Polaris has been used to help people find their way when travelling at night. The reason it can be used in such a way is because the Earth's axis points almost directly at it. This means that Polaris remains almost stationary above the northern horizon all year round, while other stars appear to circle around it. It's for this reason that it represents true north.

To find the North Star, you need to identify a group of seven stars known as the Big Dipper. This shouldn't be hard due to this constellation's distinct shape and large size. Unlike Polaris, this constellation's position moves as the stars rotate, so it will appear to be tipped in different directions depending on the time of year. You now need to identify the two pointer stars that form the outer edge of the Big Dipper. By drawing an imaginary line from these two stars up and away from the saucepan shape of the Big Dipper, you will eventually hit the handle of the Little Dipper. The brightest star on this constellation's handle will be Polaris. Knowing the location of Cassiopeia will also help identify the North Star, as it will always lie in between this constellation and the Big Dipper, no matter what time of year it is.

Contrary to popular belief, Polaris was not always located in the north, nor will it remain to be. The Earth's axis is undergoing a process known as precession, which slowly alters the direction in which the axis points, causing the North Pole to point towards a different star. By the year 4000, the effect of precession will make Gamma Cephei our new North Star.

Polaris is getting brighter

The brightness of Polaris is known to fluctuate, however over the last two centuries it has increased greatly. By comparing it to other stars, scientists now believe that Polaris has become two-and-a-half times brighter in a period of about 200 years. If this is true, Polaris has undergone changes that are 100 times larger than all current theories on stellar evolution predict. The reason for this relatively sudden change is unknown, but is definitely unusual behaviour for a Cepheid variable star.

END OF OUR SUN

The lifecycle of our nearest star

Every star that exists today, including our very own Sun, will die. Stars live a long time – from millions to trillions of years – but when it comes time for them to expire, they do so in one of two ways; either beautifully or dramatically.

We know stars produce energy and heat by nuclear fusion reactions of hydrogen nuclei in their cores that, through two main processes, create helium. The energy generated from that radiates outward, balancing the force of gravity that tries to cause the star to collapse upon itself. It is when this hydrogen begins to run out that a star enters old age.

A star's ultimate fate depends on its mass. We know that a star the mass of the Sun will go out the beautiful way. Our Sun formed 4.6 billion years ago and has been using hydrogen all of that time, but the Sun is so massive that it still retains enough hydrogen to keep going for another five billion years. At that time, the hydrogen in the Sun's core will run out and stop producing energy. The core will begin to contract as gravity takes over, the temperature and pressure rising, at which point it will become hot enough for helium to step in for hydrogen and continue the nuclear reactions. Meanwhile, hydrogen in the outer layers of the Sun will ignite in fusion reactions and it will bloat into a huge red giant that will engulf and destroy little Mercury, Venus and possibly Earth and Mars too.

A few million years later, the outer layers of gas from the red giant are cast off and blossom into what is called a planetary nebula. In images taken by the Hubble Space Telescope and the Spitzer Space Telescope, the latter of which can peer in infrared through the dust of the nebula, these look like beautiful butterfly-shaped clouds of colourful gas. By studying these nebulas we can learn more about the fate of our own Sun and planets. Gradually the nebula disperses but the core of the star remains. About the size of Earth, the core no longer produces energy from nuclear reactions, but is tremendously hot, up to 100,000 degrees Celsius (180,000 degrees Fahrenheit). We call this a white dwarf.

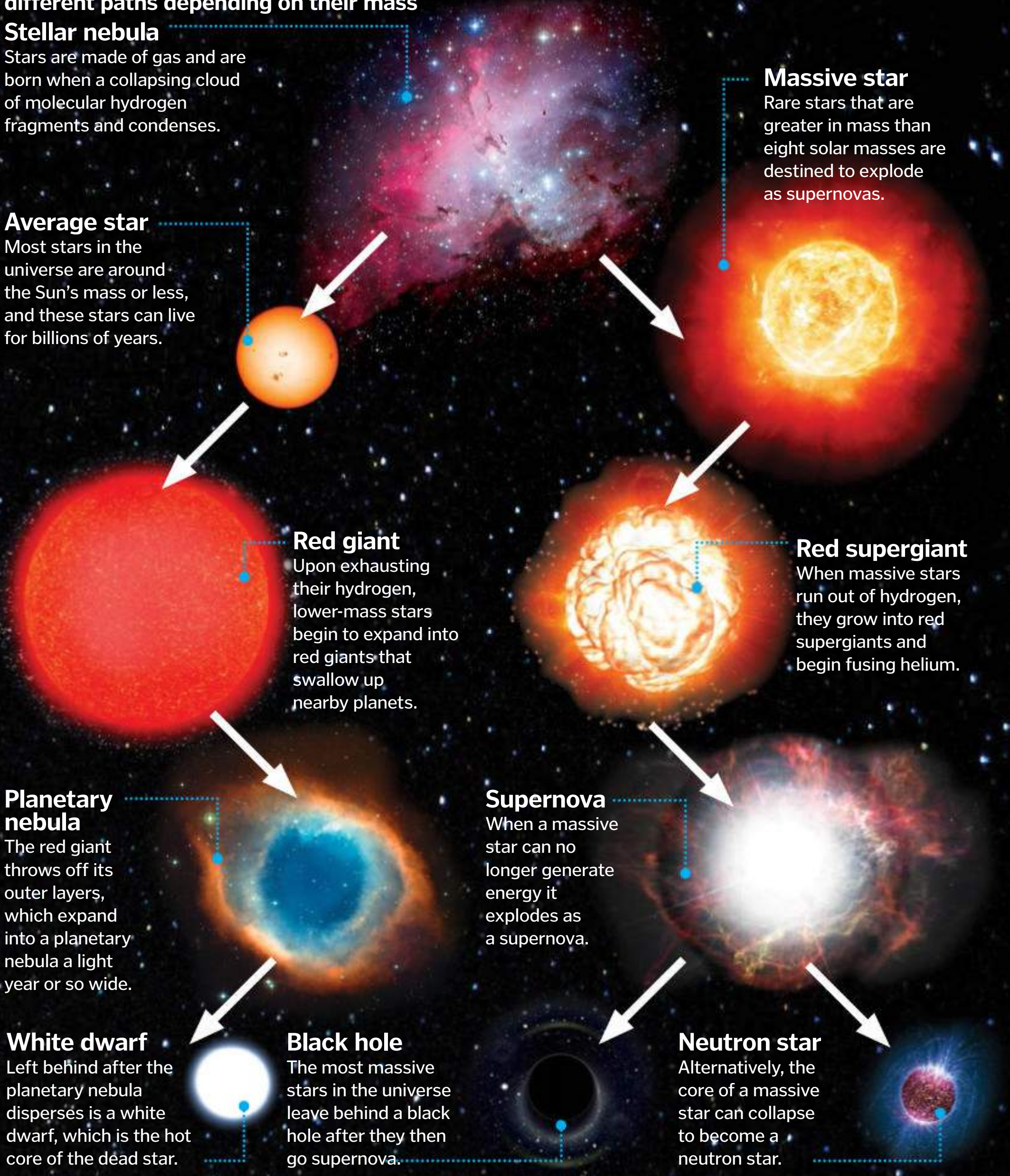
Some white dwarfs in close-orbiting binary systems are faced with eventual complete destruction. Sometimes they will siphon gas from their companion star, growing more massive with the stolen material until they become so massive – more than 1.44 times the mass of the Sun, that they explode as a so-called Type Ia supernova. Alternatively, two white dwarfs in a binary system can collide with one another, also resulting in the creation of an incredible supernova.

However, not all supernovas are a result of white dwarfs. The stars that go the opposite evolutionary paths to the white dwarfs meet their end in a relatively more sudden and just as cataclysmic manner. Those stars are the ones that become more massive than eight times the mass of the Sun collapse when they run out of hydrogen, causing an internal shock wave that essentially rips the star apart. These supernovas – designated as both Type Ib and Type II supernovas – leave either neutron stars or black holes as remnants from their demise.

Dying stars produce all the known heavy elements in the universe through their nuclear reactions and they spread them into interstellar space when they die. Planetary nebulas, for example, produce much of the carbon, oxygen and nitrogen found in the universe. Supernovas release all the heavier elements, either forged inside the star or through the violence of the explosion. This material is gradually recycled through molecular gas clouds that are forming the next generation of stars. The elements that made Earth and everything around us, were originally created in a distant star that died catastrophically billions of years ago.

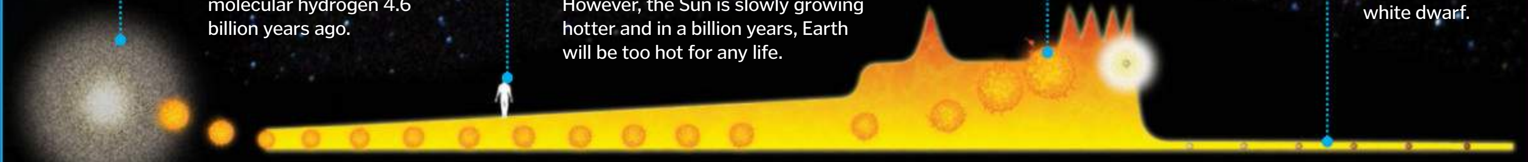
THE LIFE CYCLE OF A STAR

When stars are born, their lives can take one of two different paths depending on their mass



Timeline of a Sun's life

Our Sun's life will span around 10 billion years before it evolves to become a white dwarf. Over its life it will grow brighter and hotter before starting to run out of hydrogen, expanding into a red giant that will be 200 to 300 million kilometres (124 to 186 million miles) in diameter and swallow up the inner planets. This red giant will evaporate into a planetary nebula, leaving behind an inert but white-hot white dwarf.



SUPERNOVA

When massive stars die they produce some of the biggest bangs in the universe

The brightest stars in the universe are also the ones that shine for the shortest time. A massive star, which unleashes a brilliant torrent of light, uses up its hydrogen so fast that it only lives for a few million years, compared to the 10-billion-year lifetime of our Sun, a much smaller star. This is because a massive star has so much mass that it takes a lot more energy to prevent it from collapsing under its own gravity, so it uses up its hydrogen much faster.

When this star runs out of hydrogen, the core contracts a little and the temperature rises enough for the star, in rapid-fire succession, to begin fusing helium, which produces carbon. As the temperature rises, carbon begins to fuse into neon, then oxygen and then silicon, creating shells of these elements like onion layers inside the star until the core contains only iron. At this point, the star cannot process iron any further, and so energy production suddenly stops dead and the star collapses in on itself.

In a matter of a few fleeting seconds, the star's collapsing outer layers rebound off the core, which becomes incredibly compressed. The resulting outward-bound shock wave tears the star apart in a catastrophic supernova, which can produce more energy in an instant than the Sun can in its entire lifetime. It is so bright it can be seen across the entire universe – astronomers regularly discover supernovas in other galaxies, but the last supernova to be seen in our galaxy exploded in 1604.

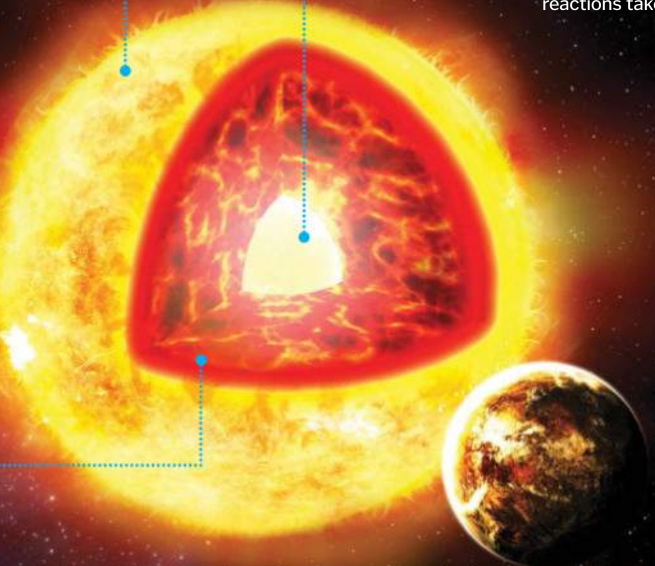
The debris from this – literally – astronomical explosion becomes a gaseous supernova remnant that, like a planetary nebula, disperses into space. The most famous supernova remnant is the Crab Nebula in the constellation Taurus, which is the debris of a star that exploded in 1054 CE. Meanwhile, the core is so compressed that positive protons and negative electrons are forced together to produce neutral neutrons – a neutron star that's only about ten kilometres (6.2 miles) across. In the most extreme cases with the most massive stars, the core can compress even further to become a black hole, consuming planets, other nearby stars and even light itself in the process.

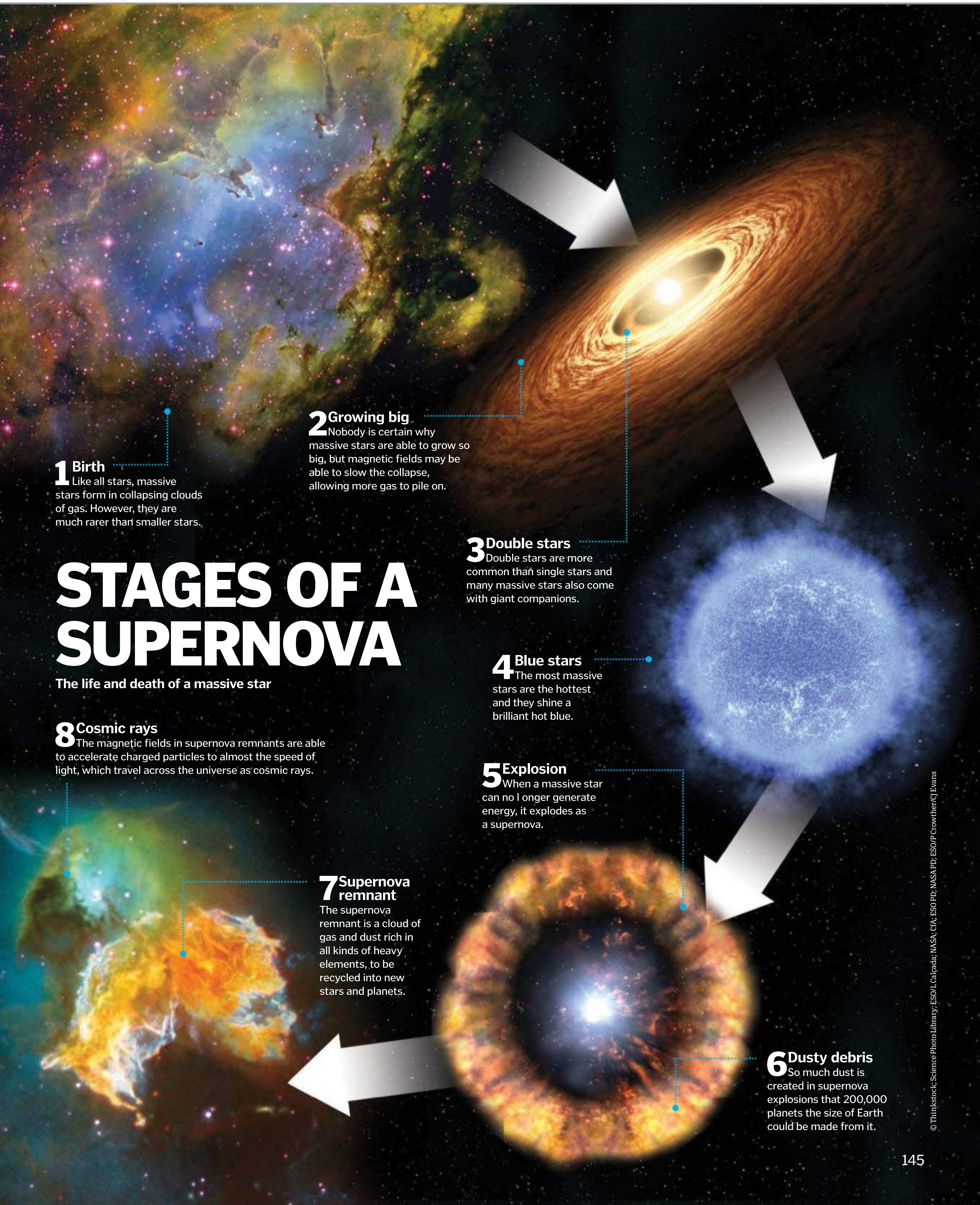
Stellar remnant

When a star explodes it spews its guts out into interstellar space at speeds of around ten per cent of the speed of light. We see the debris as a nebula. Shock waves ripple through the nebula as the expanding material collides with shells of gas and dust that had been ejected by the star during previous outbursts. This can heat the gas in the remnant so that it becomes so hot it produces plenty of X-rays. Gradually, the remnant cools and merges with the diffused, spread out gas in interstellar space. The remnant is rich with heavy elements from everything from calcium to silver and gold. Eventually, gravitational forces sweep up the material from the supernova into a new star-forming nebula, starting the cycle again.

What are stars made of?

When a star is born, it is made from about three-quarters hydrogen and almost a quarter helium, with only trace amounts of other gases. It is hottest within its core – the Sun's core, for example, is a blistering 15 million degrees Celsius (27 million degrees Fahrenheit). Here the nuclear fusion reactions take place. Stars the mass of the Sun mainly do this through the proton-proton chain reaction, where two hydrogen atoms fuse into a helium-2 isotope that decays into deuterium, which then fuses with another hydrogen atom into helium-3. Via a further series of reactions, helium-3 can be transformed into helium-4. Gradually the core fills up with this helium 'ash' while the energy is radiated away through the inner two-thirds of the star, before being transported to the surface by convection currents. It can take millions of years for this energy to eventually reach the surface!





STAGES OF A SUPERNOVA

The life and death of a massive star

1 Birth
Like all stars, massive stars form in collapsing clouds of gas. However, they are much rarer than smaller stars.

2 Growing big
Nobody is certain why massive stars are able to grow so big, but magnetic fields may be able to slow the collapse, allowing more gas to pile on.

3 Double stars
Double stars are more common than single stars and many massive stars also come with giant companions.

4 Blue stars
The most massive stars are the hottest and they shine a brilliant hot blue.

5 Explosion
When a massive star can no l onger generate energy, it explodes as a supernova.

6 Dusty debris
So much dust is created in supernova explosions that 200,000 planets the size of Earth could be made from it.

7 Supernova remnant
The supernova remnant is a cloud of gas and dust rich in all kinds of heavy elements, to be recycled into new stars and planets.

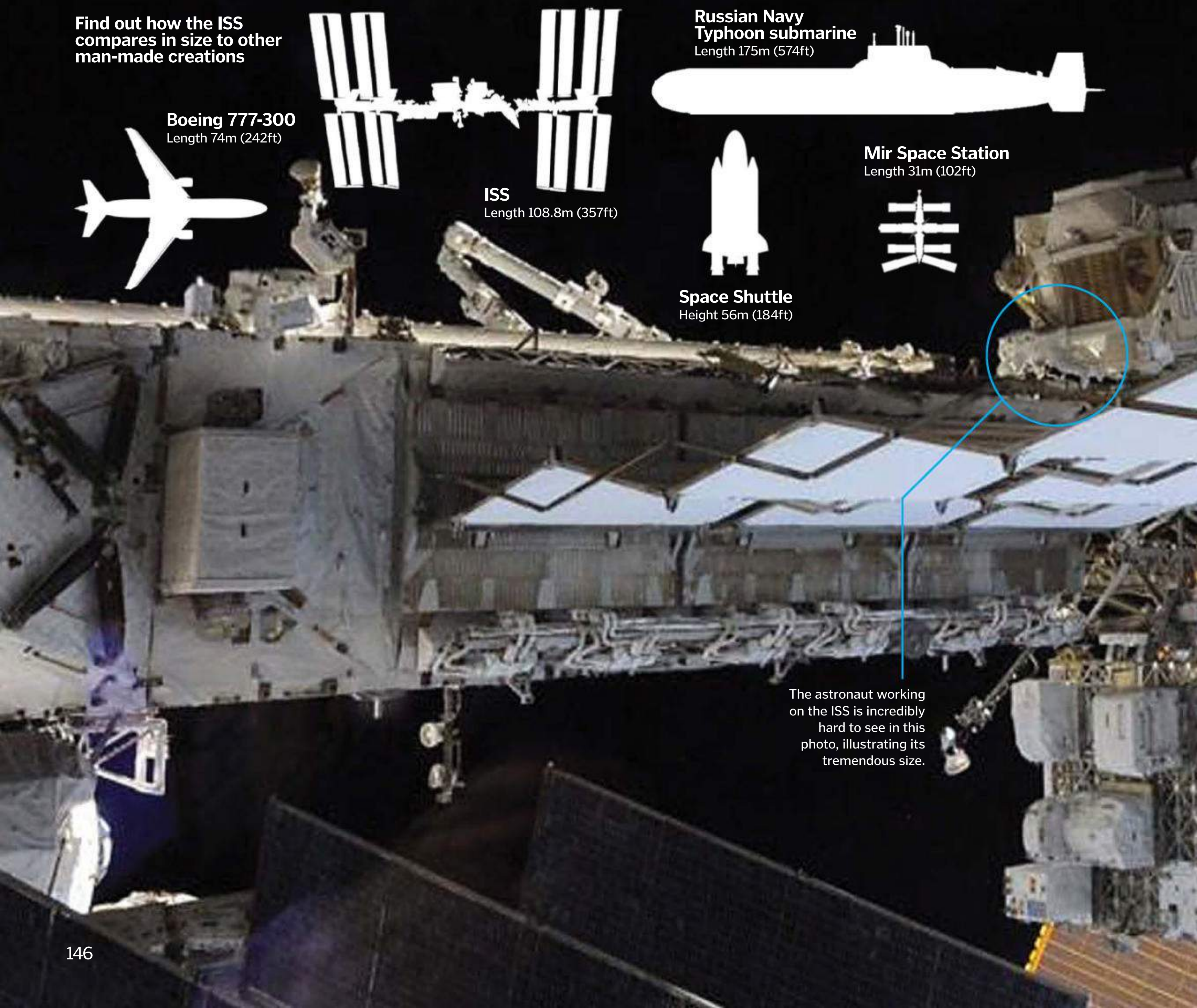
8 Cosmic rays
The magnetic fields in supernova remnants are able to accelerate charged particles to almost the speed of light, which travel across the universe as cosmic rays.

How big is the ISS?

Learn just how massive humanity's home in orbit has become

The size of the International Space Station is incomparable to anything else ever launched into space. With a total mass of approximately 420,000 kilograms (925,000 pounds), it resides 400 kilometres (250 miles) above Earth in one of the lowest possible orbits, meaning that it's visible with the naked eye from the ground. The ISS measures 108.8 metres (357 feet) from end to end, just shy of an American football field's length. Much of its size is a result of the eight solar arrays that power the ISS, giving it a wingspan of 73 metres (240 feet). The 0.4 hectares (one acre) of solar panels produce enough electricity to power the equivalent of 40 homes back on Earth. Living space on the ISS is comparable to a six-bedroom house, equipped with a gym, two bathrooms and a 360-degree bay window, providing unrivalled views of Earth for the crew of up to six members.

At the time of its tenth anniversary back in 2010, the ISS had travelled over 2.4 billion kilometres (1.5 billion miles) and hosted more than 200 people. The ISS is still our best space laboratory; the research potential related to both life on Earth and in space is still vast, but the future of the ISS has been in danger. A decision had to be made as to whether it was worth keeping a piece of 1990s solar-powered technology that costs billions of dollars every year to operate and maintain. The United States had previously considered decommissioning the ISS by 2016, but more recently NASA and Roscosmos have agreed to keep the station in orbit until 2024, after which Russia will focus on a station of their own. So the ISS will continue to serve humanity for a few more years at least.



The astronaut working on the ISS is incredibly hard to see in this photo, illustrating its tremendous size.

"The ISS measures 108.8 metres (357 feet) from end to end, just shy of an American football field's length"

15 FACTS YOU NEVER KNEW ABOUT ECLIPSES

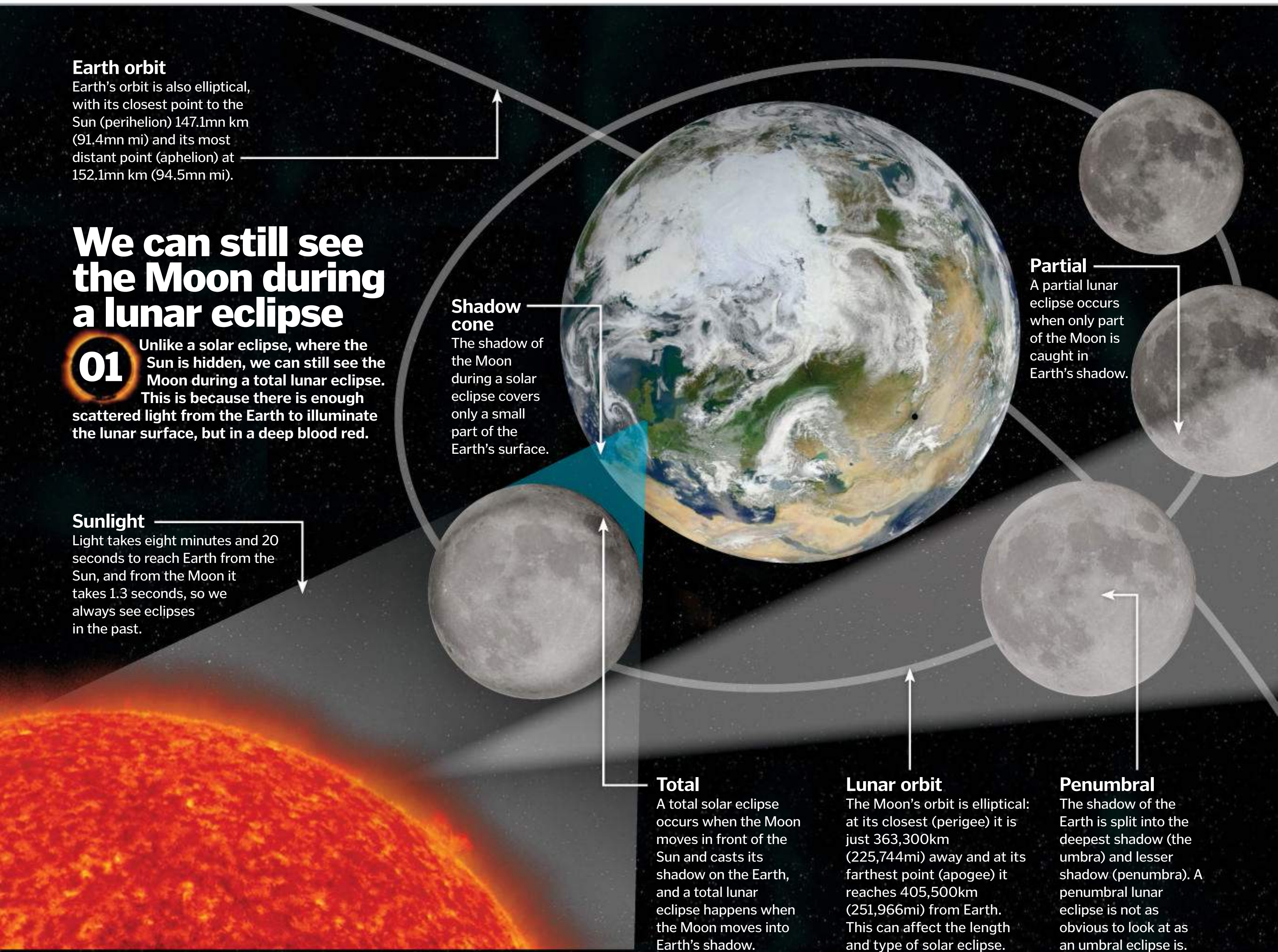
Eclipses are one of nature's most amazing spectacles, a result of our Moon's orbit around our planet

Have you ever seen the sky turn pitch black during the day? We don't mean the grey dark of a rainy day, but dark like the night. The only time you will ever see this is during a total solar eclipse, which is one of nature's most breathtaking eclipses. It happens when the Moon moves in front of the Sun for a few minutes, blocking its light and underneath the Moon's shadow darkness falls.

