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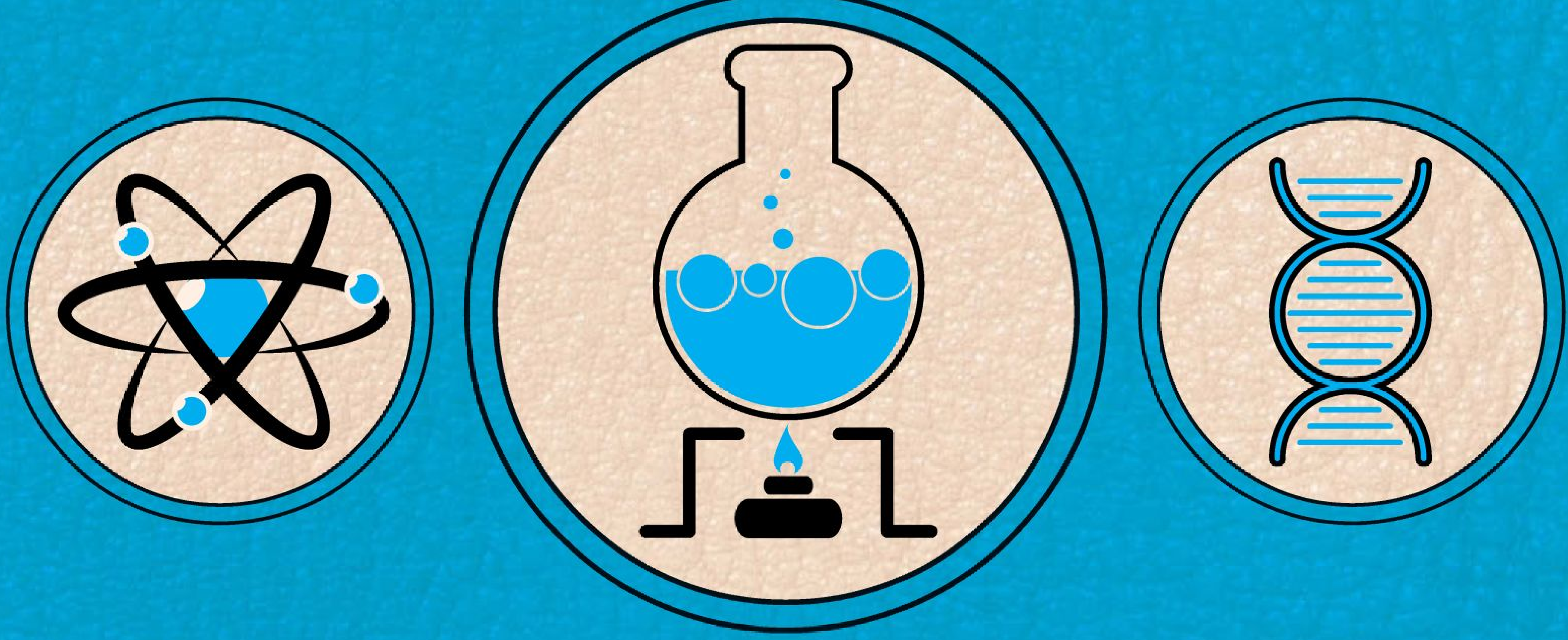
HOW IT WORKS

AMAZING SCIENCE

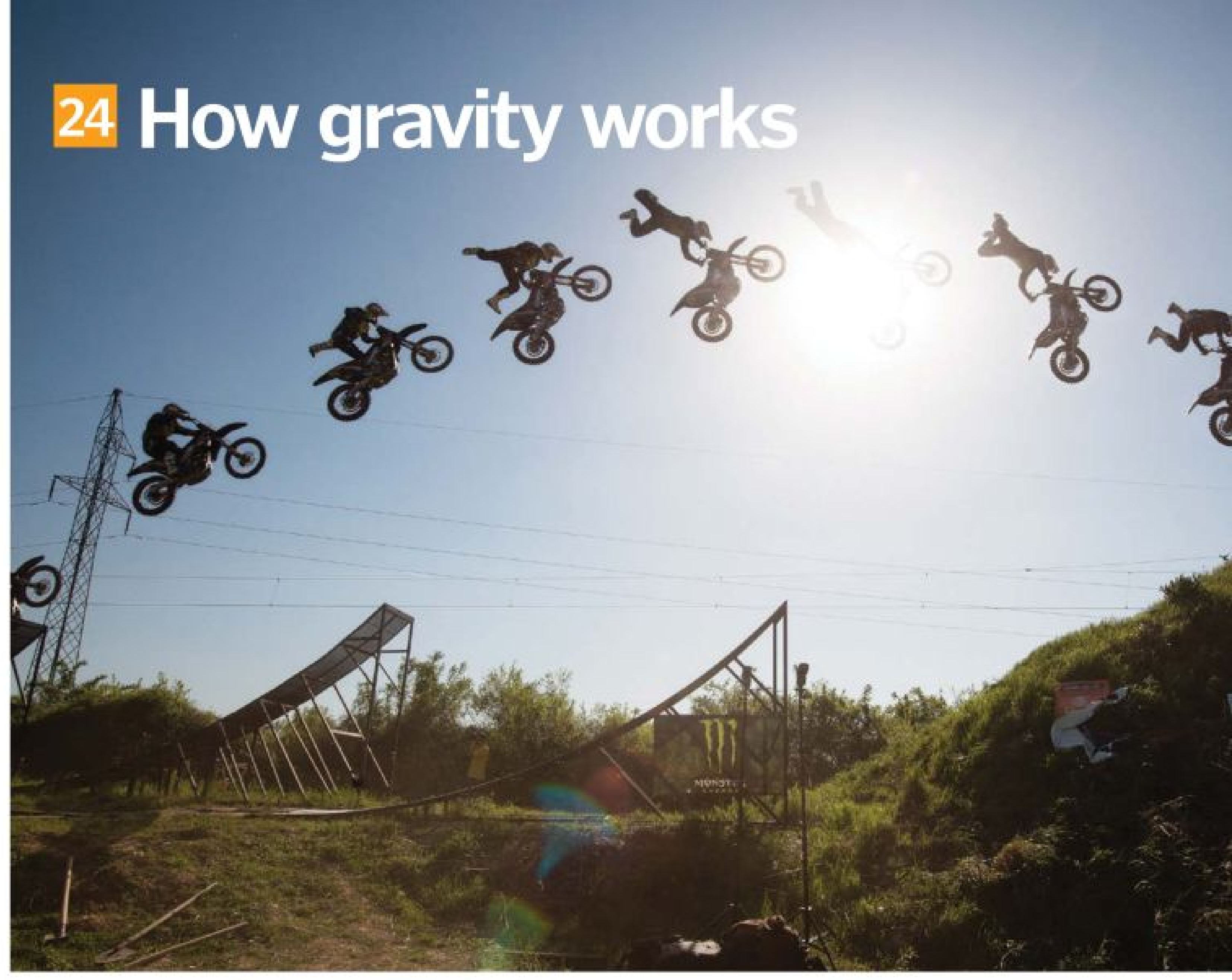


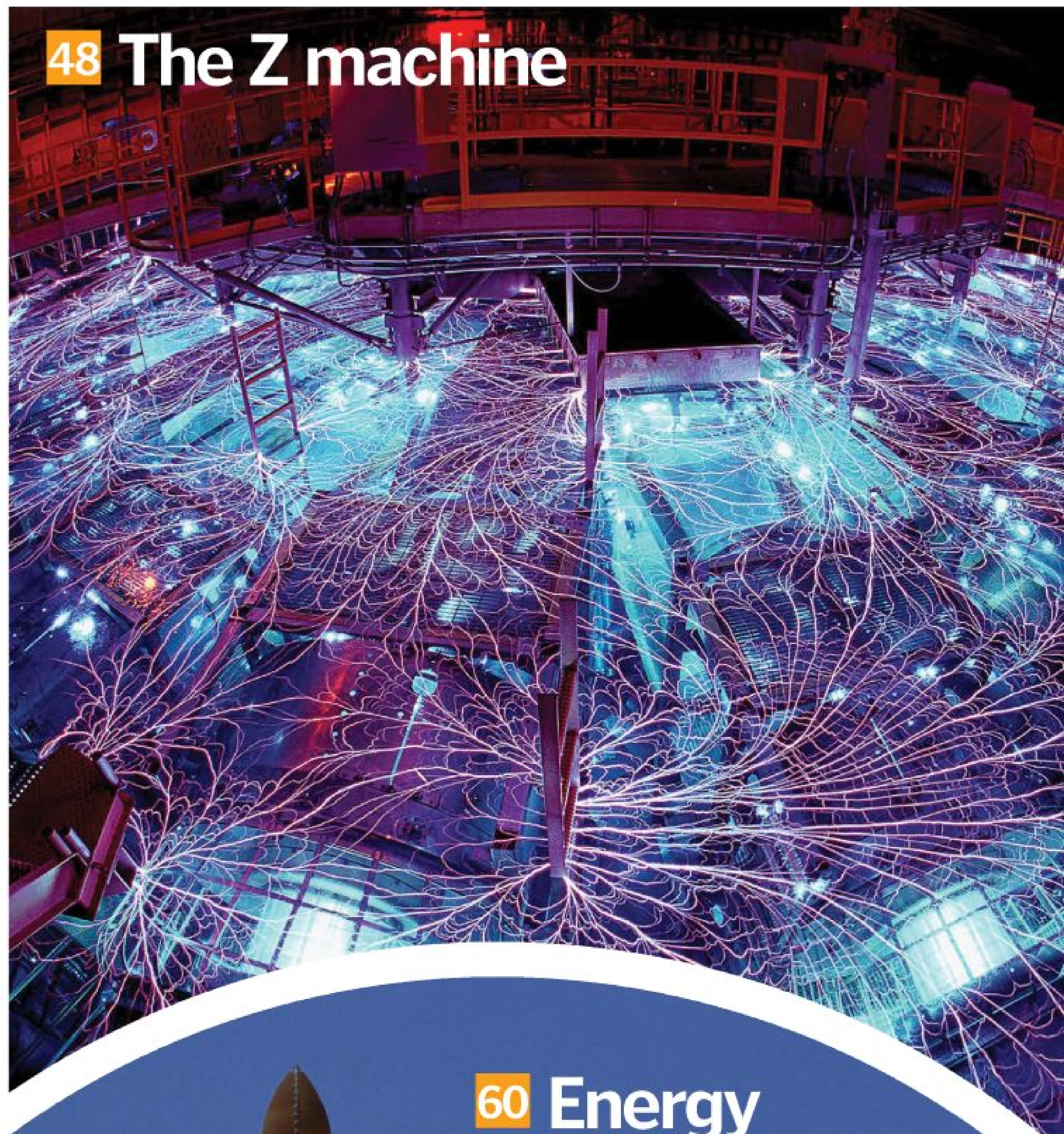
CONTENTS

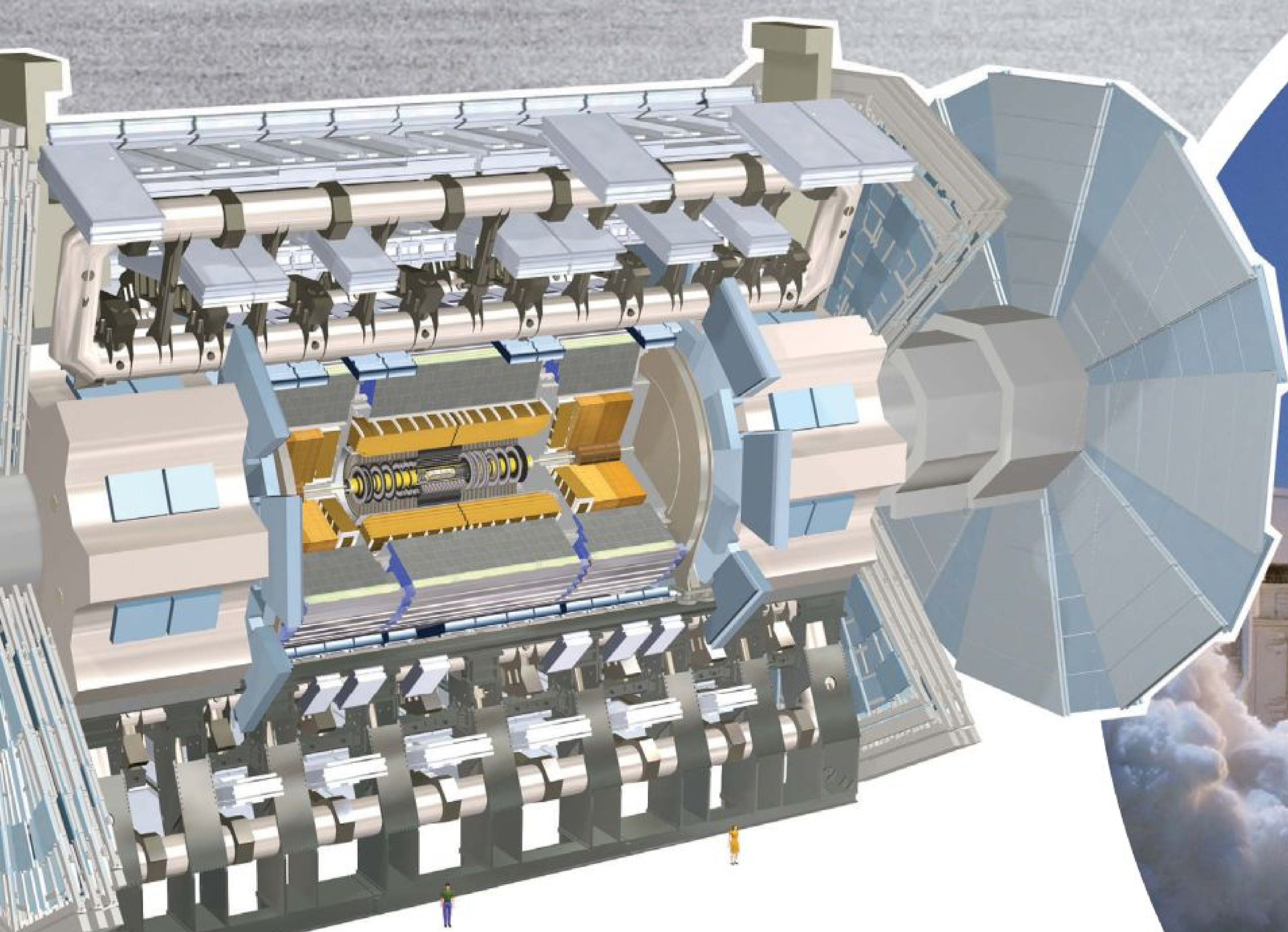
18 Science of forensics

30 Science of sport

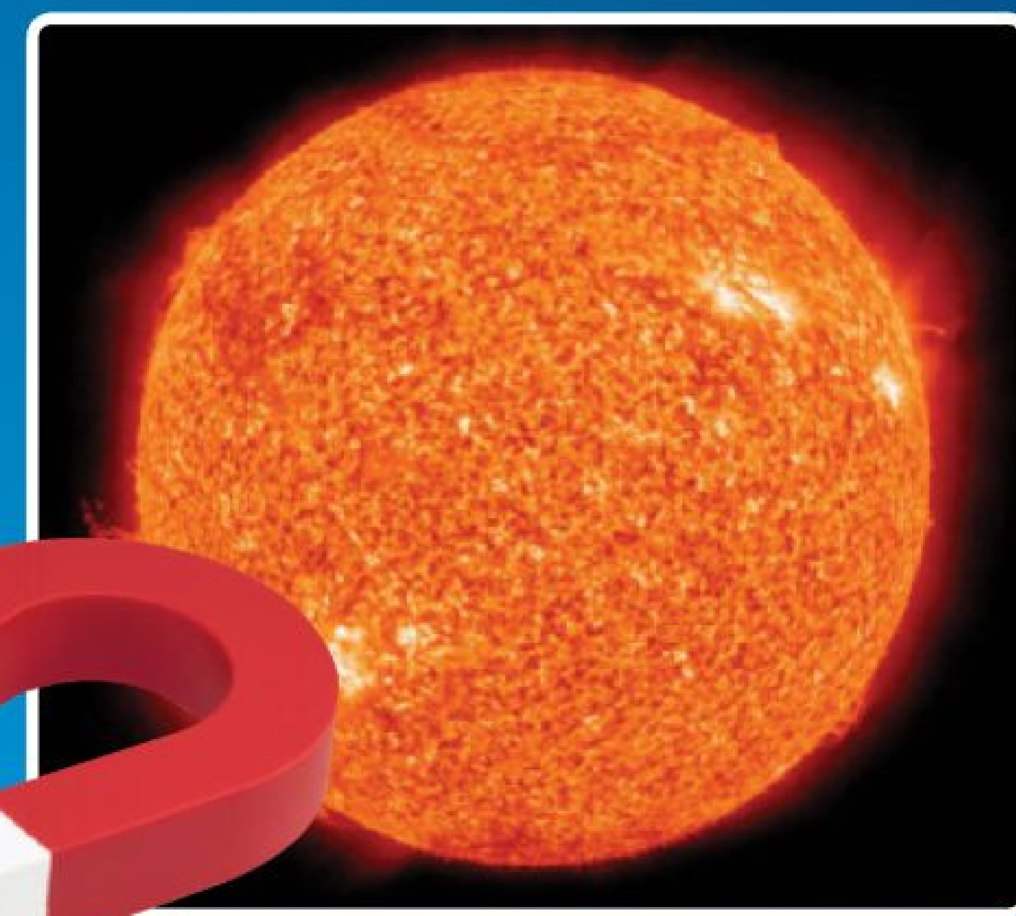
16 Stephen Hawking

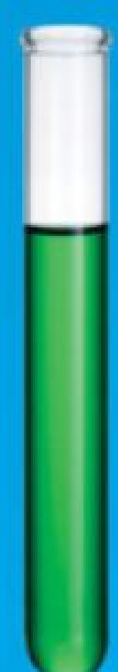




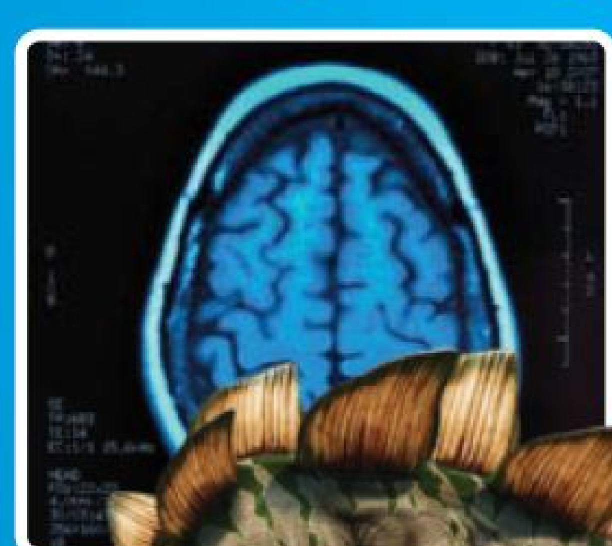


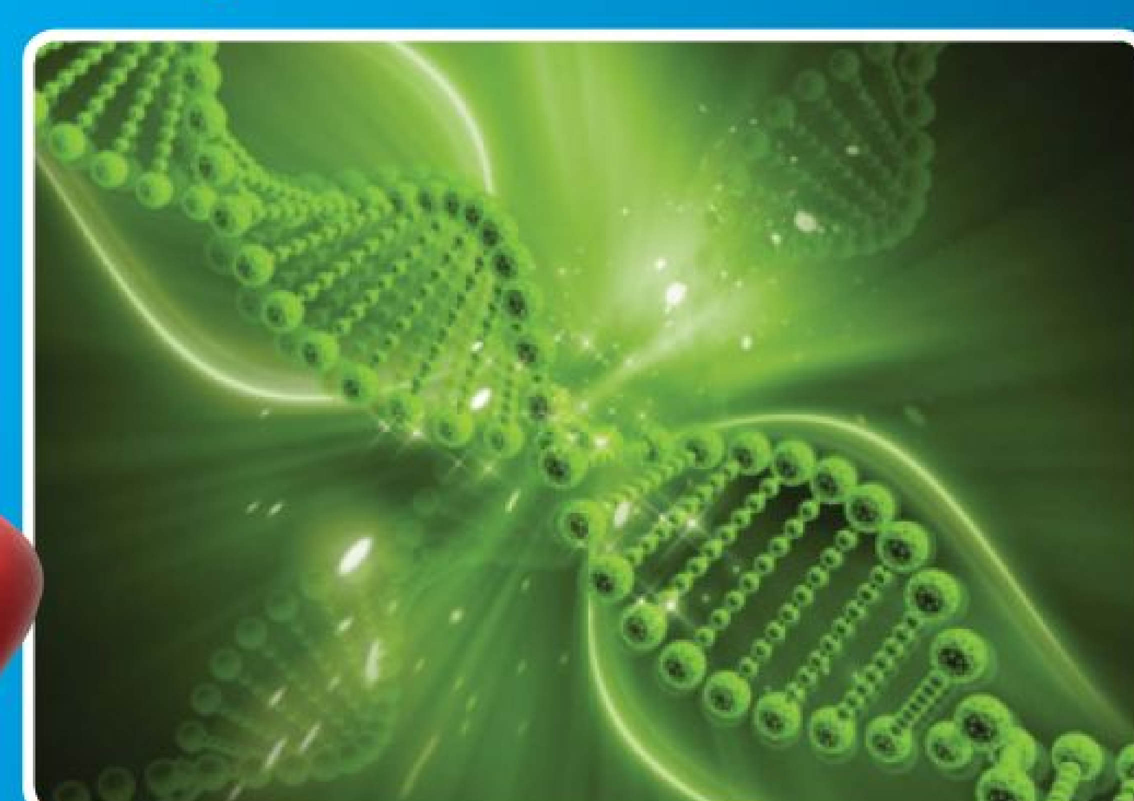
50 AMAZING FACTS ABOUT SCIENCE



From Earth's geology to the complex workings of the human body and on to the farthest reaches of outer space, HIW presents some fascinating insights that will blow your mind

Like you, we love learning about science. And luckily, every day is a school day on **How It Works** magazine because there's *always* something new and remarkable to discover about the world we live in. From the very moment we're born we begin to take in information about the planet around us, and as we get older it becomes only natural to grow curious and start asking questions like how and why.

So not only does this special **How It Works** feature reveal 50 of the most amazing science facts, but it also explains the equally amazing principles that lie behind them, helping you to get a handle on *why* each fact works the way it does.

When we announced on Twitter we were running a feature about incredible scientific trivia, our feed was immediately inundated by readers keen to share their favourite nuggets of information. And after sifting through the hundreds of fantastic entries that came in from all over the world – and doing some of our own research – we selected the best of the bunch.

Topics cover everything from the origins of the cosmos to how the cells in our bodies work, so over these eight jam-packed pages, you will discover a wealth of mindblowing knowledge to astound you and everyone you know as we explain the science behind some of the universe's most amazing facts.

HEAD 2 HEAD
SUPERSTARS

1. HOTTEST

Bug Nebula
The hottest star in the Milky Way is at the centre of the Bug Nebula 3,500 light years away. Its surface temperature is 35 times hotter than the Sun's.

2. OLDEST

Caffau's star
A star with a very strange composition (full name SDSS J102915+172927) at the edge of our galaxy is suspected to be more than 13 billion years old.

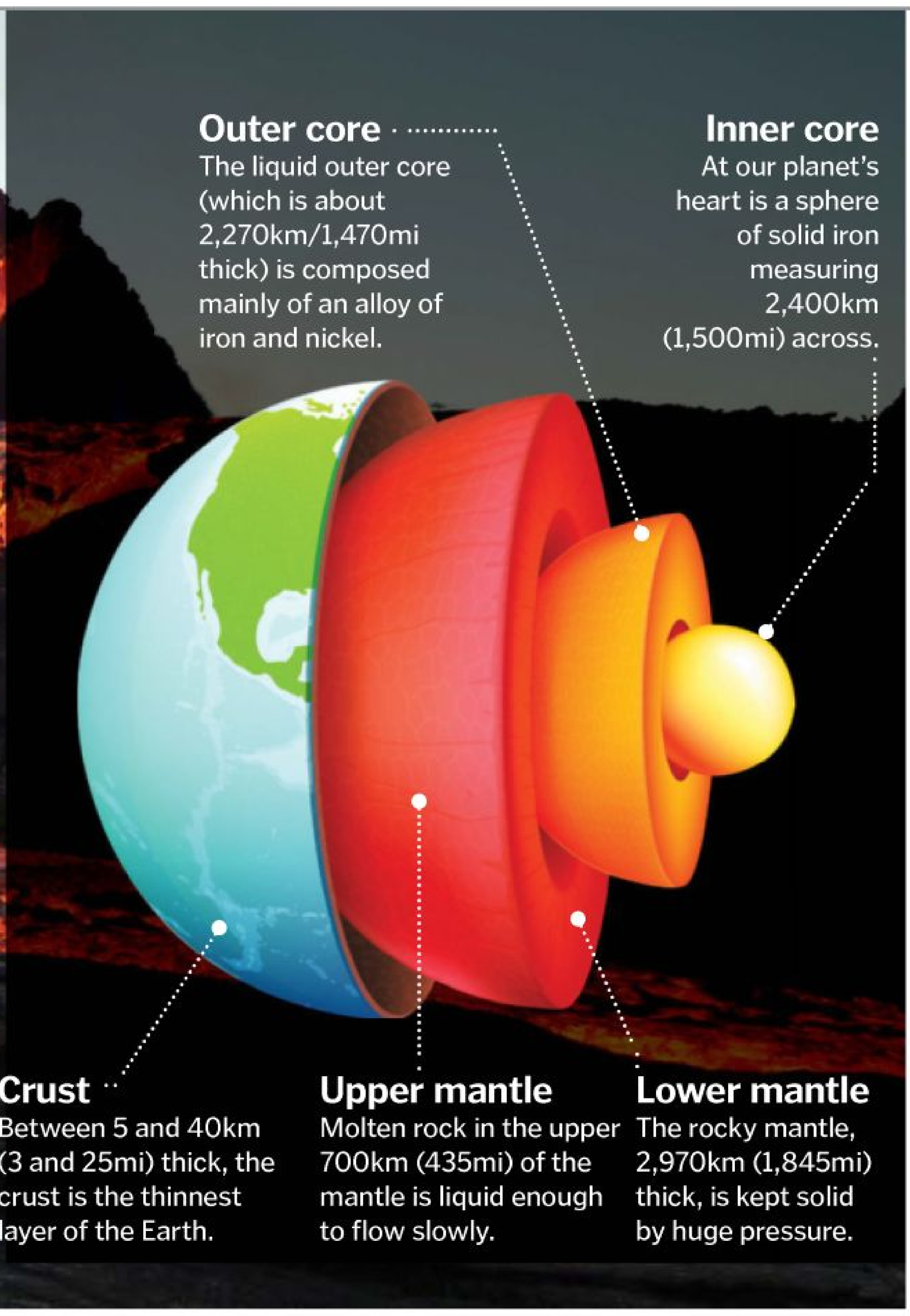
3. FARTHEST

Big Bang galaxies
The most distant stars are over 13 billion light years away, in galaxies that formed shortly after the Big Bang.

DID YOU KNOW? *The oldest living thing in the world is a 200,000-year-old patch of seagrass off Formentera, Spain*

1. 84% of the Earth's volume is molten rock

Most of the Earth's volume is contained in the mantle, a rocky layer 2,970 kilometres (1,845 miles) thick, sandwiched between the planet's core and crust. Despite temperatures approaching 4,300 degrees Celsius (7,772 degrees Fahrenheit) near the core, most of the mantle is solid due to the huge pressure it is under. Earthquakes are an important source of information about what lies beneath our feet. By studying how seismological waves spread through the planet, geologists can deduce its structure. Certain waves, for example, can't travel through liquids, leading scientists to conclude that the planet's outer core is liquid.



2. You can't see a laser beam in space

A laser is a highly focused beam of light. So focused, in fact, that none of its photons deviate from their path and enter your eyes, unless they are reflected by particles of dust. In the almost-perfect vacuum of space there is no matter so lasers are invisible, despite what many a science-fiction film might suggest.

3. Babies have around 100 more bones than adults

Babies have about 300 bones at birth, with cartilage between many of them. This extra flexibility helps them pass through the birth canal and also allows for rapid growth. With age, many of the bones fuse, leaving 206 bones that make up an average adult skeleton.

4. The Eiffel Tower can be 15cm taller during the summer

When a substance is heated up, its particles move more and it takes up a larger volume – this is known as thermal expansion. Conversely, a drop in temperature causes it to contract again. The mercury level inside a thermometer, for example, rises and falls as the mercury's volume changes with the ambient temperature. This effect is most dramatic in gases but occurs in liquids and solids such as iron too. For this reason large structures such as bridges are built with expansion joints which allow them some leeway to expand and contract without causing any damage.

5. Butterflies taste with their feet

Butterflies' hind feet, technically known as tarsi, are covered in chemoreceptors – tiny organs which allow them to taste something just by standing on it. This anatomical quirk enables a female butterfly to pick a leaf suitable for her caterpillars to eat before she lays her eggs. More generally, once it has spotted a tasty-looking flower, a butterfly can sample the goods quickly before settling down to feed.

6 Muscles can remember

The first time you perform an action – tying shoelaces, for example, it feels awkward, but with enough repetition it becomes second nature. The brain stores sets of motor instructions, allowing such tasks to be executed without conscious effort. Muscle memory is retained for a long time, so skills like driving a car are rarely completely lost.

7 Pumice is the only rock that can float

Pumice is formed when hot, highly pressurised lava is ejected from a volcano. The sudden drop in pressure and rapid cooling trap bubbles of gas in the rock, giving it a lower density than water.

8 Only diamond can cut diamond

Diamonds are carbon, with each atom bound with strong covalent bonds to four neighbours in a rigid lattice. Diamonds tend to grow in octahedral shapes, and some of the octahedron's faces are weaker than others. Jewellers can cut along these planes with special tools coated in diamond dust.

“Plants continually replenish our planet’s oxygen levels through photosynthesis”

9. 20% of Earth’s oxygen is produced by the Amazon rainforest

Our atmosphere is made up of roughly 78 per cent nitrogen and 21 per cent oxygen, with various other gases present in small amounts. The vast majority of living organisms on Earth need oxygen to survive, converting it into carbon dioxide (CO_2) as they breathe.

Thankfully, plants continually replenish our planet’s oxygen levels through photosynthesis. During this process, CO_2 and water are converted into energy, releasing oxygen as a by-product. Covering 5.5 million square kilometres (2.1 million square miles), the Amazon rainforest cycles a significant proportion of the Earth’s oxygen, absorbing large quantities of CO_2 at the same time.

10. Dynamite may contain nuts

Dynamite’s explosive ingredient is nitroglycerin, absorbed onto clay particles for stability. Nitroglycerin is made with glycerol, which can be extracted from peanuts. This said, there are other ways of producing nitroglycerin as well.

11. The brain does not feel pain

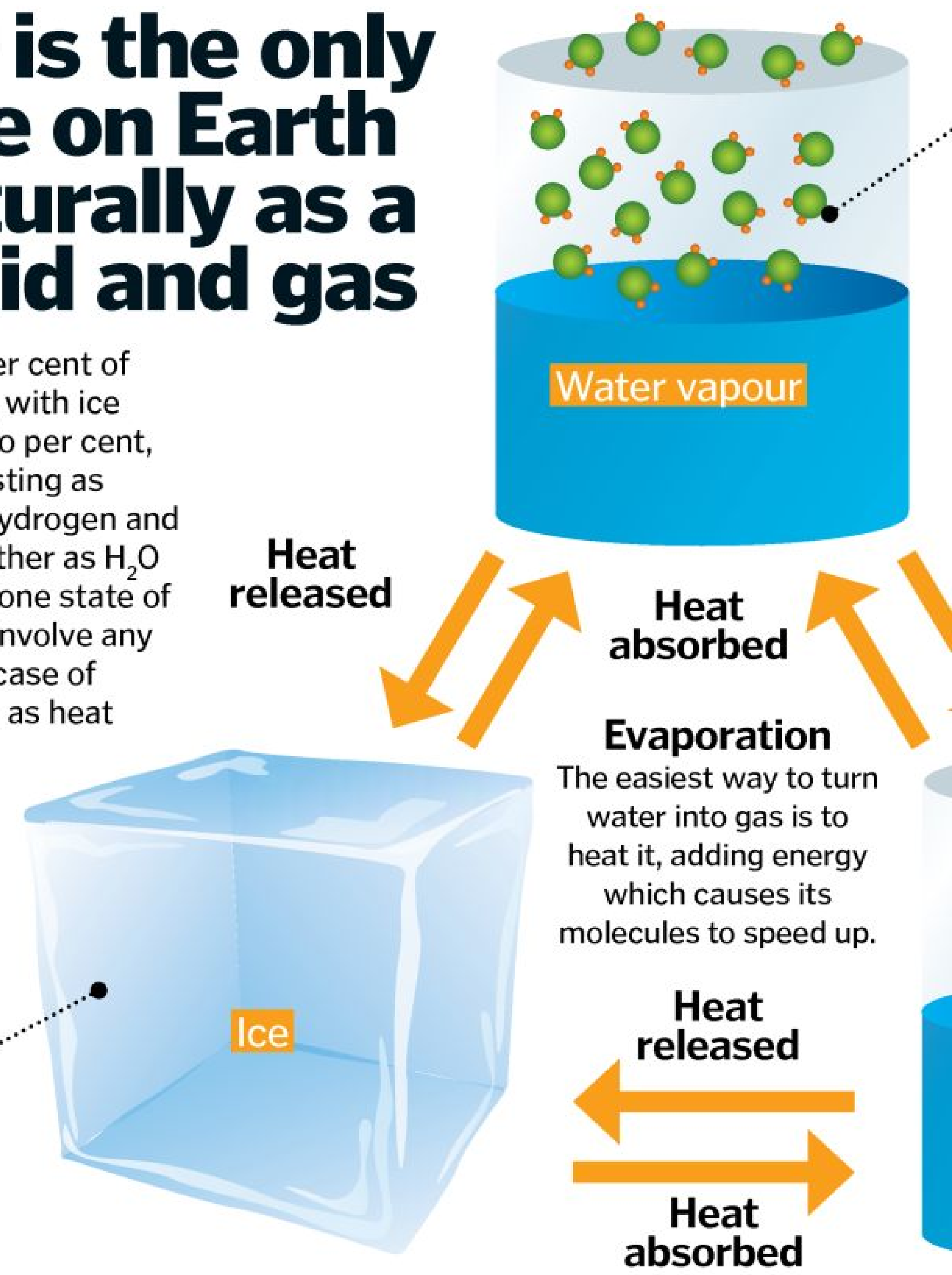
We feel pain thanks to nociceptors – sensory receptors which send signals to the spinal cord and brain, alerting us to danger and enabling us to react. Nociceptors are found throughout the body, particularly just under the skin, but they are entirely absent from one place: the brain. When you have a headache, it isn’t actually your brain that’s suffering but the tissues around it which include muscles, sinuses and the membranes that protect the organ.

12. Some metals are so reactive that they explode on contact with water

There are certain metals – including potassium, sodium, lithium, rubidium and caesium – that are so reactive that they oxidise (or tarnish) instantly when exposed to air. They can even produce explosions when dropped in water! All elements strive to be chemically stable – in other words, to have a full outer electron shell. To achieve this, metals tend to shed electrons. The alkali metals have only one electron on their outer shell, making them ultra-keen to pass on this unwanted passenger to another element via bonding. As a result they form compounds with other elements so readily that they don’t exist independently in nature.

13. Water is the only substance on Earth found naturally as a solid, liquid and gas

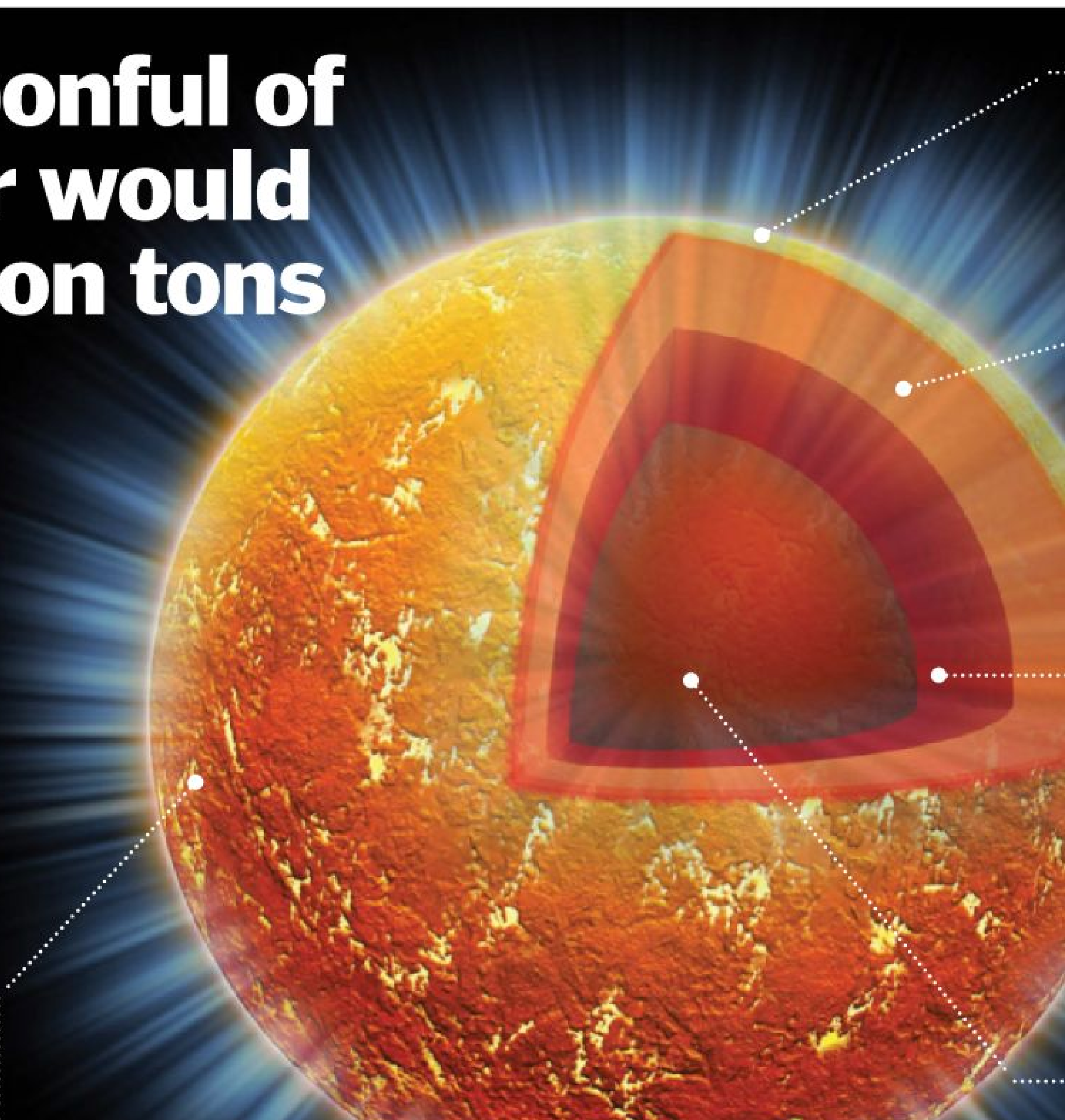
At any one time, over 98 per cent of our planet’s water is liquid, with ice making up a little under two per cent, and only a tiny fraction existing as vapour. Water is made of hydrogen and oxygen atoms, bound together as H_2O molecules. Changing from one state of matter to another doesn’t involve any chemical changes but is a case of adding or removing energy as heat or pressure, affecting the behaviour of the H_2O. In liquid water, molecules move freely. Cool it down and, as they lose energy, the molecules slow down until the point where they form a rigid structure: ice.



Solid
In ice, the H_2O molecules have very little energy and lock into a rigid lattice.

14. A teaspoonful of neutron star would weigh 6 billion tons

A neutron star is the remnants of a massive star that has run out of fuel. The dying star explodes in a supernova while its core collapses in on itself due to gravity, forming a super-dense neutron star. Astronomers measure the mind-bogglingly large masses of stars or galaxies in solar masses, with one solar mass equal to the Sun’s mass (that is, 2×10^{30} kilograms/4.4×10^{30} pounds). Typical neutron stars have a mass of up to three solar masses, which is crammed into a sphere with a radius of approximately ten kilometres (6.2 miles) – resulting in some of the densest matter in the known universe.



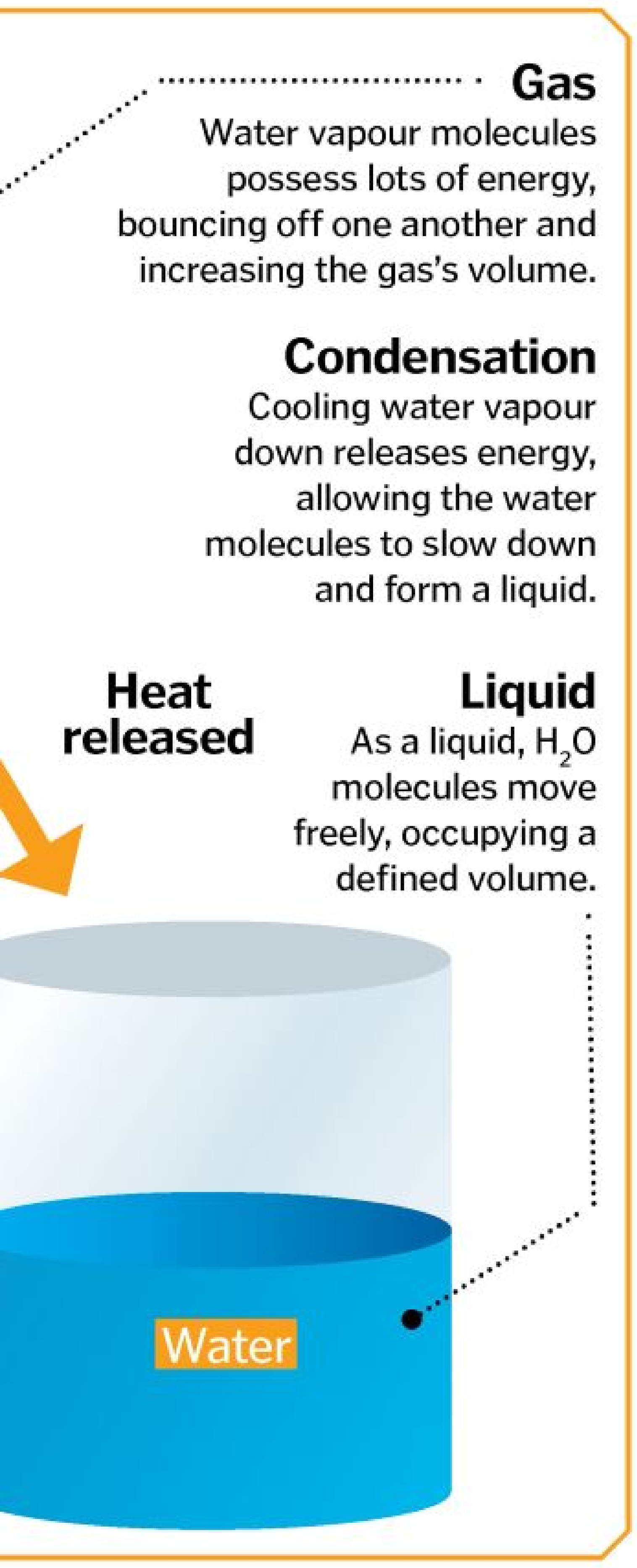
Neutrinos
Neutrinos produced by superfluid in the inner core escape, allowing the star to cool as it loses energy.

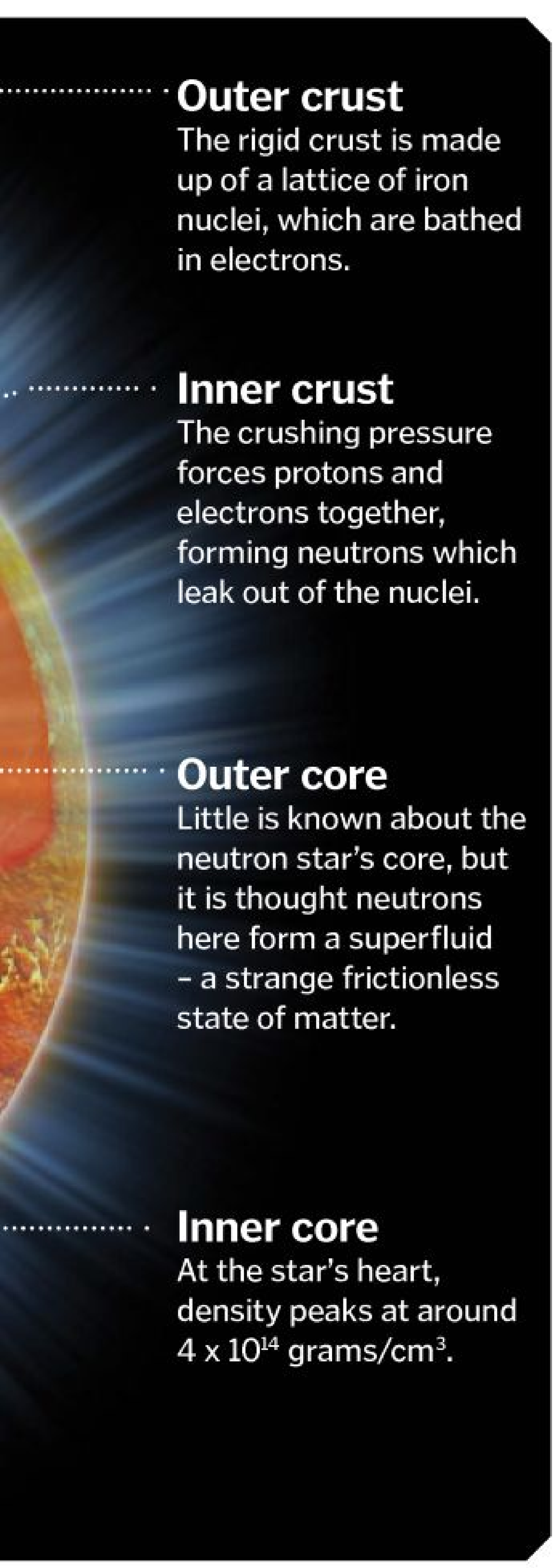
Stegosaurus used its spinal and tail plates for what?

A Self-defence **B** Attracting mates **C** Keeping cool

Answer:
Strangely, despite their sharp, large and impressive appearance, the Stegosaurus's plates were merely used for regulating internal body temperature. The plates contained blood vessels and acted like radiators, releasing excess body heat when needed.

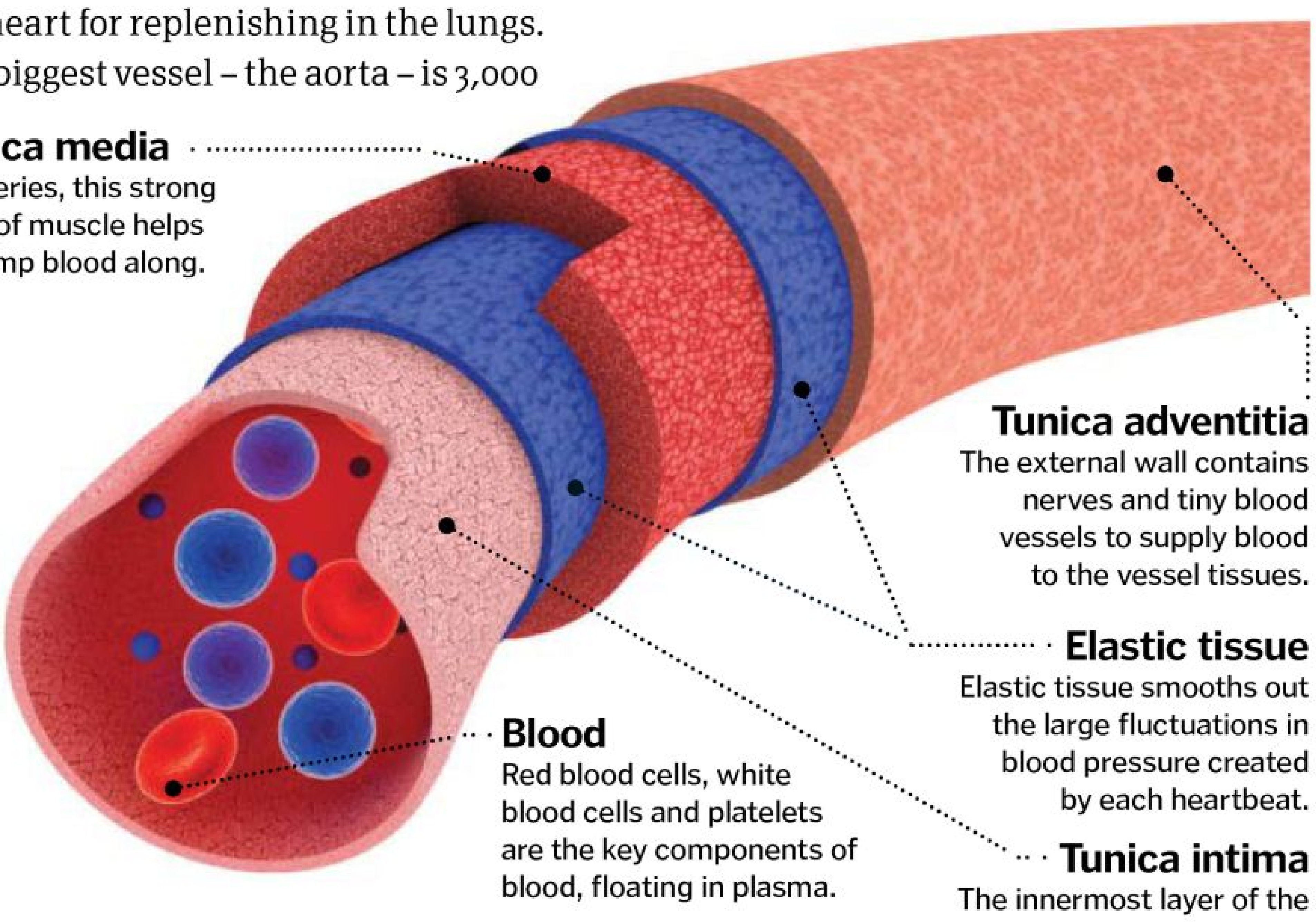
DID YOU KNOW? *Absolute zero is the lowest possible temperature, although it's theoretically impossible to achieve it*





15. Your blood vessels would circle the world two and a half times if laid end to end

Blood vessels are hollow tubes that carry blood around your body, delivering vital oxygen, nutrients and water. Arteries carry oxygen-rich blood away from the heart, minute capillaries deliver it to the tissues, while veins transport the deoxygenated blood and waste back to the heart for replenishing in the lungs. The biggest vessel – the aorta – is 3,000 times wider than the smallest capillaries, where red blood cells (which carry the oxygen) have to line up in single file to squeeze through. These red blood cells are unusual in that they have no nucleus, meaning they can dedicate even more space to transporting oxygen.



16. Chalk is made of trillions of microscopic plankton fossils

Tiny single-celled algae called coccolithophores have lived in Earth's oceans for 200 million years. Unlike any other marine plant, they surround themselves with minuscule plates of calcite (coccoliths). Just under 100 million years ago, conditions were just right for coccolithophores to accumulate in a thick layer coating ocean floors in a white ooze. As further sediment built up on top, the pressure compressed the coccoliths to form rock, creating chalk deposits such as the white cliffs of Dover. Coccolithophores are just one of many prehistoric species that have been immortalised in fossil form, but how do we know how old they are? Over time, rock forms in horizontal layers, leaving older rocks at the bottom and younger rocks near the top. By studying the type of rock in which a fossil is found palaeontologists can roughly guess its age. Carbon dating estimates a fossil's age more precisely, based on the rate of decay of radioactive elements such as carbon-14.

17. In 2.3 billion years it will be too hot for life to exist on Earth

Over the coming hundreds of millions of years, the Sun will continue to get progressively brighter and hotter. In just over 2 billion years, temperatures will be high enough to evaporate our oceans, making life on Earth impossible. Our planet will become a vast desert similar to Mars today. As it expands into a red giant in the following few billion years, scientists predict that the Sun will finally engulf Earth altogether, spelling the definite end for our planet.

18 The 9m-long Stegosaurus had a brain the size of a walnut

This peaceful prehistoric herbivore was certainly big but not very clever. Animal intelligence is often estimated using the encephalisation quotient, or EQ, which compares an animal's brain weight to that of other 'typical' similarly sized creatures. Cold-blooded animals usually have lower EQs than warm-blooded mammals, but Stegosaurus still lags in the dino smarts rankings, with smaller carnivores like Velociraptor occupying the top spots.

19 Blonds have more hair

The average blond has 140,000 hairs on their head, compared to 110,000 for brunettes and 90,000 for redheads. Blond hair tends to be finer than other hair colours.

20 Every day a human produces 300 billion new cells

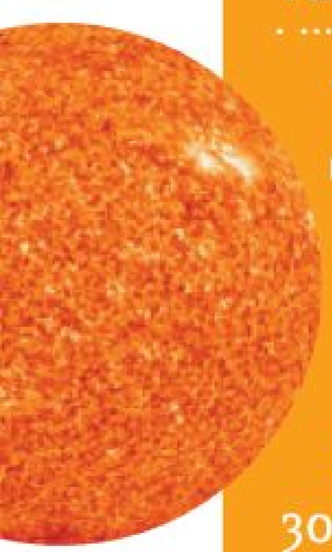
Your body renews itself continually as old cells are discarded and new ones created. On average, cells live for eight years. Some, however, last just a few days, whereas others (like brain cells) are with you for life.

21 An electric eel can produce 650 volts

Electric eels get their spark from specialised cells called electrocytes. These create a negative charge of about -0.1 volts by controlling the flow of ions across cell membranes. When an eel spots its prey, these thousands of tiny batteries join forces to deliver a mind-numbing shock.

22 E=mc²

Einstein's famous equation states that energy (E) and matter (represented by m for mass) are one and the same (c is the speed of light). So matter can be viewed as an extremely concentrated form of energy. This principle is demonstrated in nuclear fission and fusion reactions which transform mass into vast amounts of energy.



23 It takes 8 minutes, 19 seconds for light to travel from the Sun to the Earth

In space, light travels at 300,000 kilometres (186,000 miles) per second. Even at this breakneck speed, covering the 150 million odd kilometres (93 million miles) between us and the Sun takes a considerable time. And eight minutes is still very little compared to the five and a half hours it takes for the Sun's light to reach Pluto.

24 Every living thing has at least one parasite living on/in it

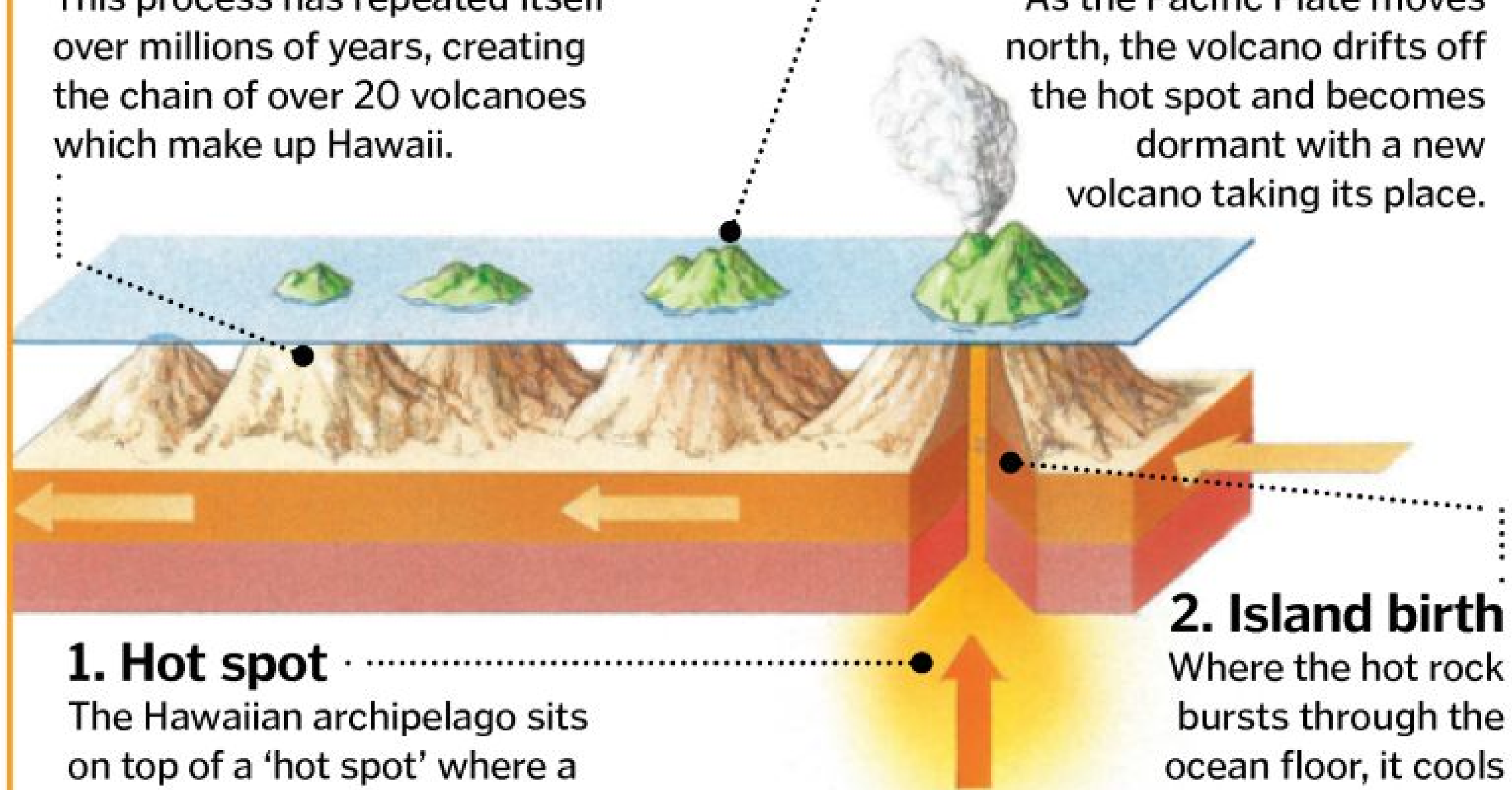
The majority of species on Earth are parasites, including everything from cuckoos to intestinal worms, bacteria and viruses. These organisms have co-evolved with their hosts, developing an arsenal of tricks to take advantage of them. In fact, many consider parasites to be a dominant force that drives evolution.

25 Space is not a complete vacuum

A vacuum is a space utterly devoid of any molecules, particles or any matter. Yet even the deepest recesses of our universe contain a few hydrogen atoms and photons per cubic metre.

