

THE MAGAZINE THAT FEEDS MINDS

HOW IT WORKS

INSIDE



4G MOBILE NETWORKS
SPEED TO RIVAL YOUR HOME INTERNET CONNECTION

SCIENCE ENVIRONMENT TECHNOLOGY HISTORY SPACE

SENSORY SYSTEM
How senses help you discover the world

COMET STORMS
Where do deadly ice rocks come from?

INCREDIBLE STORY OF EARTH

A NATURAL HISTORY UNLIKE ANY OTHER

ATMOSPHERE • OCEANS • TECTONICS • CLIMATE
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RACING BIKES
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+ LEARN ABOUT
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■ FOSSILS ■ PACEMAKERS

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LASERS
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THUNDERBOLT
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WELCOME




The magazine that feeds minds!

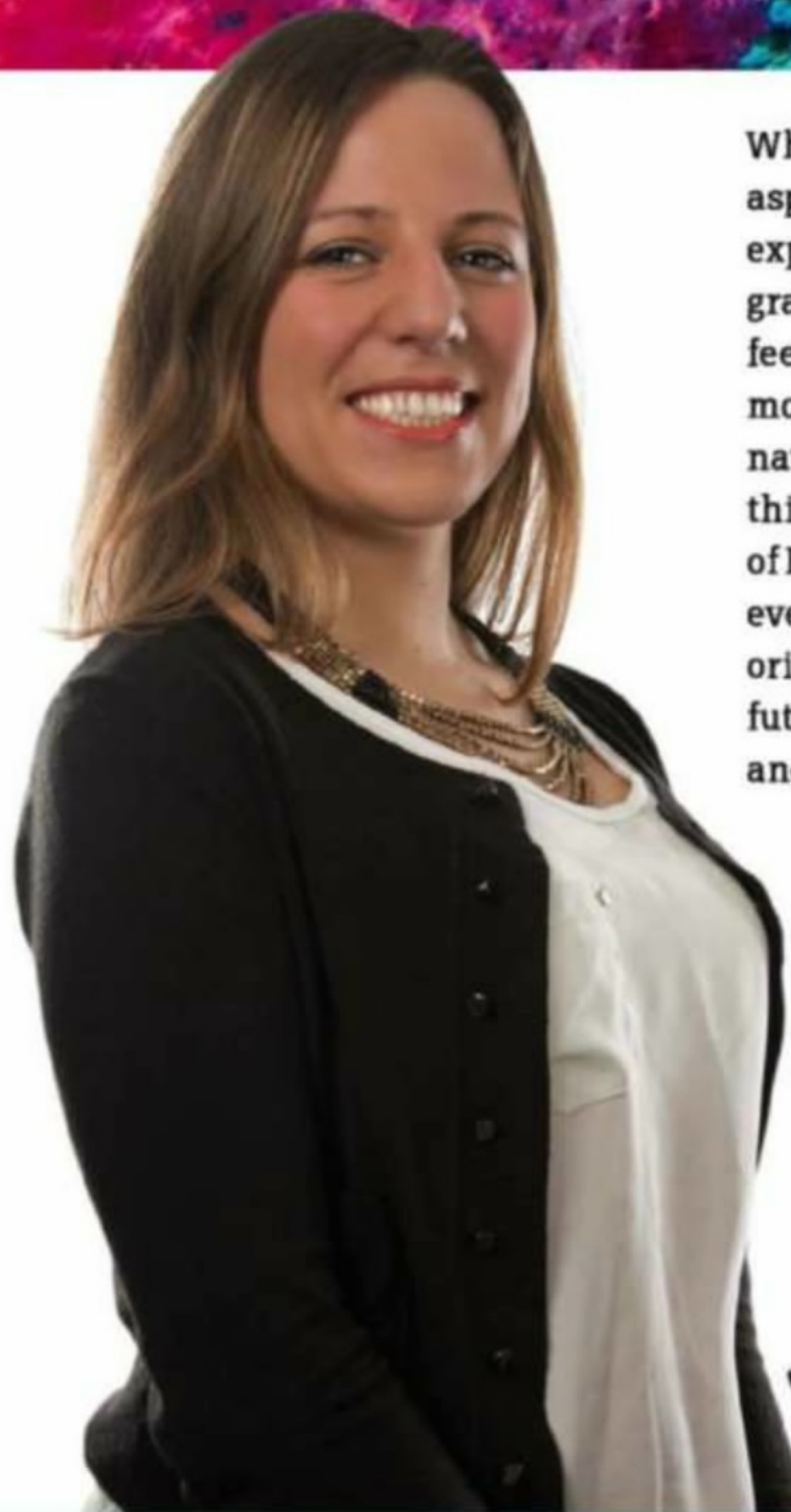
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Take the plunge and explore the diverse habitats of the ocean

Get in touch

Have YOU got a question you want answered by the How It Works team? Get in touch via:

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-  howitworks@imagine-publishing.co.uk
-  www.howitworksdaily.com
-  @HowItWorksmag



When we marvel at the wider universe with aspirations of discovering new worlds and exploring deep space, we perhaps take for granted the miracle that is lying beneath our feet. This issue HIW is offering you the motherload: a comprehensive guide to the natural history of the planet we call home, the third rock from the Sun. Discover the wonder of Earth's formation, the nature of its ever-changing surface, the extraordinary origins of life and even get a glimpse into the future at what our planet could look like in another 4.5 billion years' time.

Also this month we're delighted to welcome a new team member into the fold. Joining the How It Works roster is staff writer Laura Mears whose appetite for science extends to educating young scientists with her own immune system cartoon strip and building her own radio telescope for listening to radio waves. Enjoy the issue.

Helen **Helen Porter**
Editor

What's in store...

The huge amount of information in each issue of How It Works is organised into these key sections:



-  **Science**
Uncover the world's most amazing physics, chemistry and biology
-  **Technology**
Discover the inner workings of cool gadgets and engineering marvels
-  **Transport**
Everything from the fastest cars to the most advanced aircraft
-  **Space**
Learn about all things cosmic in the section that's truly out of this world
-  **Environment**
Explore the amazing natural wonders to be found on planet Earth
-  **History**
Step back in time and find out how things used to work in the past

Meet the team...



Robert
Features Editor
Charting the entire history of Earth was an epic experience. Check in for a wondrous journey starting on page 12.



Helen
Senior Art Editor
Commissioning bespoke artwork of an Ancient Greek theatre was very enlightening. See the result on page 74.



Laura
Staff Writer
Ever wondered about the man behind the Nobel prize? This issue we chart the life of Alfred Nobel.



Adam
Senior Sub Editor
It was a journey of discovery descending through the ocean and seeing how life has adapted to a wide range of challenges.

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The magazine that feeds minds!



MEET THE EXPERTS

Find out more about the writers in this month's edition of *How It Works*...

Vivienne Raper Fossil formation



Our geophysics expert Vivienne got out her palaeontology brush this issue to sweep away the mystery of fossil formation. Find out how a dinosaur turns to stone over millennia step by step.

Ben Biggs 4G mobile networks



This issue Ben is taking a look at the communications technology of the moment - 4G - to help get your brain around how a mobile phone can achieve internet speeds that rival your home PC setup.

Aneel Bhangu Sensory system



From hearing and taste to sight, touch and smell, Aneel reveals how the complex human senses work together as a system to ensure you stay alive and to help you 'make sense' of the world around you.

Jonathan O'Callaghan Comet storms



Features Editor Jonathan from our sister title *All About Space* lent a hand to explain how these fascinating icy objects tear through galaxies and what happened during the Late Heavy Bombardment period.

Ella Carter Marine habitats



With a degree in oceanography under her belt, Ella was the perfect candidate to write our feature about the many layers which make up the ocean and the diverse flora and fauna that call the sea home.

What's inside a camcorder?
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Orion nebula imaged like never before

Perhaps its last hurrah as it draws to the end of its service, the Herschel space telescope captures a breathtaking view of the Orion B molecular cloud



The Horsehead Nebula is one of the most popular and imaged space phenomena in the universe, with amateurs and professionals alike blown away by both its beauty and scale. And that wonder is set to reach new heights now that the European Space Agency's (ESA's) Herschel Space Observatory has captured the iconic nebula and the surrounding Orion B molecular cloud in unprecedented detail.

The picture isn't a single take but constructed from a series of images shot by Herschel with wavelengths ranging from 70-250 micrometres, covering an angle of 4.5 x 1.5 degrees. The nebula, seen towards the top-right of the picture, is five light years tall and is located approximately 1,300 light years from Earth. The Hubble Space Telescope also contributed a closeup of the nebula (shown opposite).

Its beauty aside, what is actually most interesting about this Herschel image is that it captures the molecular cloud in incredibly long wavelengths. This enables astronomers to visualise the glow emanating directly from the cold gas and dust in the region – the material that will eventually collapse into a new generation of stars. By analysing these areas scientists are hoping to better understand the processes involved in star formation.

"You need images at all scales and at all wavelengths in astronomy in order to understand the big picture and the small detail," said Professor Matt Griffin, principal

investigator on Herschel's SPIRE instrument. "You can see all the things we look for in Herschel images – the filaments, the bubbles; the wispy material, the reddish material that hasn't yet actually started to form stars. You can also see nebulosity where material has been lit up from inside by stars."

Unfortunately, this unique snapshot may be the last for Herschel, with it scheduled to run out of coolant any day now. It launched on 14 May 2009 and, over the last four years, the infrared telescope has gone a long way to improving our understanding of how galaxies evolve and the chemistry of the Milky Way.

"You need images at all scales and at all wavelengths in astronomy to understand the big picture and the small detail"



The Horsehead Nebula and surrounding Orion B molecular cloud. The region is seeing incredibly active star formation

The new face of British science



Meet the new CEO of the British Science Association

As the new chief executive of the BSA, what will your role entail day to day?

So far it has been trying to get a handle on everything that happens here, as we have a huge range of activities occurring. We have things in secondary schools, primary schools, an annual festival, we work with the media to try and instigate conversation between scientists and journalists, and at the moment I am just trying to get my head round all of that while meeting the staff, trustees and partners. I'm trying to find out how the place works, as it will be my role to try and knit our different activities together and also to clearly articulate what we are offering to people.

Who is your scientific hero?

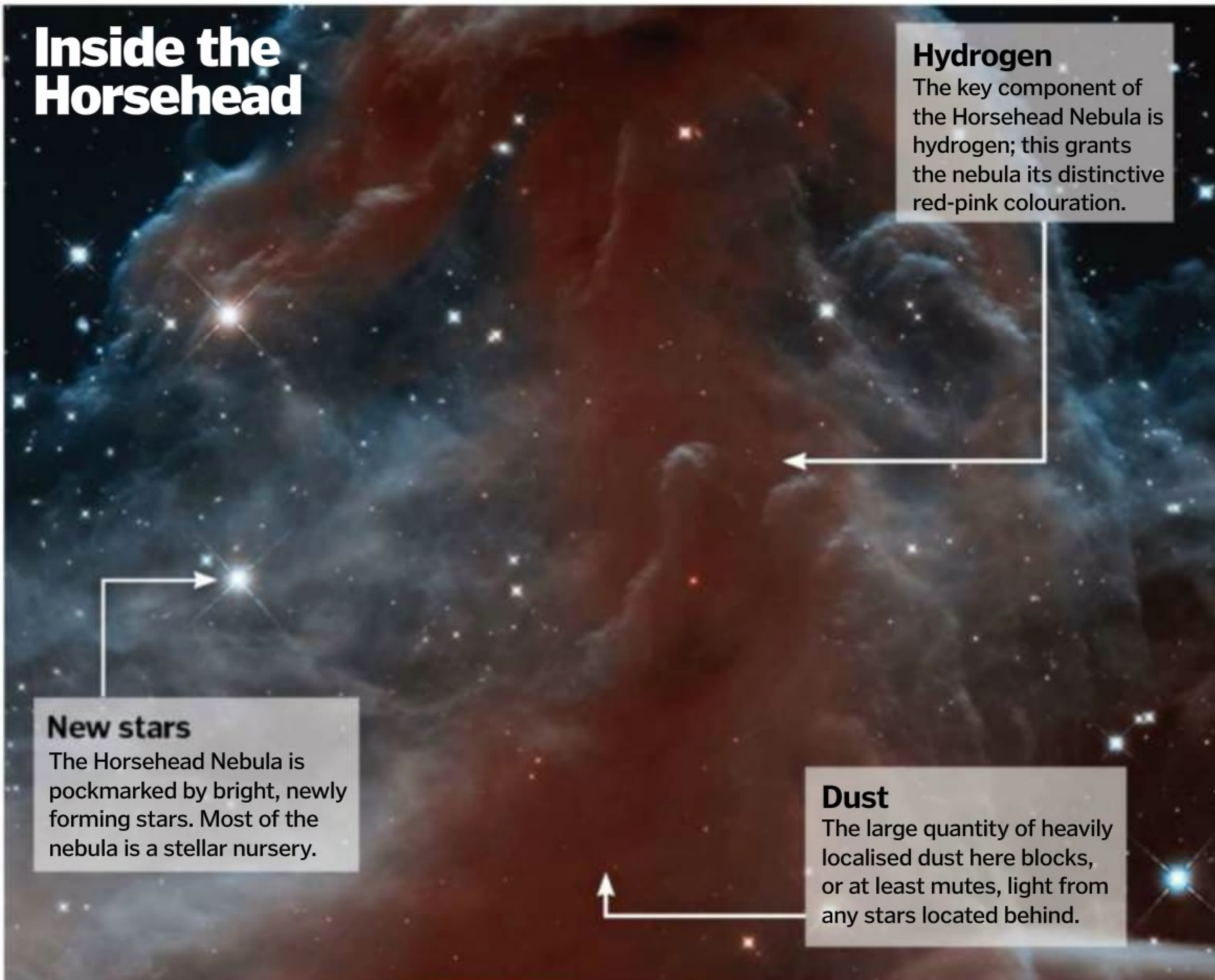
While there have been scientists that have inspired me intellectually, where I have really loved their work – people like Richard Dawkins and Charles Darwin – I wouldn't say either of those were my heroes. This is going to sound pretty cheesy, but if you were to ask me who has inspired me most in terms of making science such a large part of my life, it would have to be my teachers at school. They were the ones who were always there when I came up with bizarre questions about whatever it is I was asking about at the time, regardless of whether it was evolution or nuclear fusion. They are the ones I find most inspiring.

What can visitors expect to see at the British Science Festival 2013?

Well, they can expect a citywide festival of science, with lots of inspiring speakers and events [for all ages]. More specifically, we've got a new strand of events called 'You heard it here first' and that is an idea that explores the new emerging fields in research. We are looking at things that will hopefully be hitting the news in five years' time, but we want people to come along to see the really fascinating things on the cusp of discovery.

To learn more about the BSA, visit: www.britishsociety.org

Inside the Horsehead



Hydrogen

The key component of the Horsehead Nebula is hydrogen; this grants the nebula its distinctive red-pink colouration.

New stars

The Horsehead Nebula is pockmarked by bright, newly forming stars. Most of the nebula is a stellar nursery.

Dust

The large quantity of heavily localised dust here blocks, or at least mutes, light from any stars located behind.



Hope for endangered Tasmanian devils

Rare marsupials are facing extinction due to a transmissible form of cancer, but help is in sight

Scientists have found that cancer cells have evolved mechanisms to sneak past the Tasmanian devil's immune system. With this information, they can now start making a vaccine which could protect the animal from extinction. The Tasmanian devil is a marsupial unique to the Australian island of Tasmania. Since the Nineties, devils have been battling a form of cancer that causes facial tumours, preventing them from feeding.

Devil facial tumour disease (DFTD) is one of just three known contagious cancers. Normally cancer can't be transmitted as the immune system is able to recognise cancer cells from other individuals as 'foreign' and destroy them.

However, because devils are an inbred island species they're genetically so similar that cells from other devils are almost identical. DFTD has been responsible for the death of between 20 and 50 per cent of the population, and the species could face extinction as early as 2035.

The tumour cells are able to switch off genes in the major histocompatibility complex (MHC), a region of DNA that codes for proteins which sit on the surface of cells and alerts the immune system to infection or cancer. But with some of these genes deactivated, the tumour can go undetected. By vaccinating healthy devils with modified tumour cells, it's hoped their immune systems will be primed to recognise DFTD.

'Super-pig' created in lab

A UK laboratory made famous by creating the first-ever cloned animal - Dolly the sheep - has managed to produce a special piglet which is resistant to disease. The piglet, which is currently only known as 'Pig 26', was created at Edinburgh's Roslin Institute and is being seen by commentators as a massive step towards producing commercial genetically modified (GM) meat.

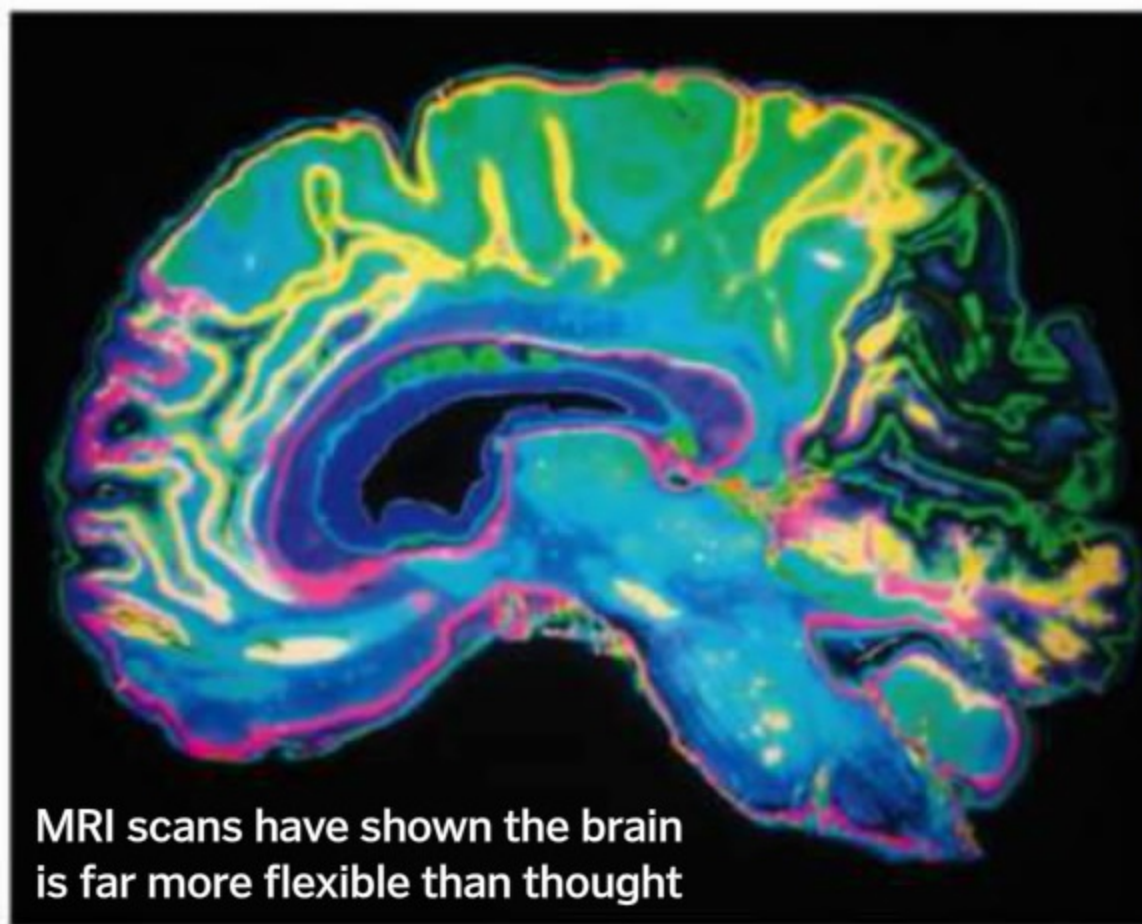
Gene editing involves making an incision into an animal's DNA and then inserting new, beneficial genetic material. In the case of Pig 26, this centred on introducing a gene taken from African pigs that made it immune to the prevalent African swine fever, which can kill most European pigs within 24 hours of infection.

According to researchers at the Roslin Institute, the new technique of gene editing has seen their success rate jump to roughly 15 per cent compared to the one per cent of test cases up until now. The rise in successful adoption of the new genetic material, it is hoped, will lead to increased resistance to such diseases and viruses in livestock.



Brain 'mobilises' to find car keys

Research reveals the brain marshals many regions when tasked with a targeted search



MRI scans have shown the brain is far more flexible than thought

According to new research by scientists at the University of California, Berkeley, USA, when humans lose something - such as the remote control or their car keys - and begin searching for it, the brain automatically calls regions typically used for other tasks into action to help locate the missing object.

Speaking on the publication of the results, lead author of the study, Professor Tolga Çukur, said: "Our results show that our brains are much more dynamic than previously thought, rapidly reallocating

resources based on behavioural demands, and optimising our performance by increasing the precision with which we can perform relevant tasks."

The results, which pooled a number of studies, were achieved through the use of MRI technology, with people imaged as they were tasked with finding objects and/or people in videos. The data showed that many parts of the brain, but particularly the prefrontal cortex - traditionally associated with abstract thought processes - were engaged during the searching tasks.

This day in history 16 May: How It Works issue 47 goes on sale, but what else

218 CE

Teenage emperor

14-year-old Marcus Aurelius Antoninus Augustus is made emperor of Rome following Caracalla's assassination.

1527

Florence rules

The Florentines drive out the royal House of Medici for a second time, re-establishing the city as a republic.



1568

Mary flees

Mary, Queen of Scots, escapes from Scotland to England across the Solway Firth.

1770

Let them eat (wedding) cake

14-year-old Marie Antoinette (right) marries the future king of France, Louis-Auguste.



1822

Greek loss

During the Greek War of Independence Turkish forces capture the town of Souli.

Genome of 'living fossil' is sequenced

Ancient fish related to first land animals has its genes decoded



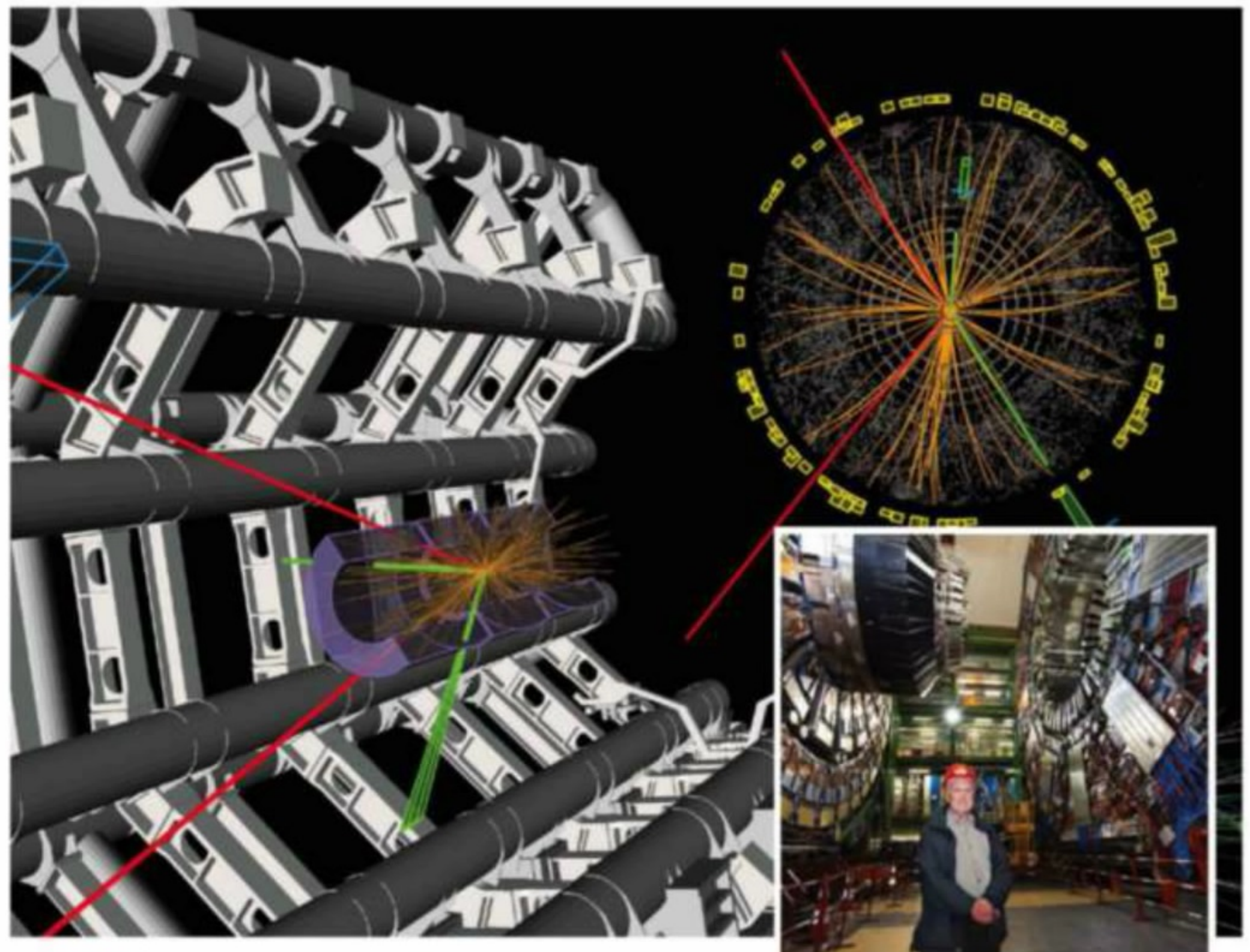
The coelacanth was thought to have become extinct during the Cretaceous-Palaeogene event that wiped out the dinosaurs 65 million years ago. However, in 1938 one turned up in a fishing net in South Africa. Now its genome has been sequenced and scientists hope that it could offer clues about the evolution of modern animals.