Total solar eclipses are rare and in a way it is an incredible stroke of luck that we have them. The Sun's distance from Earth just happens to be about 400 times the Moon's distance from our planet. The Sun also happens to be about 400 times larger than the Moon, so thanks to this magic ratio they appear about the same size in the sky, meaning that during an eclipse the Moon can fit precisely over the Sun. We have to say 'about' a lot because Earth's orbit and the Moon's orbit are not circular but elliptical, meaning sometimes they can be a bit further away, or a bit nearer. This results in the Sun sometimes appearing larger than the Moon during some eclipses, leaving a ring of light from the Sun around the Moon's silhouette. We call this an annular eclipse.

An eclipse begins at 'first contact' when the Moon's disc first touches the Sun's disc. You won't notice a change in the light at this point – in fact it won't get dark until the Moon has practically covered all of the disc – this is 'second contact' when the far limb of the Moon's disc touches the Sun's apparent disc. Totality – which is how we describe the Sun being blocked by the Moon – can last for several minutes. 'Third contact' happens when totality ends and the Moon begins to move away from the Sun and daylight returns once more. 'Fourth contact' is when the Moon moves completely off the Sun and the eclipse ends.

The Moon is very slowly moving away from Earth at a rate of 3.8 centimetres (1.5 inches) per year, so eventually it will appear too small to completely cover the Sun. Luckily, this day won't arrive for at least another 500 million years!



We can still see the Moon during a lunar eclipse

01 **Unlike a solar eclipse, where the Sun is hidden, we can still see the Moon during a total lunar eclipse. This is because there is enough scattered light from the Earth to illuminate the lunar surface, but in a deep blood red.**

The length of totality can vary

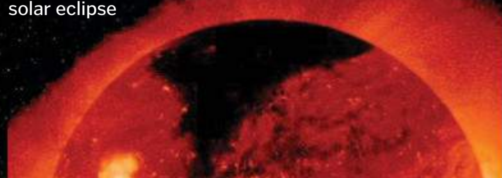
02 **Some eclipses are very short, with totality lasting just a couple of minutes. Others can last six or seven minutes. The reason for the difference is a result of the elliptical orbits of Earth and the Moon. When the Moon is closer to Earth in its orbit, it moves faster. The same for the Earth around the Sun, and this all affects the speed at which we see the Moon move across the Sun during a solar eclipse.**

Totality – the point at which the Sun is 100 per cent covered by the Moon – can last for several minutes

You can see the Sun's atmosphere

03 **The Sun has an atmosphere, split into two parts. The lower part is called the chromosphere where the temperature rises from 6,000 to 20,000 degrees Celsius (10,832 to 36,032 degrees Fahrenheit). The upper part is called the corona and can reach temperatures in excess of 1 million degrees Celsius (1.8 million degrees Fahrenheit). During totality you can see this corona as flares of light around the hidden Sun. You might also catch a glimpse of the chromosphere as a red tinge at the edge of the Moon at third contact.**

The Sun's outermost atmosphere, called the corona, is made prominent during a solar eclipse



You can see the planets during an eclipse

04 **If you are lucky enough to see a total solar eclipse, take a few moments to also glance around the sky. In the darkness the stars and planets will pop out. Closest to the Sun will be Venus and Mercury, but you could also see other planets, depending where in the sky they are at the time.**

During a total eclipse, you should be able to see the stars and naked eye planets – depending on the time of year – as the sky turns dark

UK solar eclipses are rare

05 Total solar eclipses seen from the UK are very rare. The last one was in 1999 and the next won't be until 23 September 2090, where Cornwall will be in the umbral shadow for two minutes and ten seconds. However, there will be partial solar eclipses visible in 2018 (only Shetland, Orkney and the northern coast of Scotland), 2021, 2022 and 2026.

Solar eclipse hunters will need a passport

06 There are plenty of opportunities to view a solar eclipse over the next ten years if you are willing to travel. Following the eclipse this March, there are total solar eclipses on 9 March 2016 (Indonesia, the Pacific), 21 August 2017 (USA), 2 July 2019 (Argentina and Chile) and the same again on 14 December 2020, 4 December 2021 (Antarctica), 20 April 2023 (Indonesia and Australia) and 8 April 2024 (Mexico, USA, Canada). There are also annular eclipses in 2016, 2017, 2019, 2020, 2021, 2023 and 2024.

They can create diamond rings

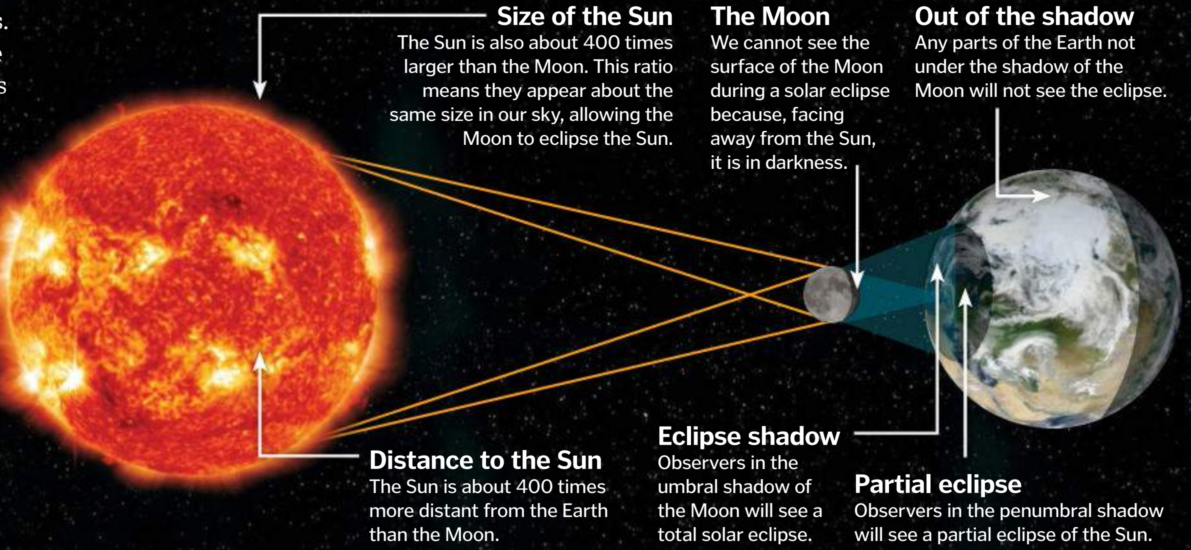
07 Just at the moment totality begins or ends, a spectacular effect takes place that is called the 'diamond ring' – a bright burst of light appears, looking very much like the jewel in a diamond ring. This is caused by sunlight bursting through gaps between mountains on the edge of the Moon.

Sunlight bursting through gaps between mountains on the Moon creates a 'diamond ring'

How a solar eclipse forms

A solar eclipse is a consequence of an alignment of the Earth, Moon and Sun

Eclipses are all a result of orbits. The Moon orbits the Earth once every 27.3 days. The Earth orbits the Sun once every 365.2 days. Their orbits are elliptical, meaning their distance from their parent body can change throughout an orbit. The tilt of the Moon's orbit relative to the ecliptic (the path of the Sun through the sky) is 5.1 degrees. A solar eclipse happens only when the Moon crosses the ecliptic at the exact position that the Sun is at that moment in time.



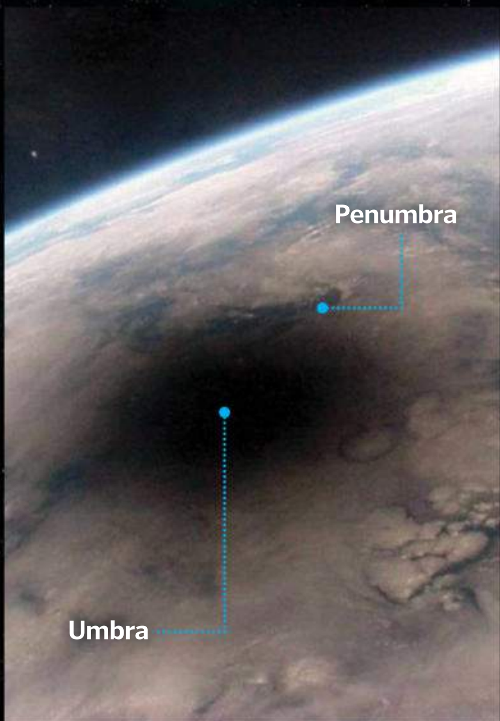
Solar and lunar eclipses come in pairs

08 There is always a lunar eclipse either two weeks before or two weeks after a solar eclipse. This is because the alignment between the Sun, Moon and Earth is still close enough that, a fortnight before or after a solar eclipse, when the Moon is on the other side of the Earth, the Moon can fall into Earth's shadow.

The characteristic reddish hue of a lunar eclipse will often appear not long before or after a solar eclipse

The Moon's shadow moves very fast

09 The Moon's shadow moves quickly across the face of the Earth, from west to east, faster than the speed of sound – the eclipse shadow at the equator travels at 1,730 kilometres (1,075 miles) per hour the Moon orbits Earth at 3,400 kilometres (2,113 miles) per hour, counterbalanced by the Earth's rotation at 1,670 kilometres (1,038 miles) per hour. This is why the Moon moves across the sky faster than the Sun.



There is more than one type of shadow

10 A shadow is divided into two parts – the umbra and the penumbra. The umbra is the central, deepest part of the shadow. The penumbra is where only part of the source of light is blocked. Total eclipses are seen in the umbra, while partial eclipses are seen in the penumbra.

They require syzygy

11 Eclipses occur during a particular alignment of the Sun, Moon and Earth called syzygy, which is when all three bodies are arranged in a straight line.

Ancient eclipses

12 In the past, total solar eclipses have often deemed to be bad omens or portents of doom, or the anger of the gods, prompting both wars and peace to begin. However, as far back as the ancient Babylonians and Chinese in the 25th century BCE, astronomers have been able to predict the motion of the Moon and the Sun and when eclipses would occur.

You can see a lunar eclipse this year

13 Lunar eclipses are much more common than solar eclipses, occurring twice a year in different parts of the world. The next total lunar eclipse visible from the UK will be on 28 September 2015, followed by another on 21 January 2019, with several partial eclipses between those two dates.

Eclipses are relatively rare

14 On average, total solar eclipses happen every 18 months, although sometimes it can be several years between eclipses. They don't occur every month because the Moon's orbit is tilted with respect to the Earth's orbit around the Sun, so it is only rarely that the Moon's path across the sky intersects with the Sun's.

They must be observed with care

15 It is very dangerous to look direct at the Sun without using special eclipse glasses or a telescope with a specialist solar filter. This is because the Sun is so bright it can damage your eyesight, or even permanently blind you. Even if 99 per cent of the Sun's surface is blocked by the Moon, the remaining per cent is still intense enough to burn your retina. So here are some safe options for observing eclipses, or the Sun in general.

If using eclipse glasses, check they do not have any damage. Even a pinhole could damage your eyesight.

Try projecting the image of the Sun through a telescope and onto a piece of white card. Keep the finderscope covered, in case small children accidentally look through it. Gaps between leaves in trees can also act as natural pinholes to project the Sun's image

You can also use specialist solar filters and telescopes. Produced by companies such as Coronado and Lunt, these can be a bit expensive but they allow you to view the Sun at other wavelengths of light, such as hydrogen-alpha, which appears orange, blocking out the dangerous light.

Eclipses on other planets

Solar eclipses do occur on other planets and moons in our Solar System, but because they do not have the size ratio that we have between the Earth and our Moon, their eclipses are not as spectacular. Mercury and Venus cannot have eclipses because they do not have any moons. Mars's two moons are too small to totally obscure the Sun, but the rovers on the Red Planet have photographed Phobos (the larger of the pair) moving in front of the Sun in a kind of partial eclipse. We can see eclipses taking place on Jupiter with our back-garden telescopes, in the form of the shadows of its four major moons cast on the uppermost cloud layer of the giant planet. Astronomers call these 'shadow transits' and several can happen at once. We can also see Jupiter's moons go into eclipse in the shadow of Jupiter. Similar eclipses can take place on all of the giant planets of the outer Solar System, and even on the dwarf planet Pluto where its largest moon Charon can eclipse the distant Sun a couple of times each century.

The shadow of the Jovian moon Ganymede can be seen transiting across the surface of gas giant Jupiter

Capturing asteroids

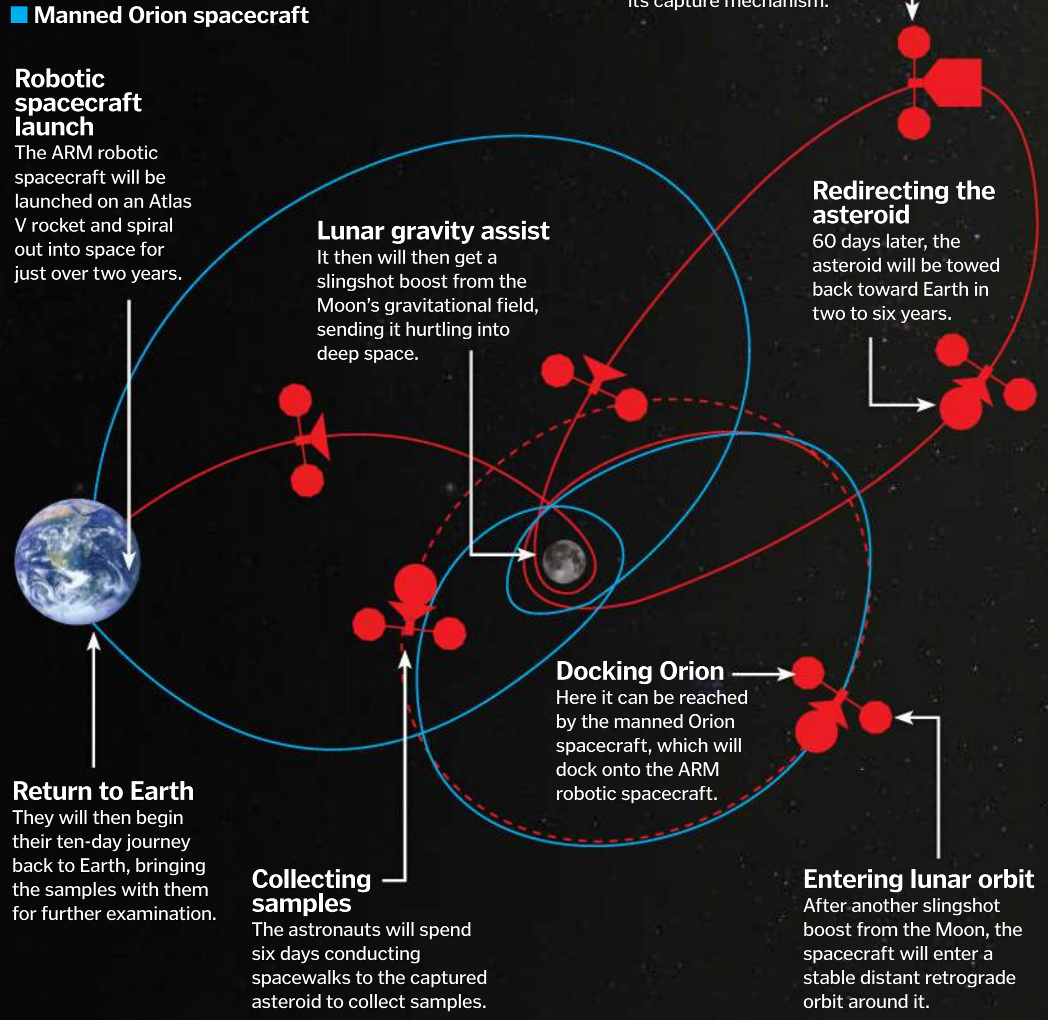
NASA's mission to redirect an asteroid into the Moon's orbit

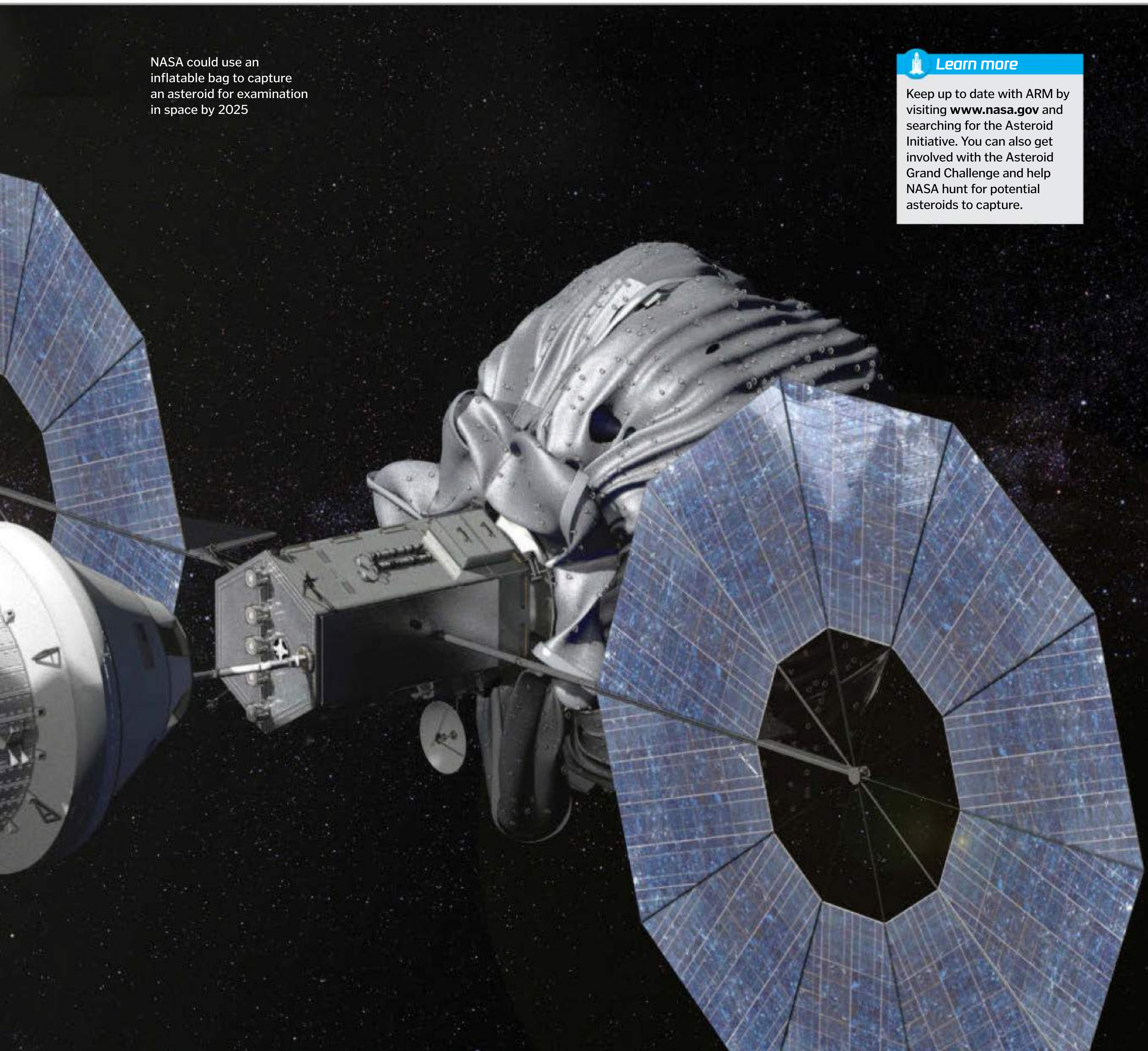
While the European Space Agency was busy with the Rosetta mission to land a probe on a comet, NASA has been developing its next space exploration plan. The Asteroid Redirect Mission (ARM) involves launching a robotic spacecraft in 2019 that will capture an asteroid and redirect it into the Moon's orbit. Astronauts will then visit it aboard an Orion spacecraft in the 2020s and collect samples that could hold clues to the origins of our Solar System and life on Earth. It is also hoped that the mission will prove a number of the capabilities humans will need to reach Mars, something NASA is hoping to achieve in the 2030s.

There are currently two concepts for the ARM robotic spacecraft, and NASA will choose the best one for the job in 2015. Along with citizen astronomers, it is also using telescopes to study the thousands of near-Earth asteroids and identify good candidates for both of the proposed spacecraft to collect. Although it is hoped the mission will also demonstrate techniques for defending Earth from impacts in the future, the asteroid chosen for the ARM mission won't pose any threat to us. It could remain in the Moon's orbit for hundreds of years and even if it did approach Earth, it would be so small that it would burn up in the atmosphere and disintegrate before reaching the surface.

The ARM flight plan

How long will NASA's trip to an asteroid take?

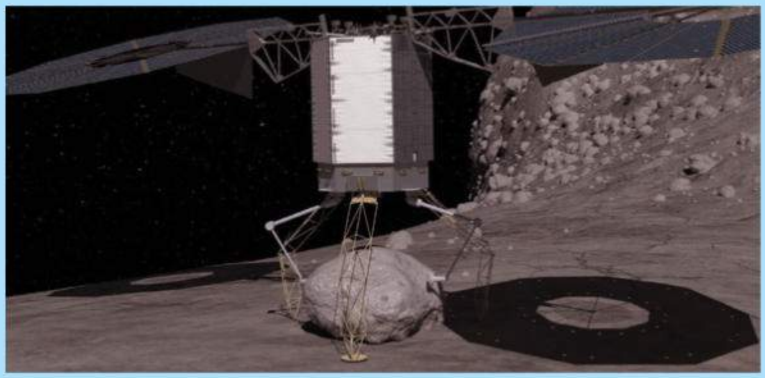




NASA could use an inflatable bag to capture an asteroid for examination in space by 2025

Learn more

Keep up to date with ARM by visiting **www.nasa.gov** and searching for the Asteroid Initiative. You can also get involved with the Asteroid Grand Challenge and help NASA hunt for potential asteroids to capture.

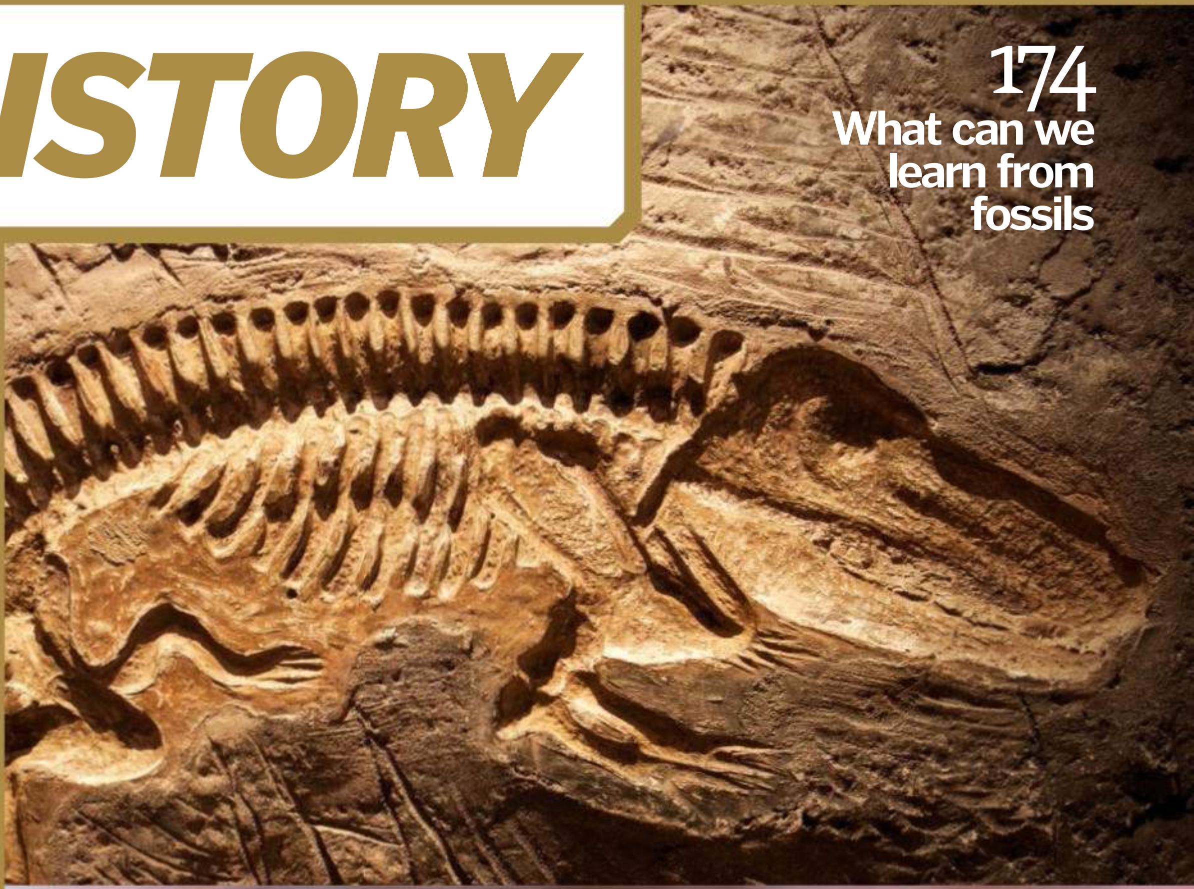


Robotic spacecraft concepts

The first of the two concepts for the ARM robotic spacecraft involves capturing a small asteroid in a 15-metre (50-foot)-long inflatable bag before towing it toward the Moon's orbit. The second uses robotic arms to retrieve a small boulder from the surface of a much larger asteroid.