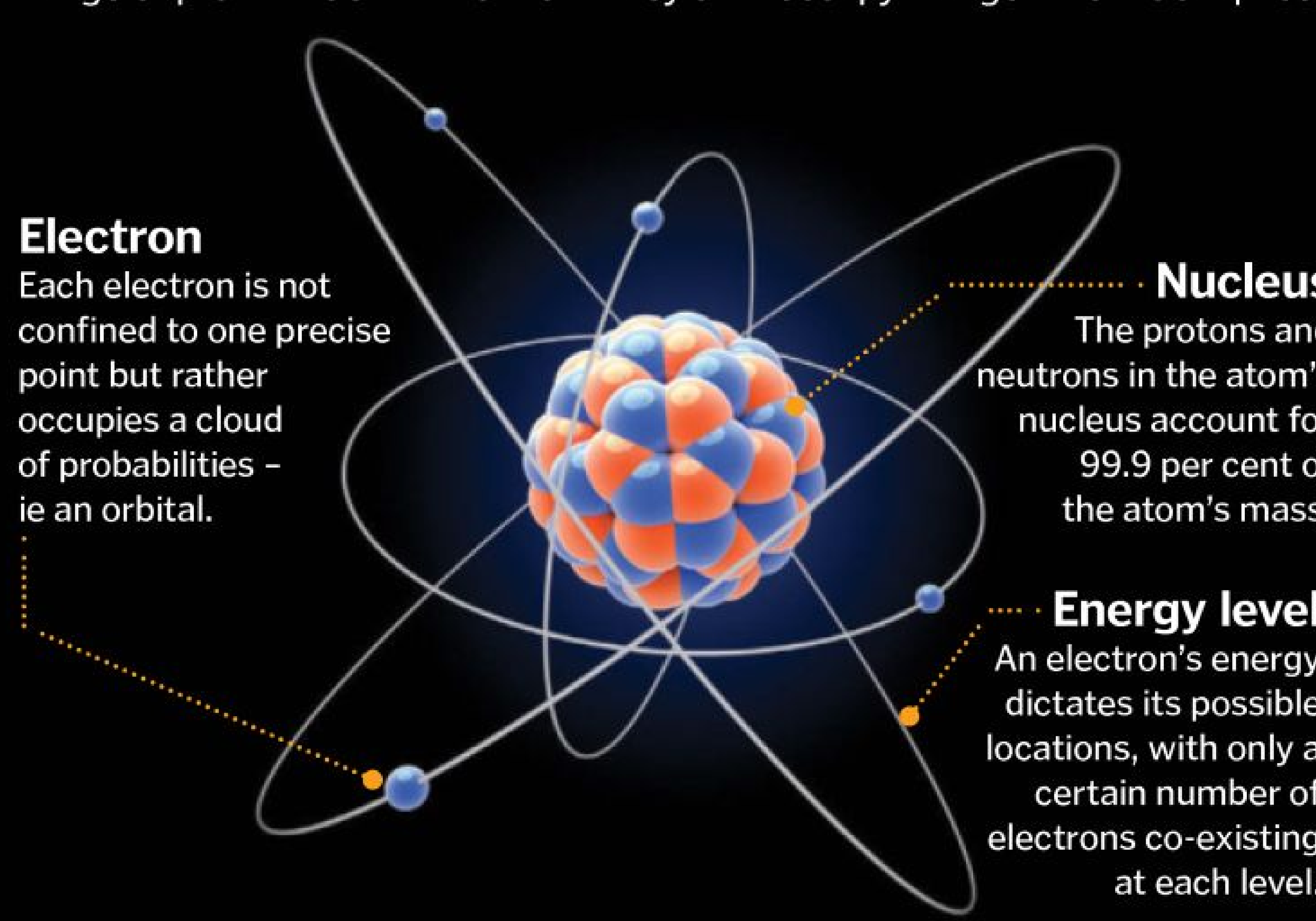
26. Hawaii moves 7.5cm closer to Alaska every year

The Earth's crust is split into gigantic pieces called tectonic plates. These plates are in constant motion, propelled by currents in the Earth's upper mantle. Hot, less-dense rock rises before cooling and sinking, giving rise to circular convection currents which act like giant conveyor belts, slowly shifting the tectonic plates above them. Hawaii sits in the middle of the Pacific Plate, which is slowly drifting north-west towards the North American Plate, back to Alaska. The plates' pace is comparable to the speed at which our fingernails grow.



27. If you took out all the empty space in our atoms, the human race could fit in the volume of a sugar cube

The atoms that make up the world around us seem solid, but are in fact over 99.99999 per cent empty space. An atom consists of a tiny, dense nucleus surrounded by a cloud of electrons, spread over a proportionately vast area. This is because as well as being particles, electrons act like waves. Electrons can only exist where the crests and troughs of these waves add up correctly. And instead of existing in one point, each electron's location is spread over a range of probabilities – an orbital. They thus occupy a huge amount of space.



28. The Sun's fuel won't last for ever

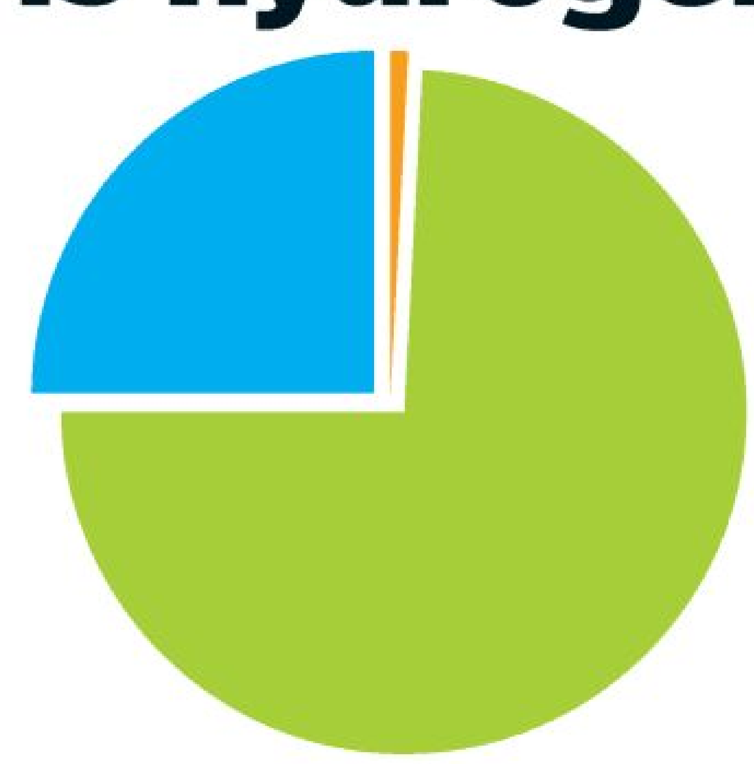
The Sun is fuelled by hydrogen, fusing 620 million tons of hydrogen nuclei into helium each second. This reaction produces solar radiation, which we experience as light and heat, but which also showers us with neutrinos – tiny particles that can pass through matter. In fact, at this very second billions of neutrinos are passing through your body. The Sun is about 4.5 billion years old and, after comparing it to similar stars in our galaxy, astrophysicists reckon it is about halfway through its hydrogen burning stage. That leaves us another 5 billion years before its fuel begins to run low.

Stellar cloud
This dense cloud of gas contracts under gravity, giving birth to a new star.

Protostar
If the star is massive enough, its temperature reaches 10 million Kelvin, allowing the star to fuse hydrogen.

Main-sequence star
Stars similar to our Sun in size continue to burn hydrogen until their supplies run out.

29. Three-quarters of the universe is hydrogen



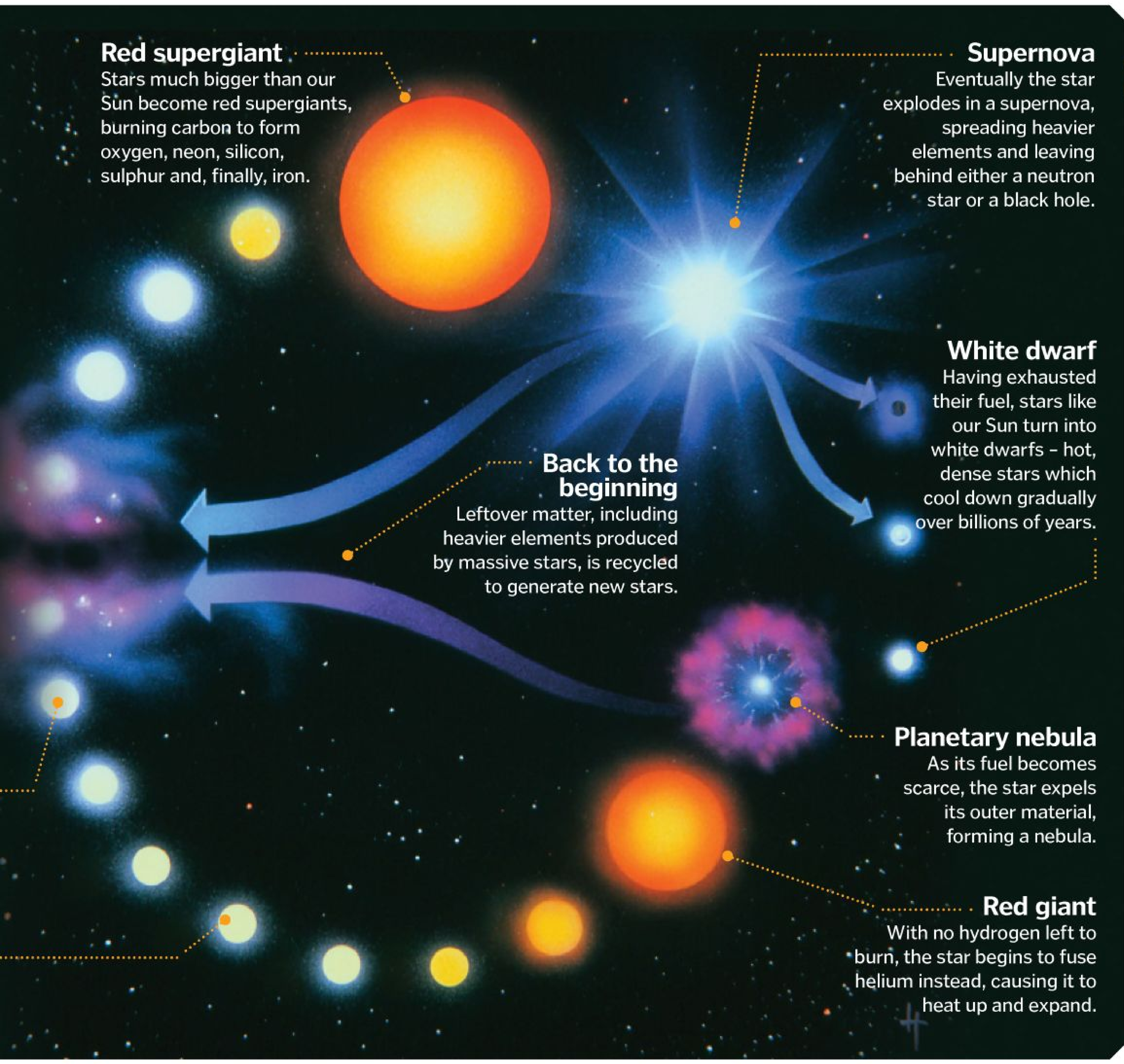
- Hydrogen: 74%
- Helium: 25%
- Heavier elements: 1%

176,792kg

BIGGEST-EVER ANIMAL

A female blue whale is the largest and heaviest animal ever recorded on Earth. It's probably bigger than any land animal that ever walked the planet too, including the dinosaurs.

DID YOU KNOW? *Human DNA sequences are around 50 per cent identical to those of a banana!*

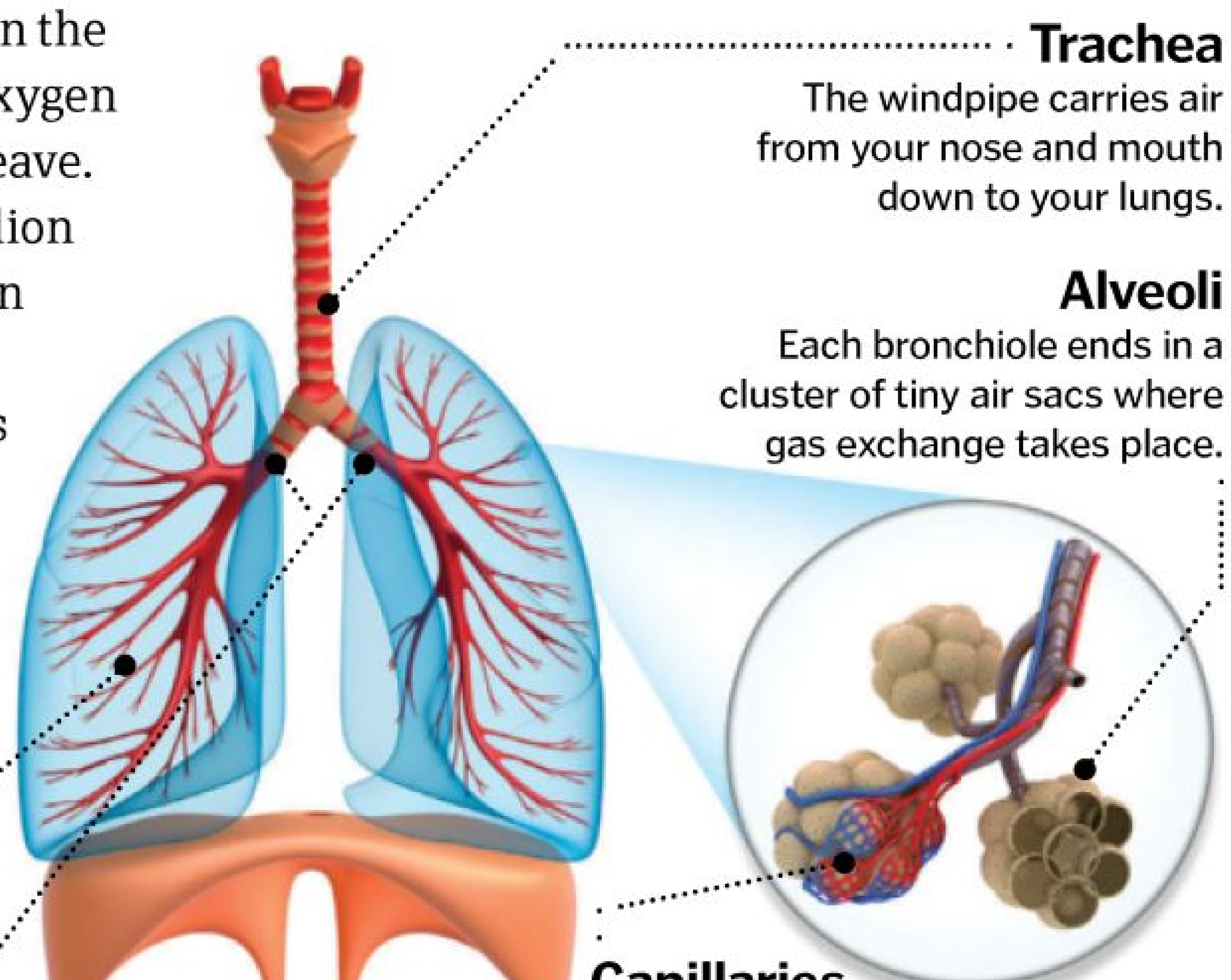


31. Lizards can walk on water

Fringes of skin on the outer edges of the Central/South American basilisk lizard's hind toes increase the feet's surface area, making this impressive trick possible. The lizard slaps its feet down as it runs, creating an upward force and trapping bubbles of air. Its feet also push sideways, helping it to stay upright.

30. The surface area of the lungs is equivalent to a tennis court

The lungs facilitate gas exchange between the air we breathe and our blood, allowing oxygen to enter the body and carbon dioxide to leave. This exchange takes place inside 700 million alveoli, tiny hollow air sacs wrapped in an intricate network of blood vessels. The membrane across which the gases pass is about two micrometres (0.00008 inches) thick, 50 times thinner than a sheet of paper and its total surface area adds up to 70 square metres (750 square feet).



32. The universe expands in all directions hourly

Our universe is growing continually, with the space between objects expanding just like an inflated balloon. This fact wasn't discovered until the 1920s, when Edwin Hubble observed that distant galaxies are rushing away from us. Not only that, but the farther a galaxy is from us, the faster it moves away. This groundbreaking observation also implied that the whole universe must once have been contained in a single point, giving rise to the Big Bang theory. According to this model, the cosmos was born 13.7 billion years ago, with all its energy compressed into one incredibly hot and dense point which has been expanding and cooling ever since.

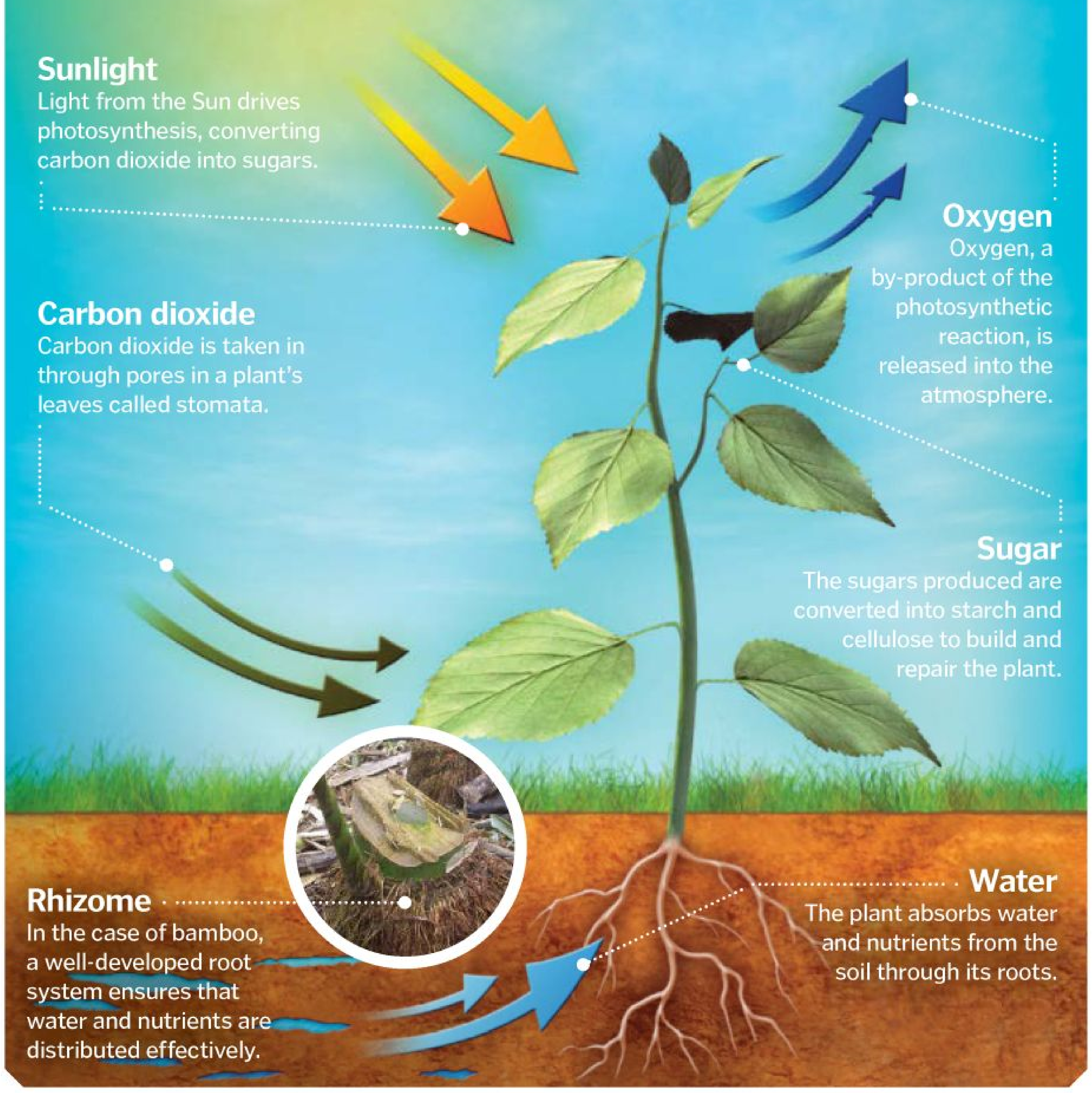
Even more surprisingly, the universe's expansion is accelerating. The reason behind the universe's swelling has been dubbed 'dark energy', but very little is known about this mysterious force which is thought to occupy a staggering 70 per cent of the universe.

33. At light speed it would take 2.5 million years to reach our galactic neighbour

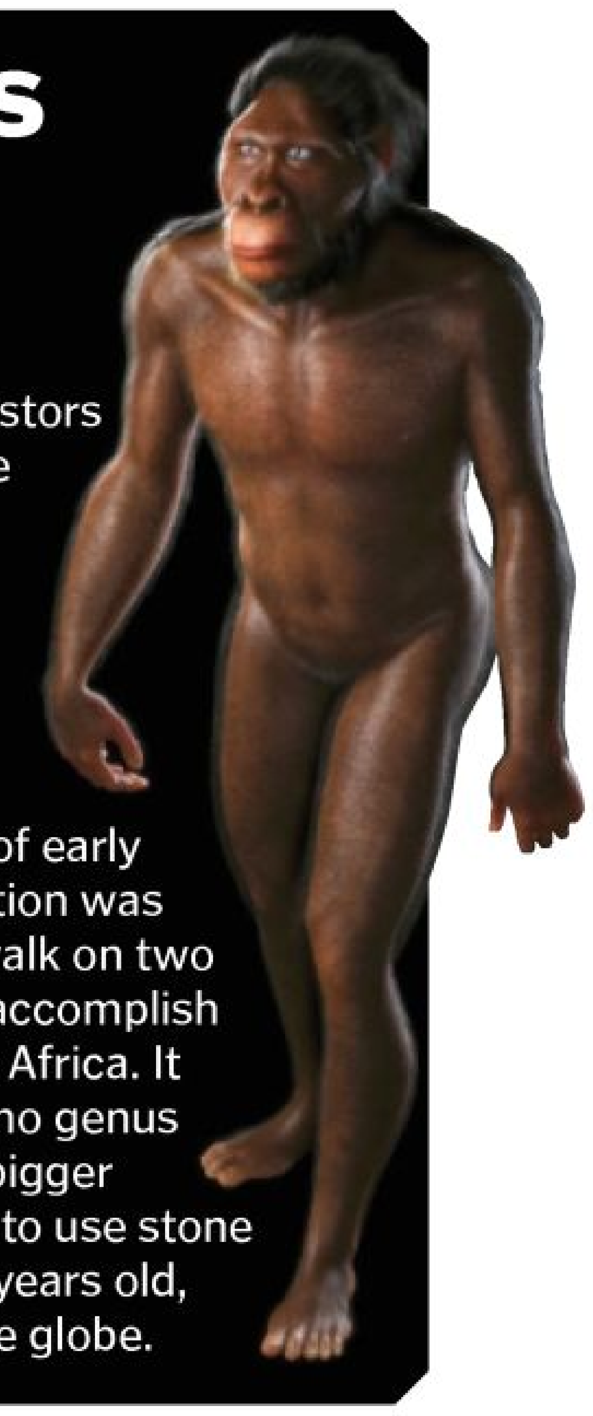
Andromeda is one of our galaxy's closest neighbours, but popping over to borrow some sugar would be quite a trek. By measuring the apparent brightness of its stars, astronomers have estimated that Andromeda is 2.4×10^{19} kilometres (1.5×10^{19} miles) away. To avoid drowning in zeros, scientists prefer to measure such distances in light years. As its name suggests, a light year is the distance travelled by light in one year – in other words, a whopping 9.5 trillion kilometres (about six trillion miles) – making Andromeda 2.5 million light years away.

34. Bamboo is the fastest-growing plant on Earth

While trees grow mostly from the end of their branches, bamboo is actually a grass, so it grows very differently. A bamboo shoot is split into segments which can all host cell division (ie growth), allowing the bamboo to extend a bit like a telescope Equally vital to its record-smashing growth rates (60 centimetres/24 inches per day) is the plant's rhizome, an underground network of roots connecting a cluster of canes. Like all plants, bamboo gets its energy from photosynthesis, but the rhizome enables it to distribute nutrients and water where they are most needed.



35. Early humans date back up to 7 million years



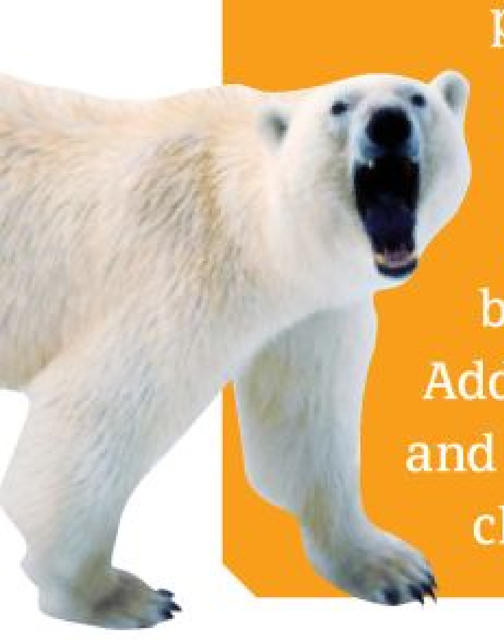
It's difficult to define the point when our ancestors became 'human', but one important milestone occurred when the human lineage diverged from that of our closest living relatives: chimpanzees. The last ancestor we shared with chimps lived about 7 million years ago – a relatively short time ago in the 2 billion odd years since life first appeared on Earth. Since then there have been 15-20 different species of early hominid. Another key chapter in human evolution was the beginnings of bipedalism – the ability to walk on two feet. Australopithecus was the first genus to accomplish this feat around 4 million years ago in eastern Africa. It wasn't until 2.4 million years ago that the Homo genus appeared. Their distinguishing feature was a bigger brain and they were the first of our ancestors to use stone tools. Homo sapiens are only about 200,000 years old, emerging in Africa before migrating across the globe.

36. Gravity is only 3% weaker 100km above the Earth

According to the laws of gravity, any two objects with mass attract each other. For this effect to be noticeable, one of the objects needs to have a considerable mass; at roughly 6×10^{24} kilograms (1.3×10^{25} pounds), our planet fits the bill nicely. Gravity decreases the farther you are from Earth's centre, but given that standing on its surface you are already 6,370 kilometres (3,960 miles) away from the core, a 100-kilometre (62-mile) increase makes a relatively small difference. Air pressure, on the other hand, is caused by the sheer weight of the air molecules above you. Standing at sea level, the air above you causes a pressure equivalent to about 1,000 kilograms (2,205 pounds). Luckily this pressure pushes on us in all directions. Water weighs about 800 times more than air, so exerts a far greater pressure; in fact, at just ten metres (33 feet) underwater, the pressure would be double.

37 Polar bears are nearly undetectable by infrared cameras

Thermal cameras detect the heat lost by a subject as infrared, but polar bears are experts at conserving heat. The bears keep warm due to a thick layer of blubber under the skin. Add to this a dense fur coat and they can endure the chilliest Arctic day.



38 Stomach acid is strong enough to dissolve razor blades

Your stomach digests food thanks to highly corrosive hydrochloric acid with a pH of 2 to 3. This acid also attacks your stomach lining, which protects itself by secreting an alkali bicarbonate solution. The lining still needs to be replaced continually, and it entirely renews itself every four days.

39 Alpha radiation can be deadly but a sheet of paper can stop it

As an unstable radioactive atom decays, it ejects particles and energy, producing alpha, beta and gamma radiation. Alpha particles carry the strongest charge so can cause the most harm. Their large mass, however, stops them penetrating very far into matter, so they're only likely to cause damage if ingested.

40 The Earth is a giant magnet

Earth's inner core is a sphere of solid iron, surrounded by liquid iron. Variations in temperature and density create currents in this iron, which in turn produce electrical currents. Lined up by the Earth's spin, these currents combine to create a magnetic field, used by compass needles worldwide.

AMAZING VIDEO!

SCAN THE QR CODE FOR A QUICK LINK

Watch the mega-tides at the Bay of Fundy

www.howitworksdaily.com

DID YOU KNOW? *The cornea in the eye is the only tissue in the body that doesn't require blood*

41. Nerve impulses can travel as fast as 200mph

Electrical signals are the body's principal means of communication, controlling everything from your heartbeat to pain. The nervous system is a network of millions of neurons – tiny messenger cells which transmit information using electrical signals called nerve impulses. By controlling the flow of ions, each neuron can build up an electrical charge and transmit it down its axon, a long branch which passes the impulse on to the next neuron. The speed of nervous impulses varies but the fastest signals are carried within motor neurons. These relay messages from the brain telling muscles to contract.

42. The difference between tides can be as great as 17m

The extreme tides in eastern Canada's Bay of Fundy are caused by tidal resonance. All over the globe, high tides occur every 12 and a half hours. The Bay of Fundy is peculiar in that it takes 13 hours for seawater to slosh into the mouth of the bay, to its head and then back out to sea, roughly matching the rhythm of the tides. As each tide rises, it therefore amplifies the water's sloshing motion – just like someone giving a child on a swing a small push at just the right moment. These two bulges result in two high tides, which sweep around the globe at intervals of 12 and a half hours.

43. Energy is neither created nor destroyed

Known as the law of conservation of energy, this principle is key to understanding our entire universe. Energy can't be created or destroyed, but it can change form. Think about a moving car, for example. Chemical energy contained in the fuel is converted into mechanical energy by the motor. This propels the car forward, transforming into kinetic energy. Step on the brake and this energy is converted into heat and sound. Energy sometimes seems to disappear, but this usually means it is being stored as potential energy, like a stretched spring. Although energy is never destroyed, it can be 'lost' when converted into unwanted forms, eg a traditional light bulb expends lots of energy as heat rather than light.

44. Venus is the only planet to spin clockwise

Our Solar System started off as a swirling cloud of dust and gas which eventually collapsed into a spinning disc with the Sun at its centre. Because of this common origin, all the planets move around the Sun in the same direction and on roughly the same plane. They also all spin in the same direction (counterclockwise if observed from 'above') – except Uranus and Venus. Uranus spins on its side, while Venus defiantly spins in the complete opposite direction. The most likely cause of these planetary oddballs are gigantic asteroids which knocked them off course in the distant past.

45. Sound moves faster in water than air

Sound is a vibration. It travels as a compression (or longitudinal) wave when particles (molecules or atoms) collide with one another, passing on the vibration. Sound therefore can't cross a vacuum but needs a medium to pass through, and its speed is determined by the properties of that medium. In general, sound travels fastest in a solid, then a liquid and slowest in a gas. Inside a solid, particles are packed tightly together, meaning vibrations are passed on easily. In a liquid particles are more spaced out, making it harder for vibrations to be transmitted from one particle to the next, but they can travel faster than when passing through a gaseous medium like air.

Air

At room temperature, sound travels through air at 344m (1,129ft)/sec. Lower the thermostat and the drop in air density slows it down significantly.

Water

Sound travels at 1,500m (4,921ft)/sec through water, as it's a much denser medium than air.

Steel

The rigid structure of steel allows sound waves to travel at a swift 6,000m (19,685ft)/sec – 17 times faster than through air.

46. The Great Barrier Reef is the biggest living structure

Stretching from the north-east coast of Australia, the Great Barrier Reef is the world's largest coral reef system. The 2,600-kilometre (1,616-mile)-long structure is made of millions of tiny living animals – coral polyps – whose hard calcium carbonate exoskeletons give the reef its structure. Like all coral reefs, the Great Barrier Reef provides an incredible range of marine habitats. As well as 400 species of coral alone, the Great Barrier Reef supports thousands of other animals and plants including over 1,500 fish species.

47 A flea can accelerate faster than the Space Shuttle

A jumping flea reaches dizzying heights of about eight centimetres (three inches) in a millisecond. Acceleration is the change in speed of an object over time, often measured in 'g's, with one g equal to the acceleration caused by gravity on Earth (9.8 metres/32.2 feet per square second). Fleas experience 100 g, while the Space Shuttle peaked at around 5 g. The flea's secret is a stretchy rubber-like protein which allows it to store and release energy like a spring.

48 If you could drive up, you'd arrive in space in about an hour

The Kármán Line at 100 kilometres (62 miles) in altitude is generally accepted as the boundary of space. Driving at a leisurely 90 kilometres (56 miles) per hour, a trip to space would therefore take just 67 minutes.

49 Stretched out, the DNA from one human cell would be 2m

The DNA in each cell contains all the instructions necessary to build a person, coiled up tightly inside chromosomes in the nucleus. There are roughly 3 billion chemical letters (bases) in your DNA.

50 The gas cloud Sagittarius B2 contains a billion, billion, billion litres of alcohol

The alcohol in question is vinyl alcohol as opposed to ethanol. Although scientists don't yet know how it got there, it's thought these molecules could provide clues as to how complex organic compounds form in space.

Fantastic science machines

We explore the super-smart scientific instruments that are helping researchers make big breakthroughs day in, day out

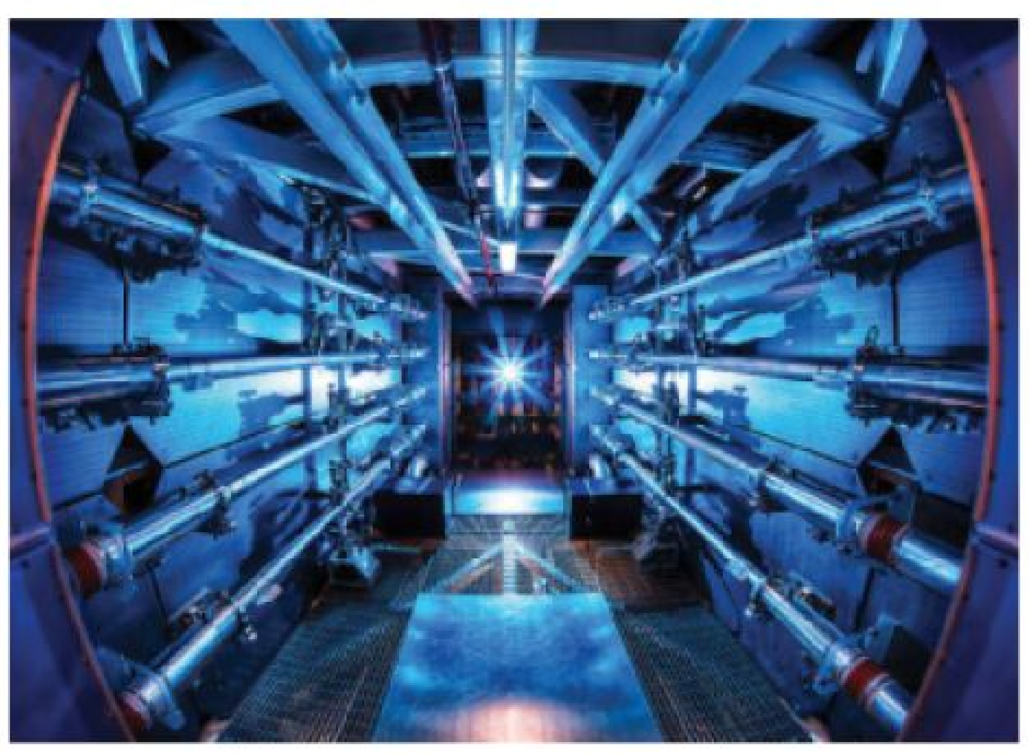
DID YOU KNOW? *The James Webb Space Telescope is sensitive enough to spot a penny about 40km (25mi) away!*

The world's biggest laser

At California's National Ignition Facility (NIF), 192 lasers are poised and ready to unleash four million joules of energy on their target: a pea-sized pellet of frozen hydrogen. Making up the world's highest energy laser system, their goal is to create the intense pressures needed to initiate nuclear fusion – the reaction that powers the Sun. On Earth, fusion could one day provide an almost limitless source of carbon-free energy.

To spark a fusion reaction, hydrogen isotopes deuterium and tritium must be forced together. This means mimicking the temperatures and pressures at the Sun's core. NIF's ultraviolet laser beams travel through a system of amplifiers 1,500 metres (4,920 feet) long, ramping up their energy by a factor of a quadrillion. The beams are focused on the tiny gold casing surrounding the fuel pellet. The hot metal releases a pulse of X-rays, which in turn compress the fuel, sending its temperature soaring to 100 million degrees Celsius (180 million degrees Fahrenheit) while the pressure skyrockets to 100 billion times that of Earth's atmosphere. As the deuterium and tritium are forced together they fuse, releasing the energy locked away in their atomic nuclei.

Currently, powering NIF's lasers takes up far more energy than the fusion reaction they produce releases. NIF's goal is to break even – a milestone known as ignition – which will pave the way for the first commercial reactors.



Hubble's successor

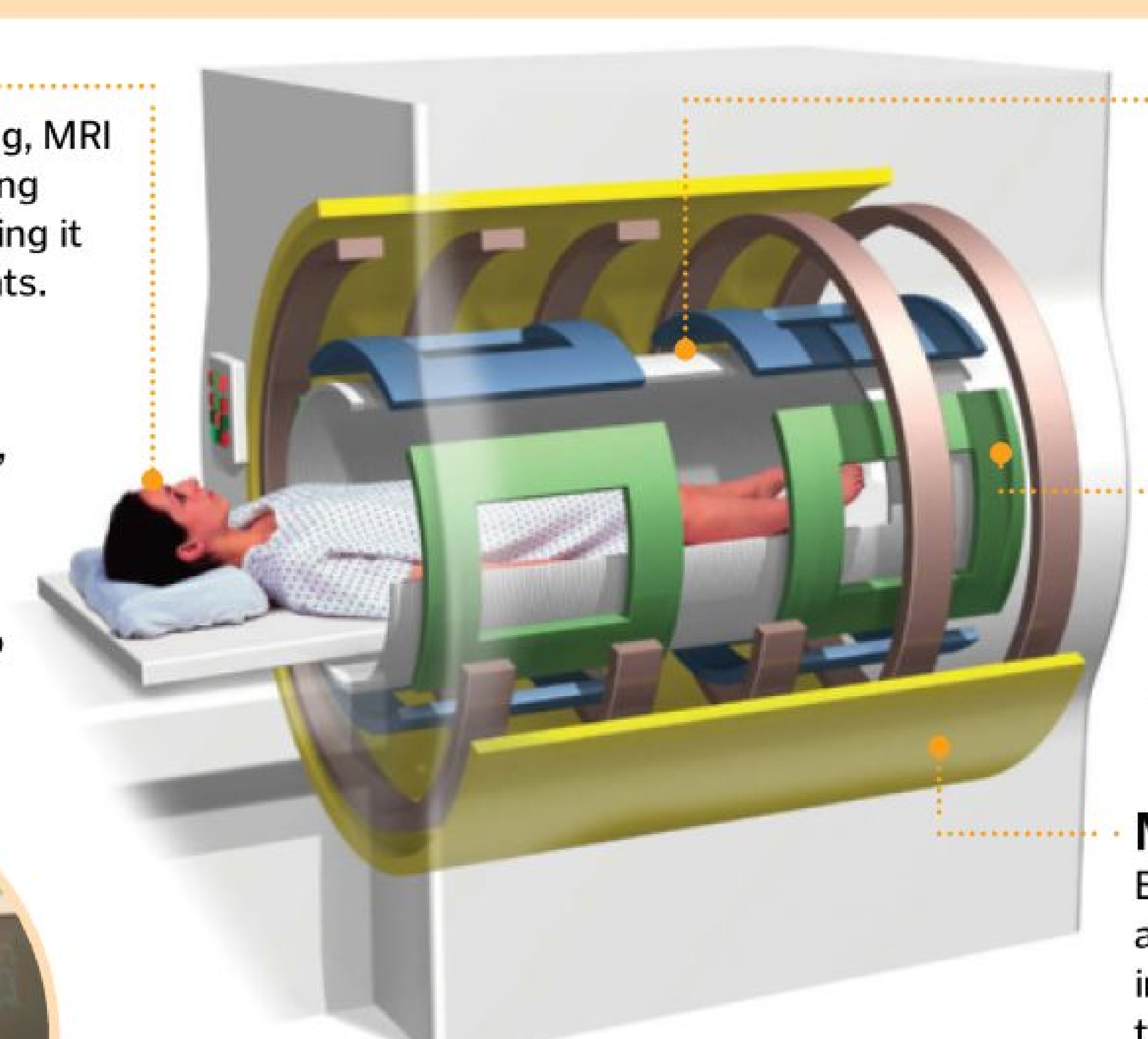
Due to launch in 2018, the James Webb Space Telescope (JWST) will pick up where Hubble left off in its investigation of our universe's origins. Its 6.5-metre (21-foot) mirror will collect the faint infrared light emitted by stars and galaxies, imaging and measuring its spectrum with four specialised instruments. As the earliest galaxies move away from us, the light they emit is shifted towards the red end of the spectrum. JWST's infrared-sensitive instruments will grant astronomers a glimpse back in time, allowing them to study the evolution of stars, planetary systems and entire galaxies.

A number-crunching computing colossus

Filling a basketball court-sized room at the US Oak Ridge National Laboratory, Tennessee, the Titan supercomputer is taking scientific research to the next level. Titan can perform 17.59 thousand trillion calculations per second, enabling scientists to simulate complex processes in incredible detail, from our planet's atmosphere to nuclear reactions. Titan owes its awesome computing power to a combination of traditional central processing units (CPUs) and graphics processing units (GPUs). Originally developed for videogaming, GPUs are capable of running hundreds of calculations in parallel, dramatically increasing processing power while limiting energy consumption. Although Titan recently lost its title of world's fastest supercomputer to China's Tianhe-2, many argue Titan's higher degree of specialisation makes it a more useful tool for scientists. Earlier this year, the supercomputer got to work on six flagship research projects, whose aims include increasing the efficiency of biofuels and working out how we can best mitigate climate change.

Patient
Unlike X-ray imaging, MRI gives off non-ionising radiation only, making it harmless for patients.

Computer
In a different room, a computer pieces together the data recorded by the scanner to build up 2D or 3D images.



Transceiver (not shown)
A transceiver sends and receives radio signals, identifying the different types of tissue that they encounter.

Gradient coils
These coils alter the main magnetic field across different axes to select a precise area to image.

Main magnetic coil
Electricity running through a wire coil produces an intense magnetic field at the heart of the scanner.

Revealing our bodies' secrets

With roughly 20,000 scanners worldwide, magnetic resonance imaging (MRI) has revolutionised medicine. Under the MRI's intense magnetic field, hydrogen atoms inside the patient act like tiny magnets, lining up to match the field. By measuring how these nuclei respond to radio waves, the scanner can determine what type of tissue they belong to and map the patient's body. This enables doctors to diagnose anything from brain tumours to torn ligaments. MRI scans of the future will take things to the next level. Using more powerful magnetic fields, the latest scanners produce much higher-resolution images. Other research focuses on developing contrast agents – substances which allow particular structures to appear more clearly. By increasing the speed at which a scanner takes snapshots, we can produce 3D 'movies' to record real-time brain activity or drug metabolism.

> "After three years' worth of particle collisions, CERN finally confirmed the existence of the Higgs boson"

CERN's Compact Muon Solenoid (CMS) also helped search for the Higgs boson and dark matter

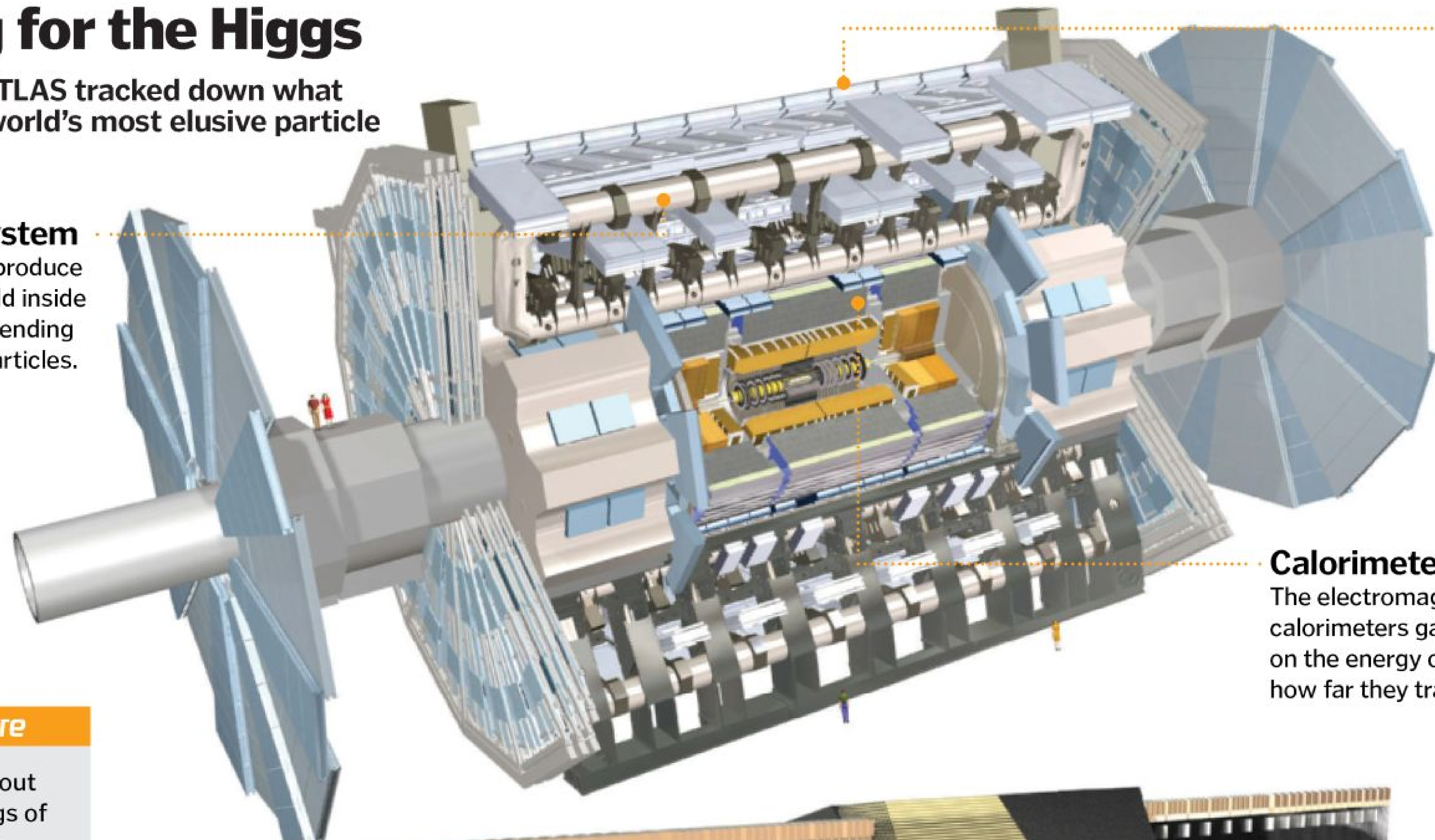
Rebooting the LHC

CERN's Large Hadron Collider (LHC) is the largest research instrument ever built and one of the most sophisticated pieces of machinery in the history of science. Accelerating protons and ions to almost the speed of light around a 27-kilometre (16.8-mile) ring, it smashes these particles together to probe the structure of our universe. As well as the accelerator itself, each of the LHC's four main particle detectors is a feat of engineering. The largest – ATLAS (detailed below) – weighs 7,000 tons, packing in six specialised subdetectors fine-tuned to track the showers of minuscule particles produced by proton collisions at its heart. The huge amount of data generated by LHC's detectors is then processed by the Grid – a global network of over 200,000 computers.

After three years' worth of particle collisions, CERN's physicists finally confirmed the existence of the famous Higgs boson, and the LHC shut down in early-2013 for a well-earned break. But it's not over yet; engineers are giving the atom smasher an upgrade, allowing it to almost double the energy of its collisions when it starts up again in 2015. Higher-energy collisions will boost the LHC's chances of pinning down some of the rarest particles in existence. For example, physicists hope to spot dark matter, the inscrutable substance they believe makes up a quarter of our universe's mass. The rebooted LHC will also go on the prowl for supersymmetric particles, whose existence would validate supersymmetry, the leading theory for what happens beyond the realms of our current understanding of physics. According to this model, each particle we know is paired up with an as-yet-undiscovered 'superpartner'. None of these mysterious particles showed their faces during the LHC's first run, but the physics community will be hot on their heels when the search resumes in 2015.

Hunting for the Higgs

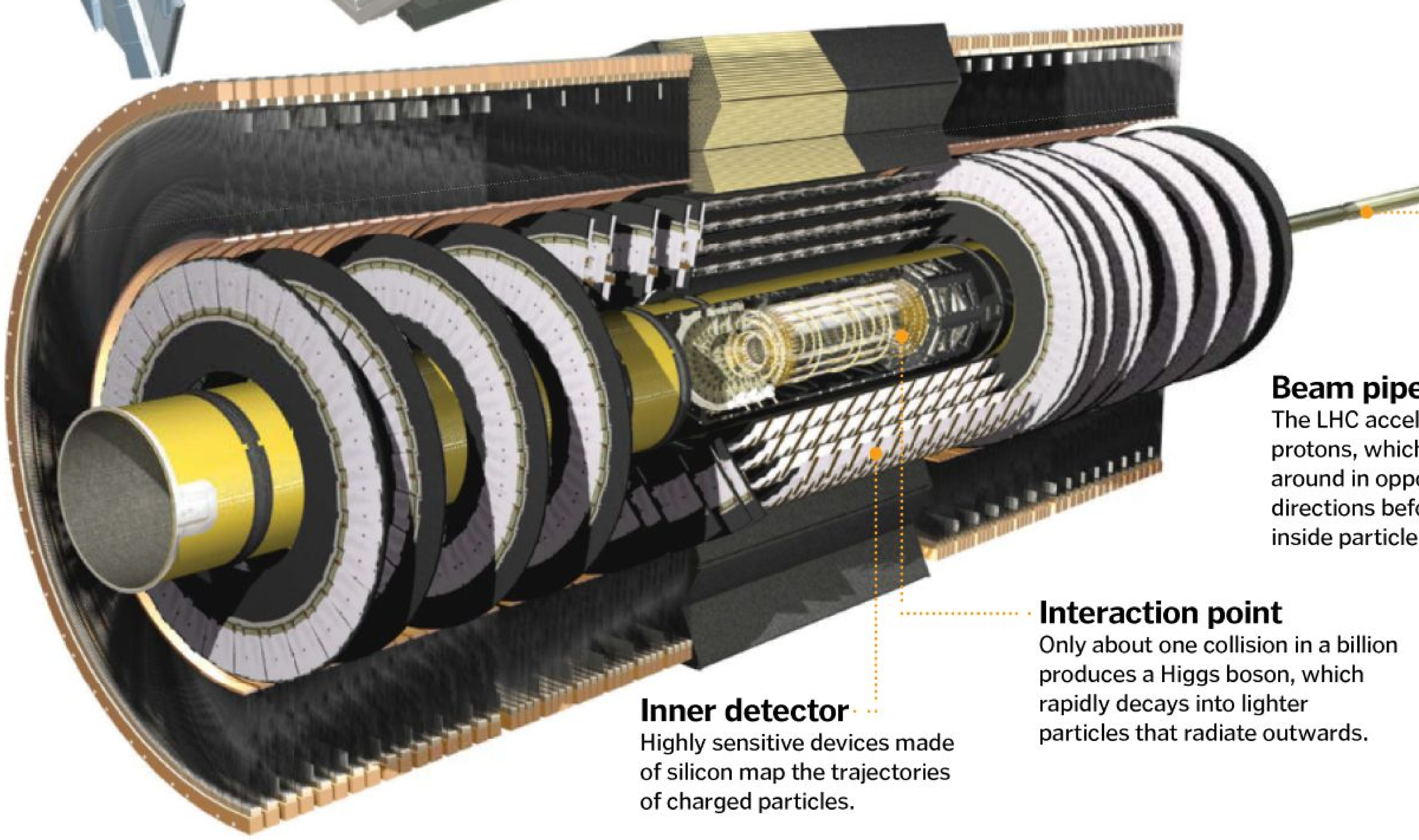
Find out how ATLAS tracked down what was once the world's most elusive particle



Muon spectrometer
Only muons travel to the outer reaches of ATLAS, where the spectrometer tracks their paths.

Magnet system
Gigantic coils produce a magnetic field inside the detector, bending the paths of particles.

Calorimeters
The electromagnetic and hadronic calorimeters gather further data on the energy of particles and how far they travel.



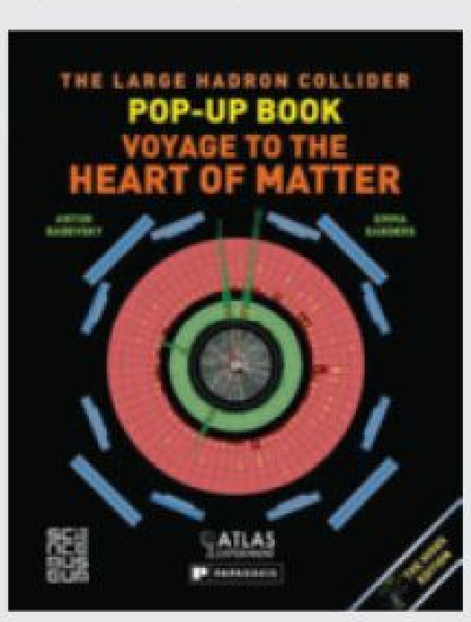
Beam pipe
The LHC accelerates protons, which speed around in opposite directions before colliding inside particle detectors.

Interaction point
Only about one collision in a billion produces a Higgs boson, which rapidly decays into lighter particles that radiate outwards.

Inner detector
Highly sensitive devices made of silicon map the trajectories of charged particles.

Learn more

Find out more about the inner workings of the LHC with this amazing pop-up book released to tie in with a special exhibition at the Science Museum. **How It Works** readers can get 25 per cent off the £24.99 RRP by ordering a copy on 01273 488005 and quoting the code: R4335. This offer ends on 30 April 2014 – don't miss out!



5 TOP FACTS
ROOM FOR ERROR

Pricey short circuit
1 Just days after starting up in 2008, a short circuit at the Large Hadron Collider caused damage estimated at £30 million ($50 million). It was closed for over a year.

Hubble's fuzzy pictures
2 When Hubble first launched, a flawed mirror meant it could not focus properly. Thankfully, a corrective system was added and our view of the cosmos was revolutionised.

Abandoned accelerator
3 In 1991, construction began on the Superconducting Super Collider – which would dwarf the LHC. However, two years later the project was aborted due to lack of funding.

Speeding neutrinos
4 In 2011, physicists using the OPERA detector in Italy were led to believe that neutrinos were travelling faster than light. But it was later confirmed as a faulty connection.

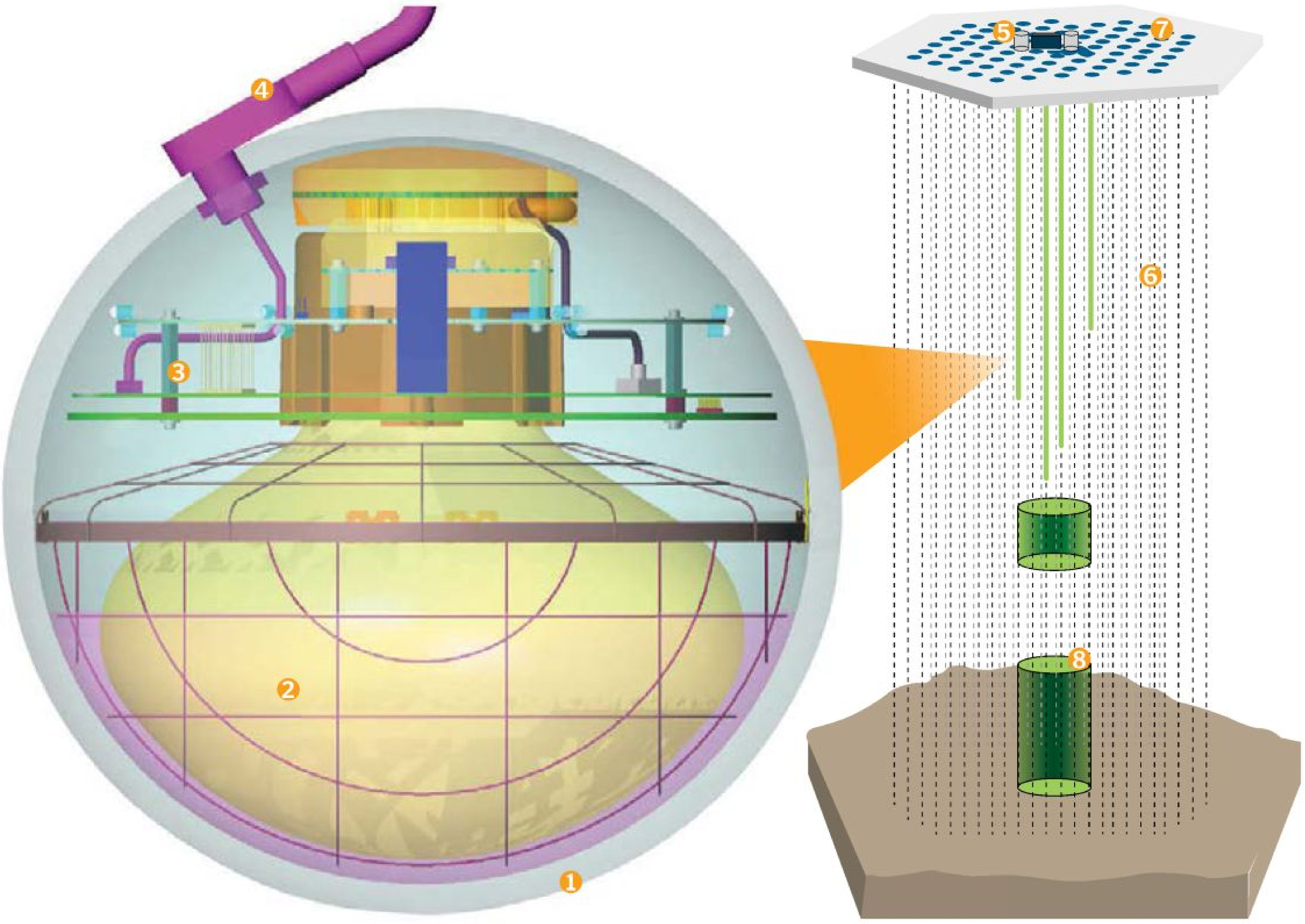
Challenger disaster
5 One of the most tragic scientific failures took place in 1986, when space shuttle Challenger broke apart minutes after launch, killing its seven crew members.

DID YOU KNOW? *The D-Wave quantum computer is up to 3,600 times faster than commercial computers*

IceCube: a new era of astronomy

In an underground lair worthy of a Bond villain, the IceCube neutrino detector sits beneath 1,500 metres (4,920 feet) of Antarctic ice. At this depth, the crushing pressure has squeezed any air bubbles out of the ice and no light shines through. This makes it the ideal hunting ground for high-energy neutrinos – cosmic messengers produced in violent cosmic events. With no charge and almost no mass, these ghostly particles travel through space unhindered, carrying information about the cosmos. To intercept neutrinos, scientists buried thousands of detectors, keeping watch over a cubic kilometre (0.24 cubic miles) of ice. When a neutrino passes through and interacts weakly with the ice, it produces other particles which can be spotted by IceCube's photomultiplier tubes. After two years of searching, IceCube recently spotted 28 high-energy neutrinos. This discovery confirms scientists' hopes that neutrinos can be studied on Earth. By tracing their origins, they hope to learn about gamma-ray bursts, black holes and other events millions or even billions of light years away.