The coelacanth is actually more closely related to humans than modern fish like tuna. It measures up to 1.8 metres (5.9 feet) long and four of its eight fins are fleshy, resembling the limbs of terrestrial animals. It is one of the closest living relatives to the first four-limbed vertebrates (tetrapods) to crawl out of the sea, and its genetic information might help us to better understand what early land animals were like.

The coelacanth is fascinating because its genes are evolving more slowly than most other animals. Due to its stable environment in deep-sea caves, the coelacanth has had little need to change; the depths of the ocean have remained largely the same since prehistory. It is described as a 'living fossil' and closely resembles its 300-million-year-old ancestors, offering us a rare opportunity to look back in time.



Coelacanths live at depths of 700m (2,297ft) in the ocean



'Higgs boson' may get a new name

The famous subatomic particle could be renamed after a challenge by scientists



Following the landmark discovery of a new boson that is consistent with the theorised Higgs boson, scientists have started the process to potentially rename it, stating that Professor Peter Higgs' role in its identification has been overblown.

Professor Higgs predicted the boson in a research paper written in 1964, however other researchers – including Belgian scientists Robert Brout and François Englert – also wrote extensively on the subject prior to its apparent

discovery in 2012. Due to this, a selection of new names are being drawn up as potential alternatives.

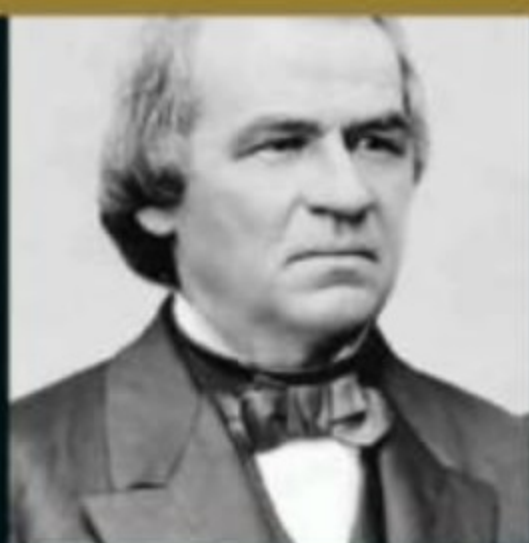
Currently, three names have been suggested, including the Brout-Englert-Higgs, SM Scalar boson and BEHGK (short for Brout-Englert-Higgs-Guralnik-Hagen-Kibble). These new names intend to honour additional scientists whose work is considered instrumental in the boson's discovery. Whether or not the tiny particle will be officially rechristened remains to be seen.

"Three names have been suggested, including the Brout-Englert-Higgs"

happened on this day in history?

1868

Close call
US President Andrew Johnson (right) is acquitted in his impeachment trial by one vote.



1920

Saint Joan
Pope Benedict XV canonises Joan of Arc (killed in 1431), making her a saint.

1929

It's all academic
The first Academy Awards are handed out in Hollywood, CA.



1966

Dylan doubles up
Bob Dylan releases one of the first double albums in rock music history.

2007

Sarkozy invested
Nicolas Sarkozy (right) takes office as the president of France.



10 COOL THINGS WE LEARNED THIS MONTH

FACTS YOU ALL SHOULD KNOW

Parasite inspires a new kind of plaster

A lab in Boston, USA, has taken inspiration from a parasitic worm that lives in the guts of fish to make a plaster for surgical wounds. The worm attaches to its host using clever spines, which pierce the skin and then expand at the tips, locking them in place. The new plaster is covered in tiny needles, with ends that swell up on contact with tissue fluids, holding the wound shut.

Pied-babblers blackmail their parents

Pied-babbler birds in South Africa deliberately put themselves in harm's way to get more food. In the safety of a tree, adult birds sometimes ignore the cries of hungry fledglings, however if they move to the danger of the ground then their parents feed them more frequently to keep them from attracting the attention of predators.

Iridium marks dinos' demise

Iridium is a rare metal of the platinum family. The Earth's crust contains very little iridium, but it is commonly found in asteroids. A 65-million-year-old belt of clay below the Earth's surface contains unusually high levels of iridium – most likely originating from a massive impact. The time frame coincides with the extinction of the dinosaurs and was key evidence in the theory that a giant space rock was responsible for their demise.

Desert rocks could harbour invisible life

Strange shiny deposits of manganese, arsenic and silica, known as desert varnish, may indicate the presence of an unidentified form of life. Earth's carbon emissions exceed the predicted level by five per cent and it is thought that undetected life forms may be the culprits. A shadow biosphere of unusual life might exist right under our noses, hidden from view by bizarre biology that we just haven't encountered before.

Vodka jelly makes chocolate less fattening

Chocolate tastes so good because of tiny fat globules, which give it a silky texture and allow it to melt just below body temperature, at 34 degrees Celsius (93.2 degrees Fahrenheit). Lowering the fat content changes these properties, making the chocolate much less tasty. But now a laboratory in Bristol has developed an alternative; using agar jelly mixed with vodka they mimic the size and consistency of the fat globules, making a low-fat – albeit alcoholic – alternative to regular chocolate.

Stem cells help sick pets

Stem cell therapy still isn't widely available for people, but our furry friends are already reaping the benefits. Stem cells taken from adult fat and bone marrow are being injected to treat many diseases, ranging from arthritis to inflammatory bowel disease. The results are promising and could help to gather evidence to support more human treatment in the future.

Bacteria contain supernova remnants

The unusual iron isotope, iron-60, has been discovered in magnetite, thought to have been made by 2.2-million-year-old bacteria in the Pacific Ocean. This isotope does not exist naturally on Earth and is likely to have arrived through space from an exploding star. The microbes used the iron to make magnetic crystal compasses for orientating themselves with the planet's magnetic field.

'Hobbit' humans shrank to fit their homeland

At just over a metre (3.3 feet) tall, *Homo floresiensis* were tiny ancient hominids that lived on a remote Indonesian island. The cause of their short stature has been contested among scientists, but it is now believed to be the result of island dwarfism. If a species becomes isolated on an island with scarce resources, evolutionary pressure to survive can favour smaller individuals, leading to a gradual decrease in size over generations. Similar miniaturisation is seen in dwarf elephant remains on some Mediterranean islands.

Phones could jump-start a car

Battery technology hasn't been able to keep up with the 'huge' advances in miniaturising electronics, and the bulky batteries in modern phones drain rapidly. By creating interlocking 3D electrodes, researchers have been able to increase the surface area inside a battery, cramming more power-generating capacity into the same space. The developers say their new batteries may be so powerful you could jump-start a car using your mobile!

Hares can't keep up with climate change

Hares seasonally alter the colour of their coat for camouflage: snowy white in the winter, muddy brown in the summer. Due to climate change, the snowy season is getting shorter and they are unable to keep up. When the snow melts, the hares are still bright white, leaving them vulnerable to predators.


INCREDIBLE





INCRECIBLE STORY OF EARTH

Ancient and teeming with life, Earth is a truly amazing planet, with a fascinating tale to tell...

 In 2013, science has revealed much about the planet we call home, from how it formed and has evolved over billions of years through to its position in the wider universe. Indeed, right now we have a clearer picture of Earth than ever before.

And what a terrifying and improbable picture it is. A massive spherical body of metal, rock, liquid and gas suspended perilously within a vast void by an invisible, binding force. It is a body that rotates continuously, is tilted on an axis by 23 degrees and orbits once every 365.256 solar days around a flaming ball of hydrogen 150 million kilometres (93 million miles) away. It is a celestial object that, on face value, is mind-bendingly unlikely.

As a result, the truth about our planet and its history eluded humans for thousands of years. Naturally, as beings that like to know the answers to *how* and *why*, we have come up with many ways to fill in the gaps. The Earth

was flat; the Earth was the centre of the universe; and, of course, all manner of complex and fiercely defended beliefs about creation.

But then in retrospect, who could have ever guessed that our planet formed from specks of dust and mineral grains in a cooling gas cloud of a solar nebula? That the spherical Earth consists of a series of fluid elemental layers and plates around an iron-rich molten core? Or indeed that our world is over 4.54 billion years old and counting? Only some of the brightest minds over many millennia could grant an insight into these geological realities.

While Earth may only be the fifth biggest planet in our Solar System, it is by far the most awe-inspiring. Perhaps most impressive of all, it's still reaffirming the fundamental laws that have governed the universe ever since the Big Bang. Here, we celebrate our world in all its glory, charting its journey from the origins right up to the present and what lies ahead. ▶

"Earth is awe-inspiring... it's still reaffirming the fundamental laws that have governed the universe ever since the Big Bang"

From dust to planet

To get to grips with how the Earth formed, first we need to understand how the Solar System as a whole developed – and from what. Current evidence suggests that the beginnings of the Solar System lay some 4.6 billion years ago with the gravitational collapse of a fragment of a giant molecular cloud.

In its entirety this molecular cloud – an interstellar mass with the size and density to form molecules like hydrogen – is estimated to have been 20 parsecs across, with the fragment just five per cent of that. The gravitationally induced collapse of this fragment resulted in a pre-solar nebula – a region of space with a mass slightly in excess of the Sun today and consisting primarily of hydrogen, helium and lithium gases generated by Big Bang nucleosynthesis (BBN).

At the heart of this pre-solar nebula, intense gravity – along with supernova-induced over-density within the core, high gas pressures, nebula rotation (caused by angular momentum) and fluxing magnetic fields – in conjunction caused it to contract and flatten into a protoplanetary disc. A hot, dense protostar formed at its centre, surrounded by a 200-astronomical-unit cloud of gas and dust.

It is from this solar nebula's protoplanetary disc that Earth and the other planets emerged. While the protostar would develop a core temperature and pressure to instigate hydrogen fusion over a period of approximately 50 million years, the cooling gas of the disc would produce mineral grains through condensation, which would amass into tiny meteoroids. The latest evidence indicates that the oldest of the meteoroidal material formed about 4.56 billion years ago.

As the dust and grains were drawn together to form ever-larger bodies of rock (first chondrules, then chondritic meteoroids), through continued accretion and collision-induced compaction, planetesimals and then protoplanets appeared – the latter being the precursor to all planets in the Solar System. In terms of the formation of Earth, the joining of multiple planetesimals meant it developed a gravitational attraction powerful enough to sweep up additional particles, rock fragments and meteoroids as it rotated around the Sun. The composition of these materials would, as we shall see over the page, enable the protoplanet to develop a superhot core. ▶

Dust and grains

Dust and tiny pieces of minerals orbiting around the T Tauri star impact one another and continue to coalesce into ever-larger chondritic meteoroids.

Gathering meteoroids

Chondrites aggregated as a result of gravity and went on to capture other bodies. This led to an asteroid-sized planetesimal.

Fully formed

Over billions of years Earth's atmosphere becomes oxygen rich and, through a cycle of crustal formation and destruction, develops vast landmasses.

“The collapse of this fragment resulted in a pre-solar nebula – a region of space with a mass slightly in excess of the Sun today”

The history of Earth

Follow the major milestones in our planet's epic development *(BYA = billions of years ago)

13.8 BYA*

Big Bang fallout
Nucleosynthesis as a result of the Big Bang leads to the formation of chemical elements on a huge scale.

4.6 BYA

New nebula
A fragment of a giant molecular cloud experiences a gravitational collapse and becomes a pre-solar nebula.

Origins of the Moon

Today most scientists believe Earth's sole satellite formed off the back of a collision event that occurred roughly 4.53 billion years ago. At this time, Earth was in its early development stage and had been impacted numerous times by planetesimals and other rocky bodies - events that had shock-heated the planet and brought about the expansion of its core.

One collision, however, seems to have been a planet-sized body around the size of Mars - dubbed Theia. Basic models of impact data suggest Theia struck Earth at an oblique angle, with its iron core sinking into the planet, while its mantle, as well as that of Earth, was largely hurled into orbit. This ejected material - which is estimated to be roughly 20 per cent of Theia's total mass - went on to form a ring of silicate material around Earth and then coalesce within a relatively short period (ranging from a couple of months up to 100 years) into the Moon.

Planetesimal

By this stage the planetesimal is massive enough to effectively sweep up all nearby dust, grains and rocks as it orbits around the star.

Layer by layer

Under the influence of gravity, the heavier elements inside the protoplanet sink to the centre, creating the major layers of Earth's structure.

Growing core

Heated by immense pressure and impact events, the metallic core within grows. Activity in the mantle and crust heightens.

Atmosphere

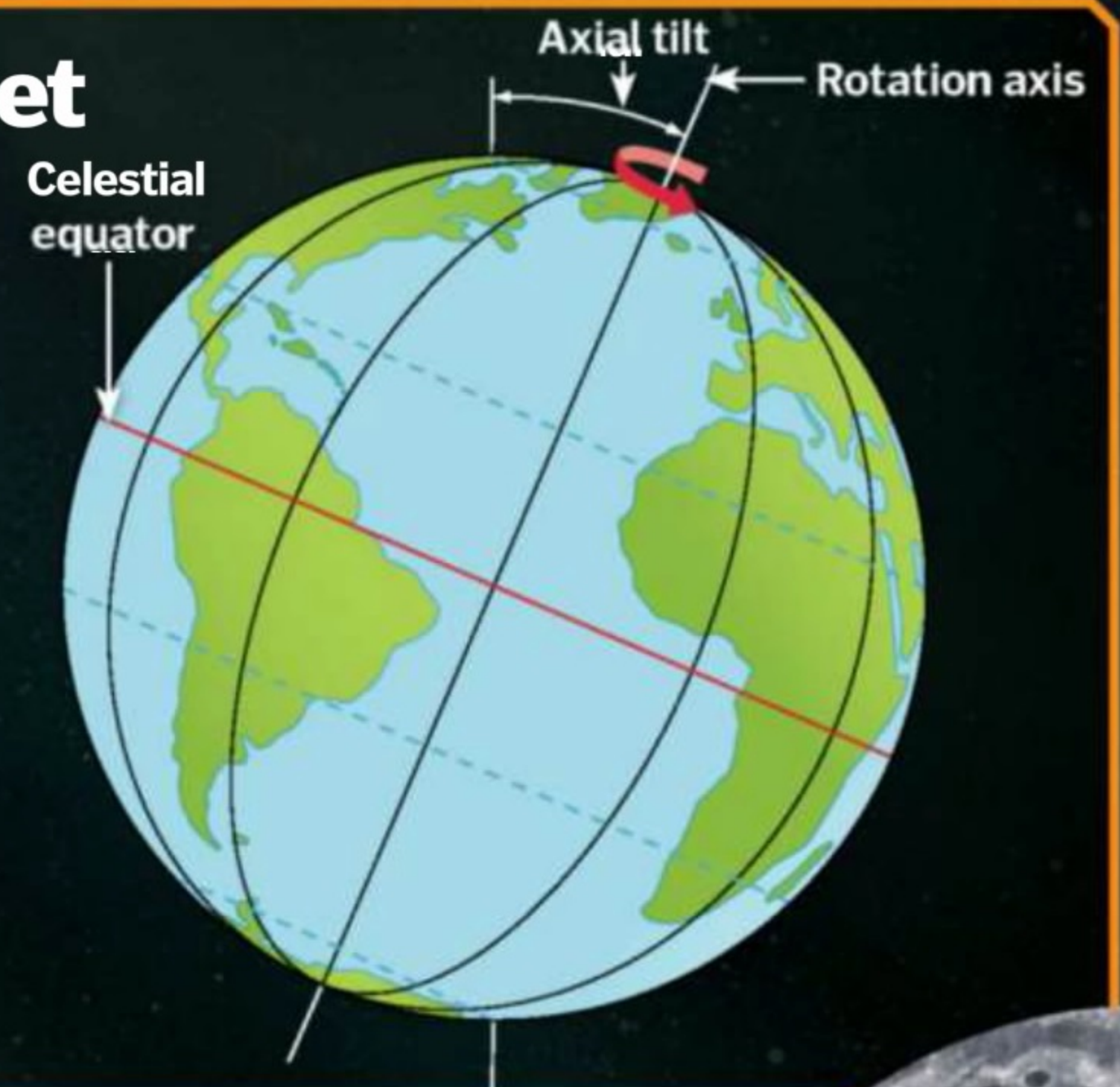
Thanks to volcanic outgassing and ice deposition via impacts, Earth develops an intermediary carbon-dioxide rich atmosphere.

Why does our planet have an axial tilt?

Earth's axial tilt (obliquity), which is at 23.4 degrees in respect to the planet's orbit currently, came about approximately 4.5 billion years ago through a series of large-scale impacts from planetesimals and other large bodies (like Theia). These collisions occurred during the early stages of the planet's development and generated forces great enough to disrupt Earth's alignment, while also producing a vast quantity of debris.

While our world's obliquity might be 23.4 degrees today, this is by no means a fixed figure, with it varying over long periods due to the effects of precession and orbital resonance.

For example, for the past 5 million years, the axial tilt has varied from 22.2-24.3 degrees, with a mean period lasting just over 41,000 years. Interestingly, the obliquity would be far more variable if it were not for the presence of the Moon, which has a stabilising effect.



4.57 BYA

Protostar

The precursor to the Sun (a T Tauri-type star) emerges at the heart of the nebula.



4.56 BYA

Disc develops

Around the T Tauri star a protoplanetary disc of dense gas begins to form and then gradually cools.

4.54 BYA

Planet

As dust and rock gather, Earth becomes a planet, with planetary differentiation leading to the core's formation.

4.53 BYA

Birth of the Moon

Theia, a Mars-sized body, impacts with the developing Earth. The debris from the collision rises into orbit and will coalesce into the Moon.

Earth's structure

As the mass of the Earth continued to grow, so did its internal pressure. This in partnership with the force of gravity and 'shock heating' – see boxout opposite for an explanation – caused the heavier metallic minerals and elements within the planet to sink to its centre and melt. Over many years, this resulted in the development of an iron-rich core and, consequently, kick-started the interior convection which would transform our world.

Once the centre of Earth was hot enough to convect, planetary differentiation began. This is the process of separating out different elements of a planetary body through both physical and chemical actions. Simply put, the denser materials of the body sink towards the core and the less dense rise towards the surface. In Earth's case, this would eventually lead to the distinct layers of inner core, outer core, mantle and crust – the latter developed largely through outgassing.

Outgassing in Earth occurred when volatile substances located in the lower mantle began to melt approximately 4.3 billion years ago. This partial melting of the interior caused chemical separation, with resulting gases rising up through the mantle to the surface, condensing and then crystallising to form the first crustal layer. This original crust proceeded to go through a period of recycling back into the mantle through convection currents, with successive outgassing gradually forming thicker and more distinct crustal layers.

The precise date when Earth gained its first complete outer crust is unknown, as due to the recycling process only incredibly small parts of it remain today. Certain evidence, however, indicates that a proper crust was formed relatively early in the Hadean eon (ie 4.6-4 billion years ago). The Hadean eon on Earth was characterised by a highly unstable,

volcanic surface (hence the name 'Hadean', derived from the Greek god of the underworld, Hades). Convection currents from the planet's mantle would elevate molten rock to the surface, which would either revert to magma or harden into more crust.

Scientific evidence suggests that outgassing was also the primary contributor to Earth's first atmosphere, with a large region of hydrogen and helium escaping – along with ammonia, methane and nitrogen – considered the main factor behind its initial formation.

By the close of the Hadean eon, planetary differentiation had produced an Earth that, while still young and inhospitable, possessed all the ingredients needed to become a planet capable of supporting life. But for anything organic to develop, it first needed water... ▶

Outer core

Unlike the inner core, Earth's outer core is not solid but liquid, due to less pressure. It is composed of iron and nickel and ranges in temperature from 4,400°C (7,952°F) at its outer ranges to 6,100°C (11,012°F) at its inner boundary. As a liquid, its viscosity is estimated to be ten times that of liquid metals on the surface. The outer core was formed by only partial melting of accreted metallic elements.

Crust

Earth's crust is the outermost solid layer and is composed of a variety of igneous, metamorphic and sedimentary rock. The partial melting of volatile substances in the outer core and mantle caused outgassing to the surface during the planet's formation. This created the first crust, which through a process of recycling led to today's refined thicker crust.

"Outgassing occurred when volatile substances in the lower mantle began to melt 4.3 billion years ago"

4.4 BYA

Surface hardens
Earth begins developing its progenitor crust. This is constantly recycled and built up through the Hadean eon.

4.3 BYA

Early atmosphere
Outgassing and escaping gases from surface volcanism form the first atmosphere around the planet. It is nitrogen heavy.

4.28 BYA

Ancient rocks
Rocks have been found in northern Québec, Canada, that date from this period. They are volcanic deposits.



Mantle

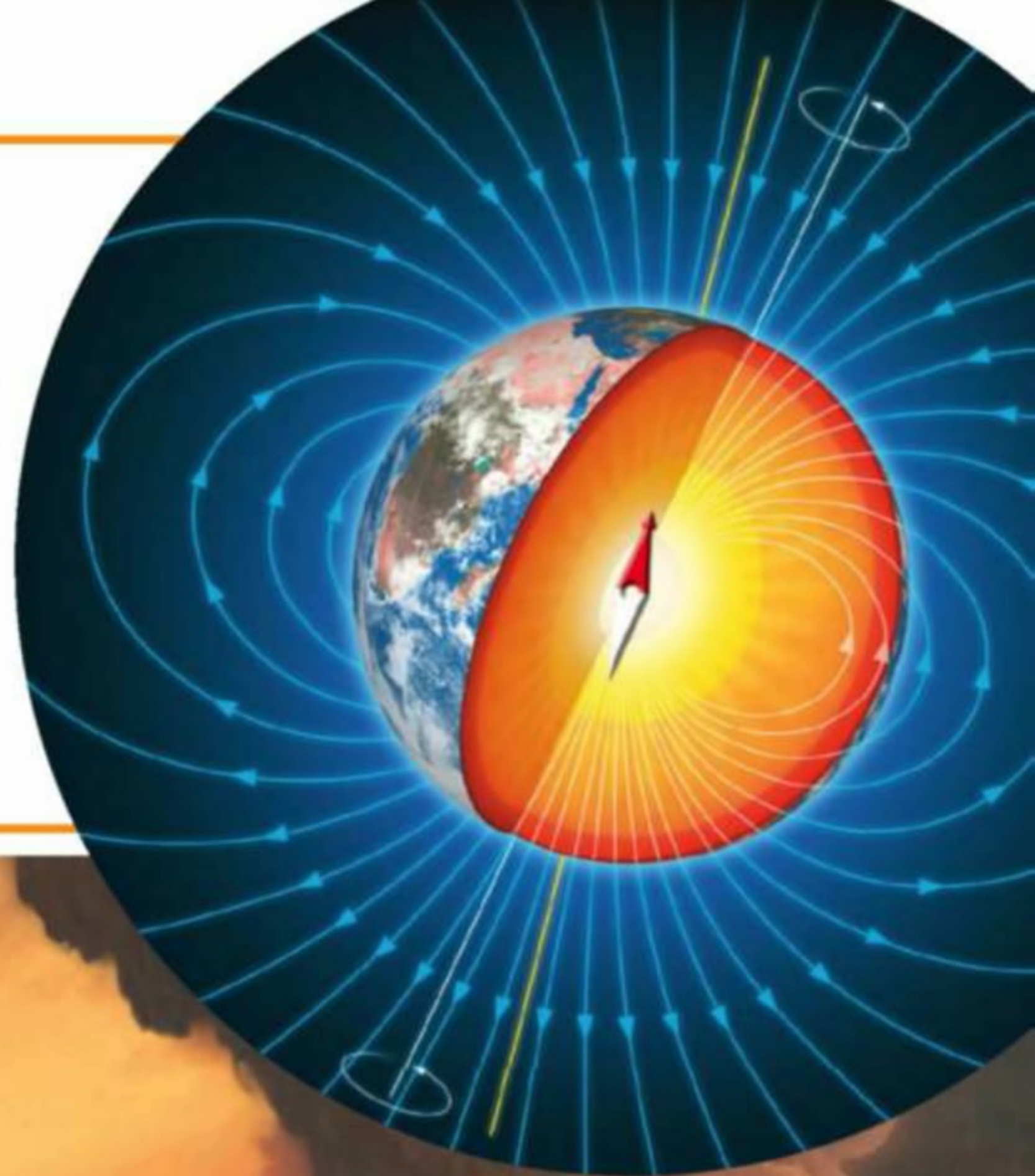
The largest internal layer, the mantle accounts for 84 per cent of Earth's volume. It consists of a rocky shell 2,900km (1,800mi) thick composed mainly of silicates. While predominantly solid, the mantle is highly viscous and hot material upwells occur throughout under the influence of convective circulation. The mantle was formed by the rising of lighter silicate elements during planetary differentiation.