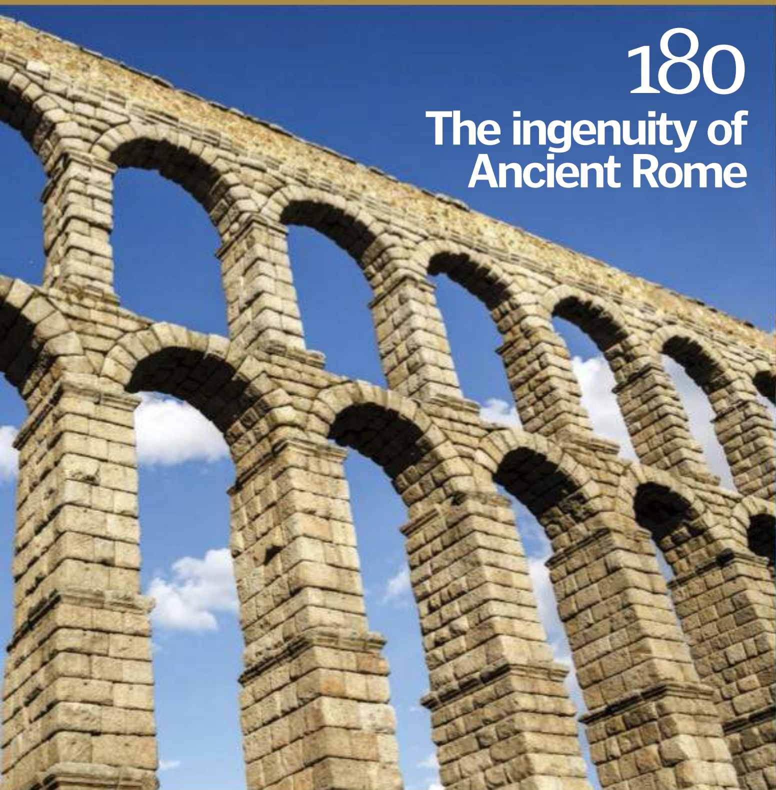
Both concepts use advanced solar electric propulsion (SEP), an efficient way to move large payloads into deep space that could be crucial for getting humans to Mars. It involves using the craft's many solar panels to generate electricity, which is then used to ionise the atoms of propellant gas. Magnets are then used to push the ions out the back of the craft and repel them away to create thrust. Although the thrust is weaker than that produced by traditional rocket fuel, it can be sustained for longer to build up acceleration, making it ideal for long deep-space missions.

HISTORY



174
What can we learn from fossils

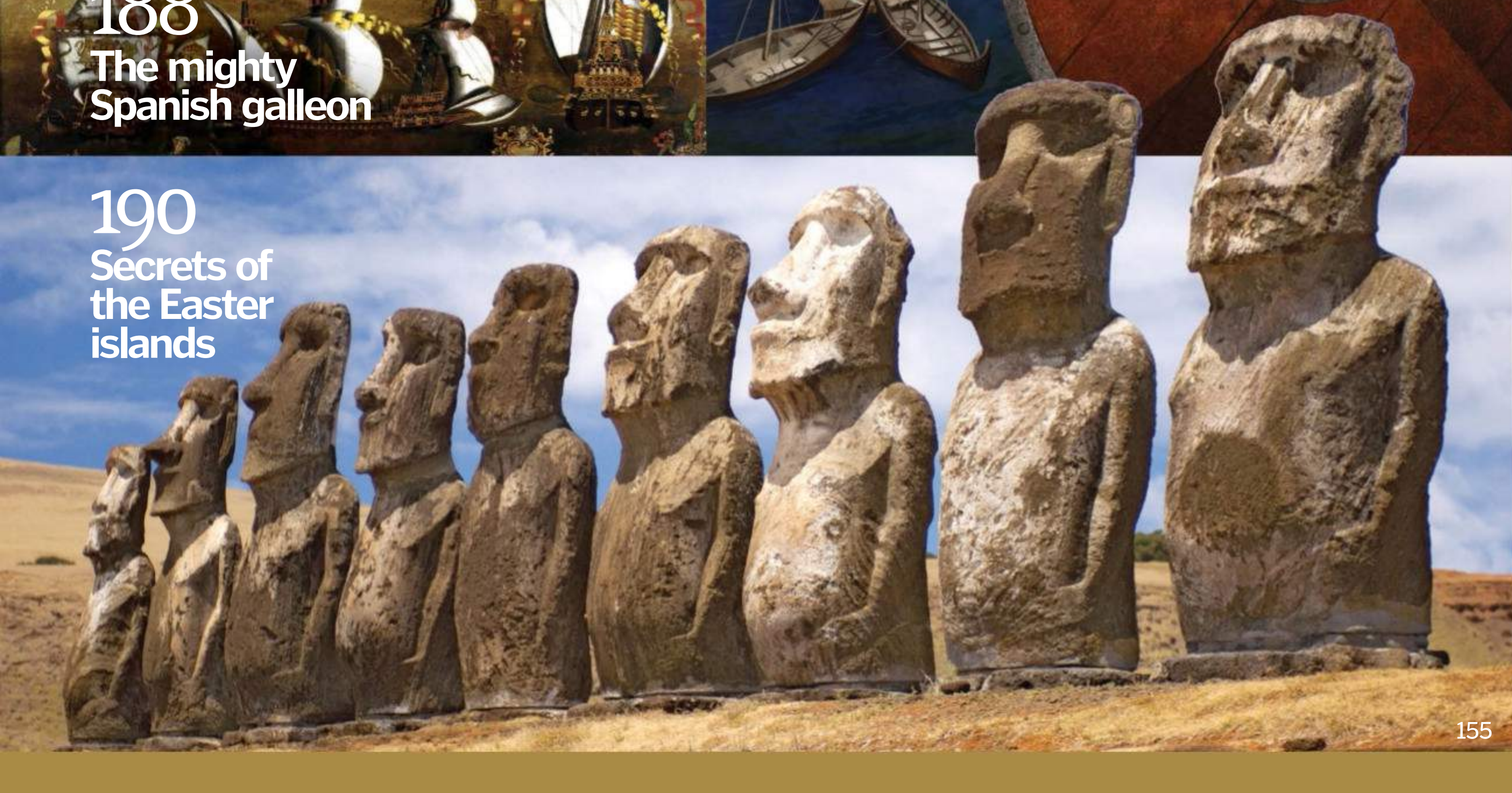
186
The eruption of Vesuvius



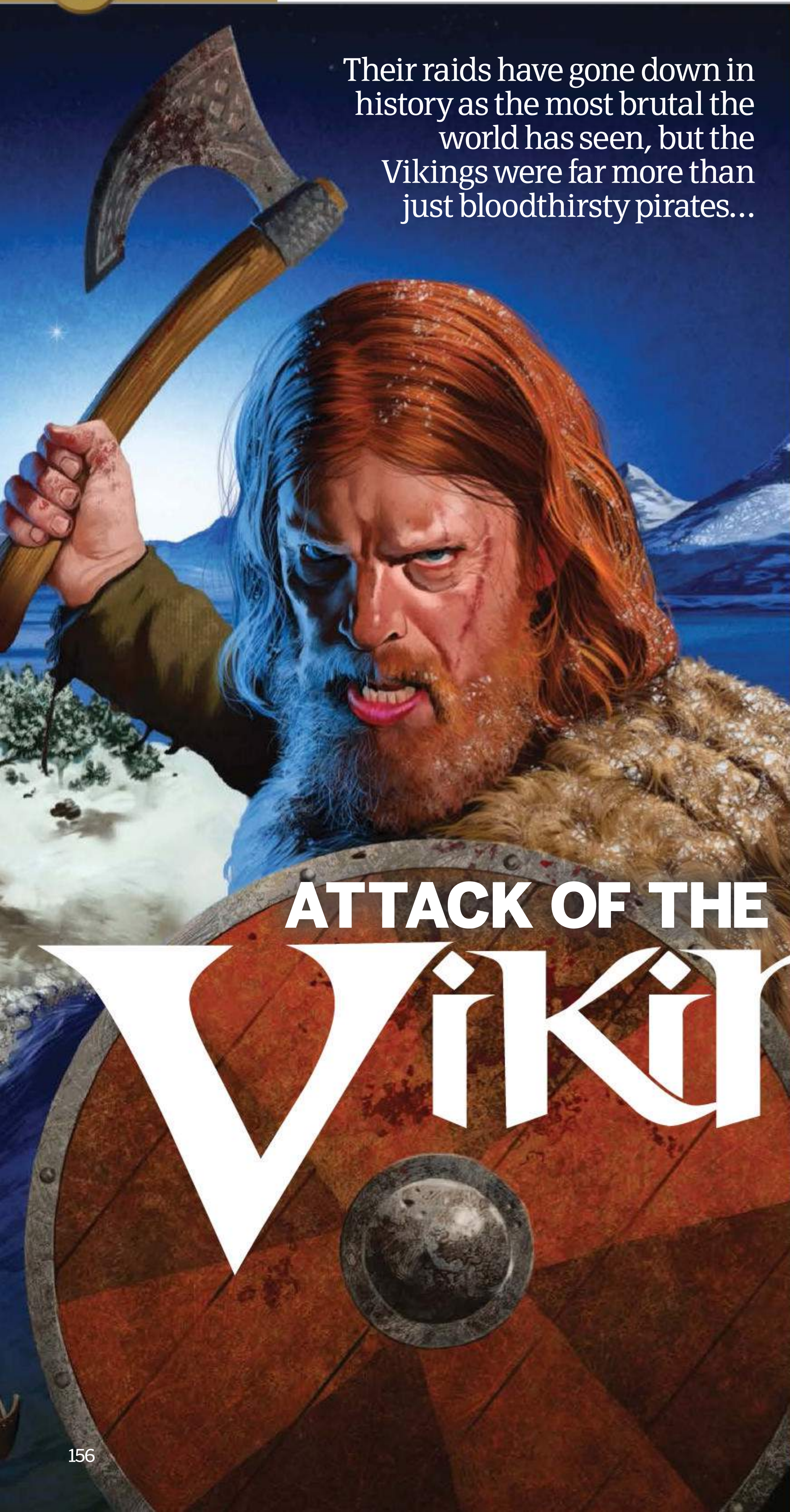
180
The ingenuity of Ancient Rome

156
Vikings – pillagers or pioneers?

188
The mighty Spanish galleon



190
Secrets of the Easter islands



Their raids have gone down in history as the most brutal the world has seen, but the Vikings were far more than just bloodthirsty pirates…

ATTACK OF THE VIKINGS

Planet Earth has been home to some pretty terrifying civilisations over the years, but few would deny that the most fearsome of all were the Vikings. Best known for their mighty dragonships and bloodthirsty raids, these warriors from the north spent their days scouring the oceans in search of their next unfortunate target.

Unlike the Romans 1,000 years before, whose ambitions had been to conquer, the early Vikings set sail in search of treasure and slaves. Between the 8th and 11th centuries, they pillaged and plundered towns across Europe, ruthlessly killing anyone who stood in their way with a single blow of an axe, and capturing any bystanders to be sold on to wealthy citizens back home.

But what is considered most monstrous of all is the fact that their favourite targets were humble, undefended monasteries. These were packed full of gold and silver used in worship, along with valuable gifts from generous members of the parish, and were often located on remote islands – difficult for the townspeople to reach, but very easy for a seafaring warrior to get to. With only a few unarmed monks between them and the loot, it's easy to see why the Vikings took such a liking to these unbecoming treasure troves.

But the Norsemen were not mindless killers – far from it. Though some undeniably did revel in the excitement of a raid, the majority left their homes with a more humane motive: to feed their families. Scandinavia's bitter climate meant the land wasn't generally suitable for farming, and overpopulated towns were struggling to produce enough food. The Vikings were desperate to find new farmland on more fertile shores, so set about developing ships that were strong enough to withstand a long journey across the stormy North Sea.

Their expert ship-building skills, imaginative navigation techniques and entrepreneurial spirit meant that they were able to explore further than any civilisation before them, setting up countless trading posts along the way, while the wealth accumulated from hit-and-run raids allowed them to continue running their farms back home. Over the years, they began to colonise their new-found territories, and Viking settlers could soon be found throughout Europe.

Viking warriors

Despite their ruthless killing sprees, the early Viking raiders were primitive warriors. Their attacks were uncoordinated, and they lacked the numbers of their opponent armies. However, what these raiders had mastered was the element of surprise. By travelling in small fleets, Viking longboats could arrive on enemy shores completely undetected, leaving very little time for the townspeople to prepare for battle. It also meant that they could leave as swiftly as they had come.

As time went on, the raids grew in size, intensity and speed. By 851, the fleets had grown from three ships to over 300, and they formed a 'Great Army' of thousands. Unlike the early raiding parties who settled for merely hit-and-run attacks, this army had a very different purpose: to conquer.

Clothing materials

Wool

Though Vikings are best known for being fierce warriors, many were also able farmers. Wool from sheep was spun into yarn and then woven into cloth to make tunics, cloaks and mittens.

Linen

Vikings made linen from flax – a type of plant. After harvesting the crops, famers would soak the stems in water and beat them. The stems could then be pulled apart into stringy fibres.

Animal skins

During the winter, animals were slaughtered and the skin from cows and goats was hung and stretched out to dry in order to make leather. Reindeers, wolves and bears were also hunted for their fur.

Vikings' deadliest weapons

Axe

Contrary to being big and cumbersome, Viking axes were actually lightweight and easy to handle. They could be swung or thrown with head-splitting force, and the injuries they inflicted were usually fatal.

Bow and arrow

These cleverly designed weapons had a range of over 200 metres (656 feet). Arrows would have been fired at the enemy at the very beginning of a battle, warriors could then close in to fight at a closer range.

Sword

Viking swords were difficult to make, and therefore rare and expensive. Only true warriors would own one. The rarest and most powerful was one called the Ulfberht, which was made of very high-quality steel for its day.

Spear

These were the most common weapons among the peasant class, as the spearheads were made of iron and therefore cheap to make. They were usually two to three metres (6.6 to 9.8 feet) long and could be used for throwing or thrusting.

Knife

These were the only weapons that could be owned by everyone, even slaves. The seax was slightly heavier than a normal knife but much easier to hide than a sword, so was useful for making quick, unexpected slashes.

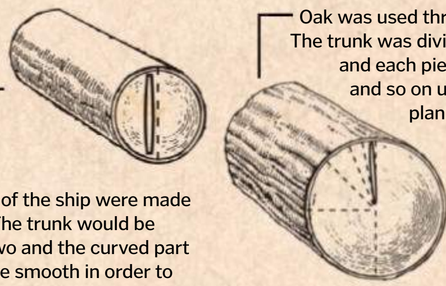
Viking voyages

The Vikings ruled the waves, and all thanks to one spectacular piece of craftsmanship: the longboat. Norse shipbuilders had mastered their art to such an extent that their boats were stronger, faster and more navigable than any civilisation before them. Their voyages took them as far east as Baghdad and as far west as North America, centuries before Christopher Columbus had even set sail, making them the first Europeans to discover the New World. They plotted the complex network of Russia's rivers and estuaries, often dragging their ships for great distances over land, and even took to travelling by camel when water was scarce. Though raids were a quick and easy way to accumulate wealth, they were hardly a long-term solution.

As time went on, the Vikings established several trade posts across Europe and the Middle East, trading Scandinavian goods like walrus ivory, soapstone and animal skins in return for slaves, silk and spices. Soon the Vikings were dominating the markets. With their growing wealth and power, the Vikings were able to take on bigger challenges in the form of sieges and invasions, and swiftly set about conquering cities across Europe. The Viking empire was born.

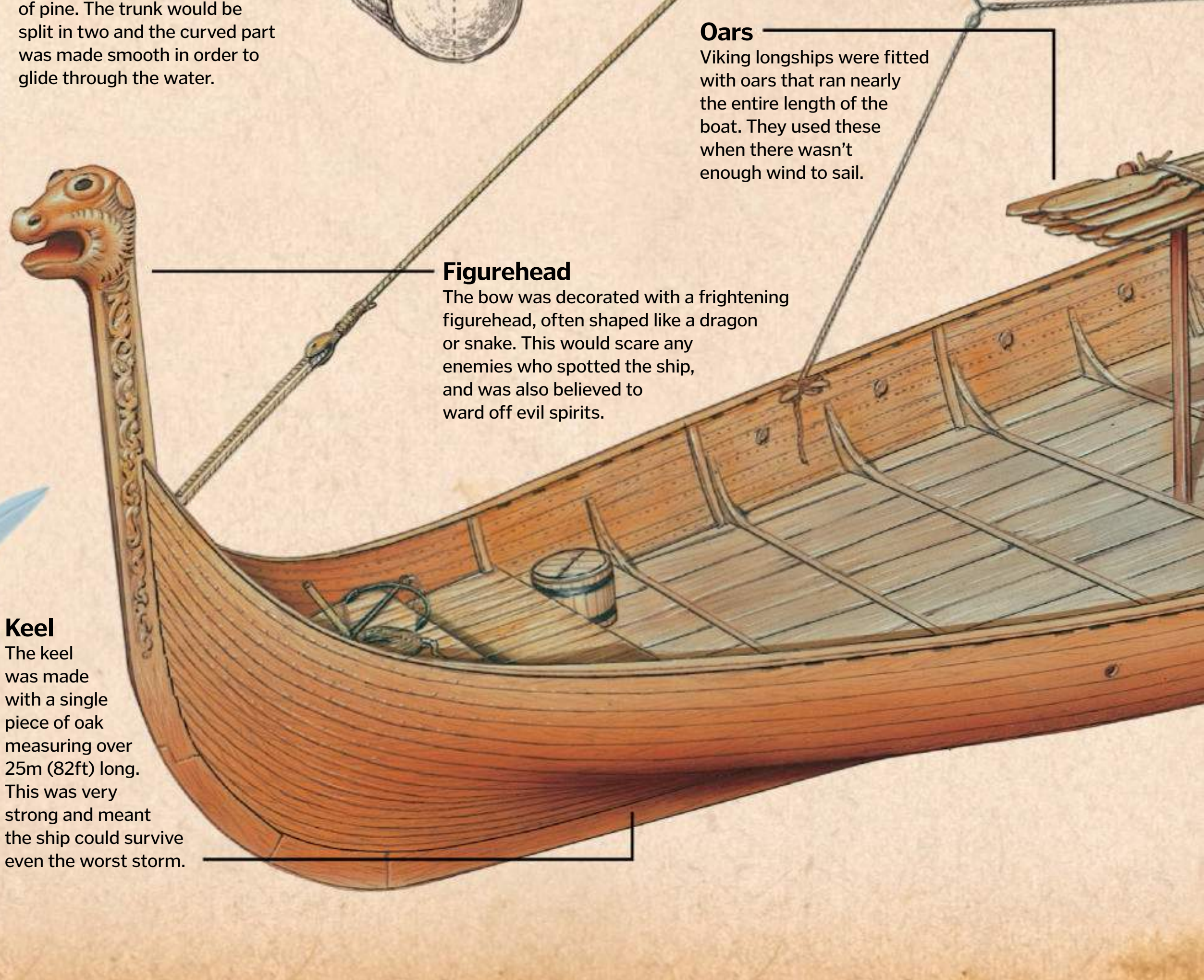
Building materials

Ships were made of wood which was fashioned into planks with axes and carving knives, rather than saws.



Oak was used throughout the ship. The trunk was divided in two pieces and each piece was cut in two and so on until around 20-30 planks were obtained.

The oars of the ship were made of pine. The trunk would be split in two and the curved part was made smooth in order to glide through the water.

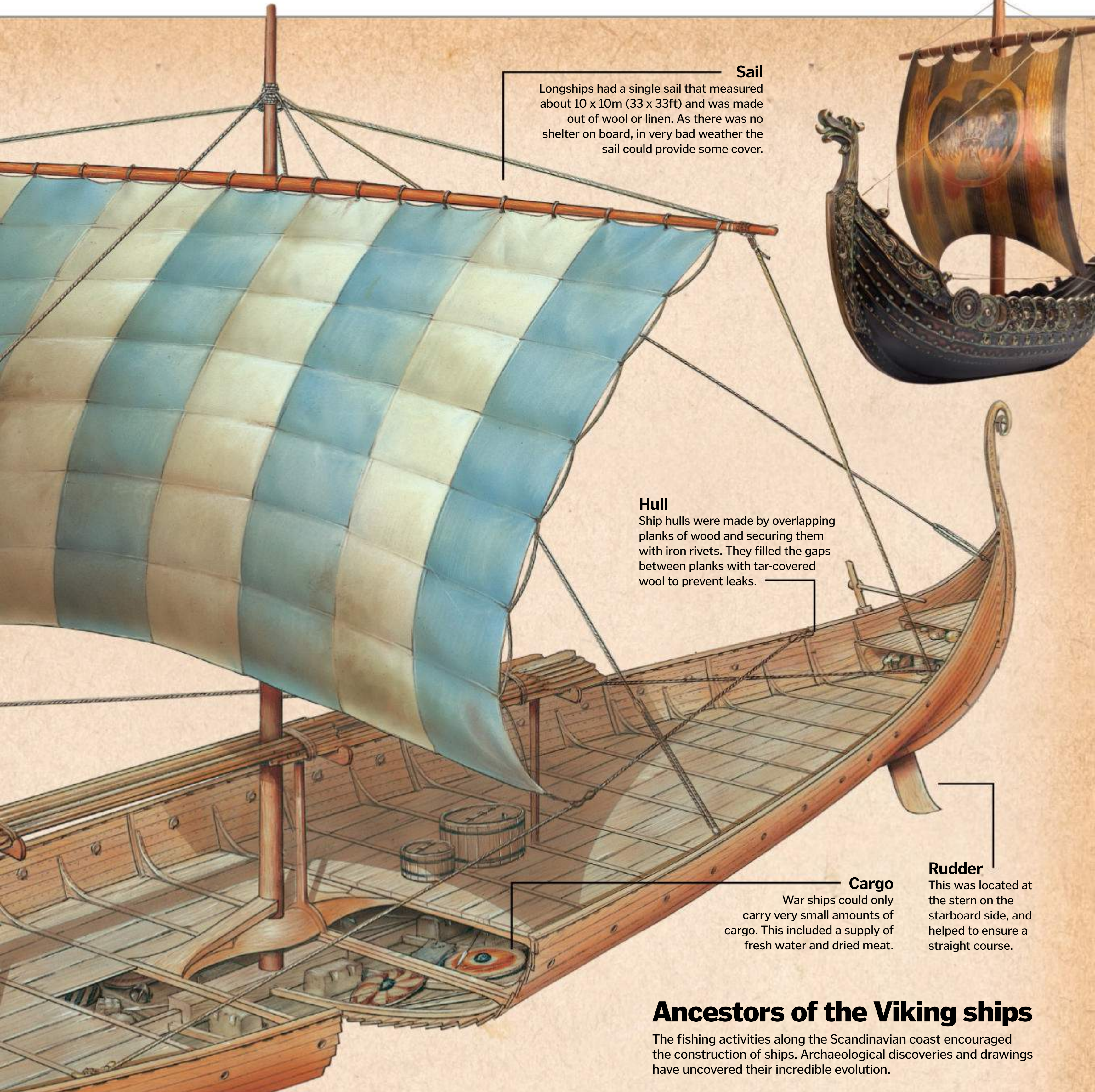


Oars
Viking longships were fitted with oars that ran nearly the entire length of the boat. They used these when there wasn't enough wind to sail.

Figurehead
The bow was decorated with a frightening figurehead, often shaped like a dragon or snake. This would scare any enemies who spotted the ship, and was also believed to ward off evil spirits.

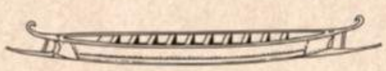
Keel
The keel was made with a single piece of oak measuring over 25m (82ft) long. This was very strong and meant the ship could survive even the worst storm.

DID YOU KNOW? *Vikings had excellent hygiene, bathing at least once a week – more than other Europeans of the time!*

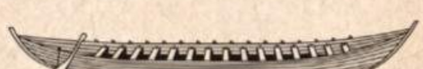


Ancestors of the Viking ships

The fishing activities along the Scandinavian coast encouraged the construction of ships. Archaeological discoveries and drawings have uncovered their incredible evolution.

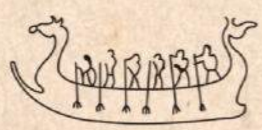


Hjortspring boat, 350 BCE

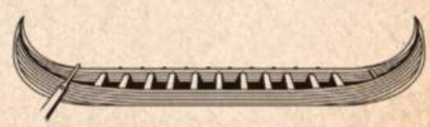


Nydam boat, 300 CE

Neolithic boat, 3500 BCE



Halsnøy boat, 100 CE



Kvalsund boat, 700 CE

5 Most infamous Viking raids

01 Lindisfarne, 793 CE
Perhaps the most notorious raid in Viking history, this was the first to take place on English soil, and therefore the most unexpected. It involved the plundering of a remote island monastery in Northumbria, one of the most sacred places in Britain.