The IceCube neutrino detector is located at the South Pole in Antarctica



1 Glass pressure sphere
Each of IceCube's 5,160 detectors - digital optical modules (DOMs) - is protected from the surrounding pressure by a transparent, basketball-sized sphere.

2 Photomultiplier tube
When a neutrino interacts with ice, it makes charged particles that emit faint light, detected by the PMT.

3 Mainboard electronics
Signals from the PMT are converted to digital data that can be recorded and analysed at the surface.

4 Cable penetrator
The sensor is connected to the outside world by this cable, via which it receives power and transmits data.

5 IceCube lab
Data from the detector's optical modules is combined in the surface lab and sent by satellite to be processed.

6 Strings
The optical modules sit 1,450-2,450m (4,757-8,038ft) under the surface, spaced out along 86 vertical strings.

7 IceTop
An array of detectors on the surface records showers of particles generated by cosmic rays.

8 DeepCore
More densely spaced, specialised optical modules make up DeepCore, a subdetector which is designed to pick up lower-energy neutrinos.

Quantum computer makes waves

In May 2013, NASA and Google splashed out on a D-wave 2 (pictured below), the first commercially available quantum computer. We spoke to Dr Rupak Biswas, deputy director of the Exploration Technology Directorate at the Ames Research Center, to find out its potential.

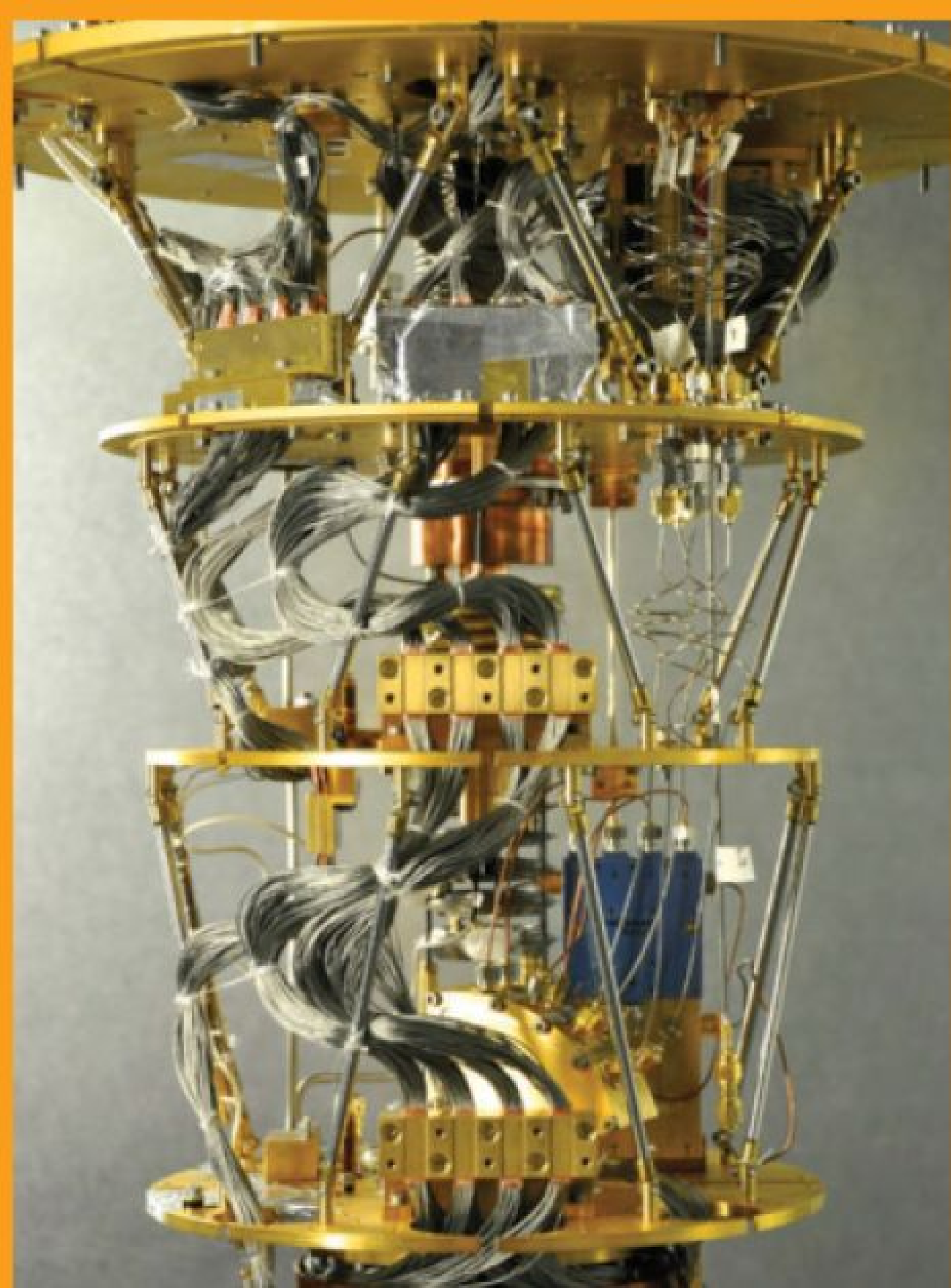
What kind of problems is NASA investigating with the D-wave computer?
NASA has a bunch of difficult optimisation or search problems. Say you want to plan a certain navigation route for the Mars rover; there are many ways of charting that route, but you want to minimise the resources you use. This is a hard optimisation problem because there are many ways of doing it and many variables at play.

How can a quantum computer solve this problem more effectively?
On a classical computer, you make assumptions and reduce the problem's complexity so you can get a solution in a reasonable amount of time, but there's no guarantee it's the optimal solution. With quantum computing you can look at all possible solutions simultaneously.

How does the basic functioning of a quantum computer differ from a conventional one?
In a classical computer you have millions of bits, each of which is a 0 or a 1. In a quantum computer you have qubits, which are 0, 1 and all numbers between 0 and 1 at once.

How does the D-wave solve a problem?
The trick to solving a problem on a quantum computer is solving the same problem many times. Each time you get a different answer with a probability, and the one with the highest probability is the best answer.

What is next for quantum computing?
The D-wave machine is just one way of making a quantum computer – a whole community will grow around quantum computing, which will take time. But now we're beyond the conceptual stage, scientists can play around with quantum computers and think about how these machines could be used [most] efficiently in the future.



© NASA

Stephen Hawking

Pioneering theories across both physics and astronomy, Hawking is one of the most acclaimed astrophysicists of all time

On 8 January 1942 Stephen William Hawking was born in Oxford, England, but moved to London with his family after World War II. His mother was one of the first women to study at Oxford University in the Thirties, while his father was an important medical researcher. Like many other respected physicists – notably Albert Einstein – Hawking did not particularly excel when he was at school. Despite being clearly bright he was frequently one of the underachievers in his class, preferring instead to focus his pursuits outside the classroom on his own personal projects.

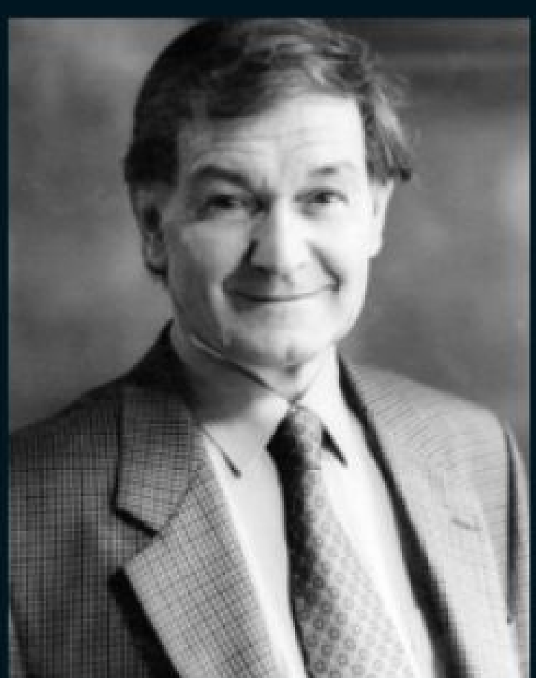
Throughout his life Hawking's research has been dominated by cosmology, specifically the universe and black holes, although his arrival at this subject was not direct. He had originally wished to study mathematics but instead enrolled in Physics at Oxford University as a mathematics course was not available, and later undertook a PhD in Cosmology at Cambridge University, despite (by his own account) spending little more than an hour a day on his studies. In his early-twenties Hawking was diagnosed with amyotrophic lateral sclerosis (ALS), the disease that would confine him to a wheelchair and severely restrict his movement in later life, to the point that today he can move only his eyes and one cheek. However, his condition has failed to quell his research, and his importance within the scientific community is still readily apparent.

After finishing his PhD at Cambridge Hawking began working on a theory with friend and colleague Roger Penrose to investigate the supposed appearance of singularities in space-time based on Albert Einstein's theory of general relativity. This led to Hawking's assertion that immediately after the Big Bang the universe was full of tiny black holes. In 1974 he proposed that black holes eject information and material as a form of radiation, known today as Bekenstein-Hawking Radiation, Jacob Bekenstein being an Israeli theoretical physicist with whom Hawking collaborated on the theory. Soon after he began conducting

IN THEIR FOOTSTEPS
Those inspired by their work


© Paul Clarke

Dr Brian Cox
The popular English television presenter and astrophysicist has made a name for himself with his articulate, fun and informative programmes about space. He cites many of Hawking's teachings and theories in his work and the two have collaborated on numerous occasions.



Sir Roger Penrose
English mathematical physicist Roger Penrose worked extensively with Hawking in the Eighties and Nineties, specifically on space-time, which led to their co-publication of *The Nature Of Space And Time* in 1996. His more recent work in the realms of general relativity and cosmology employs several of Hawking's theories.

A life's work

1942
Born on 8 January in Oxford, England, exactly 300 years after the death of esteemed astrophysicist Galileo Galilei.

1959
Hawking goes to University College, Oxford, where his father studied. As mathematics is not taught at the College, he studies physics, despite his father's wish for him to do medicine.


© MMP Cambridge

1962
Achieves a first-class honours degree in Natural Science.

1963
Heads to Cambridge to study for a PhD in Cosmology. The same year, he is diagnosed with amyotrophic lateral sclerosis.

1965
Marries Jane Wilde, with whom he has three children.

1970
Proves for the first time that black holes are able to emit radiation.

Professor Hawking experienced a zero-gravity flight aboard a Boeing 727 in 2007

> "The zero-g part was wonderful and the higher-g part was no problem… Space, here I come!"

lectures at Caltech, in Pasadena, California, and Gonville and Caius College in Cambridge, England.

By this point Hawking had had three children with his now ex-wife, Jane Wilde, whom he married in 1965. Robert Hawking was born in 1968, followed by Lucy (1969) and Timothy (1979). In 1985 Hawking was diagnosed with pneumonia and, following a tracheotomy operation, he completely lost his speech, and soon after he lost the ability to care for himself, requiring 24-hour nursing. A Californian computer programmer, David Mason, heard of Hawking's plight and presented him with a speaking program that could be controlled by head or eye movements alone, enabling Hawking to select words on a screen to piece together sentences, paragraphs or even entire lectures. Indeed, Hawking continues to write books, publish papers and give lectures. His book *A Brief History Of Time*, (1988) shot to the top of bestsellers' lists worldwide and stayed there for many years, with 25 million copies sold around the globe to date. Hawking released more accessible books in 2001 and 2005: *The Universe In A Nutshell* And *A Briefer History Of Time*, respectively. With his daughter Lucy he has written children's books too, *George And The Big Bang* being the latest.

Hawking has been the recipient of countless accolades throughout his life. His 14 honours include the Albert Einstein Medal (1979), the Order of the British Empire (1982) and the Presidential Medal of Freedom (2009). He has declined knighthood from the Queen of England as he dislikes the concept. Today Hawking holds the position of director of research at the Centre for Theoretical Cosmology at Cambridge University.

Much of Hawking's research has revolved around the basic laws that govern the universe. His has postulated that the universe began as a 'big bang' and will end with black holes, and his co-discovery of Bekenstein-Hawking Radiation emitted by black holes is a consequence of his theory that cosmology and quantum theory are inherently linked. His more recent research suggests that there is no edge of the universe and that the birth of the universe was determined entirely by the laws of science, outlined in his title *The Grand Design* (2010). He has presented a number of popular television shows, including *Into The Universe* (2010) in which he posits that, if aliens do exist, humanity should avoid contact with them at all costs lest they decide to conquer our planet. He has also proposed a number of theories regarding time travel and wormholes, and believes it is possible that a theoretical spacecraft flying in orbit around a black hole would be able to travel forward in time.

Hawking's fascination with space has seen him retain a desire to visit the cosmos himself. In 2007, at 65 years of age, Hawking rode aboard a zero-gravity Boeing 727, which enabled passengers to experience weightlessness by freefalling from the sky, and he later reiterated his ambition to explore space himself.

"The zero-g part was wonderful and the higher-g part was no problem," Hawking said after the experience. "I could have gone on and on. Space, here I come!" His next foray into the cosmos will be aboard Sir Richard Branson's Virgin Galactic vehicle in 2013.

Hawking speaks via a voice program controlled by his right cheek

© NASA

Black holes have played a pivotal role throughout Hawking's research career

© NASA

THE BIG IDEA
Black holes

Throughout Hawking's career, black holes have been a key area of his research. In 1976 he proposed that all information within a black hole disappears but, almost 30 years later, he recanted his previous theory and instead suggested that black holes may allow information to escape in jets.

FIVE THINGS TO KNOW ABOUT… Stephen Hawking

Eccentricity
Hawking's family were often described as eccentric, with dinner frequently seeing the family eating in silence while reading books. The family car was a London taxi and his parents also made fireworks in their greenhouse.

Active
Before he developed the disease that would paralyse him Hawking was very active. He had a passion for dancing and was a member of Oxford University's rowing team.

Celebrity
He has played himself in a variety of TV shows including *The Simpsons*, *Star Trek: The Next Generation* and others.

Unproven theories
He is adamant time travel is possible, believes there is a single unifying theory for cosmology and quantum mechanics, and hopes we'll one day colonise other planets.

The Grand Design
His latest academic book, *The Grand Design*, outlines his belief that God could be compatible with modern science but that the Big Bang must have been the consequence of the laws of physics.

1974
Named a fellow of the Royal Society and earns the Albert Einstein Award. Later honoured with the Pius XI Gold Medal for Science by Pope Paul VI.

1975
Publishes his first book, *The Large Scale Structure Of Space-Time.*

1979
Becomes the Lucasian Professor of Mathematics at Cambridge, a position dating back to 1663 that has only been held by 14 other people including Sir Isaac Newton (above), through to 2009.

1982
Receives a CBE from the Queen of England.

1988
A Brief History Of Time: From The Big Bang To Black Holes is published, one of Hawking's most famous and bestselling books.

1993
Publishes a popular collection of essays entitled *Black Holes And Baby Universes.*

2001
Publishes *The Universe In A Nutshell*, a more accessible account of the universe as a whole than his previous books.

2009
Awarded the Presidential Medal of Freedom, the highest civilian honour in the United States.

Science of forensics

What goes on behind the police tape in the real-life CSI?

The area of forensic investigation has captured the public's imagination ever since global smash TV show *CSI: Crime Scene Investigation* first exploded onto our screens in 2000, but incredibly it's a field of criminal investigation that can trace its origins all the way back to the seventh century.

History has it that a market stall owner used the fingerprints of a man who owed him money to prove his identity and, from these inauspicious beginnings, a whole new area of criminology was created.

Today, the first people (after police) at the scene of a crime will be the CSI team, keen to preserve the integrity of the environment to boost the chances of capturing the perpetrator without any evidence being disturbed, although the word 'team' can be something of a misnomer.

Depending on the size of the local force, the CSI team can often consist of a single field officer, trained in multiple areas, who will work methodically around the room, first taking photos, and then collecting clues such as fingerprints, clothing, hair and broken glass which could lead to the culprit. However, for large-scale incidents like murders, up to four people will be involved, including a specialist photographer and a crime scene manager.

Alexandra Otto was a crime scene investigator for 11 years before moving to Bournemouth University, Dorset, UK, to become a demonstrator of forensic science in 2006. In an interview with How It Works she explains the process stage by ▶

At the crime scene…

How does a forensics team approach the scene of a murder?

Forensic toolkit

The must-have gear no CSI should be caught without

Mask and gloves
These essential pieces of protective wear ensure that no investigators contaminate a crime scene with their own DNA.

Evidence bags
All pieces of evidence will be carefully placed in these sterilised plastic bags for later analysis in a laboratory.

Digital camera
A CSI will take hundreds of photographs of the scene as well as the surrounding area to serve as evidence in court.

5 TOP FACTS
FORENSICS MYTHS

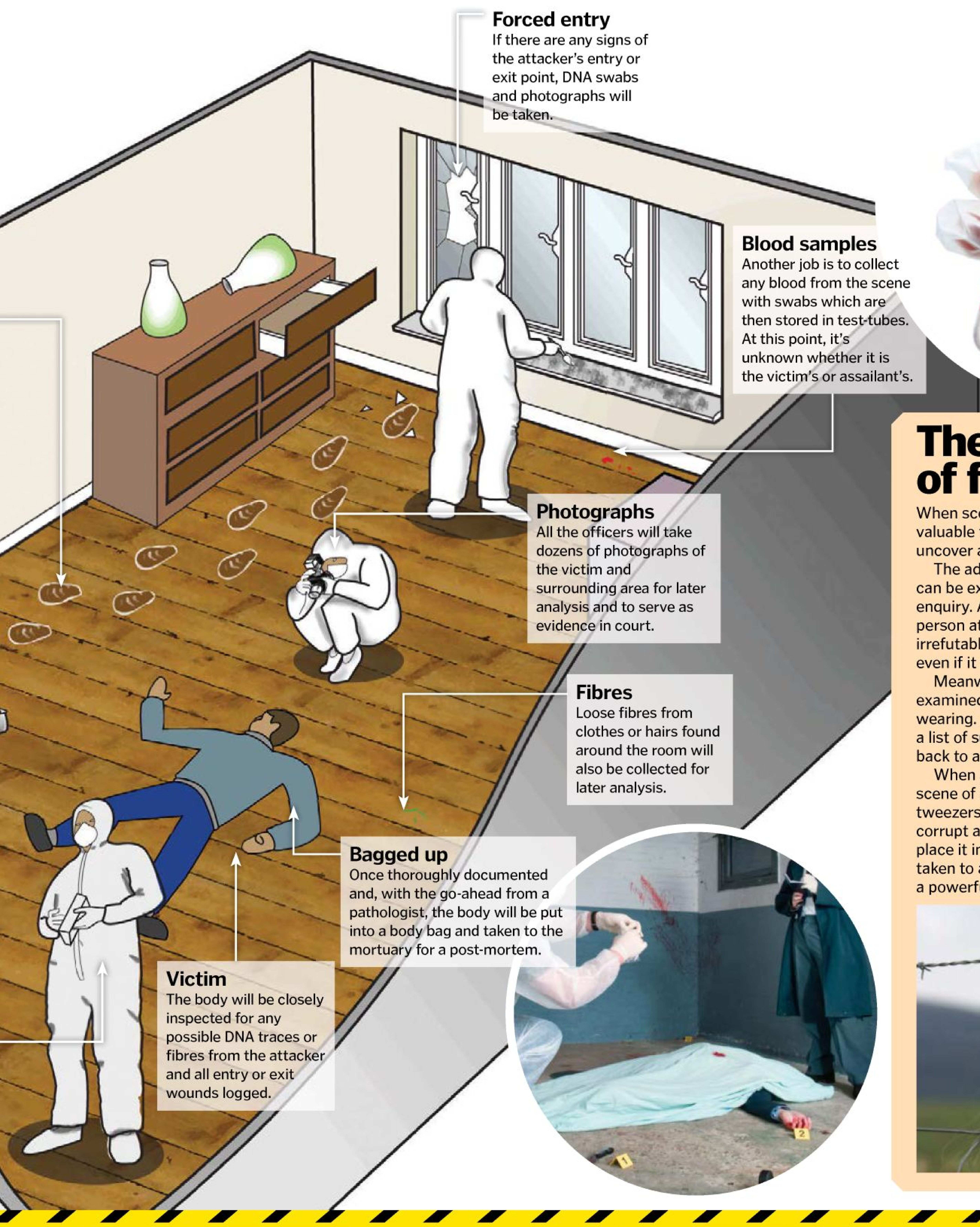
1 Blue light finds blood
While an alternative light source (ALS) can find bodily fluids, blood is located using luminol, a chemical that reacts with haemoglobin and causes the blood traces to glow.

2 Superfast results
In stark contrast to the seconds or minutes that DNA analysis takes on television, a real DNA test will usually take around 7-14 days to return any meaningful data.

3 Bullet = gun
While you can often match a bullet to the gun that fired it, if the bullet has been damaged or the gun has been modified, making a match is much more difficult.

4 DNA always gets results
Even if investigators find DNA, they can't always establish whose it is. Not many people have their DNA on file, so only people with previous convictions get flagged up.

5 Chalk outline
Chalk outlines are not used to mark around dead bodies as doing so may contaminate evidence. Instead, photos and tape markers are used for analysis of the scene.



The importance of fibres

When scouring a crime scene, two of the most valuable finds that a forensic officer can uncover are hair and clothing fibres.

The advantage of finding a hair is that DNA can be extracted from it, opening a line of enquiry. Although it can't directly place a person at the scene like fingerprints, it is irrefutable proof that there is a link somewhere, even if it has been planted.

Meanwhile, fibres of clothes can be minutely examined to determine what someone was wearing. This can then be used to whittle down a list of suspects as certain fibres can be traced back to a specific manufacturer.

When anything of this nature is found at the scene of a crime, forensic officers will use tweezers to pick up the item, so as not to corrupt any potential DNA, and immediately place it in an evidence bag. The bag is then taken to a lab, where it can be examined under a powerful microscope and any DNA extracted.

Fingerprinting powder
Two different types of powder are used at the crime scene; which one depends on the type of surface.

Tape
Adhesive tape is used to lift a copy of a fingerprint from a surface.

Luminol
This is a chemical which glows in the dark in the presence of blood, illuminating even trace amounts.

Flashlight
A torch is essential for looking in dark nooks and crannies for crucial evidence or during crime scenes at night.

Tweezers
In order to avoid smudging potential fingerprints or damaging fibres, tweezers are used to pick up small pieces of evidence.

> "Before even entering the room, we will scour the area outside the crime scene to see if there are any clues"

stage from the moment they get the call to the scene to the end of the case.

"First, we'll get a call from the control room that took the report of the incident, head down to the crime scene and talk to any police officers or home owners. Before even entering the room, we will scour the area outside the crime scene to see if there are any clues we can find.

"Then, we will move inside the room, having put on protective suits, gloves and masks. The masks are to avoid any chance of us accidentally contaminating the scene with saliva or anything like that. We will take lots of photos of all areas of the room. These will primarily be for the prosecution, but they are also disclosed to the defence. Next, we go around collecting evidence in bags, such as any blood on a window, fibres from clothes or envelopes the intruder may have opened.

"The next stage is to dust for fingerprints. We will then use tape to lift the prints, which will be bagged in a special envelope and sent to a fingerprints expert, while the rest of the evidence goes to a lab. We would never touch a body until the forensic pathologist has been and studied it. Then the body would get put in a body bag and taken to the mortuary.

"Once all the evidence has been analysed in the lab, we would get the results, which we would pass to the CID who would continue the investigation. We could get called to court to give our side of the investigation, but the detective and analytical work are done by the police and lab teams."

Until fairly recently, much of the laboratory work carried out in Britain was done by the

Anatomy of a fingerprint

What the experts are looking for when trying to match a print

Loops
This pattern will rise up at an angle, curve over and swoop back down, returning back to the starting point of the pattern.

Whorls
These are individual rings, each one encircling the one inside it. Just over a third of fingerprints look like this.

Arches
The least common of all fingerprints, these look a bit like a hill, swooping up from the left, then down toward the right.

The process of fingerprinting

1. Collection

Fingerprints can be found in several ways. The most common is taking a high-resolution photograph of a print that is already visible. However, if no prints are visible at a scene, investigators can dust surfaces with powders such as aluminium flakes, take pictures, then collect them by sticking tape onto the powdery surface and removing them along with the imprint. An alternate light source (ALS) can be used in a darkened room.

2. Processing

The print is fed into a computer, which analyses the patterns and tries to find a match with any on its database. If any matches are flagged, fingerprint experts examine the two images by eye.

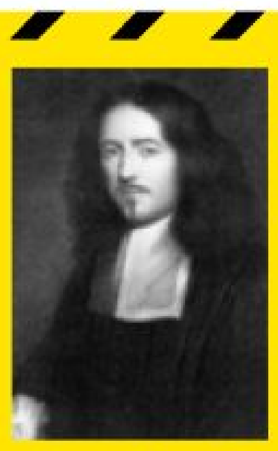
3. Decision

Examiners use the ACE-V method in fingerprint analysis, which stands for Analysis, Comparison, Evaluation and Verification. The first stage is to establish if there is enough of a print in terms of quality or quantity to verify a match. After that, they look at images of the print and the potential match to see if they are similar. If it's decided that they do match closely enough, the final stage is to bring in a second examiner to perform the same process for verification.

Fathers of fingerprinting

We have a few people to thank for the development of fingerprint forensics

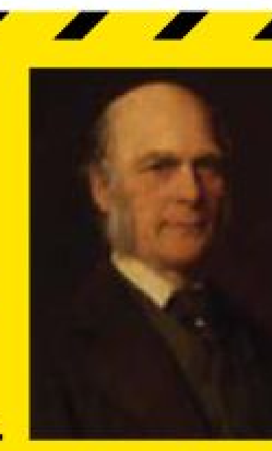
1686
Marcello Malpighi notes fingerprints are unique to the individual, after studying patterns on our fingers.



1858
Magistrate of Indian district Hooghly, William Herschel uses fingerprints to force locals to confess to crimes.

1880
Henry Faulds publishes his reseach in *Nature*, suggesting that fingerprints could be used to catch criminals.

1892
Sir Francis Galton writes the book *Finger Prints* and devises a method to identify and record fingerprints.



STRANGE BUT TRUE
A HUMAN TOUCH

Which Australian animal has human-like fingerprints?

A Kangaroo **B** Koala **C** Wombat

Answer:
Even when viewed under a microscope, it is practically impossible to distinguish a koala's fingerprints from human ones. This is thought to be a recent evolution as fellow marsupials don't have human-like fingerprints.

DID YOU KNOW? *The acid in quicklime is able to erode our fingerprints, although they will grow back in around 30 days*

Forensic Science Service (FSS), which was run by the government, but losses of around £2 million ($3.3 million) per month forced the department to close. The workload for analysing the results of the crime scene then got contracted out to private companies.

"The private companies are very good," reveals Otto. "The only problem is contamination. The great thing about the FSS was that they were world-renowned and their labs were always incredibly clean. Unfortunately the private companies sometimes aren't quite so careful and contaminations do occur. When you're working with DNA, which is obviously such a small thing, you have to be really careful."

After removing a body from a crime scene, it's placed in a sterilised bag and transported to a mortuary where it's kept until the forensic pathologist is able to perform a post-mortem, determining time and cause of death.

Meanwhile, lab analysis of any pieces of evidence is taking place. This can be anything from looking at a piece of thread under a microscope to see what the suspect was wearing to processing any DNA fragments to see if there is a match on the database.

A fingerprint is left on a surface due to the sweat glands in the finger creating a latent mark. Alternatively, if a person presses with enough force in wet paint or other malleable surfaces, this would also leave a print.

"Smooth surfaces like glass will require a flake powder containing aluminium or gold flakes," Otto explains. "Rough surfaces will need a more granular powder. This powder ▶

DNA profiling

The discovery of DNA was a massive milestone in forensics. Watson and Crick proposed the idea of the double helix in 1953, but in 1984 British geneticist Alec Jeffreys discovered a method to use variations in a person's DNA to identify them.

The most common method uses short tandem repeats (STRs). These are structures within the human genome consisting of one to five bases and are repeated half a dozen times through the DNA system. When DNA copies itself, mutations occur, giving each individual their unique code. Profilers will take 10-13 STR markers from DNA found at the scene of a crime and compare that with DNA taken from the person they are interested in.

STRs are useful in DNA identification because the STR markers vary noticeably in humans, reducing the chance of an error, and also because they can be easily magnified when profilers are inspecting the DNA strands.

A CSI will spend a lot of their time in the lab, analysing evidence collected at crime scenes

Putting a face to DNA

Until now, the only clues the police were able to use to physically identify a criminal is witness or CCTV evidence. However, teams from Erasmus University Medical Centre in Rotterdam and Pennsylvania State University have identified five genetic variants that have an effect on the face. This means that the same DNA that can identify who you are on the inside could in the future also help police construct a reasonably accurate re-creation of a face, including the tip of the nose, position of the eyes and general face shape.

This breakthrough was achieved by making 3D images of nearly 600 people from a variety of ethnic backgrounds and linking the differences in face shape to the differences in DNA, isolating the genes that controlled what we look like.

While still not yet fully tested and some way from being able to be used as evidence in court, this new method of forensic profiling has very exciting potential to help investigators drastically narrow down their list of suspects.

“Now that people are aware of the power of forensic evidence, criminals are able to manipulate the system”

adheres to the sweat that creates fingerprints so we can get a clear image of the print.”

As fingerprints are unique to the individual, the discovery of fingerprints on a doorframe or a person’s body provides irrefutable proof that they were there. While fingerprints found at a scene cannot be dated, and the added confusion of planted evidence the culprit could use to frame someone else, fingerprints provide an invaluable resource to police officers who need to link a suspect with a location.

Once fingerprints have been collected, they are analysed by a dactyloscopy expert and run through a computer that will search its database of fingerprints, collected over several decades, to try and find a match.

The whole basis of fingerprint evidence is centred on the unique pattern of whorls, loops and arches that make up every fingertip. As yet, no one has ever found two people with exactly matching fingerprints, so a positive match is taken as fairly solid evidence of a person’s connection with the crime.

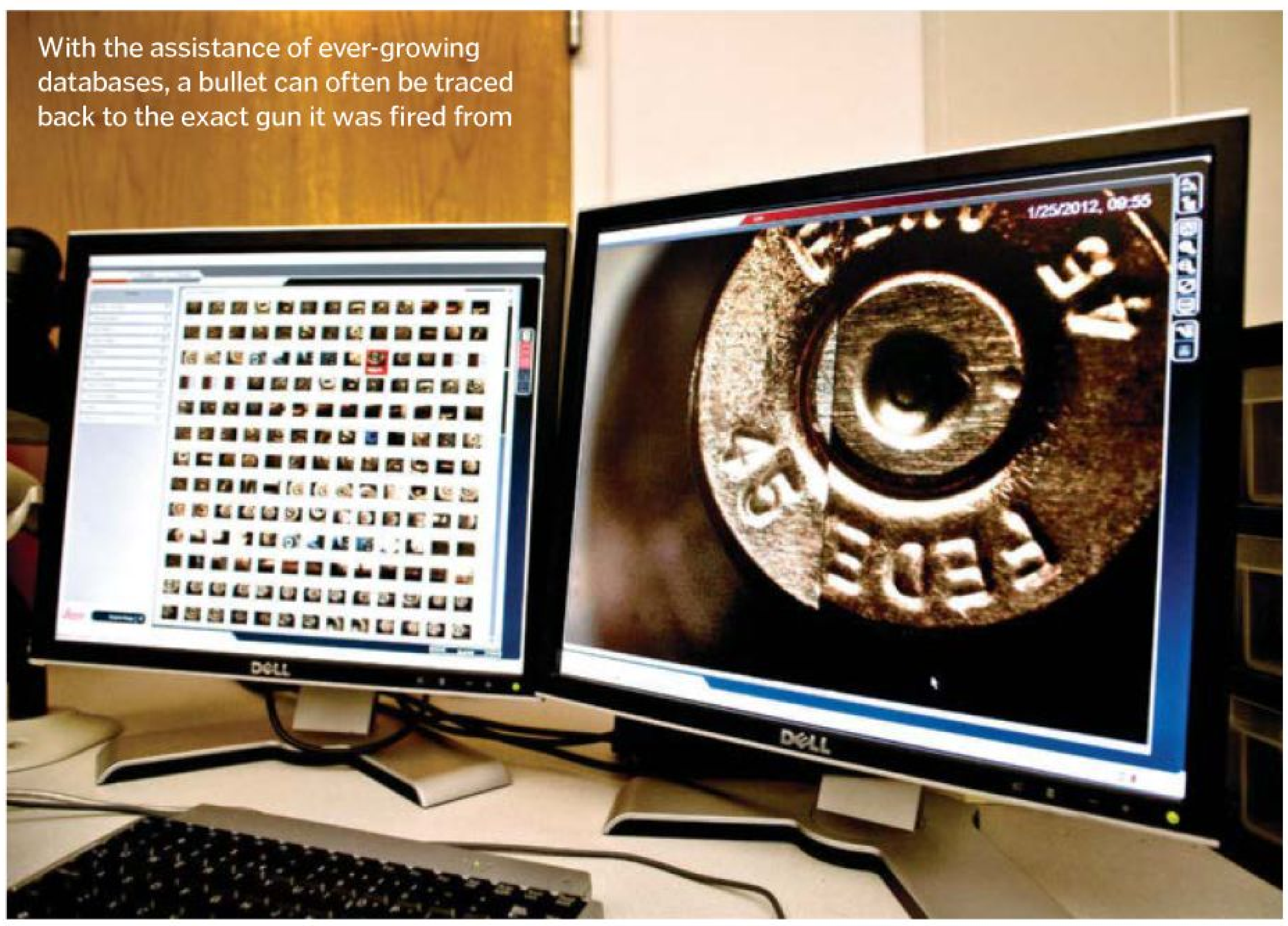
Recent advances in fingerprinting have enabled forensic investigators to even detect high-quality fingerprints from food, a previously tricky area of investigation. A modified form of powder suspension, which is a tar-like substance, will reveal a fingerprint quite clearly even on smooth surfaces, meaning that we now have another way in which to connect people with a crime.

The other key area for forensic investigators is DNA matching. This is a much more recent development, with the technique only emerging in the 1980s, but is able to create matches with incredible accuracy. DNA profiling is where a section of a person’s DNA, which is unique to them, is matched with DNA found at a crime scene, which can come in the form of blood, a strand of hair or even oil from a nose print that had been pressed up against a window. If a match is found, you can be fairly certain someone was there, if not when or why.

Obviously though, linking a person with the scene of the crime won’t automatically result in a conviction. Now that people are aware of the power of forensic evidence, criminals are able to manipulate the system, planting DNA evidence to throw investigators off the scent. Forensic evidence can go as far as showing who has touched a certain object or whose DNA was found in the area, but it is still up to the police to decide what to do with the evidence put in front of them, much like non-forensic evidence such as witnesses and alibis.

Unfortunately, the other key limitation to DNA and fingerprint evidence is that the person to whom they belong needs to be known to the police. Fingerprints and DNA are run through

Another aspect of crime scene investigation is collecting and examining ballistics evidence, if a gun has been used in the crime



With the assistance of ever-growing databases, a bullet can often be traced back to the exact gun it was fired from

Ballistics in focus

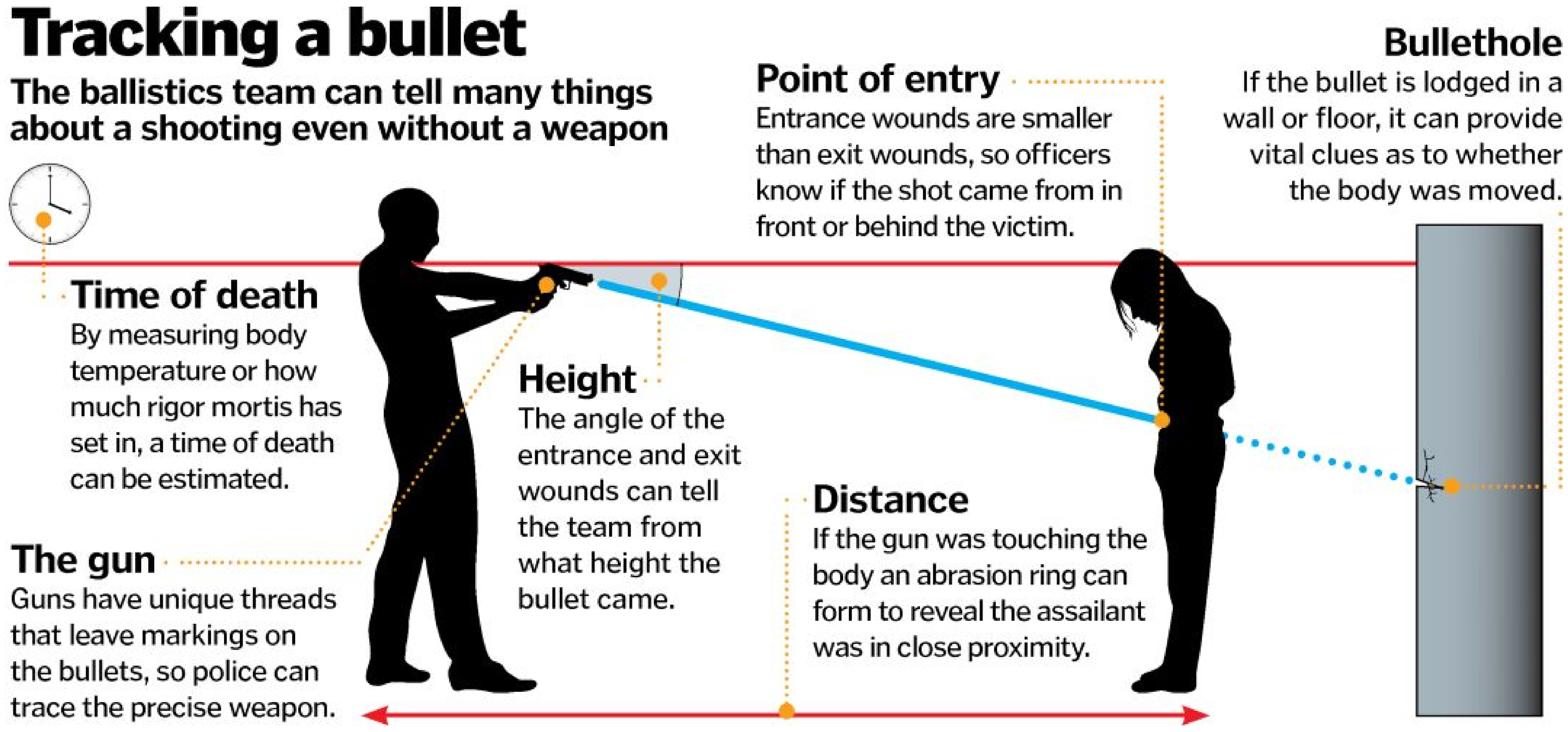
Unless a gun has been modified or the ammunition badly damaged, forensic officers are often able to trace a bullet back to the weapon that fired it, due to marks made by the firearm’s unique pattern of grooves and threads.

When establishing the cause of death, ballistics experts and medical officers will work together to determine various aspects of the shooting, such as the distance and angle from which a person has been shot judging by the entry wound and potential exit wound.

Assistance to law enforcement officers now comes in the form of the instant shooter identification kit, which can work out in minutes if a person has recently fired a gun by analysing gunpowder residue on their hands.

Tracking a bullet

The ballistics team can tell many things about a shooting even without a weapon



KEY DATES
HISTORY OF FORENSICS

1788
JC Mayers writes that 'the arrangement of skin ridges is never duplicated in two persons'.

1886
Henry Faulds believes fingerprints could be used to identify criminals. He is rebuffed by Scotland Yard.

1953
Watson and Crick discover that DNA is handed down by a person's parents and is unique to the individual.

1984
Alec Jeffreys develops genetic profiling, which links DNA from a crime scene with DNA taken from a suspect.

1988
Colin Pitchfork becomes the first person to be convicted in the UK using DNA evidence.

DID YOU KNOW? *Studying insects at a crime scene is called forensic entomology. Development of fly larvae can reveal time of death*

the national database to find a match, but if the police do not have either on file, they will hit a dead-end in the investigation. An officer can only take DNA and fingerprints when someone is arrested and a recent law in the UK has determined that anyone who hasn't been convicted of a qualifying offence has to have their records destroyed within six months. However, the benefit of the DNA database is that more and more cold cases are being solved, due to people's DNA being taken, fed into the computer and matched with DNA taken from a crime scene years ago, leading to many retrospective convictions.

Forensics alone cannot force a conviction, but they certainly can assist the police in constructing a case for the prosecution.

Whenever a gun is involved in a crime, ballistics is another major area that falls under the forensics team's remit.

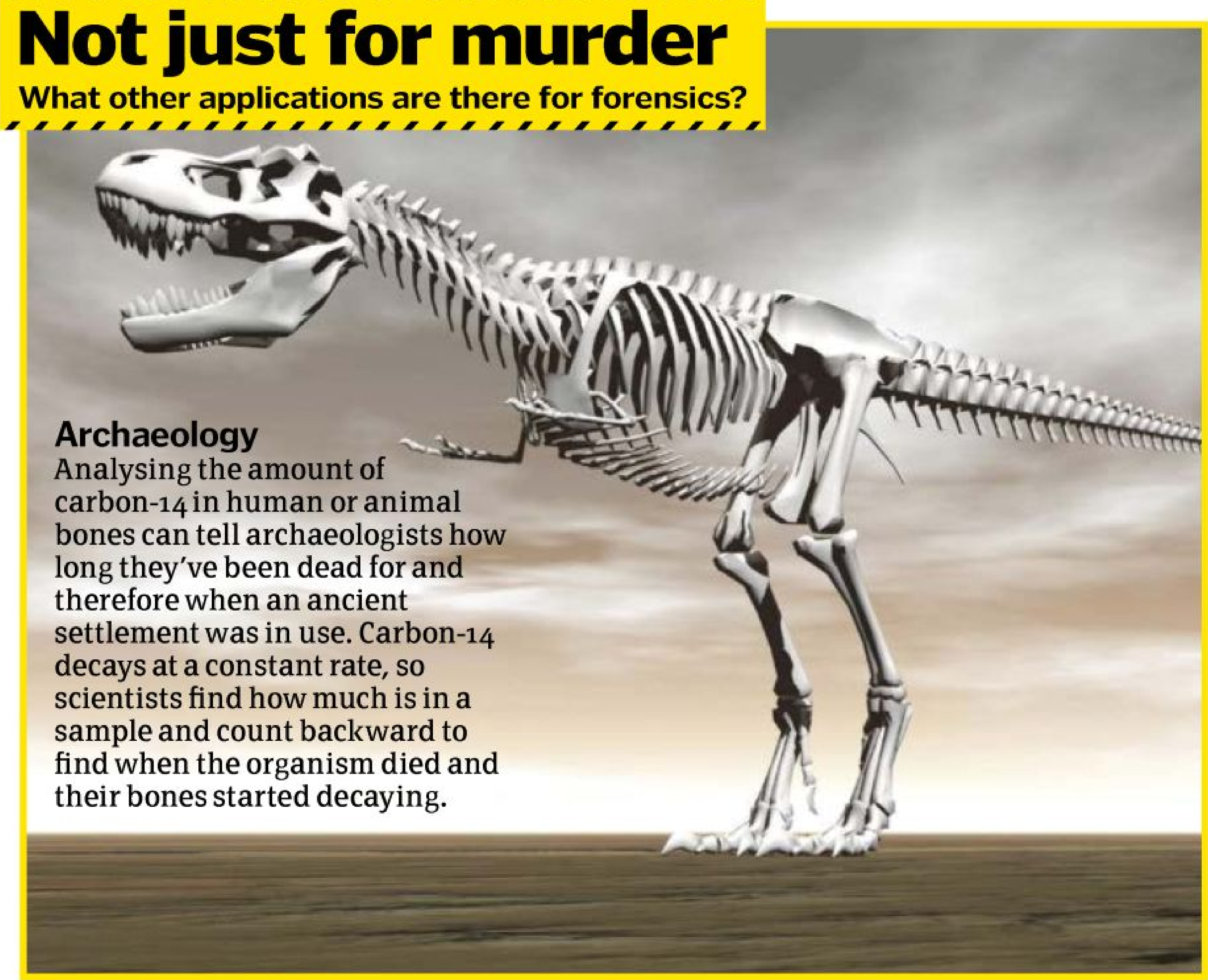
"One of the things we can determine is the directionality of ballistics, so where the bullet came from", Otto explains. "Apart from if a gun is modified, matching the bullet to the gun is a very precise science. Each gun has grooves that are particular to that exact firearm, not just the brand, so we can trace the gun with real certainty. Less reliable is firearm residue. Studies here have shown that there is a real similarity between gunpowder residue and brake dust, for example, so that is an area that needs further investigation."

We have to ask Otto about the influence of *CSI*. The hit US TV show has been phenomenally successful in the 14 years since its premiere and has spawned two direct spin-off series, *CSI: Miami* and *CSI: New York*, as well as inspiring several other detective shows, but is its immense success a boost or hindrance to the world of forensic investigation?

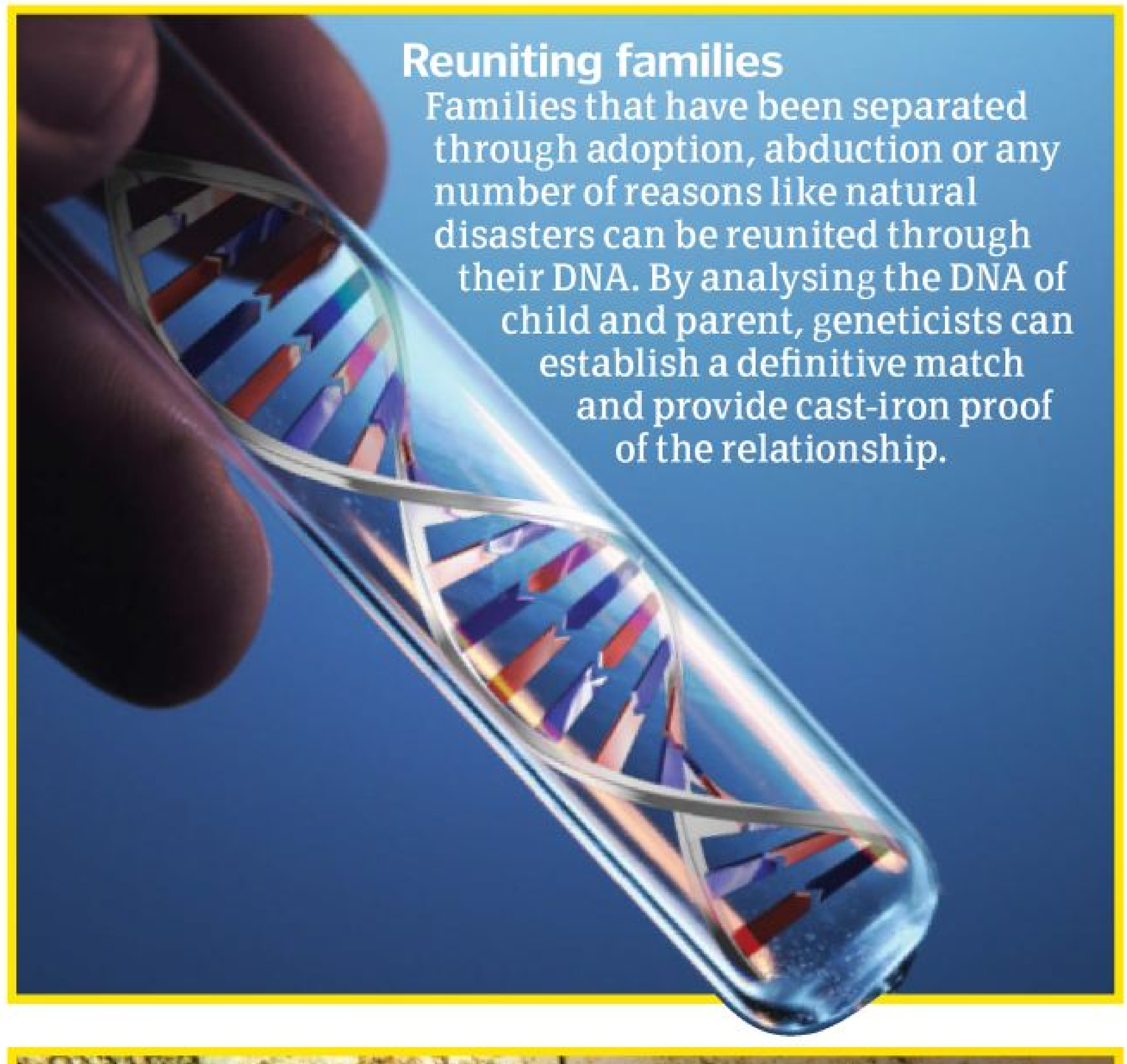
"Of course I watch *CSI*. I need to know what my students are watching. The show is very good, but it does give people a different idea about crime scene investigators. In the show they do everything. They interrogate witnesses, forensically investigate the scene, do the lab work, everything. In reality, we don't do much of that side of things at all. In fact, when my students first arrive I tell them that the life of a CSI is not like on the TV at all.

"It does give the wrong impression about how things work too. Whereas they get DNA results straight away, we generally have to wait about a week to two weeks minimum for results to come back. Having said that, forensics is quick in the courts. It helps to identify the person because of the individuality of DNA, and it has been proven that DNA profiling stands up in the court of law. I don't think the advantages of DNA can ever be overvalued."

Not just for murder
What other applications are there for forensics?

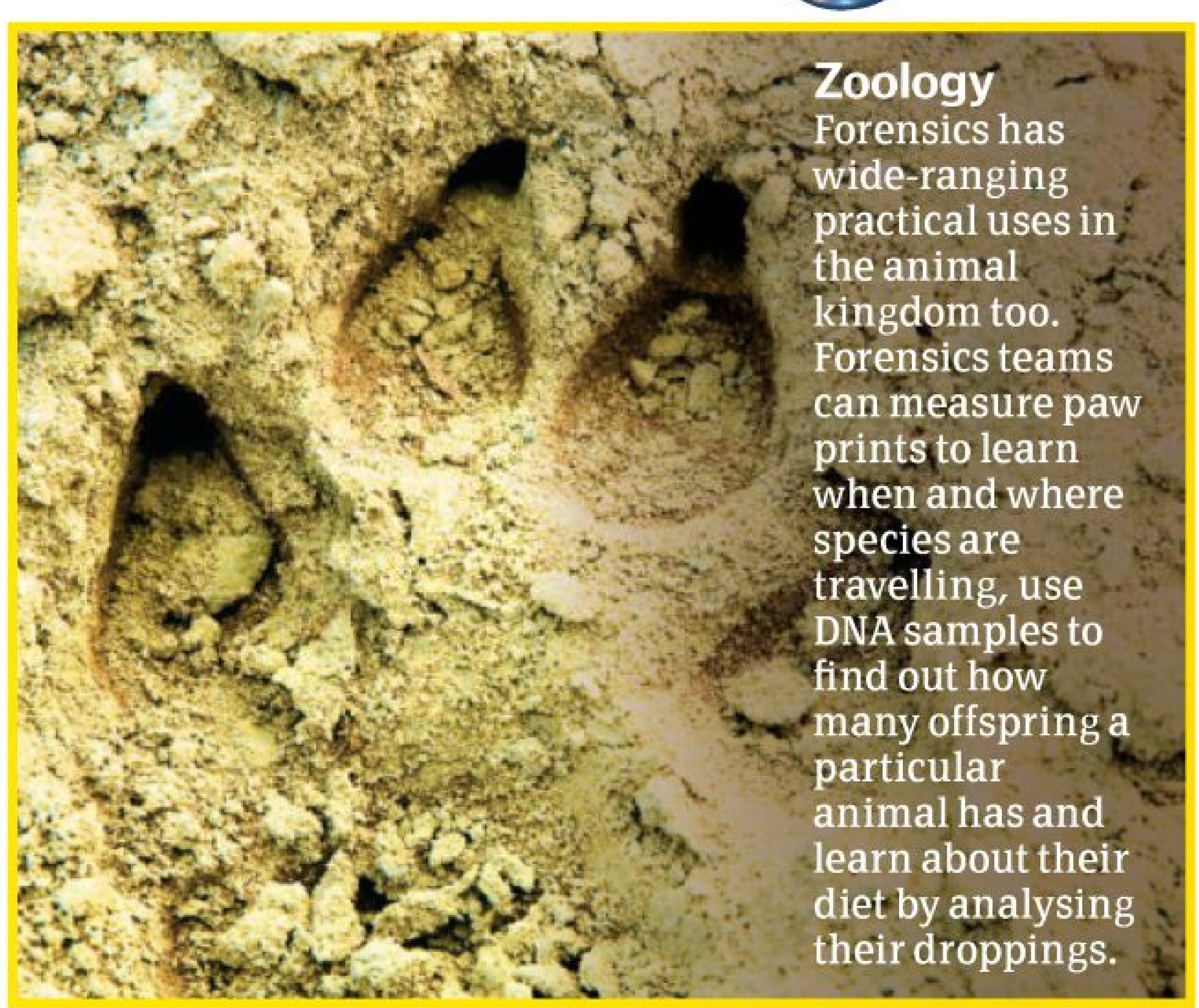


Archaeology
Analysing the amount of carbon-14 in human or animal bones can tell archaeologists how long they've been dead for and therefore when an ancient settlement was in use. Carbon-14 decays at a constant rate, so scientists find how much is in a sample and count backward to find when the organism died and their bones started decaying.

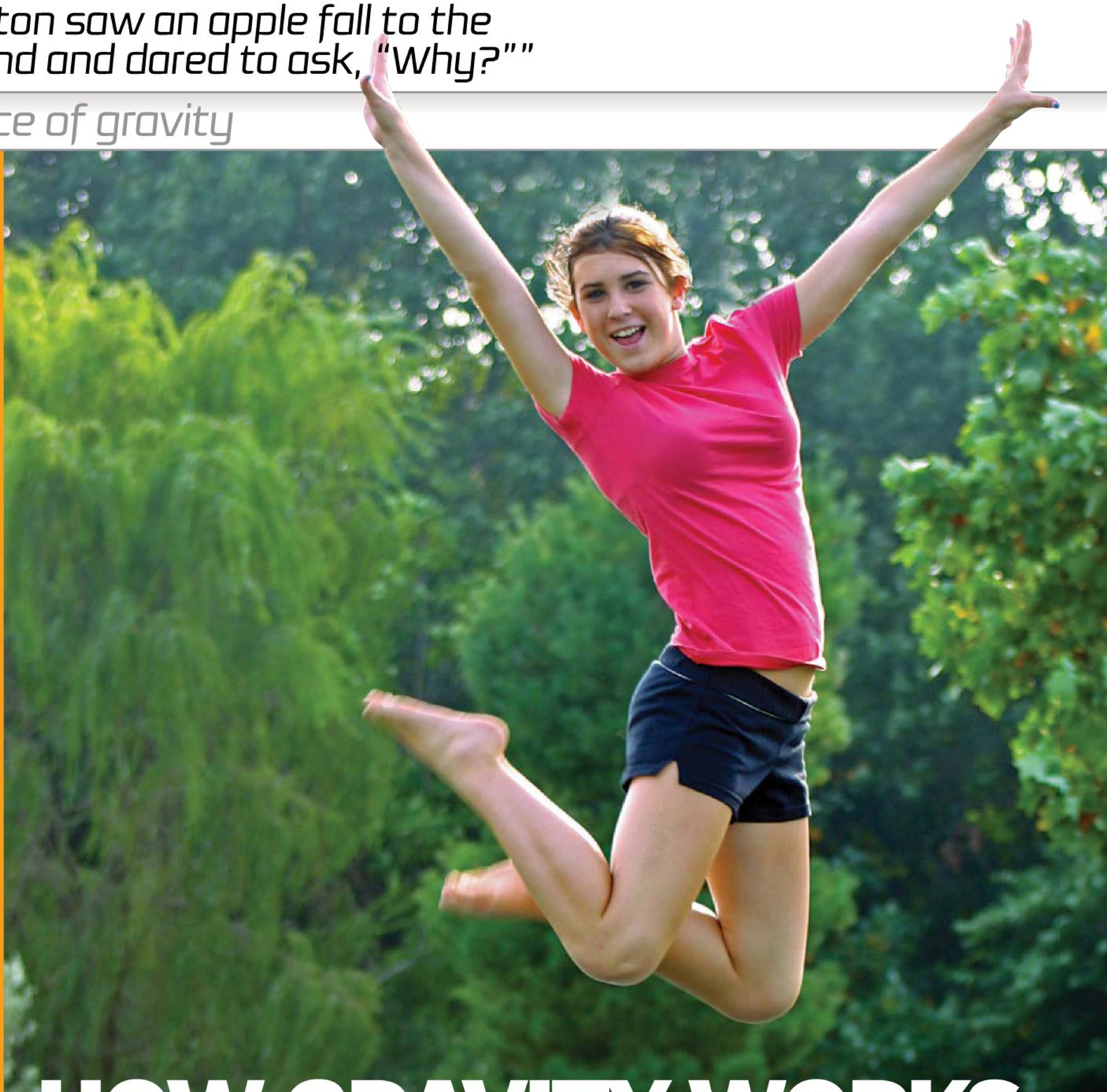


Reuniting families
Families that have been separated through adoption, abduction or any number of reasons like natural disasters can be reunited through their DNA. By analysing the DNA of child and parent, geneticists can establish a definitive match and provide cast-iron proof of the relationship.

Fraud
Technology is a key part of many criminal investigations, so the field of technology forensics is growing. Experts can determine the last person to use a computer, locate and date emails and even pinpoint a person's current location using IP addresses.



Zoology
Forensics has wide-ranging practical uses in the animal kingdom too. Forensics teams can measure paw prints to learn when and where species are travelling, use DNA samples to find out how many offspring a particular animal has and learn about their diet by analysing their droppings.



HOW GRAVITY WORKS

Unravel the mysterious force that formed the stars and keeps our feet on the ground

Of all Isaac Newton's revolutionary discoveries, perhaps none was more ambitious than unravelling the enigma of gravity. In the 1660s, Newton saw an apple fall to the ground and dared to ask, "Why?" Why doesn't the apple drift slowly upward? Why does water always seek the lowest place? Why does the Moon stay in orbit and not catapult into space? In his day, it was a question of near-religious significance.

Instead of meditating on divine mysteries, Newton drew up formulas. His law of universal gravitation, as presented in his 1687 treatise *Principia*, states that every particle of matter in the universe attracts every other particle of matter in the universe with a measurable force called gravity (named for the Latin 'gravitas', or weight). The strength of the gravitational force increases with mass and decreases with distance. In other words, the larger the object, the more gravity it exerts, and the closer you are to the object, the greater the pull.