Inner core

The heaviest minerals and elements are located at the centre of the planet in a solid, iron-rich heart. The inner core has a radius of 1,220km (760mi) and has the same surface temperature as the Sun (around 5,430°C/9,800°F). The solid core was created due to the effects of gravity and high pressure during planetary accretion.

Magnetic field in the making

Earth's geomagnetic field began to form as soon as the young planet developed an outer core. The outer core of Earth generates helical fluid motions within its electrically conducting molten iron due to current loops driven by convection. As a result, the moment that convection became possible in Earth's core it began to develop a geomagnetic field - which in turn was amplified by the planet's rapid spin rate. Combined, these enabled Earth's magnetic field to permeate its entire body as well as a small region of space surrounding it - the magnetosphere.



Shock heating explained

During the accretion to its present size, Earth was subjected to a high level of stellar impacts by space rocks and other planetesimals too. Each of these collisions generated the effect of shock heating, a process in which the impactor and resultant shock wave transferred a great deal of energy into the forming planet. For meteorite-sized bodies, the vast majority of this energy was transferred across the planet's

surface or radiated back off into space, however in the case of much larger planetesimals, their size and mass allowed for deeper penetration into the Earth. In these events the energy was distributed directly into the planet's inner body, heating it well beneath the surface. This heat influx contributed to heavy metallic fragments deep underground melting and sinking towards the core.

4.1 BYA

Brace for impact

The Late Heavy Bombardment (LHB) of Earth begins, with a period of intense impacts pummeling many parts of the young crust.

4 BYA

Archean

The Hadean eon comes to an end and the Archean period begins.

3.9 BYA

Ocean origins

Earth is now covered with liquid oceans due to the release of trapped water from the mantle and from asteroid/comet deposition.



3.6 BYA

Supercontinent

Our world's very first supercontinent, Vaalbara, begins to emerge from a series of combining cratons.

Supercontinent development

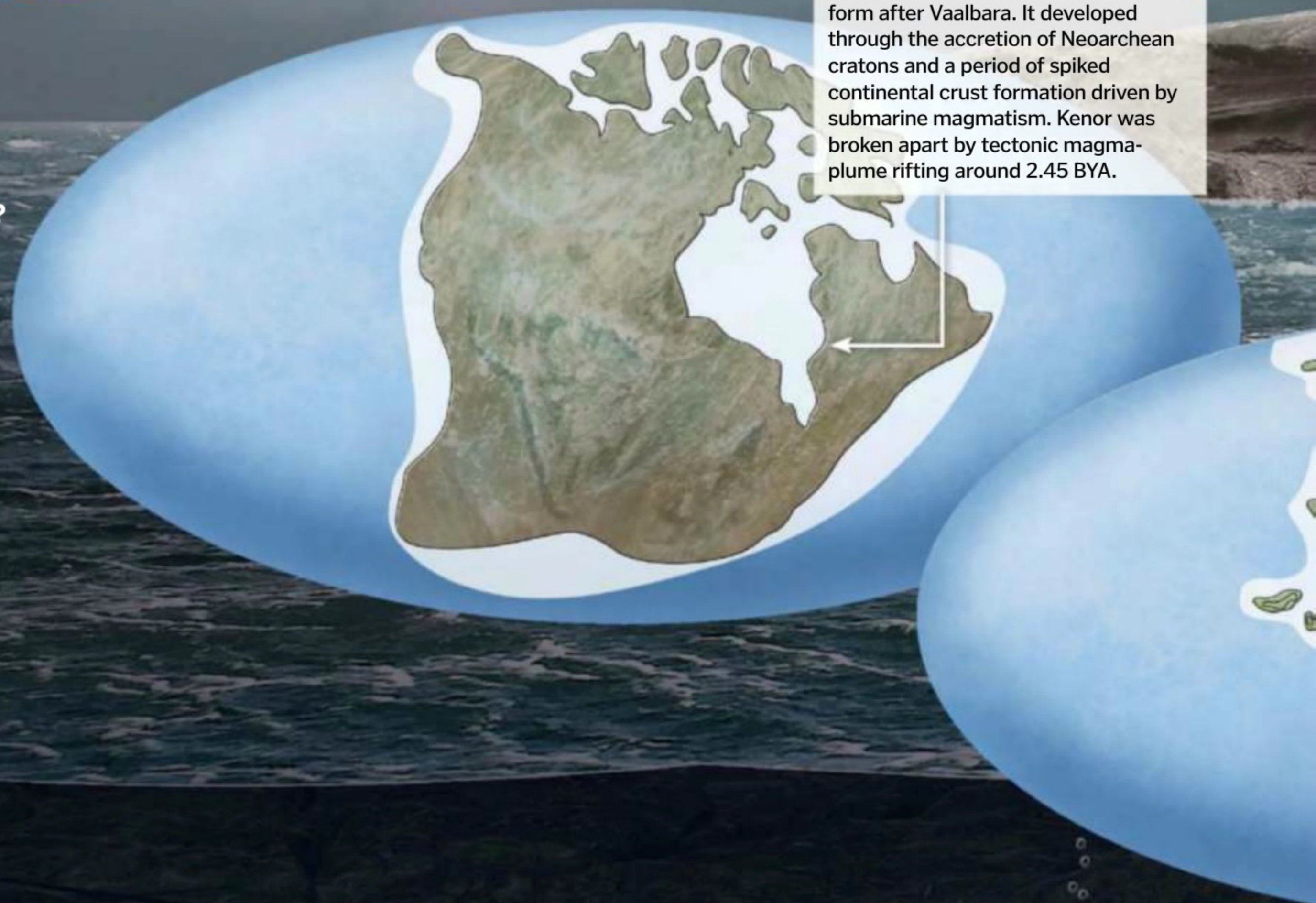
Where did the earliest landmasses come from and how did they change over time?

It started with Vaalbara...

Approximately 3.6 billion years ago, Earth's first supercontinent – Vaalbara – formed through the joining of several large continental plates. Data derived from parts of surviving cratons from these plates – eg the South African Kaapvaal and Australian Pilbara; hence 'Vaal-bara' – show similar rock records through the Archean eon, indicating that, while now separated by many miles of ocean, they once were one. Plate tectonics, which were much fiercer at this time, drove these plates together and also were responsible for separating them 2.8 billion years ago.

Kenor

Believed to have formed in the later part of the Archean eon 2.7 BYA, Kenor was the next supercontinent to form after Vaalbara. It developed through the accretion of Neoproterozoic cratons and a period of spiked continental crust formation driven by submarine magmatism. Kenor was broken apart by tectonic magma-plume rifting around 2.45 BYA.



Formation of land and sea

Current scientific evidence suggests that the formation of liquid on Earth was, not surprisingly, a complex process. Indeed, when you consider the epic volcanic conditions of the young Earth through the Hadean eon, it's difficult to imagine exactly how the planet developed to the extent where today 70 per cent of its surface is covered with water. The answer lies in a variety of contributory processes, though three can be highlighted as pivotal.

The first of these was a drop in temperature throughout the late-Hadean and Archean eons. This cooling caused outgassed volatile substances to form an atmosphere around the planet – see the opposite boxout for more details – with sufficient pressure for retaining liquids. This outgassing also transferred a large quantity of water that was trapped in the planet's internal accreted material to the

surface. Unlike previously, now pressurised and trapped by the developing atmosphere, it began to condense and settle on the surface rather than evaporate into space.

The second key liquid-generating process was the large-scale introduction of comets and water-rich meteorites to the Earth during its formation and the Late Heavy Bombardment period. These frequent impact events would cause the superheating and vaporisation of many trapped minerals, elements and ices, which then would have been adopted by the atmosphere, cooled over time, condensed and re-deposited as liquid on the surface.

The third major contributor was photodissociation – which is the separation of substances through the energy of light. This process caused water vapour in the developing upper atmosphere to separate into molecular hydrogen and molecular oxygen, with the former escaping the planet's influence. In turn, this led to an increase in the partial pressure of oxygen on the planet's surface, which through its interactions with surface materials gradually elevated vapour pressure to a level where yet more water could form.

The combined result of these processes – as well as others – was a slow buildup of liquid

"This erosion of Earth's crustal layer aided the distinction of cratons – the base for some of the first continental landmasses"

3.5 BYA

Early bacteria

Evidence suggests the earliest primitive life forms – bacteria and blue-green algae – begin to emerge in Earth's growing oceans.

3.3 BYA

Hadean discovery

Sedimentary rocks have been found in Australia that date from this time. They contain zircon grains with isotopic ages between 4.4 and 4.2 BYA.



2.9 BYA

Island boom

The formation of island arcs and oceanic plateaux undergoes a dramatic increase that will last for about 200 million years.





Rodinia
 Maybe the largest supercontinent ever to exist on Earth, Rodinia was a colossal grouping of cratons – almost all the landmass that had formed on the planet – that was surrounded by a superocean called Mirovia. Evidence suggests Rodinia formed in the Proterozoic eon by 1.1 BYA, with a core located slightly south of Earth’s equator. Rodinia was divided by rifting approximately 750 MYA.

Pangaea
 The last true supercontinent to exist on Earth was Pangaea. Pangaea formed during the late-Palaeozoic and early-Mesozoic eras 300 MYA, lasting until 175 MYA when a three-stage series of rifting events left a range of landmasses that make up today’s continents. Interestingly, the break-up of Pangaea is still occurring today, as seen in the Red Sea and East African Rift System, for example.



water in various depressions in Earth’s surface (such as craters left by impactors), which throughout the Hadean and Archean eons grew to vast sizes before merging. The presence of extensive carbon dioxide in the atmosphere also caused the acidulation of these early oceans, with their acidity allowing them to erode parts of the surface crust and so increase their overall salt content. This erosion of Earth’s crustal layer also aided the distinction of cratons – stable parts of the planet’s continental lithosphere – which were the base for some of the first continental landmasses.

With liquid on the surface, a developing atmosphere, warm but cooling crust and continents starting to materialise, by the mid-Archean (approximately 3.5 billion years ago) conditions were ripe for life, which we look at in depth on pages 20-21. ▶

A closer look at Earth’s evolving atmosphere

Earth has technically had three atmospheres throughout its existence. The first formed during the planet’s accretion period and consisted of atmophile elements, such as hydrogen and helium, acquired from the solar nebula. This atmosphere was incredibly light and unstable and deteriorated quickly – in geological terms – by solar winds and heat emanating from Earth. The second atmosphere, which developed through the late-Hadean and early-Archean eons due to impact events and outgassing of volatile gases through volcanism, was anoxic – with high levels of greenhouse gases like carbon dioxide and very little oxygen. This second atmosphere later evolved during the mid-to-late-Archean into the third oxygen-rich atmosphere that is still present today. This oxygenation of the atmosphere was driven by rapidly emerging oxygen-producing algae and bacteria on the surface – Earth’s earliest forms of life.

2.8 BYA
Breakup
 After fully forming circa 3.1 BYA, Vaalbara begins to fragment due to the asthenosphere overheating.

2.5 BYA
Proterozoic
 The Archean eon draws to a close after 1.5 billion years, leading to the start of the Proterozoic era.

2.4 BYA
More oxygen
 The Earth’s atmosphere evolves into one that is rich in oxygen due to cyanobacterial photosynthesis.

2.1 BYA
Eukaryotes
 Eukaryotic cells appear. These most likely developed by prokaryotes consuming each other via phagocytosis.

1.8 BYA
Red beds
 Many of Earth’s red beds – ferric oxide-containing sedimentary rocks – date from this period, indicating that an oxidising atmosphere was present.



The development of life

Of all the aspects of Earth's development, the origins of life are perhaps the most complex and controversial. That said, there's one thing upon which the scientific community as a whole agrees: that according to today's evidence, the first life on Earth would have been almost inconceivably small-scale.

There are two main schools of thought for the trigger of life: an RNA-first approach and a metabolism-first approach. The RNA-first hypothesis states that life began with self-replicating ribonucleic acid (RNA) molecules, while the metabolism-first approach believes it all began with an ordered sequence of chemical reactions, ie a chemical network.

Ribozymes are RNA molecules that are capable of both triggering their own replication and also the construction of proteins – the main building blocks and working molecules in cells. As such, ribozymes seem good candidates for the starting point of all life. RNA is made up of amino acids, which themselves are built from nucleotides, biological molecules composed of a nucleobase (a nitrogen compound), five-carbon sugar and phosphate groups (salts). The presence of these chemicals and their fusion is the base for the RNA-world theory, with RNA capable of acting as a less stable version of DNA.

This theory begs two questions: one, were these chemicals present in early Earth and, two, how were they first fused? Until recently, while some success has been achieved in-vitro showing that activated ribonucleotides can polymerise (join) to form RNA, the key issue in replicating this formation was showing how ribonucleotides could form from their constituent parts (ie ribose and nucleobases).

Interestingly in a recent experiment reported in *Nature*, a team showed that pyrimidine ribonucleobases can be formed in a process that bypasses the fusion of ribose and nucleobases, passing instead through a series of other processes that rely on the presence of other compounds, such as cyanoacetylene and glycolaldehyde – which are believed to have been present during Earth's early formation.

In contrast, the metabolism-first theory suggests that the earliest form of life on Earth developed from the creation of a composite-structured organism on iron-sulphide minerals common around hydrothermal vents.

The theory goes that under the high pressure and temperatures experienced at these deep-sea geysers, the chemical coupling of iron salt and hydrogen sulphide produced a

Fish

The world's first fish evolved in the Cambrian explosion, with jawless ostracoderms developing the ability to breathe exclusively through gills.

Insects

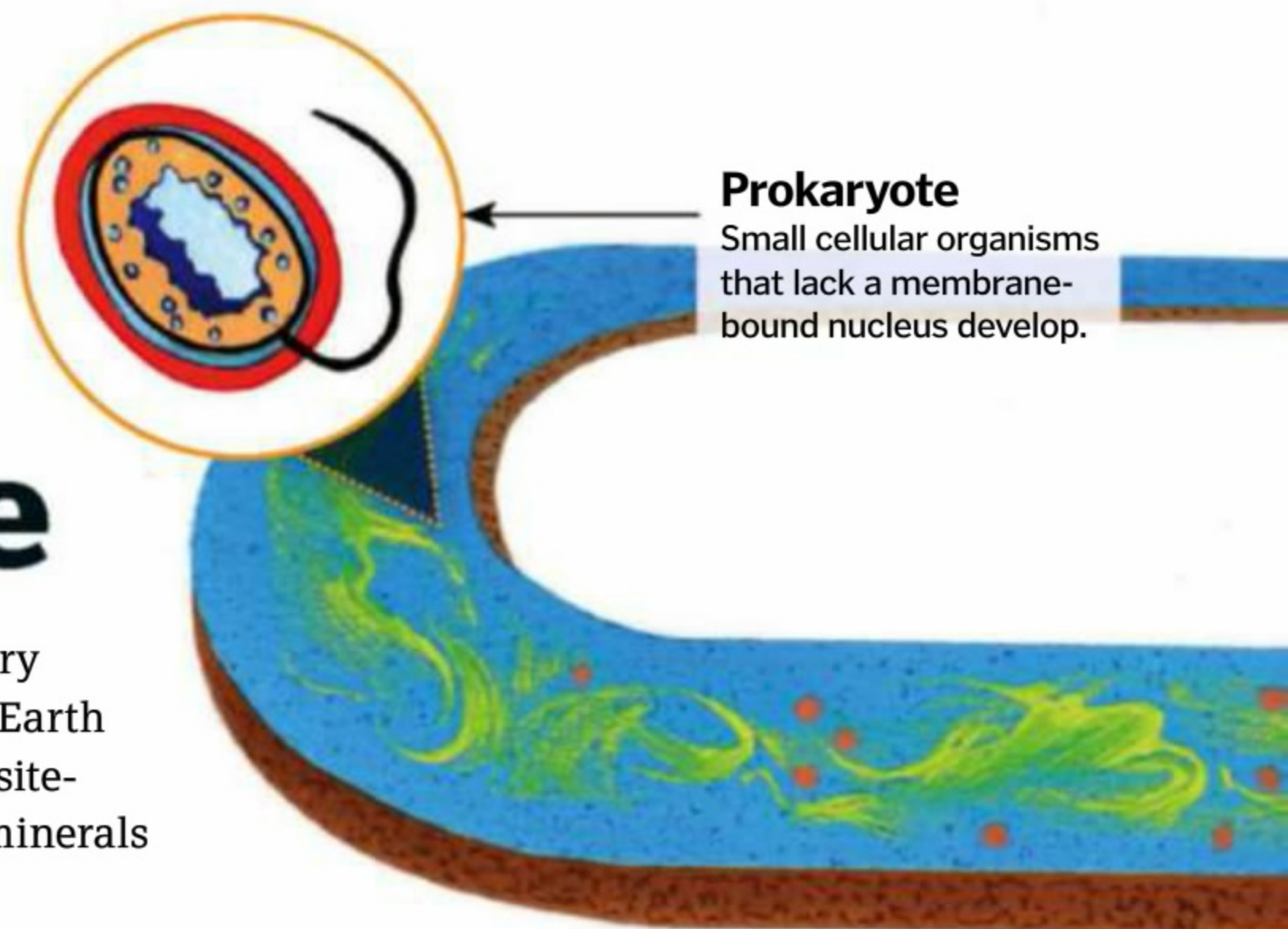
During the Devonian period primitive insects begin to emerge from the pre-existing Arthropoda phylum.

composite structure with a mineral base and a metallic centre (such as iron or zinc).

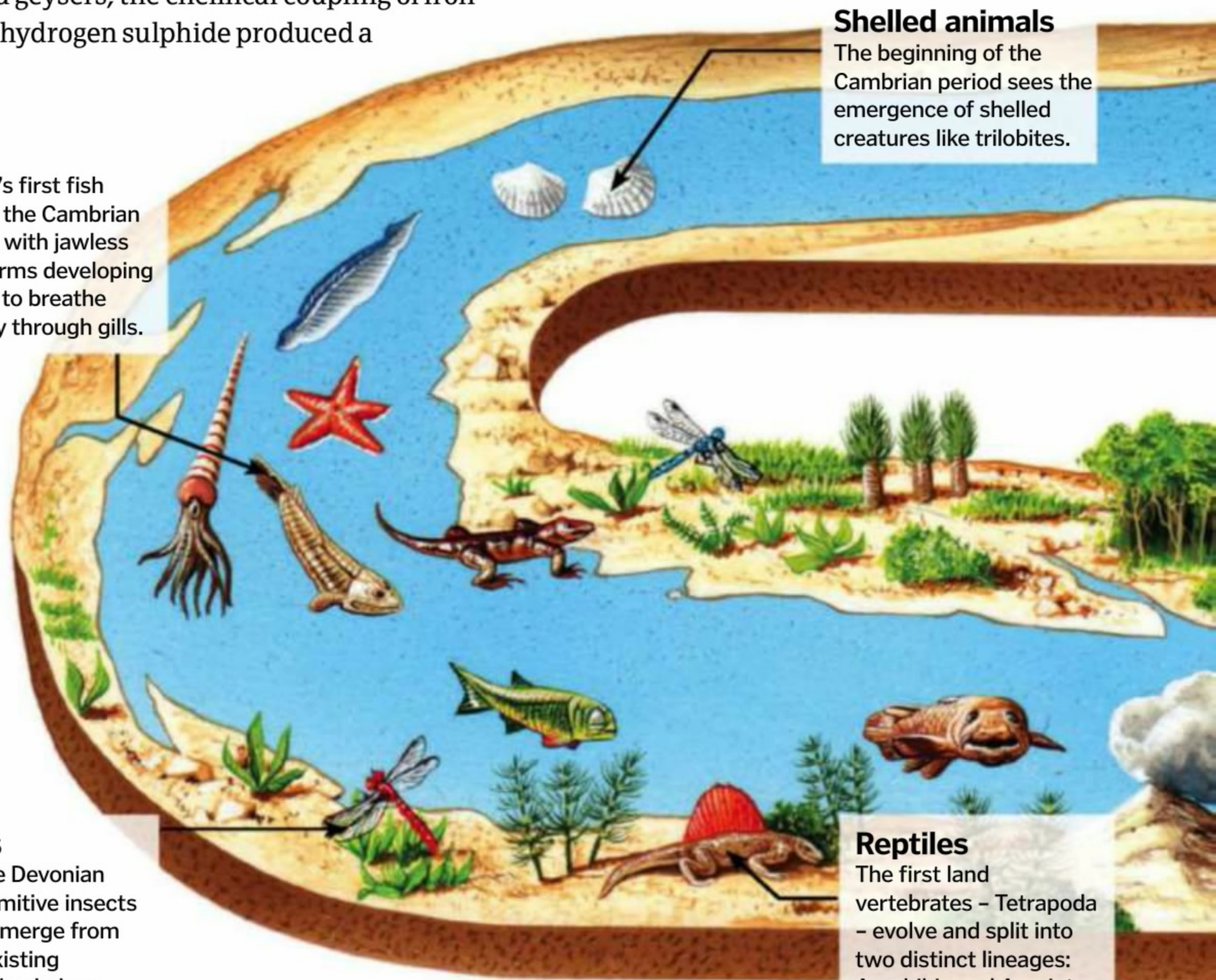
The presence of this metal, it is theorised, triggered the conversion of inorganic carbon into organic compounds and kick-started constructive metabolism (forming new molecules from a series of simpler units). This process became self-sustaining by the generation of a sulphur-dependent metabolic cycle. Over time the cycle expanded and became more efficient, while simultaneously

producing ever-more complex compounds, pathways and reaction triggers.

As such, the metabolism-first approach describes a system in which no cellular components are necessary to form life; instead, it started with a compound such as pyrite – a mineral which was abundant in early Earth's oceans. When considering that the oceans during the Hadean and early-Archean eons were extremely acidic – and that the planet's overall temperature was still very high – a



Prokaryote
Small cellular organisms that lack a membrane-bound nucleus develop.



Shelled animals
The beginning of the Cambrian period sees the emergence of shelled creatures like trilobites.

Reptiles
The first land vertebrates – Tetrapoda – evolve and split into two distinct lineages: Amphibia and Amniota.

1.4 BYA

Fungi

The earliest signs of fungi according to current fossil evidence suggest they developed here in the Proterozoic.

1.2 BYA

Reproduction

With the dawn of sexual reproduction, the rate of evolution steps up a gear.

542 MYA

Explosion

The Cambrian explosion occurs – a rapid diversification of organisms that leads to the development of most modern phyla (groups).



541 MYA

Phanerozoic

The Proterozoic eon draws to a close and the current geologic eon – the Phanerozoic – commences.