02 Rathlin Island, 795 CE
The shorelines of Ireland were rich with monasteries, making them ideal targets for Viking raiders. The first recorded Irish raid was on Rathlin Island, where a monastery was plundered and burned.

03 Martyrs Bay, 806 CE
The wealthy monastery of Iona in Scotland was victim to a series of Viking attacks, but during the worst raid 68 monks were massacred in Martyrs Bay. By 825, the monastery had been completely abandoned.

04 Seville, 844 CE
The first raid in Spain for which there is definite evidence took place in Seville and the city was held for several weeks. However, the Vikings suffered severe losses, and they only escaped by ransoming their prisoners.

05 The Siege of Paris, 885-6 CE
Hundreds of ships, and possibly tens of thousands of men, arrived at the gates of Paris in late November 885 in an attempt to raid the city. Their efforts to break through the walls failed, but the emperor allowed them to sail further down the Seine.

Viking conquests

Thanks to their po werful longships and advanced navigation skills, Vikings were able to establish an empire of trade and colonies

Illustrations by Stian Dahlslett **www.dahlslett.com**

What happened to the Vikings?

By the early 12th century, the age of the Vikings had come to an end. In Britain, the events leading up to the Battle of Hastings in 1066 saw the Viking king Harald Hardrada defeated, and the city of Jorvik was later burned to the ground. But what we often forget is that the new king – William the Conqueror – was a descendent of the Vikings, though it would have been hard to tell. Settlers across Europe had become so absorbed into the local populations that they bore little resemblance to the heathens who had first arrived there; the Old Norse language was left behind, save for a few words, as was the pagan religion. Christian missionaries set sail for Scandinavia, slowly converting the remaining pagans and as a result Viking raids petered out. When the raids eventually stopped, the rest of Europe no longer saw the Norsemen as Vikings, but Danes, Swedes, Norwegians and Icelanders.

Harald Hardrada was killed in the Battle of Stamford Bridge, just a few weeks before the Battle of Hastings

101 GIGANTIC FACTS ABOUT DINOSAURS

THE TRUTH BEHIND NATURAL HISTORY'S BEHEMOTHS

01 THE WORD 'DINOSAUR' MEANS TERRIBLE LIZARD

The word 'dinosaur' was first used in 1841 by biologist Sir Richard Owen. It is from the Greek word 'deinos', meaning terrible or great, and 'sauros', meaning lizard.

02 DINOSAURS WERE NOT LIZARDS

Despite being named 'terrible lizards', dinosaurs were anatomically very different from other reptiles and are not that closely related.

FACT 3

200 TONS

NO DINOSAUR EVEN CAME CLOSE TO THE WEIGHT OF A BLUE WHALE

04 CAVEMEN NEVER MET THE DINOSAURS

The reign of the dinosaurs came to an end 66 million years ago, but humans have only been around for 200,000 years. Our ancestors did not share a world with the dinosaurs, but they did encounter sabre-toothed cats and woolly mammoths.

05 NO ONE KNOWS WHAT COLOUR DINOSAURS REALLY WERE

The coloured pictures of dinosaurs seen in textbooks are guesswork based on what we know about animals today, but scientists have analysed melanosomes (pigment cells) found in fossils and are piecing together their real colours.

FACT 6
5cm
STEGOSAURUS HAD A BRAIN THE SIZE OF A PLUM

07 TRICERATOPS HAD UP TO 800 TEETH

Triceratops might be known for their horns, but these icons of the Cretaceous period had another special feature. They had hundreds of teeth, stacked on top of one another in groups of three to five in piles called 'dental batteries'.

08 NOT ALL PREHISTORIC REPTILES WERE DINOSAURS

Over 230 million years ago, the Earth was dominated by large mammal-like reptiles like Dimetrodon and Lystrosaurus. They might look like dinosaurs, but they are actually more closely related to modern mammals.

A BRIEF HISTORY OF DINOSAURS

Around 230 million years ago, the world was a very different place. The land was joined together to form a single continent, and the dominant animals were reptiles. These enormous animals included some of the largest creatures to have ever walked the Earth.

Over the course of their 165-million-year reign, the world underwent tremendous changes. The landmasses tore apart, and the climate became cooler and wetter. Seas appeared and disappeared, and plants started to dominate the land, covering the landscape in ferns, horsetails and conifers.

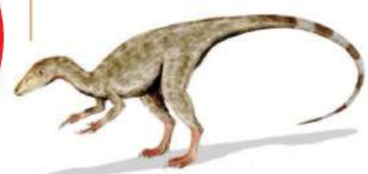
Over the course of the Mesozoic Era, dinosaurs came to inhabit every landmass, diversifying into a huge variety of weird and wonderful shapes. All dinosaurs are thought to be descended from a small two-legged ancestor weighing just a few kilograms, but some evolved claws for grasping, others had bony armour, spikes, scales and horns, and some became enormous four-legged giants with extremely long necks and tails. Over time, dinosaurs became larger and larger on average.

These enormous animals were reliant on the environment for their survival, but 66 million years ago disaster struck. Around this time, a colossal asteroid struck the Earth, volcanic eruptions spewed ash into the sky, and high oxygen levels fuelled fires on the ground. The sea level dropped and 75 per cent of life on the planet perished.

Mammals could keep warm, were able to reproduce more rapidly and could burrow underground, so they quickly came to dominate the post-dinosaur world. Although the large dinosaur species died out in the mass extinction event, some of the theropods survived. They had evolved to become smaller over time, so were better able to cope with the changing environment. There is mounting evidence that birds descended from these adaptable dinosaurs.

The dinosaurs are some of the most successful animals to have ever lived on Earth. They dominated the planet for over 150 million years, and despite suffering catastrophic losses at the time of the mass extinction event 66 million years ago, their ancestors are still among us and still manage to colonise every corner of the planet.

FACT 9
3.5KG
COMPSOGNATHUS, ONE OF THE SMALLEST DINOS, WAS ONLY JUST LARGER THAN A CHICKEN



Compsognathus
Late Jurassic
Europe

SAUROPODS

These long-necked giants are among the largest animals to have ever lived

10 SAUROPODS WERE HUGE HERBIVORES

The four-legged dinosaurs with long tails and necks are known as sauropods. The most common were Diplodocus and Camarasaurus.

11 DIPLODOCUS HAD 15 VERTEBRAE IN ITS NECK

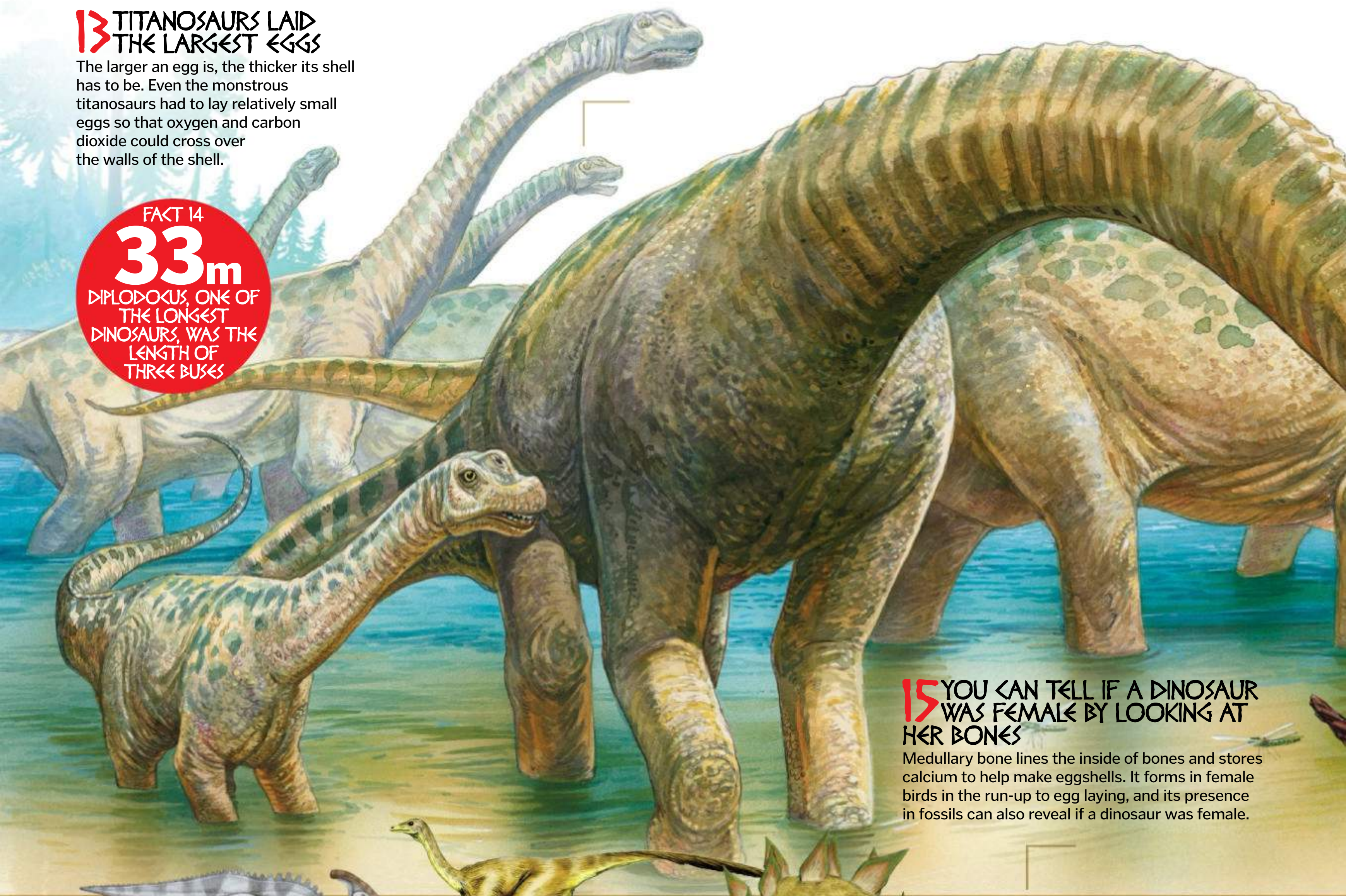
At least, we think it did – there are very few complete specimens. For comparison, a human has seven neck vertebrae.

12 SAUROPODS DID NOT LIVE IN WATER

Early ideas about how sauropods like Diplodocus lived portrayed them walking underwater like hippos. They had nostrils on the top of their heads, and scientists thought they would use their necks like snorkels. However, with large bodies, the crushing weight of water would have prevented them from breathing, and we now know they lived on land.

13 TITANOSAURS LAID THE LARGEST EGGS

The larger an egg is, the thicker its shell has to be. Even the monstrous titanosaurs had to lay relatively small eggs so that oxygen and carbon dioxide could cross over the walls of the shell.



FACT 14

33m

DIPLODOCUS, ONE OF THE LONGEST DINOSAURS, WAS THE LENGTH OF THREE BUSES

15 YOU CAN TELL IF A DINOSAUR WAS FEMALE BY LOOKING AT HER BONES

Medullary bone lines the inside of bones and stores calcium to help make eggshells. It forms in female birds in the run-up to egg laying, and its presence in fossils can also reveal if a dinosaur was female.

Charonosaurus
Late Cretaceous
China

22 HADROSAURS HAD DUCK-LIKE BILLS

Hadrosaurs were the first dinosaurs found in North America, and since the 19th century, hundreds have been unearthed. These herbivores had a very distinctive appearance, with duck-like beaks adapted for clipping vegetation, and crested heads that might have been helped to transmit sounds over long distances.

23 ORNITHOMIMIDS LOOKED AND LIVED LIKE OSTRICHES

Ornithomimid means 'bird mimic', and these two-legged dinosaurs really do look familiar. They had long, muscular legs, large, rounded bodies and long necks with small heads. Like modern ostriches, these dinosaurs were extremely fast on their feet.

24 DINOSAURS DIDN'T HAVE TWO BRAINS

Stegosaurus had a tiny brain, but at the base of its spine there was an enlarged space. Scientists once thought it might have housed a second, larger brain to control its legs, but this idea has been discredited as birds have a similar opening to store the energy-rich substance glycogen.

25 PACHYCEPHALOSAURS HAD THICK SKULLS

Pachycephalosaur means 'thick-headed lizard'. The bone at the top of their skull could be up to 25cm (10in) thick, and their faces were covered in bumps and spikes. These dramatic features could have been for fighting, or they might just have been for show, like the antlers on modern deer.

16 ANKYLOSAURUS WAS ONE OF THE LAST SURVIVING DINOSAURS

These heavily armoured dinosaurs had clubbed tails, weighed over 4,000kg (8,818lb) and were covered in bony plates. They were extremely tough, and no predator could tackle a full-grown adult.

FACT 18

18.5m

SAUROPOSEIDON WAS ABOUT THREE TIMES TALLER THAN A GIRAFFE

17 HERDS OF DINOSAURS WERE FOSSILISED TOGETHER

At a bonebed in Alberta, Canada, at least 27 ceratopsids with frilled heads and horns were found buried together.

19 PTEROSAURS WEREN'T DINOSAURS

Pterodactyls are the iconic flying dinosaurs, but they weren't actually dinosaurs at all. Dinosaurs were all land animals. Quetzalcoatlus, the largest pterosaur of all, had a 12m (39ft) wingspan, making it the largest animal that ever flew.

20 BIG BODIES KEPT DINOSAURS WARM

This process is known as 'thermal inertia'. The larger the body of an animal, the lower the surface-to-volume ratio – preventing heat escaping from the skin.

21 THE SEA LEVEL DROPPED AS THE DINOSAURS WENT EXTINCT

At around the time the dinosaurs went extinct, the sea level fell by 150m (492ft) in just 1 million years, and inland seas dried up.

26 DINOSAURS HAD FEATHERS

Despite what you might see in textbooks, museums and even in this article, we now know that most dinosaurs were not all scaly and bald. We have known for a while that the two-legged theropods had feathers, but in 2014 a very distantly related beaked dinosaur found in Siberia was also found to have feathers, suggesting scales were replaced early in dinosaur evolution.

27 CERATOPSIANS HAD HORNED FACES

The most famous ceratopsian is Triceratops, but there were other dinosaurs with horns and frills. These huge herbivores started to appear around 160 million years ago, and it is thought the frill was used as protection against predators, to impress potential mates and as a radiator to get rid of excess heat.

NESTS & EGGS

28 ALL DINOSAURS LAID EGGS

Dinosaurs all reproduced by laying eggs like modern-day birds, and some of the hatchlings were thousands of times smaller than the full-grown adults.

29 SOME DINOSAURS CARED FOR THEIR YOUNG

Adult Psittacosaurus have been found alongside the fossilised remains of their young, and the bones of older babies have been found in the nests of Maiasaura, indicating that they probably helped to raise their young.

30 THE LARGEST DINOSAUR EGG WAS OVER 60CM LONG

The largest dinosaur eggs were found in Mongolia in the 1990s, and measured around 45cm (17.7ft) across. Compared to the size of the adults, they are still surprisingly small.

31 SOME OF THE BEST DINOSAUR FOSSILS ARE BABIES

A 113-million-year-old fossilised baby dinosaur found in Italy still contains traces of preserved soft tissue, including intestines and tail muscles.

32 BABY DINOSAURS GREW RAPIDLY

Sauropods like Diplodocus weighed a tiny 5kg (11lb) at birth, and grew to 10,000 times their size within just 30 years. Fossilised embryos show sauropod bones filled with blood vessels, bringing nutrients to allow rapid growth.

33 THERE ARE TWO MAIN TYPES OF DINOSAUR EGG

Dinosaur eggs can be divided into two main categories – spheroidal and elongated. Rounder eggs were laid by herbivores such as sauropods, while elongated, bird-like eggs were laid by theropods.

34 OVIRAPTORS DIDN'T STEAL EGGS

The name 'Oviraptor' means egg thief, but these dinosaurs weren't criminals. They were actually devoted parents, and fossilised nests found in Mongolia show they arranged their eggs in spiral layers.

TYRANNOSAURUS REX

35 YOU PROBABLY COULDN'T OUTRUN A TYRANNOSAURUS

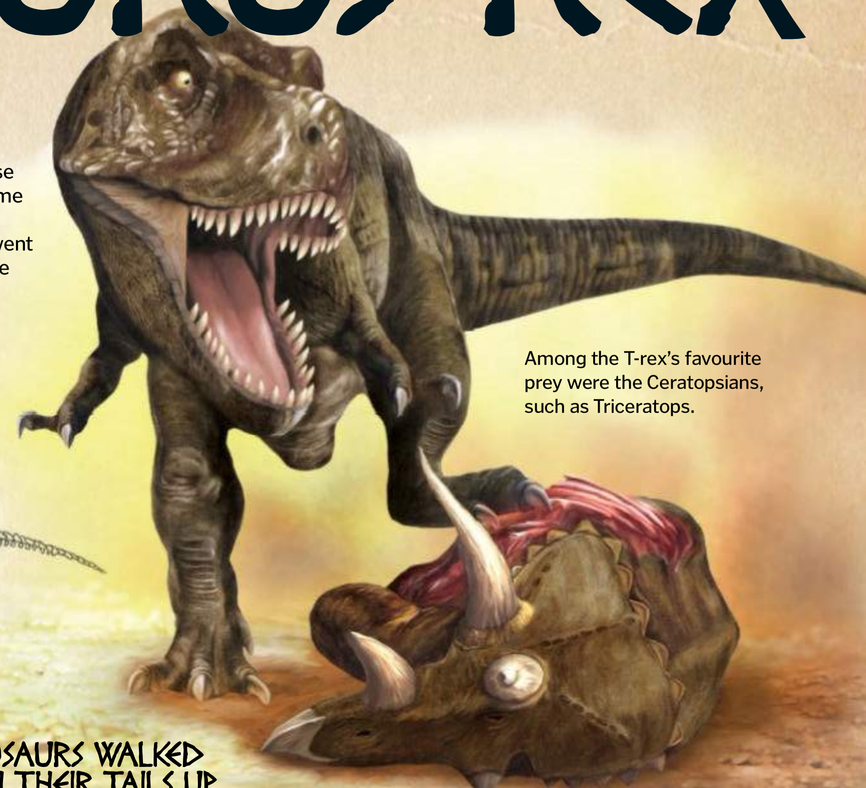
Computer simulations of T-rex running suggest that it had a top speed of around 29km/h (18mph). Not quite fast enough to catch up with a car, like in *Jurassic Park*, but quick enough to catch any human that's not an athlete.

36 THE LARGEST TYRANNOSAURUS FOSSIL IS CALLED SUE

Complete dinosaur fossils are incredibly rare, but there is one T-rex specimen that stands out from the rest. Sue is over 12.8m (40ft) long and stands over 3.9m (13ft) high. She is on display at the Chicago Field Museum and is the most complete specimen ever recovered.

37 STEGOSAURUS NEVER MET TYRANNOSAURUS

Despite being depicted together, these two would never have been in the same place at the same time. Stegosaurus lived during the Jurassic period and went extinct around 80 million years before T-rex first appeared at the end of the Cretaceous period.



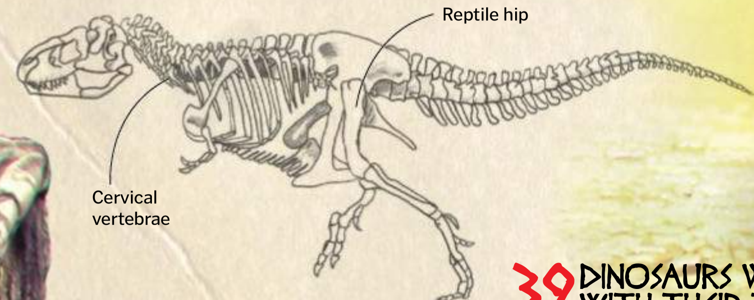
Among the T-rex's favourite prey were the Ceratopsians, such as Triceratops.

HEAD

It measured 1.5m (4.9ft) long, and had eye and nose cavities. The skull was of thick and heavy bone, although in some points it was pretty flexible.

38 SOME DINOSAURS HAD A WISHBONE

The 'V'-shaped wishbone you find in your Sunday roast is also present in meat-eating theropods such as T-rex.

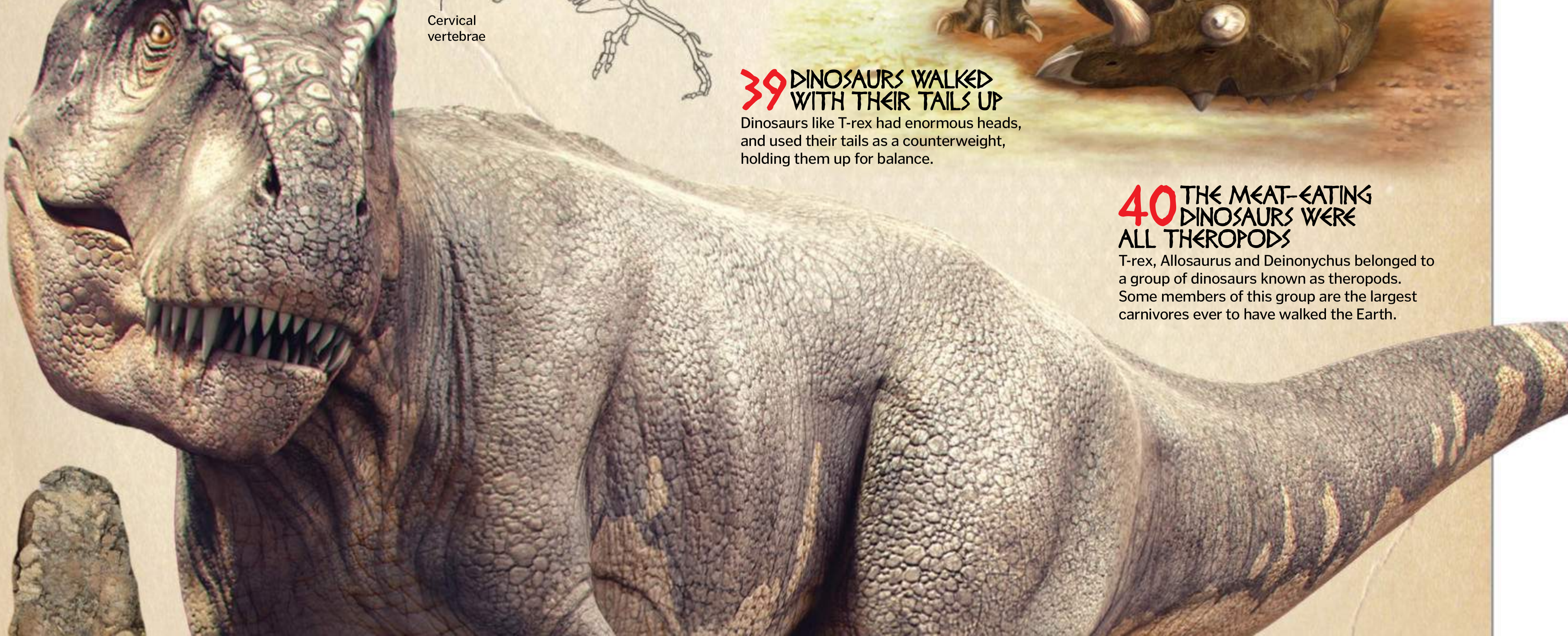


39 DINOSAURS WALKED WITH THEIR TAILS UP

Dinosaurs like T-rex had enormous heads, and used their tails as a counterweight, holding them up for balance.

40 THE MEAT-EATING DINOSAURS WERE ALL THEROPODS

T-rex, Allosaurus and Deinonychus belonged to a group of dinosaurs known as theropods. Some members of this group are the largest carnivores ever to have walked the Earth.



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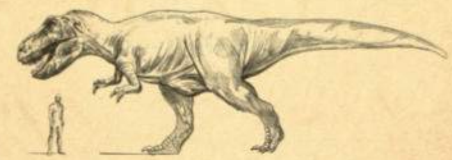


LENGTH 12.5m
WEIGHT 5,000kg
DIET Carnivorous

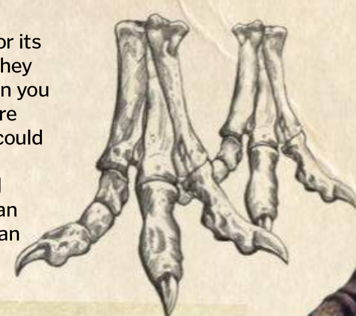
GENUS Tyrannosaurus
CLASSIFICATION Theropoda; Coelurosauria; Tyrannosauroidea

41 T-REX HAD TEETH THE SIZE OF BANANAS

The largest Tyrannosaurus rex teeth measured 30cm (12in) in length. There has been much debate as to what they were used for, but scientists generally agree that T-rex was both a hunter and a scavenger. Broken T-rex teeth found in the fossilised tailbones of Hadrosaurs indicate that hunts weren't always successful.

42 T-REX HAD STRONGER ARMS THAN A HUMAN

T-rex is often ridiculed for its stumpy little arms, but they were much stronger than you might imagine. They were used for grasping prey, could move rapidly and were capable of lifting around 200kg (440lb), more than three times as much as an adult man.

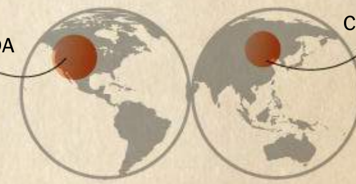


43 THE MOST EXPENSIVE FOSSIL IS WORTH MORE THAN $8 MILLION

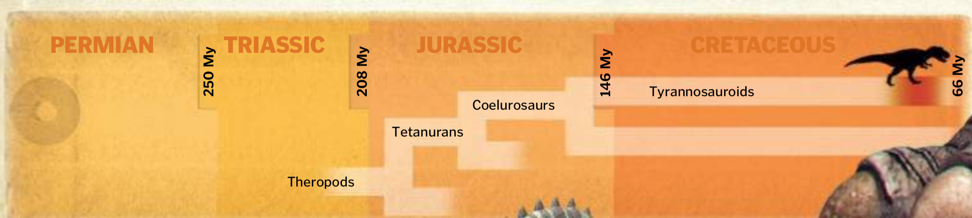
The famous Tyrannosaurus rex fossil known as Sue fetched $8.36 million at auction back in 1997 and is likely to be worth significantly more than that today.