Here is Newton's brilliantly simple formula for calculating the force of gravity between two objects, where m_1 and m_2 are the masses of the two objects, r is the distance between the two objects' centres of gravity, and G is the universal gravitational constant: $F = G\frac{m_1 m_2}{r^2}$

Perhaps the most surprising thing about Newton's law is its universality. Though it can be difficult to conceive, not only is there a gravitational attraction between the apple and the Earth, but there's also a gravitational attraction between you and the apple. Essentially, any two objects that have mass – whether cosmically huge like a galaxy or infinitely small like an atom – exert a gravitational force on each other.

If that's true, though, why don't we swerve toward the street when a large truck passes, or get pinned to the base of a skyscraper? Because that 'big G' in Newton's equation is actually incredibly small – roughly 6.67×10^{-11} Newtons (square

THE STATS
GRAVITY IN NUMBERS

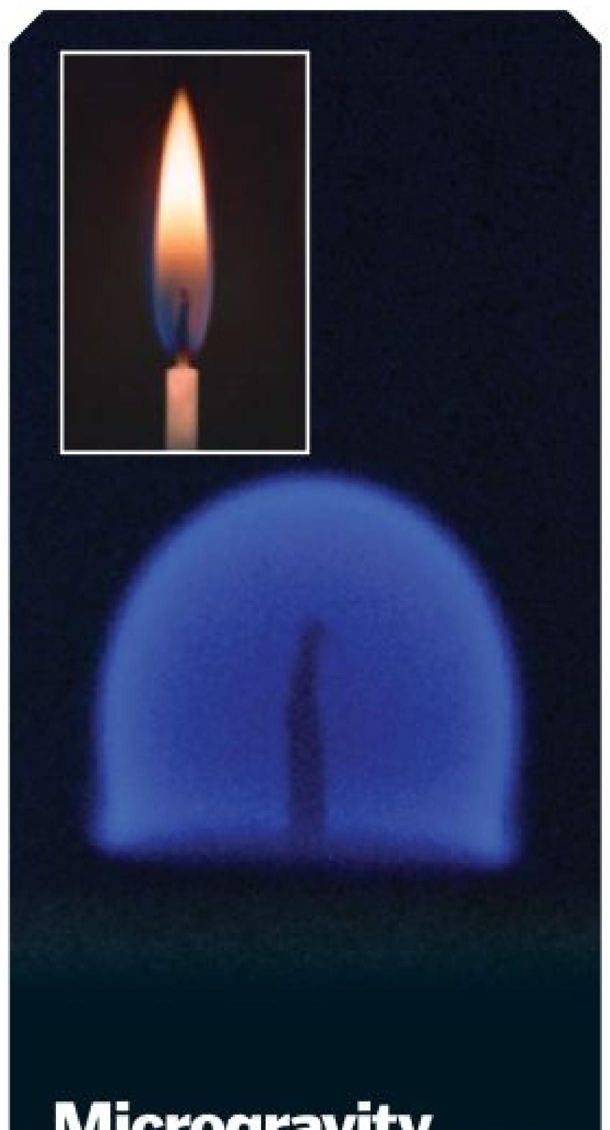
ACCELERATION OF GRAVITY ON EARTH **9.8m/s²**

GRAVITATIONAL CONSTANT (G) **6.67×10^{-11} Nm²/kg²**

TERMINAL VELOCITY OF A SKYDIVER **~60m/s**

ACCELERATION OF GRAVITY ON THE SUN **274m/s²**

DID YOU KNOW? *The value of the universal gravitational constant ('big G') wasn't measured until 70 years after Newton's death*



Microgravity

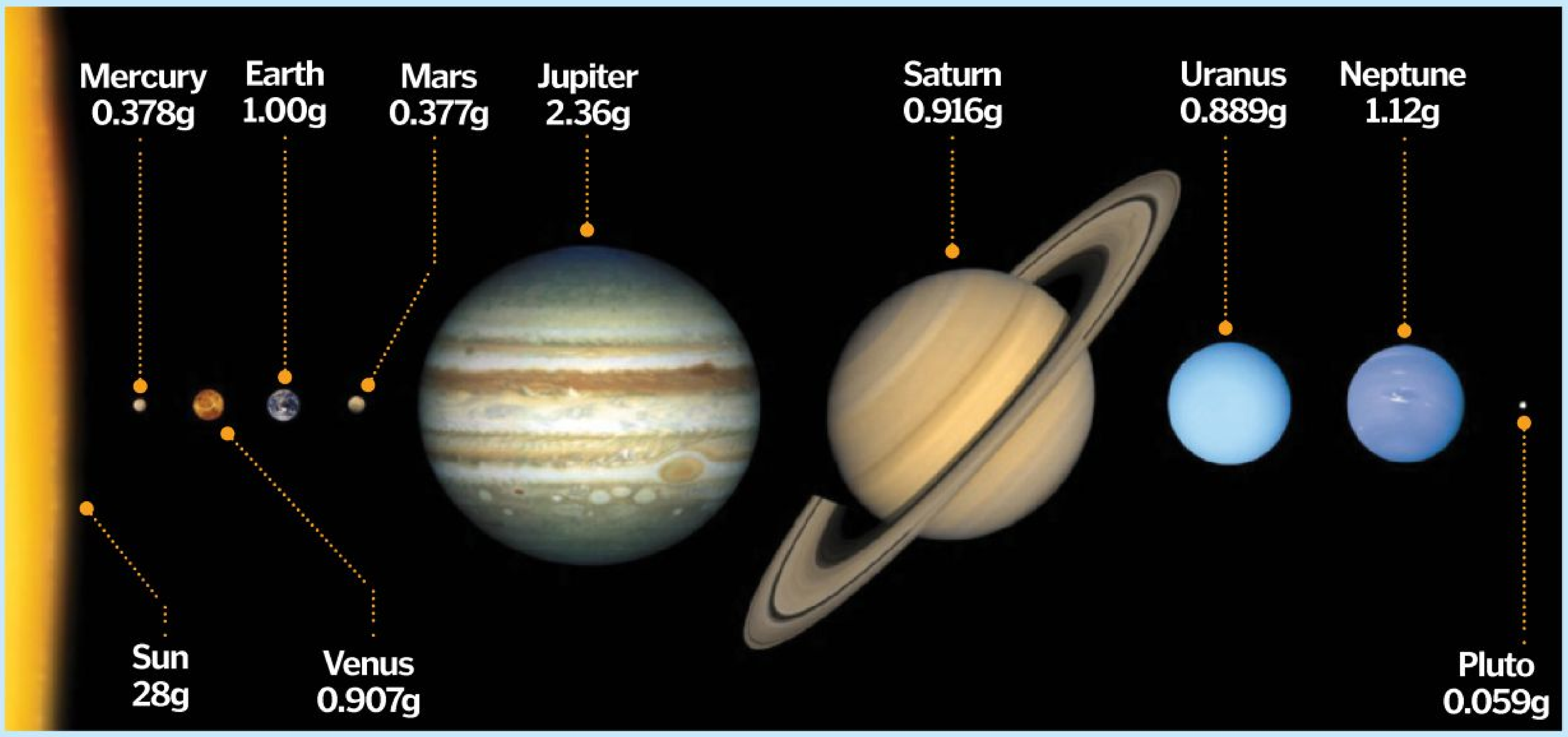
Scientists use the orbiting ISS to conduct experiments in the weakened gravity 370 kilometres (230 miles) above the Earth's surface. In a microgravity environment, flames aren't drawn upward by convection currents. The steady, slow-burning flame of microgravity allows scientists to better understand the process of combustion both on our planet and beyond…

Gravity through the Solar System

As Newton theorised back in the 17th century, every particle of matter exerts a gravitational pull on every other particle of matter. If you concentrate a large amount of matter in one place, it will create a much greater gravitational pull than a loose smattering of particles.

Mass is the measurement of how much matter is in a particular object. The greater the mass, then the more gravitational influence it will possess. Every planet, moon, star and galaxy in the universe has a different mass and therefore generates a unique gravitational pull.

The mass of the Earth pulls a falling object toward the ground at a rate of 9.8m/s² (32.2ft/s²). In contrast, the mass of the Sun is 333,000 times greater than the Earth. As a result, a falling object near the surface of the Sun would be pulled downward at a rate approaching 274m/s² (899ft/s²), 28 times faster than on our planet.




Gravity is the weakest force of nature, which is why a magnet can easily 'defy' it to pick up metal objects below

metres/kilograms); yes, the decimal point is 11 digits to the left. Unless the combined mass of the two objects is very, very large, the force of gravity between them is undetectable.

The Earth qualifies as a very, very large object with a mass of 5.97219×10^{24} kilograms (1.31664×10^{25} pounds). In comparison, your mass (not weight) is probably closer to 70 kilograms (154 pounds). If you plug the Earth's mass into Newton's equation as m_1, your mass as m_2, and then use the radius of Earth for r, you get an answer of 686 Newtons (154.2 pounds force).

That is the gravitational force between you and our planet – in other words, the force that your mass exerts through gravity, aka your weight on the surface of the Earth. If you were to run the same numbers at a jumbo jet's cruising altitude of around 12,200 metres (40,000 feet) above sea level, however, you would actually exert a whole two Newtons less, because there is a greater distance between your centre of gravity and the centre of the Earth. ▶

How orbits work

There are over 900 satellites currently orbiting the Earth. But how do they stay in orbit without any engines? Satellites in orbit don't require power as they're really in controlled freefall. A satellite is launched into space in the nose of a rocket. That rocket must provide enough thrust to escape the surface gravity. Once in space, the satellite is released on a perpendicular trajectory. But instead of flying away from the planet, the satellite 'falls' into an elliptical orbit determined by the long-distance gravitational pull of the planet.

> "Little g is critical because it explains why objects fall to the Earth at a consistent rate"

Thanks to Newton's second law of motion, we know that force equals mass multiplied by acceleration (expressed as f = ma). Using Newton's gravity equation on page 40, we figured out the gravitational force between you and the Earth. Since we know the combined mass of you and the Earth, we can then solve the acceleration of gravity (a = f/m). The answer, 9.8m/s² (32.2ft/s²), is also known as 'little g'. Little g, like big G, is a constant, but it's only a constant for objects on or near the surface of the Earth. This means that little g on, say, the Moon or near the Sun is a whole different story.

Little g is critical because it explains why objects fall to the Earth at a consistent rate, even when they are of wildly different masses. For instance, if you push a BMW Sedan and a bowling ball off the top of the Burj Khalifa hotel in Dubai – currently the tallest building in the world – they will both hit the ground at exactly the same time. The only exceptions are objects with low mass and a lot of surface area, like a feather or a parachute, which float down slowly as the result of upward drag. This wouldn't be the case, however, in an airless environment – for example, a laboratory vacuum or the surface of the Moon – where, believe it or not, the feather and the bowling ball would fall at precisely the same rate.

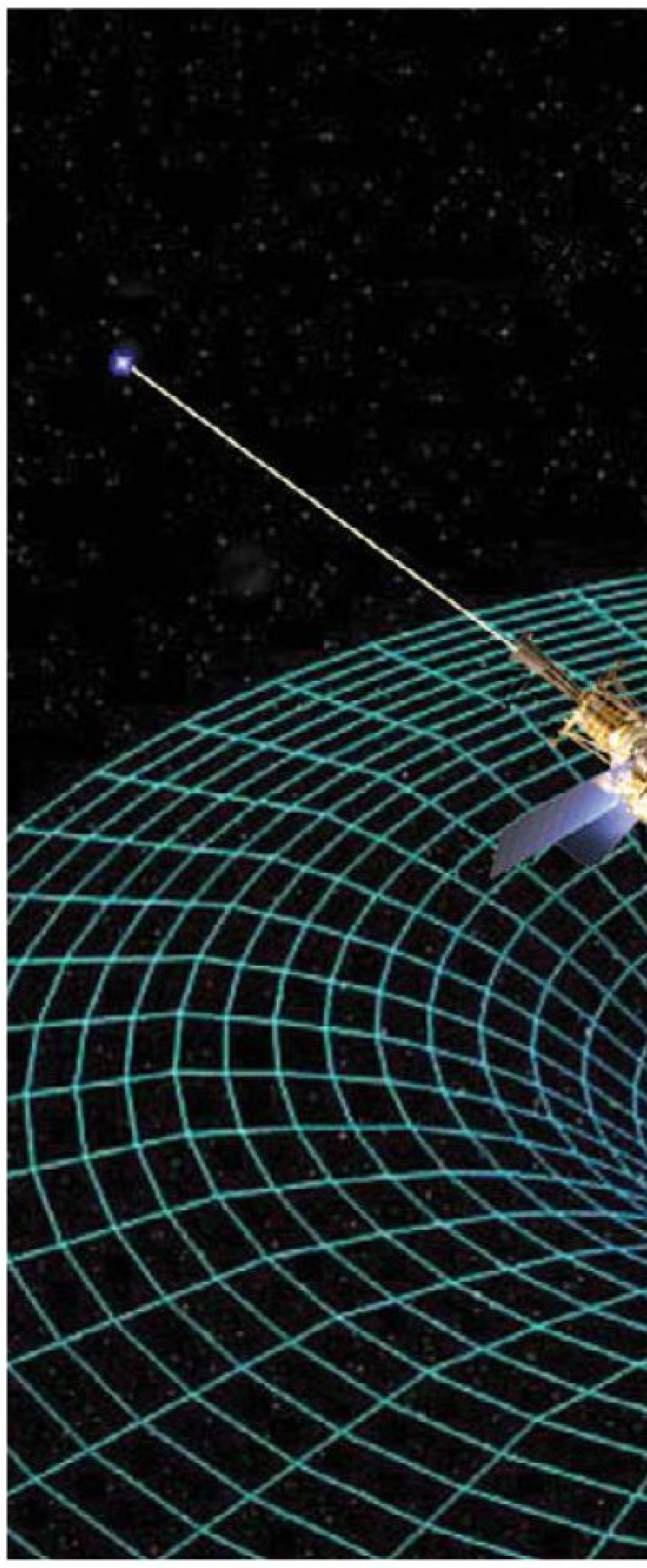
Notice that gravity is the force of attraction between *two* objects; that is, it's a two-way process. Not only are you attracted to Earth with a force of 686 Newtons (154.2 pounds force), but the Earth is attracted to you with an equal force. In fact, if you fall out of a tree and accelerate toward the Earth at 9.8m/s² (32.2ft/s²), the Earth also accelerates towards you. But that's impossible, right? The world doesn't jostle out of orbit every time some klutz tumbles out of a tree. The difference is in the rate of acceleration. If a = f/m and f is 686 Newtons, then the rate of acceleration gets slower and slower as mass gets bigger and bigger. Yes, the Earth technically accelerates towards you and every other falling object, but that rate of acceleration is so tiny – and the Earth's inertia and momentum so great – that no wiggle is remotely detectable.

While Newton's universal law of gravitation gives us the physics to calculate the force and acceleration of gravity just about anywhere in the universe, it doesn't explain what gravity is and how it works at an atomic level.

Albert Einstein took up that challenge with his general theory of relativity, published in the early-20th century, which explained gravity as a curve in the space-time continuum. Beyond our three-dimensional universe, Einstein argues, is a fourth dimension of space and time. Objects with large masses, like planets, can warp the space-time dimension like a bowling ball on a trampoline. If you try to roll a marble across the trampoline, it will be drawn toward the bowling ball. The same is true for planets as they swirl in orbit around a huge celestial body like the Sun, or a cosmic beam of light that bends as it passes a black hole.

But even Einstein's revolutionary theory didn't explain the mechanism at work in gravity. What is it, exactly, that carries this force between two objects? Today, many physicists believe that the gravitational interaction is carried by undetectable, massless particles referred to as gravitons. Others talk of gravitational waves – barely detectable shockwaves of gravitational force created by the collision of neutron stars or the explosion of a supernova.

Despite the limits of our understanding, what began as an apple falling from a tree in the 17th century has led to remarkable insight into the mysterious forces that guide the universe. Gravity, the force that keeps our feet firmly on the ground and dictates global tides with the passing of the Moon, appears to be the same ancient force that bound together primordial cosmic elements to form the first stars and galaxies. If nothing else, it's something to mull over the next time you're falling out of a tree...



What goes up...

A fun way to experience weightlessness on Earth is to leave it momentarily. The flight of this motorbike follows a parabolic curve – the same path flown by NASA aircraft to ready astronauts for zero-gravity

Acceleration
Cruising across flat ground, the bike experiences normal gravity as it reaches a speed of around 104km/h (65mph).

Horizontal to vertical
When the bike hits the 45-degree ramp, it's forced upward against gravity, increasing the gravity force – G force – felt by the rider.

Liftoff
The second the motorbike is airborne, the force of gravity drops to zero, giving the rider a weightless sensation.

True weightlessness
At the top of the parabolic arc, the rider experiences the closest thing to true weightlessness on Earth, minus the drag of air resistance.

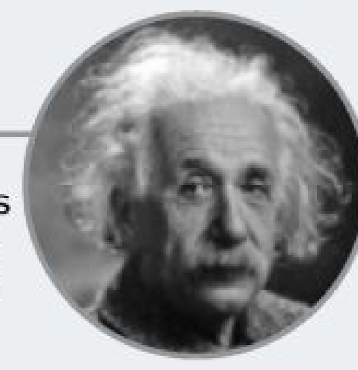
KEY DATES
GRAVITY TIMELINE

1543 Nicolaus Copernicus placed the Sun as the gravitational centre of our Solar System.

1604 Galileo Galilei (right) uses his inclined plane experiments to measure the acceleration of falling objects.

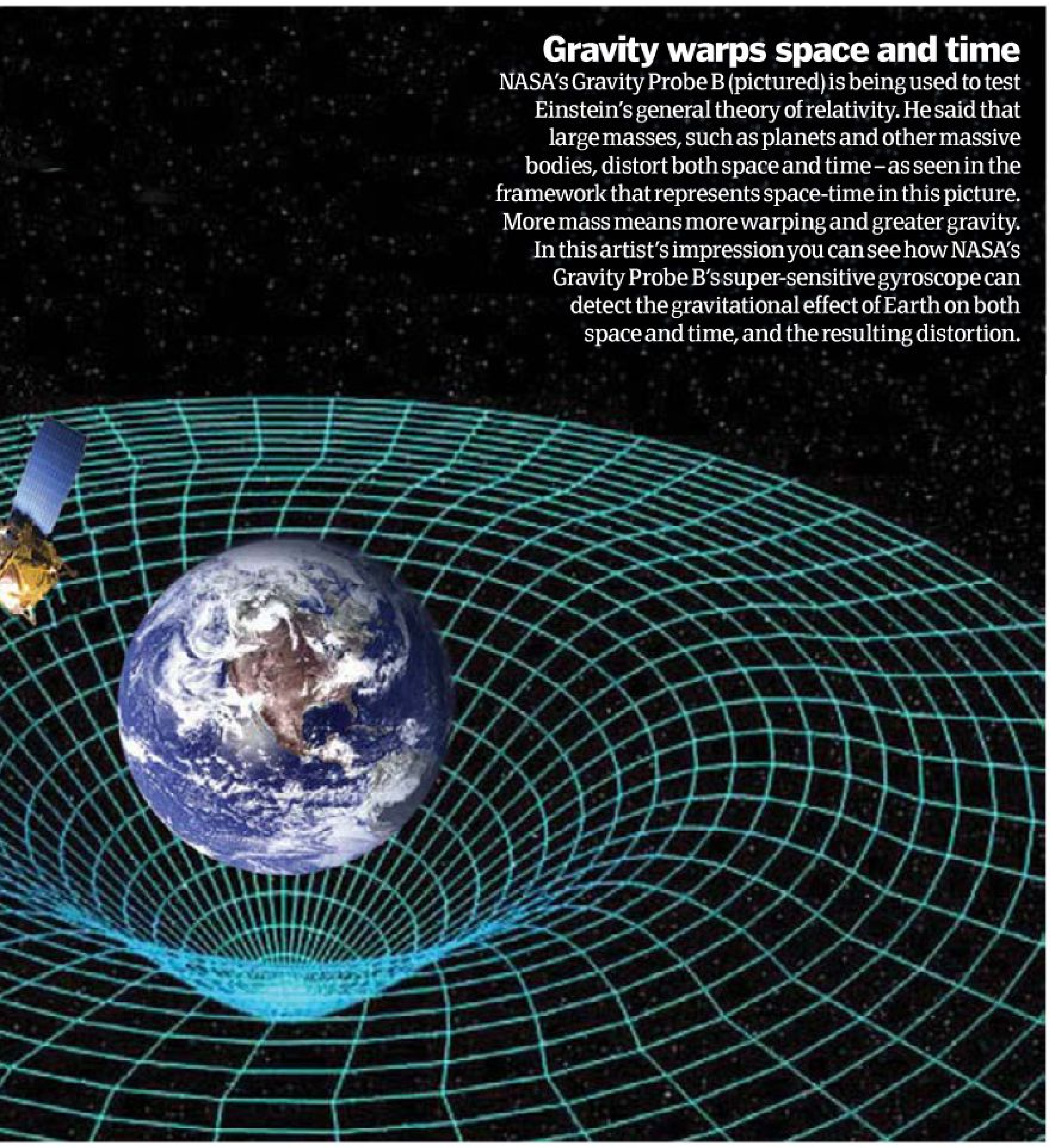
1687 Isaac Newton publishes his *Philosophiae Naturalis Principia Mathematica*, containing the law of universal gravitation.

1915 Albert Einstein (right) publishes his theory of general relativity, which explains gravity as a disturbance in the space-time continuum.



1976 A rocket probe confirms Einstein's theory that gravity slows the passing of time.

DID YOU KNOW? Due to topographical features, the gravity of the Hudson Bay area in Canada is the lowest on Earth



Gravity warps space and time

NASA's Gravity Probe B (pictured) is being used to test Einstein's general theory of relativity. He said that large masses, such as planets and other massive bodies, distort both space and time – as seen in the framework that represents space-time in this picture. More mass means more warping and greater gravity. In this artist's impression you can see how NASA's Gravity Probe B's super-sensitive gyroscope can detect the gravitational effect of Earth on both space and time, and the resulting distortion.

Finding the centre of gravity

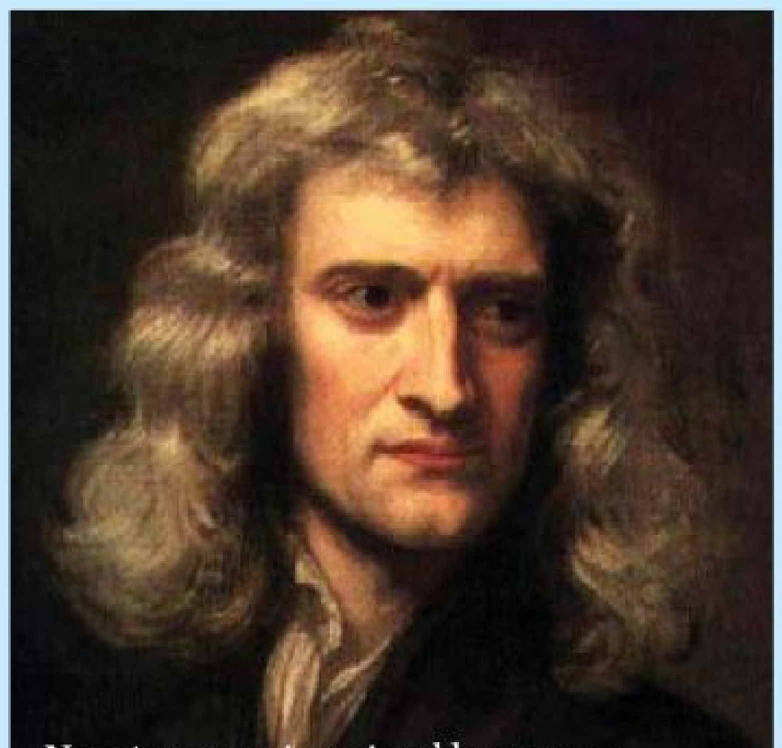
To calculate the acceleration of gravity, you need to know the distance between the centres of gravity of object one and object two. But how do you work out these centres of gravity? For a sphere like the Earth, it's easy. The centre of gravity is the exact centre of the sphere. The distance, then, between your centre of gravity and the Earth's centre of gravity is equal to the Earth's radius. For odder shapes like an apple or the human body, the centre of gravity is defined as the average centre of the object's mass. In practice, you can locate the centre of gravity of any object by finding its balancing point.

Coming down
With a take-off speed of 104km/h (65mph), a bike launched from a 45-degree ramp travels 22m (70ft) before gravity pulls it back to Earth.

Landing
On the bike's landing, the rider experiences greater than normal gravity. An inclined landing ramp decreases the G force.

Measuring gravity

Thanks to Newton, gravity is a measurable force. Not coincidentally, the international standard unit of force is called a Newton (N). On Earth's surface, roughly 0.98N equals the downward force of gravity on 100 grams of mass. Likewise, one kilogram of mass exerts a downward force of 9.8N. To calculate the force of gravity, physicists use the formula f = ma (force = mass x acceleration). Since the acceleration of gravity is $9.8m/s^2$ on Earth – ie little g – we can easily calculate the Newton force of any mass. The average person's mass is 70 kilograms, which multiplied by 9.8 gives you 686N – the force by which gravity keeps us all securely grounded.



Newton was inspired by many scientists including Robert Boyle, Simon Stevin and René Descartes

A hammer vs a feather

Newton's law of universal gravitation states that an object with greater mass will exert a greater gravitational force. But force is not the same as acceleration. The question of which object lands first is a matter of acceleration. When you do the maths, you find that every object – regardless of its mass – has the same acceleration of gravity near the Earth's surface. Take a look:

$$a = f/m; \text{ or } a = (m \times 9.8m/s^2)/m; \text{ or } a = 9.8m/s^2$$

The only reason the feather falls slower on Earth is air resistance. In a perfect vacuum like space, in contrast, the feather and the hammer land at precisely the same time.

The periodic table

Unlock the wealth of information inside this handy guide to all the elements

The periodic table makes scientists' jobs easier by providing a visual guide to each element's main properties.

An element is a substance made from just one type of atom – carbon, for example. The Big Bang produced a handful of very light elements – mostly hydrogen and helium – which were fused inside stars into many heavier elements, like iron. Add to these another 14 elements produced by radioactive decay and you have our universe's 98 naturally occurring elements.

But it doesn't end there. By bombarding atomic nuclei with protons or smaller nuclei, scientists have synthesised 20 more elements. Produced inside nuclear reactors or particle colliders, these are the heaviest elements in the table, with atomic numbers 99 to 118. Since they are all radioactive, they decay rapidly – some after a few days or weeks, but many in a few fleeting milliseconds. This leaves scientists very little time to assess the properties of new discoveries. While they await official recognition, these elements are assigned temporary names such as Ununoctium.

The periodic table organises all 118 elements in order of increasing atomic number. This long list is then split into rows (called periods) according to how many electron shells each element has. Many of an element's chemical properties are determined by the configuration of electrons sitting in their shells. Elements with just one electron in their outer (valence) shell, for instance, react very easily. Elements in the same column (called a group), meanwhile, have similar electron configurations and therefore share characteristics like reactivity.

A number of other patterns can be found across the entire table. Metallic properties, for example, gradually disappear as you move from the bottom-left corner to the top-right.

Non-metals
With a dull finish, non-metals don't conduct heat or electricity well.

Transition metals
These are hard, with high melting and boiling points.

Poor metals
These malleable metals have fairly low melting and boiling points.

Alkali metals
With just one electron each, alkali metals are very reactive elements.

Metalloids
Despite looking metallic, metalloids are brittle and most act like non-metals.

Alkaline earth metals
Keen to give up two electrons, these metals bond easily.

Halogens
Halogens are just one electron shy of full shells, making them very reactive.

Lanthanoids
These soft metallic elements, known as rare earth metals, are very reactive.

Noble gases
With full outer shells, noble gases rarely react with other elements.

Actinoids
Actinoid radioactive elements exist naturally, while others are manmade.

Period \ Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H Hydrogen 1.01																	2 He Helium 4.01
2	3 Li Lithium 6.94	4 Be Beryllium 9.01											5 B Boron 10.81	6 C Carbon 12.01	7 N Nitrogen 14.01	8 O Oxygen 15.99	9 F Fluorine 18.99	10 Ne Neon 20.18
3	11 Na Sodium 22.99	12 Mg Magnesium 24.31											13 Al Aluminium 26.98	14 Si Silicon 28.08	15 P Phosphorus 30.97	16 S Sulfur 32.65	17 Cl Chlorine 35.45	18 Ar Argon 39.95
4	19 K Potassium 39.10	20 Ca Calcium 40.08	21 Sc Scandium 44.96	22 Ti Titanium 47.97	23 V Vanadium 50.94	24 Cr Chromium 51.99	25 Mn Manganese 54.94	26 Fe Iron 55.85	27 Co Cobalt 58.93	28 Ni Nickel 58.69	29 Cu Copper 63.55	30 Zn Zinc 65.38	31 Ga Gallium 69.72	32 Ge Germanium 72.64	33 As Arsenic 74.92	34 Se Selenium 78.96	35 Br Bromine 79.91	36 Kr Krypton 83.79
5	37 Rb Rubidium 85.47	38 Sr Strontium 87.62	39 Y Yttrium 88.91	40 Zr Zirconium 91.22	41 Nb Niob 92.91	42 Mo Molybdenum 95.96	43 Tc Technetium (97.91)	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.91	46 Pd Palladium 106.42	47 Ag Silver 107.87	48 Cd Cadmium 112.41	49 In Indium 114.82	50 Sn Tin 118.71	51 Sb Antimony 121.76	52 Te Tellurium 127.6	53 I Iodine 126.91	54 Xe Xenon 131.29
6	55 Cs Caesium 132.91	56 Ba Barium 137.33	57-71	72 Hf Hafnium 178.49	73 Ta Tantalum 180.95	74 W Tungsten 183.84	75 Re Rhenium 186.21	76 Os Osmium 190.23	77 Ir Iridium 192.22	78 Pt Platinum 195.08	79 Au Gold 196.97	80 Hg Mercury 200.59	81 Tl Thallium 204.38	82 Pb Lead 207.2	83 Bi Bismuth 208.98	84 Po Polonium (208.98)	85 At Astatine (209.98)	86 Rn Radon (222.02)
7	87 Fr Francium (223)	88 Ra Radium (226)	89-103	104 Rf Rutherfordium (261)	105 Db Dubnium (262)	106 Sg Seaborgium (266)	107 Bh Bohrium (264)	108 Hs Hassium (277)	109 Mt Meitnerium (268)	110 Ds Darmstadium (271)	111 Rg Roentgenium (272)	112 Cn Copernicium (285)	113 Uut Ununtrium (284)	114 Fl Flerovium (289)	115 Uup Ununpentium (288)	116 Lv Livermorium (292)	117 Uus Ununseptium	118 Uuo Ununoctium (294)

Lanthanoids	57 La Lanthanum 138.91	58 Ce Cerium 140.12	59 Pr Praseodymium 140.91	60 Nd Neodymium 144.24	61 Pm Promethium (145)	62 Sm Samarium 150.36	63 Eu Europium 151.96	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93	68 Er Erbium 157.26	69 Tm Thulium 168.93	70 Yb Ytterbium 173.05	71 Lu Lutetium 174.97
Actinoids	89 Ac Actinium (227)	90 Th Thorium 232.04	91 Pa Protactinium 231.04	92 U Uranium 238.02	93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

STRANGE BUT TRUE
ELEMENTARY BIOLOGY

What's the most abundant element in your body?

A Hydrogen **B** Carbon **C** Gold

Answer:
Our bodies are mostly water (H_2O), so as a result hydrogen makes up 67 per cent of the average human body's total 7 x 10^{27} atoms. Because hydrogen is very light, however, it only accounts for around ten per cent of our mass.

DID YOU KNOW? *The element mercury owes its unusual chemical symbol – Hg – to hydrargyrum, Latin for 'liquid silver'*

Building blocks

Take a glance at the key information displayed in each element on the table

Atomic number
The number of protons and electrons in the element.

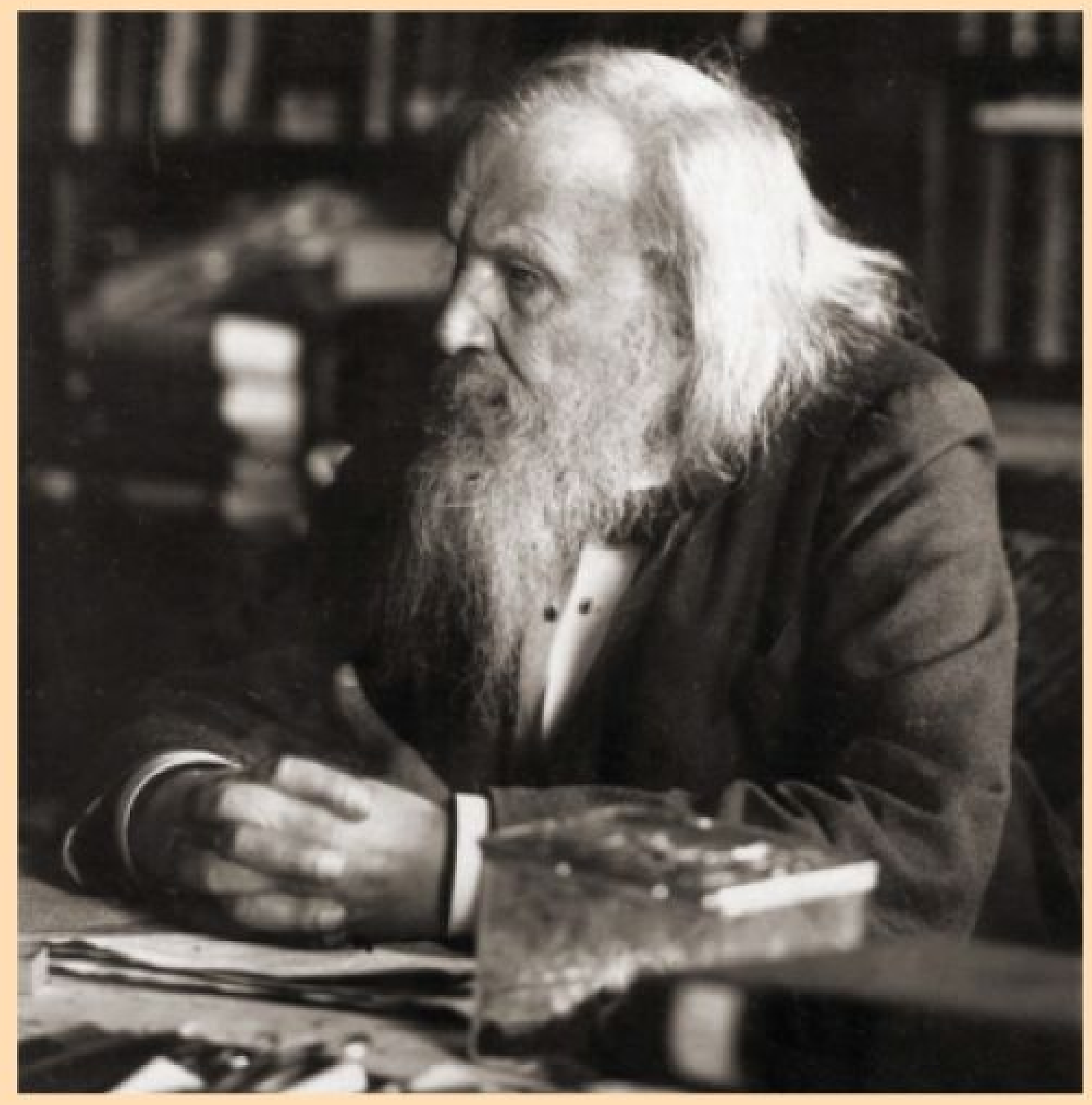
Chemical symbol
One or two letters used as a short form to represent the element.

Title
The element's full name for those who don't know their symbols.

Atomic mass
The mass of an atom, which is measured in atomic mass units. This also takes into account the atom's neutrons.

Mendeleev's table

Russian chemist Dmitri Mendeleev published one of the earliest versions of the periodic table in 1869, laying the foundations for the table we know today. Ordering over 60 known elements according to their atomic weight, he noticed that elements with similar properties occurred at regular intervals – in other words, periodically. Grouping elements to reflect these trends, three gaps remained. Mendeleev concluded that undiscovered elements must fill these gaps, deducing some of their properties from their position in the table. The discovery of gallium, scandium and germanium soon after confirmed Mendeleev's predictions, and scientists worldwide adopted his table. Over the years, Mendeleev's table has been updated to include previously unknown groups of elements such as the noble gases, and re-ordered by atomic number to create a more accurate arrangement.

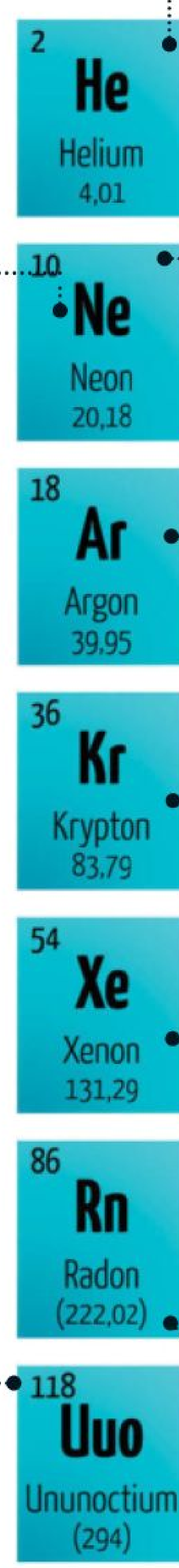


Grouping the elements

The table's 18 groups, displayed in columns, have the most in common due to their shared electron configurations. Trends also exist within groups. For example, as you move from top to bottom, you need more energy to tear an electron away from its atom (ie ionisation energy increases).

Within periods, the table's horizontal rows, similar patterns exist but they are generally weaker. Periods owe their shared characteristics to having the same number of electron shells. Generally, as you move from left to right, elements become more reactive and their size (atomic radius) increases.

Group 18 (noble gases)



Helium
Outer shell electrons: **2 (out of 2)**
Protons in nucleus: **2**
How reactive relative to other elements:
Very unreactive

Neon
Outer shell electrons: **8 (out of 8)**
Protons in nucleus: **10**
How reactive relative to other elements:
Very unreactive

Argon
Outer shell electrons: **8 (out of 8)**
Protons in nucleus: **18**
How reactive relative to other elements:
Very unreactive

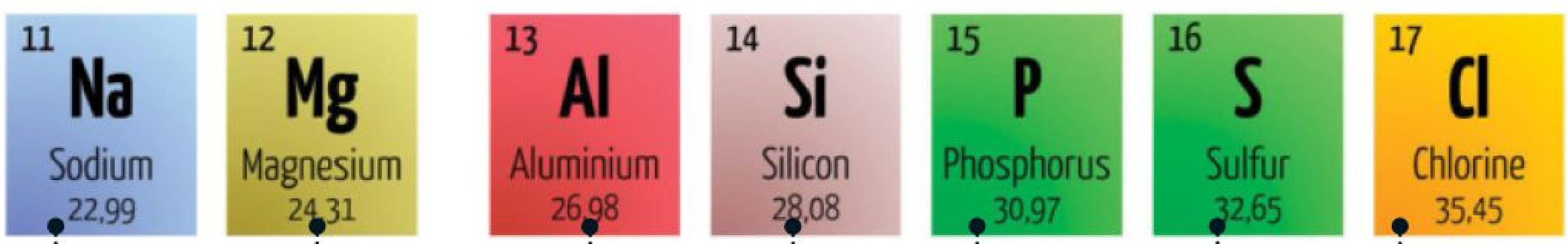
Krypton
Outer shell electrons: **8 (out of 8)**
Protons in nucleus: **36**
How reactive relative to other elements:
Very unreactive

Xenon
Outer shell electrons: **8 (out of 8)**
Protons in nucleus: **54**
How reactive relative to other elements:
Very unreactive

Radon
Outer shell electrons: **8 (out of 8)**
Protons in nucleus: **86**
How reactive relative to other elements:
Very unreactive

Ununoctium
Outer shell electrons: **8 (out of 8)**
Protons in nucleus: **118**
How reactive relative to other elements:
Very unreactive

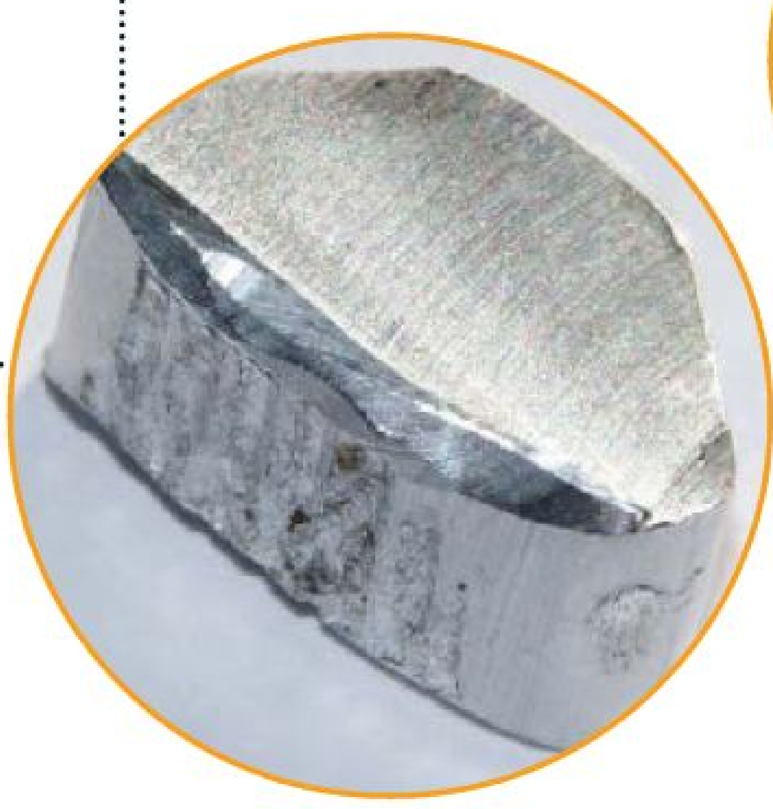
Period 3



Sodium
Outer shell electrons: **1**
Protons in nucleus: **11**
How reactive relative to other elements:
Extremely reactive

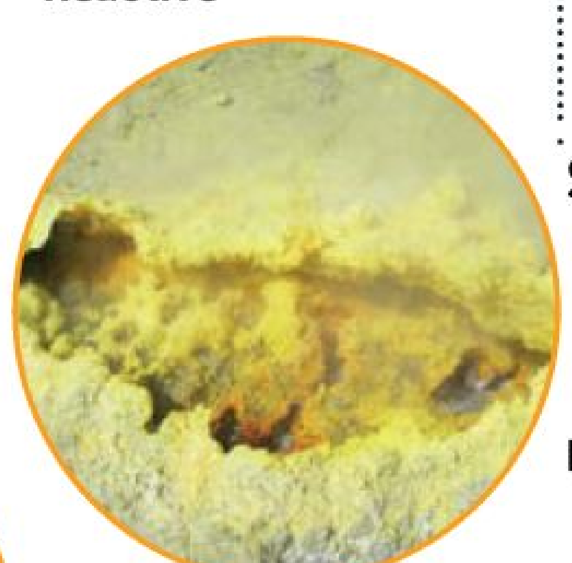
Magnesium
Outer shell electrons: **2**
Protons in nucleus: **12**
How reactive relative to other elements:
Highly reactive

Aluminium
Outer shell electrons: **3**
Protons in nucleus: **13**
How reactive relative to other elements:
Reactive



Silicon
Outer shell electrons: **4**
Protons in nucleus: **14**
How reactive relative to other elements:
Relatively unreactive

Phosphorus
Outer shell electrons: **5**
Protons in nucleus: **15**
How reactive relative to other elements:
Reactive



Sulphur
Outer shell electrons: **6**
Protons in nucleus: **16**
How reactive relative to other elements:
Reactive

Chlorine
Outer shell electrons: **7**
Protons in nucleus: **17**
How reactive relative to other elements:
Highly reactive

> "Muscles are the driving force behind sporting ability, but there is a trade-off between power and endurance"

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.

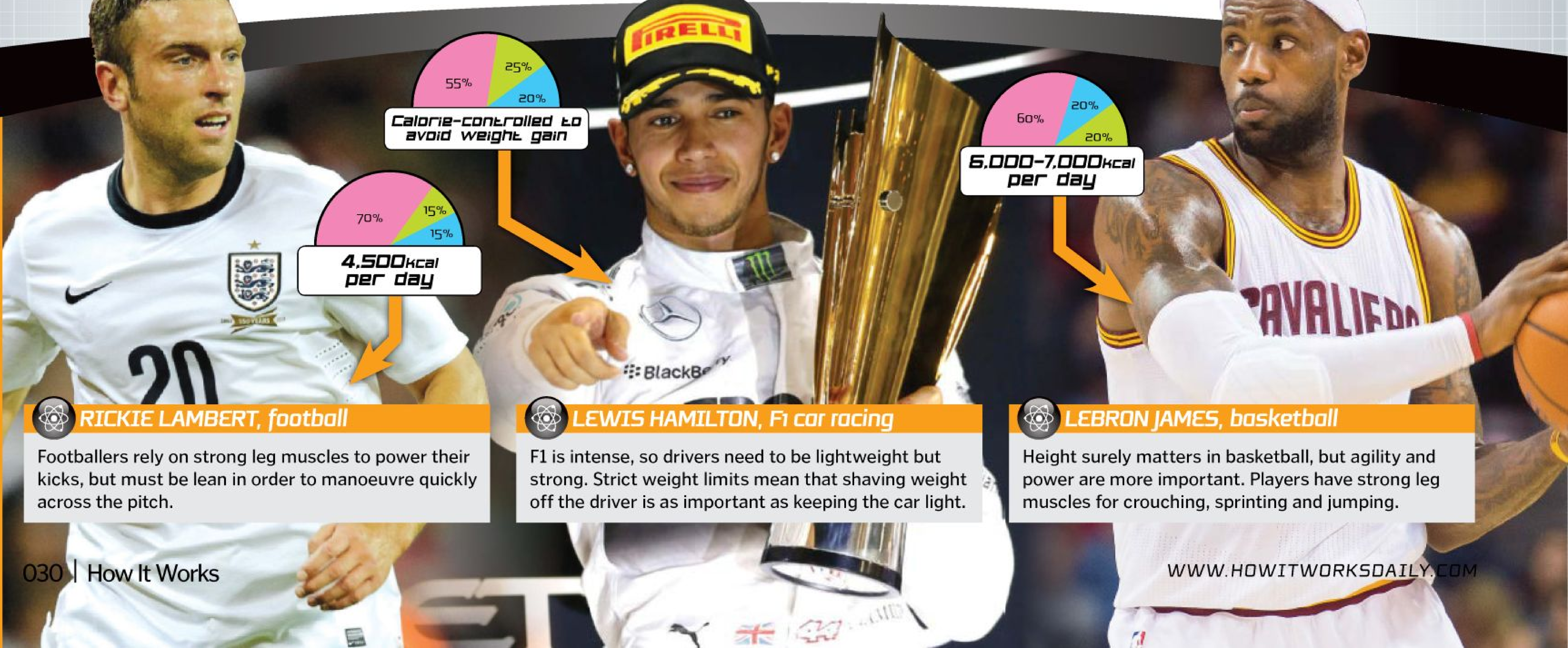
MICHAEL PHELPS, swimming

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

Carbohydrate Fat Protein

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.

5 TOP FACTS OLYMPIC MEDALLISTS

Michael Phelps, USA

1 US swimmer Michael Phelps is by far the most prolific Olympic medal winner, taking home 18 gold, two silver and two bronze medals between 2004 and 2012.

Larisa Latynina, USSR

2 Larisa Latynina was a phenomenal gymnast, winning nine gold, five silver and four bronze medals between 1956 and 1964. She excelled at a number of events, from the balance beam to the uneven bars.

Paavo Nurmi, Finland

3 The Finnish long-distance runner Paavo Nurmi won nine gold and three silver medals between 1920 and 1928, proving his ability both on the track, and cross country.

Mark Spitz, USA

4 Swimming legend Mark Spitz won nine gold medals, one silver and one bronze between 1968 and 1972. Seven of his gold medals were awarded in a single year.

Carl Lewis, USA

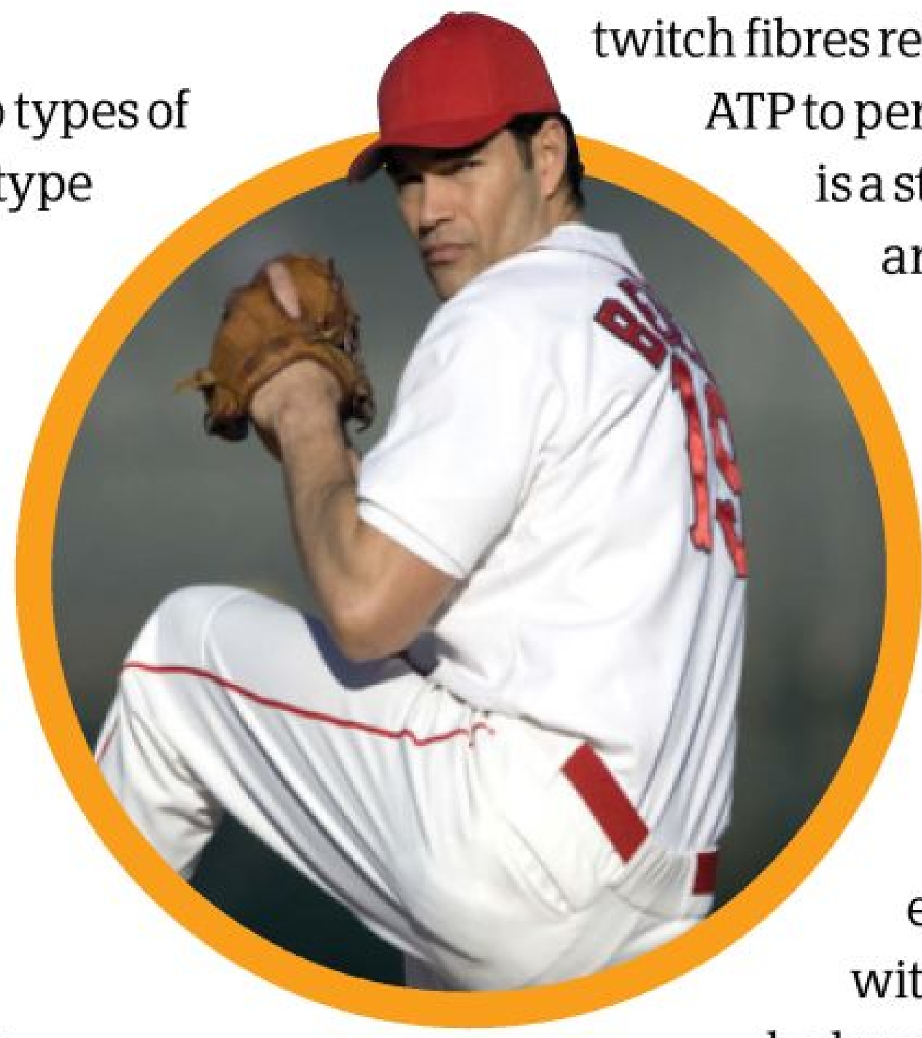
5 Runner and long jumper Carl Lewis won nine gold medals and one silver in his Olympic career. He won the long jump in four consecutive Games between 1984 and 1996.

DID YOU KNOW? *Sabine Lisicki broke the record for the fastest women's tennis serve in 2014, hitting the ball at 211km/h (131mph)*

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.

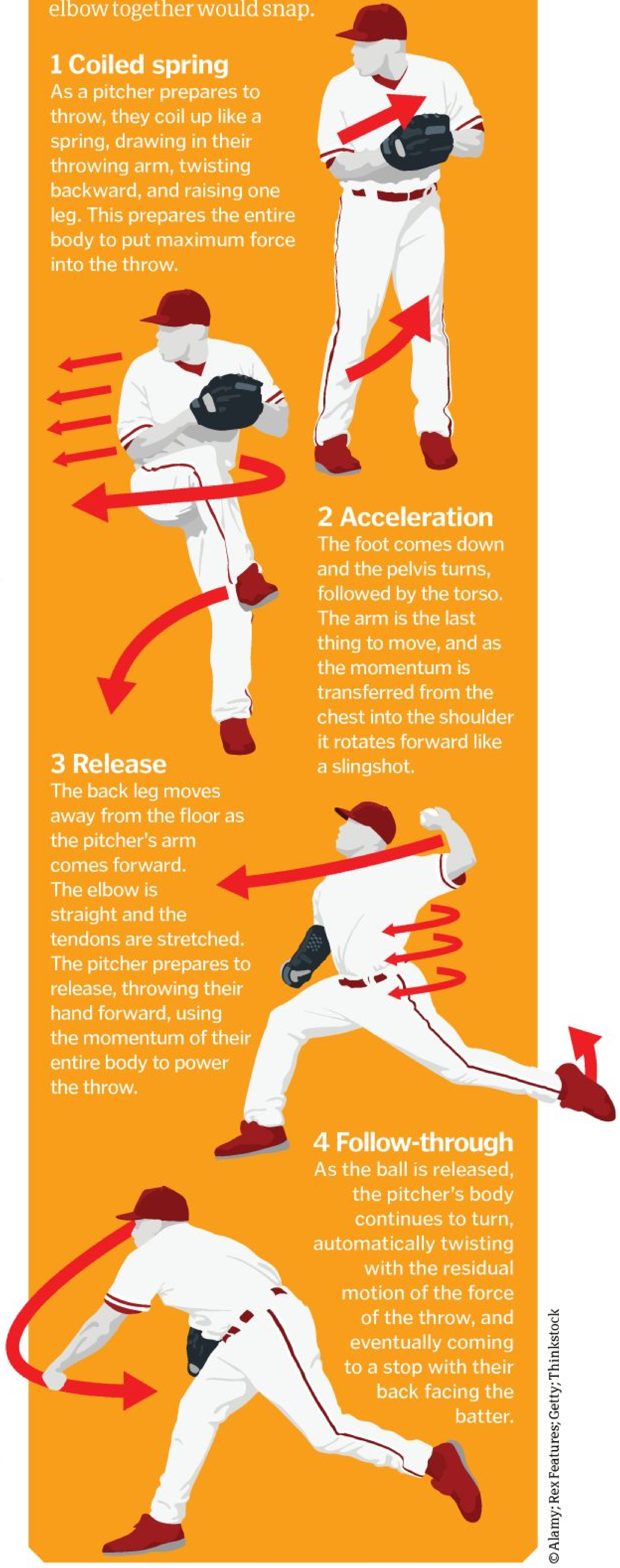
A molecule known as creatine phosphate is used to quickly restoring ATP for reuse, supplying an additional eight to ten seconds of activity without oxygen. Glucose can also be burnt anaerobically creating a smaller amount of ATP, and giving around 90 seconds of breathing-free muscle power. A men's 100-metre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

"As the muscles work, waste products like carbon dioxide, potassium and acids start to build up"

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

1. FAST

Shelly-Ann Fraser-Pryce
The current 100-metre women's world champion is Jamaican Shelly-Ann Fraser-Pryce, who set a time of 10.75 seconds at the Olympic Games in 2012.

2. FASTER

Carmelita 'The Jet' Jeter
Carmelita Jeter achieved the second-fastest recorded 100-metre sprint, covering the distance in an incredible 10.64 seconds.

3. FASTEST

Florence Griffith-Joyner
US athlete Florence Griffith-Joyner set the world record for the women's 100-metre sprint in 1988 with a time of 10.49 seconds.

DID YOU KNOW? *The world marathon record is two hours, two minutes and 57 seconds, set in 2014 by Dennis Kimetto*

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 important to stretch and strengthen the area after the initial healing process.

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.

"Contrary to popular belief, lactate acts to neutralise the acid, not to create it"

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 be broken down to produce more energy.

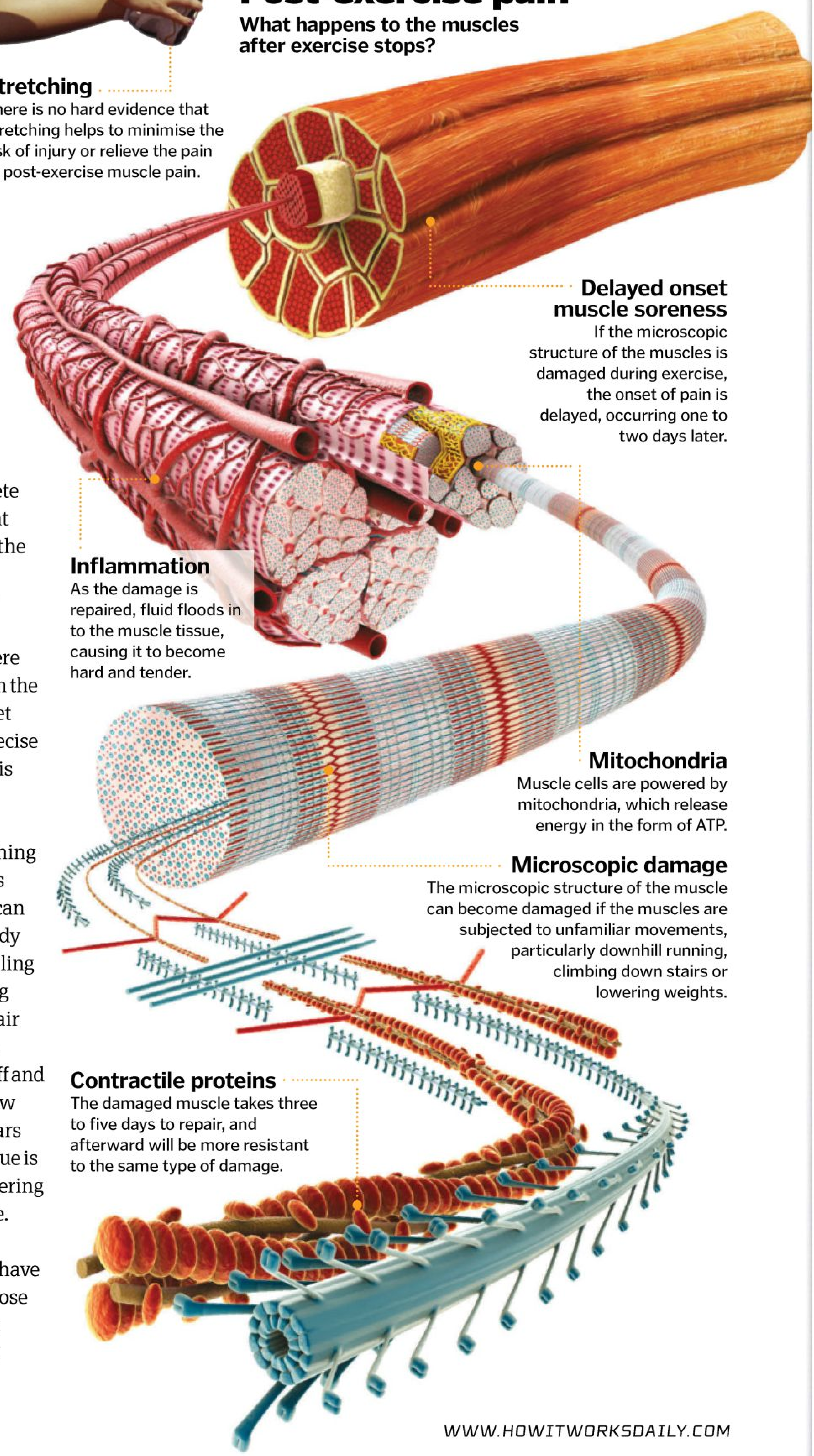
The more an endurance athlete trains, the better they become at using up the H+ and the slower the lactate builds, meaning elite athletes can exercise for longer before feeling the burn.