106 MYA

Spinosaurus

The largest theropod dinosaur ever to live on Earth, weighing up to 20 tons, emerges.





Earth

Our planet forms out of accreting dust and other material from a protoplanetary disc.



Solar nebula

The solar nebula is formed by the gravitational collapse of a fragment of a giant molecular cloud.

A journey through time

See how life evolved over millions of years to fill a range of niches on Earth

Cyanobacteria

Photosynthesising cyanobacteria – also known as blue-green algae – emerge over the planet's oceans.



Eukaryote

Eukaryotes – cellular membrane-bound organisms with a nucleus (nuclear envelope) – appear.

Sponges

Sponges in general – but particularly demosponges – develop throughout the seas.

Fungi

Primitive organisms that are precursors to fungi, capable of anastomosis (connection of branched tissue structures), arrive.



Pterosaurs

During the late-Triassic period pterosaurs appear – the earliest vertebrates capable of powered flight.

Dinosaurs

Dinosaurs diverge from their Archosaur ancestors during the mid-Triassic era.

Mammals

While pre-existing in primitive forms, after the K-T extinction event mammals take over most ecological niches on Earth.

Humans

Humans evolve from the family Hominidae and reach anatomical modernity around 200,000 years ago.

model similar to the iron-sulphur world type is plausible, if not as popular as the RNA theory.

There are other scientific theories explaining the origins of life – for example, some think organic molecules were deposited on Earth via a comet or asteroid – but all return to the notion that early life was tiny. It's also accepted that life undertook a period of fierce evolution and adaptation to the ever-changing Earth. An Earth that, as we shall see on the final two pages, is still changing to this day. ▶

65.5 MYA

K-T event

The Cretaceous-Palaeogene extinction event occurs, wiping out half of all animal species on Earth.

55 MYA

Birds take off

Bird groups diversify dramatically, with many species still around today – such as parrots.

2 MYA

Homo

The first members of the genus Homo appear here in the fossil record.

350,000 years ago

Neanderthal

Neanderthals evolve and spread across Eurasia. They become extinct 220,000 years later.

200,000 years ago

First human

Anatomically modern humans evolve in Africa; 150,000 years later they start to move farther afield.



Changing Earth

As we have seen, from the formation of Earth 4.54 billion years ago, it has been in a permanent state of flux. From its changing internal structure, altering topographical layout via plate tectonics, through to its evolving atmosphere and the constantly transforming types of life that have inhabited every possible ecological niche, Earth has never stopped developing.

Even today, our world is still evolving, with a series of cycles both maintaining and changing Earth's environment. Here we take a closer look at some of the key cycles, explaining how they work and what could be in store for the future of our planet.

Photosynthesis

Plants absorb carbon dioxide and transform it into oxygen through the process of photosynthesis. Plants are Earth's primary converter of atmospheric carbon. Upon death, carbon contained in plants is transferred to the soil.

3. Infiltration

Water falling onto the surface can seep deep into the soil and rock to become groundwater via subsurface flows.

2. Precipitation

Driven inland or into cooler, higher areas, the atmospheric vapour condenses to form water droplets and is deposited via rain/snow etc.

4. Surface flow

When infiltration is not possible, deposited water returns to sea level on the surface, via rivers and streams.

5. Inflow

Water is redeposited in Earth's oceans or lakes. Evaporation – either by underground heating or a warm climate – recurs, and the cycle restarts.

1. Evaporation

Water on the Earth's surface – either in the oceans or on land – evaporates in warm conditions, rising up as vapour into the atmosphere.

Animal respiration

Animal respiration – including that of humans – is a key exchanger of oxygen in Earth's atmosphere into carbon dioxide and, in the case of certain species such as cows, other gases like methane too.

The carbon cycle

The carbon cycle is a biogeochemical cycle in which carbon is transferred throughout Earth's biosphere, geosphere, pedosphere (soil layer), hydrosphere and atmosphere. Carbon-based molecules are constituents of all organic compounds and, as such, their distribution through the Earth is crucial for maintaining every single life form, including us. Follow some of the major steps in the carbon recycling process now in our illustration.

Atmospheric exchange

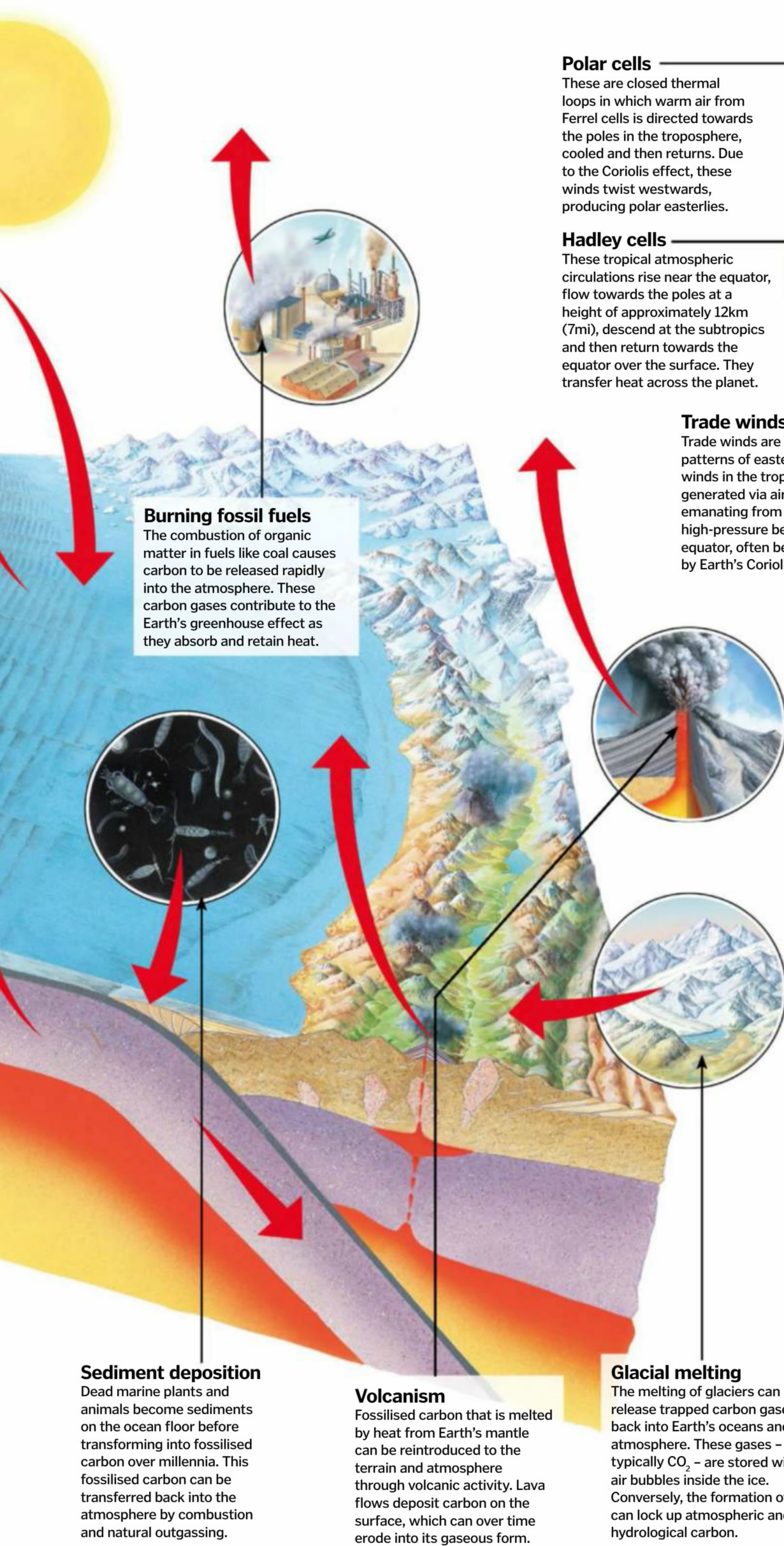
Carbon exists in Earth's atmosphere in two main forms: carbon dioxide and methane. These gases leave the atmosphere by dissolving in large bodies of water – such as oceans and lakes – and, in the case of carbon dioxide, by photosynthesis in the biosphere.

Hydrothermal vents

Trapped fossilised carbon can be released through tectonic plate movements. Converging and subduction zones at oceanic plates can also release carbon gases via hydrothermal vents and volcanism.

The water cycle

The water – otherwise known as hydrologic – cycle is the route by which H₂O is continuously processed in its various states throughout Earth's spheres via evaporation, condensation, precipitation, infiltration and surface/subsurface flows. Liquid water is a unique feature to Earth in the Solar System and, as with carbon, an intrinsic component in the sustainability of life as we know it. As a result its never-ending transition from one medium and location to another is of vital importance to the health of the biosphere in general. Follow the main stages in the water cycle in the step-by-step diagram to the left.



Burning fossil fuels
The combustion of organic matter in fuels like coal causes carbon to be released rapidly into the atmosphere. These carbon gases contribute to the Earth's greenhouse effect as they absorb and retain heat.

Sediment deposition
Dead marine plants and animals become sediments on the ocean floor before transforming into fossilised carbon over millennia. This fossilised carbon can be transferred back into the atmosphere by combustion and natural outgassing.

Volcanism
Fossilised carbon that is melted by heat from Earth's mantle can be reintroduced to the terrain and atmosphere through volcanic activity. Lava flows deposit carbon on the surface, which can over time erode into its gaseous form.

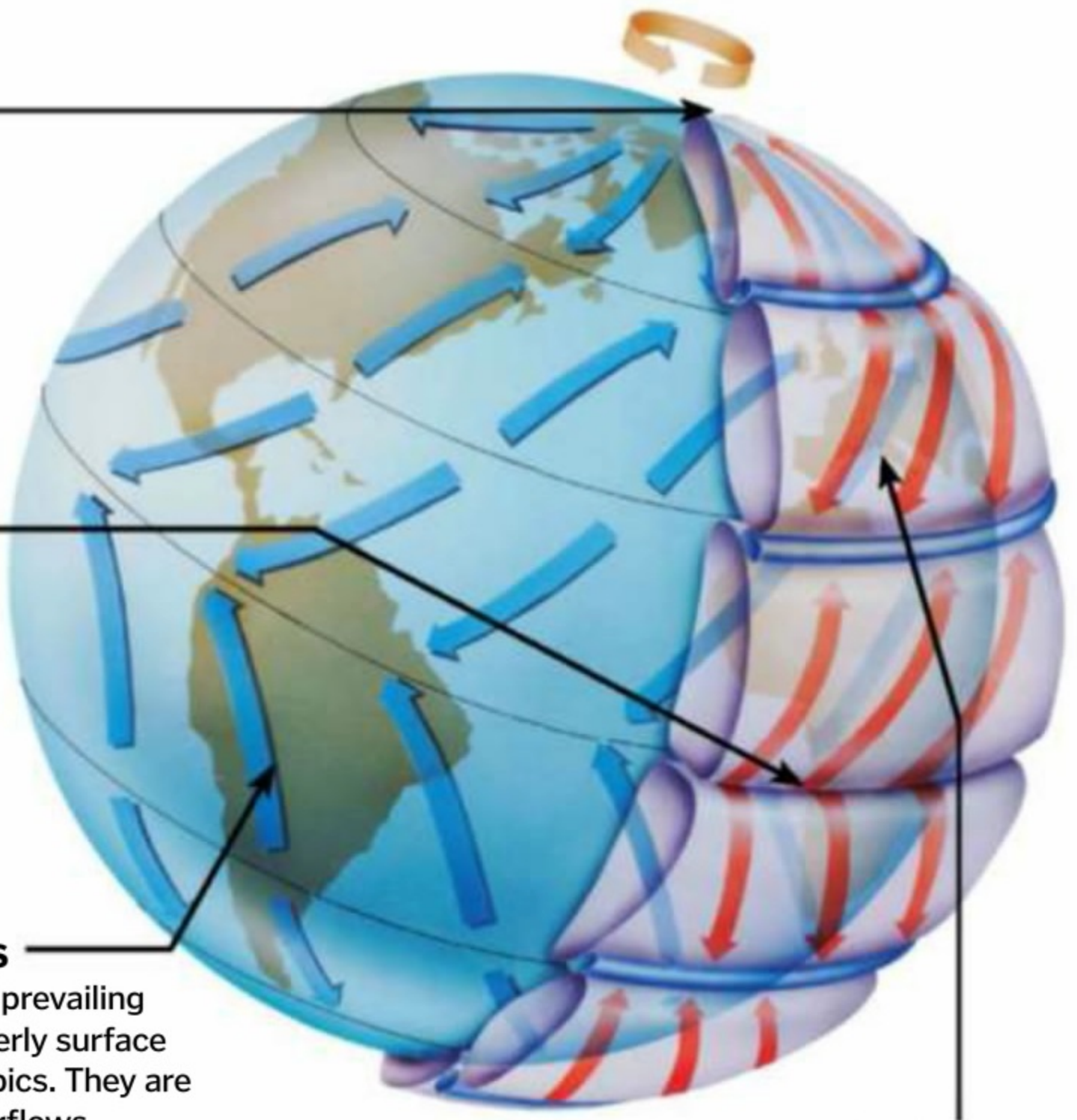
Glacial melting
The melting of glaciers can release trapped carbon gases back into Earth's oceans and atmosphere. These gases – typically CO₂ – are stored within air bubbles inside the ice. Conversely, the formation of ice can lock up atmospheric and hydrological carbon.

Polar cells
These are closed thermal loops in which warm air from Ferrel cells is directed towards the poles in the troposphere, cooled and then returns. Due to the Coriolis effect, these winds twist westwards, producing polar easterlies.

Hadley cells
These tropical atmospheric circulations rise near the equator, flow towards the poles at a height of approximately 12km (7mi), descend at the subtropics and then return towards the equator over the surface. They transfer heat across the planet.

Trade winds
Trade winds are prevailing patterns of easterly surface winds in the tropics. They are generated via airflows emanating from subtropical high-pressure belts towards the equator, often being deflected by Earth's Coriolis effect.

Ferrel cells
Ferrel cells sit between Hadley and Polar cells and act as an intermediary, transferring heat from Hadley cells towards Polar cells and vice versa. Unlike the Hadley and Polar cells, Ferrels are not closed loops.



Global wind system
The circulation of wind on Earth is split into six belt-cells, with three in each hemisphere driven by Earth's rotation. There are the Hadley cells, which dominate the tropical atmosphere and heavily influence the generation of tropical rain belts, trade winds and jet streams. At the top and bottom, the Polar cells produce polar easterly wind flows, while Ferrel cells sit between the other two and serve as conduits. The interaction of these six cells is critical to a balanced climate, with heat generated in equatorial regions carried towards the poles, and vice versa.

What the future holds

While determining the story of Earth over the past 4.5 billion years is difficult, predicting its future – especially across long time frames – is comparatively simple. The story ends with the dying Sun, with Earth engulfed in approximately 7.5 billion years' time. By this point the game will have been up for us for many years, with the expanding red giant star having left nothing but a scorched, barren lump of carbon. Indeed, the fragility of our world cannot be overstated. From large-scale impact events like the space rock that wiped out the dinosaurs, through to the potential for massive near-Earth supernovas bombarding the planet and on to the mass extinction of oxygen-producing plants by rising solar radiation, Earth as we know it today will not last – just as the fiery Hadean Earth didn't last billions of years ago. Nothing in life is permanent, and all we can hope for is that sooner rather than later we find another planet equally as special, to which we might one day relocate and make our new home.



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From the display options to bespoke apps and how it is mounted, the Pebble is all about customisation



Next-generation smartwatches

Explore some of the innovative technology which is taking the humble timepiece to a whole new level



The Pebble concept is a smartwatch that can communicate with any Android or iOS device using Bluetooth wireless technology. It can alert you to incoming calls or emails with a silent vibration, display text messages from a smartphone (these are known as push notifications) on its face, or control music on your phone. All you have to do to set up these features is download the Pebble app to your device – but believe it or not, these are just a few of its basic functions.

The Pebble also has app functionality, such as the pre-installed golf rangefinder and GPS cycling application that enables you to monitor speed and distance travelled. This technology itself isn't new and watches already exist with similar hardware solutions (for example, GPS hardware manufacturer Garmin offers a range of wristwatches with dedicated speedometer

features). But via a smartphone the Pebble watch can download many more apps and run several of them on a single device, with software development kits (SDKs) available to give developers full control of the watch and create entirely new Pebble apps. It's similar to the process in which smartphone developers can create apps for the iPhone or an Android phone and then upload them to communal stores.

Another key selling point of the smartwatch is the electronic paper (ePaper) display, which is similar to the eInk screens on modern eReaders, like the Kindle. It can be customised to show the face of your choice: a classic clock face, digital or more conceptual design and you can even design your own watch face if you wish. But undoubtedly the ability to switch between a range of functions other than just telling the time has to be the Pebble's biggest draw. ⚙

What is IFTTT?

Building on its smartphone communications and simple push notifications, the Pebble watch has employed the IFTTT ('if this then that') service. This is an internet communications tool that works via ifttt.com to build connections and allow websites and social media to generate messages under certain conditions, using personal accounts as well as public profiles. The user creates an account and then generates a 'recipe' with the 'if this then that' statement – 'this' being the trigger and 'that' the action to take. IFTTT currently can access 60 channels that include Twitter, Facebook, LinkedIn and various email accounts, with the trigger being anything from a keyword in a tweet to an attachment in an email. For example: if you add a new photo to Instagram, it can automatically pass into your Dropbox account. The recipe can be changed so a notification is sent to the Pebble when this happens, or if you're tagged on Facebook, or if a certain person emails you, etc.

KEY DATES ONES TO WATCH

1940s

The first slide-rule watches with logarithmic scales in addition to timekeeping (right) start to appear.



1975

Pulsar brings out the world's first calculator watch with a stylus for its tiny buttons.

1982

Seiko launches the D409 memory watch with its 112 bytes of memory for storing calculations.

1991

Swatch brings out the Beep, a modified watch that accepts pager messages.



2006

Garmin introduces the improved Forerunner 205 athlete training watch (left) with more sensitive GPS.

DID YOU KNOW? A recent patent for a flexible, wrist-mounted device filed by Apple suggests an 'iWatch' isn't far off

Evolution of smartwatches

Historically, the definition of a 'smartwatch' has been a watch that has functionality beyond merely timekeeping. So, at the time in the Seventies and Eighties, Nintendo's game wristwatches (a watch with a built-in LCD game) or Casio's famous calculator watches were the first smart forerunners.

Of course they have evolved with the rise of computing, GPS and mobile phones to include radios, thermometers, compasses, heart-rate monitors and more. With the miniaturisation of consumer technology, they can now include cameras, be used as mass storage devices and even serve as

media players. A combination of the latest technologies comes together to create today's smartwatches that act more like a mobile wrist computer than the one-trick timepiece of yesteryear.

Microchip processors for modern watches easily compete with the CPUs found in desktop machines of the late-Nineties, the wide availability of GPS means the wearer can easily navigate and track speed, while Bluetooth and other communications technologies enable the watch to tap into boundless other resources beyond its own physical capabilities.



Inside the Pebble

We tear apart this state-of-the-art watch to see what makes it tick

Button

The Pebble's buttons are spring-loaded and incorporate gaskets to remain watertight.

Casing

The housing is sealed and waterproof up to five atmospheres in both fresh and saltwater.

Vibration motor

When activated by a message or other programmed trigger, this module vibrates the watch.

Motherboard

The nerve centre of the Pebble contains an accelerometer, a 120MHz ARM chip and 32MB of serial flash memory.

ePaper

The display uses a Sharp Memory LCD for a 144 x 168px ePaper display.

Ribbon cable

This strip supports the four buttons, three LEDs and Bluetooth 2.1 antenna.

Display film

This covers three LEDs that act as a backlight for the whole watch face.

Power

A 3.7V, 130-milliamp, USB-rechargeable battery allows for over seven days' use on a single charge.

Screen

Both scratch and shatter resistant this covers the display and also features an anti-glare coating.



"The most common homing technology locks on to infrared radiation, such as the heat from a jet exhaust"

How do homing missiles always stay on target?

Missile technology has come on leaps and bounds since the unguided V-2 rockets of WWII, but how do these explosive devices navigate today?

Modern missiles can be guided to a target, often by their own systems. The most common kind of homing technology detects and locks on to infrared (IR) radiation, such as the heat from a jet exhaust. Modern systems detect two wavelengths: 3-5 micrometres and 8-13 micrometres. The second wavelength isn't absorbed by the atmosphere, so it's much easier to track. This also makes flares - the intense infrared countermeasures that are ejected by a target in order to lure the missile off course - less effective.

Missiles are essentially rockets fitted with an explosive warhead and an infrared detection

sensor connected to a flight computer. These sensors are often made of mercury cadmium telluride to pick up the specific IR wavelengths emitted by the enemy target.

However, sometimes missiles need to be fed targeting information constantly from their launcher, while the on-board flight control system steers the weapon. Indeed, on some occasions this means the target will be 'painted' with a laser; that energy signature will then guide the missile. Others still make use of mounted cameras which let an operator direct the missile post-launch and guarantee it's not duped by any countermeasures.



A C-130 Hercules launches flares that can be used to draw away homing missiles during a training mission

Taking out a missile

Homing tech can be used for defence as well as attack, as this anti-missile system shows...



4. Acquisition
When it gets to a close enough position, the interceptor's own on-board IR systems lock on to the target.

5. Interception
The missile steers itself towards the incoming bomb, exploding when close enough and destroying them both.

3. Interceptor homing missile
The interceptor is launched, initially targeted at the course the hostile weapon was detected on.

2. Radar station
The launch is detected by a radar station and a targeting trajectory is instantly fed to the interceptor.

1. Enemy missile
A ballistic is fired from a hostile state or aircraft many miles away.

KEY DATES

PACEMAKER FIRSTS

1958

The first battery-driven pacemaker is used, but the pulse generator is an external box which the patient wears.



1960

Two years later, the world's first fully internal pacemaker is implanted in Uruguay.

1975

The first lithium battery is introduced, greatly prolonging the life span of pacemakers.



2009

In New York a Wi-Fi-enabled pacemaker is implanted, which can communicate with the patient's doctor daily.

2011

Medtronic makes a tiny pacemaker the size of a Tic Tac. It is currently undergoing research.

DID YOU KNOW? Pacemakers are classified based on the number of heart chambers that they 'pace'

How pacemakers work

Learn how these cutting-edge devices are giving tired hearts a new lease of life



The heart has a natural pacemaker called the sinoatrial node. This fires electrical impulses which regulate our heartbeat. Certain conditions cause this natural pacemaker to malfunction though, which is where artificial pacemakers come into play.

There are several different types of artificial pacemaker, each suited to certain conditions. For those with irregular or very slow heartbeats, a permanent pacing device will send out an impulse to control every single beat. For those who have occasional problems, meanwhile, a responsive pacemaker will take over only when it detects irregular cardiac rhythms.

The power supply for artificial pacemakers needs to be long-lasting and reliable. The most commonly used type is a lithium battery, which has been proven to last for ten years. At that stage they won't suddenly cut out, as specialist equipment can detect those low on power in plenty of time. They can then be swapped out for a new one in a second minor procedure.

Pacemaker aftercare

A pacemaker is implanted as a day-case procedure under a local anaesthetic. The pacemaker box is put just beneath the skin in the upper left-hand corner of the chest; they can easily be felt in those fitted with them.

The main environments people with pacemakers should avoid are those with strong magnets, which can affect the pacing capability and also the position of the machine. This means steering clear of MRI scanners and certain electric motors, which generate electromagnetic fields. Microwaves and airport security gates are perfectly safe, and certain modern pacemakers are even designed to be MRI compatible too.

Electrode connector box

Fine wire electrodes run from this box to the chambers of the heart, which transmit the electrical impulse that control its rate.

Electrodes

Either one or two wires are connected here, which are then carefully placed into position inside the heart.