FOUND IN...

The Tyrannosaurus rex was found in what is now North America, just like its cousins the Daspletosaurus, the Gorgosaurus and the Albertosaurus. The Tarbosaurus and the Guanlong, a primitive tyrannosaur of the Jurassic period, were discovered in Asia.



PHYLOGENETIC TREE



44 THERE WAS A DINOSAUR CALLED 'IRRITATOR'

Irritator was a fish-eating spinosaur first described in 1996. It got its name because the fossilised head had been modified by fossil hunters with car body filler to make it look more impressive. The scientists understandably found this very irritating.

45 DINOSAURS DIDN'T LIVE IN THE SEA

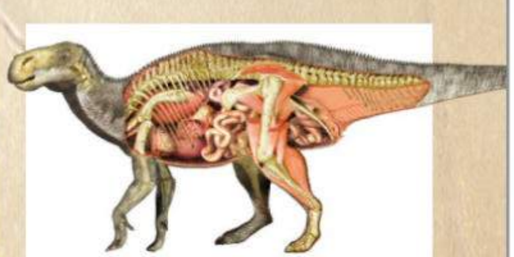
Dinosaurs were land animals and were not closely related to the famous sea-dwelling Plesiosaur, but Spinosaurus was semi-aquatic and could run along the riverbed.

46 NO DINOSAUR COULD FLY

Dinosaurs were all land-dwelling reptiles, and despite the fact that they are the ancestors of modern birds, none of them could fly.

47 ARCHAEOPTERYX IS THE FIRST FOSSIL EVIDENCE OF EVOLUTION

Archaeopteryx was the first feathered dinosaur to be discovered, linking birds and dinosaurs. The breakthrough came in 1861, just two years after Charles Darwin published his theory of evolution.



48 DINOSAURS WERE NEITHER WARM NOR COLD BLOODED

It was long thought that dinosaurs were cold blooded, like reptiles, but new evidence suggests that they were mesothermic – able to burn energy to make some body heat, but not warm blooded like mammals.

CLASSIFICATION

Dinosaurs can be split into two major groups, with many more subdivisions

49 THE MEAT-EATING DINOSAURS WALKED ON TWO FEET

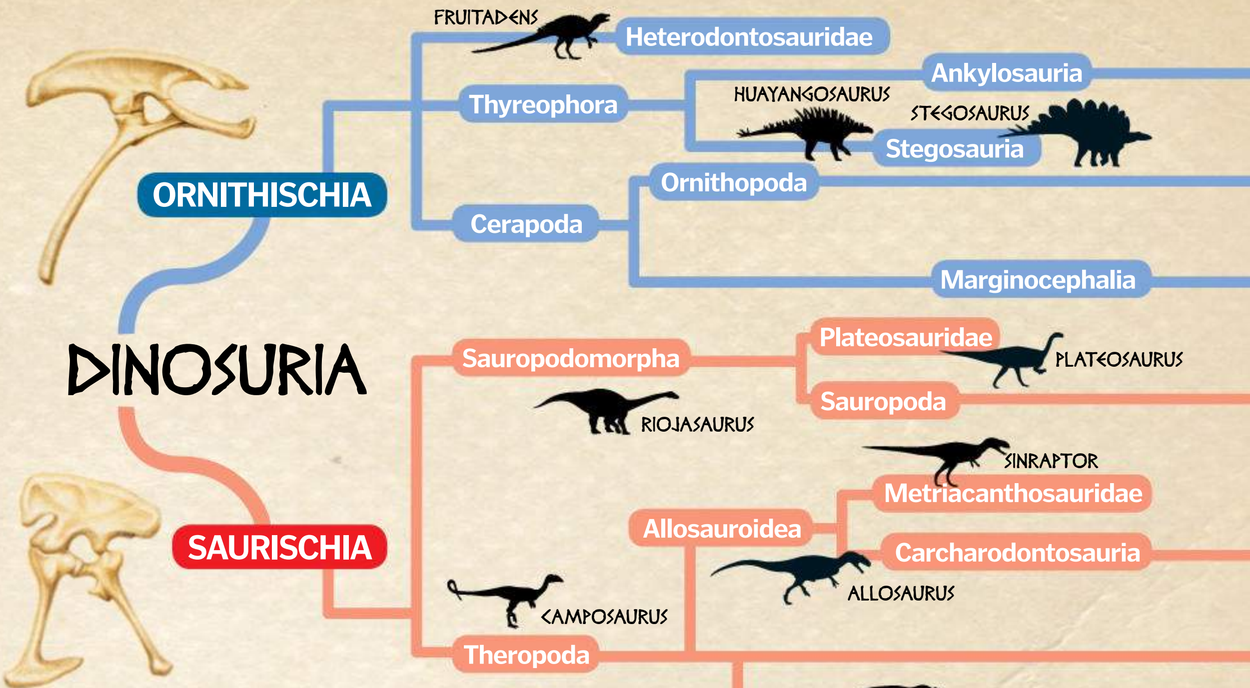
All the carnivorous dinosaurs were theropods (although not all theropods were carnivores) and walked upright on their two hind legs. They typically had hollow bones, three main fingers on each hand and foot, and sharp, curved teeth and claws used for hunting and eating.

50 DINOSAURS EITHER HAD LIZARD HIPS OR BIRD HIPS

Dinosaurs can be divided into two major groups based on their hipbones. The Ornithischia, or 'bird-hipped' dinosaurs had a pubic bone that pointed toward the tail, and the Saurischia, 'lizard-hipped' dinosaurs pointed toward the head. Interestingly, birds evolved from lizard-hipped dinosaurs.

51 MOST DINOSAURS ATE PLANTS

Dinosaurs are often portrayed as fearsome hunters, but the majority of species were herbivores. Even some of the ferocious-looking theropods actually ate plants and used their sharp claws for digging.



TYRANNOSAURIDAE FAMILY TREE

Gorgosaurus ■ Daspletosaurus ■ Albertosaurus ■ Tarbosaurus ■ Tyrannosaurus

56 DINOSAURS LIVED DURING THE MESOZOIC ERA

Dinosaurs ruled the Earth for 165 million years, in a time period known as the Mesozoic Era. This era can be split into three periods, Triassic, Jurassic and Cretaceous

57 DINOSAURS FIRST APPEARED 230 MILLION YEARS AGO

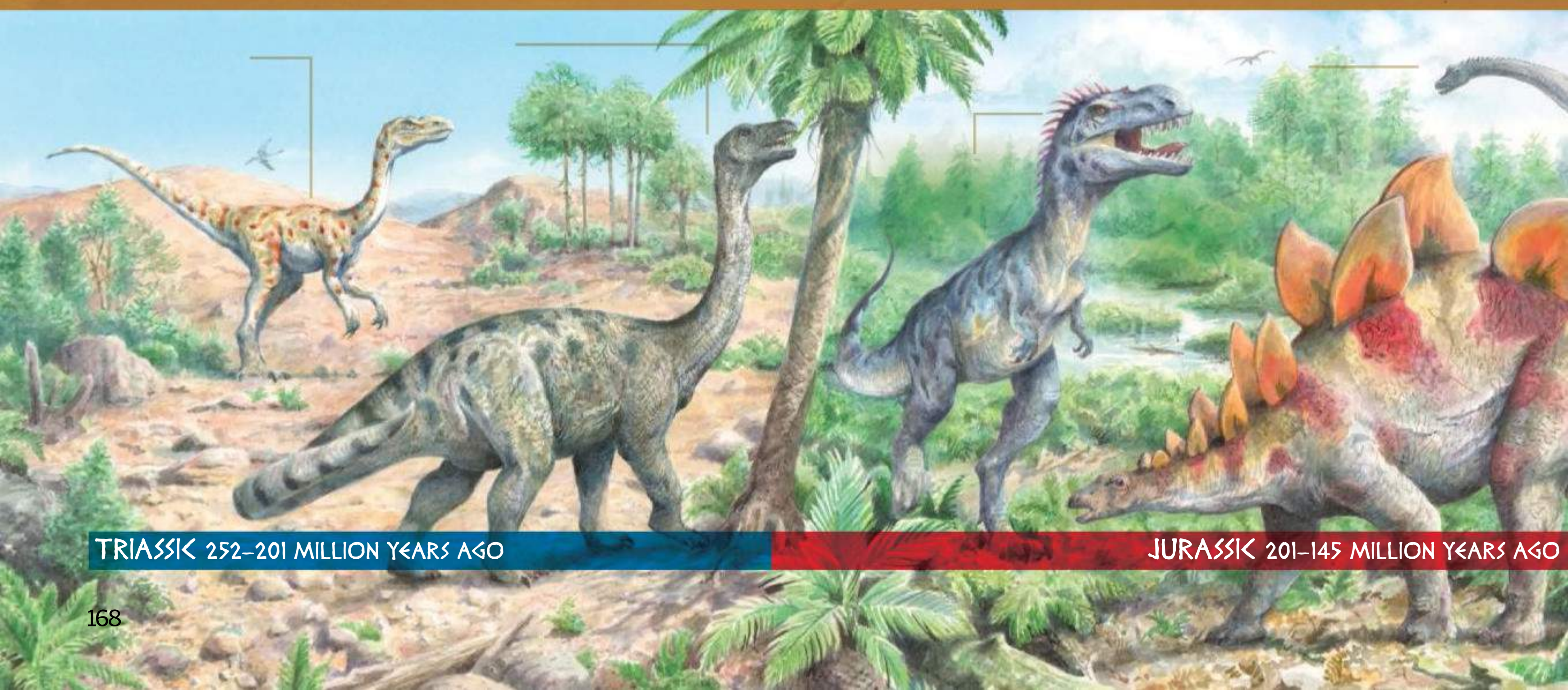
Dinosaurs evolved during the Triassic period, between 250 and 200 million years ago. The warm, dry conditions were perfect for breeding reptiles.

58 VOLCANIC ERUPTIONS CONTRIBUTED TO THE EXTINCTION OF THE DINOSAURS

Huge lava flows are present in the fossil record for about 500,000 years before the extinction of the dinosaurs, and many scientists think eruptions contributed to their extinction by filling the air with a thick cloud of ash.

59 EARLY DINOSAURS LIVED ON THE CONTINENT OF PANGAEA

When dinosaurs first appeared, the landmasses of the Earth were joined into a supercontinent called Pangaea. This later fractured into two continents – Laurasia and Gondwana.



52 THERE WERE MORE THAN 700 SPECIES OF DINOSAUR

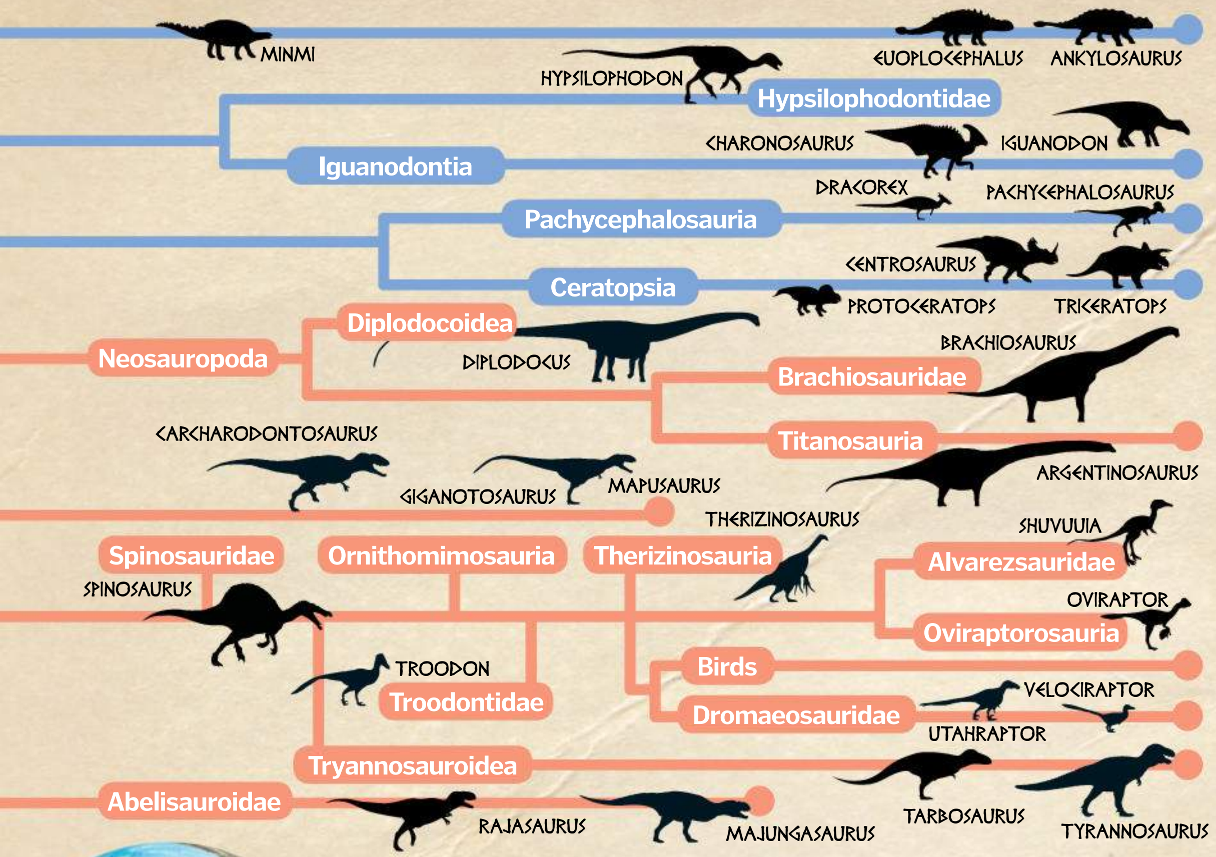
To date, over 700 species of dinosaur have been identified, but only around 300 have been confirmed as entirely unique. There are more yet to be found, so this number will continue to change.

53 THERE ARE HUNDREDS OF DINOSAURS YET TO BE FOUND

It is estimated that we have only found around a tenth of the dinosaur species that ever existed. Some are buried in rocks we cannot reach, while others lived in areas where conditions did not favour fossil formation.

54 THERE WERE FEWER DINOSAUR SPECIES THAN WE THOUGHT

Hundreds of species of dinosaur have been named, but very few baby dinosaurs have ever been found. Scientists have reviewed the evidence again and have found that some smaller species might actually be the babies of larger species, and that as they grew their head and body shapes changed.



55 DINOSAURS ARE STILL ALIVE TODAY

In the 19th century the fossilised remains of a feathered dinosaur called Archaeopteryx were discovered, and since then evidence linking dinosaurs to birds has stacked up. It is thought that early birds started to evolve from the carnivorous theropods in the late Jurassic, and a few managed to survive the mass extinction, giving rise to the bird species we see today.

60 SEA LEVELS WERE AT AN ALL-TIME HIGH IN THE CRETACEOUS

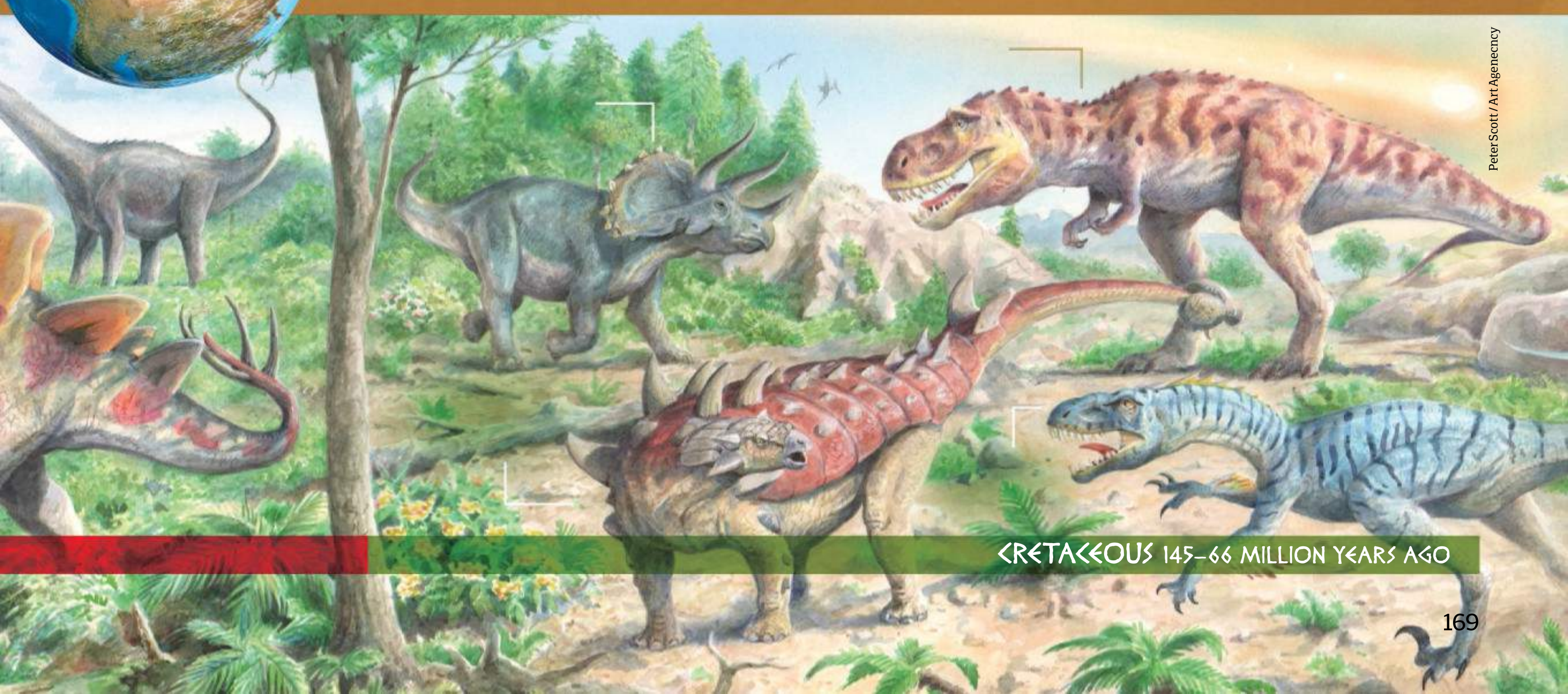
During the Cretaceous period, sea levels rose and fell dramatically, and large areas of land disappeared under water. At times the sea was 100-250m (330-820ft) higher than it is today.

61 HIGH OXYGEN LEVELS FUELLED FIRES DURING THE EXTINCTION EVENT

During the Cretaceous period, oxygen levels in the atmosphere were much higher than they are now, which may have helped to fuel fires after the famous meteor impact 66 million years ago, contributing to the mass extinction.

62 THEY EXPERIENCED MORE THAN ONE MASS EXTINCTION

There was a mass extinction at the end of the Triassic period, when many land animals died out, leaving room for the evolution of some of the giants of the dinosaur world.



63 ARMOURED DINOSAURS ARE KNOWN AS 'THYREOPHORA'

Stegosaurus and Ankylosaurus are famous for their armour plating and were members of a group of dinosaurs called Thyreophora. Anklosauria were the most heavily armoured and had bony plates, spikes and clubbed tails.

64 DINOSAUR'S LEGS ARE POSITIONED BENEATH THEIR BODIES

Crocodiles and lizards walk with their legs out to the sides, but dinosaurs have their legs underneath their bodies, allowing them to run faster.

65 SOME DINOSAURS SWALLOWED ROCKS

Many plant-eating dinosaurs have been found with groups of rounded stones inside their ribcages, indicating they swallowed stones to aid digestion, like modern birds.

66 SOME DINOSAURS HAD A MIXTURE OF DINOSAUR-LIKE AND BIRD-LIKE FEATURES

Birds are descended from small theropods. They walked upright on two legs and fossil evidence shows that some of them had feathers.

67 DINOSAURS LIVED IN A CHANGING WORLD

Around 250 million years ago, all of Earth's landmasses were joined in a supercontinent known as Pangaea. During the reign of the dinosaurs, this landmass split apart, first into two and then into the seven continents we see today.

68 PALEONTOLOGISTS STUDY FOSSILS

Scientists that study dinosaur remains are known as palaeontologists. Anthropologists study human remains, and archaeologists study artefacts.

69 SOME HERBIVORES HAD SELF-SHARPENING TEETH

As their jaws closed, the teeth of some plant-eating dinosaurs would grind against each other, wearing the surface into a sharp point.

70 HADROSAURS HAD THE MOST TEETH

The duck-billed dinosaurs had up to 50 rows of teeth stacked on top of one another, making a total of over 1,000.

76 THE LONGEST DINOSAUR NAME HAS 23 LETTERS

Micropachycephalosaurus means 'tiny thick-headed lizard'. It might have the longest name, but it was only about 1m (3.3ft) long.

71 DINOSAURS HAD GIANT FLEAS

Fossilised remains reveal that dinosaurs in the Cretaceous and Jurassic were hosts to giant flea-like insects measuring ten times the size of modern fleas.

72 ORNITHOPODS WALKED ON TWO LEGS

Dinosaurs like Iguanodon and the duck-billed Hadrosaurs walked upright on two legs, and lived in herds like modern-day antelope.

73 ONE DINOSAUR IS NAMED AFTER THE HARRY POTTER BOOKS

Dracorex hogwartsia ("dragon king of Hogwarts") was a pachycephalosaur with a large bulge on its forehead and a dragon-like spiked frill.

74 DINOSAURS SURVIVED FOR 165 MILLION YEARS

People often think of the dinosaurs as being evolutionary failures, but they survived for a staggering 165 million years, far more impressive than the 200,000 years managed so far by humans.

FACT 75

35m

ARGENTINOSAURUS WAS LONGER THAN A BLUE WHALE

77 MANY DINOSAURS HAD HOLLOW BONES

Birds have hollow bones, which helps to keep their weight down for flight and enables a unique way of breathing – sauropods and theropods had hollow bones too.

78 LOTS OF DINOSAURS WERE SMALLER THAN US

Diplodocus, Triceratops, T-rex and Stegosaurus were all enormous, but many of the two-legged raptors and some of the herbivores were smaller than we are.

HUNTING DINOSAURS

Fossils have be found on every continent on Earth...

79 NORTH AMERICA HAS EXCAVATED THE MOST DINOSAUR FOSSILS

North America, Argentina and China have more than their fair share of dinosaur fossils. Areas with desert-type environments prevented the build-up of thick layers of plants, leaving the remains easier to find under sand and rock.

80 THE FIRST DINOSAUR FOSSIL WAS FOUND IN ENGLAND

The first dinosaur to be scientifically documented was Megalosaurus, formally named by William Buckland in 1824. The fossils were found in a quarry in Oxford.

81 FOSSILISED DINOSAUR HIGHWAYS ALLOW US TO RETRACE ANCIENT STEPS

Enormous mudflats captured the imprints of dinosaur footprints, and some were preserved as fossils. Utah in the United States is particularly famous for its dinosaur trackways, which can be found on what used to be an ancient muddy floodplain.

82 NEW DINOSAURS ARE DISCOVERED EVERY YEAR

There are hundreds of dinosaur fossils still to be discovered, and a new dinosaur is found and named approximately every seven weeks.

83 CHICXULUB CRATER MARKS THE ASTEROID IMPACT THAT KILLED THE DINOSAURS

Chicxulub crater in Mexico is a 66 million-year-old, 180km (112mi)-wide impact created by a 10km (6mi)-wide asteroid. It is thought to represent the aftermath of the impact that killed the dinosaurs. In 2016, scientists plan to drill into the crater to learn more about its history.

84 DINOSAUR BONES CAN BE RECOGNISED BY DISTINCTIVE SKULL HOLES

All dinosaurs have the same basic skull, with two holes for jaw muscles behind the eye and an air socket between the eyes and nose.

85 DINOSAUR BONES CAN BE AGED BY RADIOMETRIC DATING

Carbon dating doesn't work on dinosaur bones, so scientists estimate the age of fossils by measuring radioactive isotopes in the surrounding rocks.

95 DINOSAURS WEREN'T THE FIRST REPTILES TO RULE THE EARTH

Around 300 million years ago amphibians dominated the planet, but as the climate got warmer, reptiles took over. There were the 'bowl lizards' or pelycosaurs, mammal-like reptiles called therapsids, and archosaurs, from which dinosaurs, crocodiles and pterosaurs eventually evolved.

96 DINOSAURS LIVED FOR UP TO 300 YEARS

Paleontologists estimate the large dinosaurs had life spans ranging from 75 to 300 years. However, these estimates were made based on information we have about cold-blooded animals – if they were warm-blooded they would have had shorter lives.

97 TROODONS WERE PROBABLY THE CLEVEREST DINOSAURS

Troodons lived around 77 million years ago and were about two metres (6.6 feet) long. They were carnivores, walked on two legs and had relatively large brains for their body size. They are also thought to be related to modern birds.

98 AMBER INSECTS DON'T CONTAIN DINOSAUR DNA

Jurassic Park is based on the idea that you could extract dinosaur DNA from blood preserved inside the bodies of mosquitoes encased in amber. Unfortunately, despite several attempts to recover DNA from preserved insects, it seems as though it doesn't actually survive inside the amber.

DID YOU KNOW? *Smilodon, the sabre-toothed cat, first appeared over 62 million years after the extinction of the dinosaurs*

86 MORE THAN 100 DIFFERENT DINOSAURS LIVED IN BRITAIN

Britain used to form a land bridge that connected Europe to North America, and has been described as a dinosaur paradise. It was home to over 100 different species, including armoured ankylosaurs, giant sauropods and three different types of fearsome tyrannosaur.

87 THERE'S NO ACTUAL BONE IN A DINOSAUR FOSSIL

When dinosaurs died, their bones were covered in sediment that was compressed and turned to rock. Over time, the bone itself dissolved away, leaving a bone-shaped hole in the rock, which then filled with minerals, forming a cast.

88 MOST DINOSAUR FOSSILS WERE FOUND BY AMATEURS

There are many more amateur fossil hunters than professionals, and they can cover much more ground. The largest T-rex fossil ever was found by an amateur.

89 THERE ARE TWO MAIN TYPES OF FOSSIL

Body fossils show the actual shape of dinosaur remains, while trace fossils show evidence of their lives, like footprints and nests.