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.

Post-exercise pain

What happens to the muscles after exercise stops?



2.45 METRES

HIGH JUMP WORLD RECORD

The men's high jump world record was set in 1993 by Cuban athlete Javier Sotomayor, who leapt over a bar a staggering 2.45m (8.04ft) off the ground.

DID YOU KNOW? *The resting heart rate of an elite athlete is ca 40 beats per minute, compared to 70 for an untrained person*

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 the head in line with the straight body and facing down toward the floor of the pool.

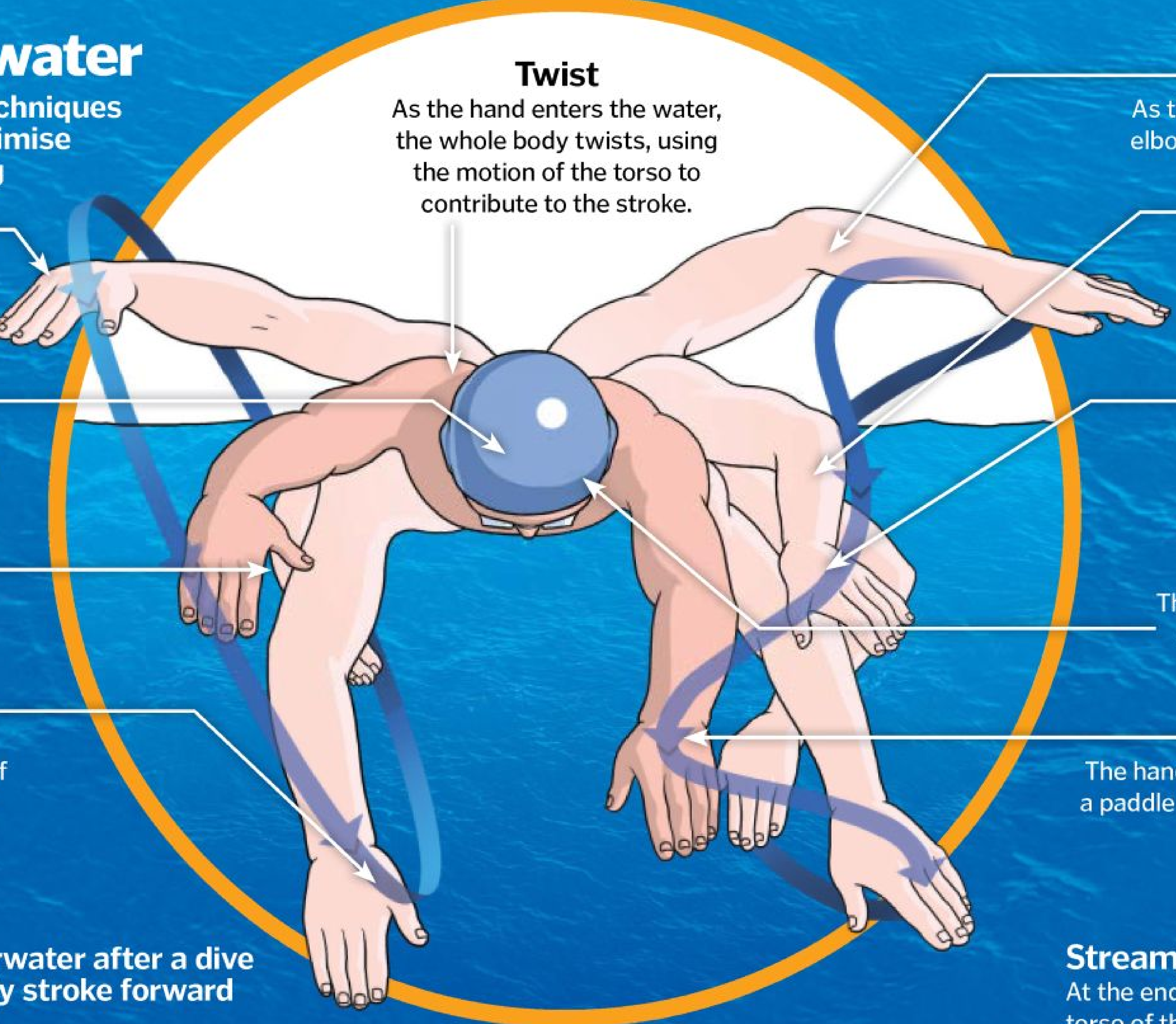
With each stroke, freestyle swimmers rotate from side to side, using the core muscles in their backs and shoulders to contribute to each movement. This allows them to efficiently slice through the water, and also enables them to reach farther with each arm movement, pulling more water back with their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



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

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.

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.

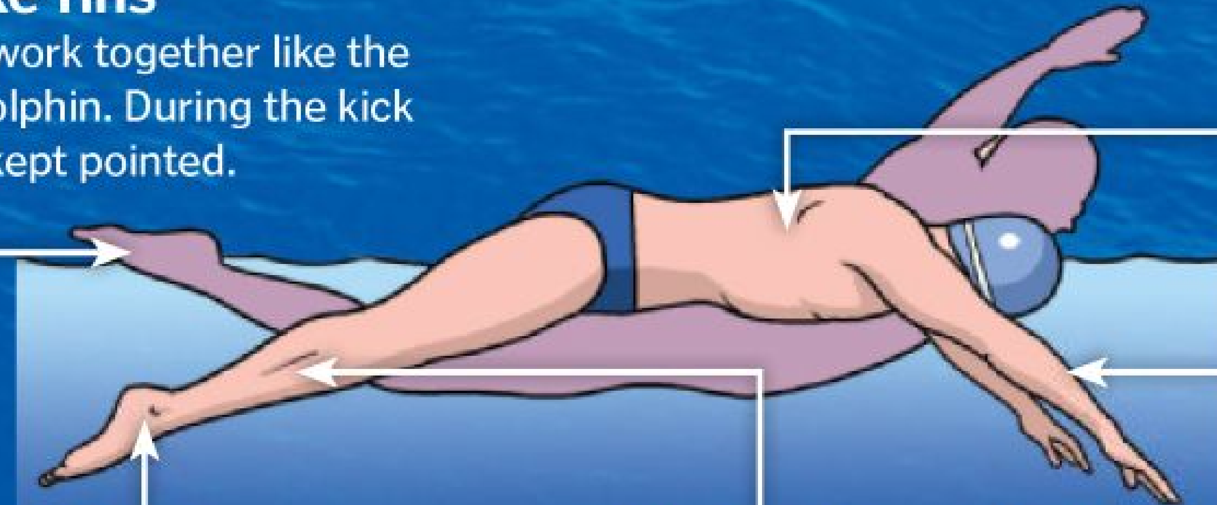
Sculling
With a sculling stroke, the elbow is bent and the arm moves in an S-shape through the water.

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



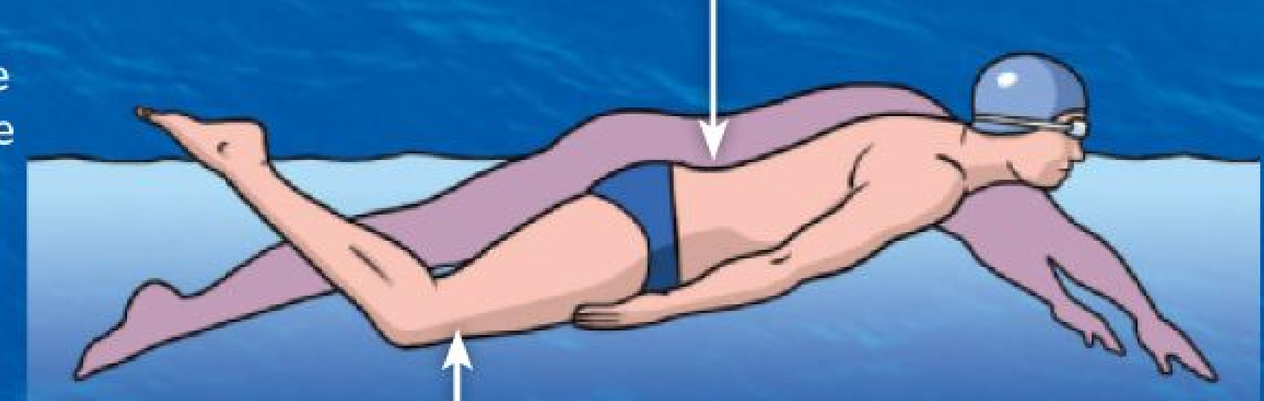
Feet like fins
The feet work together like the fin of a dolphin. During the kick they are kept pointed.

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.

AMAZING SCIENCE EXPERIMENTS THAT YOU CAN DO AT HOME

You need neither a laboratory nor a degree in quantum physics for these…

Modern science is steeped in the theories of the traditional categories of chemistry, physics and biology. Each area is broad enough to help organise the diverse and wondrous nature of the world around us. They aid the pursuit of scientific knowledge for all, information that we can use to better understand the laws that govern us, the Earth, and the wider universe, as well as benefit us day-to-day. And thanks to a growing worldwide network of scientists pushing the boundaries of discovered knowledge, science is being continuously filled with new and exciting discoveries that would never have been dreamed of even 100 years ago.

Excitingly, these discoveries are not exclusively available to just a select circle of academics and scientists. Any one can embark on a mission of scientific discovery thanks to the fascinating process of experimentation, whereby a person can simply imagine a scenario or a theory before going and testing it themselves. Indeed, it's thanks to individuals challenging accepted norms and imagining a better world that some of society's greatest tools and machinery have been invented, from the solid rocket boosters capable of taking a man to the moon to the simple light bulb illuminating a room.

In this feature, the **How It Works** team aims to showcase the joy of scientific experimentation, with 20 of the very best 'do it yourself' projects that anyone can undertake in their own home. Using little more than a handful of household products and everyday apparatus, these experiments are not only incredibly fun to engage in, they also demonstrate fundamental scientific processes and help to highlight some of the forces and substances that we make use of every day. From the power of steam and convection, through to the vibratory nature of sound and awesome effects of vacuums, and on to the malleable nature of plastics (among many others), we hope that the following 20 projects help you to better understand how the world works and spur you on to perform your very own experiments.

So, what are you waiting for? Don that lab coat, put on those protective goggles and raid your kitchens and bathrooms, as adventure and knowledge awaits!

Disclaimer
While the following experiments are guaranteed to amaze and astound, they should all be conducted with the utmost care. If any member of the experimenting team is under 18, parental supervision should be ensured at all times. In addition, ensure all members of the experimenting team wear protective clothing – including protective eye goggles – and that no substance is mishandled or ingested. It must be noted that Imagine Publishing and its staff cannot be held responsible for injury or distress caused by engaging in any of the following experiments.

ICON KEY:
Difficulty – This shows the difficulty on a scale from one to five, five being the hardest.
Time – This denotes the length of time needed to complete the experiment.
Danger – The danger level of the experiment. Green = low, Amber = medium, Red = high.

Equipment
Cola
Diet cola
Diet lemonade
Orangeade
Mentos
Toothpicks

STAND BACK WHEN THE REACTION STARTS

5min

Mentos and cola jet

How well does this famous experiment work with other liquids?

You may have seen this popular experiment loads of times before, but does it also work with other liquids? Here's our step-by-step guide to how to test the Mentos and cola jet.

Variables
Would other sweets work? What else could you use to cause this reaction?

STEP 1
Place one of your fizzy drinks on a flat surface outside, away from any electrical equipment, and open the lid (ensure as little gas as possible escapes).

STEP 2
Align two toothpicks on top of the bottle, and place one of the Mentos between them. Take care not to drop it in.

STEP 3
Quickly pull the toothpicks away and step back. After a second or two, the whole bottle fizzes up and the liquid shoots upwards in a vertical column.

STEP 4
Repeat the experiment with other fizzy drinks, and observe the different heights of the ejected liquids.

WHAT HAVE YOU LEARNED?

This explosive reaction is due to the thousands of tiny pits, or dimples, on the surface of the minty Mentos. The intensity of the reaction is determined by the surface tension of the soda being used, ranging from the lowest (diet orangeade) to the highest (diet cola). As the Mentos come into contact with the soda, a huge number of bubbles are created at their surface, covered in a surfactant known as 'gum arabic'. These sweets are dense, so they sink rapidly, producing more bubbles as they pass through the liquid that, in turn, create further bubbles. You can prove this by washing the Mentos in water before dropping them into the soda. The now-smooth sweets will produce no reaction.

Why do some drinks outperform others? It's partly due to the presence of the artificial sweetener aspartame, which makes the surface tension of the liquid much less than without it. This was present in our diet cola and lemonade, but not the regular cola or orangeade. The lower the surface tension in the liquid, the faster the bubbles can form.

DO NOT APPLY PLASTIC TO ORGANIC SURFACES

24 hr

Fantastic plastic

Understand the meaning of the phrase 'plastic fantastic' with this simple home experiment

Equipment
Saucepan
Food colouring
Spatula
Stove
Starch
Water
Glycerine (from a pharmacy)
Vinegar
Tin foil

STEP 1
To start, take your saucepan and add four tablespoons of water and a single tablespoon of starch. Then add a teaspoon of vinegar and glycerine to the mixture and stir vigorously until it is completely mixed together.

STEP 2
Now take the saucepan and place it on the stove on a low heat. Stir the mixture continuously as it warms up. As the mixture heats it will begin to transform from a murky liquid into a clear gel. When the transition is complete, the gel should be completely transparent.

STEP 3
When the gel turns clear and begins to bubble, add your food colouring and mix it in. Then take the saucepan off the stove and spread the gel across a sheet of tin foil into any shape you desire. Try to make it as thin a spread as possible. Once achieved, leave the tin foil in a safe place for 24 hours. If the experiment has been conducted properly, after this time the gel will have hardened into a sheet of homemade plastic.

Variables
What happens if you add more glycerine to the mix? Does this make the plastic harder or more malleable?

WHAT HAVE YOU LEARNED?

This experiment helps demonstrate the ease of construction and versatility of plastic, highlighting the reason for its widespread use in society. Plastics are made from a variety of synthetic or organic solids and typically are polymers of a high molecular mass. Due to this, they are very malleable, a quality for which they are prized, as they can be easily moulded, cast, pressed or extruded into a variety of shapes. This makes plastic ideal for applications where a lightweight flexible material is desired, such as for fizzy drink bottles. This experiment shows both the malleable nature of plastic – ie how you can spread it like a paste into a bespoke form – and also how plastics are created by heating the raw ingredients and dying them for a certain colour. Interestingly, plastics are broken down into two categories – thermoplastics and thermosetting polymers. The former are plastics that do change chemically when heated and can be re-moulded continuously, while the latter are those that don't change and can only be melted and moulded once.

DO NOT EAT APPLE SEGMENTS

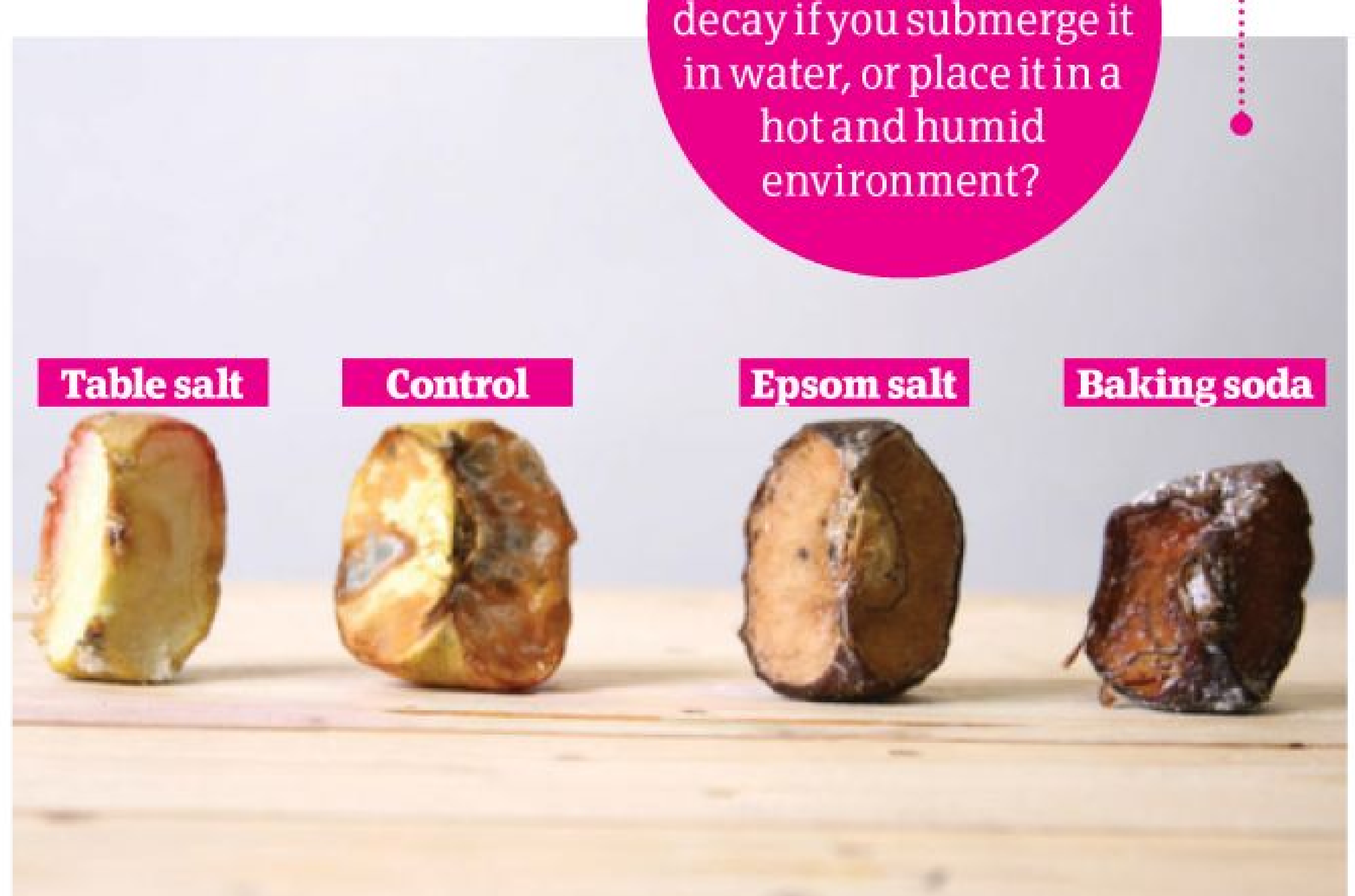
1wk

Rotting apples

Learn about the science of decay and preservation with a single, shiny apple

STEP 1
Take your four plastic cups and label them one to four. Next take your apple, cut it evenly into four segments and place each of the segments in a cup.

STEP 2
Add the table salt, Epsom salt and baking soda to each of the cups except the fourth one – this will be your control segment to compare the other apple segments to.



Variables
What happens to the apple's rate of decay if you submerge it in water, or place it in a hot and humid environment?

Equipment
A fresh apple
Knife
Four plastic cups
Table salt
Epsom salts (baths salts)
Baking soda
Spoon

STEP 3
After leaving the cups for one week in a cool, dark place, take the four apple segments out of their cups and compare their varying degrees of decay.

WHAT HAVE YOU LEARNED?

Organic substances can have their rate of decay either slowed or increased, dependent on the context of their storage. For example, table salt is a good preservative, as it removes all the moisture from the apple. Epsom salts, however, speed up the rate of decay, while placing apple in baking soda seems to merely change its colour. The key to the rates of decay is how far they can protect the apple segments against microorganisms, which thrive best in hot, moisture-rich conditions. This is why refrigerators help slow decay, as they remove moisture from the atmosphere and reduce the ambient temperature.

CATEGORY:
REACTIONS

5 min NOT EDIBLE

Giant toothpaste

Speed up the reaction of hydrogen peroxide to produce some impressive foam

STEP 1
Pour about two tablespoons of hydrogen peroxide into the bottom of an empty plastic bottle. Add food colouring for aesthetic effects, and a tablespoon of washing-up liquid as well.

STEP 2
Mix one tablespoon of yeast with two of hot – but not boiling – water.

STEP 3
Pour your yeast mixture into the bottle, but get ready because you're about to see the reaction in action…

WHAT HAVE YOU LEARNED?

The main thing to note from this experiment is that the hydrogen peroxide is being made to decompose into oxygen and water very quickly, much more so that it would naturally if left to stand. This is made possible by adding a catalyst, in this case yeast. This catalyst breaks the hydrogen peroxide down rapidly, resulting in a lot of oxygen and water being produced. By adding soap to this reaction, the release of oxygen turns the soapy water into a multitude of tiny bubbles that resemble foam. These bubbles have nowhere to go and so they fire out of the bottle. The more concentrated the hydrogen peroxide is the more oxygen it contains, releasing more of it when the reaction occurs and resulting in a more violent or larger reaction.

Equipment
Empty plastic bottle
Tray
Food colouring
Dry yeast
Hot water
Washing-up liquid
Hydrogen peroxide solution (3-6% concentration from a pharmacy)

STEP 4
The liquid in the bottle will now rise up and turn into a thick foam, safe to touch but not to ingest.

Variables
Could you use a different catalyst to produce this experiment? Is there a liquid other than hydrogen peroxide that will produce the same effect?

30 m BE CAREFUL WITH THE HOT SAUCEPAN

Colour-changing liquid

Equipment
Red cabbage
Saucepan
Sieve
Glass
Milk of magnesia
Vinegar
Spoon
Water

Make a liquid move through the entire pH scale

Variables
What other acidic and alkali liquids could you use to further this experiment?

STEP 1
First, you need to make a universal indicator that will visualise the change in pH. To do this, soak two cups of chopped red cabbage in boiling water for ten minutes, and then pass it through a sieve to obtain the resultant purple liquid.

STEP 2
Place 100ml of milk of magnesia inside a 500ml beaker and mix with water until it is half full.

STEP 3
Add 10ml of the universal indicator you made in step 1, and stir the mixture until it turns blue/purple, indicating an alkali pH.

WHAT HAVE YOU LEARNED?

Milk of magnesia contains magnesium hydroxide, which is a fairly strong alkali. When a universal indicator is added, it shows the pH of the milk of magnesia solution, which will be somewhere above pH 7. However, adding an acid such as vinegar neutralises the alkali. The universal indicator continues to show the pH level, and as more acid is added, the alkali is overpowered. This means that the liquid will move down the pH scale, gaining acidity as it does so.

STEP 4
Continue stirring your solution and start adding some vinegar, a little at a time. If you do it slowly enough, the mixture should change to light blue, then green, then yellow, and finally settle at red, indicating an acidic pH.

Equipment
Jug
Water
Juice carton
Soft metal tubing
Marker pen
Tea light candle
Sellotape (double-sided)

1hr AVOID OPEN FLAME

Steam boat

Set sail for scientific knowledge by making this steam-powered boat

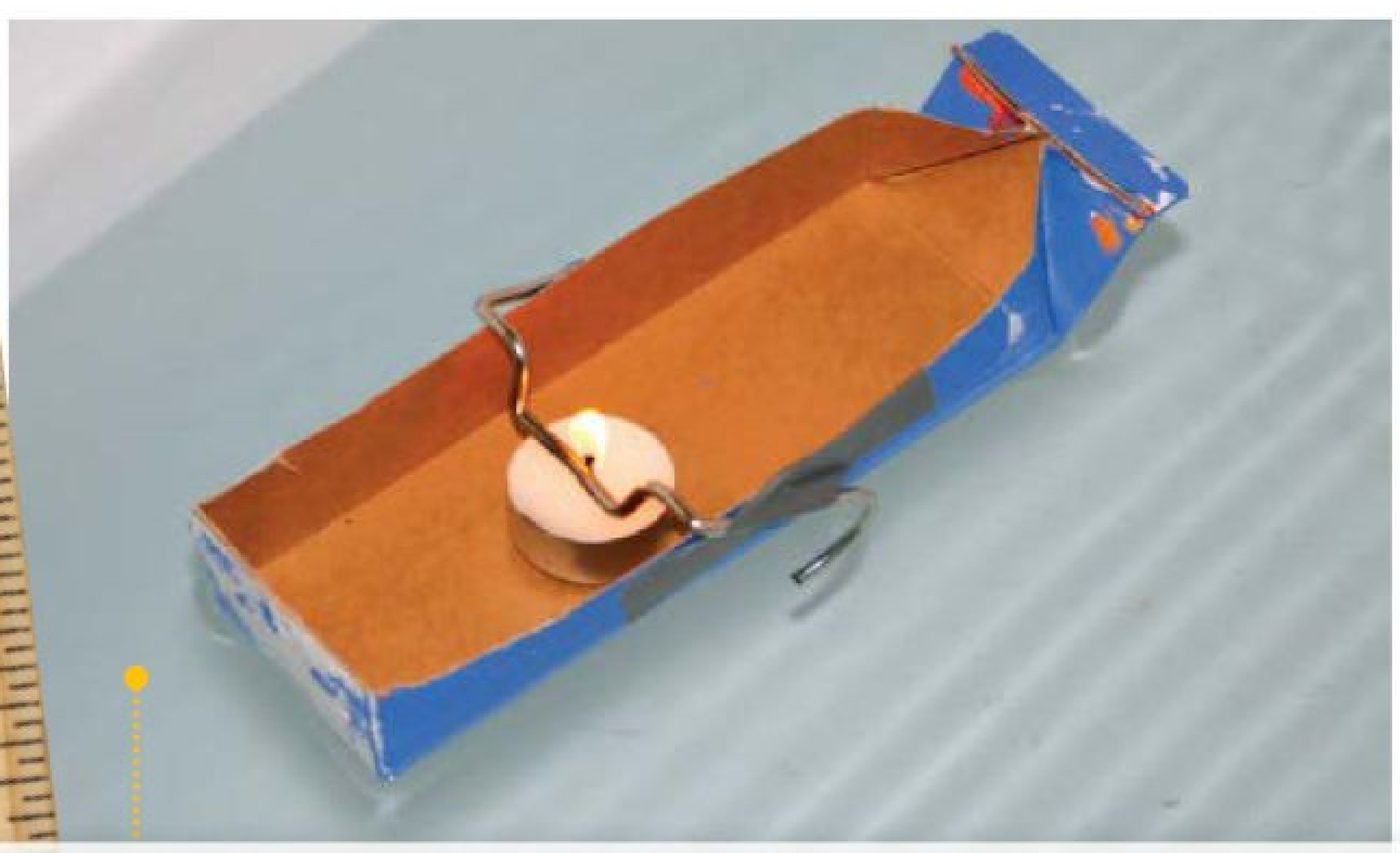
STEP 1
Take your cardboard juice carton and cut it in two, as one of the resultant halves is going to act as the body of a mini steamboat. When cutting, ensure that the sides of the carton half you choose are at least 5cm (2in) high.

STEP 2
Next, take the hollow metal tubing and wrap it around a pen to create a shape that can rest over the boat, but that also falls into the water and points backwards. You could also use an N-shape poking through the back of the boat into the water.

STEP 3
Once the metal tube is fashioned correctly, use tape to stick it onto the boat. Next, stick your candle to the base of the carton so that the wick is directly beneath the middle of the tube. The flame needs to be able to reach and heat the tube.

Variables
What happens if you add a larger candle to the boat? Does this increase its speed?

STEP 4
Pour water from your jug into the ends of your metal tubing until it's full. Hold your fingers over both ends and place it in some water, such as a bath. Take your fingers away, light the candle and wait a minute for the boat to move around.



WHAT HAVE YOU LEARNED?

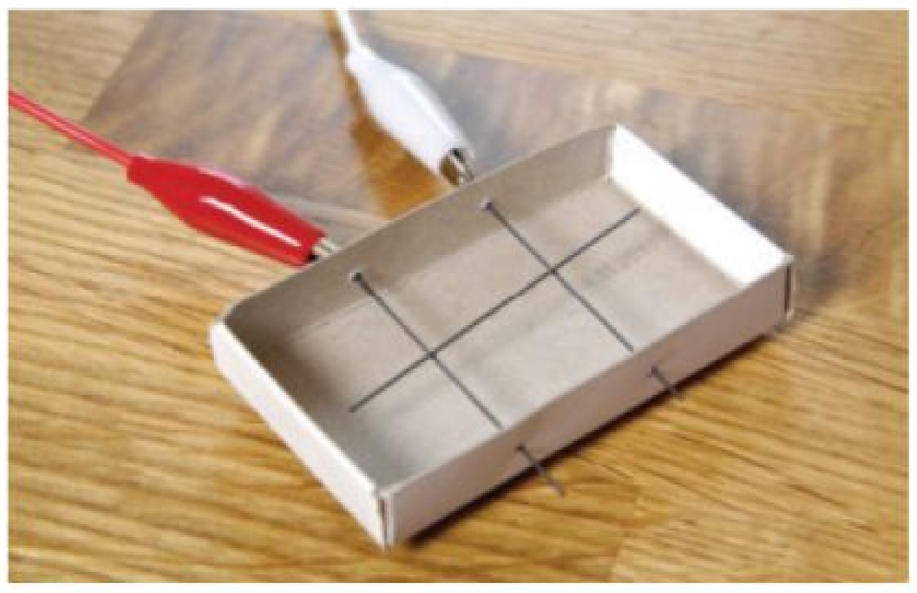
Water, when heated, is converted into steam. Steam expands down the metal tubes. This forces the water out of the tube, granting the boat a burst of momentum. However, as the steam leaves the metal tubing, the water cools it as the candle is no longer close enough to heat it, causing the steam to condense back into water and lower the pressure inside the tubing. This causes water to be drawn back into the tube for further heating. The process then repeats itself.

15m DO NOT KEEP CIRCUIT ACTIVE FOR LONG PERIODS

Mini microphone

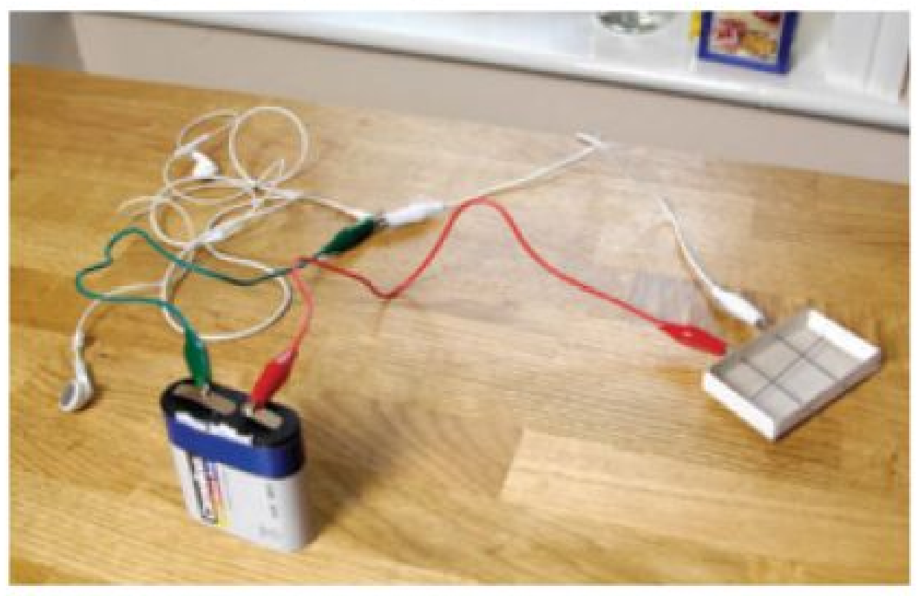
Discover how sound is generated with the aid of some basic electrical equipment

Equipment
Two pencil leads
Pencil
Scissors
Matchbox
4.5-volt battery
Earphones
Copper wire (30 centimetres)
Crocodile clips



STEP 1
Take a matchbox and empty it. Then with your pencil pierce two holes at either end, roughly 3cm (1in) apart halfway up. Ensure the holes line up with each other.

STEP 2
Snap two of your pencil leads so they are roughly 1cm longer than the tray and insert them through the holes. File down their tips with your pair of scissors to help.



STEP 3
Snap the remaining lead so it lies across the two inserted leads, without touching the sides. Add some horizontal scratches.

STEP 4
Take your copper wire and attach clips to each of the six ends. Connect your battery to one of the tray's exterior leads as well as the jack of the earphones. Using your last piece of wire, connect the other exterior lead to the headphone jack. Once the circuit is completed, try talking into the matchbox while a friend listens.

WHAT HAVE YOU LEARNED?

When you speak into the matchbox, the leads vibrate, an action that pushes against the air hundreds of times per second. A series of high-pressure compressions and low-pressure rarefactions vary the electric current flowing through the leads from the battery. It is these variations in current that the earphones can convert back into sound.

Variables
What happens if you add more leads to the tray? Does this affect the sound?

20m AVOID GETTING BAKING SODA IN EYES

Erupting volcano

STEP 1
Fill your bottle three quarters with warm water. Add two heaped tablespoons of baking soda before applying the lid and mixing the bottle until the soda dissolves.

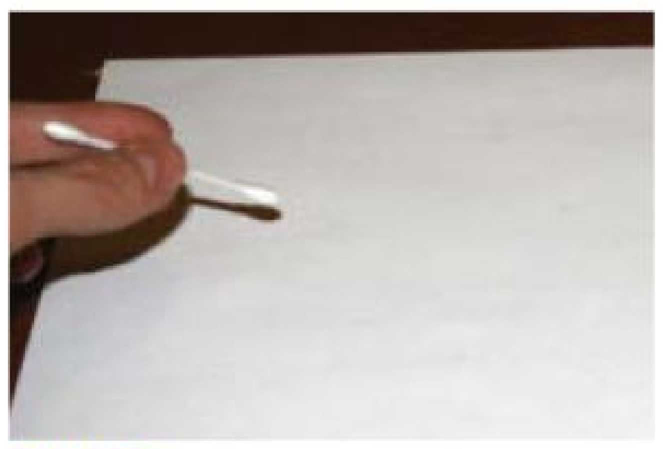
STEP 2
Now add your red food colouring to the water, as well as a decent squirt of washing-up liquid, before mixing the bottle once more.

CATEGORY:
MAKE YOUR OWN…

Invisible ink
Learn how to make your own secret messages

Equipment
Baking soda
Water
Glass
Grape juice
Cotton buds
Paintbrush

GRAPE JUICE CAN STAIN CLOTHING



STEP 1
Mix equal parts baking soda and water, and collect some on the end of a cotton swab.

STEP 2
Write your message on a piece of paper and allow it to dry until it has turned invisible.

STEP 3
Use a paintbrush to spread grape juice over your message. Watch as it reappears.

Variables
Could you use acids and alkalis other than grape juice and baking soda to perform the experiment?

WHAT HAVE YOU LEARNED?
This is an example of acids and alkalis reacting. Baking soda is an alkali, with a pH higher than neutral 7, whereas grape juice is an acid with a pH below 7. When the two come into contact, they react. In this instance, one of the results of the reaction is that the new solution changes colour.

DO NOT FIRE CANNON AT FACES

Vacuum cannon
Fire sock missiles thanks to the awesome power of a vacuum

Equipment
Vacuum cleaner
Tin foil
Two cardboard tubes
Socks
Blu-Tack
Cardboard
Scissors

Variables
What happens if you make the sock missile smaller? Does this make it fly further?

STEP 1
Wrap your socks in foil so they form a tubular/circular missile. Ensure that the missile fits in the end of one of your cardboard tubes.

STEP 2
Take one of the tubes and cut two curved semicircles in one of its ends. Then trim the tube down at the other end to about 30cm (12in).

STEP 3
Take the other tube and cut a hole in one of its ends. The hole should be roughly 10cm (4in) in from the end of the tube. Slot the 30cm (12in) tube into the tube with the hole.

STEP 4
Your tubes should slot together, with the 30cm (12in) tube clear. Tape the two so the joining is airtight. Now insert the end of the vacuum's hose into the other end of the semicircle tube and tape the joining.

STEP 5
Now turn on your vacuum and place a piece of cardboard over the shorter end of the 30cm(12in) tube. Hold your sock missile at the other end of the tube, aim at a target and release.

WHAT HAVE YOU LEARNED?
This experiment helps demonstrate the effects of pressure changes within a local environment. By sucking the air out of a sealed tube, the pressure inside it drops, as there is less air to fill the same area of atmosphere. However, the air pressure outside the tube remains at an environmental constant, creating a large pressure differential. This differential means that when the seal is broken on the tube – ie, when you release the sock missile – the higher-pressure air forces itself forward to fill the low-pressure area within the cannon. This propels the sock missile forward and out the other end of the tube. Interestingly, this is exactly how your vacuum cleaner works.

Uncover the mysteries of acids and bases with this miniature volcano

Equipment
Plastic bottle
Baking soda
Washing-up liquid
Water
Red food colouring
Vinegar
Tray
Sand

STEP 3
Put your tray on a flat surface before placing the bottle at the centre. Pile your sand up around it until you create a cone, with only a hole left at the bottle's neck.

STEP 4
Take your vinegar and pour it liberally into the top of the cone. The vinegar will fall down into the bottle and cause an eruption of red liquid to froth out and down the sides of the cone, just like a mini volcano.

Variables
What happens if you increase the temperature of the water or the amount of baking soda?

WHAT HAVE YOU LEARNED?
The eruption of the mini volcano is caused by the bringing together of an acid and a base. The vinegar contains acetic acid and the baking soda sodium bicarbonate (a base). They react to produce sodium acetate (a salt), as well as carbonic acid. The latter product is key to the eruption, as carbonic acid breaks down in water into carbon dioxide, causing a gaseous frothing of the red solution up the inside of the bottle and out over the sides of the cone. This behaviour, according to the Brønsted definition of acids and bases, is because bases decrease the concentration of hydrogen ions by accepting them from acids, which themselves are defined by their ability to give them away. In our example, this was shown by the baking soda accepting the carbonic acid's hydrogen ions, causing it to rapidly decompose in the solution and release carbon dioxide.

Equipment
Cornflour
Container
Food colouring
Water

MAKE SURE THE CONTAINER IS STABLE WHEN STANDING ON IT

10m

Walk on water

Can a liquid really support the weight of a human?

STEP 1
Stir in about two parts cornflour to one of water. Add food colouring if you want.

STEP 2
Keep stirring and adding cornflour/water until the liquid becomes thick.

STEP 3
Give your liquid a squeeze, or step on it. The more pressure you apply, the more it solidifies.

STEP 4
Letting go of the 'solid' will return it to a liquid again.

Variables
Use something with a higher starch content. Will this effect be more apparent?

WHAT HAVE YOU LEARNED?

Newton's laws dictate that the only thing that can change the viscosity of a liquid is temperature. This type of liquid is commonly known as a 'non-Newtonian' fluid, because of its apparent breaking of Newton's rules. Starch particles in the cornflour contain non-crystalline structures that can absorb water. Increasing the force and pressure on the starch-water mixture increases the number of these structures that form, meaning more water is absorbed and the liquid appears to be thicker, or almost solid. Release this pressure and the structures disappear, allowing the water to spread out again and return the mixture to a liquid.

5m

DON'T PLAY WITH MATCHES

Balancing act

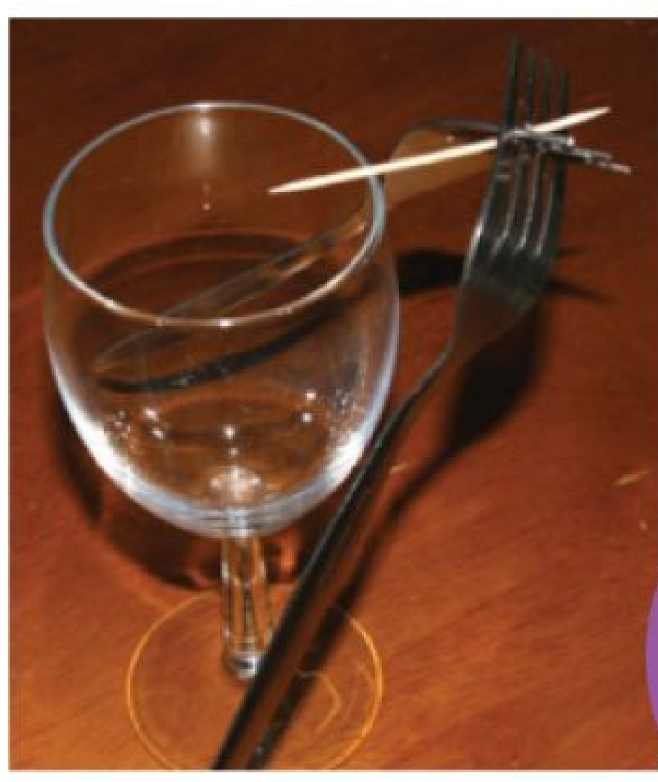
Make forks balance in mid-air, all thanks to gravity

STEP 1
Wedge the forks together at their spokes. You might want to avoid using your best set.

STEP 2
Insert a toothpick between the forks at a middle point, and find the balance point of the combined toothpick and forks.

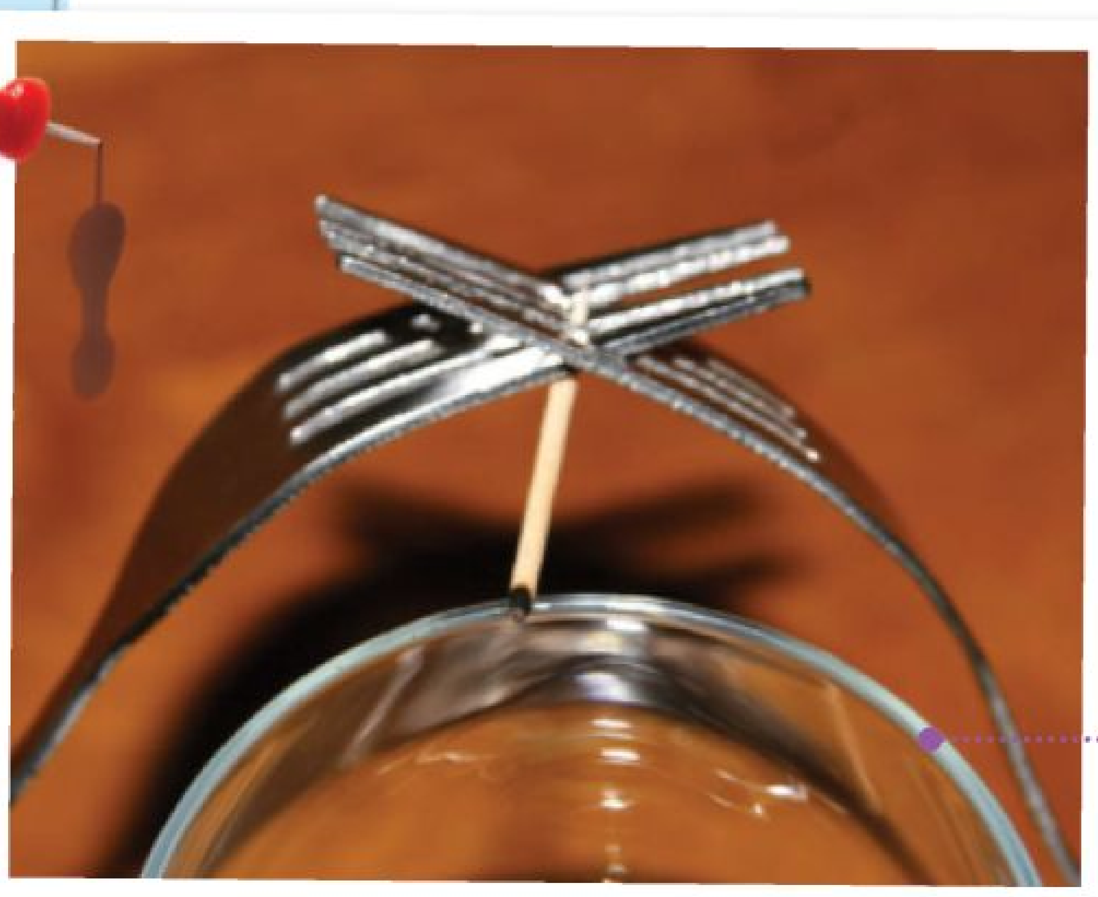
STEP 3
Rest the toothpick and forks on the edge of a glass. It might be tough, but eventually you should be able to get the whole thing balanced.

STEP 4
Light a match and burn the end of the toothpick in the glass. It'll burn down to the edge of the glass and then stop.



Equipment
Two forks
Toothpick
Glass
Match

Variables
How many forks or other objects could you balance at once?



STEP 5
You'll now find that the whole contraption appears to be balanced on almost nothing.

WHAT HAVE YOU LEARNED?

This experiment is all about the centre of gravity. The centre of gravity of an object is the point at which the majority of its mass is located. By combining the forks, we've given them a new centre of gravity. This point is where the forks will appear to balance in all directions, in this instance directly below the toothpick resting on the rim of the glass. Burning off the end of the toothpick makes no difference – the whole thing is balanced around a central point.

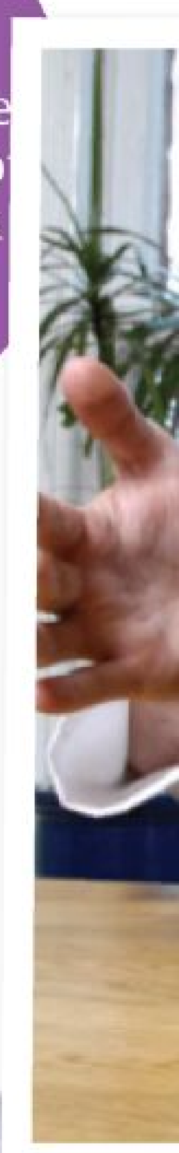
20m

DO NOT PLACE FINGERS UNDER

Mighty egg shells

Discover the awesome power of certain geometrical shapes with four eggs

Variables
What happens if you move the eggshells towards the centre of the books? Does this allow yo to add more or less than when the shells are positioned at the corners?



Equipment
Four eggs
Sellotape
Pen
Scissors
Heavy objects (bricks, planters, books)

STEP 1
Taking one of your four eggs, carefully tap the pointy end on a table until a small hole is created. The main body of the eggshell needs to remain as much intact as possible, so take your time and try to extract the egg's contents with minimum of collateral damage.

STEP 2
Next, taking the empty egg shell, stick a piece of sellotape around its centre and then draw a line in the centre of the band of tape. Depending on the size of your eggshell, it may be worth adding another layer of tape for stability.

STEP 3
Once the eggshell is taped, carefully break off all remaining pieces of eggshell from the pointy end up to the taped line. Then, taking your scissors, cut around the line so that you are left with an even dome of shell. Finally, remove the remaining tape from the dome.

CATEGORY:
FORCES IN ACTION

1 hr

NEVER FIRE THE ROCKET AT PEOPLE

Water rocket

Blast off to planet science with Isaac Newton's laws of motion

Equipment
Plastic bottle
Card
Sellotape
Cork
Air pump (needle adaptor)
Water

Variables
What if the bottle is filled with a fizzy drink? Does this make the rocket fly higher than with water?

STEP 1
Take your cork and insert the air pump's needle through it lengthways. If the needle is too short, cut the cork down until it pops out of the end.

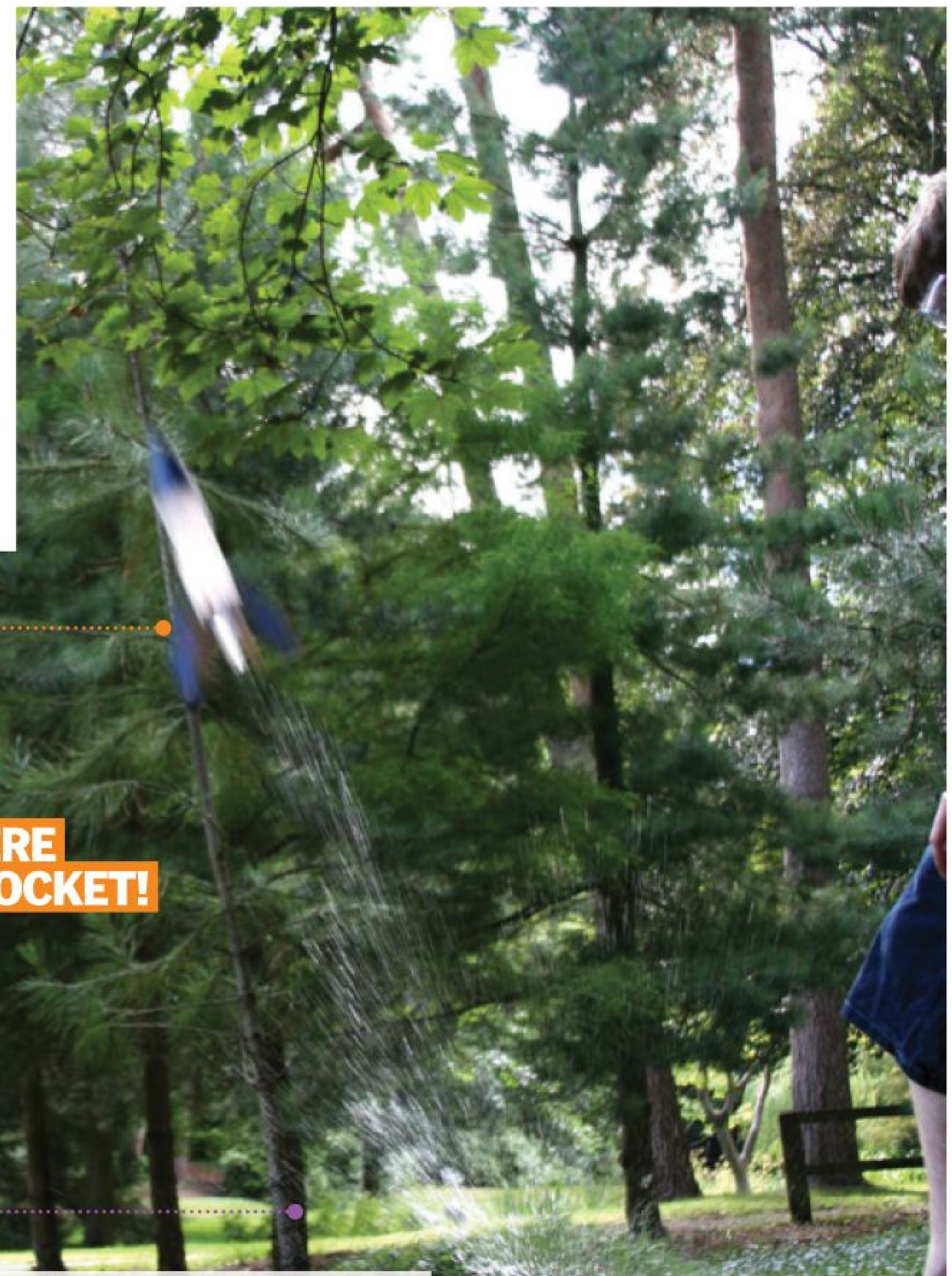
STEP 2
Take your sheet of card and cut four stabiliser fins and a curved dome for your bottle. These will make the bottle look like a small rocket and allow it to stand freely.

STEP 3
Turn the bottle the right way up and fill it one-quarter full with water. Now take your cork and push it into the opening. The cork must fit very tightly.

STEP 4
You now need to do the same for all three of the remaining eggs, ensuring all are of the same height. Once you have four completed egg domes, lay them out on a clear table in a rectangle. Ensure that there are no obstacles or valuables in the vicinity. Then, taking your heavy objects one by one, try stacking them on top of the eggs shells. Amazingly, if you have prepared correctly, the domes take an unbelievable amount of weight.

WHAT HAVE YOU LEARNED?
This experiment vividly demonstrates the inherent strength in specific shapes. The dome's arch is one of these shapes, as any weight placed upon its apex is spread evenly throughout its curve. If placed on a single complete egg, the downward force of the heavy planter would cause it to smash instantly. However, when placed on top of four even-height domes, the force is balanced and distributed by their series of arches. This principle is why bridges are commonly built with an arch structure, as it helps evenly distribute the load of what it is supporting into the earth. Other shapes such as triangles also share this inherent ability to absorb and distribute loads, as can be seen in skyscraper supports and the Eiffel Tower.

STEP 4
Once this is achieved, connect your air pump to the needle adaptor and turn the rocket over so that it rests on its fins. Then, making sure you are in an open, outdoor environment, place the rocket on the earth and begin to pump air into the bottle. While pumping, ensure that you stand well back from the rocket. If the setup is correct your rocket will blast off, shooting up into the air.



BE CAREFUL WHERE YOU AIM YOUR ROCKET!

WHAT HAVE YOU LEARNED?
Regardless of the size and scale of a rocket – ranging from the awesome solid-state rocket boosters used on NASA shuttle launches to this small bottle rocket – Isaac Newton's laws of motion remain constant. These state that any object will remain in one position unless a force acts upon it. When that force acts upon an object it makes it change speed or direction, and finally that when the force acts upon the object, the object will move in the opposite direction with equal force. This is clearly demonstrated in this experiment. When the rocket is initially placed down, there is no force acting upon it – unless of course the wind blows it over – so it remains stationary. However, as pumping begins, pressure is built up inside the bottle and the force of the air pushing on the contained water finally becomes too much for the cork to contain. This causes the cork to be pushed out of the bottle's neck and the water to rush out at high pressure in one direction. Consistent with Newton's third law, the bottle is then propelled with an equal force in the other, launching it into the air.

10m

HOT WATER CAN BURN

Convection currents

Discover how hot and cold liquids interact

Equipment
Small glass
Glass jar
Sticky tape
Food colouring
Warm water
Cold water
Knife/skewer

Variables
What if you reverse the water temperatures? Will the coloured water stay sitting in the cup?

STEP 1
Heat water but do not boil it, and pour it into a cup or glass smaller than the large glass jar. Add food colouring, and then cover the cup with sticky tape.

STEP 2
Put the cup at the bottom of the glass jar and fill the jar with cold water, being careful not to mix water from the cup and the jar.

STEP 3
Pierce the tape on the cup in the jar with a knife and observe the coloured water moving out of the cup, eventually changing the colour of the jar's water.

WHAT HAVE YOU LEARNED?

Heat can move through gases and liquids by convection. A heated gas or liquid will rise in the same medium, such as a hot air balloon, because heat causes it to expand and become less dense. Colder air or liquid will fall to replace it, creating what is known as a 'convection current'.

10m

KEEP LIQUIDS AWAY FROM FLAMES

Liquid layers

See density in action by making a tower of liquids

Variables
What other liquids and objects could you use? How many different discernible layers do you think you could fit into a cylinder of this size?

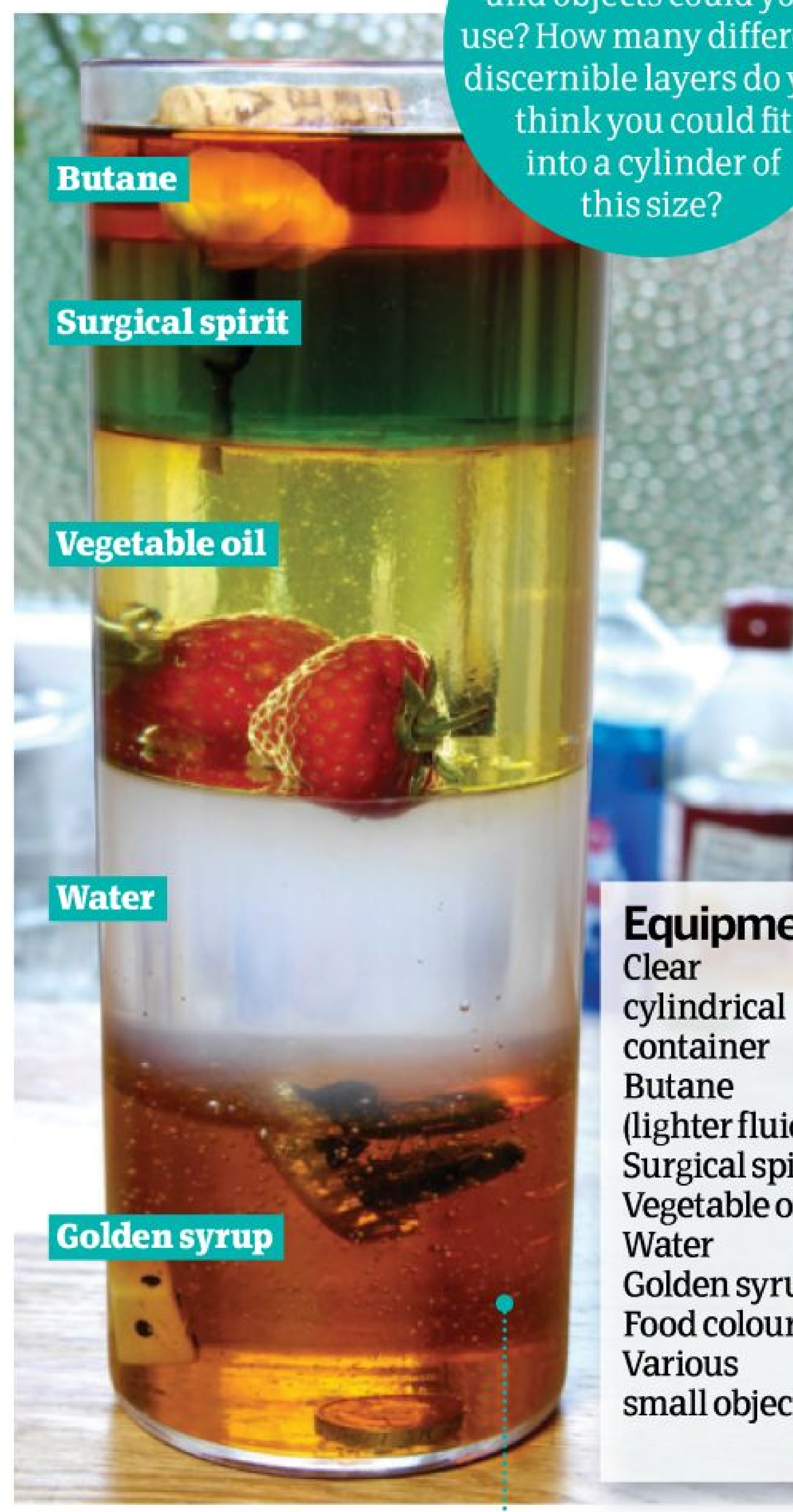
STEP 1
Starting with the syrup, pour the liquids into the centre of the container, making sure they don't touch the side (as this could ruin results later).

STEP 2
Work down the list of ingredients from syrup in order, as per step 1. We added food colouring to some of our liquids to make the separation more obvious.

STEP 3
Now you should have several layers of liquid. Any liquids that have mixed should separate over time.

STEP 4
Drop your objects in one by one. We've used some heavy and some light ones to get a nice spread. Make sure you start with those that are denser.

STEP 5
Voila! Your liquid layer tower is complete.



Equipment
Clear cylindrical container
Butane (lighter fluid)
Surgical spirit
Vegetable oil
Water
Golden syrup
Food colouring
Various small objects

WHAT HAVE YOU LEARNED?