Pulse generator case

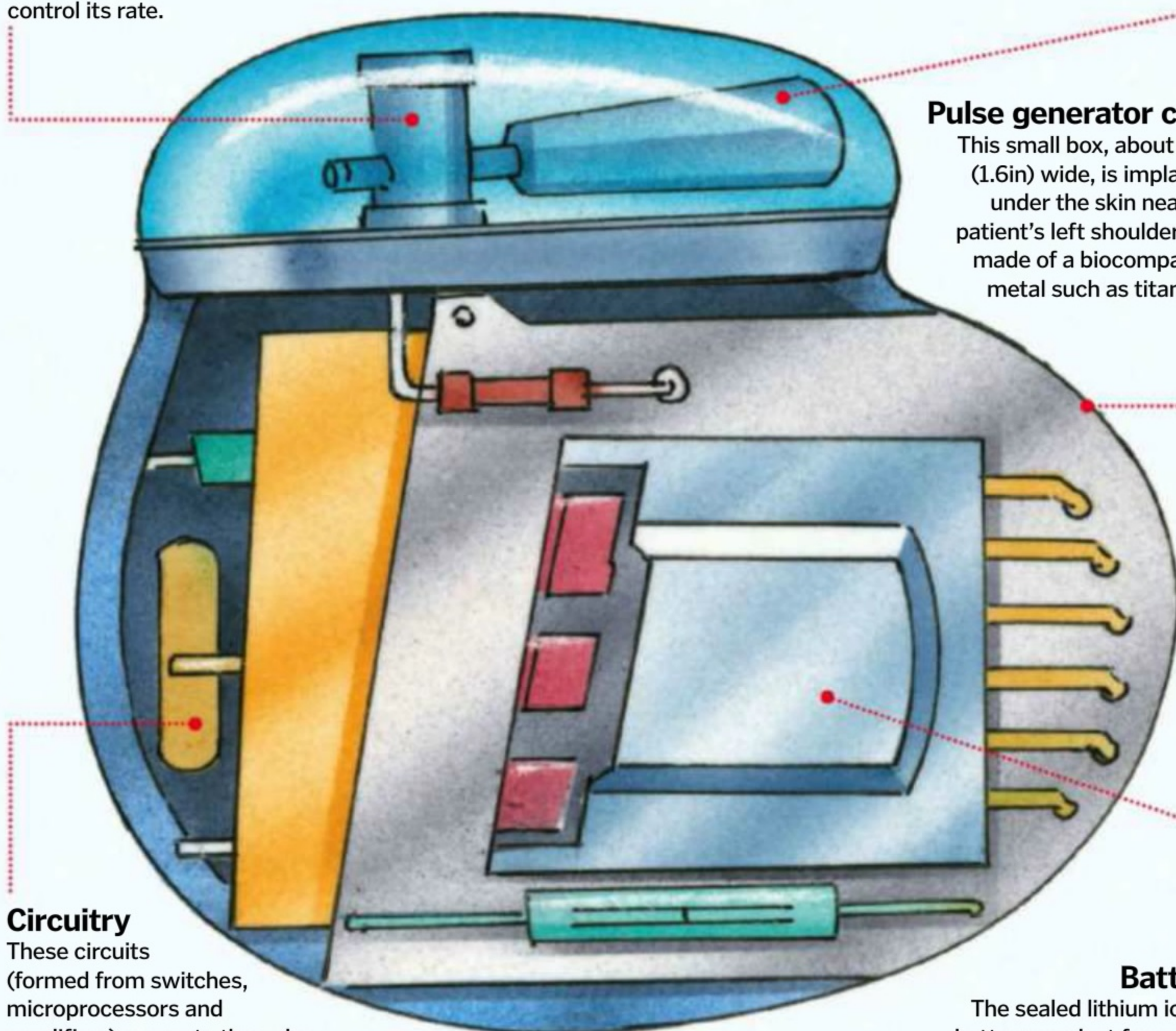
This small box, about 4cm (1.6in) wide, is implanted under the skin near the patient's left shoulder. It is made of a biocompatible metal such as titanium.

Circuitry

These circuits (formed from switches, microprocessors and amplifiers) generate the pulse at a predetermined rate, or can also fire the pacemaker on an 'as-needed' basis.

Battery

The sealed lithium iodine battery can last for up to a decade, and generates the energy for each paced impulse sent to the organ.



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Personal CNC for Home or Hobby

Don't Let Your Tools Hold Back Your Creativity

Tormach Personal CNC machines are the ultimate workshop tool. Whether you're a jeweler, artist, prototype builder, engineer, model maker or hobbyist, a Tormach PCNC will expand your possibilities and enable your ideas.

The PCNC 1100 Features:

- 3-Axis CNC Milling Machine cuts aluminum, steel, plastic, wood and more
- Table size 26" x 8"
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- Stiff cast iron frame
- Space-saving footprint
- Requires single-phase 230VAC 50/60Hz electrical service
- Optional accessories: Reverse Engineering CNC Scanner, 4th Axis, Digitizing Probe



www.tormach.com

Steel Clutch Plate for Reproduction Case 65 Steam Traction Engine machined with the PCNC 1100



3-Axis Mill

\$8480

USD (plus shipping)



Shown here with optional stand, LCD monitor, machine arms, and accessories.





"To capture moving images the CCD transfers each frame to an extra sensor behind the main imager"

How camcorders work

Learn how the latest digital video cameras capture and record hi-def footage



Modern digital recorders fundamentally work in the same way as the original analogue camcorders of the Eighties – those bulky, VCR-recording devices wielded on the shoulder. They both comprise a lens, imager and storage medium, but the main differences are that today's camcorders convert analogue data to a digital form and that the technology as a whole has miniaturised to a far more practical, handheld level.

A camcorder uses a lens to focus patterns of light from a scene onto an imager – a CMOS sensor or charge-coupled device (CCD). The latter is a small semiconductor that houses around half a million photosites – tiny diodes sensitive to light that measure the number of photons that strike it before converting them into an electrical charge. The strength of this charge tells the camcorder during playback how intense the light at that point should be. Colour is recorded by measuring the levels of green, red and blue, because any colour can be replicated with a mix of these three primary shades.

Of course, CCDs in camcorders have to record moving images, so the device must capture multiple frames. To do this, the CCD transfers each frame of video to an extra sensor behind the main imager in a small relay system. This second sensor transmits the electric charges at each of the photosites to the analogue-to-digital converter, while the first layer wipes itself blank, ready to capture the next image.

The latest top-of-the-range camcorders pack an unbelievable amount of technology into a tiny body, relative to the video recorders we started with 30 years ago. The Hitachi Super Hi-Vision, for example, can shoot 33 megapixels (7,580 x 4,320 resolution) at 120 frames per second. That's 4 billion pixels caught each moment – the same kind of detail seen on an IMAX cinema screen.



Video recorder tech

We take a peek at the technology enabling us to shoot ever-better home movies

Laser reader

Some older models of camcorders include a laser reader/writer for recording to and reading from miniDVDs.

Curved body

Camcorders can be made shockproof (ie protected from falls) by padding the corners and building a solid frame with a curved shape that's inherently strong.

Spindle

A small motor can drive the miniDVD on a spindle at around 500 spins a second.

Lens

The lens screws on to the top of the imager and focuses the light on the sensor underneath.

Materials

Typically made out of light but durable plastic, some specialised camcorders (like the GoPro HERO3) are also sealed in order to make them waterproof.



KEY DATES

VIDEO RECORDERS

1966

Sony introduces the CV-2000 VTR camera, the world's first consumer home video recorder.

1976

JVC launches an alternative standard to the Betamax video player: the VHS format (right).



1983

VHS and Betamax camcorders go head to head with the launch of the Sony Betamovie.



1992

Sharp is the first manufacturer to put a colour LCD screen on its camcorders (left).

1995

Digital cameras emerge; the Sony DCR-VX1000 has a FireWire port to upload directly to a PC.

DID YOU KNOW? Jerome Lemelson tried to patent the camcorder in 1977, but his idea was rejected for being too unrealistic!

Analogue vs digital

The main difference between a digital and analogue camcorder is the way data is recorded. Analogue camcorders record it as magnetic patterns, usually on magnetic VHS tape. The two main problems with this is that analogue recording takes up a lot of physical space in the form of bulky cassette tapes, a lot of logical space on a hard disk drive and analogue data can also 'fade' each time it's copied, as the original recording signal isn't replicated

precisely. Digital camcorders, on the other hand, add an analogue-to-digital converter stage to the end of the capture process, transforming the analogue signal into a series of binary 1s and 0s. Digitising the data this way allows it to be compressed into a much smaller logical volume on a memory card or solid-state drive. Data can also be reproduced exactly, so it doesn't suffer from degradation over time like analogue.

The Panasonic HDC-TM300 uses three full-HD MOS sensors, which between them can capture a total 9,150,000 pixels



CMOS battery
Maintains power to the CMOS chip that stores basic data such as date and time, even when the camcorder is turned off.

Logic board
This contains all the chips for processing the image data, converting it into a digital format and sending it to the storage device.

Making sense of sensors

A CMOS (complementary metal-oxide-semiconductor) sensor is an image sensor that often takes the place of a CCD (charge-coupled device) in mobile phones, webcams and DSLR cameras. CMOS sensors use tiny transistors located at each pixel to read each point individually. The transistors take the electron charge that has been converted from the captured point of light and amplify it, before transferring it across wires.

As CMOS sensors combine image processing and capture on the same device, it generally uses less power than a CCD, has less lag and requires fewer costly processes during manufacture. For these reasons, CMOS sensors are common in mobile phone cameras where cheaper, power-efficient components are vital. As the wires in CMOS sensors make them prone to image noise, they tend to have lower-quality results than CCDs, so the latter are often used in higher-end imaging tech.

Image sensor
Moving images are captured at this point, by a CCD or CMOS sensor.

LCD display
Since the early-Nineties, a small LCD display has replaced the original viewfinder and become the standard.

© DK Images; Canon; Panasonic; Sharp; Groink



"Packet-switching networks are an evolution of an older telephony system called circuit switching"

4G mobile networks are finally at our doorsteps, but how does the tech work and what does it mean for telecommunications?

How 4G works

 4G mobile networks are one of the most exciting technological developments in recent years. With network providers now rolling out 4G services across the US and UK, many people are looking to upgrade from their current 3G handsets to take advantage of its huge benefits. Although the new mobile network standard is yet to be set in stone, even the most basic 4G services are in another league from previous generations in terms of the speed and accuracy with which they deal with data: indeed, 4G is potentially at least ten times faster than the speediest 3G connection available. So how have the network providers achieved this astonishing leap?

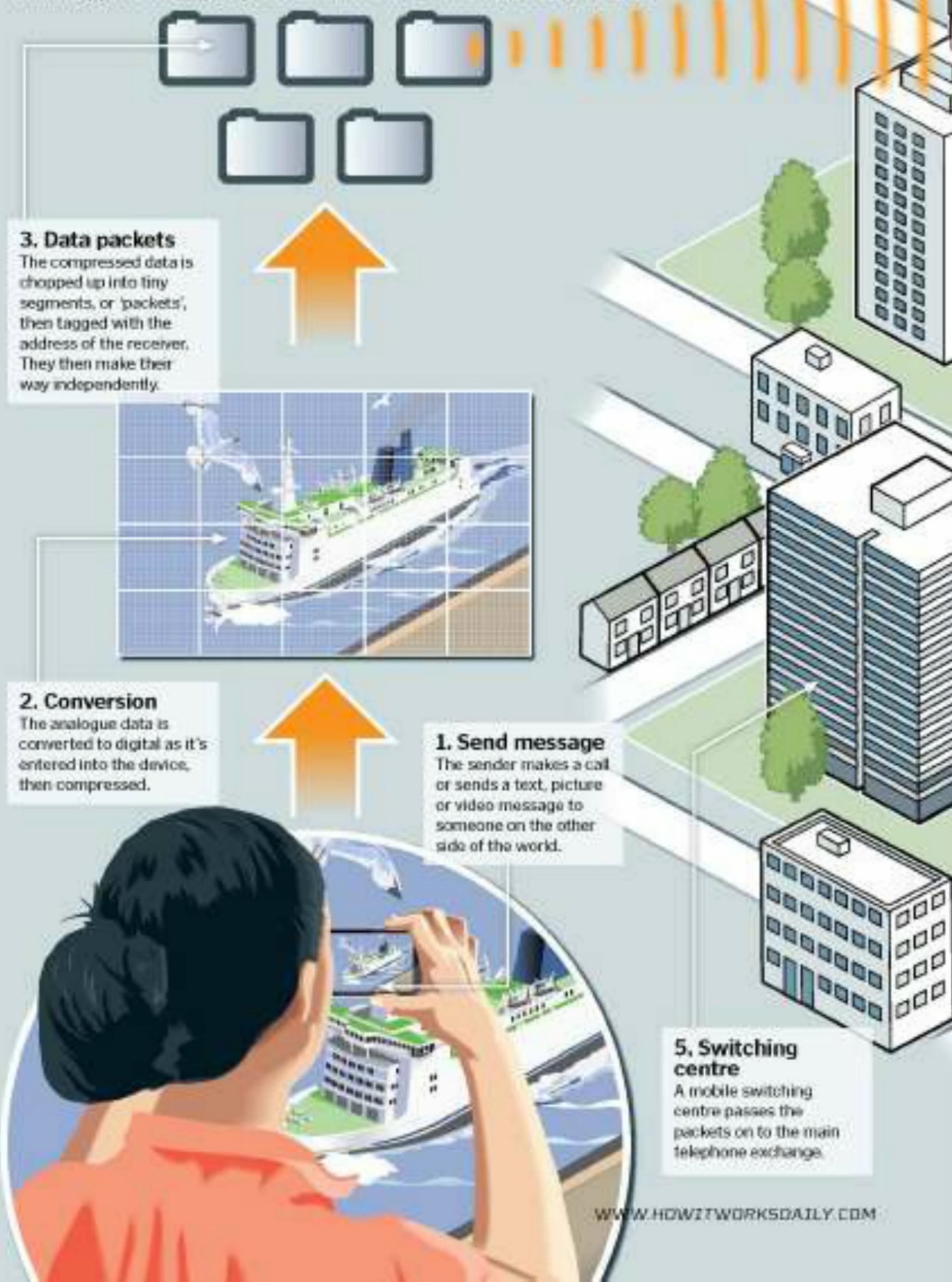
Both 4G and 3G networks are based on IP (Internet protocol), so they use the same basic standards to send and receive information to and from the web. The difference is that when 3G was introduced in 2001, mobile networks had been using a different set of standards for its voice calls and there seemed no reason to question why 3G shouldn't have one set of protocols for voice and another for multimedia messaging. As it turns out, it's a pretty inefficient way of using the network, so 4G ultimately aims to make voice calls completely IP-based along with text and multimedia messaging. It means that data will be sent and received as and when it is needed in something called a packet-switching system.

Packet-switching networks are a natural evolution of an older telephony system called circuit switching, where a line would be dedicated to the user for the duration of their task. In old telephone systems, it meant that long-distance calls would cost a lot of money, because thousands of miles of cable would be tied up for the length of the call.

Packet switching effectively irons out all the inefficiencies of the old system. To begin with, for VoIP (voice over internet protocol), while you're talking on the phone, the other person is usually listening, which means that only half the line is in use at any given time and so the file size for that data can be cut in half. Over ▶

A trip through the network

What happens when you place a call or send a message using 4G LTE?



3. Data packets
The compressed data is chopped up into tiny segments, or 'packets', then tagged with the address of the receiver. They then make their way independently.

2. Conversion
The analogue data is converted to digital as it's entered into the device, then compressed.

1. Send message
The sender makes a call or sends a text, picture or video message to someone on the other side of the world.

5. Switching centre
A mobile switching centre passes the packets on to the main telephone exchange.

Kansas City, USA, can boast the world's fastest home internet service (100 times faster than current broadband). The super-speedy one-gigabit-per-second Google Fiber line costs \$70 (£45) a month to rent.

DID YOU KNOW? It's estimated that 4.75 billion people will have 4G mobile broadband by 2016

4. Base station

The nearest LTE radio antenna (mobile base station) within the cell picks up the packets and relays them to the next stage.

8. Satellite station

For long-distance communications, the packets are beamed up to an orbiting satellite. Overseas messages may be sent via a submarine cable.

9. Back down the line

Once the packets have travelled via satellite or under water, the process is reversed: from telecoms tower, main exchange, switching centre, base station through to the recipient.

7. Telecommunications tower

From here, the message is sent either to a satellite Earth station or a coastal exchange, depending on which is the quickest route.

10. Receive message

The recipient's device stitches the packets back together, decompresses the data and converts it back into the original text message/video/picture/phone call.

6. Telephone exchange

As the message is destined for an international recipient, the packets are passed to a telecommunications tower.



“Generally 4G mobile users can expect to get mobile network download speeds in excess of 10Mbps”

▶ the course of a telephone conversation you will spend several seconds in complete silence, so the data created for that is utterly redundant and can be removed to further reduce file size. On top of this, the packet-switching system only sends and receives data whenever you need it along thousands of different network paths as opposed to a single dedicated line.

The mobile phone using the internet protocol chops the data into a series of streamlined payloads of data (ie packets) and attaches an address to each one that tells various network equipment where they need to be sent. As they're forwarded through the system, routers deal with each of the packets on a case-by-case basis, so the packets will take many different routes to the final destination. The cheapest and least congested lines, whether via satellites or underwater cables, are chosen for optimum cost and efficiency. When the packets arrive, the receiving device stitches them back together using the instructions in the packets.

There are a number of other things that 4G does which help it out-perform previous generations. It has both a higher capacity and a higher data rate, which means that it can support more users each using a greater volume of data simultaneously. For a user base ever-more obsessed with uploading high-definition videos and taking high-resolution photos then sharing them with their friends all over the world, this makes both sending and receiving an order of magnitude quicker.

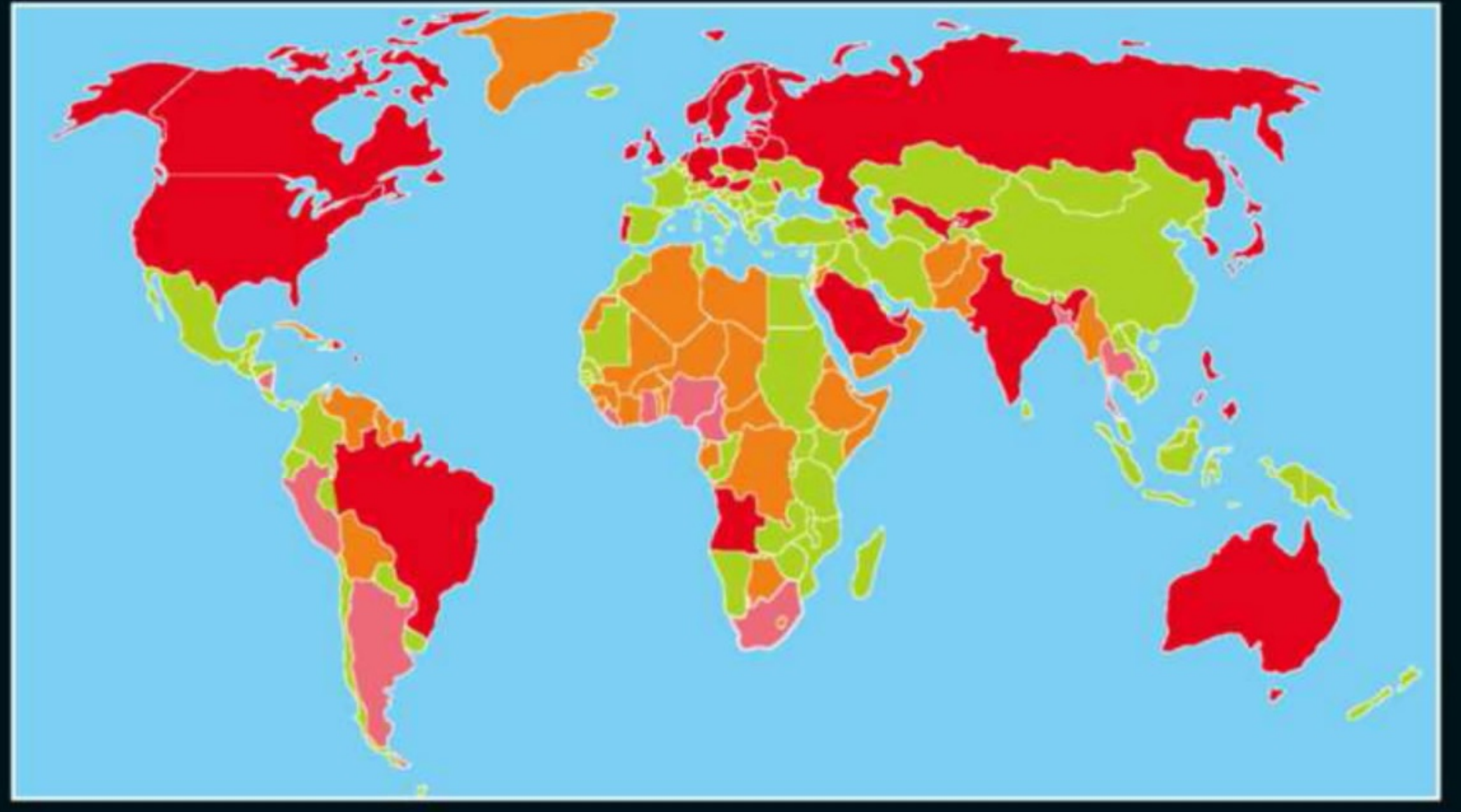
Another way 4G appears faster is by having less latency – the time it takes to get a response to your instruction. By reducing this to well below the standard for real-time (a latency of up to 50 milliseconds), you get snappier responses online plus no lag or echo when making a phone call. Finally, 4G makes better use of the part of the electromagnetic spectrum that it occupies, with revolutionary new encoding techniques allowing more data to be pushed along every hertz of its bandwidth.

A look at world coverage

This is a current map of mobile network coverage across the planet. Note that '4G' is a marketing term and not all 4G networks are the same, so those countries in pink either have the slower WiMAX and HSPA+ standards, or are in the process of upgrading to LTE.

Key

- 4G (LTE/WiMAX/HSPA+)
- 3G (850/1,900/2,100)
- GSM



Generally, 4G mobile users can regularly expect to get mobile network download speeds in excess of ten megabits per second (Mbps) or more, which is typical of a home internet connection and many times faster than a 3G connection – even on a really good day. With improving infrastructure that could be significantly faster though; the limits for some 4G systems run to 50Mbps and beyond.

The three main flavours 4G comes in are HSPA+ (High Speed Packet Access), WiMAX – which is an evolution of a wireless home broadband system used in North America for remote locations, and 4G LTE (Long Term Evolution). This latter protocol is fastest of the three and theoretically can be upscaled quite cheaply to be even speedier.

Your 4G mobile phone contains 2G and 3G mobile networking chips too, and that's because 4G networks are far from ubiquitous at the moment. They still rely on a mix of the

different mobile networking protocols to send and receive data, which is especially important in regions where there is no 4G coverage, which would be complete 'dead zones' for 4G mobile phone users otherwise.

Probably the coolest thing about 4G mobile networks is that they are much more than a sum of their component parts. 4G is capable of sending and receiving data at significantly higher rates than previous generations, compensating for power cuts and congestion by rerouting data through alternative routes – and doing all this intelligently without human help.

But not all of the technology that goes into 4G is new or particularly revolutionary. You could say it's simply the inevitable result of increased demand from businesses and consumers, combined with the advanced smartphone technology network providers can now take advantage of... But we still think it's an amazing technological leap all the same.

Against the clock: 3G vs 4G

We pitch a typical 3G network connection against 4G LTE to see how they compare when completing a few everyday tasks

	Download a 20MB game	Stream music	Stream an HD video	Post a photo to Facebook	Watch a YouTube video
4G	<25 seconds	<1-second buffer (with no playback buffering)	<30-second buffer (with no playback rebuffering)	<1 second	<1-second buffer (with no rebuffering)
3G	<3 minutes	<10-second buffer (with some playback buffering)	1-5-minute buffer (with playback rebuffering)	<25 seconds	<20-second buffer (with some rebuffering)

1894

Sir Oliver Lodge (right) first transmitted radio signals to reveal their potential for communication.



1946

The first truly mobile calls were placed from pricey radio systems installed into cars in NYC.

1983

The world's first 1G mobile phone network is launched in Chicago, IL, USA.



1991

2G mobile networks are introduced and mobile phone use rapidly starts to snowball.

2012

EE's 4G service goes live in 11 UK cities, including London, Manchester and Cardiff.