FACT 90

77 tons

ARGENTINOSAURUS, THE HEAVIEST DINOSAUR, WEIGHED THE SAME AS A BOEING 737

91 FOSSILISED FOOTPRINTS TELL US HOW DINOSAURS MOVED

Preserved dinosaur tracks revealed some theropods could run at 43.5km/h (27mph).

92 DINOSAURS RAN ALONG RIVERBEDS

Fossilised dinosaur tracks found in Australia reveal a superhighway where two-legged dinosaurs travelled on tiptoe through a fast-moving river.

93 THE MOST ANCIENT DINOSAUR FOSSILS WERE FOUND IN TANZANIA

One of the earliest-ever dinosaur fossils found is a 243-million-year-old dog-sized dinosaur called Nyasasaurus parringtoni. Bones from two different individuals were excavated in the 1930s, but weren't properly studied until 2012.

94 DINOSAUR FOSSILS ARE FOUND ON ALL SEVEN CONTINENTS

Dinosaur fossils have been found in the very northern parts of Canada, right down to the frozen wastes of Antarctica.

99 RAPTORS WERE COVERED IN FEATHERS

Of all the dinosaurs, the most feathery were the theropods. Velociraptors were covered in a layer of feathers, and so too was T-rex. Many other dinosaurs had spiny quills or feathery stubs.

100 MAMMALS USED TO EAT DINOSAURS

Repenomamus robustus was a 1m (3.3ft)-long mammal that lived 125 million years ago in China. One specimen was found with dinosaur remains inside it.

101 BRONTOSAURUS MIGHT HAVE BEEN A REAL DINOSAUR AFTER ALL

Brontosaurus is famous for not being a real dinosaur – the fossils were mixed up and the head of a Camarasaurus was placed on the body of an Apatosaurus. However, in 2015, a new study of the bones revealed that Brontosaurus has a longer and thinner neck than Apatosaurus and thus might be a distinct species after all.

FINDING FOSSILS

How are prehistoric remains uncovered and what can scientists learn from them? How It Works digs up the facts…

Ever since Mary Anning first began piecing together the fossils of Jurassic beasts in the early-19th century, scientists have been learning more and more about the dinosaurs that ruled the world millions of years ago. Buried deep beneath the ground for aeons, the remains of countless extinct creatures are waiting to be unearthed by palaeontologists, who can gradually unlock their secrets.

Dinosaurs and other prehistoric fossils have been discovered around the world for thousands of years, with reports of 'dragon bones' found in China more likely indicating some of the earliest dino finds. However, it wasn't until the brilliant scientists of the Enlightenment in the late-18th and early-19th centuries that it became clear just how old these ancient skeletons really were. Before long, fossil hunting became an obsession for naturalists and amateurs alike, with the strange extinct 'lizards' being discovered at sites all over the globe.

Though ground-penetrating radar now helps archaeologists identify hidden underground remains, modern palaeontologists still often rely on the same methods their 19th-century predecessors did: plain luck. Of course, through a greater understanding of geology, as well as by searching in so-called fossil hotspots, it's possible to predict where fossils will likely be found. Once a fossil site has been identified, the long and delicate process of unearthing the dino remains begins.

Digging for fossils can be as simple as sieving through sand and silt in the search for tiny teeth, or cracking open large rocks with a hammer and chisel to see what may be lying within. Hills, quarries, mountainsides and ravines are often prime locations for fossil finds, as the deep layers of rock have become exposed by millions of years of erosion. In these cases heavy diggers and drills are crucial to reach the finds. Dozens of scientists, students and even enthusiastic volunteers are employed with brushes and trowels during the course of an excavation. However, because of the delicate nature of specimens that are millions of years old, it can often take what must seem like another million to safely uproot an entire dinosaur skeleton.

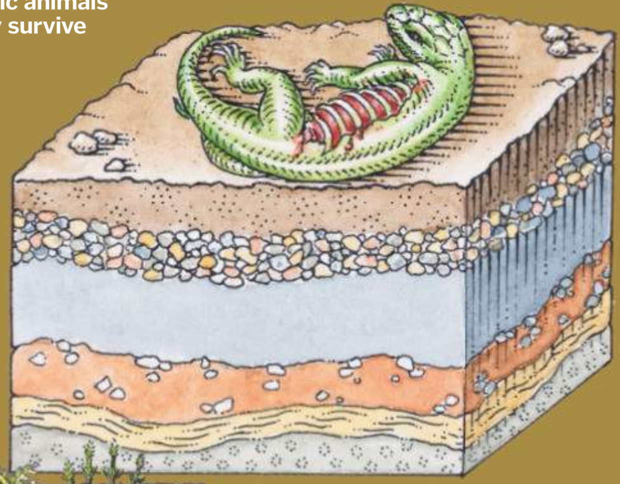
Of course, palaeontologists do much more than just dig up old bones. Mixing together the disciplines of geology and biology, palaeontology is the study of fossils to reveal the history of life on Earth. So, once the fossilised remains have been fully excavated, the real work can begin back in the lab. Here scientists painstakingly remove any residual earth and stone from the specimens in preparation for full analysis. Electron microscopes, CAT scanners and X-ray machines are all employed to gather as much information about the creature as possible.

By studying the shape, length and arrangement of each fossilised bone, palaeontologists have been able to determine not only what certain dinosaurs looked like and how they moved, but also what they ate. The discovery of indentations on fossilised arm bones similar to those found on modern birds has also indicated that many species of dinosaur were actually feathered.

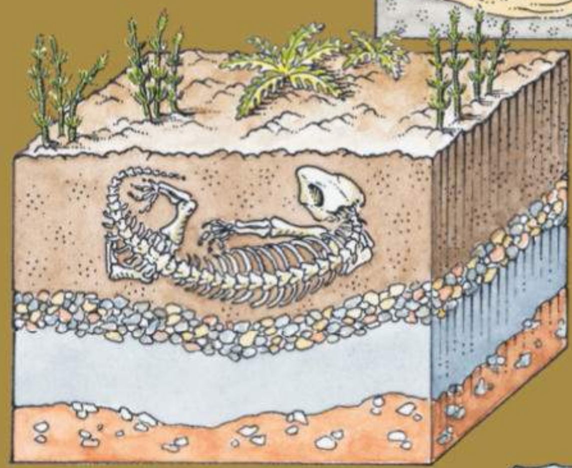
Bigger, stranger and ever-more unbelievable dino discoveries are being made all the time, each one challenging past theories and shedding new light on the distant land of the Mesozoic beasts. Thanks to the pioneering work of the scientists and enthusiasts of the past, each new fossil found could slot yet another piece of the prehistoric jigsaw into place.

HOW FOSSILS FORM

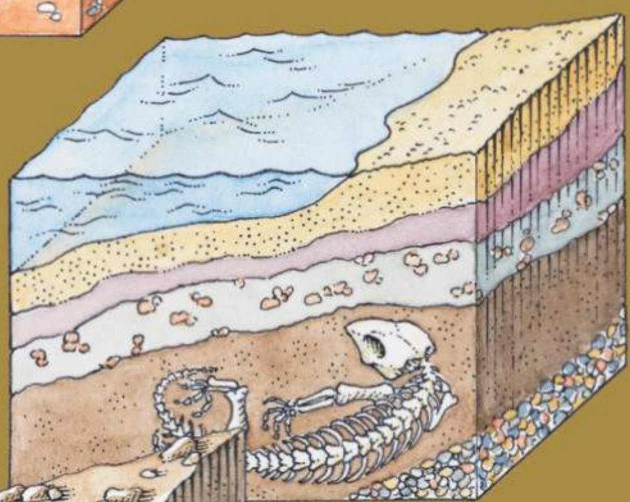
How do the remains of prehistoric animals become fossils, and why do they survive through the ages?



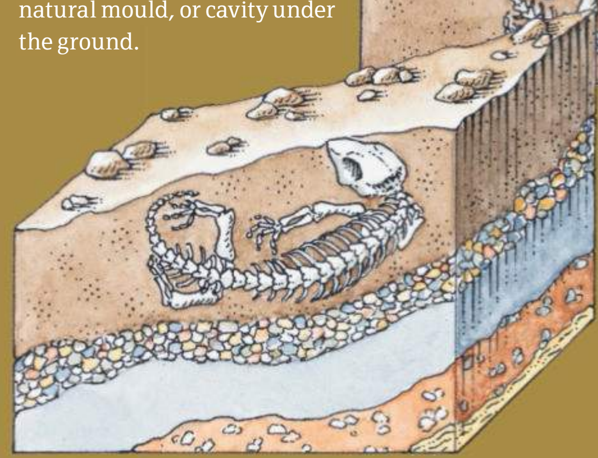
1 After death, a dinosaur's remains would often just rot and erode away completely, leaving not even a skeleton behind. However, in the right conditions, where the remains are kept safe from weather and hungry scavengers, the process of fossilisation can begin.



2 Over a long period of time, shifting sands, soil and sediment entirely cover the skeleton, encasing it in the ground. Any remaining soft tissue such as skin and organs, decays away entirely, leaving only the creature's bones. At this stage the remains are only partly fossilised.



3 As rising sea levels and shifting materials leave the skeleton further underground, the earth around the skeleton hardens under immense pressure. Eventually the bones entirely dissolve, leaving their shape behind in a natural mould, or cavity under the ground.



4 Over time, mineral deposits slowly gather in the creature's mould, chemically replacing the original bone. As sea levels recede away and materials shift around, the fossil draws closer to the surface. Eventually it can be found either entirely exposed or close to the topsoil.

DIGGING FOR DINOSAURS

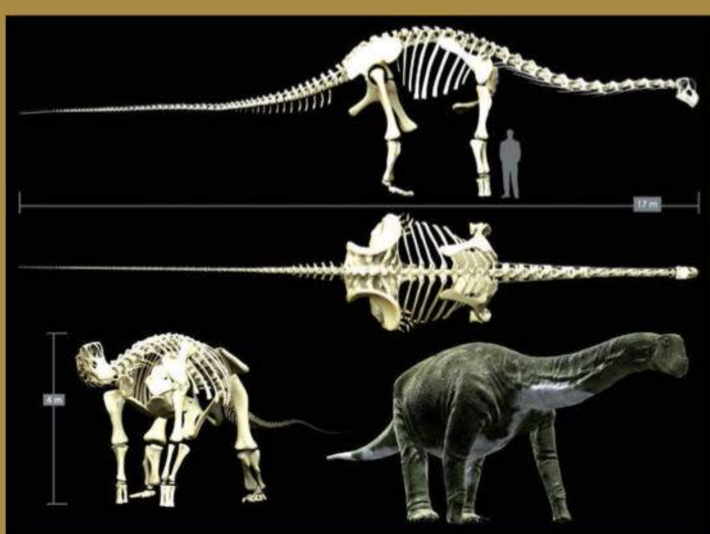
How palaeontologists discover and unearth prehistoric giants

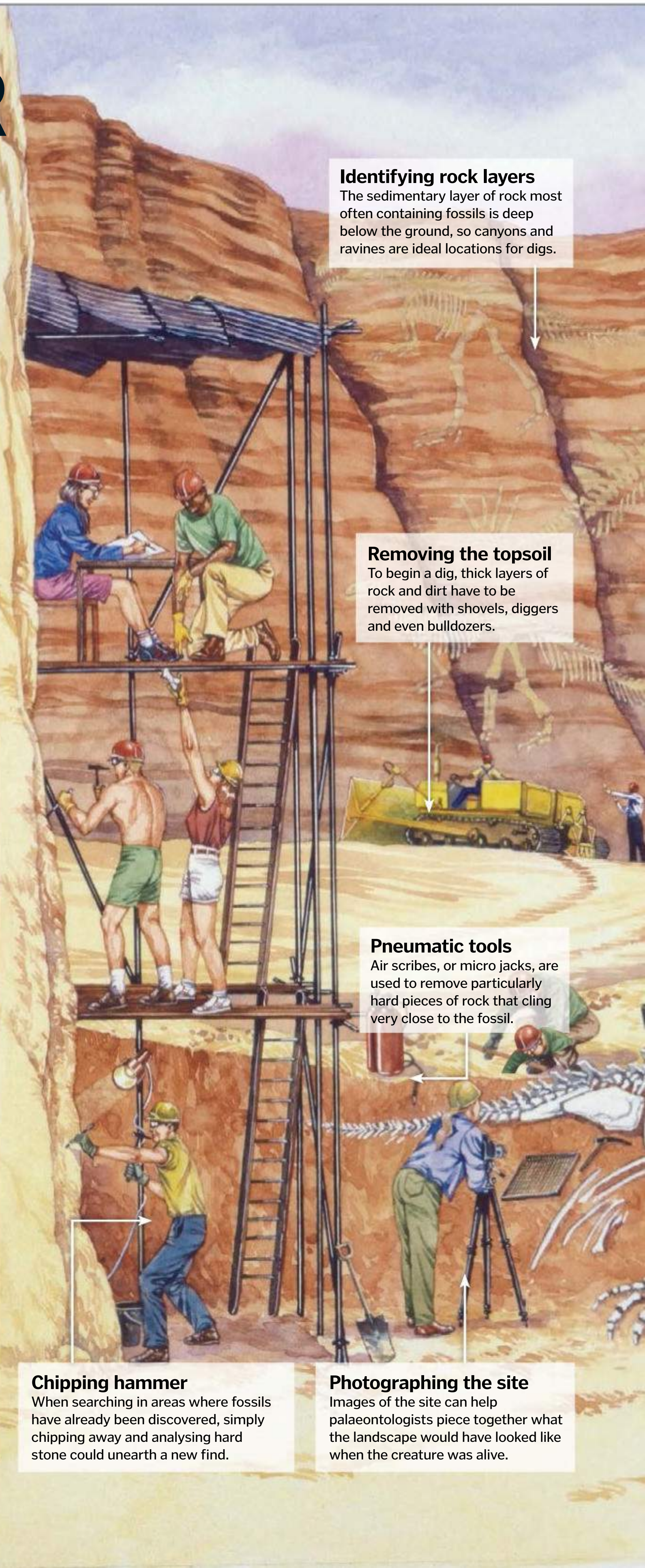
Bulldozers, hammers, chisels, drills and even dynamite – you'd be forgiven for thinking these were part of a construction-site inventory. In fact, they are the basic tools a palaeontologist will use to uncover the mysteries of the past. From removing tons of topsoil with diggers and other heavy machinery, to carefully clearing away clinging dust and debris with delicate brushes, the process of fully excavating a dinosaur skeleton can take many years.

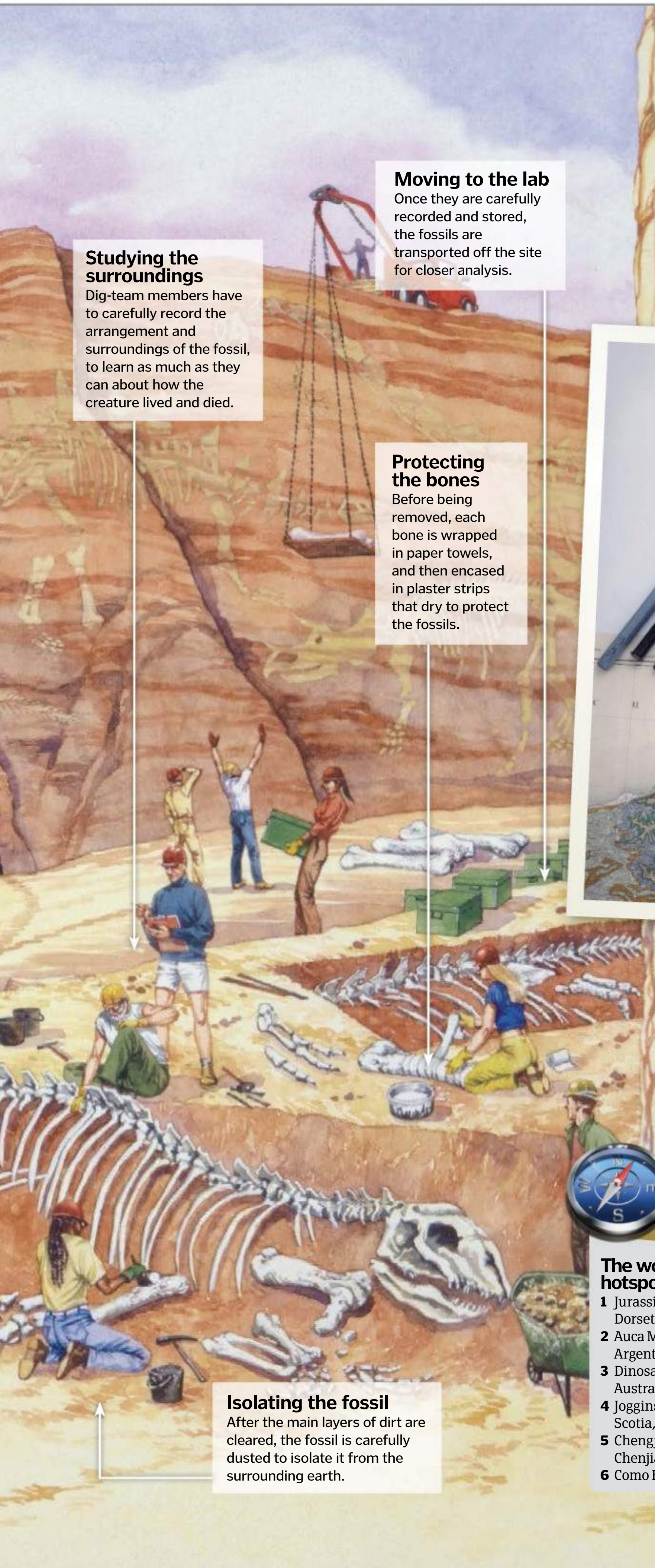
The largest dino fossil

Even in this ancient time when giants ruled the Earth, sky and sea, Dreadnoughtus schrani truly was a behemoth of a creature. Standing over two-storeys tall and weighing as much 60 tons, the remains of this beast were found by a team in Patagonia, Argentina, and have been dated back over 77 million years. A member of the titanosaur sauropod group of dinosaurs, Dreadnoughtus was a plant-eater and is to date the largest known land animal ever to have lived.

Two Dreadnoughtus titanosaurs were found at the site, and it's believed the pair died in a massive flash flood, which would explain why their remains were so complete. The preservation of the skeletons enabled scientists to take full advantage of 3D-printing technology, scanning in each individual bone into a digital format for even greater scrutiny. This 3D rendering of Dreadnoughtus provided even greater insight into how it likely looked and moved.







Studying the surroundings
Dig-team members have to carefully record the arrangement and surroundings of the fossil, to learn as much as they can about how the creature lived and died.

Moving to the lab
Once they are carefully recorded and stored, the fossils are transported off the site for closer analysis.

Protecting the bones
Before being removed, each bone is wrapped in paper towels, and then encased in plaster strips that dry to protect the fossils.

Isolating the fossil
After the main layers of dirt are cleared, the fossil is carefully dusted to isolate it from the surrounding earth.

Tools of the trade
What do you need for a fossil dig?

Chisels
Chisel blades come in a range of sizes for either cracking apart larger stone or trimming away a rock face.

Hammers
Crack and chipping hammers are essential for carefully removing and trimming hard rock. They are also needed for working with chisels.

Sieve
Not all fossils come in huge sizes, so wire sieves are perfect for sifting through sand and silt for teeth and other small remains.

Maps
If travelling to more remote locations, and for making reliable notes for reference, a good map and compass are a must.

Brushes
Small, soft bristles are ideal for working with delicate remains, while larger, harder brushes are best for removing thicker dust.

Journals and reference
Accurately recording everything you find, where it's found, as well as referencing what it could be, is vital for making new discoveries.

ON THE MAP

The world's fossil hotspots
1. Jurassic Coast, Devon and Dorset, UK
2. Auca Mahuevo, Patagonia, Argentina
3. Dinosaur Cove, Victoria, Australia
4. Joggins Fossil Cliffs, Nova Scotia, Canada
5. Chengjiang Fossil Site, Chenjiang County, China
6. Como Bluff, Wyoming, USA

War Elephants

The tanks of their day, war elephants brought victory to battlefields from Britain to Vietnam

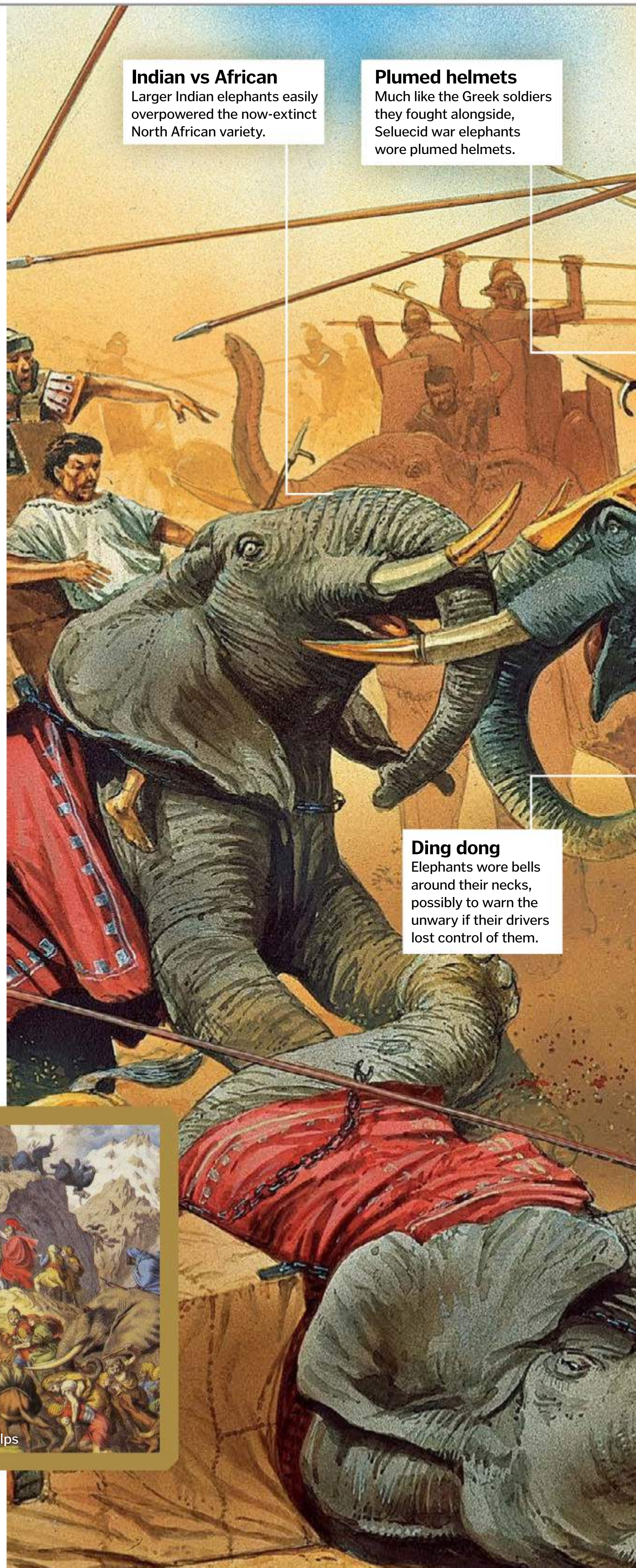
We may not think of elephants as particularly fearsome creatures, but across Asia, Africa and the Middle East, generals were quick to recognise the value of these giant herbivores in battle. However, no civilisation used them as prolifically as the multiple kingdoms of India.

If conventional cavalry were able to shatter lines of soldiers on foot and change the course of battle, then elephants could amplify that. Furthermore, the sight of an elephant charging into the fray, trunk flailing and tusks raised, men crushed beneath its mighty feet, had a psychological impact that would go unmatched until the age of the tank.

First mentioned in the Sanskrit epics of the 5th and 4th centuries BCE, war elephants became such a common sight in Ancient and Medieval India that chroniclers enthused that "where there are elephants, there is victory!" War elephants in India were typically crewed by two to four men on a 'tower', usually armed with bows and arrows, but spears and lances were also common. Covered in bells, flags and bright colours, the elephants could also be armoured with steel plates sewn between layers of cloth, padded leather or chainmail, depending on the wealth of the prince, sultan or Mughal Emperor for whom they fought.

More fearsome still, 6th century CE Chinese traveller Sung Yun recorded swords, scythes, maces and scraps of chain tied to the elephant's trunk. Blades were also attached to the tusks – sometimes dipped in poison – and there are horrific accounts of enemy soldiers being tossed in the air then cut in two by a single flick of the elephant's mighty head.

From the 16th and 17th centuries, elephants were even mounted with firearms such as the terrifying gajnal 'elephant barrel' canon and fielded in combat against the expanding British Empire, before finally falling out of use toward the end of 19th century.