The same amount of two or more liquids with different masses will rest at different levels if mixed, because the heavier ones have a higher density and vice versa. Lighter liquids 'sit' on the heavier ones, as they are unable to move through them. Density is a measure of how much mass is squashed into a particular volume (mass divided by volume). If two liquids have the same volume but different densities, the one with the higher density will be heavier, as more mass is packed into the same volume.

Equipment
Two clear glasses
Blue food colouring
A white flower with long stem
Sellotape
Craft knife
Water

Variables
What happens if you split the stem four ways and place the quarters in four different-coloured dyed solutions? Do the petals colour evenly, or do they change from petal to petal?

1hr

SECURE STEM FIRMLY WHEN CUTTING

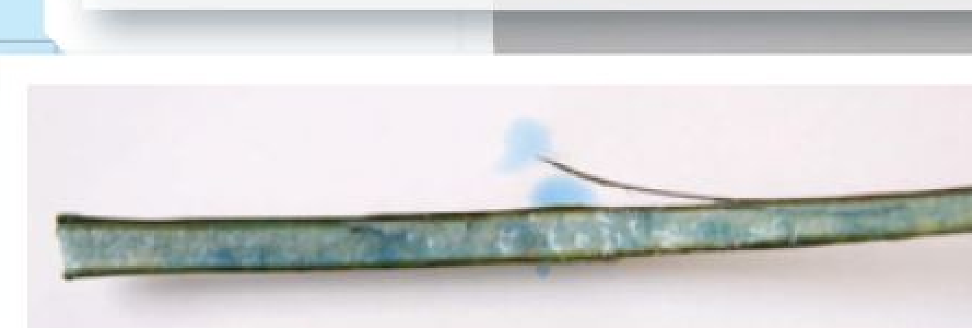
Multicolour flower

Learn about plant anatomy with this technicolour scientific test

STEP 1
First, take your white flower and your craft knife and carefully slice its stem into two equal parts. When cutting, stop when half of the stem is split. Once this is done, wrap a piece of tape around the stem where the cut stops in order to prevent further separation.

STEP 2
Fill both glasses two-thirds full with tap water and add your food colouring to one of them. Add as much food colouring as you can, as its intensity will determine the visual outcome of the experiment.

STEP 3
Add the flower's half-stems to the water, one side in the dyed water. Place the flower outside in the sun. After one hour, return and check the flower's petals.



WHAT HAVE YOU LEARNED?

This demonstrates the mechanism that plants use to absorb water from their roots and transport it to their petals. Plants draw water up from the ground through their stem via the xylem, a series of vertically-arranged cells that run from root to tip. Nutrients from the soil are absorbed by the plant this way and help it grow and produce leaves and petals for photosynthesis. As the plant loses moisture from its leaves, due to evaporation from sunlight, more water is continuously drawn up through the xylem. In this experiment, half of the water being drawn up via the xylem is coloured, causing the petals to absorb the dye.

CATEGORY:
DENSITY AND PRESSURE

Egg in a bottle

MATCHES WILL BURN

Is it really possible to get an egg into a bottle with heat alone?

STEP 1
Boil an egg in water for about five minutes. Let it cool and then peel off the outer shell.

STEP 2
Light two matches and drop them into the bottle, placing the egg on top. The neck must be smaller than the egg.

STEP 3
Wait a few seconds after the matches go out, and the egg will be pulled into the bottle.

STEP 4
To get the egg back out, blow hard into the bottle to increase the air pressure.

Equipment
Egg
Glass bottle
Matches
Water
Saucepan

Variables
Could you use something else other than an egg to repeat the experiment?

WHAT HAVE YOU LEARNED?
The lit matches heat the air inside the bottle. This hot air expands and leaves the bottle, being replaced by cooler air (see our convection currents experiment for another example of this in action). This is because the air inside the bottle is now at a lower pressure than that inside. Higher pressure air outside tries to move into the bottle and, as it does so, forces the egg inside.

Sticky bubbles

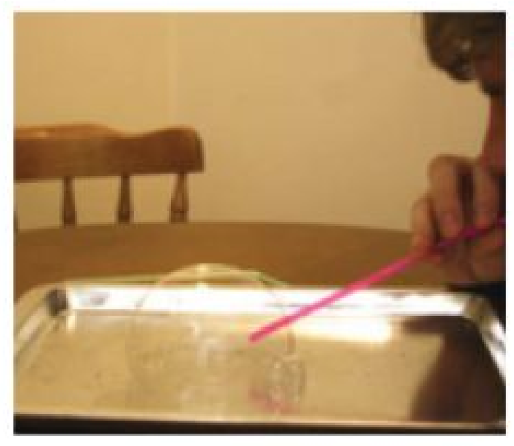
DO NOT SWALLOW

Create some impressive big bubbles, thanks to a unique stabilising agent

Equipment
Bowl
Straws
Washing-up liquid
Beaker
Water
Glycerin
Tablespoon

WHAT HAVE YOU LEARNED?
It's glycerin that's the secret ingredient here. Bubbles often pop because water evaporates, but glycerin draws in more water – a process known as 'hydroscopy' - from the surrounding environment and prolongs their life.

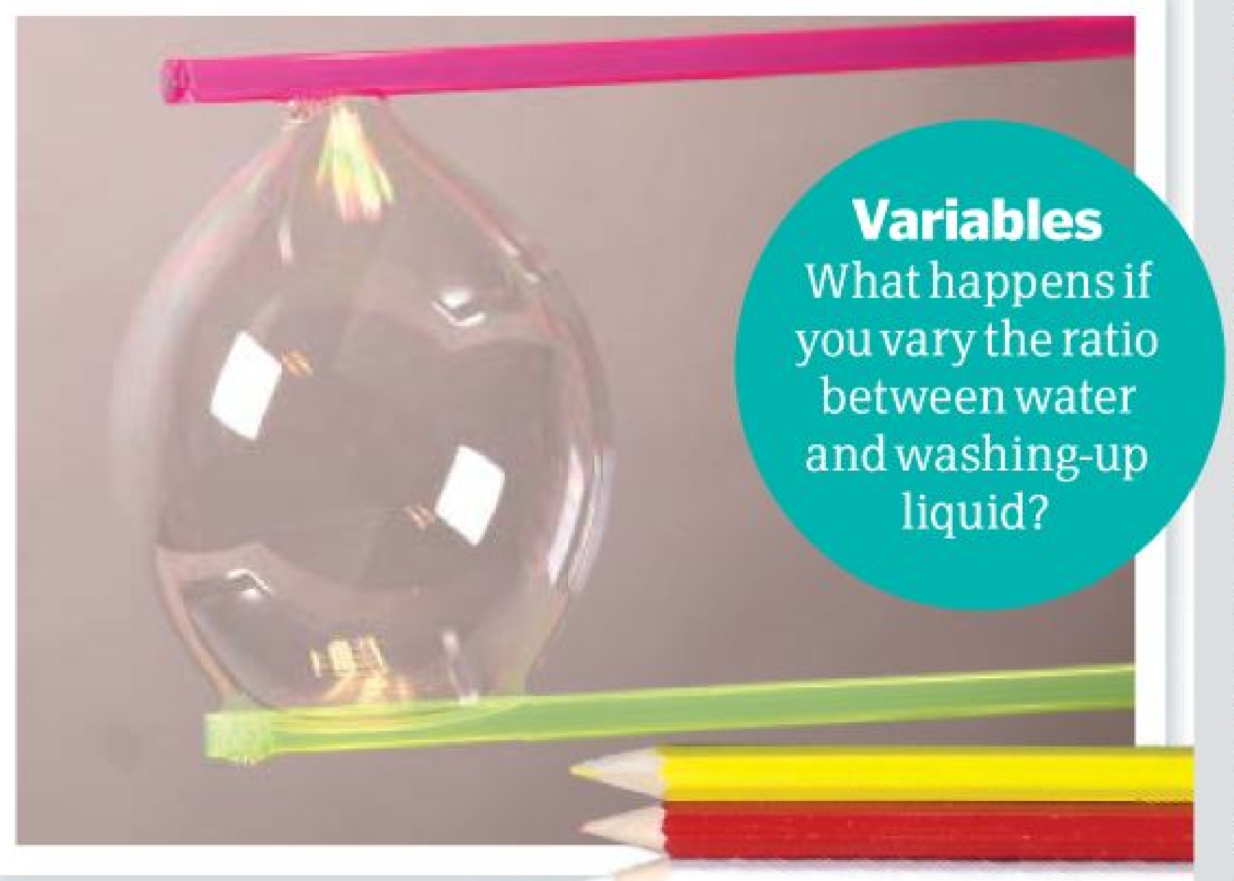
STEP 1
Mix about 250ml of water with two tablespoons (30ml) of washing-up liquid and one tablespoon (15ml) of glycerin. Stir until all the glycerin has mixed in.



STEP 2
Dip a straw into your solution and start blowing some bubbles. You should find that the bubbles are stronger than normal bubbles that you could make with washing-up liquid.

STEP 3
Try stretching a bubble between two straws. You should find that their strength allows them to be stretched into an oval shape.

STEP 4
See how big you can blow a bubble on a tray or other clean surface (dirt will still cause them to pop). You'll find that the bubbles last much longer than normal.



Variables
What happens if you vary the ratio between water and washing-up liquid?

Instant can crusher

DO NOT TOUCH THE CAN WHEN IT'S HOT

How to make your own implosion

STEP 1
Empty the soda can and then add about three teaspoons of water.

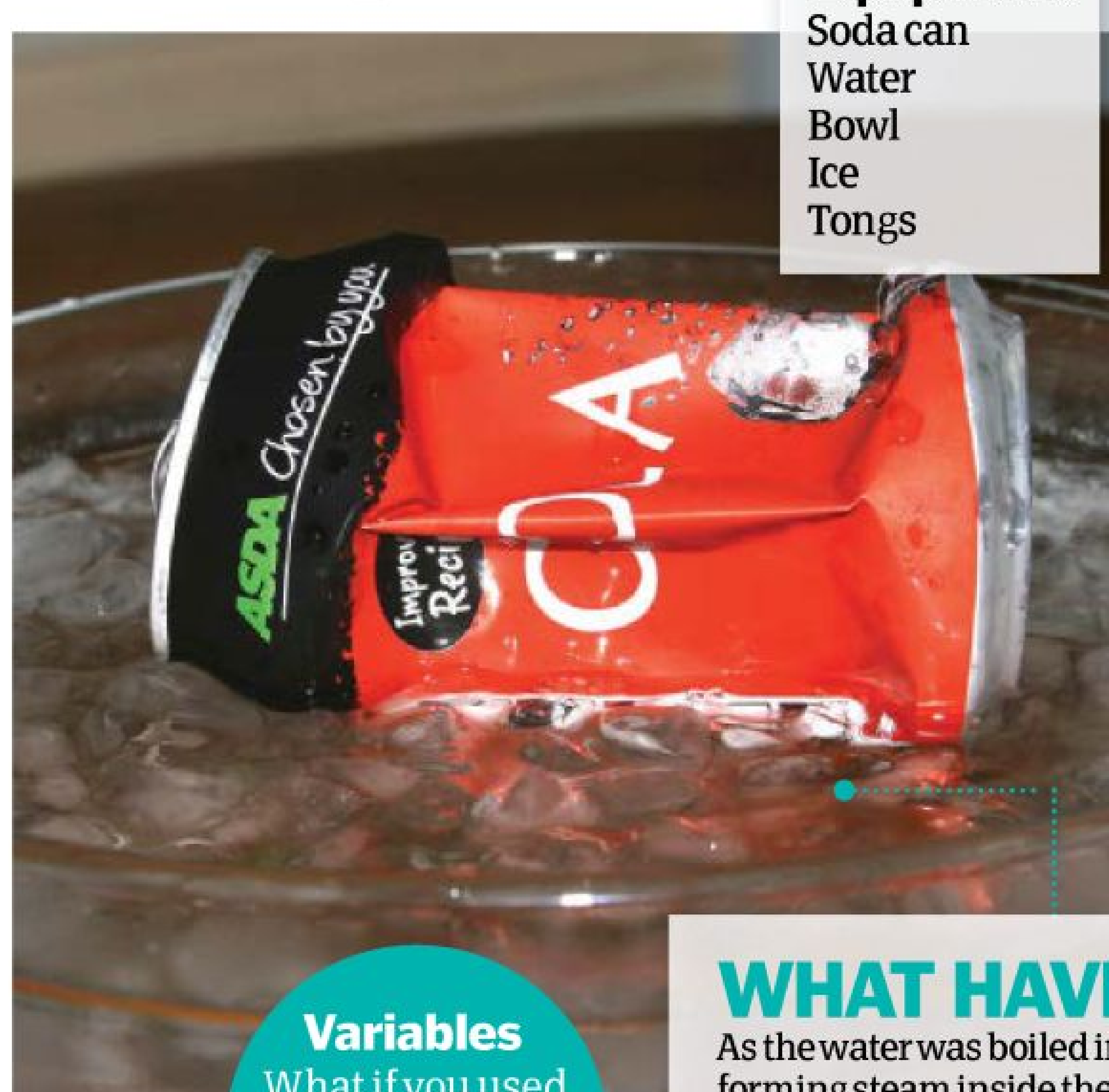
STEP 2
Fill a bowl with water. We added ice cubes to lower the temperature.

STEP 3
Place the can on a hob or stove (must not be gas), on medium heat.

STEP 4
Pick up the can with metal tongs no more than a minute after you hear the water boiling.

STEP 5
Turn it upside down and quickly plunge it into the bowl of water, where it will instantly be crushed.

Equipment
Soda can
Water
Bowl
Ice
Tongs



Variables
What if you used warm water? Could you still crush the can?

WHAT HAVE YOU LEARNED?
As the water was boiled in the can, it turned from a liquid to a gas, forming steam inside the can. However, when the can was turned upside down and placed in the water, this steam turned back into a liquid. The change from a gas pushing outwards into a liquid caused an implosion. The air pressure of the can dropped compared to that outside, so as the air rushed in it collapsed it.

GLOSSARY

Acid/Alkali (Colour-changing liquid)
A chemical substance with a pH less than neutral 7/ A chemical substance with a pH greater than neutral 7

Ambient (density and pressure)
In terms of pressure, its ambient quality refers to the amount of pressurised force placed upon an object from the surrounding medium.

Apex (Mighty egg shells)
In geometry, an apex is a corner or intersection of a shape that is higher than all others.

Catalyst (Giant toothpaste)
A substance that accelerates the rate of a chemical reaction without undergoing any permanent change.

Compound (Erupting volcano)
A chemical compound is a pure substance that consists of two or more different chemical elements.

Condensation (Steam boat)
The change of matter's physical state from a gaseous phase into a liquid phase. Water vapour condenses into water when cooled.

Convection (Convection currents)
The tendency of hotter, less dense materials to rise, and colder, denser liquids and gases to sink due to gravity, often resulting in a transfer of heat.

Force (Water rocket)
Any type of influence that causes an object to undergo a change in shape, speed or direction.

Implosion (Can crusher)
A concentration of matter and energy due to inwardly pushing forces resulting in the collapse of an object, directly opposite to an explosion.

Ions (Mini mic)
An atom or molecule where the total number of possessed electrons is not equal to the total number of possessed protons, consequently giving it a net positive or negative electrical charge.

Photosynthesis (Flower)
A chemical process in which carbon dioxide in the atmosphere is converted into various organic compounds via energy harvested from direct sunlight.

Polymer (Fantastic plastic)
A synthetic or organic substance that has a molecular structure made primarily (or totally) of identical and repeating bonded units.

Surface tension (Mentos & cola)
The tension or attraction of particles in a liquid.

Surfactant (Mentos & cola)
A compound that lowers the surface tension of a liquid. Due to this property, they are commonly used in paints, detergents, emulsions and inks.

Tablespoon (various)
One tablespoon of a liquid is equal to three teaspoons

Vacuum (Vacuum cannon)
A volume of space that is empty of matter and has a gaseous pressure that is significantly less than that of standard atmospheric pressure.

Volume (Liquid layers)
The space an object/gas occupies.

Albert Einstein

The foremost scientist of his age, Einstein is considered the most influential physicist of all time

Albert Einstein was born on 14 March 1879, in Ulm, Germany. He is considered the most influential physicist of the 20th Century, formulating both the theories of special and general relativity, concepts that still underpin much in the fields of physics and astrophysics today. In 1921 he was awarded the prestigious Nobel Prize in Physics for his explanation of the photoelectric effect – a process where electrically charged particles are released from a substance when exposed to electromagnetic radiation.

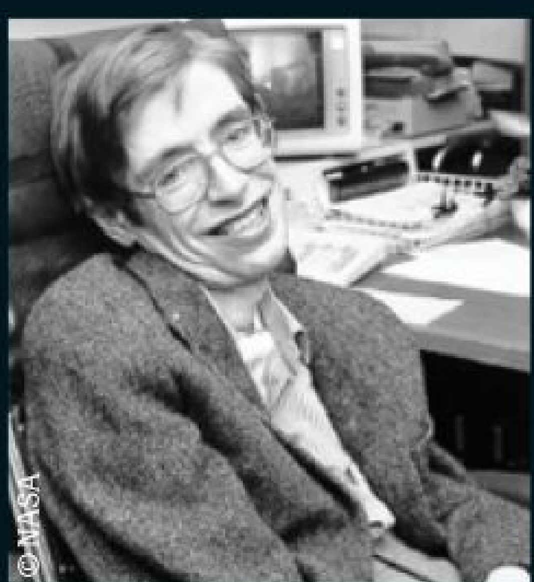
Einstein's first real contact with science came when he was a young boy, instigated by his intrigue with his father's compass. Confused by the invisible forces that seemed to be acting upon the needle, he went through his early years fascinated by such forces. Spurred on by reading the work of Aaron Bernstein, which introduced him to the concepts of electricity and light, Einstein dedicated his later teenage years to the nature of light, writing a scientific paper entitled 'The Investigation Of The State Of Aether In Magnetic Fields'.

Despite a great love for the sciences, Einstein unfortunately had a troubled education. He frequently skipped classes while attending the Swiss Federal Polytechnic School, and his father's failed business led to much disruption, with Einstein having to move frequently. This led to a period where he was forced to take a position at the Swiss patent office in Bern, a role significantly less prestigious than his desired doctorate.

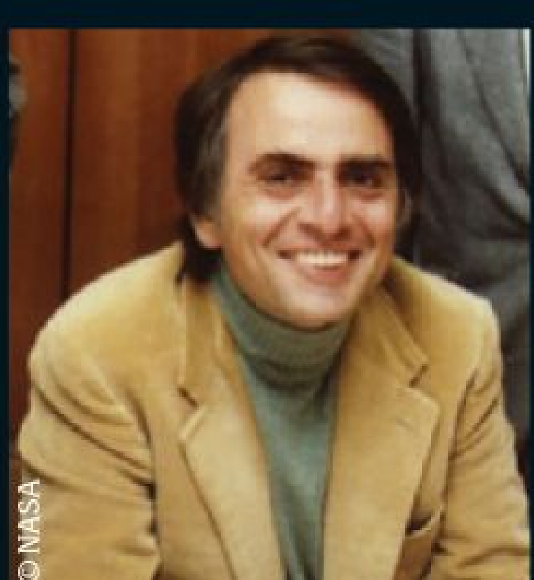
In hindsight, though, the position at the patent office was ideal, as the work left much time for him to theorise on the properties and nature of light. Then, suddenly, in 1905 Einstein made a breakthrough, starting what is now termed his 'miracle year'. In that time he published four papers: the first on the photoelectric effect, the second on the existence of atoms, the third introducing the mathematical theory of special relativity and the fourth on the theory of relativity. Famously, Einstein published the last paper almost as an afterthought, despite it containing the key equation for which he is famous: $E=mc^2$.

At first the scientific establishment ignored Einstein's papers. Fortunately, though, they caught the attention of the foremost scientist of the age: Max Planck, the founder of quantum theory. Through Planck, Einstein became a respected

IN THEIR FOOTSTEPS
Those inspired by their work



Stephen Hawking
The English theoretical physicist has acknowledged a debt to Einstein. Most famous for his theorems regarding gravitational singularities, Hawking has published many books, his most famous being *A Brief History Of Time*. In a recent interview with *Time*, when asked what he would ask Einstein if he were alive today, Hawking said: "I would ask him why he didn't believe in black holes."



Carl Sagan
American astrophysicist Carl Sagan often commented on the importance of Einstein and was a proponent of the power of science, stating that: "Those afraid of the universe as it really is will prefer the fleeting comforts of superstition. But those with the courage to explore the weave and structure of the cosmos will penetrate its deepest mysteries."

A life's work

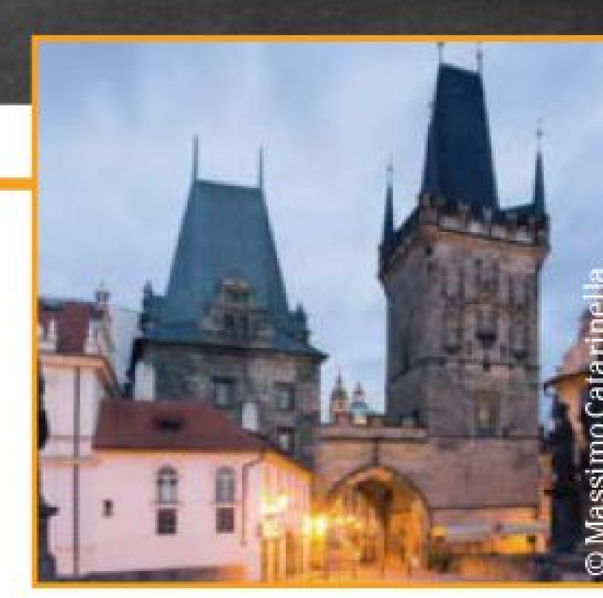
1879
Einstein is born on 14 March in Ulm, Germany.

1896
After renouncing his citizenship in the German Kingdom of Württemberg to avoid military service, Einstein enrolled in a four-year mathematics and physics teaching course in Zurich.

1905
Referred to as his annus mirabilis (miracle year), 1905 proved to be Einstein's most productive, releasing four groundbreaking papers on the photoelectric effect, Brownian motion, special relativity and the equivalence of matter and energy.

1906
Einstein receives a doctoral degree from the University of Zurich.

1908
He becomes lecturer at the University of Bern.



1911
With his family, Einstein moves to Prague, where he acts as professor at the Karl-Ferdinand University.

Einstein renounced his German citizenship in 1896 to avoid military service

THE BIG IDEA

Einstein's most important thinking explained

$$E=mc^2$$

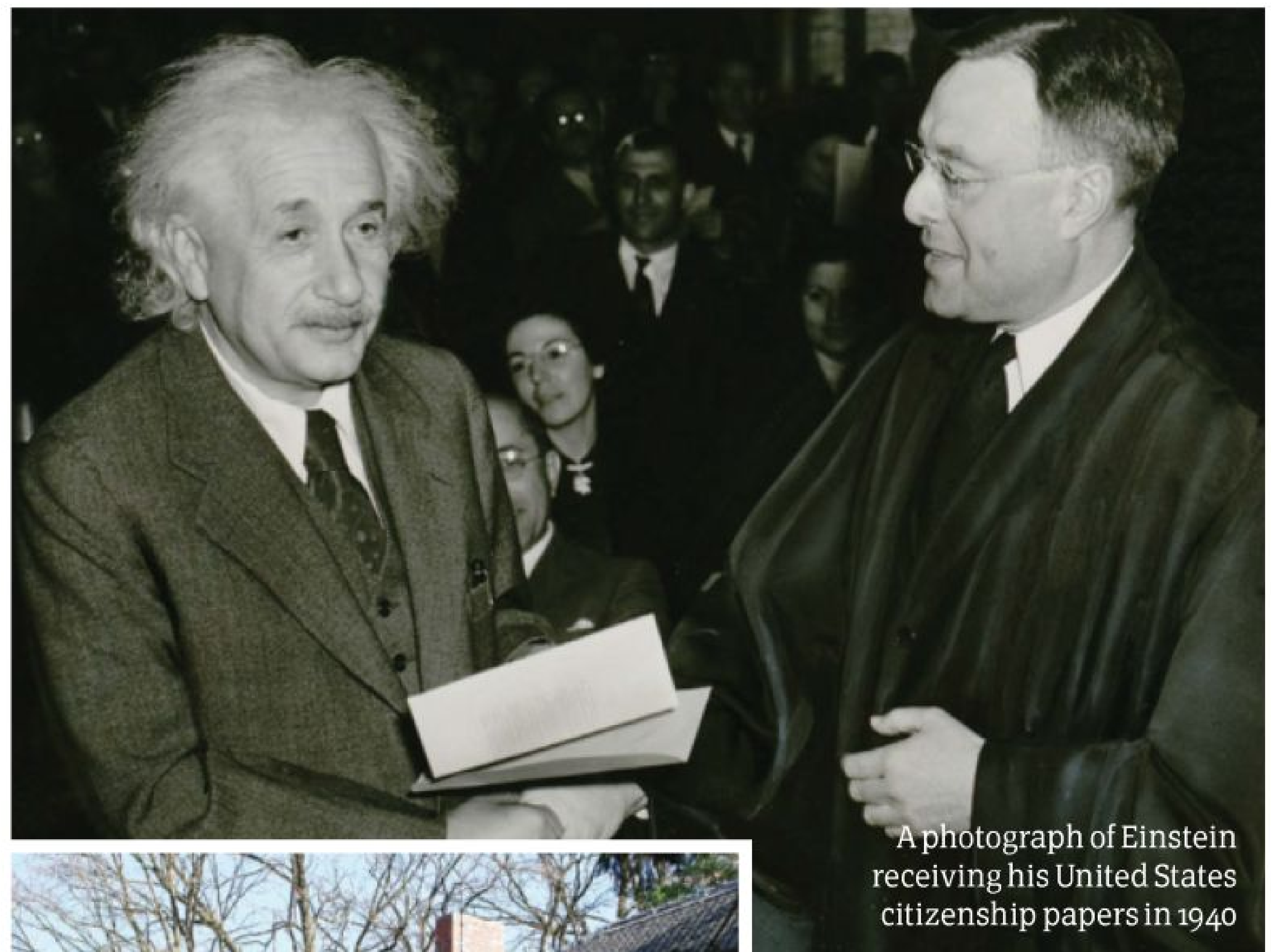
This equation shows that the increased relativistic mass of a body comes from the energy of motion of it when divided by the speed of light squared. It shows that mass and energy are the same physical entity and can be changed into each other directly.

member of the international community, attending the prestigious Solvay conferences and being offered increasingly important positions at Europe's foremost universities.

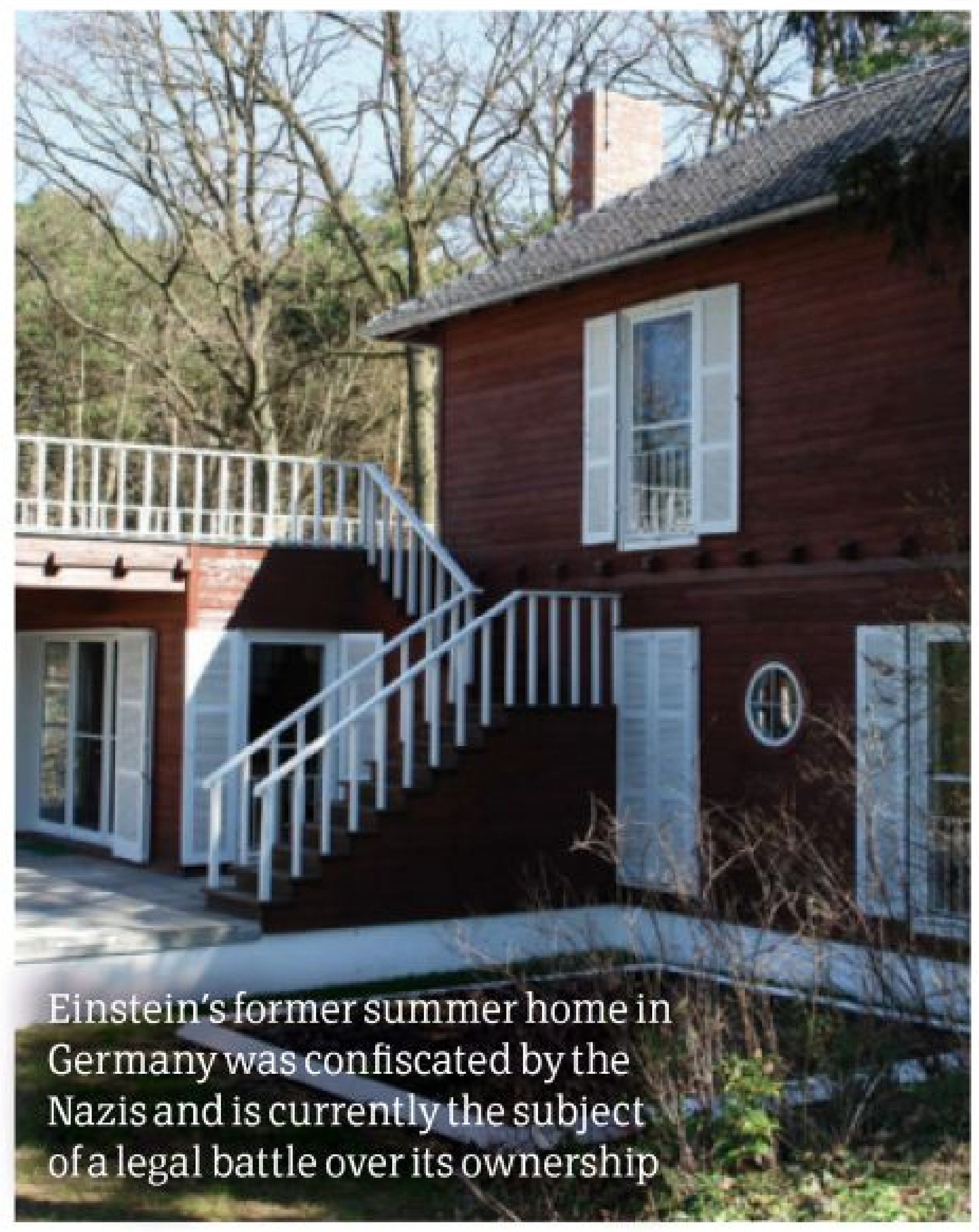
After completing his theory of general relativity in November 1915, Einstein's work was interrupted by World War I. Being a life-long pacifist, Einstein opposed the war and spoke frequently on its folly. After its conclusion, Einstein toured the world, but his period away from Europe was soon to be made permanent, with Einstein fleeing Nazi Germany in 1933. He settled in America and was granted US citizenship in 1940.

While in America, though he was not immediately convinced that an atomic bomb was possible, Einstein had encouraged the US government, including personally writing to President Roosevelt, to research nuclear chain reactions using uranium in response to German advances in the field. He did not work directly on the project to build a bomb, despite it being heavily based on his own work. According to reports, Einstein was on vacation when the first atomic bomb was dropped on Hiroshima, Japan. This action and its aftermath led to him undertaking anti-nuclear campaigns and lectures for the rest of his life.

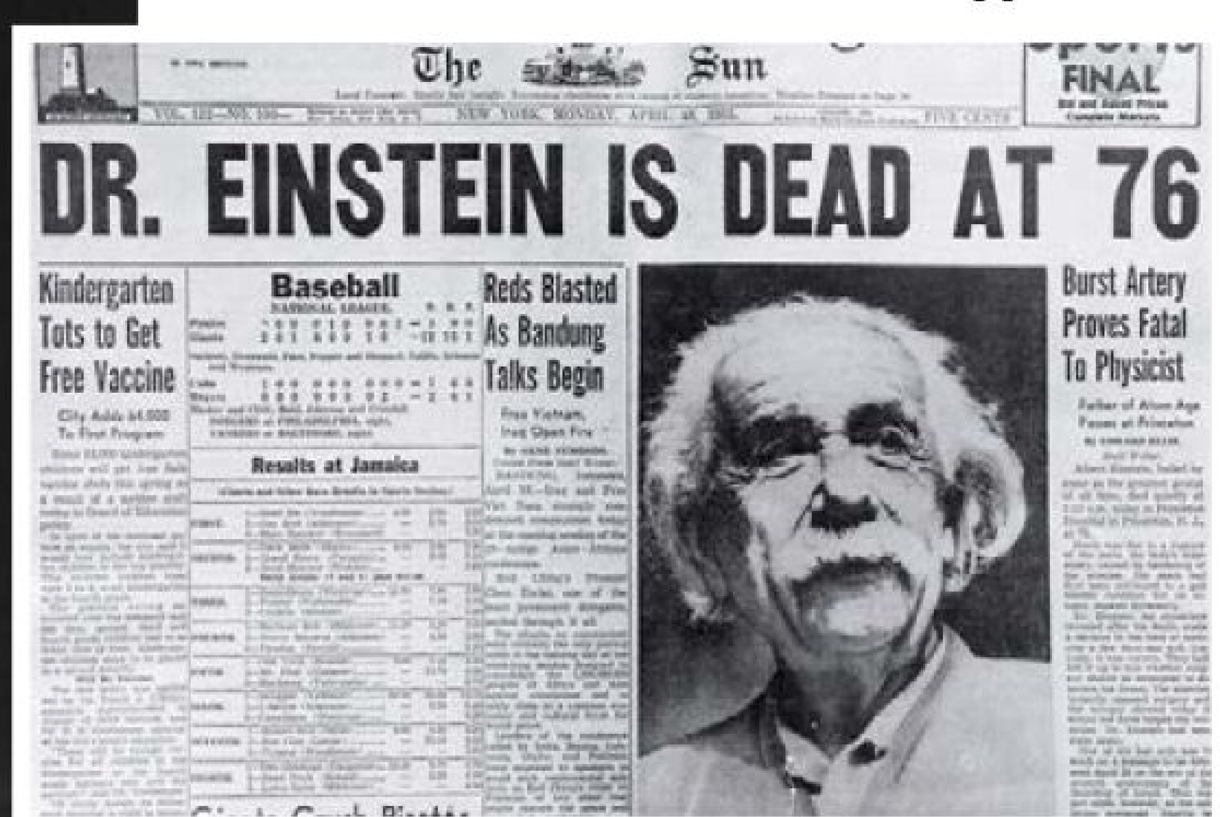
Einstein's later years saw him pioneer numerous key theories including wormholes, multi-dimensional models and the possibility of time travel, as well as discovering his unified field theory. The latter was to be an all-embracing theory that would unify the forces of the universe and physics into one framework. The theory was never completed, however, with Einstein dying of an aortic aneurysm in 1955. Despite this, his huge legacy of work endures to this day, with many of his predictions ratified and built upon by the current generation of scientists.



A photograph of Einstein receiving his United States citizenship papers in 1940



Einstein's former summer home in Germany was confiscated by the Nazis and is currently the subject of a legal battle over its ownership



The Sun

FINAL

DR. EINSTEIN IS DEAD AT 76

Kindergarten Tots to Get Free Vaccine

Baseball

Results at Jamaica

Reds Blasted As Bandung Talks Begin

Burst Artery Proves Fatal To Physicist

By the end of his life, Einstein was a global icon, and his death in 1955 was front-page news

> "In 1905 Einstein made a breakthrough, starting what is now termed his 'miracle year'"

FIVE THINGS TO KNOW ABOUT... Einstein

Boy of few words
According to reports, Einstein seldom spoke as a child and when he did, it was very slowly. Accounts state he did this until he was nine.

Point of inspiration
Einstein's interest in science was reportedly sparked by his father's compass. At the age of five he thought there must be some force in the apparently empty space that acted on the needle.

Slow to start
Einstein did not receive outstanding grades while at school and when he left could not get a university position. Instead he went to work in the Swiss patent office.

Nuclear pacifist
Einstein was a pacifist and while initially supporting the use of atomic weapons as a deterrent, later campaigned for nuclear disarmament and world peace.

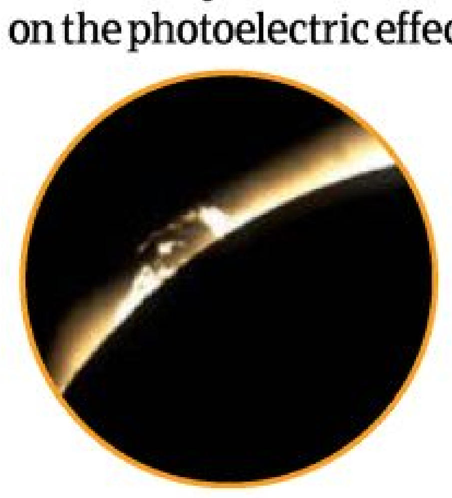
Man with two brains
After his death in 1955, Einstein's brain was removed for preservation by Thomas Stoltz Harvey in an attempt to discover what made him so intelligent.

1912
After a single year in Prague, Einstein moves back to Switzerland, taking up a professorship at his alma mater, the Swiss Federal Institute of Technology in Zurich.

1915
Einstein completes his general theory of relativity.

1919
A solar eclipse provides dramatic observable evidence that his general theory of relativity is correct, making him a worldwide celebrity.

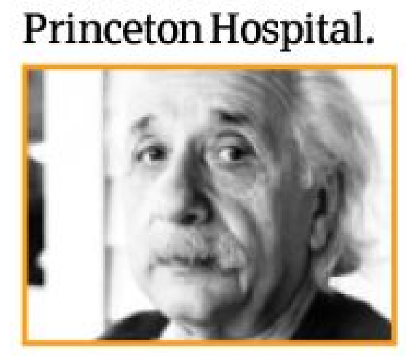
1921
16 years after its publication in 1905, Einstein wins the Nobel Prize in Physics for his work on the photoelectric effect.



1933
Einstein and his family flee from Nazi Germany to settle in the United States. He takes a post at the Institute of Advanced Study at Princeton University.

1939
Fearing the Nazis would develop the world's first atomic bombs, Einstein writes to US President Franklin Delano Roosevelt, urging him to launch an American program of nuclear research.

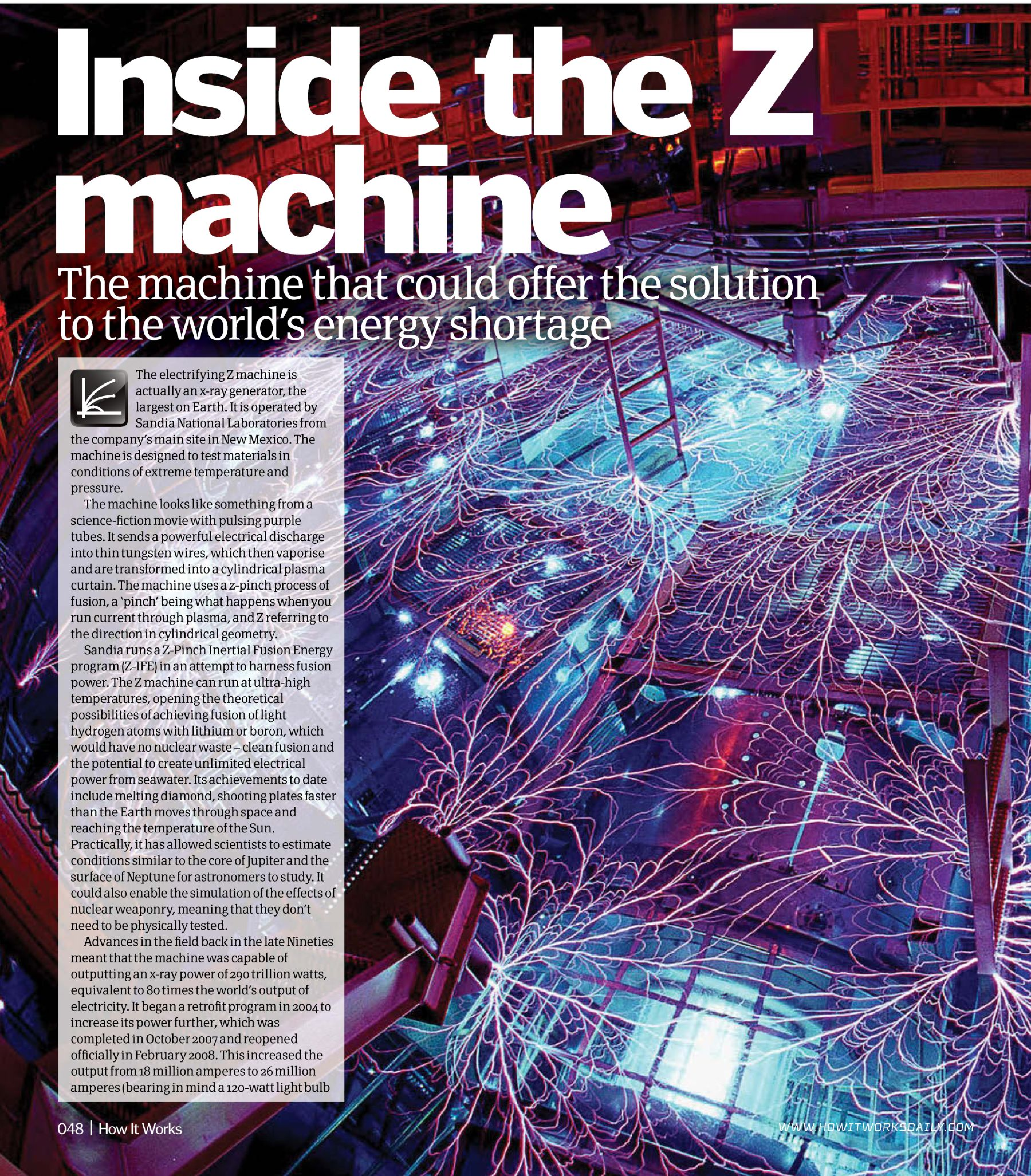
1955
At the age of 76, Einstein dies from heart failure at Princeton Hospital.



How to create 2 billion degrees Kelvin

Inside the Z machine

The machine that could offer the solution to the world's energy shortage



The electrifying Z machine is actually an x-ray generator, the largest on Earth. It is operated by Sandia National Laboratories from the company's main site in New Mexico. The machine is designed to test materials in conditions of extreme temperature and pressure.

The machine looks like something from a science-fiction movie with pulsing purple tubes. It sends a powerful electrical discharge into thin tungsten wires, which then vaporise and are transformed into a cylindrical plasma curtain. The machine uses a z-pinch process of fusion, a 'pinch' being what happens when you run current through plasma, and Z referring to the direction in cylindrical geometry.

Sandia runs a Z-Pinch Inertial Fusion Energy program (Z-IFE) in an attempt to harness fusion power. The Z machine can run at ultra-high temperatures, opening the theoretical possibilities of achieving fusion of light hydrogen atoms with lithium or boron, which would have no nuclear waste – clean fusion and the potential to create unlimited electrical power from seawater. Its achievements to date include melting diamond, shooting plates faster than the Earth moves through space and reaching the temperature of the Sun. Practically, it has allowed scientists to estimate conditions similar to the core of Jupiter and the surface of Neptune for astronomers to study. It could also enable the simulation of the effects of nuclear weaponry, meaning that they don't need to be physically tested.

Advances in the field back in the late Nineties meant that the machine was capable of outputting an x-ray power of 290 trillion watts, equivalent to 80 times the world's output of electricity. It began a retrofit program in 2004 to increase its power further, which was completed in October 2007 and reopened officially in February 2008. This increased the output from 18 million amperes to 26 million amperes (bearing in mind a 120-watt light bulb

Remodelling
1 The task of dismantling the machine in 2004 was undertaken to replace its 20-year-old equipment.

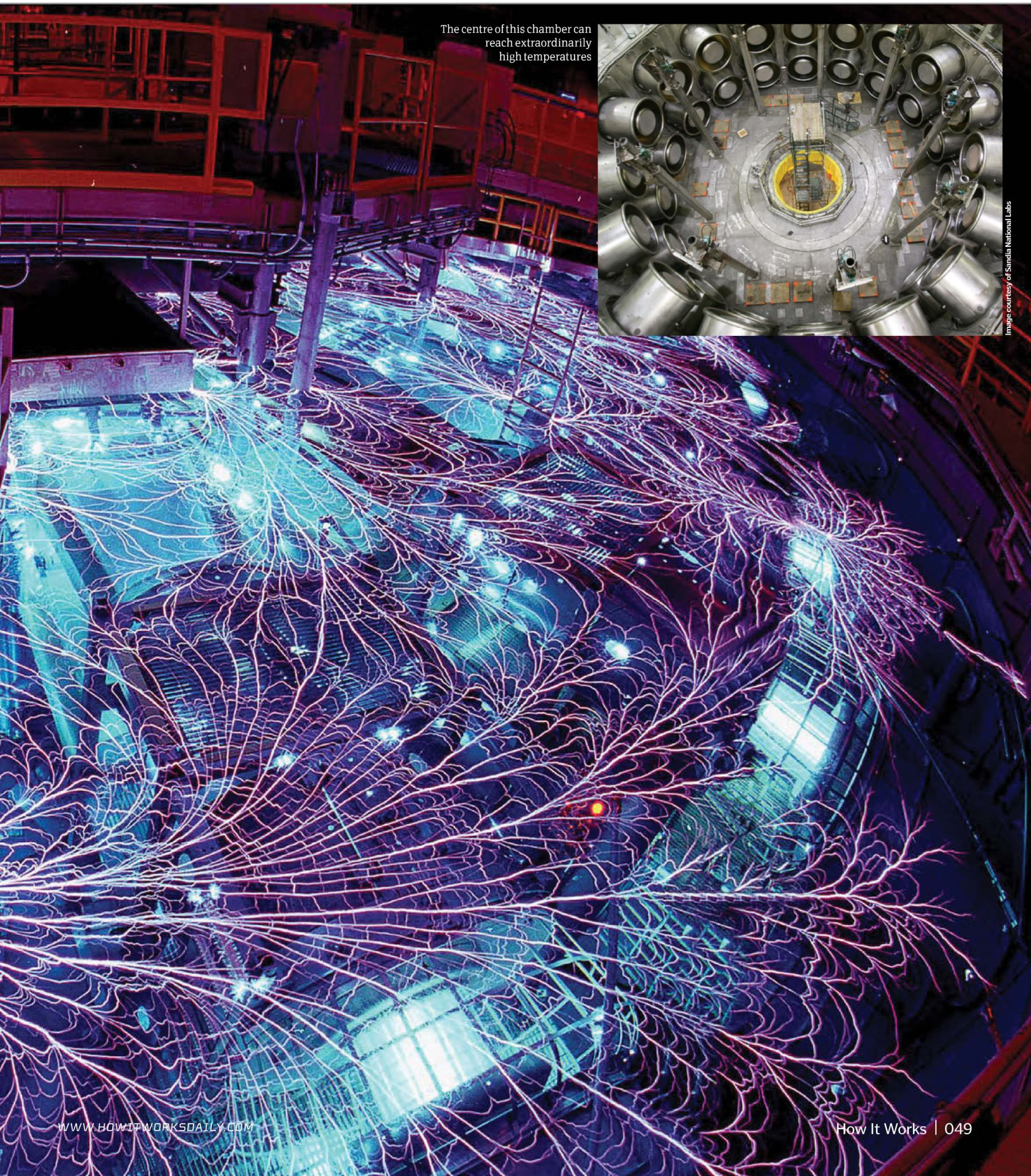
Save on power
2 Its work could stop our dependence on non-renewable fuels such as coal and gas extraction for energy.

In its roots
3 The machine was constructed as the Particle Beam Fusion Accelerator II back in 1985.

Book it out
4 The Z machine was overbooked before its remodelling with requests from labs and researchers.

Small target
5 The massive amount of power focuses entirely on a target the size of a spool of thread.

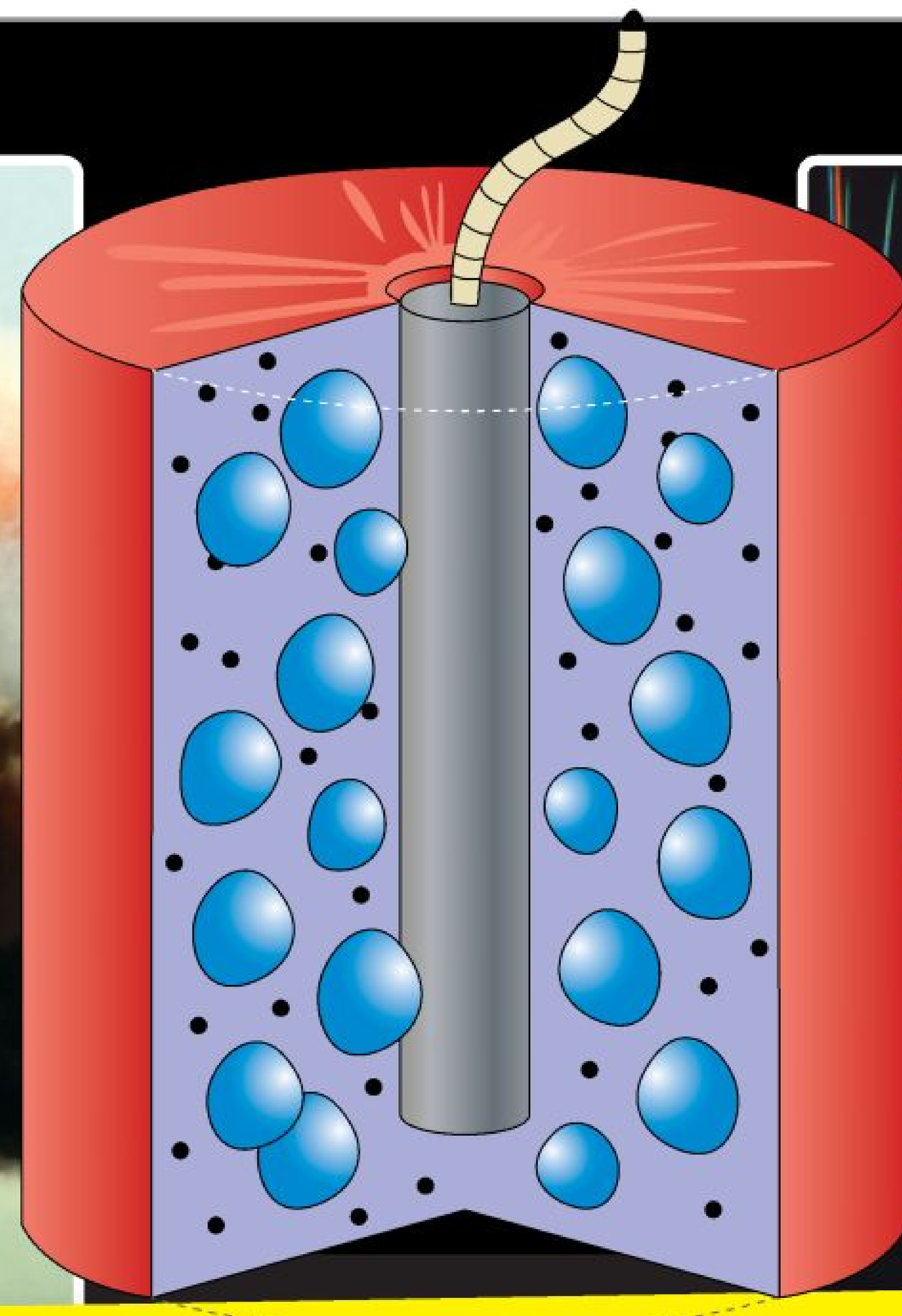
DID YOU KNOW? The Z machine is housed at Sandia's main site in Albuquerque, New Mexico



The centre of this chamber can reach extraordinarily high temperatures

Image courtesy of Sandia National Labs

Why do materials ignite?



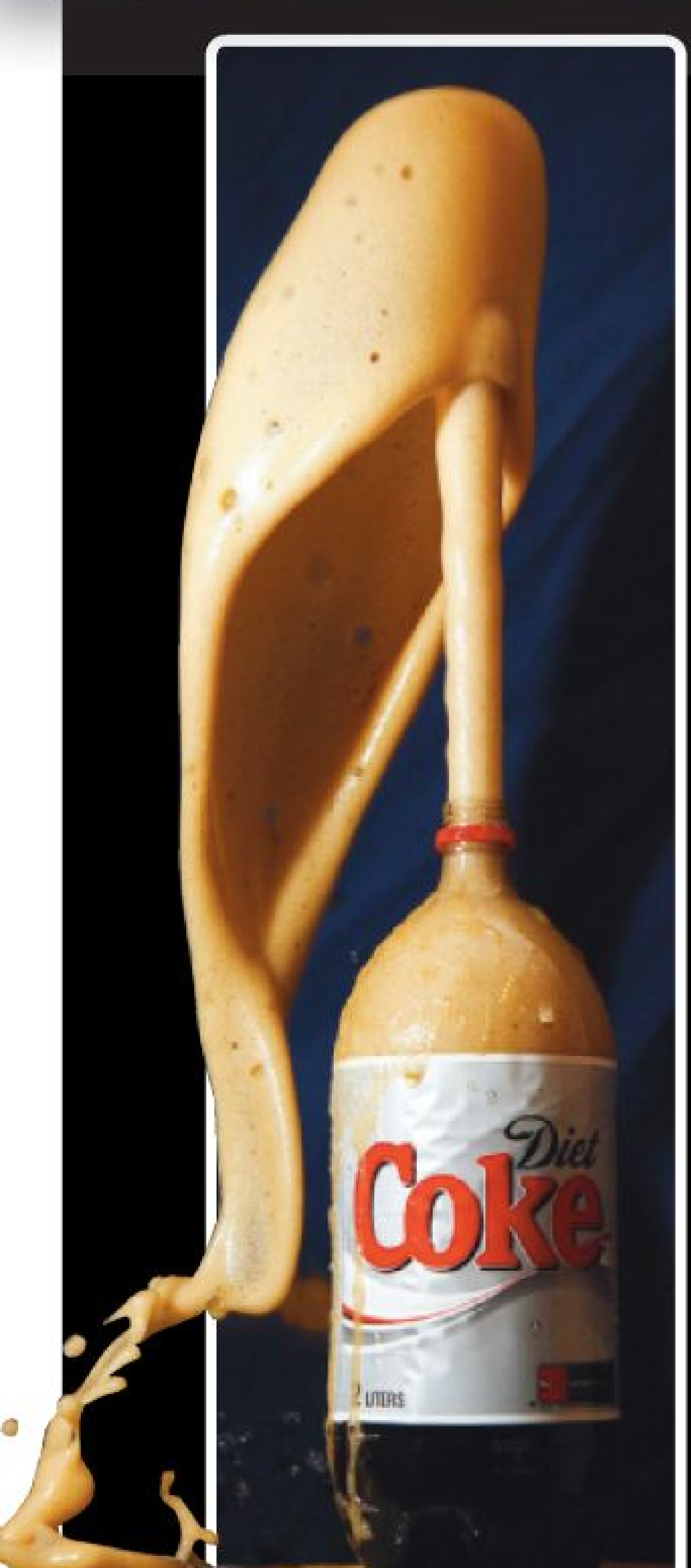
Rock blasting

Special effects

THE SCIENCE OF EXPLOSIONS

FIREWORKS • VOLCANOES • DEMOLITION • SPECIAL FX & MORE

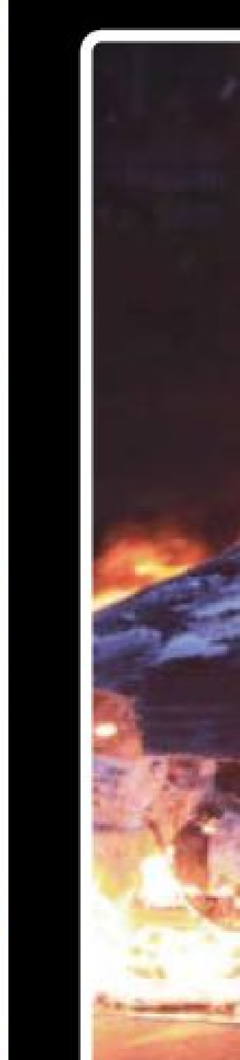
Revealing the crazy chemistry at work behind really big bangs



We might not hear an almighty bang, but we experience explosions all the time. From the intentional ones, such as your car's internal combustion engine, to the kind we can't ignore, like violent blasts of ash and magma spewing from a volcano or a fireball the size of the Sun in a Hollywood blockbuster. This sudden release of energy, combined with scalding temperatures and expanding gas, occurs when an explosive has reacted with a detonator, which is often a spark or a flame.

Explosions blow things up because the sheer force and speed of the expansion pushes them out, like blowing up an inflatable ball until it pops. The only difference is that blowing up a ball happens a lot more slowly! The billowy flame that usually comes with an explosion is from that spark igniting and being carried outward by the expanding gas, while the deafening boom is caused by airwaves travelling at incredible speeds.

Explosive materials are categorised as 'high' or 'low' explosives, according to the speed at which they expand. Materials that detonate by an explosive shock wave are classed as high explosives because the chemical reaction moves faster than the speed of sound. Low explosives, on the other hand, are materials that deflagrate, or 'burn down.' This is when combustion moves through a gas or an explosive material at subsonic speeds. For this reason they're better at moving objects, like in an internal combustion engine or fireworks. Deflagration systems are often found in the kind of explosives we use for constructive reasons, such as demolition and mining. They rely on us being able to control explosions, and you can discover exactly how we do this over the next six pages.



RECORD BREAKERS
LOUD NOISES

300dB

LOUDEST EXPLOSION EVER

When a meteoroid slammed through the Earth's atmosphere and exploded mid-air over Russia in 1908, creating a blast estimated at 300 decibels. It released the same energy as 185 Hiroshima bombs.

DID YOU KNOW? *The word explode comes from the Latin theatrical term explodere, meaning "to drive out through clapping"*

“Around 200 BCE, the Chinese noticed that bamboo sticks in their bonfires exploded with a bang”

INCREDIBLE FIREWORKS

THE SPARK BEHIND YOUR NEW YEAR CELEBRATIONS EXPLAINED

Fireworks were first invented by the Chinese, pretty much by accident. Around 200 BCE, they noticed that bamboo sticks in their bonfires exploded with a bang. This happened because the fast-growing bamboo traps pockets of air inside its stalks, so when the oxygen comes into contact with the fire, a huge reaction takes place, resulting in light and sound.

The Chinese took this a step further and created the first form of gunpowder, mixing sulphur, saltpetre (potassium nitrate), arsenic disulphide and honey. When set on fire, this produced an explosion caused by the sulphur and honey acting as the energy source for the reaction and the potassium nitrate providing the oxygen. Honey was replaced with energy-dense charcoal and the mixture was put in tubes and angled at enemies who were terrified by the loud bangs and bright sparks. At this point, fireworks divided into weaponry and spectacular crowd-pleasing displays.

In the 1830s, scientists in Italy realised that by adding a metallic salt like strontium or barium and chlorine powder, the light that was created took on the colour of the salt. Slow-burning gunpowder was used as a fuse to fire the rocket into the air, while inside, potassium-rich gunpowder allowed for a bigger reaction, faster and hotter with a more impressive explosion.

Fireworks are a scientific marvel, taking an example of nature – the oxygen in a bamboo stick causing an explosive reaction – and turning it into a spectacle.