DID YOU KNOW? The first mobile network set up by AT&T in 1947 linked a VHF radio system to the telephone network

Inside a 4G mobile phone

The iPhone 5, the sixth-generation Apple smartphone, was one of the first to include superfast mobile broadband in the form of LTE network compatibility. It is, of course, compatible with 3G and earlier technologies too, which is just as well for the UK in particular because it went on sale in Britain two months before EE (Everything Everywhere) 'switched on' its LTE 4G mobile network. The iPhone 5 features six microchips dedicated to the various mobile frequencies and standards, including the latest LTE bandwidth, FM radio frequencies and Wi-Fi.

Radio transceiver

This transceiver grants FM radio reception and transmission.

LTE module

The Avago dual-band LTE duplexer gives the iPhone 5 all-important access to the LTE 4G bandwidth.

GSM power amplifier

This Skyworks chip lets the phone use earlier-generation mobile network standards.

CDMA power amplifier

Several 3G bandwidths come courtesy of this Skyworks chip.

UMTS band chip

This TriQuint power amplifier and duplexer (two-way communications device) provides access to more 3G bandwidths.

Band 13 power amplifier

The Band 13 Avago chip lets the user tap into the lower end of LTE's bandwidth.

What's on the horizon for 4G networks?



EE's CTO, Fotis Karonis, talks about the rise of 4G

What has Everything Everywhere (EE) done to upgrade its network to 4G?

We have rolled out new equipment – eNodeB – that supports both 2G and 4G, improving the performance of our 2G network and enabling the rollout of 4G. We have also upgraded the backhaul from the 4G sites to enable the high speeds available in LTE. We have deployed new network equipment (evolved packet core, or EPC) in the core network to manage the 4G access network, and to support delivery of new services in the future. To introduce double-speed 4G, we have doubled the amount of 1,800MHz spectrum allocated to 4G services; this will support real-world speeds in excess of 80Mbps.

What did you buy at the 4G auction?

We successfully won 2 x 5MHz of 800MHz spectrum, and 2 x 35MHz lots of 2.6GHz spectrum. These successful acquisitions supported our existing portfolio of 1,800MHz and 2.1GHz spectrum, ensuring that EE has 36 per cent of UK airwaves.

What difference will 4G make to the average smartphone user?

4G provides speeds that are five times faster than current 3G networks and our new double-speed 4G will double the average speeds for 4GEE customers to more than 20Mbps. 4G makes downloading films and music, and uploading to Facebook, Twitter and YouTube unbelievably quick, and it makes video calling a seamless experience too.

How long before the world goes 4G?

We're seeing a [wave] of 'superphones' being released. These devices are being built for 4G, and only a 4G network can get the very best out of them. The deployment of 4G networks around the world has moved at incredible speed as operators look to meet the huge demand for data-rich services. This trend will not slow down – we know from our own customers that when they try 4G they don't ever want to go back to older network technologies.

What devices will 4G enhance?

Mobile phones

The biggest uptake for 4G will obviously be the mobile phone market, but initially only a handful of the latest smartphones will include the 4G hardware necessary to tap into the correct frequency.

Laptops

For a portable bandwidth that competes with the kind you would get at home, a laptop can be connected to a 4G network using a 4G USB internet dongle for speedy web access while out and about.

Tablets

There are already 4G tablet devices available like the Samsung Galaxy Note 10.1 LTE, the Nexus 7 by Google or the iPad 4 (aka new iPad). Unlike laptops their 4G hardware is integrated into the device.

Games consoles

Online gaming in portable games consoles will benefit from 4G tech in much the same way as multimedia messaging. A mobile 4G hotspot could even replace home broadband one day.



Comet storms

Discover how these icy rocks once rained down on the Solar System – and why another comet storm is on the cards

A comet's ion tail can extend for 150 million kilometres (93 million miles) – about the distance from the Sun to the Earth – making them the longest objects in the Solar System.

DID YOU KNOW? In late-2013 C/2012 S1 (aka Comet ISON) could light up our night skies as it rounds the Sun



Around 4 billion years ago, our Solar System was just beginning to settle down after its very turbulent genesis. The dust and gas surrounding the Sun had formed into the eight major planets, and in turn the planets were starting to stabilise in their orbits.

However, at some point around this time, something caused a huge comet storm in the Solar System. Over a period of about 200 million years – known as the Late Heavy Bombardment (LHB) – the planets and their moons were pelted by comets and other rocky objects from the outer edges of the Solar System. This comet storm is believed to be responsible for many of the craters we see on bodies like the Moon today, and could even have been the progenitor of life on Earth.

One of the key pieces of evidence we have for the LHB period was discovered during the Apollo missions. Lunar astronauts returned samples of rock which suggested that most impact melt rock on the Moon formed within a short period of time 4-3.8 billion years ago. While it's not conclusive, it's the best evidence we have that indicates a blitz of comets in our young planetary system.

The exact cause of this cosmic strike, however, is up for debate. The most likely theory is that the gas giants – mainly Jupiter and Saturn – migrated slightly in their orbits. This would have made the outer Solar System highly unstable, either pulling comets in from the outer reaches or from a now depleted inner band of the Asteroid Belt.

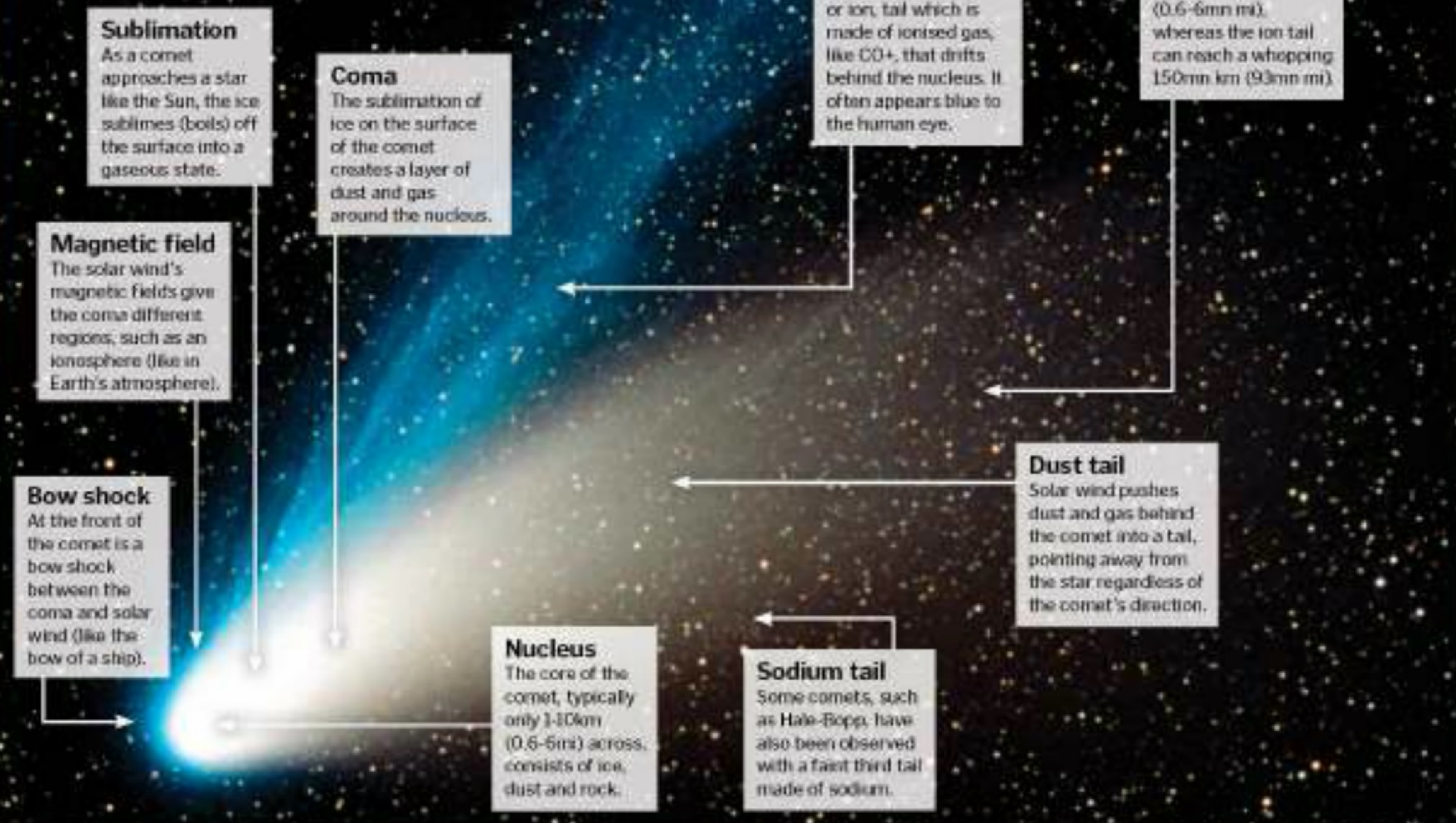
Another possibility is that the gas giants Uranus and Neptune formed much more slowly than the other planets, which would have meant that the outer Solar System had a relatively low density of material until they developed, allowing more rogue objects to make their way towards the Sun. It is the former theory, however, that carries more weight with space scientists at this time.

What we do know for certain is that something must have caused a sudden barrage of comets to enter the Solar System, and our current understanding is that there are potentially billions more with the potential to once again cause havoc.

Comets originate from one of two places: the Kuiper Belt and the Oort Cloud. The former is a region of space beyond Neptune, between 30 and 50 AU from the Sun (one astronomical unit – AU – is the

Cometary structure

From nucleus to tail, get to know a comet's makeup





▶ distance from Earth to the Sun), which contains many small bodies left over from the formation of the Solar System. It's a bit like the Asteroid Belt, but up to 200 times more massive, and unlike the Asteroid Belt it also plays host to comets. Those that come from the Kuiper Belt are known as short-period comets, like Halley's. This means that they typically swing through the Solar System on orbital periods no longer than 200 years.

By comparison, the Oort Cloud is much farther away, about 50,000 AU (or 0.8 light years) from the Sun. It is thought to be the starting point of long-period comets, like Hale-Bopp – those that pass through the Solar System with orbital periods in the thousands of years, or possibly their path is so elliptical that they never return. We haven't ever directly observed this cloud, but the appearance of long-period comets from seemingly all portions of the sky suggests there must be some distant reservoir of these objects out in the galaxy.

The other major difference between these two regions is the number of objects they contain. While the Kuiper Belt is thought to play host to hundreds of thousands to millions of these icy rocks (known as Kuiper Belt objects, or KBOs), the Oort Cloud could be home to billions.

What this means for us is that these two vast regions have enough firepower to decimate pretty much every celestial body in the Solar System, but thankfully most of their objects are in stable positions, and only occasionally do a few venture into the Solar System. As explained earlier, this is what is thought to have happened 4 billion years ago but on a much larger scale; something disturbed the outer Solar System, sending a comet storm careering inwards and pummeling anything in its path. But could we really experience another period of bombardment like this?

Our Sun is believed to pass about 200,000 AU from another star every 2 million years, which may be the cause of stray comets being flung into the Solar System from the Kuiper Belt and the Oort Cloud. 1.5 million years from now, however, an orange dwarf star known as Gliese 710 could pass considerably closer to the Sun – possibly as near as 50,000 AU – which would see it pass through the Oort Cloud. Such an event, if it did occur, would be

Comet orbits

At the edge of the Solar System lurk two regions of comets: the Kuiper Belt and the Oort Cloud. Occasionally, a comet from one of these areas is nudged into an elliptical orbit with the Sun and passes into the inner Solar System. In this illustration we show what happens as it nears the Sun...

4. Direction

Both the dust and ion tails always point away from the Sun (to differing degrees) as their direction is dictated by the solar wind.

3. Tail emerges

Once within Earth's orbit, a gas tail forms behind the comet and streams outwards.

5. Escape

If the comet survives its encounter with the Sun, it will continue on its orbit and return again.

2. Coma formation

At a distance five times that between Earth and the Sun (5 AU), a coma of gas begins to develop around the comet.

1. Warming

As the comet approaches the Sun it begins to warm and ice sublimates (ie turns from solid to vapour) at its surface.

6. Cooling

As the comet moves away from the Sun the solar heating diminishes and the tails disappear.

Comets over time

A few milestone events involving comets on a crash course with other bodies

~4bn years ago (BYA)

LHB period

Possibly the interaction of the gas giants fires comets into the inner Solar System, instigating the Late Heavy Bombardment (LHB).

3.8 BYA

Bombardment ends

After 200 million years the bombardment of the Solar System ends, with most comets now remaining in the distant Oort Cloud.

July 1994

Shoemaker-Levy 9

This stray comet breaks apart and impacts Jupiter, the first such event witnessed by humans (pictured right).



AMAZING VIDEO!

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Watch a comet colliding into the Sun now!

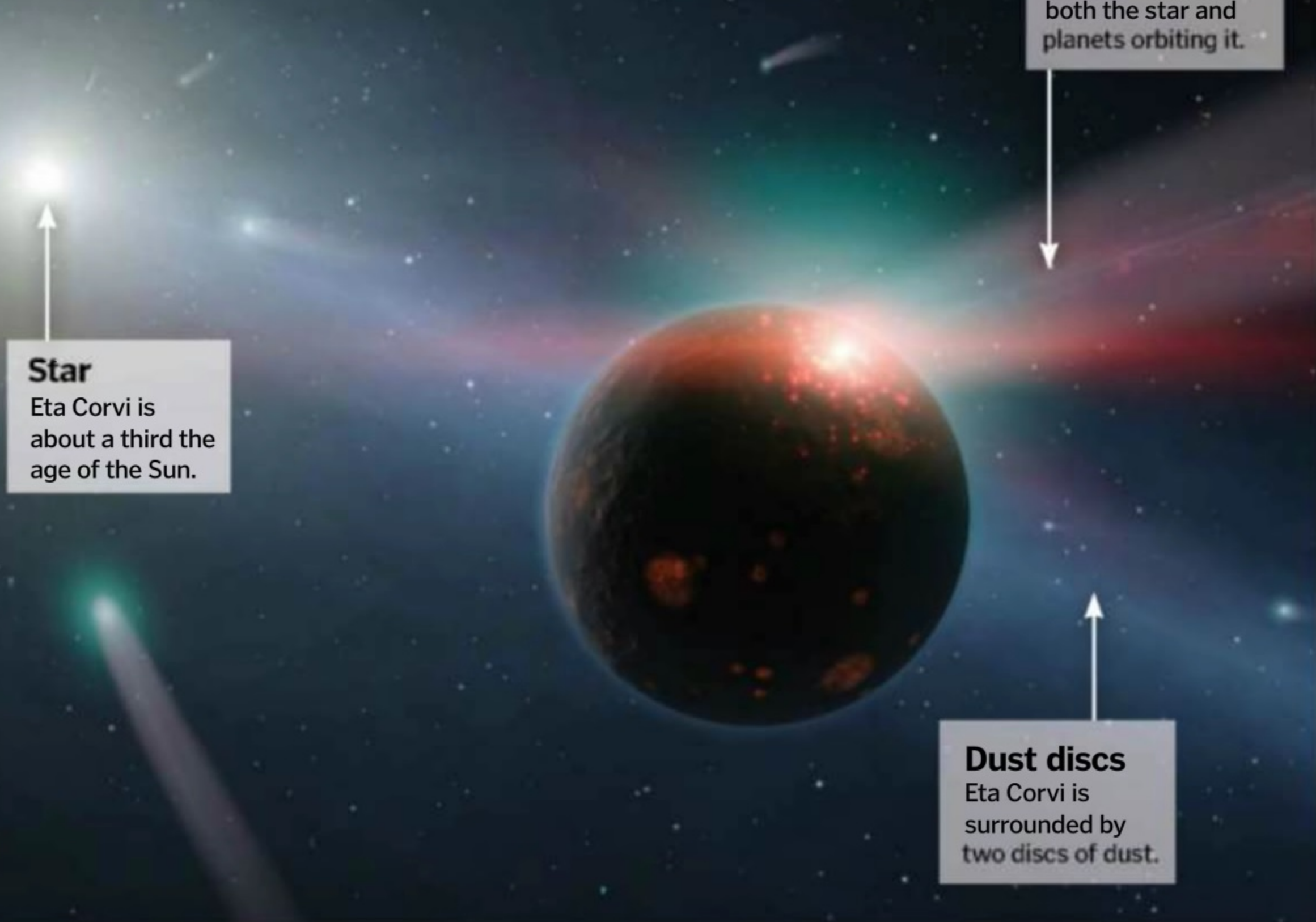
www.howitworksdaily.com



DID YOU KNOW? We know of a few thousand comets, but there could be billions more in the outer Solar System

Extrasolar comet storm

Almost 60 light years away around the star Eta Corvi, NASA's Spitzer Space Telescope has detected what appears to be a comet storm that bears similarities to the Late Heavy Bombardment period thought to have occurred in our formative Solar System. Continued observations could yield vital clues to our own beginnings.



catastrophic. The gravitational pull of the star would send the Oort Cloud into disarray, and it's likely that many objects would be sent into the Solar System. After a close encounter such as this, another period of comet showers is likely. If the Oort Cloud is as vast and populated as we think, then we are always going to be under threat from some gravitational disturbance that could push those icy bodies towards our world.

It's not just in our Solar System where comet storms are thought to have occurred though. In July 2012, NASA's Spitzer Space Telescope detected signs of a storm similar to the LHB period in a young alien planetary system around the star Eta Corvi about 60 light years from us. The telescope spotted a band of dust around this bright star close enough to be near any planets in the system, which suggests that some sort of impact occurred in this 1-billion-year-old extrasolar system. It is likely that this system is right now undergoing the same sort of comet storm we experienced 4 billion years ago.

Of course, aside from these massive comet storms where thousands of objects enter a system at any one time, we're also susceptible to much smaller 'flurries'. When a comet enters the Solar System, the heat and gravitational pull of the Sun can cause it to break apart. If a comet approaches Earth, it will either burn up in the atmosphere or, in rare cases, hit the surface. We know of several such impact events that were likely the result of comets, including the impact that ended the age of the dinosaurs 65 million years ago and the Tunguska event in 1908 when a comet exploded over part of Russia and flattened an unpopulated area 2,150 square kilometres (830 square miles) in size.

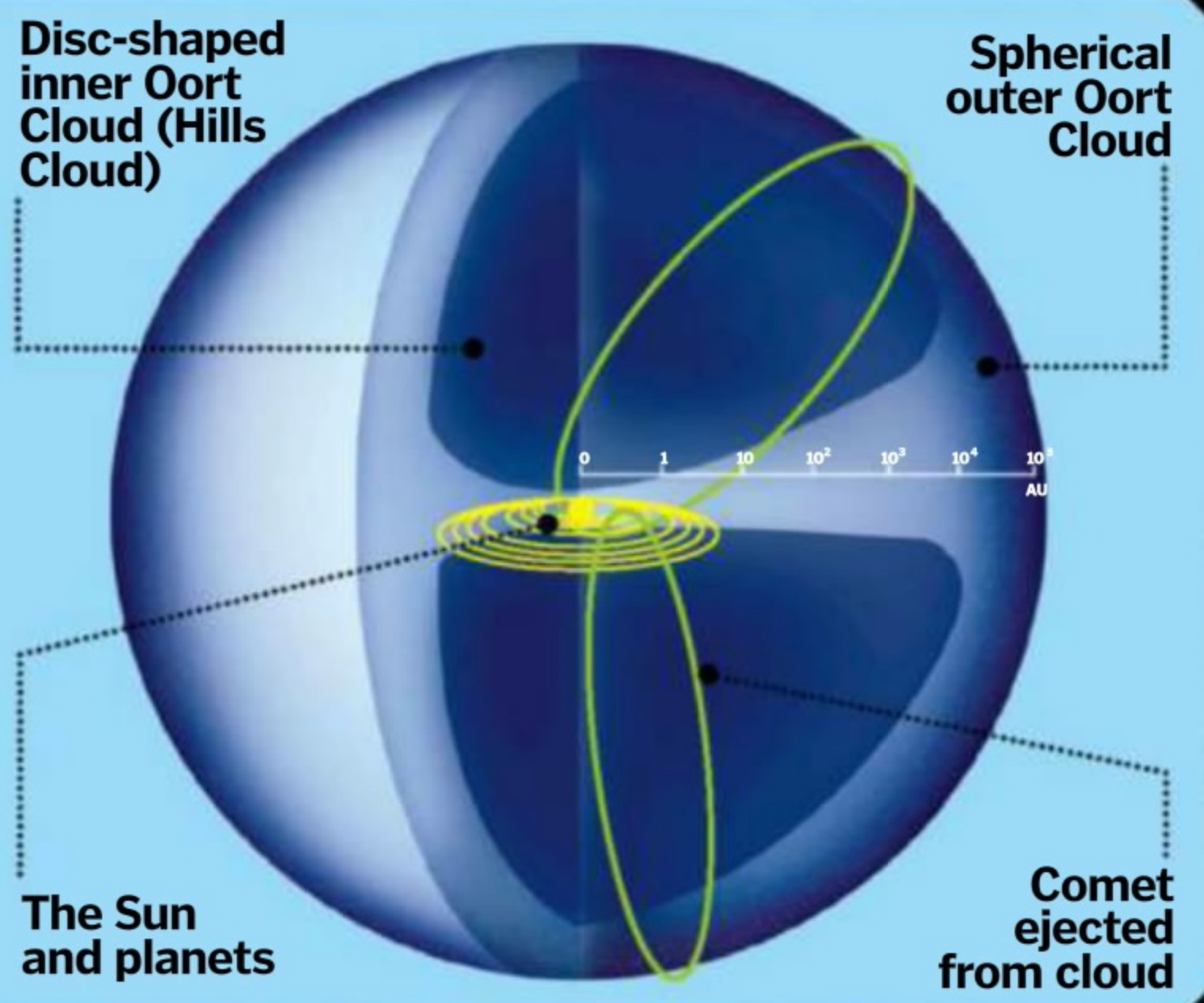
Most meteor showers seen from Earth are also the result of comets. They are usually caused by Earth passing through the tail of a comet, with its fragments then burning up in the atmosphere. Such events are minuscule compared to the LHB, but they're a constant reminder of comets' presence.

Owing to the number of comets, and their speed as they approach the Sun, it's impossible for us to track every single one. However, we are able to keep an eye on most that enter the inner Solar System, highlighted by the arrival of Comet ISON in November 2013 which could outshine the Moon in our night skies as it grazes the Sun.

By continuing to observe extrasolar systems though, we might be able to glean more information about the comet storm that pounded our Solar System 4 billion years ago during the Late Heavy Bombardment. Further evidence of this event could provide us with vital clues to our past, as well as give us an insight into what might happen to our Solar System in the future.

What is the Oort Cloud?

Approximately 50,000 times farther than the orbit of Earth around the Sun - or almost a light year away - it is thought that there is a region of rocks made of ices like water, ammonia and methane surrounding the Solar System called the Oort Cloud. This area, a quarter of the distance to the next nearest star Proxima Centauri, could be home to billions of comets left over from the formation of the Solar System and ejected into its outer reaches. Periodically a comet will enter the Solar System, and most of these are believed to originate in this vast region of our galaxy.



December 2010

Solar comets
Astronomers detect 25 comets diving into the Sun over just nine days.