War Elephants in Europe

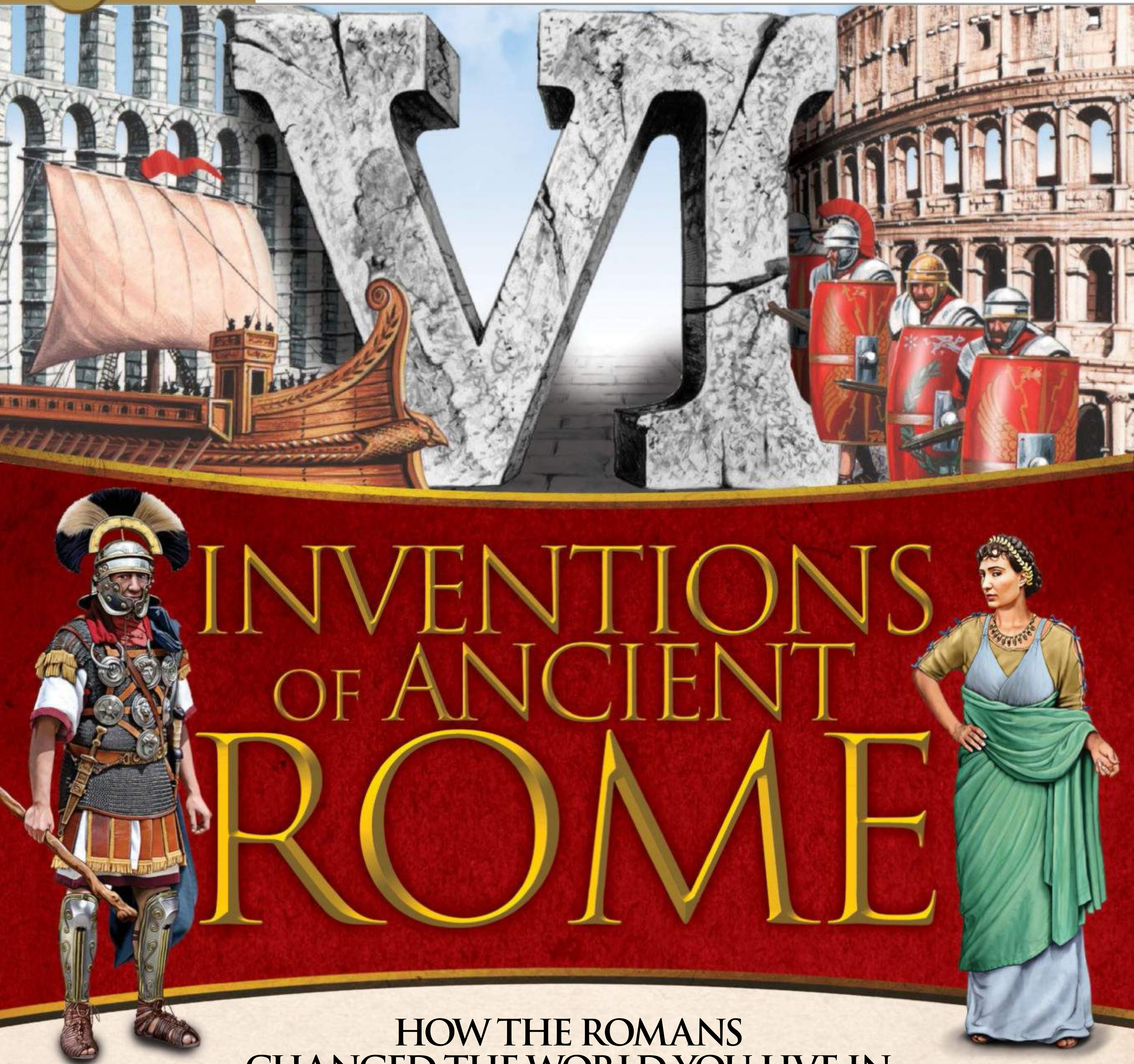
He had already faced the Persian Empire's war elephants, but it was only when Greek warlord Alexander the Great encountered army of King Porus of the Paurava kingdom of Northern India that he was truly impressed by the potential of pachyderms, forming an elephant corps of his own. Through Alexander and his successors, the use of war elephants spread across the Middle East and Greece, then into the emerging superpowers of Rome and Carthage. Though forced to rely on allies or vassal states in India and Africa for a supply of elephants, at least one elephant was used in Julius Caesar's invasion of Britain in 54 BCE (more were shipped over in 43 CE to suppress a revolt), and Carthaginian general Hannibal Barca famously marched his army and their elephants across the snow-capped Pyrenees and Alps from Spain to Northern Italy in 218 BCE.


Hannibal leads his elephants across the Alps

Were African elephants once smaller?

Ancient chroniclers were unambiguous in their preferences: Indian elephants, they wrote, were bigger and stronger than their African counterparts. As a testament to this the Battle of Raphia (217 BCE), the African elephants of the Egyptian king Ptolemy IV Philopater refused to face to the Indian elephants of Greek Seleucid king Antiochus III the Great, being intimidated by their smell, sound and greater size.

This is peculiar because modern African bush elephants are by far the largest of the species, however, the diminutive elephants of the ancient world were in fact the now-extinct North African elephant, then found in Morocco and Algeria.



INVENTIONS OF ANCIENT ROME

HOW THE ROMANS CHANGED THE WORLD YOU LIVE IN

Perhaps the greatest of all the ancient civilisations, the Roman Empire represented the age of classical antiquity and helped create the world we live in today. The massive engineering projects that were undertaken and the advances in medicine and society ensure Roman influence can still be felt now. For example, concrete and cement were first popularised in Ancient Rome, as was a type of central heating known as a hypocaust.

One of the most remarkable traits of all though, was the ability for the Romans to work all their schemes and inventions into fully functioning cities within an extensive empire. Rome itself was a bustling metropolis that no other civilisation matched in prosperity and size for centuries afterward. Nowhere else in the ancient world had grand shopping centres like Trajan's Market, specialised landfill sites such as Monte Testaccio or extensive sewer networks like the Cloaca Maxima. They were also famously proficient at town planning and building large structures.

Home life was revolutionised under the Romans. Also, as is well known, the army was an all-conquering juggernaut that took the old world by storm. To commemorate their affect on modern society and technology, we discovered just how innovative and ground-breaking this civilisation really was.

Engineering in Roman home life

The technology inside a Roman house

The citizens of Rome had to be properly housed to ensure that the vast urban sprawl could operate as an organised society. Prior to the Romans, impressive structures were built by the Egyptians and the Greeks but never on the scale of the Roman Empire with its extensive housing projects.

Roman building techniques owed a lot to Greek and Etruscan influences. Houses were one or two storeys high and included lots of different sections. Ideally adapted to the Mediterranean heat, the typical Roman house often had no windows (glass was rarely used), instead fitted with an atrium to act as an open-air courtyard in the middle of the building. Life in a house was boosted by a fully functioning public welfare system that provided grain to 300,000 of Rome's families every year. If you wanted some retail therapy, Trajan's Market had over one hundred tabernae (shops) selling a variety of goods.

Not every citizen was lucky or rich enough to own a house. Lower classes were put into one of Rome's many 'insulae' apartment buildings and there are believed to have been over 40,000 of these in the city. In fact, these apartments outnumbered family houses by 20 to one!

The Roman residence

More than just a roof above your head, the Roman house was quite complex

Building blocks
The Romans used pulleys and levers to shift large building blocks. Slaves carried out the hard graft.

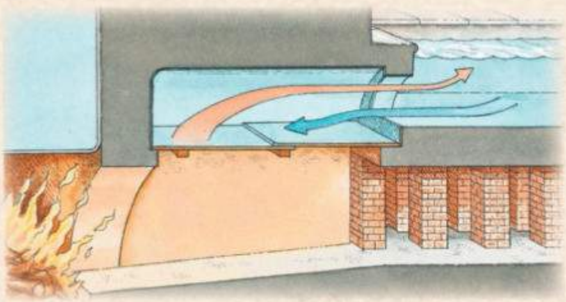
Roof tiles
A stonesman would carve thin tiles from stone. These were laid on top of wooden beams and fixed with nails.

Mosaics
Chips of stone were laid into cement to create beautiful works of art. This technique borrowed from Greece.

Heating
Larger residences were heated by a hypocaust system, an ancient method of underfloor heating.

Clay bricks
Roman bricks were fired clay. Roman legions operated mobile kilns and bricks were often stamped with the mark of the legion.

Hypocaust heating system

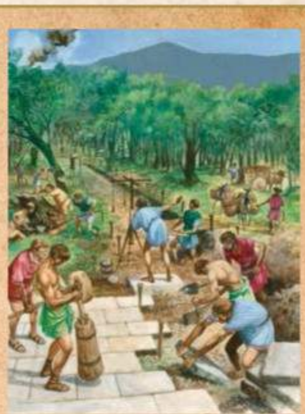


Convection currents
Underneath a raised floor, vents allowed heated air to travel freely and used convection currents to heat the tiles above. The warm air came from a wood-burning furnace.

Running the hypocaust
Slaves kept the system running by keeping the flame alight. It is still unknown how well the convection currents worked and whether some rooms got too hot because of the system.

Disadvantages
The hypocaust was reserved only for the wealthiest villas and large bathhouses. Also, the burning of wood produced toxic carbon monoxide fumes.

Roman roads



Roman roads interlinked cities and towns and allowed rapid military and administrative communications. Construction began with a trench, which was filled with a base of stones and rocks. These were packed together tightly, usually with cement, to create a firm foundation for armies to march on and chariots to ride across. Large paving stones were used on the surface. These were placed and fitted by hand along with channels on the side of the road that allowed water to run off into surrounding fields. In the UK, roads such as the A1 and A5 owe their origins to the Roman conquest of Britain.

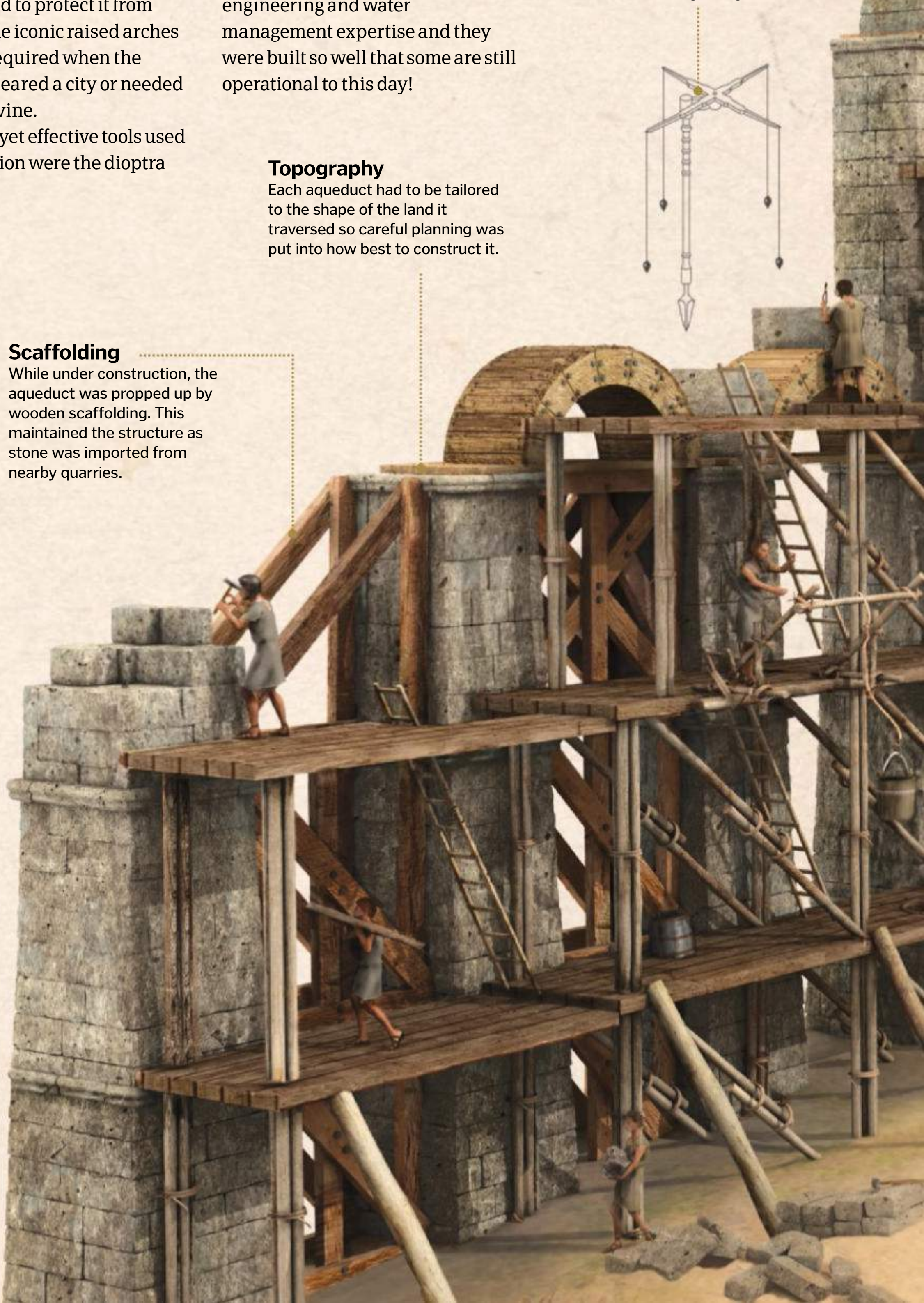
Aqueduct engineering

How the Romans built their immense water-management network

Aqueducts weren't invented by Romans but were popularised by them. These structures were the life stream of a city. 1,300 drinking fountains and 144 public toilets were located in Rome and they were all fed by the complex system of aqueducts, which brought in fresh drinking water from rural areas. The system was accompanied by an elaborate network of sewers.

Rome's main sewer was known as Cloaca Maxima and carried dirty water out of the city and into the River Tiber. The first-ever aqueduct was the Aqua Appia, built in 312 BCE. It helped relieve the demand for water in a rapidly growing Rome. Where possible, the majority of an aqueduct was built underground to protect it from enemies. The iconic raised arches were only required when the structures neared a city or needed to cross a ravine.

The basic yet effective tools used in construction were the dioptra (measured angles) and chorobates (measured horizontal planes). These were handled by skilled army engineers who designed a gravity based system with dropshafts and chutes to help the water flow. This demonstrated excellent structural engineering and water management expertise and they were built so well that some are still operational to this day!



Hydraulics
Despite having a limited knowledge of construction science, the Roman builders realised that gravity and water pressure would play a key part.

Groma
An important surveying instrument in Ancient Rome, the groma was used to measure straight lines and right angles.

Topography
Each aqueduct had to be tailored to the shape of the land it traversed so careful planning was put into how best to construct it.

Scaffolding
While under construction, the aqueduct was propped up by wooden scaffolding. This maintained the structure as stone was imported from nearby quarries.

1 Building materials
Aqueducts were primarily constructed out of limestone that was mined from neighbouring quarries. These slabs of rock were bound together by Roman concrete and cement, which was made out of durable and waterproof volcanic sand called pozzolana.

2 Planning
The building of aqueducts was often financed by the emperors themselves, so meticulous planning was put into the operation. The land needed to be surveyed by engineers to make sure it was fit for construction.

3 Construction techniques
The reinforced Roman concrete arch was an essential part of the aqueduct as it could hold the pressure and weight of the water after the wooden construction supports had been removed. Pulleys, wedges and screws were used as lifting apparatus.

4 Design and uses
The water was carried a great distance from spring to urban area and was then held in cisterns in the city and onto a network of pipes to each individual building. Aqueducts also aided a town's sewer system and protected against fires.

Flowing far

Many claim that aqueducts were one of the best Roman developments. Frequent throughout the Roman world, their effective and modern system was lost after the fall of the empire and never recovered until much, much later in human history. A lot of these structures were actually underground, but they are most fondly remembered for their overground segments with their iconic vaulted arches that were essential in their construction. As techniques improved, aqueducts were also used to supply out-of-town factories and mines with water. The longest aqueduct in Rome was the Aqua Marcia at 91 kilometres (57 miles) from source to city, but even longer systems were built across the empire.

Roman newspapers

Citizens in Rome were kept up-to-date with two daily newspapers. The *Acta Senatus* made sure the public was up to speed with what was going on in the Senate while the *Acta Diurna* was a daily gazette based on Roman news and weather. Both publications were handwritten so their circulation wasn't exceedingly high, but the *Acta Diurna* lasted two centuries of service. The *Senatus* wasn't so lucky as several emperors forbade its publication and preferred to keep Senate minutes private. They were also pioneers of the postal service. The Cursus Publicus was a state-run courier system that delivered messages throughout the Roman Empire.

Buildings

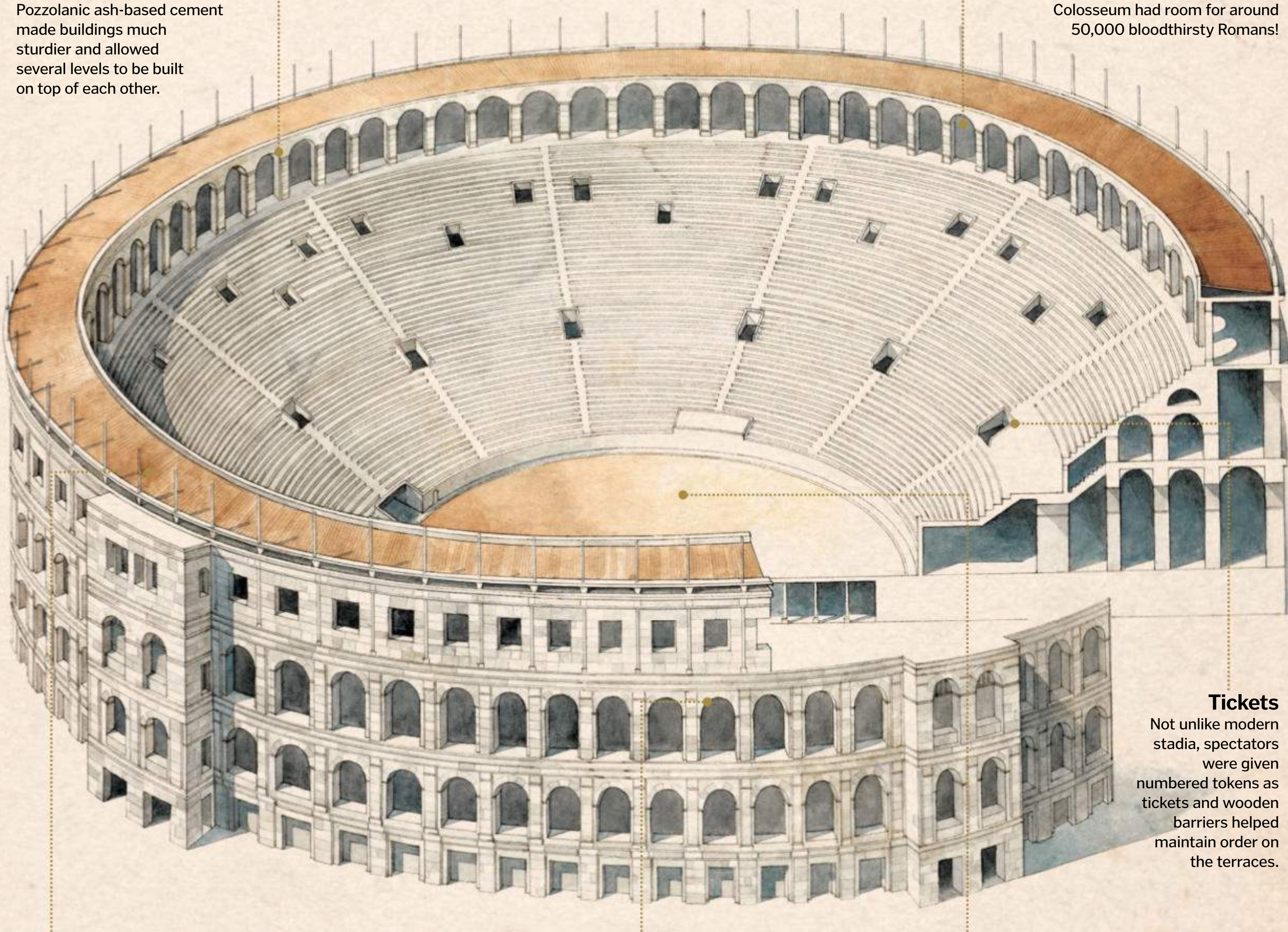
The biggest cities were home to the biggest buildings

In its prime Rome was one of the, if not the most, technologically advanced cities in the world. Containing huge, expansive buildings, revolutionary architecture and a housed, fed and watered population within its walls, the vast empire's capital in Rome was well ahead of its time.

The Colosseum became the cultural centre of Rome after its construction in 80 CE, but the capital also contained one of the largest sports stadiums of all time, the Circus Maximus, as well as other examples of stunning engineering, such as the Pantheon, the Arch of Septimius Severus and the Theatre of Pompey.

The Colosseum

How the centrepiece of the empire and its architecture was built



Concrete and cement
Pozzolanic ash-based cement made buildings much sturdier and allowed several levels to be built on top of each other.

All in a name
The name 'Colosseum' comes from the word 'colossus' which was the name of giant statues erected in the city by Emperor Nero.

Dimensions
48m (157ft) high and 189x156m (620x512ft) in length and width, the Colosseum had room for around 50,000 bloodthirsty Romans!

Tickets
Not unlike modern stadia, spectators were given numbered tokens as tickets and wooden barriers helped maintain order on the terraces.

Velarium
All the spectators in the Colosseum were protected from the hot Mediterranean sun by an awning called the velarium.

Construction
The Colosseum's outer wall was made from 100,000m^3 (3.53mn ft^3) of limestone held together by 300 tons of iron clamps.

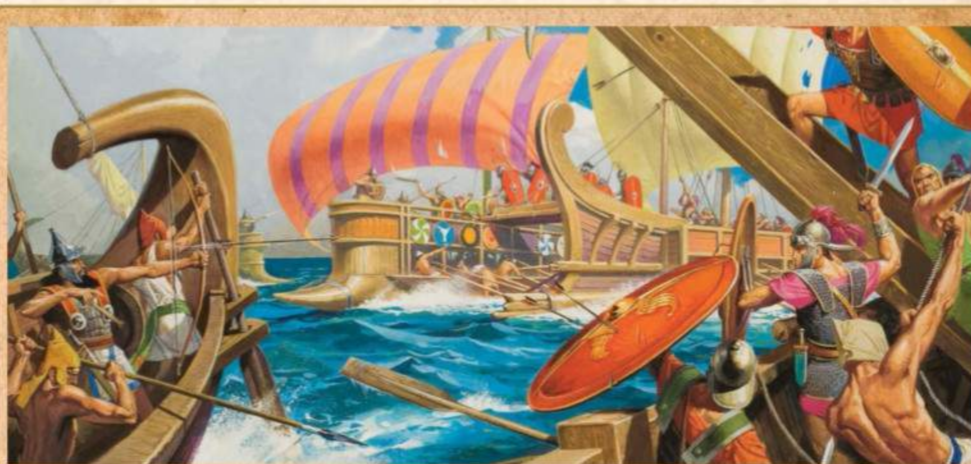
Arches
80 concrete arches meant the Colosseum had an extremely durable design, which has allowed it to stand for nearly 2,000 years!

Underground labyrinth
Underneath the Colosseum was a system of tunnels that elevated cages into the arena using a slave-run pulley system.

Military

Ingenious conquerors

On both land and sea, the Roman Empire dominated warfare for centuries, invading large portions of Europe and making significant inroads into Africa and Asia Minor. The Romans outwitted their opponents using expert battle tactics and perfectly engineered weapons and armour. Soldiers were divided into legions that served different territories and swore an oath of loyalty to the centurions. One of the main reasons why the Romans consistently beat their enemies (and what links them to today's military) is the fact that the army was a professional conscripted force. A full-time operation, a soldier was one of the highest-paid and most-respected occupations in the empire.

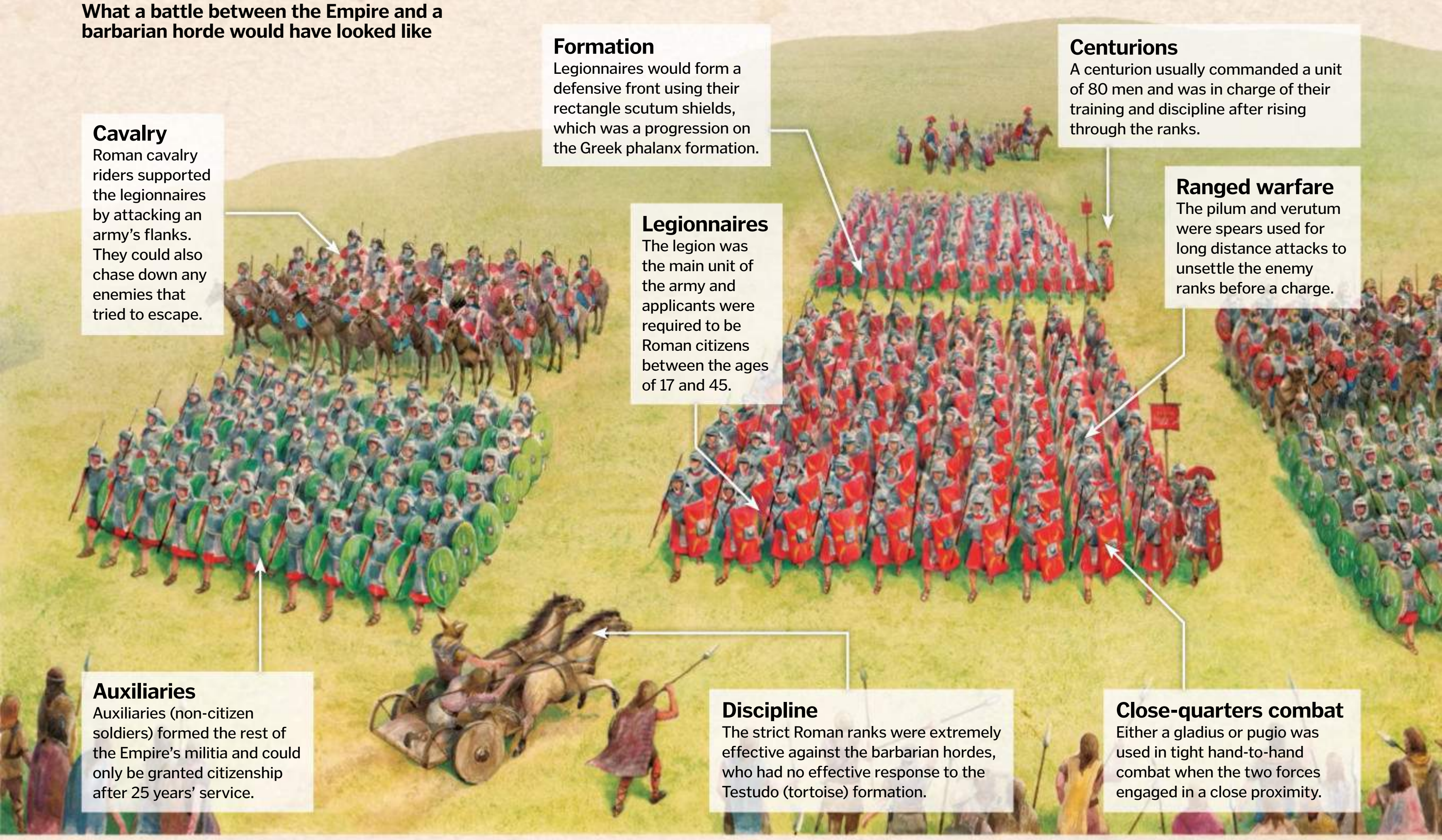


The war at sea

On the high seas of the Mediterranean, the Romans enjoyed even more dominance than on land. Using triremes and galleys propelled by teams of over 100 men, ships attacked either by ramming the opposition or boarding their ships. Owing a lot of their strategies to reverse-engineering methods learnt from the Greeks and Carthaginians, maritime superiority was essential for victory in the Punic Wars and Egypt campaigns. The senior arm of the Roman navy was known as the Classis Misenensis and except for internal civil wars, achieved total marine dominance for Rome after the Punic Wars.