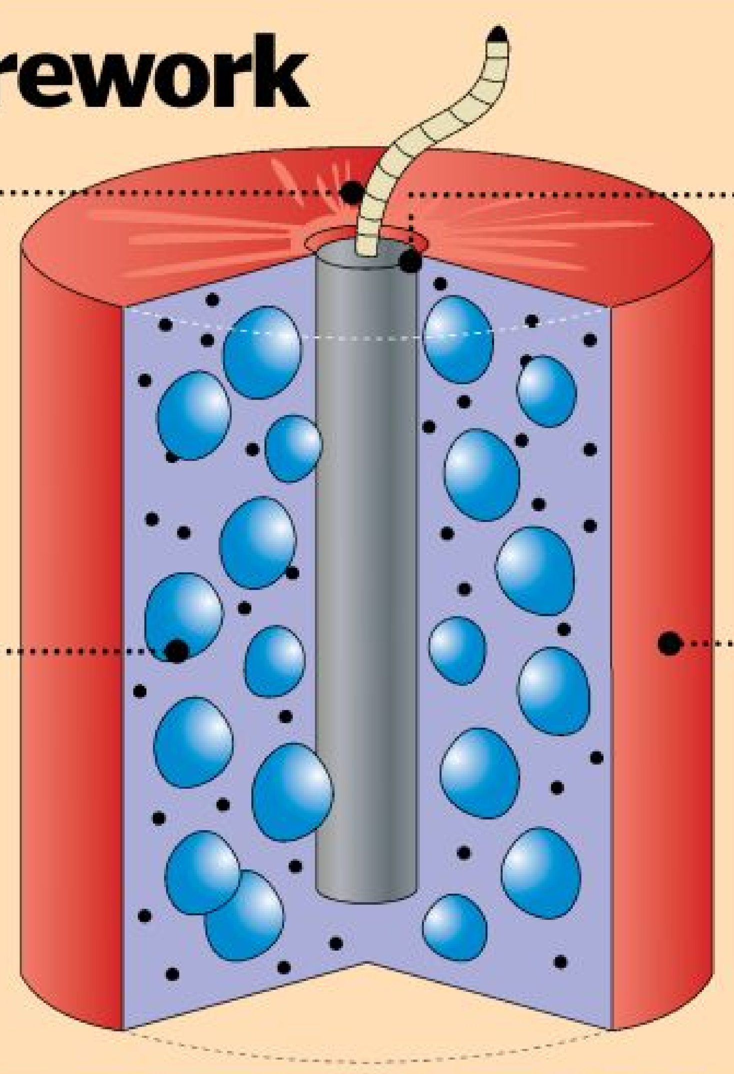
What makes the colours?

We go inside the vibrant explosion of a firework to see how it really works

Copper (blue)
Despite being reddish-brown in colour, copper emits blue light when it burns.

Strontium (red)
Strontium is the reddish element that creates the warm red light of a firework.

Anatomy of a firework



Ignition
Once the spark reacts with the gunpowder in the middle of the firework it causes an intense reaction and the gunpowder explodes outward in a shower of light.

Coloured chemicals
This layer has coloured salts reacting with the gunpowder, producing the different coloured sparks. The very middle of the firework houses a small shell that produces the signature bang.

Liftoff
The firework is blown into the sky from a mortar – essentially a tube with more gunpowder at the bottom. Once lit, the combustion spreads to the next layer of material and ignites it.

Shell
A modern firework has a plastic shell, which will explode once the charge ignites the gunpowder in the middle of the firework. This burns slowly as the firework is blown into the air.

STRANGE BUT TRUE
TASTY EXPLOSION

Switzerland made a firework out of what?

A Chocolate **B** Cheese **C** Cuckoo clocks

Answer:
On New Year's Eve 2002, the people of Zurich, Switzerland were treated to a 3m (9.8ft) high firework made of chocolate. Inside the firework it also contained 60kg (132lb) of delicious Swiss Cailler chocolates.

DID YOU KNOW? *The biggest-ever fireworks display consisted of 479,651 fireworks and took place in Dubai on New Year's Eve 2013*

The scale of reactivity

Certain elements are more reactive than others because they have a spare electron. Atoms like to have a full shell of electrons as this is what makes them stable. If an atom has seven out of a possible eight electrons in its shell, for example, it will do all it can to gain that final electron. Likewise, an atom with a single electron in its outer shell will try hard to lose it. Fluorine is the most reactive element of all, with an unmatched ability to attract electrons.

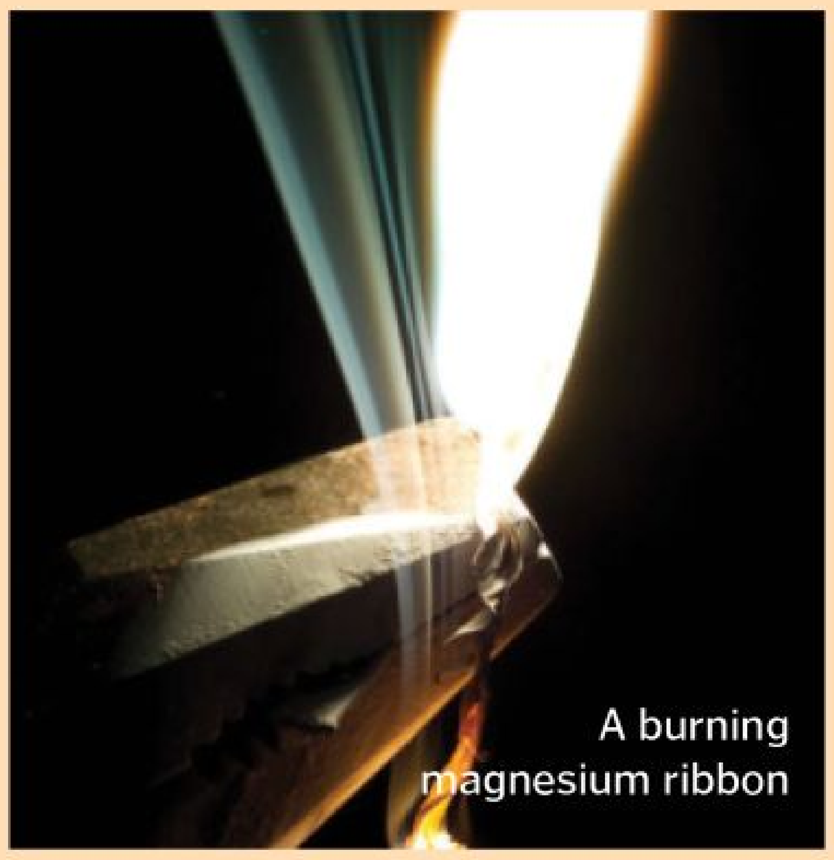
Most reactive

- Fluorine
- Caesium
- Potassium
- Lithium
- Xenon
- Helium

Least reactive

What makes a bang?

You start off with an element, such as magnesium, that is made up of a large number of molecules that contain electrons, protons and neutrons. The spark of fire will heat up the electrons and excite them. As they get more excited, they are released from their molecular bonds. This results in both a physical movement of the electrons away from the nucleus and a release of the energy that has built up during the heating stage. The energy released can trigger further interactions, in turn creating a chain reaction. The higher the initial energy of the spark, the quicker the electrons get excited, resulting in a more violent explosion.


A burning magnesium ribbon

"As [the magma] grows, little pockets of gas begin to form and rise, much like in a bottle of fizzy drink"

EXPLOSIVE VOLCANOES

WHAT CAUSES THE MOST AWE-INSPIRING EXPLOSIONS IN NATURE?

Volcanoes are some of the most massively destructive things in nature, with the ability to spew tons of red-hot magma for miles, leading to chaos and destruction. The reason behind what causes this is down to pressure. The magma, which is less dense than the rocks around it, rises to the top of the volcano.

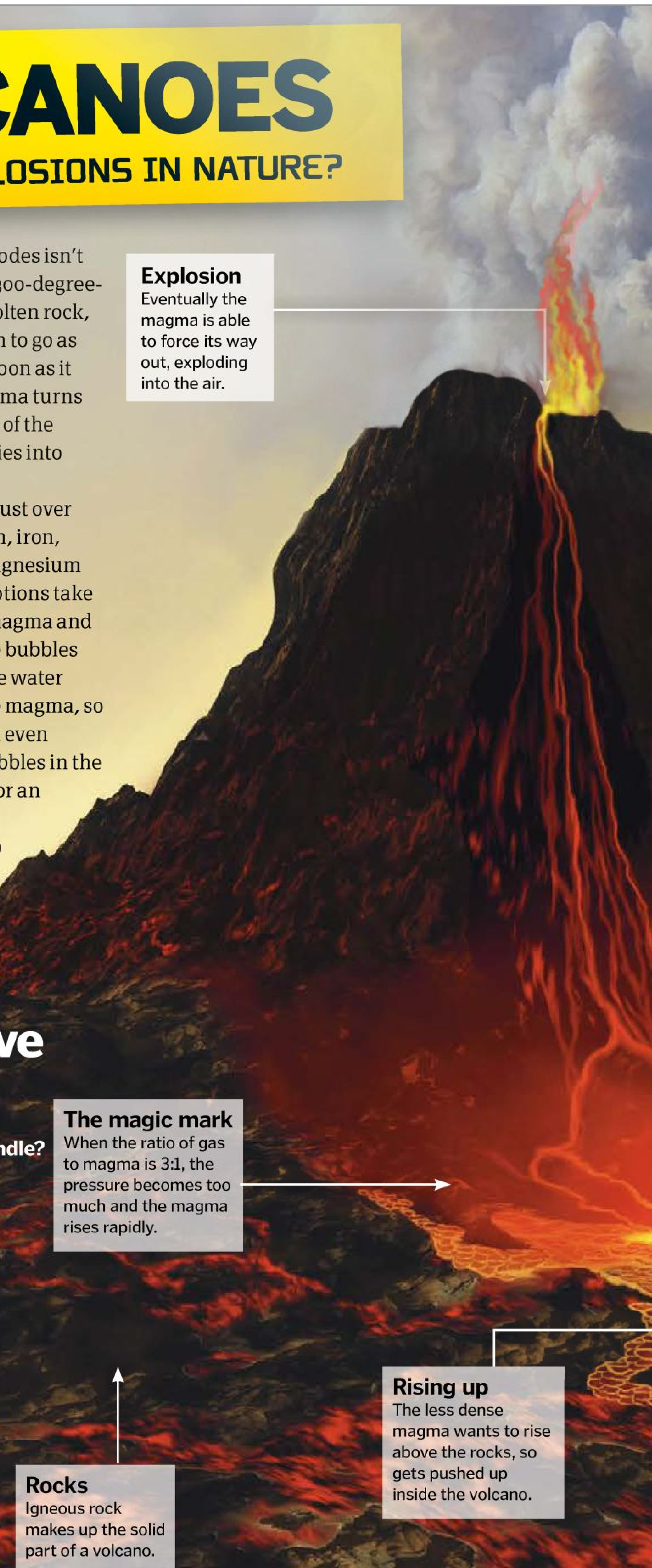
As it grows, little pockets of gas begin to form and rise, much like in a bottle of fizzy drink. This increases the pressure inside the volcano more and more, until eventually the pressure is unbearable and, just like when you take the lid off that fizzy drink, it explodes high into the sky. However, the material that explodes isn't sweetened carbonated liquid, but 1,300-degree-Celsius (2,372-degree-Fahrenheit) molten rock, hot gas and ash that has been known to go as high as 45 kilometres (28 miles). As soon as it explodes out of the volcano, the magma turns into lava, which flows down the side of the mountain, where it cools and solidifies into igneous rock.

Magma is nearly half oxygen and just over one-quarter silicon, with aluminium, iron, calcium, sodium, potassium and magnesium making up most of the rest of it. Eruptions take place when water is present in the magma and sulphur-dioxide and carbon-dioxide bubbles form. The pressure increases and the water becomes less able to dissolve in the magma, so separates. That means there's an even higher concentration of gas bubbles in the magma. The magic number for an eruption is 75 per cent gas content, which is enough to force the magma up and out.

Volcanic eruptions are among nature's most impressive spectacles

The explosive process

What happens when the pressure gets too hot to handle?



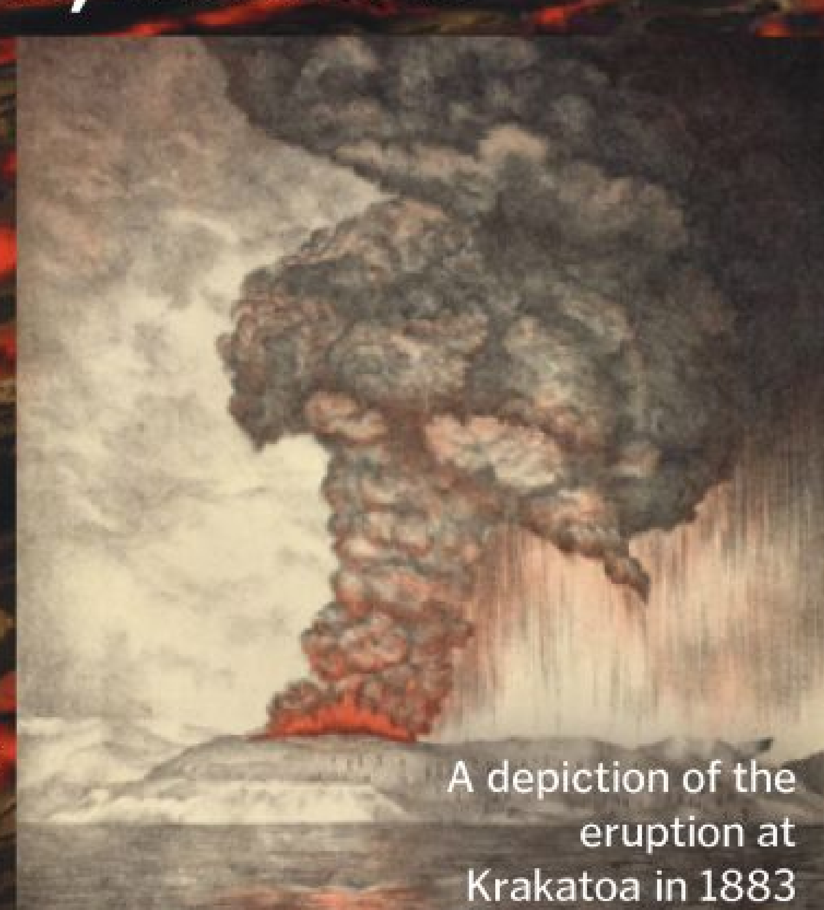
Highest, fastest, hottest, loudest

The tallest-ever volcano plume measured 45 kilometres (28 miles), which is the same as five Mount Everests.

Pyroclastic flows are incredibly fast waves of rock fragments and hot gases that can move away from the volcano at up to 480 kilometres (300 miles) per hour.

The hottest lava comes from volcanoes made up of basalt rock and can reach 1,250 degrees Celsius (2,282 degrees Fahrenheit). This is pretty impressive as Venus, the hottest planet in the solar system, only reaches 464 degrees Celsius (867 degrees Fahrenheit).

The eruption of Krakatoa in 1883 was recorded at 180 decibels from 160 kilometres (99 miles) away. This is about the same volume as a Space Shuttle launch up close.



A depiction of the eruption at Krakatoa in 1883

5 TOP FACTS
VOLCANO FACTS

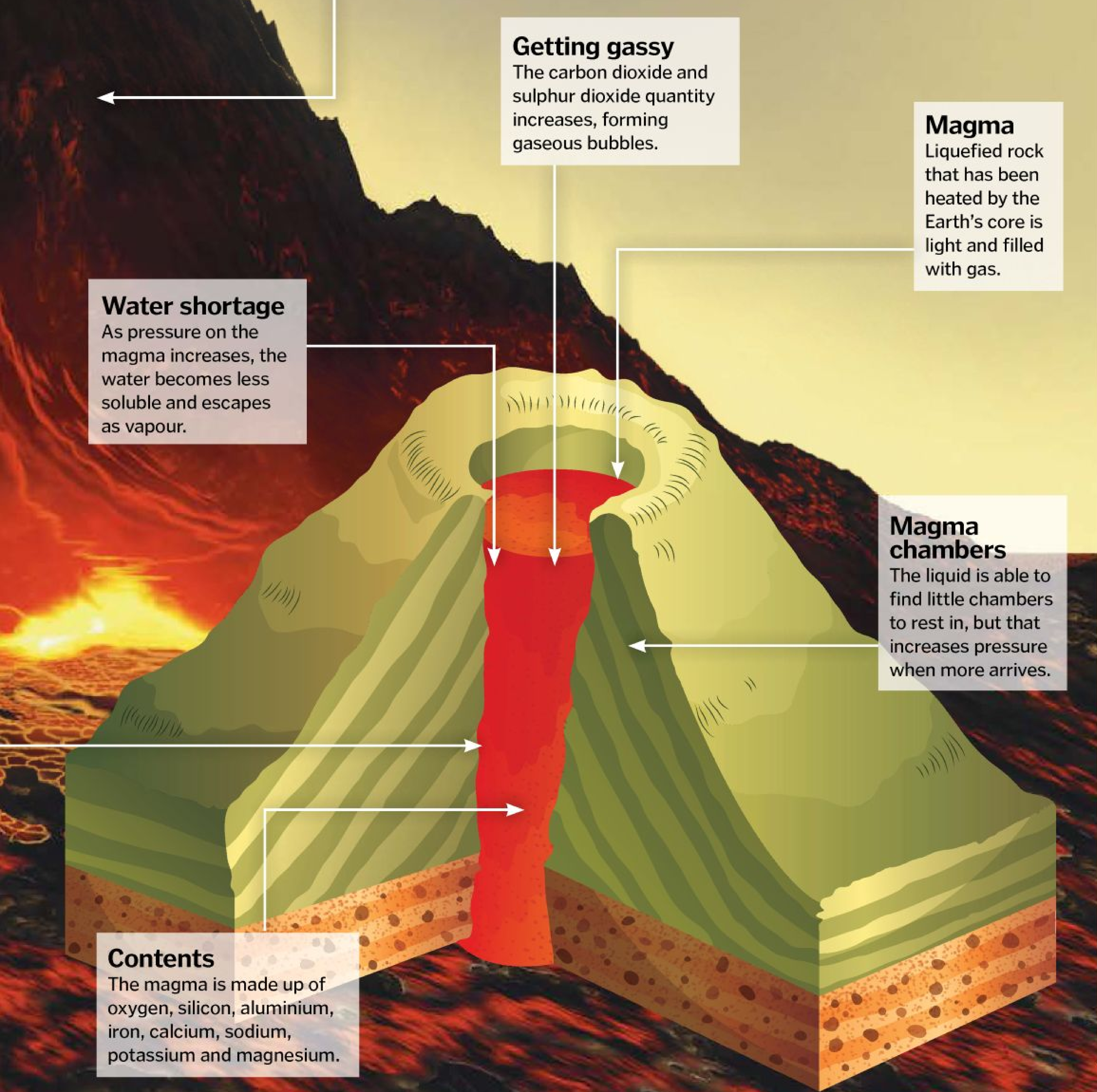
Under pressure
1 The force from an exploding volcano is about 42kg/cm2 (600psi), which is more than ten times the pressure in a fully inflated mountain-bike tyre.

Higher ground
2 Because the Earth is wider around the equator, Ecuador's Chimborazo volcano is the furthest point from the Earth's centre, even though Everest is taller.

The big one
3 The biggest explosion of all time is thought to have been the Toba supereruption in Indonesia, which may have started a volcanic winter 69,000 years ago.

The biggest one
4 We Earthlings aren't the only ones to have volcanoes. Olympus Mons on Mars is a massive 25km (15.5mi) high and 624km (388mi) across.

Krakatoa
5 One of the most famous volcanic eruptions of all time was Krakatoa in 1883. The explosion could be heard over 4,800km (3,000mi) away.




Geysers also erupt due to intense pressure underneath the surface, but unlike volcanoes, they produce hot water and steam eruptions

How to create your own homemade volcano

If you're itching to see something explosive in action, try making this home volcano

The mould
Stand a two-litre bottle on a baking tray and cover it in dough (flour, salt, cooking oil and water) or silver foil, sloping outward to create the volcano shape.

The magma
Pour in some warm water, red food colouring and six drops of washing detergent. This will increase the pressure inside the bottle when it comes to the eruption.

The lava
Pop in two tablespoons of baking soda and finally, slowly pour in some vinegar and take a few steps back because your homemade volcano is about to blow!

“When it comes to demolishing buildings, it would take ages to take it down piece by piece”

PLANNED EXPLOSIONS

A LOOK AT THE EXPLOSIONS WE CREATE ON PURPOSE

As a species, we are amazing at taking things that occur in nature and adapting them to be useful. We’ve borrowed animals’ camouflaging skills, plants’ photosynthesis abilities and the awesome power of the explosion is no different.

We make use of controlled explosions every day to help our cars move or get rid of buildings we no longer need. Even though gunpowder and explosive material can be really dangerous, if handled in the right way they can help us in fascinating ways.

When it comes to the behemoth task of demolishing buildings, it would take ages to take it down piece by piece or knock it down with tools. Wrecking balls create so much debris that the surrounding area could be at risk. That’s why using dynamite to get rid of a skyscraper is a better idea because it means that we have some kind of say in what direction it falls down, rather than leaving it to chance as could happen with other less precise methods.

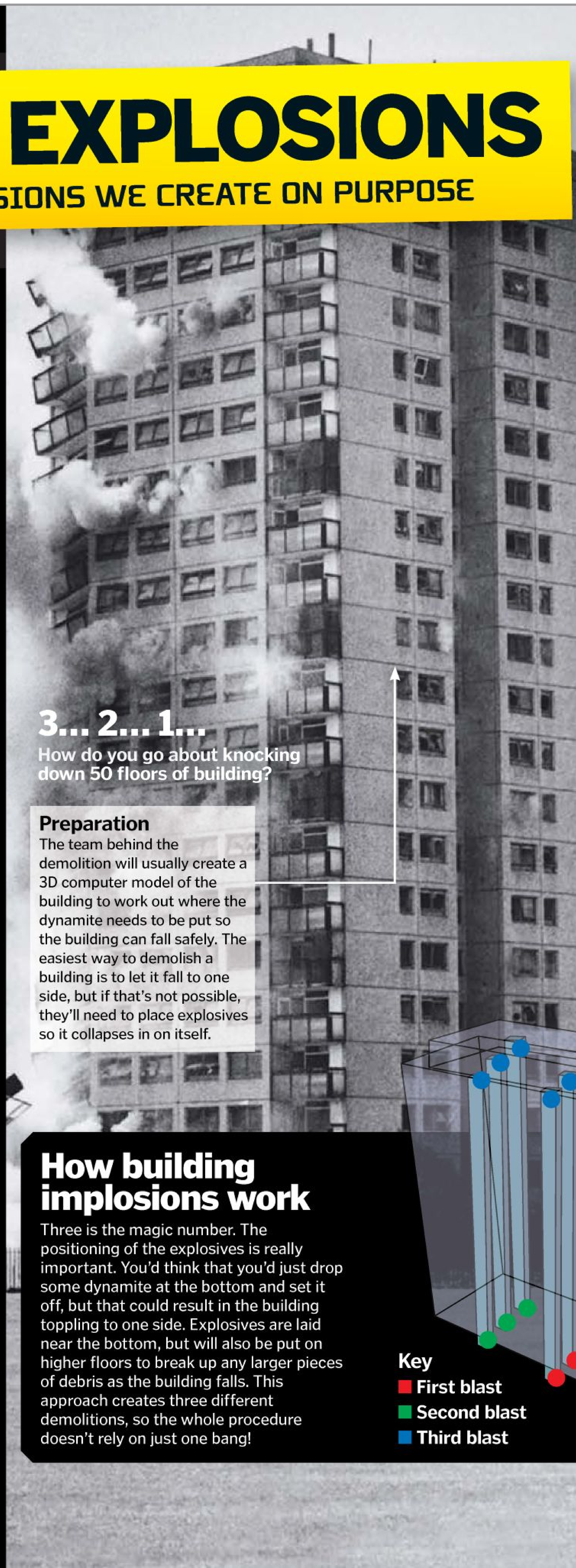
We also wouldn’t be able to get anywhere at any kind of speed without the propelling power of explosions. A series of small explosions is what forms the basis of the internal combustion engine, which is what most of our cars use.

Another use is rock blasting. Whether people are trying to get through a pile of rocks to mine or rescue trapped people, rock blasting takes a massive amount of effort out of moving tons of solid rock from an area.

If we take great enough care, explosions can be among the most useful things we can take from the world around us.

Mentos and Diet Coke

Dropping the mint or fruit-flavoured sweet into a bottle of Diet Coke creates a huge eruption of foam. This is because the rough sweets disturb the liquid molecules, creating bubbles. The sweetener aspartame lessens surface tension, so it’s easier for the bubbles to shoot higher out of the bottle.



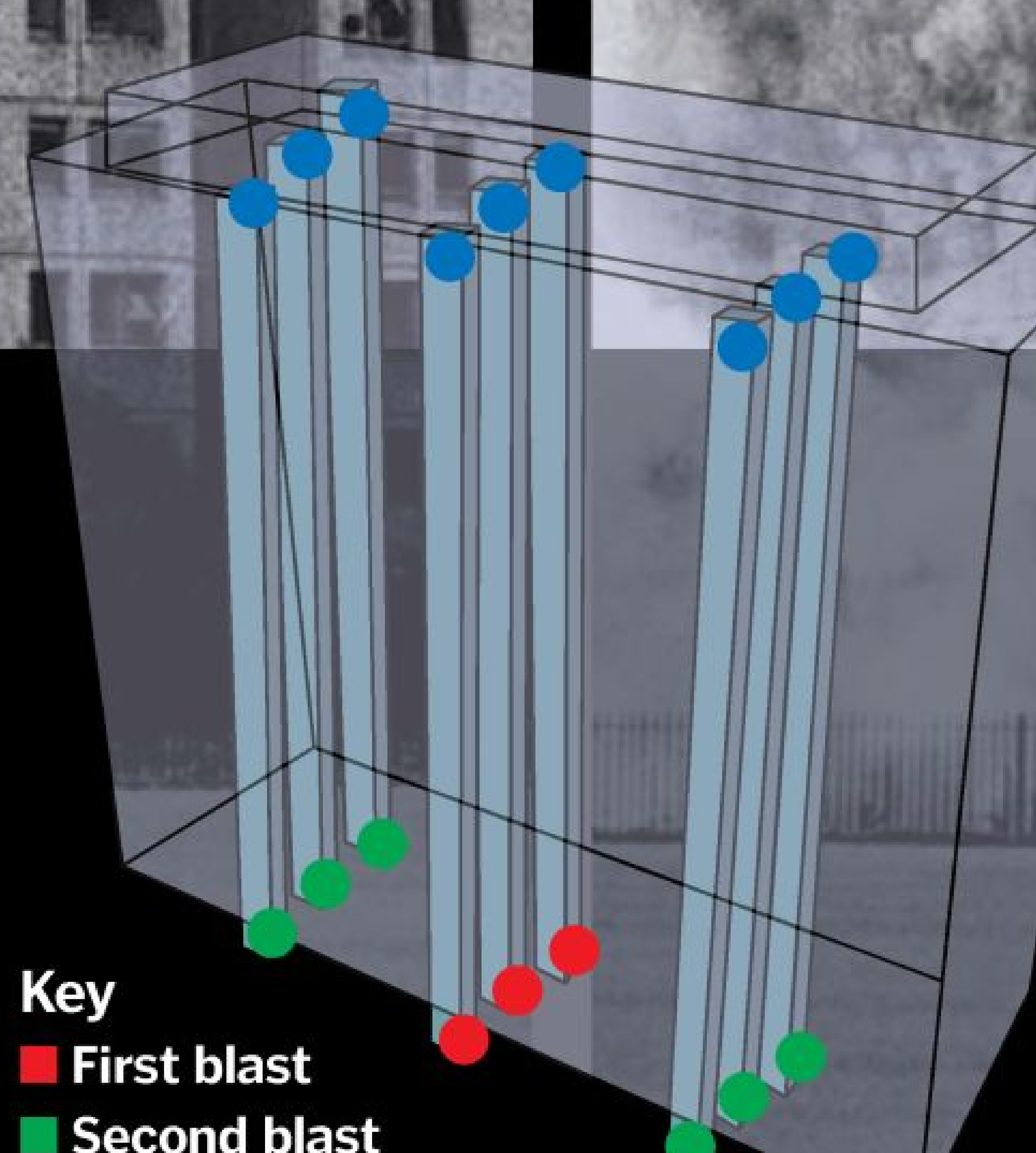
3… 2… 1…

How do you go about knocking down 50 floors of building?

Preparation
The team behind the demolition will usually create a 3D computer model of the building to work out where the dynamite needs to be put so the building can fall safely. The easiest way to demolish a building is to let it fall to one side, but if that’s not possible, they’ll need to place explosives so it collapses in on itself.

How building implosions work

Three is the magic number. The positioning of the explosives is really important. You’d think that you’d just drop some dynamite at the bottom and set it off, but that could result in the building toppling to one side. Explosives are laid near the bottom, but will also be put on higher floors to break up any larger pieces of debris as the building falls. This approach creates three different demolitions, so the whole procedure doesn’t rely on just one bang!



Key
- First blast
- Second blast
- Third blast

What caused an explosion in 1919?

A **Molasses** B **Honey** C **Crackers**

Answer:
A storage tank in Boston, USA was holding nearly 2.5 million gallons (9.5 million litres) of molasses. It suddenly exploded , shaking the nearby ground like a passing train and releasing a mighty flood of molasses into the streets.

The descent
Another reason why there are three explosions is to help it fall more uniformly. The removal of a floor higher up will make it drop down onto the floors below, pushing them directly down. If a Jenga tower is toppled incorrectly from the base, it will fall to the side, but if you whip away a layer higher up, it will fall straight downward and make for a cleaner demolition.

What's in a demolition?
The material used in building demolition varies but it's usually dynamite or Research Department explosive (RDX). It needs a massive charge, so the team will use another explosive that will be detonated remotely using an electronic charge. This small explosion will trigger the main explosion, releasing nitrogen and carbon-oxide gases at a rate of 8,230m (27,000ft) per second to blow out the building's support structures.

The Hollywood explosion

If there's one thing Hollywood loves, it's an explosion. Huge fireballs are particular crowd-pleasers, but how are they created?

The iconic explosion of the Death Star in *Star Wars – Episode IV* was produced by putting a camera directly underneath a composition of sulphur, potassium nitrate and charcoal. The mixture was ignited and the fireball headed straight down toward the camera, giving the impression of a huge, outward explosion.

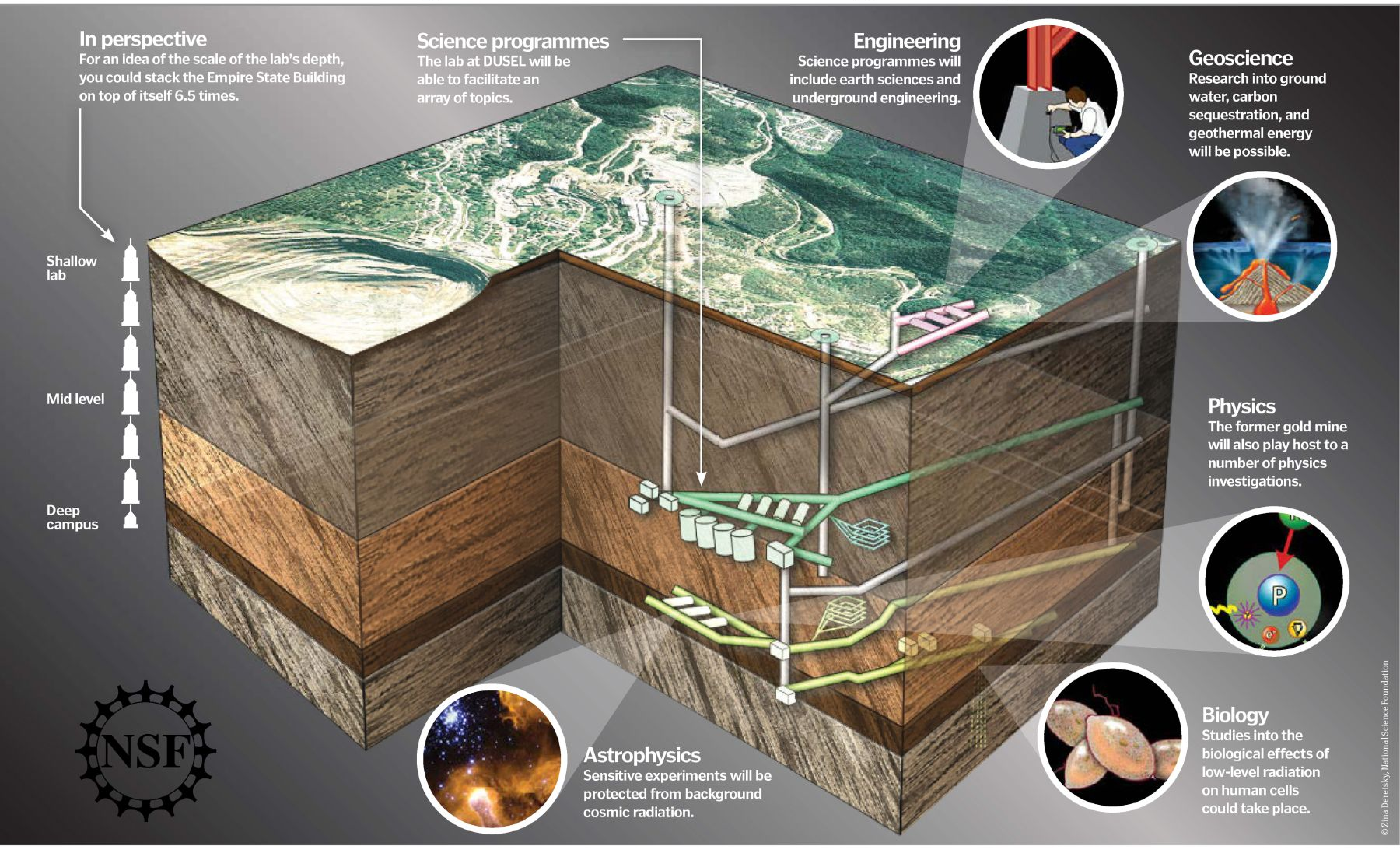
If you're in Hollywood and don't want to blow up a huge building, you'll use a model. Movies like *Independence Day* used a plaster model of the White House to destroy, because plaster looks a lot like concrete on screen.

It's bad news for film buffs who love a tough guy strolling away from a massive explosion: unless they've got a starting distance of around 360 metres (1,181 feet) from where an explosion starts by just 2.3 kilograms (five pounds) of explosive, they're going to end up pretty toasty!

Blasting rock

The most important stage in rock blasting is to bore a hole into the area you are attempting to blow up. This is essentially destroying a rock from the inside, usually to gain access to mining resources or to rescue people following a rock slide. After drilling a hole in the rock, you fill it with ammonium nitrate-fuel oil. When detonated, the explosion should expand in all directions.

The Deep Underground Science and Engineering Lab



World's deepest underground lab

The answers to our deepest scientific questions are even deeper than you think

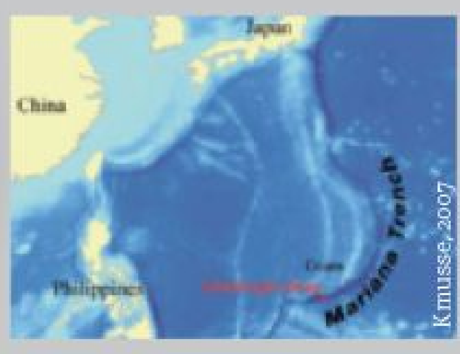
So what is DUSEL? It's the Deep Underground Science and Engineering Lab which, as far as acronyms go, makes it pretty self-explanatory. The project is currently under consideration by the National Science Foundation and if successful will be housed at 2,500 metres (8,000 feet) down in an abandoned gold mine in South Dakota. The blueprints for DUSEL include deep labs for the study of geomicrobiology. Here, scientists will examine so-called 'Dark Life', massive microbial colonies that exist without sunlight at temperatures exceeding 100°C. These colonies, which contribute to half the Earth's biomass, may also be the earliest life on Earth.

DUSEL will also include facilities for geoscientists and engineers to work hands-on with deep subterranean rock formations under massive pressure. Their discoveries could lead to better earthquake prediction technology, safer sources of drinking water as well as effective techniques for carbon sequestration.

There are ten major deep-Earth laboratories around the globe, most of them devoted exclusively to astroparticle physics – that is the science of explaining the very large with the very small. Protected from cosmic interference by miles of rock, physicists smash atoms in search of elusive dark matter and dark energy, the unexplained substances that compose over 70 per cent of the universe's mass and energy.

The main impetus for DUSEL is the study of extremely rare nuclear physics processes, like neutrino scattering, dark matter interactions, and neutrinoless double beta decay, which can only be studied in the absence of cosmic rays. Find out more about one of these experiments and why it needs to be conducted so far underground on the opposite page.

DEEPEST TRENCH



1. Mariana Trench
Depth: 11,034m (36,200ft)
Location: Pacific Ocean
Info: The deepest point in the Earth's oceans.

DEEPEST LAKE

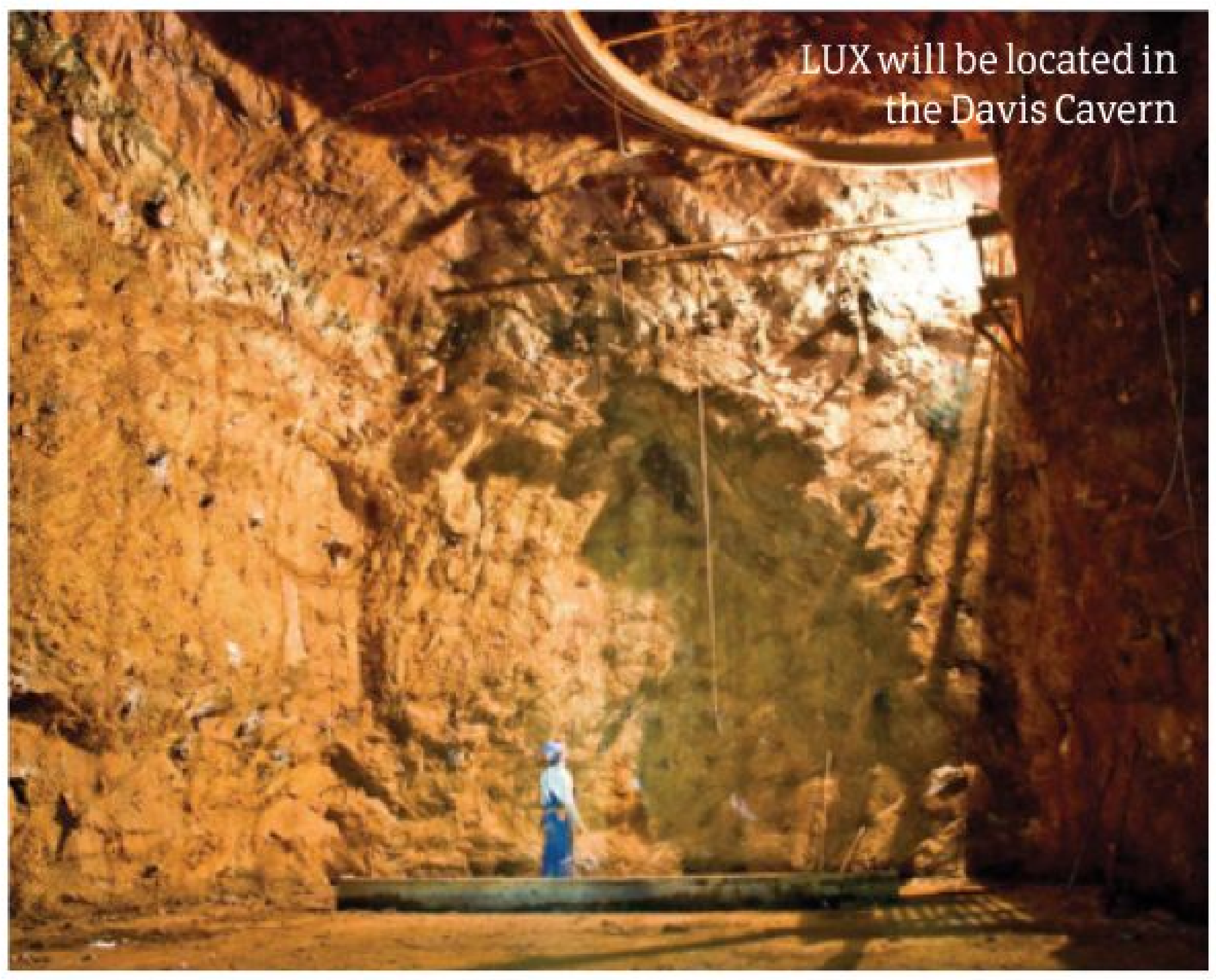
2. Lake Baikal
Depth: 1,637m (5,369ft)
Location: Siberia, Russia
Info: This continental rift lake is over a mile straight down.

DEEPEST HOLE

3. Kola well
Depth: 12,261m (40,226ft)
Location: Kola Peninsula, Russia
Info: Drilling to learn about the Earth's crust since the Seventies.

DID YOU KNOW? *The work at DUSEL could help to create better earthquake prediction technology*

Physicists at Sanford could identify WIMPS using the LUX detector



LUX will be located in the Davis Cavern

The Sanford experiment: Hunting for WIMPs

The key to finding dark matter is underground

Astrophysicists believe that 25 to 30 per cent of the known universe is very much 'unknown'. It's composed of a mysterious cosmic glue called dark matter, an invisible, atom-less substance made of inexplicably massive particles. The race to explain dark matter is one of the greatest prizes in modern science.

The physicists at the Sanford Underground Laboratory are hot on the trail of one of the leading candidates for dark matter, theoretical specks called weakly interacting massive particles, or WIMPs. At 1,500 metres (5,000 feet) below the surface, Sanford scientists are building a Large Underground Xenon (LUX) detector to spot the first confirmed WIMP in the debris of an atomic collision.

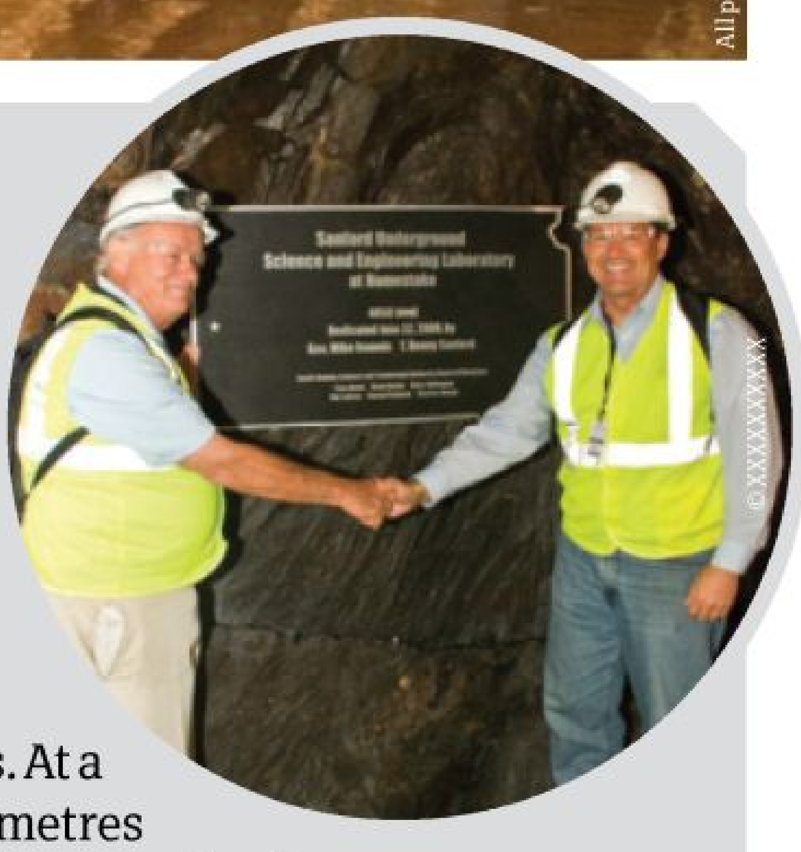
The LUX detector, the most sensitive equipment of its kind, is a cylindrical tank filled with 65 kilograms of liquid xenon and armed with 122 photomultiplier tubes (PMTs) that can sense individual photons. If underground conditions are 'quiet' enough and the detector is sensitive enough, Sanford could usher in the dawn of a new scientific age.

My, that's a big drill

All photos South Dakota Science and Technology Authority (by Bill Harlan)

A modest exterior hiding a gold mine of scientific possibility

Deep science: why underground?



Every second, your body is bombarded with thousands of cosmic rays. These super-charged particles from distant solar systems – some as old as the big bang itself – rain down on the Earth in a continuous ionic storm.

For astroparticle physicists, who are searching for infinitesimally 'quiet' signal variations in very large experiments, the background noise of the cosmic storm can be deafening. The best way to shield their highly sensitive equipment from 'false positive' background signals is to conduct their experiments hundreds or thousands of metres below solid rock.

And it works. At a massive 2,000 metres (6,500 feet) underground, only one cosmic ray particle passes through a square metre of surface area every three days. The rate on the Earth's surface is 10,000 per second, or 50 million times higher.

Deep labs

DEEPEST

1. SNOLAB
Location: Canada
Facts: Buried 2km below the surface in a Canadian nickel mine, the deepest operational lab in the world is devoted to astroparticle physics experiments, specifically the search for dark matter. It famously solved the 'Solar Neutrino Problem' by proving that neutrinos could change 'flavour', proving the existence of a solar neutrino spectrum.

BIGGEST

2. Gran Sasso National Laboratory
Location: Italy
Facts: Protected by 1,400 metres of rock, Gran Sasso's three separate subterranean labs – totalling 180,000 cubic metres –specialise in neutrino physics, including those produced by supernova explosions. The facility, located under the town of L'Aquila, Italy, was undamaged in the region's 2009 earthquake.

CONTENDER

3. DUSEL
Location: USA
Facts: The proposed Deep Underground Science and Engineering Laboratory (DUSEL) at the Homestake Mine in South Dakota – 2.5 kilometres (8,000 feet) at its deepest shaft – would be a multidisciplinary lab studying dark matter physics, geomicrobiology ('dark life' microbes that live at great depths), geothermal processes and deep-Earth engineering.

"One of energy's fundamental properties is that it cannot be created nor destroyed"

ENERGY EXPLAINED

Get back to basics and find out how energy underpins every process in the universe

On an intuitive level, we all know that energy is what makes things happen, causing the Sun to shine, allowing plants to grow, cooking food on a stove or making a basketball bounce. Whenever something heats up, cools down, moves, grows, makes a sound or changes in any way, it uses energy. And from taming fire to powering smartphones, human civilisation relies on our ability to manipulate energy. But pinning down exactly what energy *is* can be tricky.

Grab a textbook and you'll find energy described as 'the ability to do work'. Work in this context is defined as exerting a force on an object over a distance. Lifting a cardboard box off the ground constitutes work, however continuing to hold it there – although requiring effort on your part – is not work.

When work is done to an object, it gains energy. This energy is called kinetic energy if it's associated with the object's motion, as with a football speeding through the air after you kick it. When you pick up the box it is said to have gained potential energy, stored by virtue of its elevation above the ground. If you let go (mind your toes!), the box will fall, losing potential energy as it loses height, and gaining kinetic energy as it picks up speed.

One of energy's fundamental properties is that it cannot be created nor destroyed, only transformed from one type to another. Potential energy can turn into kinetic energy and vice versa limitless times. Further, mechanical, sound, heat, electromagnetic, light, chemical and nuclear energy can all be converted from one into the other.

But while you can't destroy energy, you can certainly waste it through inefficiency. When you drive a car, for example, chemical energy stored in the fuel is converted into first thermal energy and then kinetic energy which turns the car's wheels. But not all of the chemical energy released from the fuel goes into making the vehicle move. Some is converted to heat and sound, and some is used to displace air around the car – ie air resistance. Once this has occurred it's very hard to turn this wasted energy back into something useful.

5 TOP FACTS
ENERGY TRIVIA

Sunlight
1 The solar radiation beaming down on our planet from the Sun over just one hour carries more than enough energy to meet the global population's needs for a whole year.

Nuclear energy
2 Splitting just one kilogram (2.2 pounds) of uranium-235 nuclei in a fission reactor releases as much energy as over 2 million kilograms (4.4 million pounds) of coal in a power plant.

All in the mind
3 The brain is the body's most energy-greedy organ, taking up 20 per cent of the energy from your food. This energy fuels not only brain function but also its maintenance.

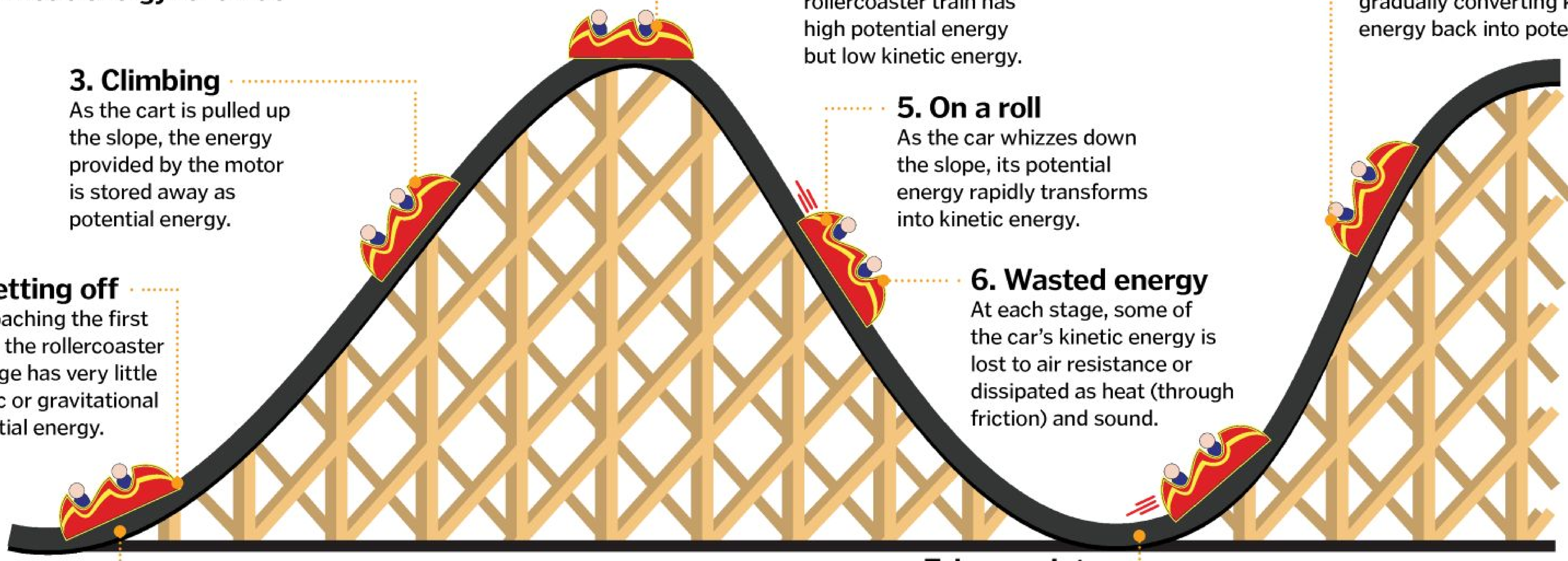
Solar diet
4 Fusion in the Sun's core converts mass into energy, causing it to lose about 4.3 billion kilograms (9.5 billion pounds) every second – still a tiny fraction of its total mass.

High-energy physics
5 A proton whizzing around the Large Hadron Collider has a comparable amount of kinetic energy to a mosquito – but this energy is concentrated in a much, much tinier body.

DID YOU KNOW? *A lightning bolt contains 5 billion joules of energy – enough to cook 100,000 slices of toast*

Energy in a rollercoaster

Find out how a rollercoaster takes potential and kinetic energy for a ride



Einstein's big idea

In 1905, Einstein revolutionised physics with a jaw-dropping revelation: matter and energy are one and the same. This fact is immortalised in the world's most famous equation: $E=mc^2$. Under the right conditions, energy can be converted into matter and vice versa. This energy comes from the ultra-strong bonds holding protons and neutrons together in atomic nuclei. The c in the equation represents the speed of light – about 1.13 billion kilometres (700 million miles) per hour – so even an object with tiny mass contains a huge amount of energy. If you could turn every atom of a paperclip into energy, you would release as much energy as the atomic bomb that obliterated Hiroshima in 1945. Doing so would, however, require extreme temperature and pressure conditions that are impossible on Earth.

$$E = mc^2$$

c
The speed of light in a vacuum: ie around 300,000,000m/s (983,600,000ft/s).

E
E is energy, which is measured in joules.

m
m represents mass, measured in kilograms.

Conservation of energy

One of our universe's most basic principles, the law of conservation of energy states that energy can be neither created nor destroyed. That is, the amount of energy in a closed system is fixed. It can, however, be transferred from one object into another, and converted from one form to another.

Although we discuss energy production, you can't create new energy – only convert existing energy to a different usable form. A photovoltaic panel, for instance, taps into the Sun's radiant energy, converting it to usable electrical energy.

Likewise, the energy that we use doesn't disappear – it just changes into other forms. Switch on your television and the heat, sound and light energy emanating from the set gradually leak back into the environment.

Throughout history, numerous inventors have attempted to design and build perpetual motion machines that would give out more energy than was put in, but conservation of energy has made such inventions impossible – at least thus far!

Throughout history we have relied on different means to get hold of usable energy, from early windmills to coal-burning steam engines. Today, we consume energy mainly as petroleum, natural gas and electricity. We tap into the energy stored in the chemical bonds of petrol or natural gas by burning these fuels, whether inside a boiler or an engine, etc.

Electricity, on the other hand, is a handy way of transporting energy converted from various more cumbersome sources into our homes or workplaces. A wind turbine, for instance, converts kinetic energy, while a nuclear reactor exploits the energy locked in atomic nuclei, generating first thermal and then electrical energy. Once inside our home, electricity can be used for heating, cooking, lighting and running all of our appliances and gadgets.

Energy is measured in joules (J), with one joule being the energy needed to apply a force of one newton (N) over one metre (3.2 feet).

In practice, a variety of different units are commonly used to measure energy in its multitude of different forms. The chemical energy in food is measured in calories – the amount it takes to raise the temperature of one gram of water by one degree Celsius. Your electricity bill, in comparison, measures the electrical energy you have used in kilowatt-hours (kWh). For some context, one kilowatt-hour is enough to run one washing machine cycle or watch seven hours of TV.

“Potential energy has its roots in the force acting between two objects and the distance between them”

POTENTIAL VS KINETIC ENERGY

The simplest way to classify energy is by dividing it into kinetic energy and potential energy. This distinction is, however, not enough to fully describe the different ways in which an object or a system can possess energy. Hence we have nine major forms of energy.

Kinetic energy is associated with motion. From an oxygen molecule through to a planet, the more mass an object has and the faster it moves, the greater its kinetic energy. The motion of different types of objects gives rise to different forms of kinetic energy.

Potential energy has its roots in the force acting between two objects and the distance between them. For example, the potential energy of a rock on top of a hill comes from the gravitational force between Earth and the rock. The more massive the rock, and the greater its height, the bigger its potential energy. Different forces give rise to potential energy under different names, as we see here.

Sound

KINETIC

Sound energy is all about vibrations. Strum a guitar string and it vibrates. This motion propagates through the air, oscillating the molecules back and forth. When the wave reaches your ear, your eardrum vibrates in turn and your brain interprets the sound. We rarely use sound waves to do work but rather as a means to communicate or entertain.

Kinetic

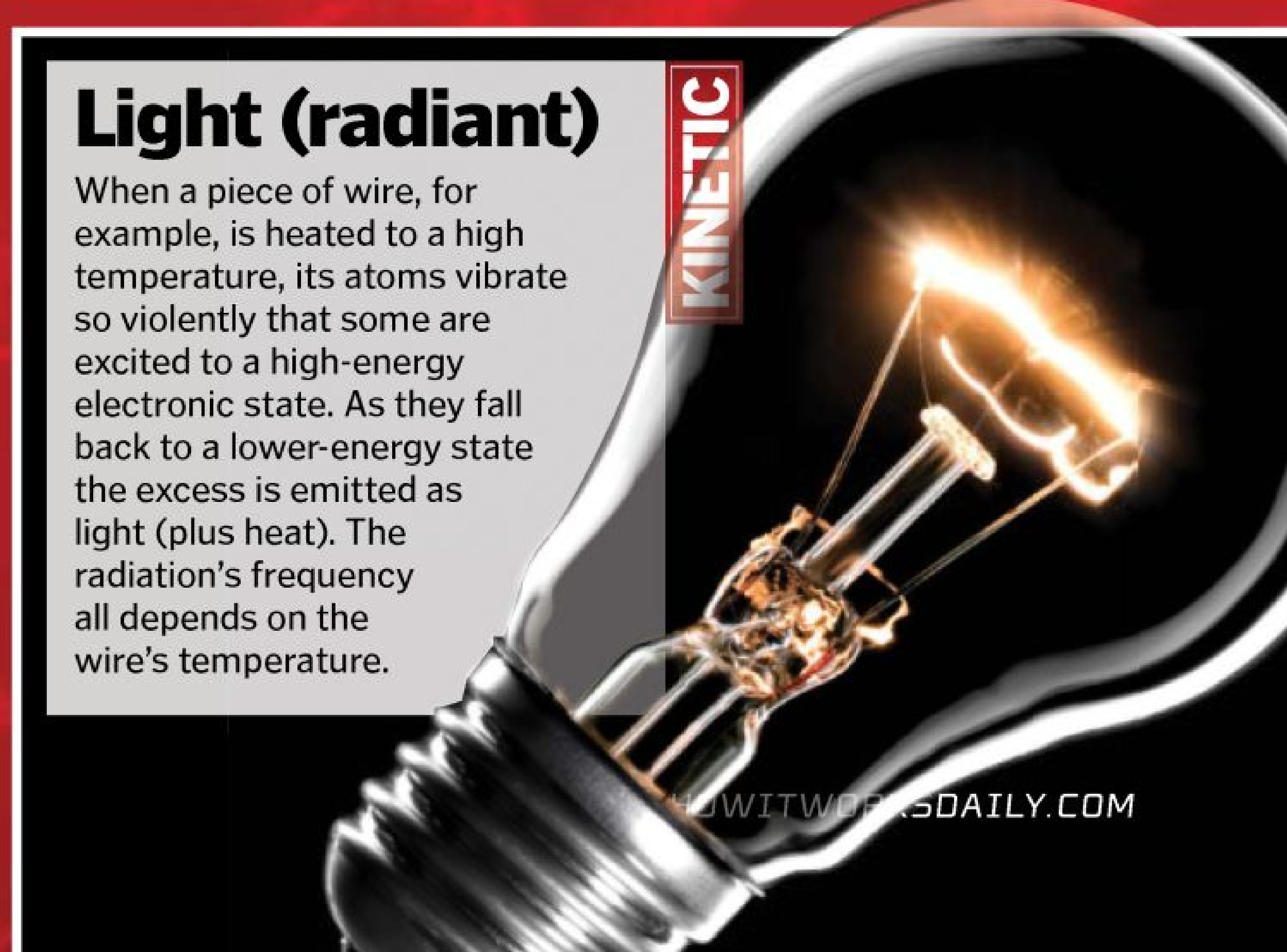
KINETIC

While sound, light and heat are all forms of kinetic energy, the term kinetic energy can also refer to the motion energy of objects on the macro scale – as opposed to invisible vibrations of tiny particles. We therefore use kinetic energy to talk about motion energy that we can see – for example, associated with a moving car or person.