July 2012

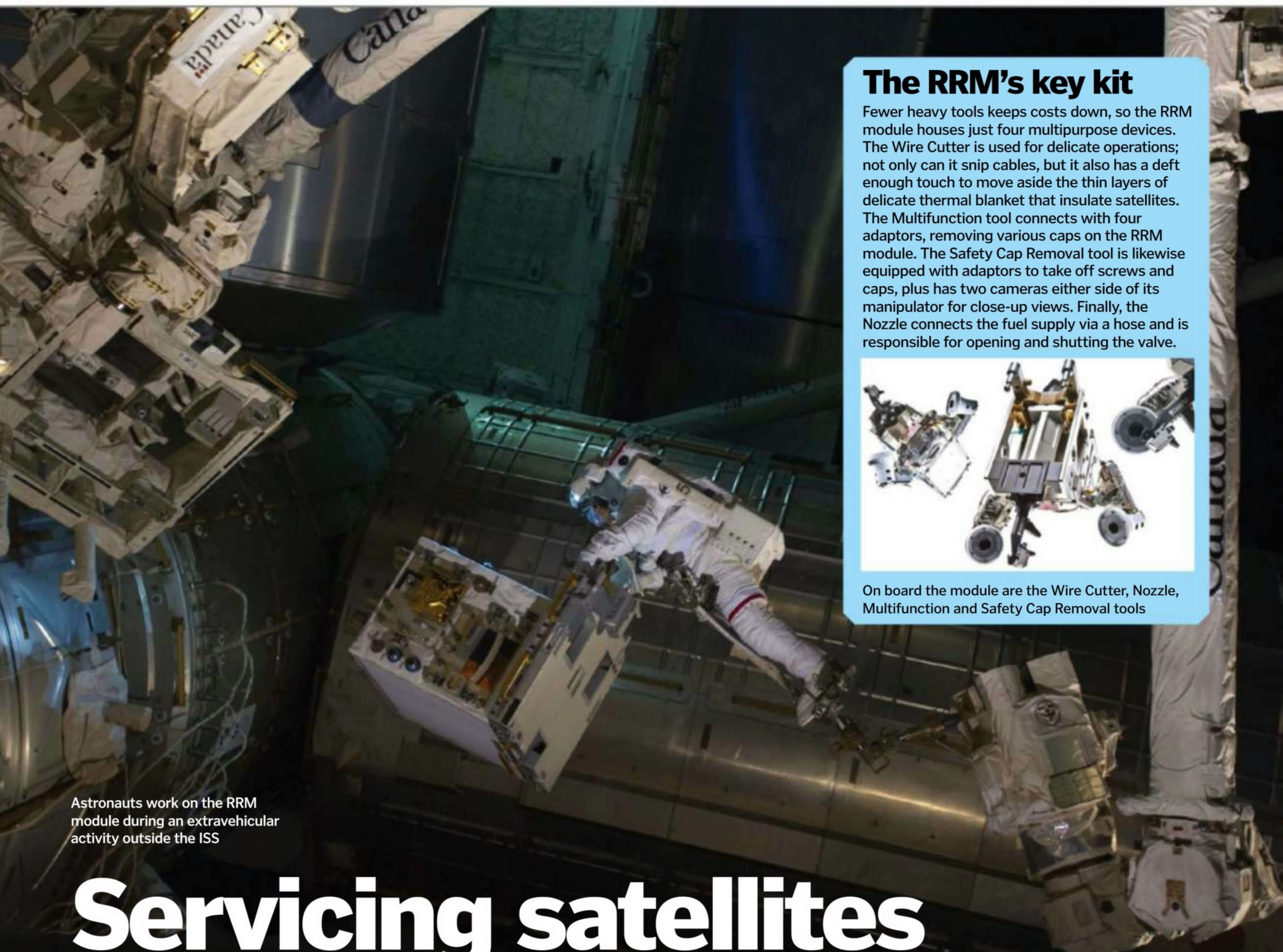
Extrasolar comet storm
NASA's Spitzer Space Telescope finds evidence of a comet shower around the star Eta Corvi, 60 light years away.

1.5mn years from now

Future bombardment?
In 1.5 million years or so, a rogue star like Gliese 710 could send comets hurtling into the Solar System once more from the Oort Cloud.



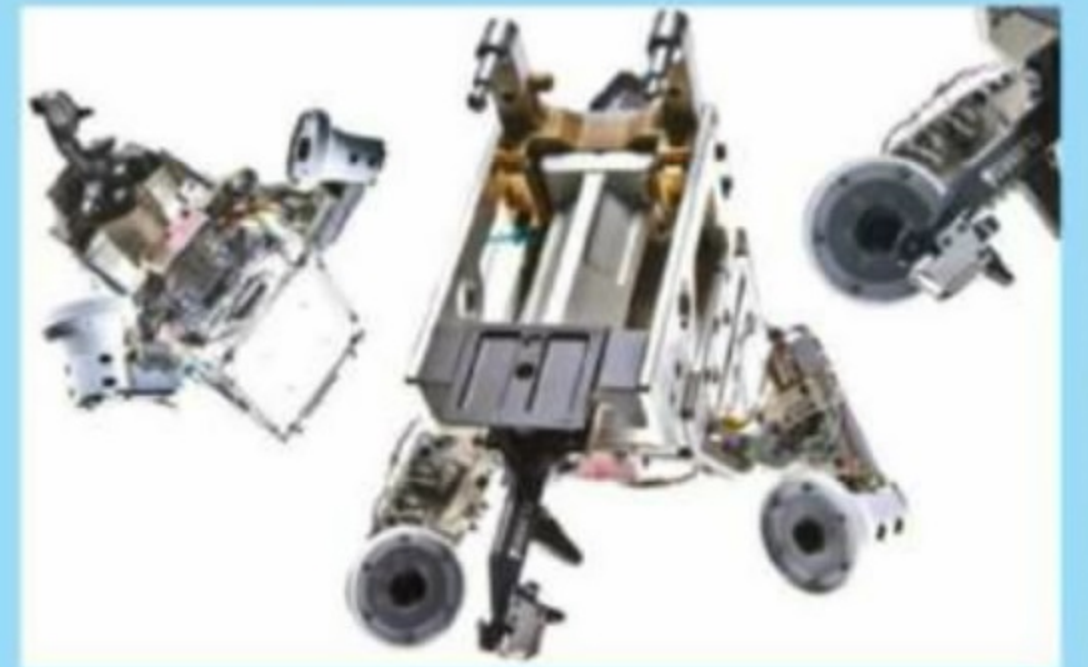
“This mission aims to demonstrate the viability of robotically maintaining spacecraft while in orbit”



Astronauts work on the RRM module during an extravehicular activity outside the ISS

The RRM's key kit


Fewer heavy tools keeps costs down, so the RRM module houses just four multipurpose devices. The Wire Cutter is used for delicate operations; not only can it snip cables, but it also has a deft enough touch to move aside the thin layers of delicate thermal blanket that insulate satellites. The Multifunction tool connects with four adaptors, removing various caps on the RRM module. The Safety Cap Removal tool is likewise equipped with adaptors to take off screws and caps, plus has two cameras either side of its manipulator for close-up views. Finally, the Nozzle connects the fuel supply via a hose and is responsible for opening and shutting the valve.



On board the module are the Wire Cutter, Nozzle, Multifunction and Safety Cap Removal tools


Servicing satellites

How are satellites refuelled and repaired while drifting out in Earth's orbit?

 At this moment satellites aren't actually serviced in space, simply because it's too difficult, expensive and risky to maintain them up there. These machines are sent into orbit with crossed fingers and, if they're lucky enough to survive until their fuel runs out, at best they become a floating relic and, at worst, a liability to other projects. But NASA's Robotic Refueling Mission (RRM) is seeking to change all that.

Currently in development, this pioneering mission aims to demonstrate the viability of robotically maintaining spacecraft while in orbit, using the International Space Station as a platform. On board, the two arms of the ISS's

Canadian robot Dextre will act as the technician, remotely controlled from Earth to approach its target in orbit, then reach into the RRM module and pick out one of four versatile tools for mending an ailing satellite. This module is very compact – around the size of a washing machine, weighs in at 250 kilograms (550 pounds) and will be loaded with 1.7 litres (0.45 gallons) of liquid ethanol fuel, to ascertain the viability of refuelling in orbit.

The RRM mission is about halfway through its tasks and is scheduled to finish before summer 2013. A dedicated refuelling craft – effectively a flying petrol station – is also in development and is slated for launch in 2015. 

Thinking ahead

You might wonder why NASA is going to all this trouble just to prove that it's possible to refuel and fix satellites in space. Why go to this much effort when the disposable nature of satellites has been a perfectly acceptable model for decades? Technology has developed to the point now where refuelling and repairing satellites is becoming more cost effective, adding years to the life of existing satellites at a fraction of the price of another launch. Not only could satellite servicing via a remote robotic station in orbit be economical for an operator, but for NASA it will enable safer and less expensive maintenance on its own orbital craft, as well as the ISS. It's also a step towards clearing up the masses of space junk already drifting in the geosynchronous zone.

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DID YOU KNOW? As well as devising the laws of planetary motion, Kepler also designed an improved refracting telescope

Planetary motion

What laws govern celestial mechanics and how do they affect space exploration?

Among 17th-century German astronomer Johannes Kepler's impressive list of groundbreaking discoveries, arguably his greatest achievement was to formulate the rules of planetary motion. He laid down the precise laws that have since become the foundation of celestial mechanics – the science behind predicting the orbits of planets, stars and all celestial bodies.

There are three laws of planetary motion and originally Kepler was tasked by fellow astronomer Tycho Brahe with verifying the observations he had made of Mars's orbit. Using data gleaned from these studies, Kepler announced his first and second laws of planetary motion four years after Brahe's death in 1605, followed by his third law in 1619.

The first law states that all planets move around the Sun in elliptical orbits with the Sun as one of the focus points. The second law states that a radius vector (or line) joining any planet to the Sun sweeps out equal areas in an equal length of time. The third (harmonic) law states that the square of the sidereal period (a full revolution) of a planet is proportional to the cube of its mean distance from the Sun.

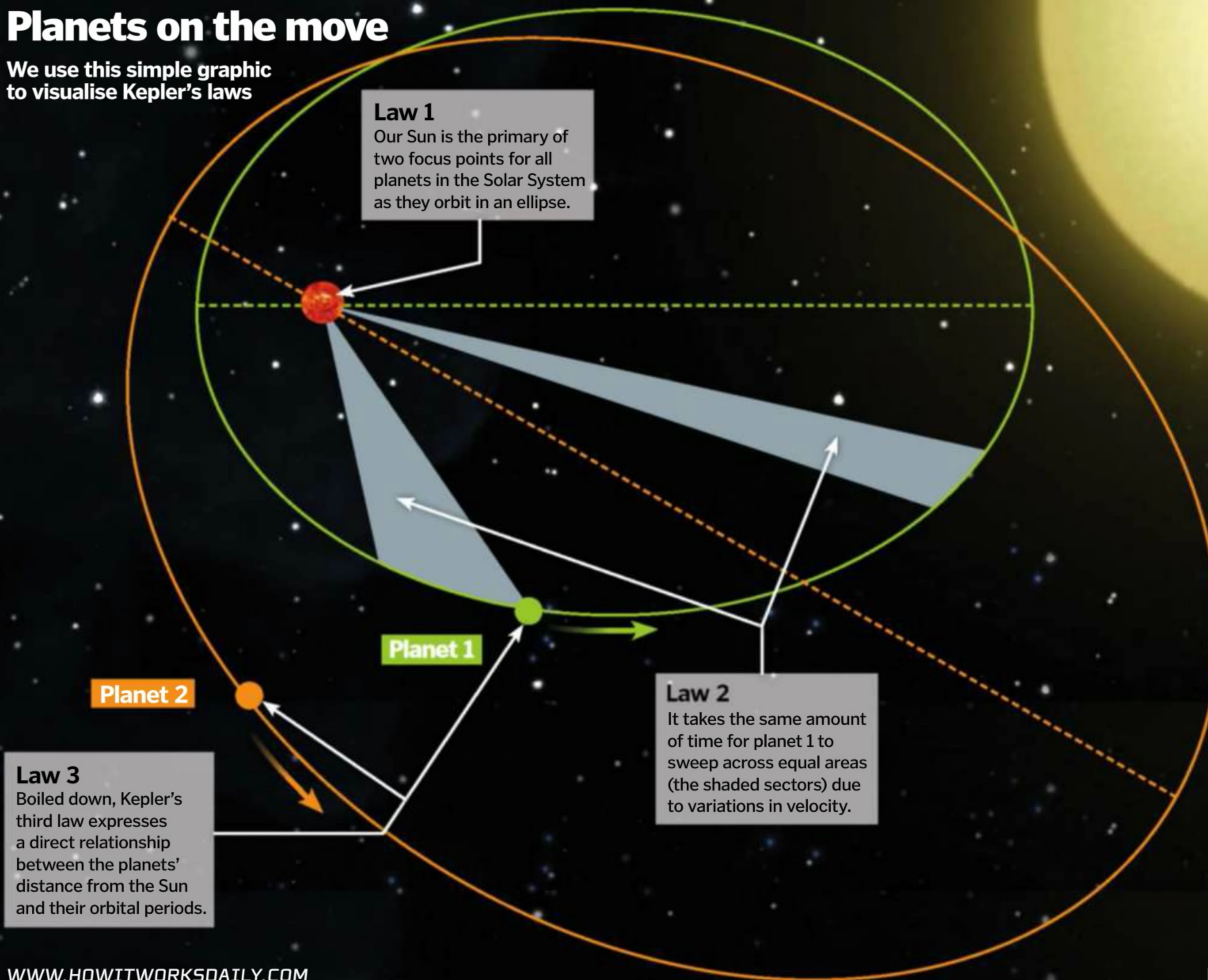
This sounds complicated and it was certainly no cinch for Kepler to formulate, however it remains a very elegant solution for calculating the positions of the planets. Perhaps the most amazing thing about Kepler's discovery is that his initial two laws were founded *prior* to the first refracting telescopes used by pioneering astronomers like Galileo Galilei.

Kepler today

Kepler himself didn't figure out why his laws were correct and it took Isaac Newton's law of gravitation to provide a full understanding of planetary motion. Kepler's laws were based on his observations of the planets in orbit around the Sun, but using Newton's gravity they have since proved broadly applicable to any relatively light object orbiting a massive one. Tracking the positions and orbits of the Solar System's planets today is fairly mundane, but planetary motion and Newtonian gravity provide the fundamentals to predict movements of both natural and artificial satellites – particularly of deep-space probes like those used in the Voyager and Cassini missions. Both of these took energy from the gravity of planets like Jupiter to 'slingshot' the craft huge distances. Without the help of Kepler and Newton's laws, working out their trajectories would have been impossible.

Planets on the move

We use this simple graphic to visualise Kepler's laws





“Due to the design of the Pioneer craft, more radiation was released from the front end than the back”

The Pioneer anomaly

Why did the Pioneer 10 and 11 spacecraft unexpectedly start to slow down?



Pioneer 10 and 11 were robotic space probes sent into the cosmos in the Seventies on missions to Jupiter and Saturn. They were designed to fly by the gas giants before venturing out of the Solar System.

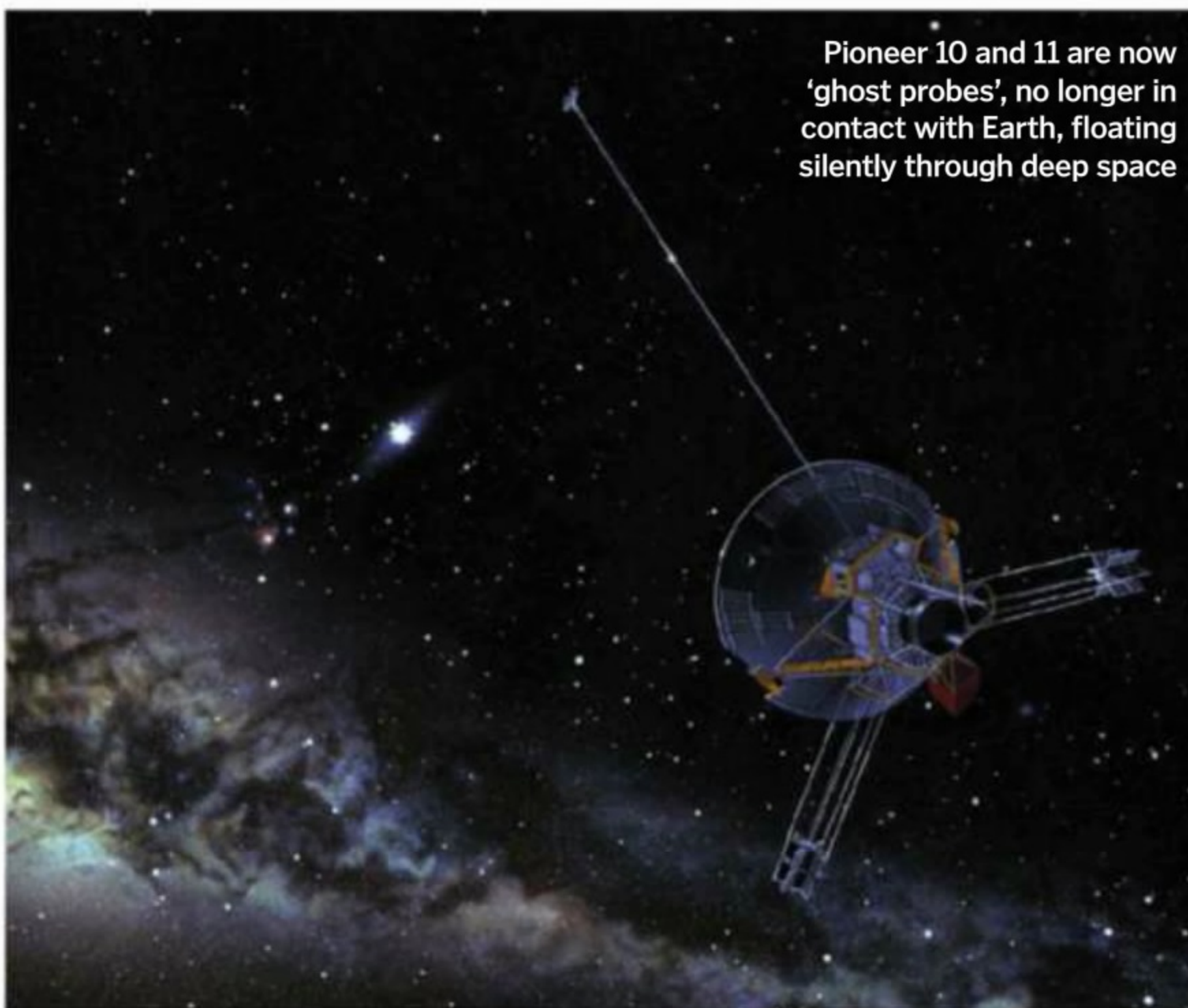
It was always assumed that the craft would slow down as they travelled through the Solar System because of the pull of gravity from the Sun. However, their radio signals showed that they were thousands of kilometres behind their expected position; in other words, they were slowing down much faster than NASA's Pioneer operators had anticipated.

The anomaly was the result of thermal recoil force. In the vacuum of space, where there are no atoms to transfer energy to, the only way that excess heat can be dissipated is by radiation. Electromagnetic radiation exerts pressure and, if

there is uneven release of radiation from different sides of the probe, then the pressure difference is sufficient to alter its trajectory. Due to the design of the Pioneer spacecraft, more radiation was released from the front end than the back, hampering their escape from the Solar System. ✿

So where is Pioneer 10 now?

In September 2012, Pioneer 10 was around 16 billion kilometres (10 billion miles) from Earth and heading in the direction of the constellation Taurus, 68 light years away. It is travelling at about 45,000 kilometres (28,000 miles) per hour. Pioneer 10 was the first man-made object to pass the main planets of the Solar System, but the Voyager 1 spacecraft has since overtaken it to become the most distant man-made object in space; it is currently on the verge of crossing into interstellar space.



Pioneer 10 and 11 are now 'ghost probes', no longer in contact with Earth, floating silently through deep space



The Gemini 12 spacecraft conducted early tether experiments. It was connected to a target vehicle by Buzz Aldrin during a two-hour spacewalk

Tethers in space

Cables linking spacecraft allow them to be towed, spun and flung, and can generate power and propulsion too



Space tethers can extend for hundreds of kilometres and must be able to endure a variety of threats from space debris, bombardment by ultraviolet radiation and atomic oxygen. This is achieved using strong yet light crystalline plastics.

Spacecraft and cargo linked by tethers are pulled apart by differences in gravitational force depending on their relative positions in space, maintaining tension on the cable. This enables the distance between objects to be stabilised or changed. Spinning tethers can be used much like a sling to fling objects through space,

or as a grappling hook to capture objects and then alter their trajectory.

Conductive copper tethers take advantage of the magnetic fields around planets to generate electrical or kinetic energy using the same principles as terrestrial generators and motors.

As the cable moves through the magnetic field a current is generated, producing electricity which can in turn power the spacecraft. Alternatively, if a current is passed through the cable it will induce a magnetic field, which will repel a planetary field, resulting in the craft's acceleration. ✿

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The supermoon phenomenon

What causes the Moon to occasionally appear bigger and brighter than usual?



The largest and most luminous Moon witnessed by Earth-based observers in 2013 will appear on 23 June at 11:32 (Universal Time). This astronomical event – known commonly as a supermoon, or more formally as perigee-syzygy – occurs on average between four and six times a year.

Because the Moon follows an elliptical orbit around the Earth its distance from our planet will vary during the lunar cycle. Twice during this 27.32-day rotation, the Moon will be closer than usual and twice it will be farther away. The farthest point from Earth in the orbit is known as the apogee, the closest point is called perigee – and the latter is up to 50,000 kilometres (31,000 miles) closer to Earth than the former.

The supermoon phenomenon we're explaining here describes the coincidence of a full Moon lunar phase at or very near to the Moon's closest approach to Earth.

The term 'supermoon' was first coined in the late-Seventies by astrologer Richard Nolle, who described it as a new or full Moon at or near its closest approach to Earth during a given orbit. According to NASA a super full Moon can appear some 14 per cent bigger and 30 per cent brighter in the night sky when it occurs within an hour of perigee. The best conditions under which to view this enlarged and dazzling lunar display is when the Moon is near the horizon. This means that familiar objects, like mountains and man-made structures, can be used as a yardstick to compare the oversized satellite.

The more intense lunar gravity at perigee also pulls high tides even higher than normal. Indeed, these perigean tides can be up to 15 centimetres (six inches) higher, depending on the local landscape. ❁



DID YOU KNOW? The Moon is being pushed away from Earth at a rate of several centimetres per year

The Moon's stages

While one half of the Moon is always lit up, the area we see is dictated by the angle of observation

Waxing gibbous

Gibbous Moons occur either side of a full Moon. The disc of a waxing gibbous grows bigger, while a waning gibbous shrinks.

Full

When the Earth is diametrically opposite the Sun, the whole surface of the Moon facing us is illuminated.

First quarter (half Moon)

Waxing crescent

During the first half of the lunar month the size of the lit area of the Moon grows (between the dark new Moon and the first half Moon). During this time the Moon is said to be waxing.

New

When between Earth and the Sun, it is known as a new Moon. At this point the side facing Earth is in complete shadow.

Last quarter (half Moon)

Waning gibbous

Occurring just after a full Moon the waning gibbous is still greater than half full of light but shrinks a little each night.

Waning crescent

The majority of a waning crescent Moon is in shadow just before the new Moon. At the equator, crescent Moons look like a smile.

Elliptical orbit in focus

The Moon appears closer to Earth because it *is* closer to Earth

Earth

The same side of the Moon is facing Earth at all times; this is known as synchronous rotation.

Moon

The Moon's path around the Earth is elliptical, so the distance between the two bodies varies across the cycle.

Perigee

When the full Moon occurs on the perigee side of the orbit, closest to Earth, the Moon will appear bigger and brighter in the sky.

Apogee

A full Moon that occurs on the apogee side of the orbit - sometimes called a micro Moon - is the point at which the Moon is farthest from us.