Romans on the battlefield

What a battle between the Empire and a barbarian horde would have looked like



How Vesuvius destroyed Pompeii

The catastrophic eruption that buried an entire city

At noon on 24 August in 79 CE, Mount Vesuvius erupted near the bay of Naples in southern Italy in what would become one of the most devastating natural disasters of ancient times.

The nearby cities of Pompeii and Herculaneum were completely buried by the ash and pyroclasts that spewed from the volcano, helping to preserve them in extraordinary detail. We also have detailed information about the eruption itself thanks to Pliny the Younger, who wrote two letters detailing what he saw from his mother's house in Cape Misenum. His famous description of the plume as "shaped like a pine" caused this type of eruption to be named a Plinian eruption.

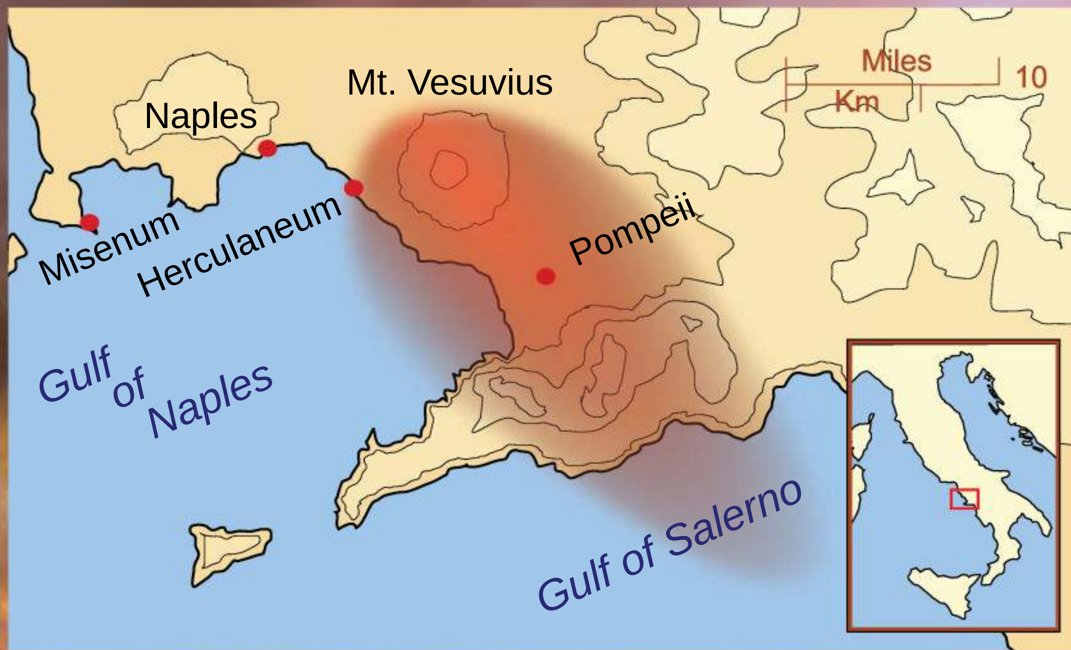
20 hours of terror

How that fateful day unfolded

1 10am, 24 August, 79 CE
For four days prior to the eruption, small earthquakes are felt throughout the city of Pompeii. As this happens every year without consequence, the inhabitants think nothing of it. Many of them congregate in the public forum, the political, religious and commercial heart of the city.

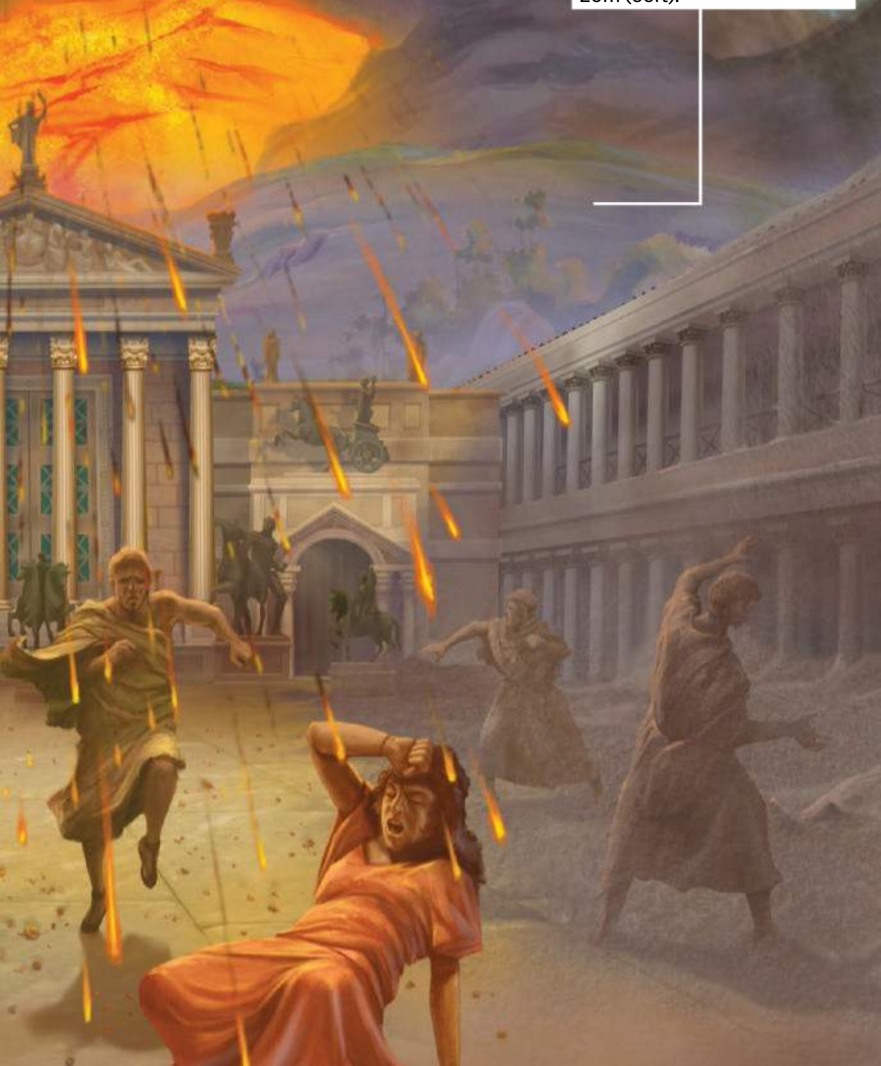
2 1pm, 24 August
After several small explosions, Vesuvius erupts, sending a tall cloud of lava and ash over 20km (12mi) into the sky. The cloud blocks out the Sun, plunging everything into darkness, and violent tremors cause buildings to collapse. People run toward the coast in search of rescue, but rough seas make escape by water impossible.

3 9pm, 24 August
Hot ash and lumps of volcanic rock rain down over Pompeii, which is downwind from the volcano. People become trapped in their houses as debris blocks the doors, and roofs begin to collapse from the weight of the ash and rock. Many people are also killed by the emissions of sulphuric gases.



4 **12am, 25 August**
The ash cloud reaches its maximum height of 30km (19mi) and then collapses, sending a pyroclastic surge of hot gas and rock down the volcano's northwest slope toward Herculaneum. Moving up to 700km/h (435mph) and with temperatures up to 400°C (752°F), the surge instantly kills everyone it touches.

5 **6am, 25 August**
As dawn breaks, the cloud collapses for the last time, sending another pyroclastic surge toward Pompeii that kills everyone in its path. By the time the eruption is over, Pompeii is buried underneath 5m (16ft) of volcanic material, while Herculaneum is buried under 20m (66ft).



"By the time the eruption is over, Pompeii is buried underneath 5m (16ft) of volcanic material"

Anatomy of the eruption

Initial explosion

After more than 800 years of inactivity, pressure inside the volcano became too great. The built-up gases burst through the thick layer of lava that had plugged the crater and a column of ash climbs upward.

Spreading cloud

The wind blows the cloud toward the southeast, and it spreads to nearly 100km (60mi) in width from side to side. Ash falls on Pompeii at a rate of 15cm (6in) per hour for an entire day.

Pyroclastic flows

As the ash cloud collapses, volcanic debris rolls down the sides of the volcano toward Herculaneum, which is 6km (3.7mi) away, and Pompeii, which is 10km (6.2mi) away. Anyone in the path of the flow had their body burned to the bone in seconds.

16th-century Spanish galleon

How did this small sailing ship change the world?

The cutting edge of European ship design at the time of its introduction, the galleon was first used in the Mediterranean Sea by the Venetian Republic, a merchant power based in the Italian city of Venice in the early-16th century, but by the second half of the century the same basic design was also in use by Portugal, England, France and Spain among others.

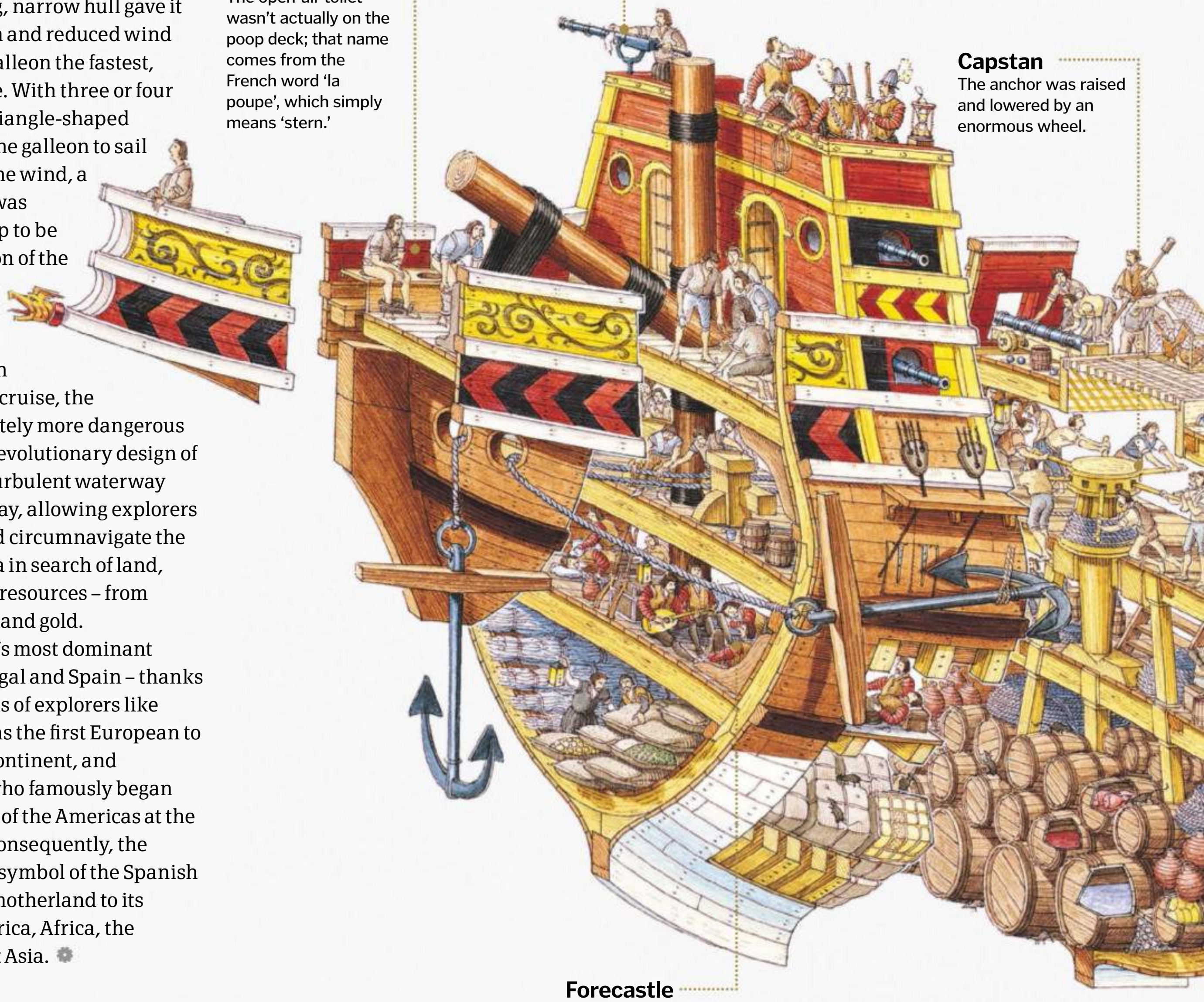
The ship's lower deck at the front (leading to that jaunty look) and long, narrow hull gave it unrivalled stability at sea and reduced wind resistance, making the galleon the fastest, nimblest vessel of the age. With three or four main sails and a single triangle-shaped lateen sail that allowed the galleon to sail against the direction of the wind, a complex rigging system was designed to allow the ship to be operated by only a fraction of the total crew should they suffer losses at sea.

While crossing the Mediterranean in the 16th century was no pleasure cruise, the Atlantic Ocean was infinitely more dangerous and unpredictable. The revolutionary design of the galleon turned this turbulent waterway into a global superhighway, allowing explorers to chart the Americas and circumnavigate the globe from Europe to Asia in search of land, trade, slaves and natural resources – from tobacco and silk, to spice and gold.

The early-16th century's most dominant naval powers were Portugal and Spain – thanks to the pre-galleon voyages of explorers like Bartolomeu Dias, who was the first European to sail around the African continent, and Christopher Columbus, who famously began the Spanish colonisation of the Americas at the end of the 15th century. Consequently, the galleon became a potent symbol of the Spanish Empire, connecting the motherland to its far-flung colonies in America, Africa, the Caribbean and Southeast Asia.

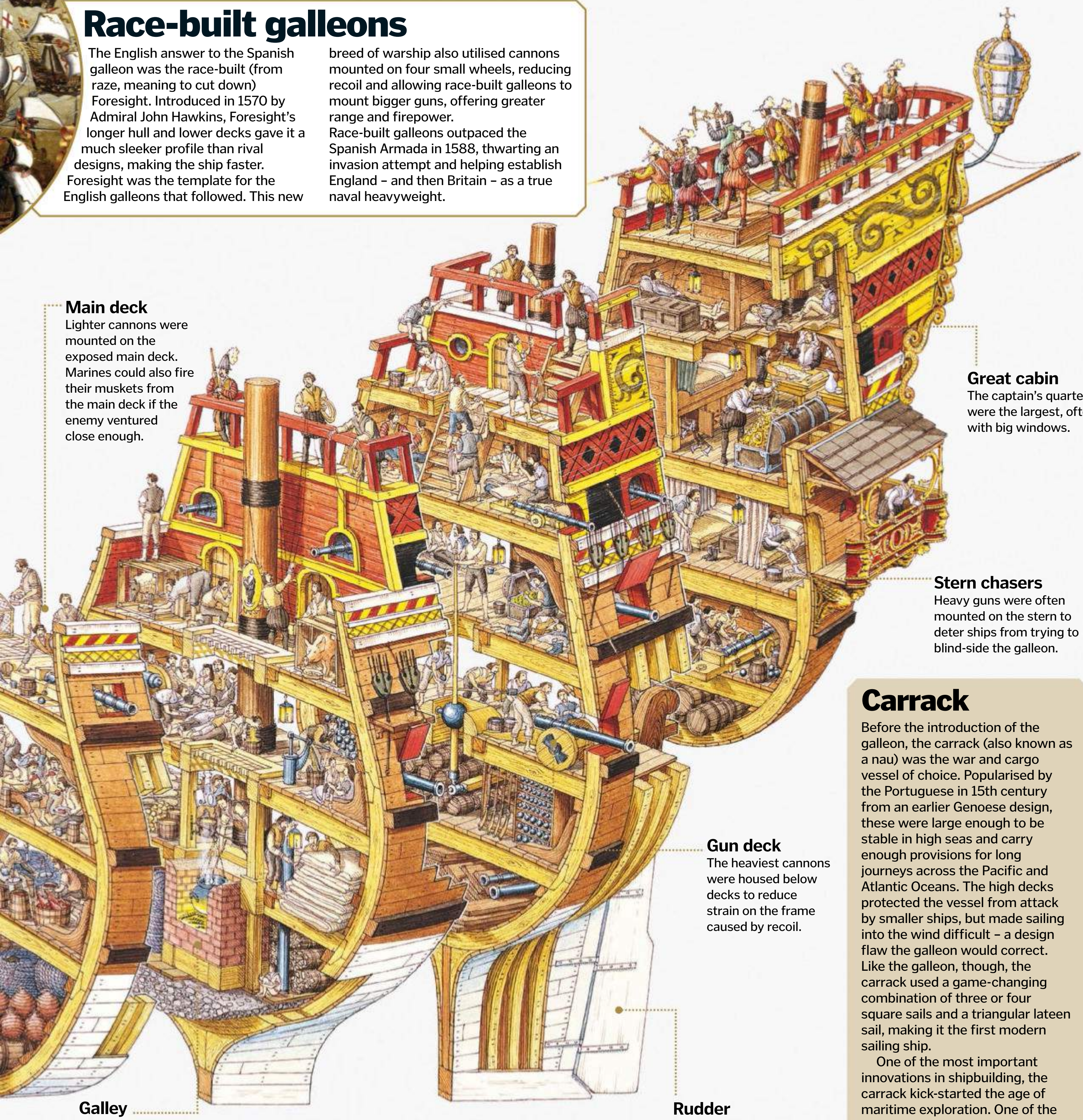
Aboard the Spanish galleon

What was life like on the high seas?



Race-built galleons

The English answer to the Spanish galleon was the race-built (from raze, meaning to cut down) Foresight. Introduced in 1570 by Admiral John Hawkins, Foresight's longer hull and lower decks gave it a much sleeker profile than rival designs, making the ship faster. Foresight was the template for the English galleons that followed. This new breed of warship also utilised cannons mounted on four small wheels, reducing recoil and allowing race-built galleons to mount bigger guns, offering greater range and firepower.
Race-built galleons outpaced the Spanish Armada in 1588, thwarting an invasion attempt and helping establish England – and then Britain – as a true naval heavyweight.



Main deck
Lighter cannons were mounted on the exposed main deck. Marines could also fire their muskets from the main deck if the enemy ventured close enough.

Great cabin
The captain's quarters were the largest, often with big windows.

Stern chasers
Heavy guns were often mounted on the stern to deter ships from trying to blind-side the galleon.

Gun deck
The heaviest cannons were housed below decks to reduce strain on the frame caused by recoil.

Galley
The kitchens had a fireplace mounted on bricks to stop the heat or sparks from setting the ship on fire.

Rudder
The long rudder was another innovation of the galleon, allowing the ship greater manoeuvrability.

Carrack

Before the introduction of the galleon, the carrack (also known as a nau) was the war and cargo vessel of choice. Popularised by the Portuguese in 15th century from an earlier Genoese design, these were large enough to be stable in high seas and carry enough provisions for long journeys across the Pacific and Atlantic Oceans. The high decks protected the vessel from attack by smaller ships, but made sailing into the wind difficult – a design flaw the galleon would correct. Like the galleon, though, the carrack used a game-changing combination of three or four square sails and a triangular lateen sail, making it the first modern sailing ship.

One of the most important innovations in shipbuilding, the carrack kick-started the age of maritime exploration. One of the most famous examples was Christopher Columbus's flagship, the Santa Maria.

The mystery of Easter Island

Who built the giant heads of Rapa Nui and why?

The most easterly island in Polynesia, approximately 3,700 kilometres (2,300 miles) west of South America in the Pacific Ocean, Easter Island could hardly be more remote. Yet it's home to some of the most incredible man-made wonders on Earth – over 887 carved stone heads, called moai, that has seen the entire 166.3-square-kilometre (64.2-square-mile) island, known as Rapa Nui by its population, designated as a UNESCO World Heritage Site.

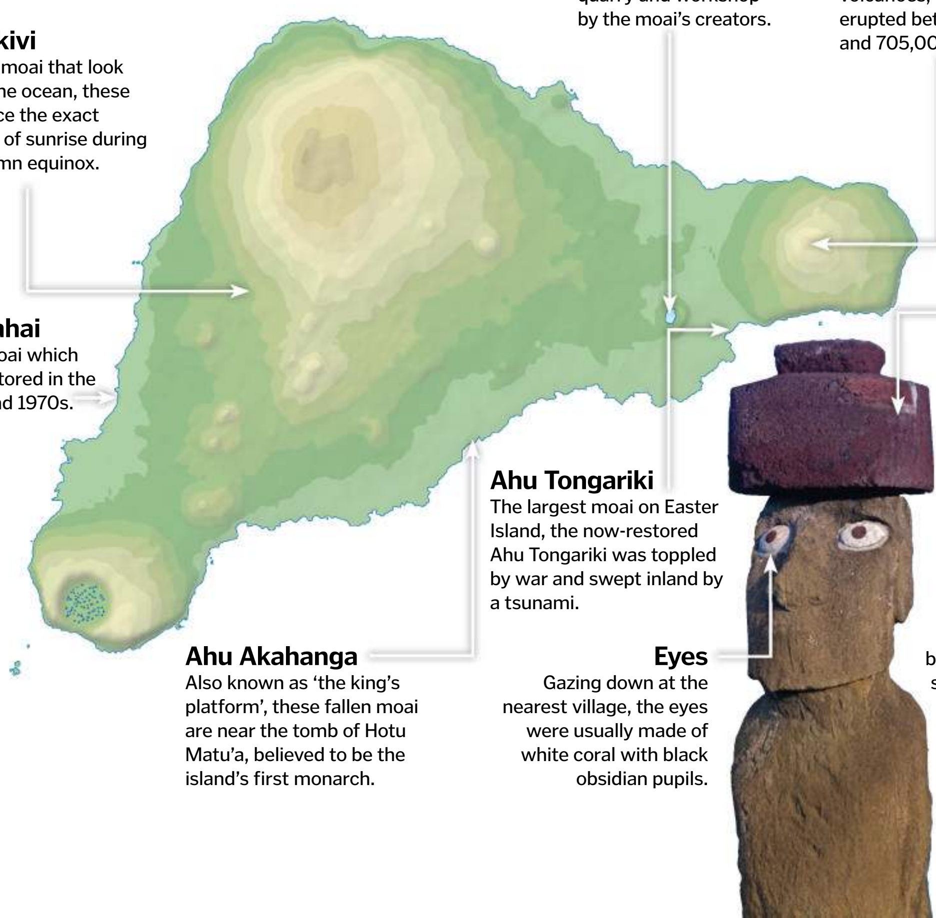
The origin of these stern-faced monoliths – which average four metres (13 feet) tall and weigh an average of 14 tons – and the society that built them is largely a mystery. What is known is that settlers travelling on wooden outrigger canoes arrived on the island between the 4th and 13th centuries and carved the moai sometime between the 10th and 16th centuries from tuff – a light, porous volcanic rock – and placed them upon platforms called ahu. Some even wear 'hats' of red scoria, representing the topknot hair styles of the Rapa Nui people. The eye sockets are believed to have held coral eyes with either black obsidian or red scoria pupils, while the bodies may have been carved with patterns that mimic the traditional tattoos of the Rapa Nui.

As for why they were carved, it may have been to honour important chieftains or warriors as some of them contained tombs in their ahu, or it may be to offer protection as with only a few exceptions they gaze over nearby villages. Ultimately it's impossible to know for certain. When Dutch explorers arrived on the island on Easter Day in 1722, the islanders that had created these breathtaking monuments had long since been divided by civil wars and many of its moai toppled, leaving only stories preserved in the oral histories of the Rapa Nui people and a forest of impassive stone heads breaking forth from the earth to stare out across the grass.

"The origin of these stern-faced monoliths and the society that built them is largely a mystery"

Treasure Island

The many moai of Easter Island



Ahu Akivi
The only moai that look toward the ocean, these seven face the exact direction of sunrise during the autumn equinox.

Ahu Tahai
Seven moai which were restored in the 1960s and 1970s.

Rano Raraku
A volcanic crater that was used as a tuff quarry and workshop by the moai's creators.

Poike
The oldest of the island's three main inactive volcanoes, Poike last erupted between 230,000 and 705,000 years ago.

Pukao
The stone cylinders that represent the figure's hair, carved from light-red scoria.

Ahu Tongariki
The largest moai on Easter Island, the now-restored Ahu Tongariki was toppled by war and swept inland by a tsunami.

Ahu
The stone platform at the base of the moai, sometimes used as a tomb.

Ahu Akahanga
Also known as 'the king's platform', these fallen moai are near the tomb of Hotu Matu'a, believed to be the island's first monarch.

Eyes
Gazing down at the nearest village, the eyes were usually made of white coral with black obsidian pupils.

What happened to their creators?

Though largely barren and sparsely inhabited by the time Europeans arrived on Rapa Nui, the island was once heavily forested and home to several now-extinct species of birds before it suffered a mysterious collapse. One theory is that the rats and chickens brought by the original settlers as a source of food laid waste to the island's limited plant life. When the last palm trees were cut down – maybe as late as the 17th century – the Rapa Nui's ability to build boats and fish for food was also restricted. As conflict between tribes for the dwindling resources became inevitable, the population plummeted and some even resorted to cannibalism.

How were they moved?

Though the carvings are impressive, getting them into place suggests a feat of engineering even more so. With no evidence of wheels or cranes – and no large animals to do all the heavy pulling – archaeologists originally believed the moai may have been moved on sledges or wooden rollers as far as 18 kilometres (11 miles) from the quarry.

Though some scholars still support this, a more recent theory is that the curved base of the moai was designed for them to be 'rocked' from side to side and then pulled forward by carefully coordinated teams of workers with ropes. Damage to the base during experiments moving replica statues is consistent with flakes of rock found along roadsides on the island.

The debate is still ongoing, but this theory may be the source of Rapa Nui folklore that recalls the statues being commanded to walk by the gods.