Thermal

KINETIC

Thermal energy is a combination of the kinetic and potential energy of its constituent particles. As the water in your kettle heats up, its molecules vibrate faster and faster until it reaches boiling point. In a steam engine, heat is converted to mechanical energy from the expansion when water is turned into vapour.



Light (radiant)

KINETIC

When a piece of wire, for example, is heated to a high temperature, its atoms vibrate so violently that some are excited to a high-energy electronic state. As they fall back to a lower-energy state the excess is emitted as light (plus heat). The radiation’s frequency all depends on the wire’s temperature.

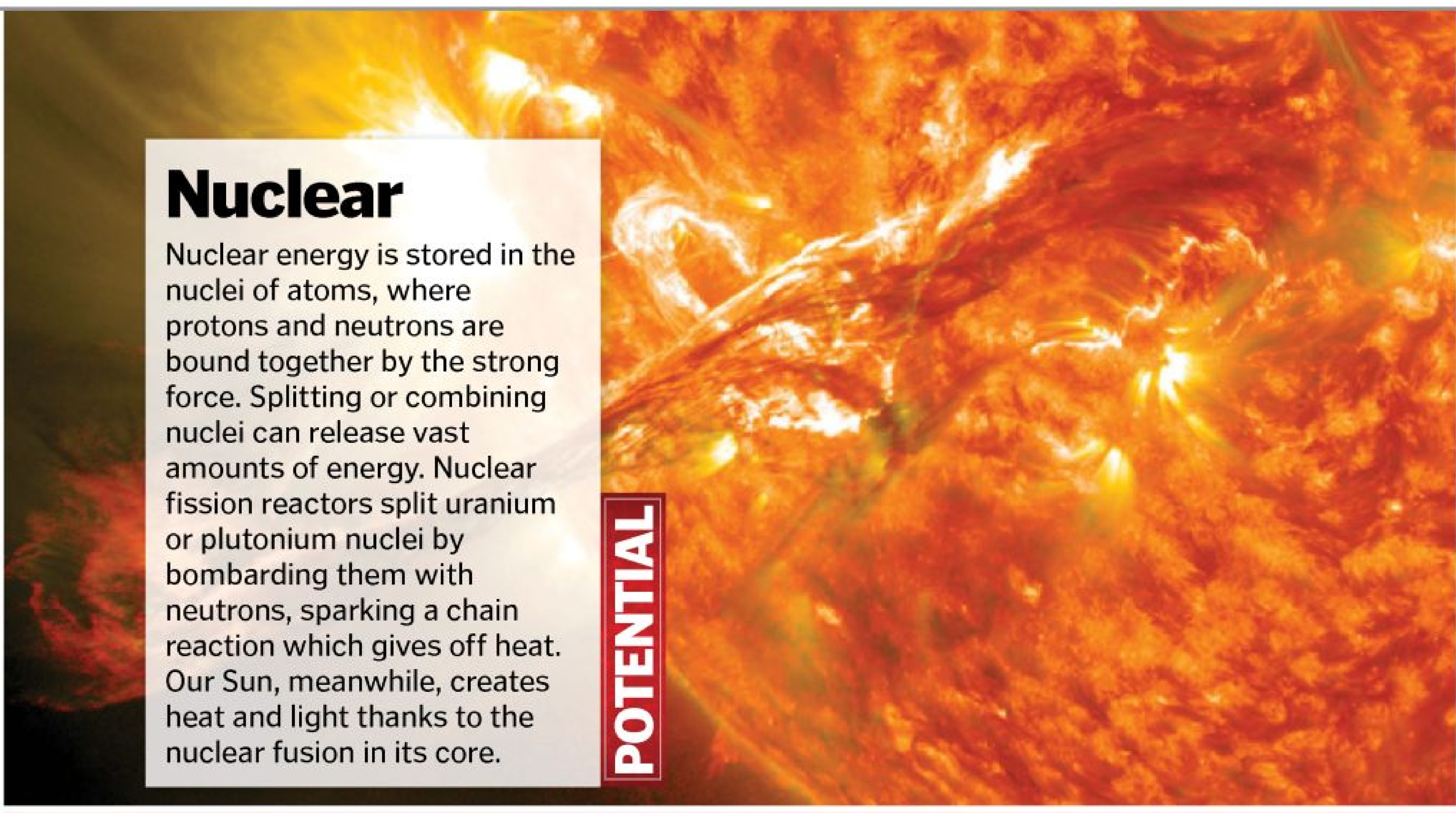
RECORD BREAKERS
WATER INTO WATTS

98.3

MOST PRODUCTIVE POWER STATION

The Itaipu hydroelectric dam between Brazil and Paraguay generates more energy than any other facility: over 98TWh. Water flows through it at up to 62,000 cubic metres (2.2 million cubic feet) per second.

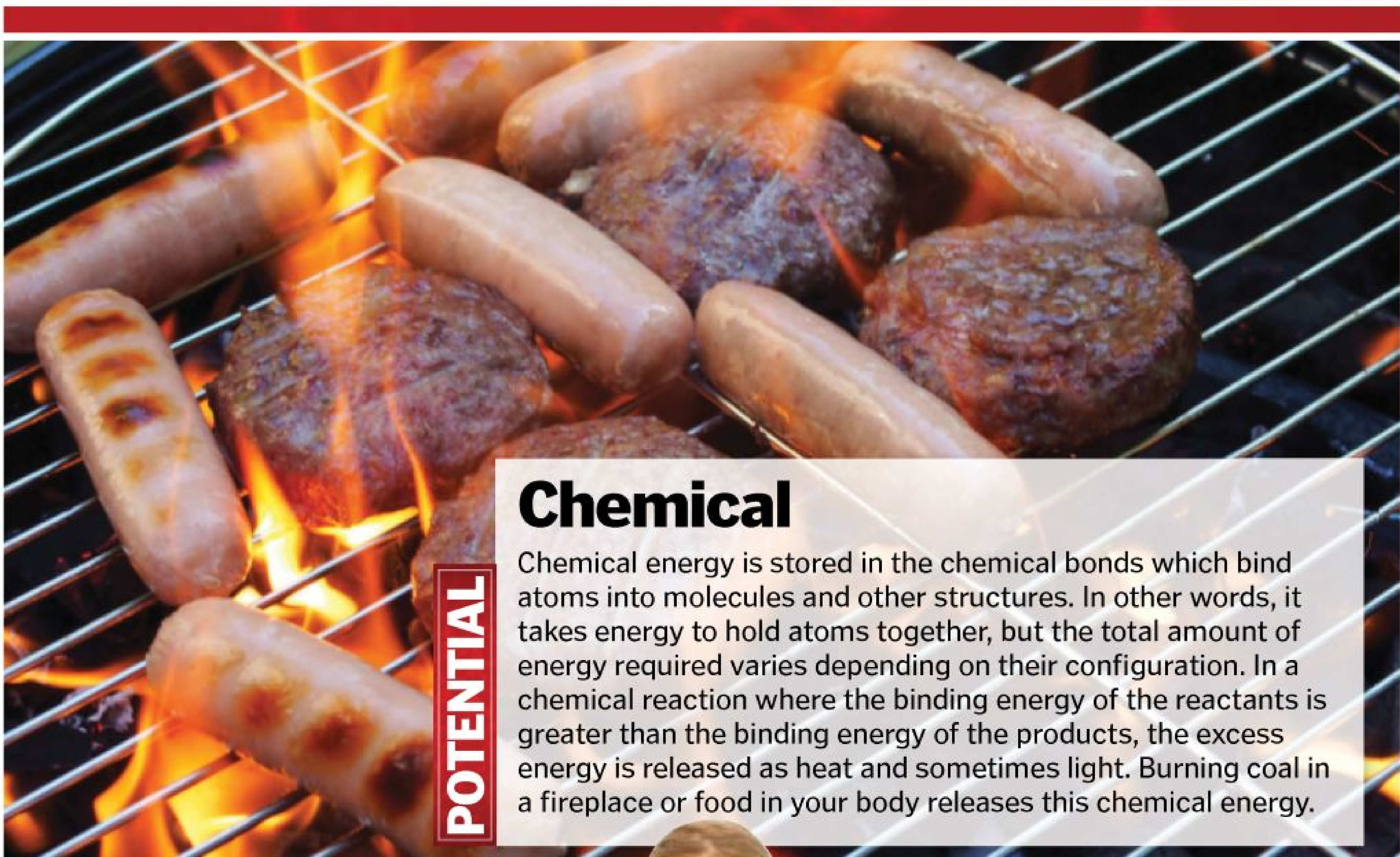
DID YOU KNOW? *On average, a US inhabitant uses over ten times as much energy than someone living in India*



Nuclear

Nuclear energy is stored in the nuclei of atoms, where protons and neutrons are bound together by the strong force. Splitting or combining nuclei can release vast amounts of energy. Nuclear fission reactors split uranium or plutonium nuclei by bombarding them with neutrons, sparking a chain reaction which gives off heat. Our Sun, meanwhile, creates heat and light thanks to the nuclear fusion in its core.

POTENTIAL



Chemical

Chemical energy is stored in the chemical bonds which bind atoms into molecules and other structures. In other words, it takes energy to hold atoms together, but the total amount of energy required varies depending on their configuration. In a chemical reaction where the binding energy of the reactants is greater than the binding energy of the products, the excess energy is released as heat and sometimes light. Burning coal in a fireplace or food in your body releases this chemical energy.

POTENTIAL

Elastic

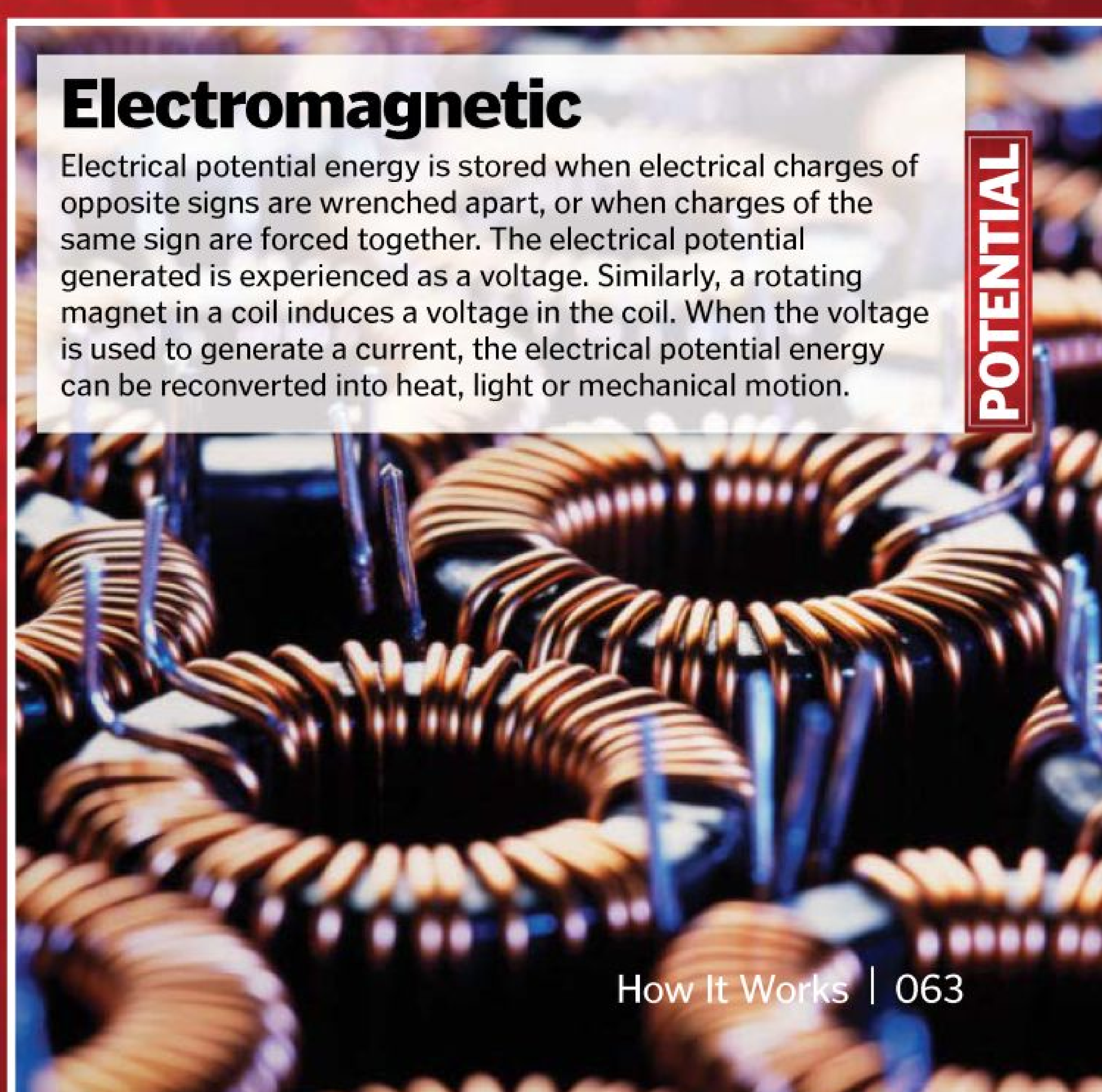
Elastic energy is the potential energy stored when an object's shape or volume is distorted – for example, when you jump on a trampoline. As the trampoline returns to its original shape, it propels you into the air, converting potential energy into kinetic energy. Not all materials have the same capacity to store elastic energy; a rubber band, for instance, can store more than a piece of string.

POTENTIAL

Gravitational

Gravitational energy stems from the gravitational field around our planet (and other bodies). It arises, for example, when a skier rides a ski lift up a mountain slope. The higher the skier travels, the more potential energy is stored up. Once they set off down the slope, this stored energy is transformed into kinetic energy as they speed up down the slope.

POTENTIAL



Electromagnetic

Electrical potential energy is stored when electrical charges of opposite signs are wrenched apart, or when charges of the same sign are forced together. The electrical potential generated is experienced as a voltage. Similarly, a rotating magnet in a coil induces a voltage in the coil. When the voltage is used to generate a current, the electrical potential energy can be reconverted into heat, light or mechanical motion.

POTENTIAL

HOW IS ENERGY TRANSFERRED?

Next time you take a hot shower, drive to work or plug in a laptop, spare a thought for the science that brings energy on demand into your home.

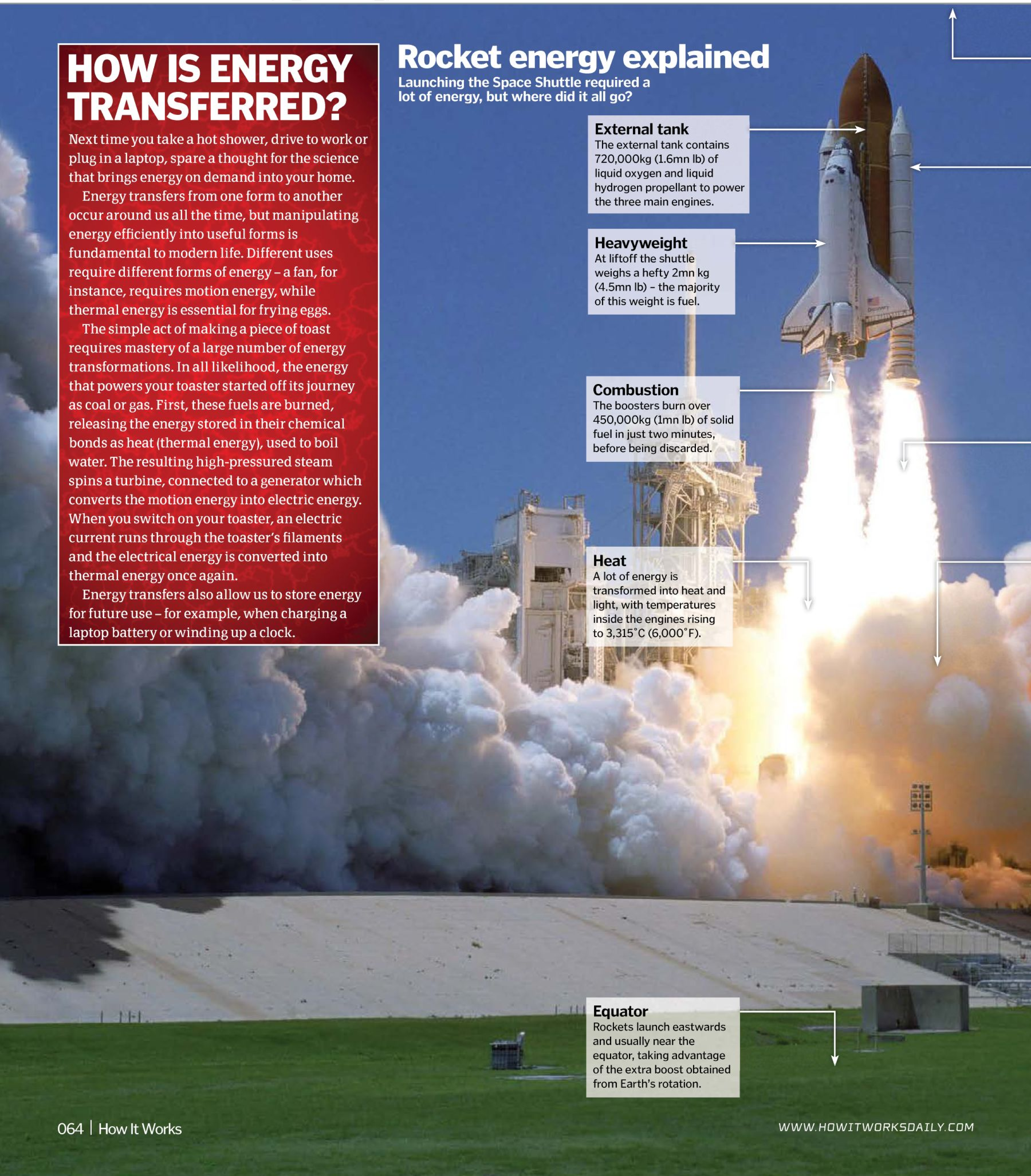
Energy transfers from one form to another occur around us all the time, but manipulating energy efficiently into useful forms is fundamental to modern life. Different uses require different forms of energy – a fan, for instance, requires motion energy, while thermal energy is essential for frying eggs.

The simple act of making a piece of toast requires mastery of a large number of energy transformations. In all likelihood, the energy that powers your toaster started off its journey as coal or gas. First, these fuels are burned, releasing the energy stored in their chemical bonds as heat (thermal energy), used to boil water. The resulting high-pressured steam spins a turbine, connected to a generator which converts the motion energy into electric energy. When you switch on your toaster, an electric current runs through the toaster's filaments and the electrical energy is converted into thermal energy once again.

Energy transfers also allow us to store energy for future use – for example, when charging a laptop battery or winding up a clock.

Rocket energy explained

Launching the Space Shuttle required a lot of energy, but where did it all go?



STRANGE BUT TRUE

JOULE MAKER

Which phenomenon releases the most energy?

A A human sneeze **B** A hurricane **C** An atom bomb

Answer:
A hurricane can release up to 10^{19} joules of energy in a day – a million times as much as an atom bomb like the one dropped on Hiroshima. Though sneezing expels droplets at high speed, the energy involved is tiny by comparison.

DID YOU KNOW? *The tips of a spinning wind turbine can travel as fast as 290km/h (180mph)*

Orbit
To enter into orbit, the shuttle needs to reach speeds of 28,000km/h (17,500mph).

Rocket boosters
Most of the energy required for liftoff comes from the shuttle's two solid fuel rocket boosters.

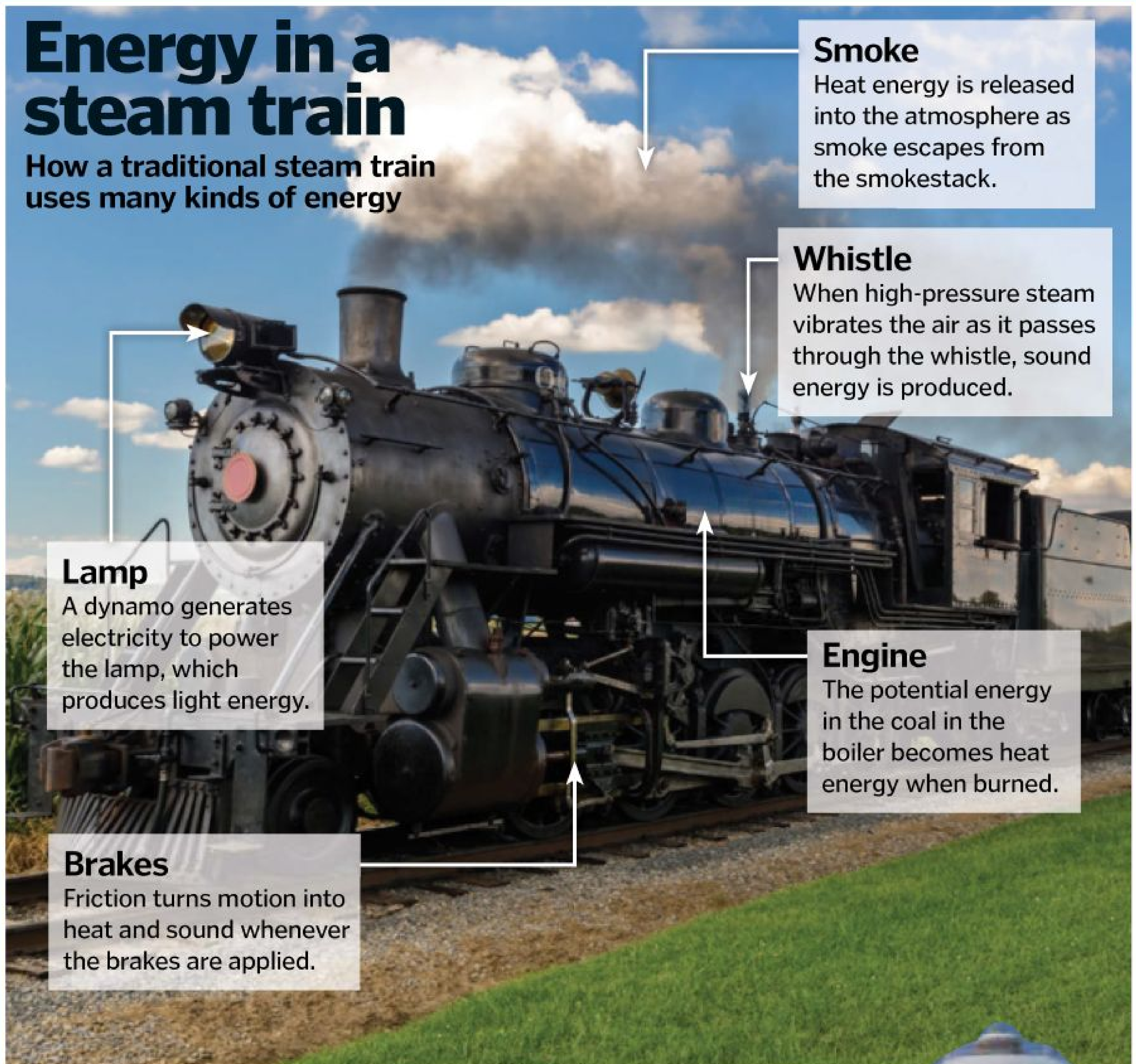
Solid fuel
As this fuel burns, it expels gas at high pressure from a nozzle to create thrust, propelling the shuttle upwards.

Total energy
Every second the shuttle launch gobbles up approximately 10^{13} joules, provided by the chemical energy stored in its fuel.

Sound
Exhaust leaving the shuttle creates vibrations and sound volumes up to a deafening 220dB.

Energy in a steam train

How a traditional steam train uses many kinds of energy



Smoke
Heat energy is released into the atmosphere as smoke escapes from the smokestack.

Whistle
When high-pressure steam vibrates the air as it passes through the whistle, sound energy is produced.

Lamp
A dynamo generates electricity to power the lamp, which produces light energy.

Engine
The potential energy in the coal in the boiler becomes heat energy when burned.

Brakes
Friction turns motion into heat and sound whenever the brakes are applied.

How energy transforms

1 Photosynthesis

Light energy is essential to plants, enabling them to convert carbon dioxide and water into glucose, thus turning radiant into chemical energy. Plants then use respiration to extract the glucose's chemical energy.

2 Filament light bulb

As electric current runs through the bulb's filament, electrical energy is changed into light energy. But traditional bulbs convert only ten per cent of incoming energy into visible light – the rest is wasted as heat.

3 Digestion

Your stomach breaks down your food to access the chemical energy stored inside sugars, fats and carbohydrates. Your muscles convert this energy into movement, generating thermal energy in the process.

4 Tennis

Whacking a tennis ball causes the ball to travel in the direction of the racket, absorbing energy from the player's arm as well as the energy imparted onto the ball by your opponent's last shot.

5 Speaker

Inside a speaker, pulses of electrical energy running through an electromagnet change its magnetic field. This causes a permanent magnet to vibrate back and forth emitting sound energy.

GOING GREEN

At any given moment, mankind is using roughly 15 terawatts of power – enough to run around 3 trillion iPads. Humans across the globe consume a total of around 500 exajoules (ie 10^{18} joules) of energy each year, and are expected to use over 50 per cent more by 2040. But our energy use is shockingly inefficient: in the US alone, an estimated 58 per cent of energy is wasted, mostly as unwanted heat.

The majority of our energy currently comes from fossil fuels, but as reserves of oil, gas and coal grow short – and concerns about global warming grow ever-more pressing – renewable energy is on the rise. Renewable sources currently meet around 16 per cent of the world's energy needs, harnessing energy from the Sun, wind, tides, biomass or geothermal heat.

For wind, tidal or hydroelectric power this involves harvesting kinetic energy and transforming it into electric energy. A hydroelectric dam, for instance, takes advantage of the potential energy of the moving water which it traps. As water gushes through the dam, its kinetic energy is captured by spinning turbines. In turn these use magnets to convert motion energy into an electrical current.

Inside the ASDEX Upgrade Fusion Reactor (Axially Symmetric Divertor Experiment) in Germany, where plasma for fusion reactions is made

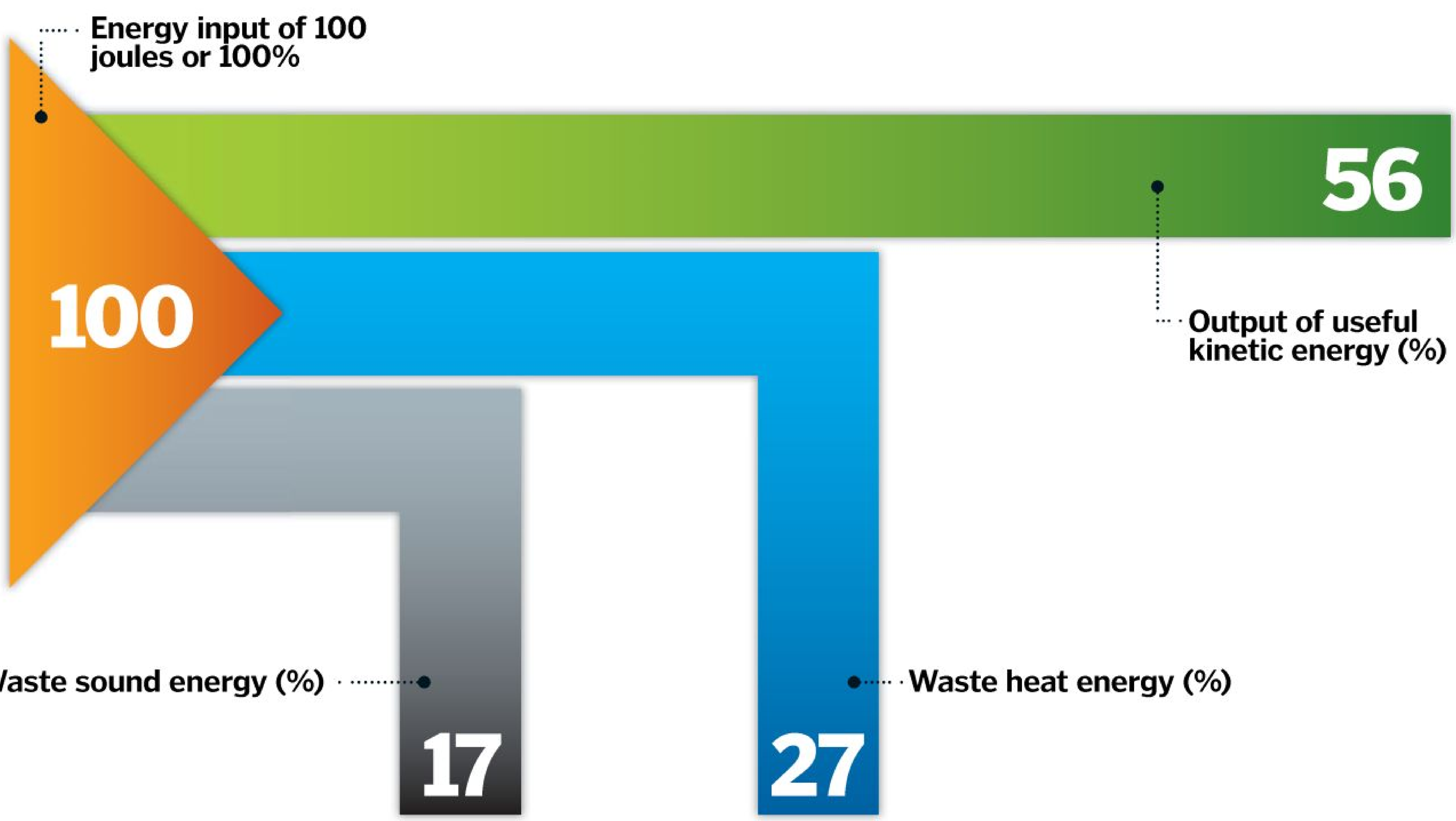
Fuelling the future

Meeting our planet's growing energy needs in a sustainable way is a tough challenge. Nuclear fusion – the process that powers the Sun – could one day be a source of practically unlimited, cheap, clean energy on Earth. The challenge, however, is creating the intense pressure and temperature conditions needed to coax hydrogen atoms into fusing and releasing some of their nuclear energy.

Cars of the future may fill up on biodiesel, ethanol or vegetable oil, or use electricity from a new source: hydrogen fuel cells. These combine hydrogen and oxygen to form water, exploiting the chemical energy released.

Visualising efficiency

No energy transfer can be 100 per cent efficient. This flow diagram illustrates the energy transfers at work inside an electric motor. With an energy input of 100 joules, the motor turns 56 joules into usable kinetic energy – in other words, it has an efficiency of 56 per cent. The remaining energy is wasted as sound and heat. This information allows engineers to pinpoint which parts of a process can be improved to make efficiency gains.



KEY DATES
ENERGY OVER TIME

1775 James Watt patents improvements on the steam engine, ushering in the Steam Age.

1830s Building on Michael Faraday's work on electromagnetism, electric generators and motors are invented.

1848 The first modern oil well is drilled in Azerbaijan. By the early-1900s it accounts for half of global production.

1945 The US detonates the first nuclear bomb, creating a blast equal to about 20 kilotons of TNT (or 84 terajoules).

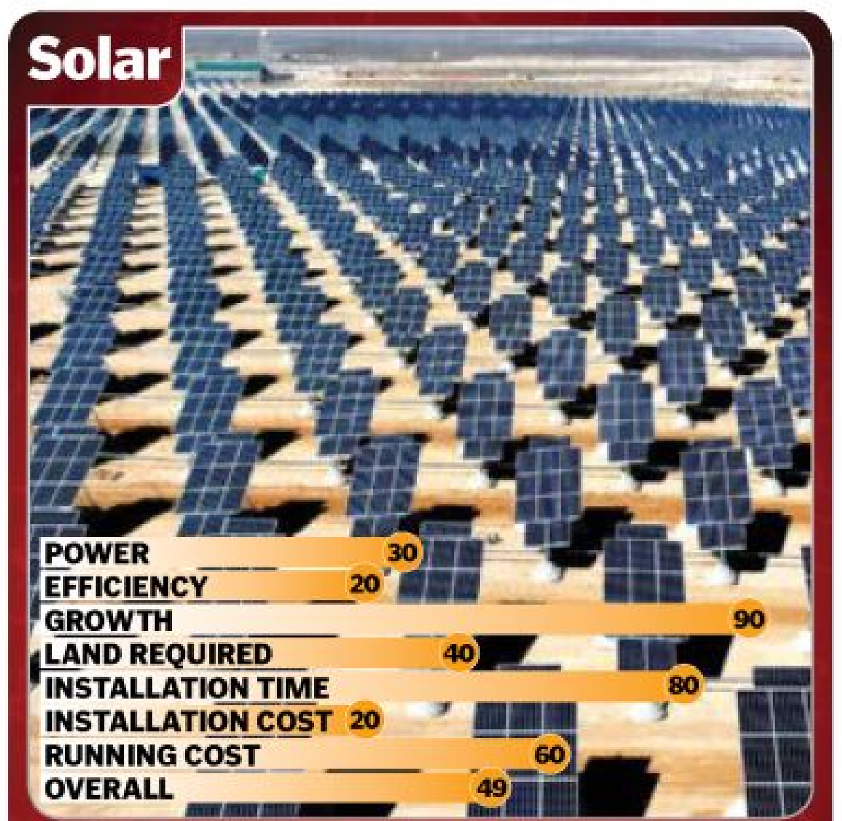
2005 The Kyoto Protocol comes into force, with 192 parties committed to limiting or reducing CO_2 emissions.

DID YOU KNOW? *A person doing hard manual labour produces roughly enough energy to power a 100W light bulb*

Renewables showdown

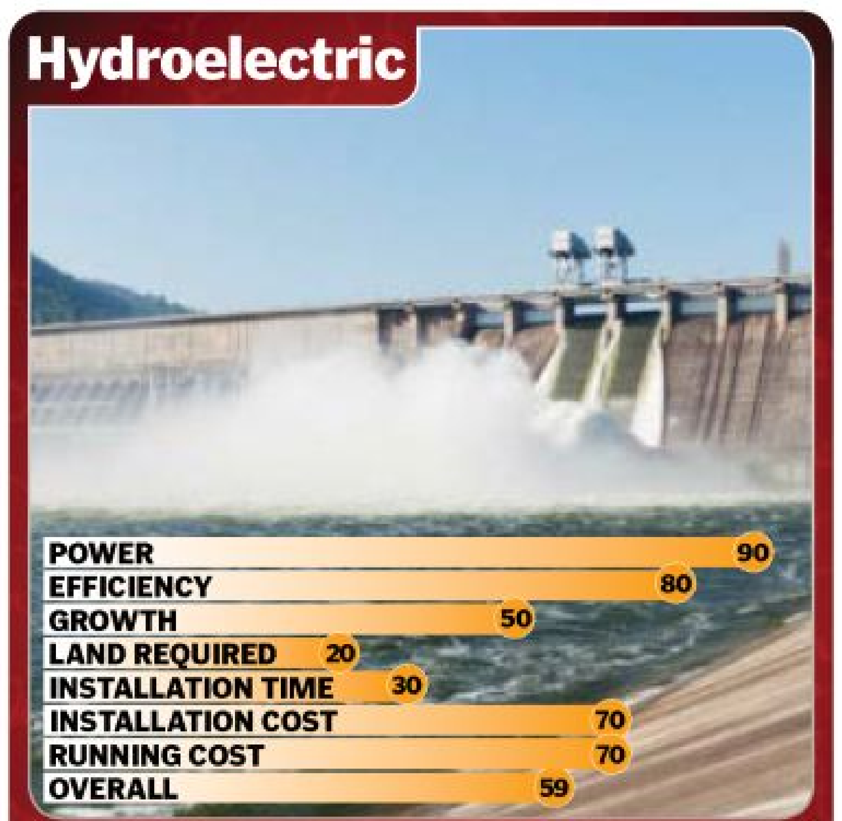
See how four major renewable energy sources square up

Solar



Solar energy is collected by photovoltaic cells, which transform light energy into electricity or thermal energy. Although the Sun provides limitless energy, the cells are quite inefficient and expensive.

Hydroelectric

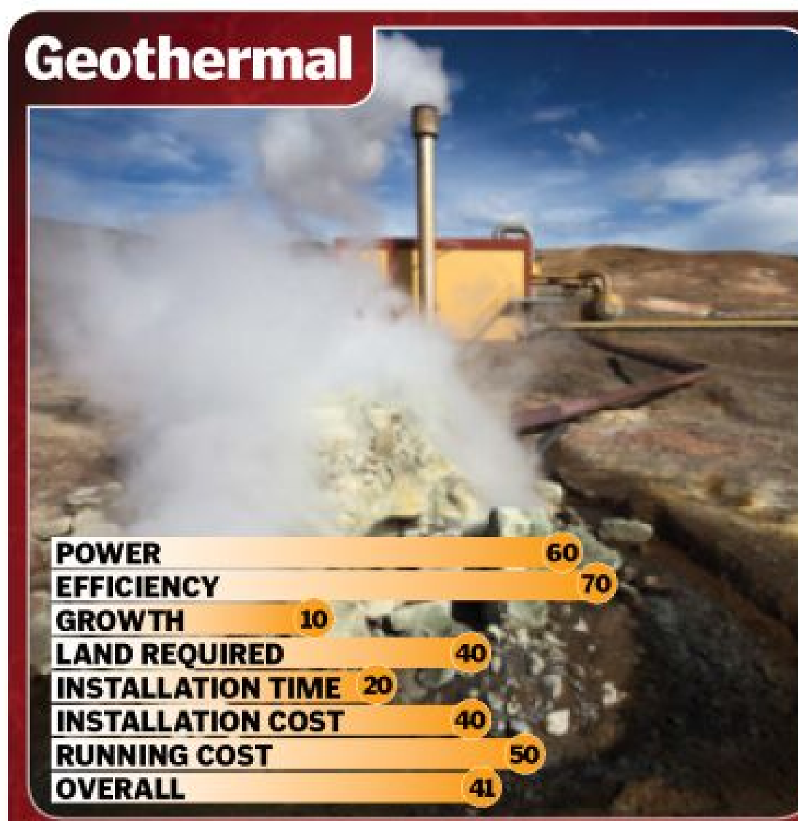


Hydropower harnesses the kinetic energy of moving water and is the largest source of renewable energy. But building a hydropower station requires damming off a river, which can harm the local environment.

Wind

Wind turbines capture the kinetic energy of the wind and convert it into electricity. Relatively efficient and cheap to install, wind energy is a fast-growing business, though some think wind farms are ugly.

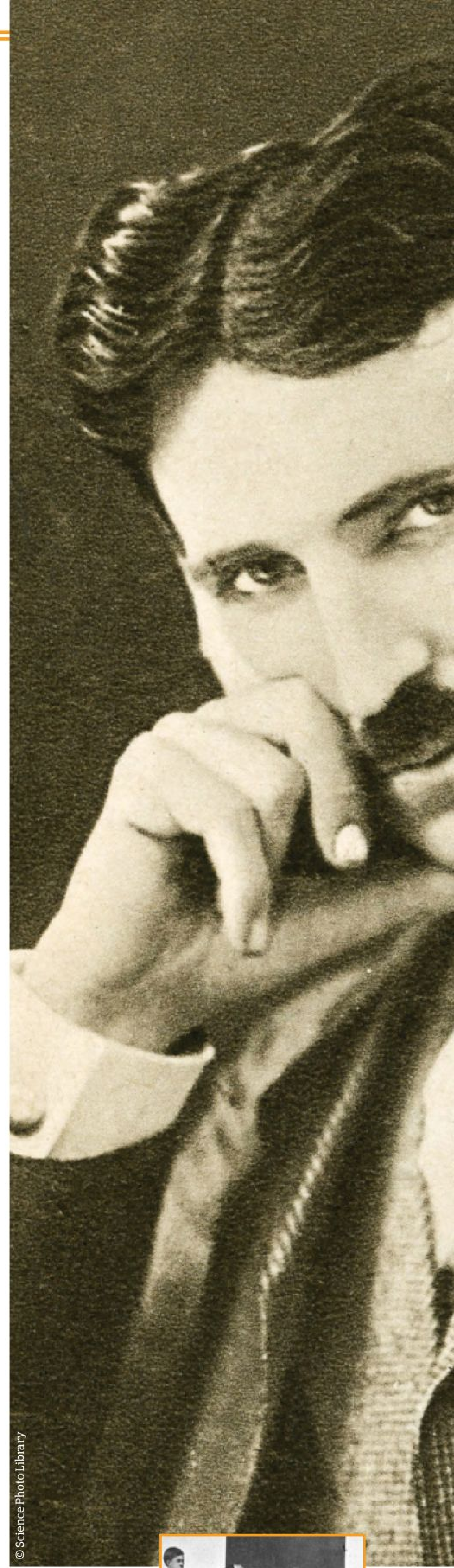
Geothermal



Geothermal power plants gather the heat produced at Earth's core. The catch is that this energy must find its own way to the surface, meaning geothermal power is limited to relatively few locations, eg Iceland.

Iceland's renewable energy jackpot

A geological stroke of luck allows Iceland to produce over 80 per cent of its energy (and 100 per cent of its electricity) from renewable sources. Straddling the Mid-Atlantic Ridge, a hub of tectonic plate activity, Iceland is dotted with over 200 volcanoes and some 600 hot springs, many of which spew out water at scalding temperatures of 250 degrees Celsius (482 degrees Fahrenheit). Exploiting this heat, geothermal energy meets 60 per cent of the country's energy needs. The hot water is used to warm houses, swimming pools and greenhouses directly, while geothermal plants also convert heat into electricity. Hydropower – made possible by the country's abundant rivers and waterfalls – makes up for a further 25 per cent of Iceland's energy requirement. This leaves 15 per cent of non-renewable energy, mostly used by oil-guzzling transport.



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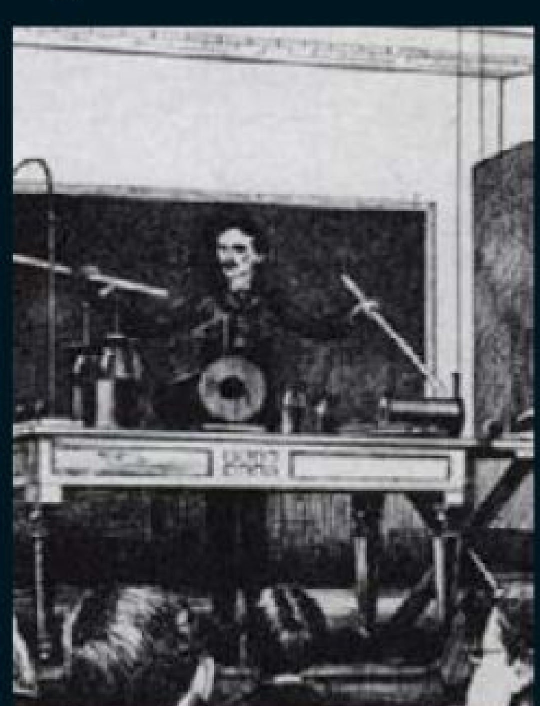
Nikola Tesla

Learn about the life of the man who invented alternating current, and discover why he was a major player in the development of commercial electricity

IN THEIR FOOTSTEPS

Those inspired by their work



Gano Dunn

A student at Columbia University, where he studied electrical engineering, and later became president of the Institute of Electrical Engineers, Gano Dunn was heavily influenced by Tesla. Writing as he assisted Tesla in his experimentations at Columbia, Dunn stated: "Tesla solved the greatest problem in electrical engineering of his time. My contact as [Tesla's] assistant at the historic Columbia University [and] high-frequency lecture afterward, left an indelible impression and an inspiration which has influenced my life."

Nikola Tesla was a Serbian-American inventor, electrical engineer and entrepreneur who, thanks to his wondrous displays of the potential applications of electricity in the late 19th and early 20th centuries, became known as the 'Wizard of the West'. Today he is most famously remembered for his invention of practical alternating current (AC) distribution, without which the advanced electrical supply systems we have today would never have been possible.

Tesla was born in the small, remote village of Smiljan in the now-defunct Austrian Empire. Nikola was the fourth of five children and, as his family moved to the town of Gospic in 1862, he enrolled at the Higher Real Gymnasium in Karlovac, completing a scheduled four-year course in just under three years. Due to his obvious academic aptitude, he carried his studies further, enrolling at the Austrian Polytechnic in Graz in 1875, where he read electrical engineering and specialised in the field of the yet-to-be-established alternating current.

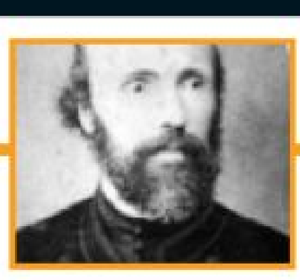
It was at the Austrian Polytechnic that he became known for his photographic memory and almost synesthesian ability to envision an item upon hearing its name in incredibly fine detail. Interestingly, Tesla later reported in his autobiography that he frequently received visions during blinding flashes that would provide solutions to particular problems he was having.

After studying he moved to Budapest, Hungary, in 1881 to work for the National Telephone Company, becoming the chief engineer. He later became responsible for the operation and maintenance of the entire country's telephone network. After this he took up a job at the Continental Edison Company in Paris, France (that of American inventor Thomas Edison), to work on designs to improve their electronic equipment and distribution systems. According to Tesla's autobiography, it was in Paris that he first conceived the induction motor.

Due to his successes in Paris he was moved by Edison to the Edison Machine Works company in New York City, USA. Tesla was offered the task of completely redesigning the company's existing direct current (DC) generators to AC versions, something Tesla had already spent a long time developing. Reportedly, Tesla was offered $50,000 if he successfully completed this task and, upon presenting a new system to Edison, inquired about his payment. Edison is reported to have broken his word to Tesla, insisting that he had been joking.

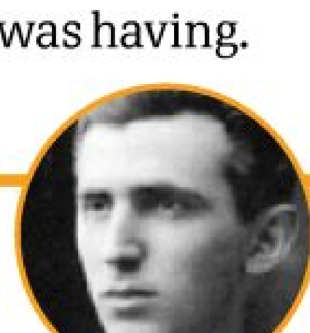
Tesla proceeded to leave Edison Machine Works – marking the start of a bitter rivalry between Edison and himself – and set up his own company, Tesla Electric Light and Manufacturing, in 1886. The next year he built his first AC induction motor and in 1888 he demonstrated it to the American Institute of Electrical Engineers. After this success

A life's work



1856 Tesla is born in the Serbian village of Smiljan, which is today located in Croatia.

1862 His family moves to Gospic and Nikola attends the Higher Real Gymnasium in Karlovac.



1875 Studies electrical engineering at the Austrian Polytechnic, Graz, where he begins his work on AC.

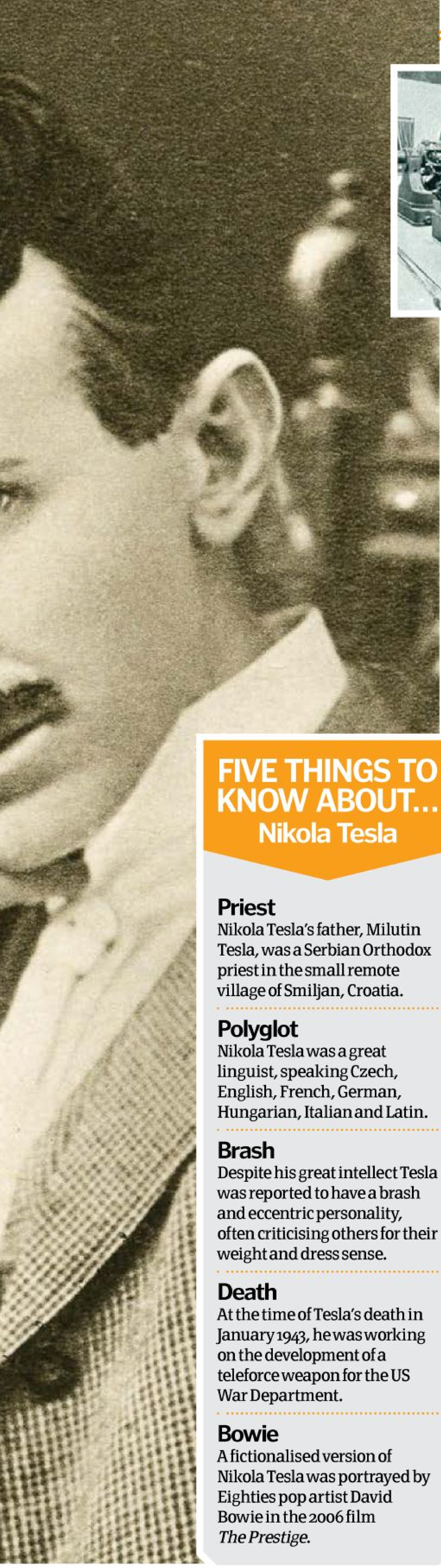
1880 Continuing his education, Tesla enrols at Charles-Ferdinand University in Prague.

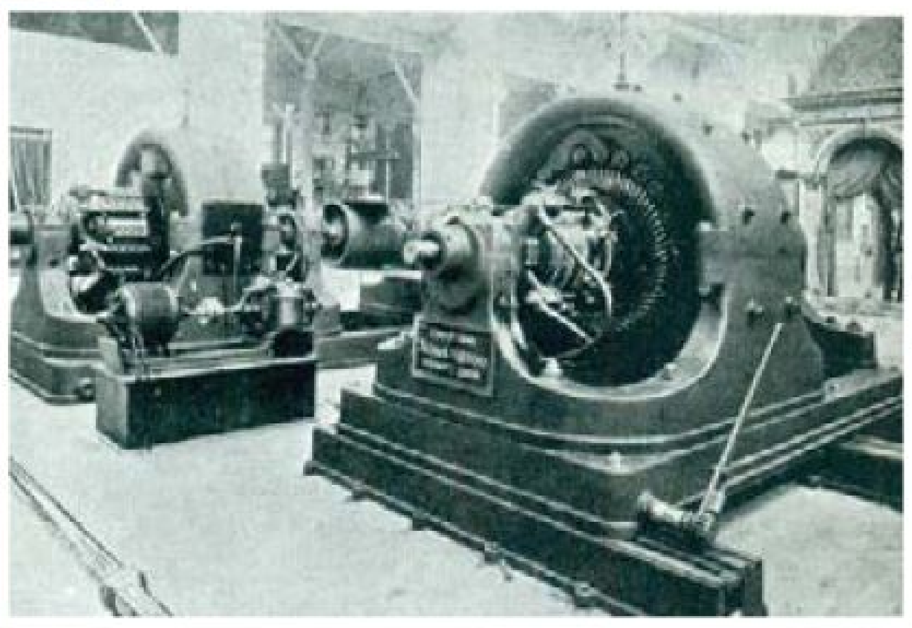
1881 Starts working at the National Telephone Company, Budapest. He goes on to become Hungary's chief telephone engineer.

1882 Moving to Paris, France, Nikola works as an engineer for the Continental Edison Company, where he makes improvements to electrical equipment.

1886 Tesla forms his own company to produce an AC motor. His investors fall out with him though and he leaves.

1887 Produces his first brushless AC induction motor, which he shows to the American Institute of Electrical Engineering. He also makes the first Tesla coil.





Left: Tesla's Polyphase alternating current exhibit at the 1893 World Columbian Exposition

FIVE THINGS TO KNOW ABOUT… Nikola Tesla

Priest
Nikola Tesla's father, Milutin Tesla, was a Serbian Orthodox priest in the small remote village of Smiljan, Croatia.

Polyglot
Nikola Tesla was a great linguist, speaking Czech, English, French, German, Hungarian, Italian and Latin.

Brash
Despite his great intellect Tesla was reported to have a brash and eccentric personality, often criticising others for their weight and dress sense.

Death
At the time of Tesla's death in January 1943, he was working on the development of a teleforce weapon for the US War Department.

Bowie
A fictionalised version of Nikola Tesla was portrayed by Eighties pop artist David Bowie in the 2006 film *The Prestige*.

> "Thanks to his wondrous displays he became known as the 'Wizard of the West'"

he joined with George Westinghouse, owner of the Westinghouse Electric & Manufacturing Company, and began to develop a polyphase electrical transmission system that would allow alternating current to be distributed over far greater distances than Edison's current DC systems. Thanks to the stable backing of Westinghouse and Tesla's in-depth knowledge of the field, soon alternating current was widely accepted as the superior distribution system (see 'The big idea' boxout).

In what is now remembered as the most high-profile and stable of Tesla's ventures, he then moved to Colorado Springs, CO, to set up a new laboratory. Here from 1899 onwards he undertook numerous wireless telegraphy experiments that led him to the development of artificial lightning, the discovery of the fact that the Earth itself is a conductor, the formation of the 'Tesla effect' and the acquisition of a number of patents regarding the wireless transmission of power.

Despite continuing to make major discoveries in physics – leading to him being nominated for a Nobel Prize three times – Tesla, due to financial difficulties, spent the latter part of his career attempting to create charged-particle beam weaponry for the United States, who had tasked him with creating a 'death ray'. He never finished the project that he claimed would 'put an end to all war' and went into semi-retirement, formulating many theoretical projects and ideas that never came to fruition.

Nikola Tesla died on 7 January 1943, aged 86, in the New Yorker Hotel suite he had lived and worked in for the last ten years of his life. A state funeral was attended by over 2,000 people, including many eminent scientists and scholars.

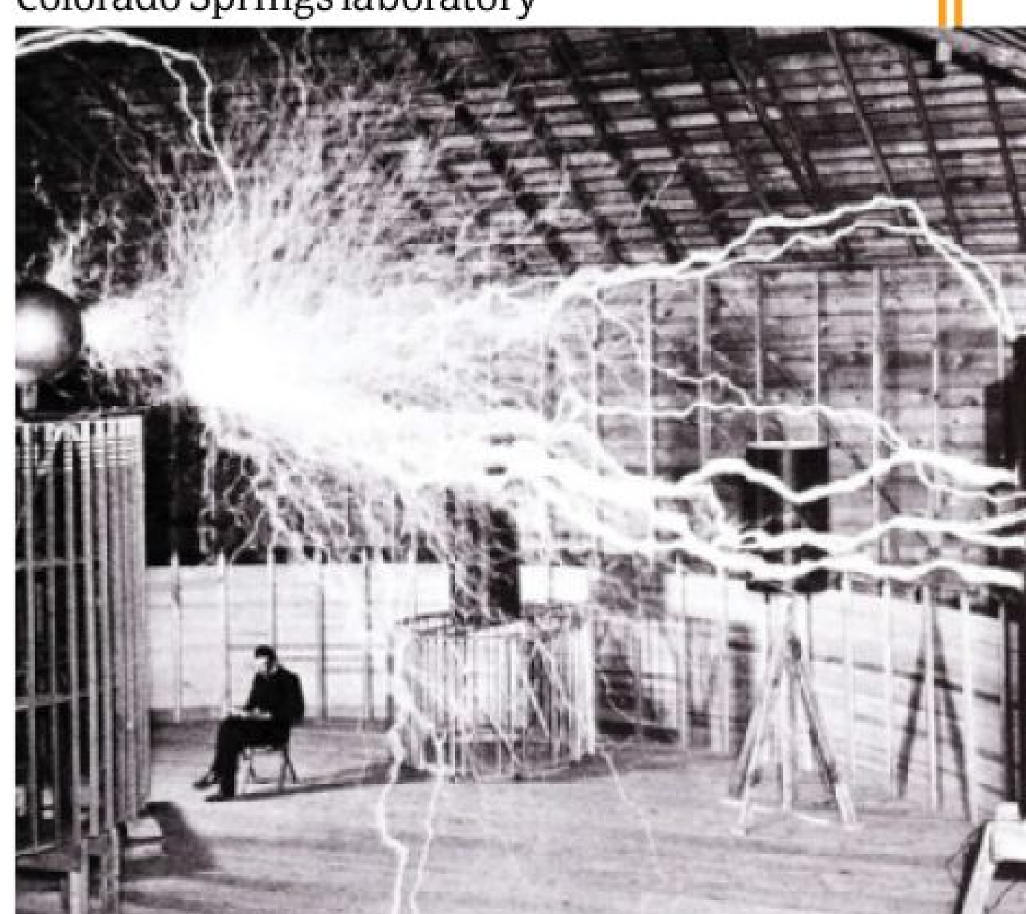
THE BIG IDEA Alternating current

Tesla's most-famous innovation explained

During the 1880s the 'War of Currents' took place between Thomas Edison and Nikola Tesla, the latter working for the Westinghouse Electric Company. For years Edison had expounded his own DC lamps and motors, and had openly criticised Tesla's AC systems as 'utterly impractical'. Edison's system consisted of generating plants feeding heavy distribution conductors, with consumer loads such as lights and motors relayed off them. This system worked but had the severe limitation that all generators needed to be located within about 1.6 kilometres (one mile) of the load.

However, after years of research and the financial backing of Westinghouse, Tesla created an AC system where a transformer was introduced between the generators and customer loads, allowing power to be transmitted at much higher voltages and, more crucially, over far greater distances. After demonstrating the advantages of his new AC system, Tesla won the war and DC systems were phased out over the next century.

A publicity shot of Nikola Tesla in his Colorado Springs laboratory



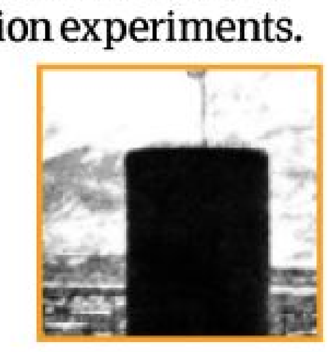
1888
Begins experimenting with X-rays using single-terminal vacuum tubes and Tesla coils.

1891
Demonstrates wireless energy transmission for the first time, which is termed the 'Tesla effect'. He also establishes his Houston Street lab in New York.

1892
He is made vice-president of the American Institute of Electrical Engineers.

1895
Tesla creates his first ever Tesla generator.

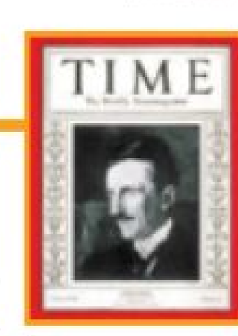
1899
Moves to Colorado Springs and sets up a lab. He carries out various wireless transmission-reception experiments.



1900
With a grant of $150,000, Tesla begins building the Wardenclyffe Tower facility. Here he hoped to demonstrate wireless telecommunications across the Atlantic, but it's not completed due to a lack of funding.

1912
Tesla is tipped to win the Nobel Prize in Physics for his work on tuned circuits using high-voltage, high-resonant transformers.

1917
Receives the highest honour from the AIEE – ironically the Edison Medal.



1931
On his 75th birthday Tesla is put on the cover of *TIME Magazine*, celebrating his achievements.

1937
Tesla publishes a treatise on the feasibility and potential applications of charged-particle beams, describing a superweapon that 'would put an end to all war'.

1943
He dies after a heart thrombus on 7 January 1943. He was in room 3327 of the New Yorker Hotel.