The world's most powerful laser

The National Ignition Facility houses the planet's biggest laser, capable of producing around 2 million joules of UV energy



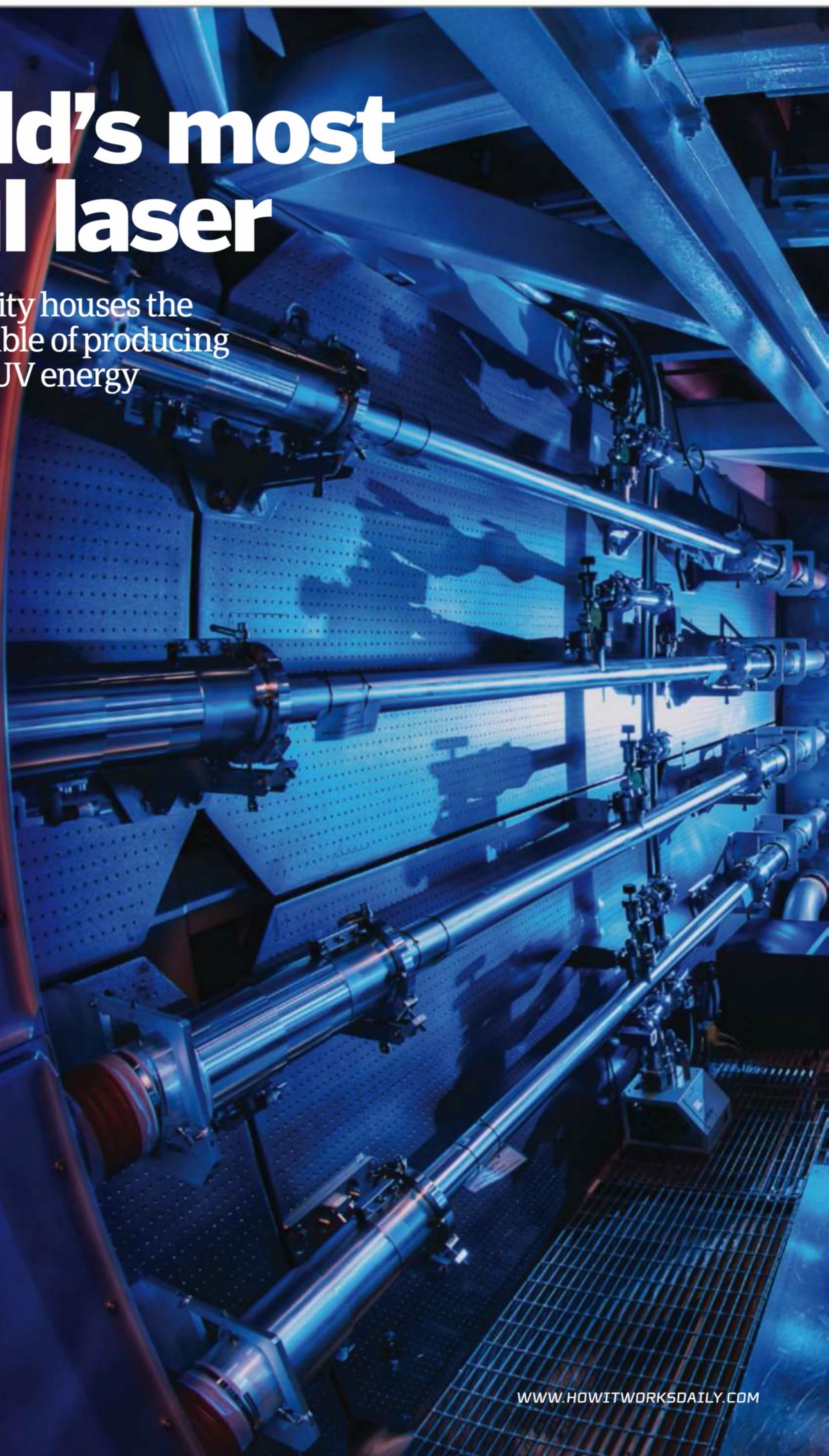
At least 60 times more powerful than its predecessors, the laser at the National Ignition Facility (NIF) in California is an impressive feat of engineering. It contains the largest optical instrument ever built, 7,500 flash-lamps, 97 kilometres (60 miles) of mirrors and fibre optics, and is roughly the size of three football pitches.

At the master oscillator of the NIF, a low-energy pulse of photons is generated using an optical fibre laser. To amplify the laser pulse it is broken down into 192 separate beams; these are then carried through fibre-optic cables to a series of amplifiers.

Powerful white flash-lamps are used to energise sheets of neodymium-impregnated phosphate glass, which energises electrons in the neodymium atoms. As the photons pass through the amplifier they cause the electrons to drop back to their 'ground state', and in the process more photons are released. The photons collide and vibrate together, creating a stream of photons all of the same wavelength and travelling in a single direction.

An optical switch in the amplifier works like a mirror and forces the photons to travel back and forth, bumping in to more electrons and producing more and more identical photons. This process boosts the power of each beam from a fraction of a joule to over 20,000 joules.

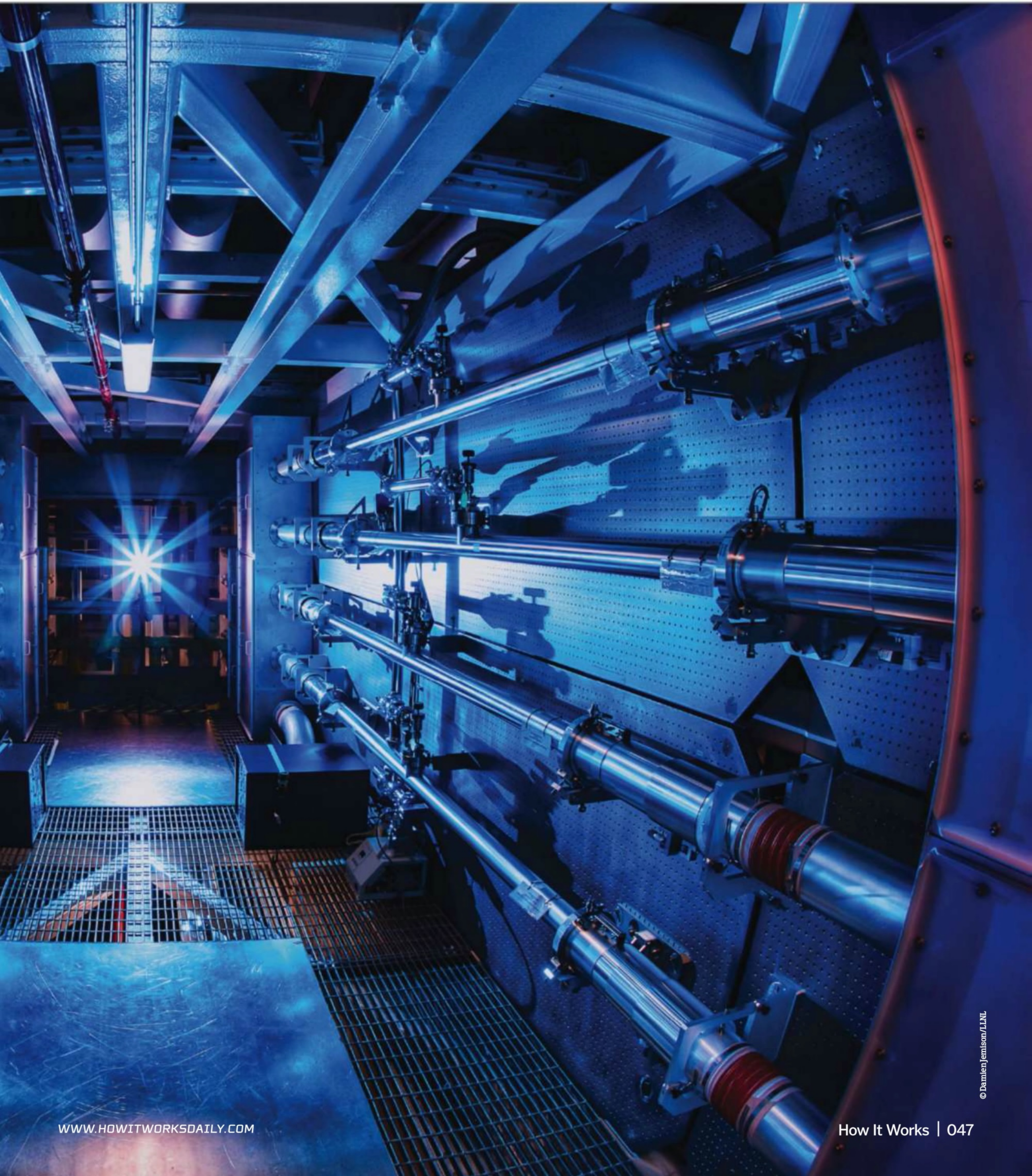
Once the beams have been amplified, two ten-storey mirrored 'switchyards' focus them into a spherical target chamber, pinpointing a target smaller than a pencil eraser. The combined power of all 192 beams heats the target to 100 million degrees Celsius (180 million degrees Fahrenheit) – more than six times hotter than the core of the Sun – and puts it under a force exceeding 100 billion atmospheres, all in less than a second. ❁



**THE
STATS**
NIF LASER

TIME **4.5 microseconds** DISTANCE TRAVELLED **1,500m** TARGET SIZE **5mm**
TARGET PRESSURE **100bn atmospheres** TARGET TEMPERATURE **100mn°C**

DID YOU KNOW? When digging the foundations for NIF, a 16,000-year-old mammoth fossil was found; it was nicknamed Niffy





“There are thousands of different stimuli that can trigger our senses, including light, heat and pressure”



Exploring the sensory system

The complex senses of the human body and how they interact is vital to the way we live day to day



The sensory system is what enables us to experience the world. It can also warn us of danger, trigger memories and protect us from damaging stimuli, such as scorching hot surfaces. The human sensory system is highly developed, with its many components detecting both physical and emotional properties of the environment. For example, it can interpret chemical molecules in the air into smells, moving molecules of sound into noises and pressure placed on the skin into touch. Indeed, some of our senses are so finely tuned they allow reactions within milliseconds of detecting a new sensation.

The five classic senses are sight, hearing, smell, taste and touch. We need senses not only to interpret the world around us, but also to function within it. Our senses enable us to modify our movements and thoughts, and sometimes they directly feed signals into muscles. The sensory nervous system that lies behind this is made up of receptors, nerves and dedicated parts of the brain.

There are thousands of different stimuli that can trigger our senses, including light, heat, chemicals in food and pressure. These ‘stimulus modalities’ are then detected by specialised receptors, which convert them into sensations such as hot and cold, tastes, images and touch. The incredible receptors – like the eyes, ears, nose, tongue and skin – have adapted over time to work seamlessly together and without having to be actively ‘switched on’.

However, sometimes the sensory system can go wrong. There are hundreds of diseases of the senses, which can have both minor effects, or a life-changing impact. For example, a blocked ear can affect your balance, or a cold your ability to smell – but these things don’t last for long.

In contrast, say, after a car accident severing the spinal cord, the damage can be permanent. There are some very specific problems that the sensory system can bring as well. After an amputation, the brain can still detect signals from the nerves that used to connect to the lost limb. These sensations

can cause excruciating pain; this particular condition is known as phantom limb syndrome.

However the sensory system is able to adapt to change, with the loss of one often leading to others being heightened. Our senses normally function to gently inhibit each other in order to moderate individual sensations. The loss of sight from blindness is thought to lead to strengthening of signals from the ears, nose and tongue. Having said this, it’s certainly not universal among the blind, being more common in people who have been blind since a young age or from birth. Similarly, some people who listen to music like to close their eyes, as they claim the loss of visual input can enhance the audio experience.

Although the human sensory system is well developed, many animals out-perform us. For example, dogs can hear much higher-pitched sounds, while sharks have a far better sense of smell – in fact, they can sniff out a single drop of blood in a million drops of water! 🌀

Which creatures can have up to a hundred eyes?

A Scallops B Spiders C Peacocks



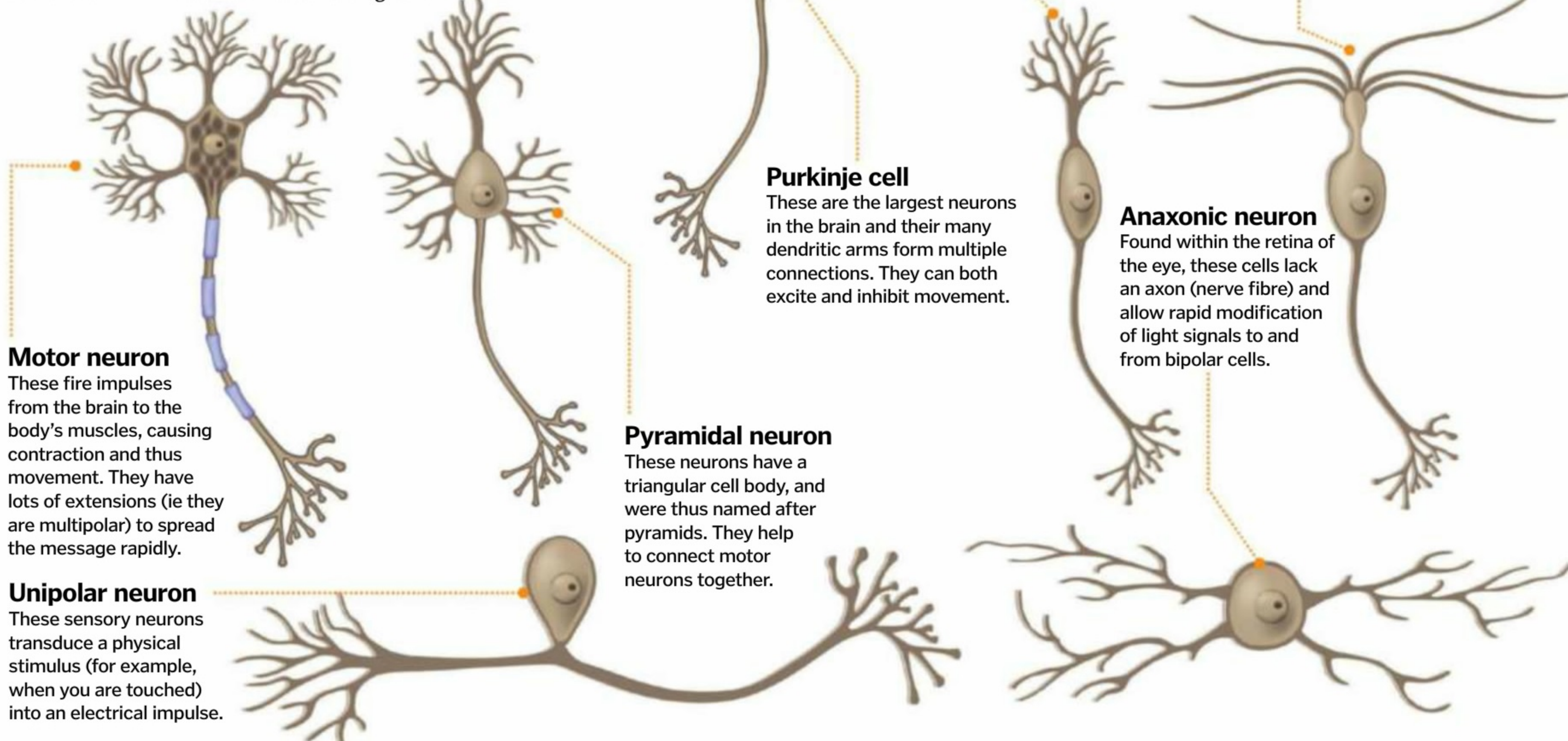
Answer:

Scallops are an underwater mollusc that amazingly can have as many as 100 eyes! Although they can't create as clear a picture as our eyes, they can detect enough light and movement to warn them of oncoming predators.

DID YOU KNOW? Taste and smell are closely linked. To test this, pinch your nose as you eat something and it will taste bland

Body's messengers

The sensory system is formed from neurons. These are specialised nerve cells which transmit signals from one end to the other - for example, from your skin to your brain. They are excitable, meaning that when stimulated to a certain electrical/chemical threshold they will fire a signal. There are many different types, and they can interconnect to affect each other's signals.



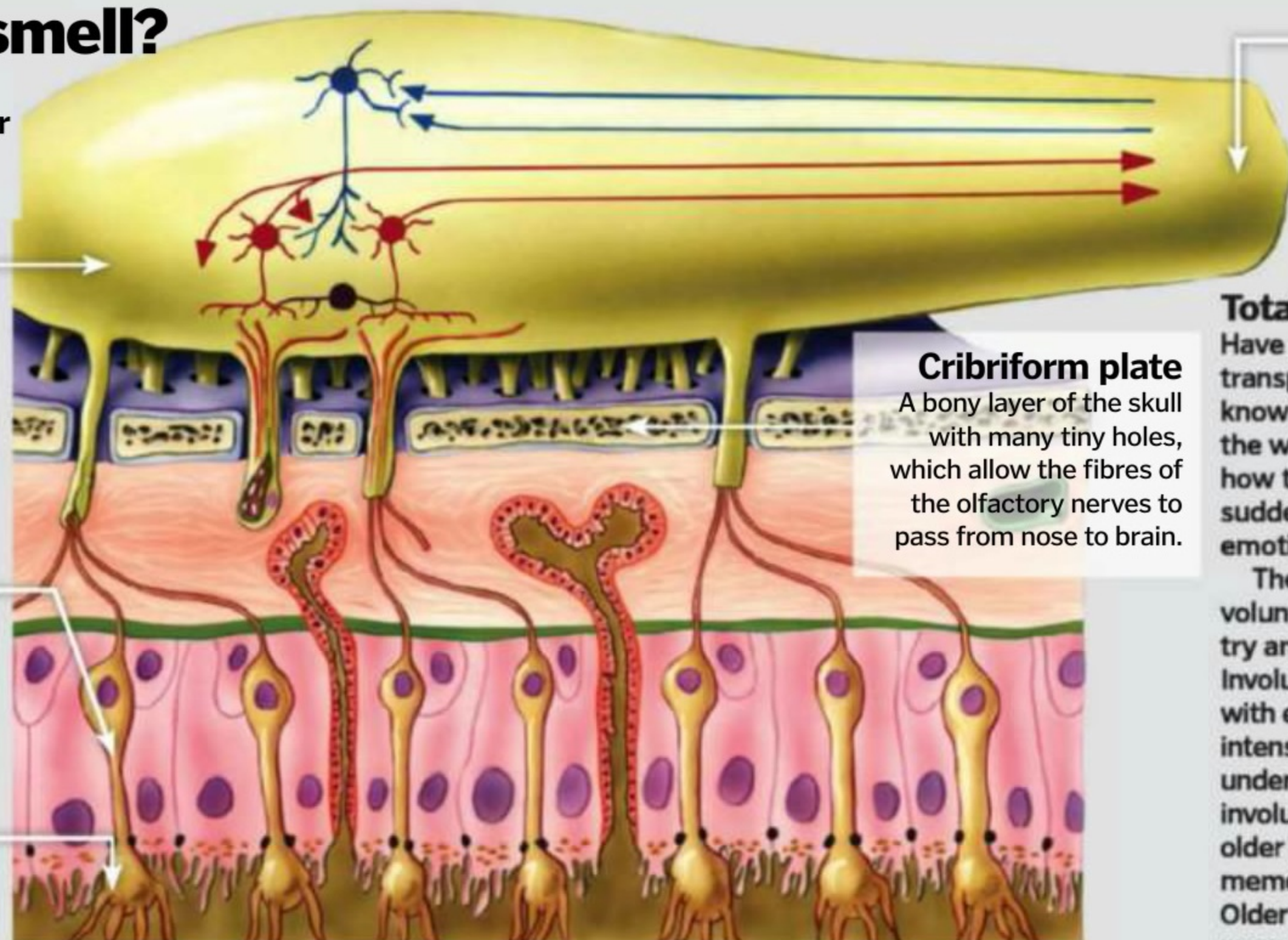
How do we smell?

Find out how our nose and brain work together to distinguish scents

Olfactory bulb
Containing many types of cell, olfactory neurons branch out of here through the cribriform plate below.

Olfactory neuron
These neurons are highly adapted to detect a wide range of different odours.

Olfactory epithelium
Lining the nasal cavity, this layer contains the long extensions of the olfactory neurons and is where chemical molecules in air trigger an electric impulse.



Olfactory nerve
New signals are rapidly transmitted via the olfactory nerve to the brain, which collates the data with sight and taste.

Total recall
Have you ever smelt something that transported you back in time? This is known as the Madeleine effect because the writer Marcel Proust once described how the scent of a madeleine cake suddenly evoked strong memories and emotions from his childhood. The opposite type of recall is voluntary memory, where you actively try and remember a certain event. Involuntary memories are intertwined with emotion and so are often the more intense of the two. Younger children under the age of ten have stronger involuntary memory capabilities than older people, which is why these memories thrust you back to childhood. Older children use voluntary memory more often, eg when revising for exams.



"Sights take on smells, a conversation can take on tastes, and music can feel textured"



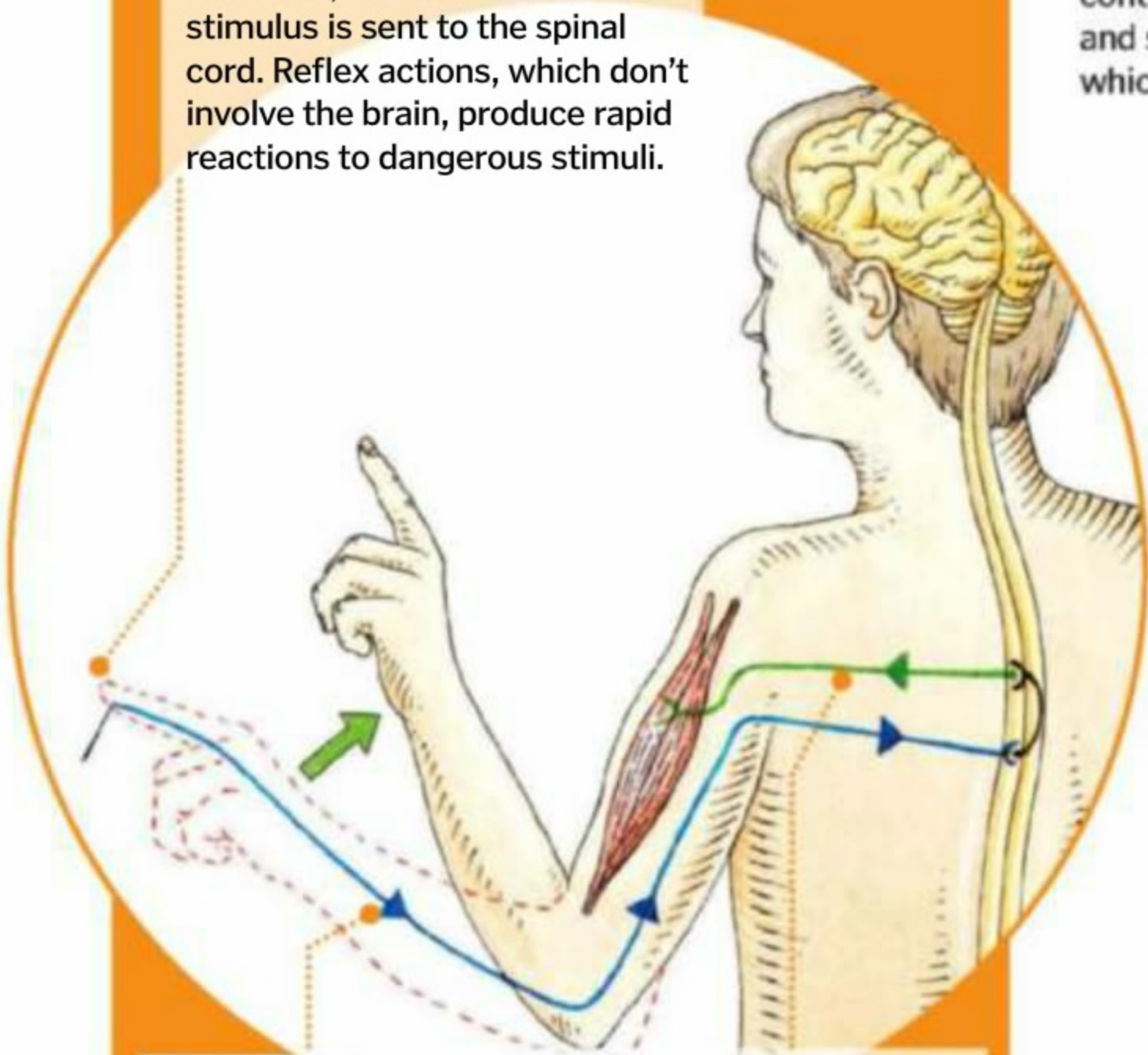
Understanding lightning reflexes

Have you ever felt something scorching hot or freezing cold, and pulled your hand away without even thinking about it? This reaction is a reflex. Your reflexes are the most vital and fastest of all your senses. They are carried out by the many 'reflex arcs' located throughout the body.

For example, a temperature-detecting nerve in your finger connects to a motor nerve in your spine, which travels straight to your biceps, creating a circular arc of nerves. By only having two nerves in the circuit, the speed of the reflex is as fast as possible. A third nerve transmits the sensation to the brain, so you know what's happened, but this nerve doesn't interfere with the arc; it's for your information only. There are other reflex arcs located within your joints, so that, say, if your knee gives way or you suddenly lose balance, you can compensate quickly.

1. Touch receptor

When a touch receptor is activated, information about the stimulus is sent to the spinal cord. Reflex actions, which don't involve the brain, produce rapid reactions to dangerous stimuli.



2. Signal sent to spine

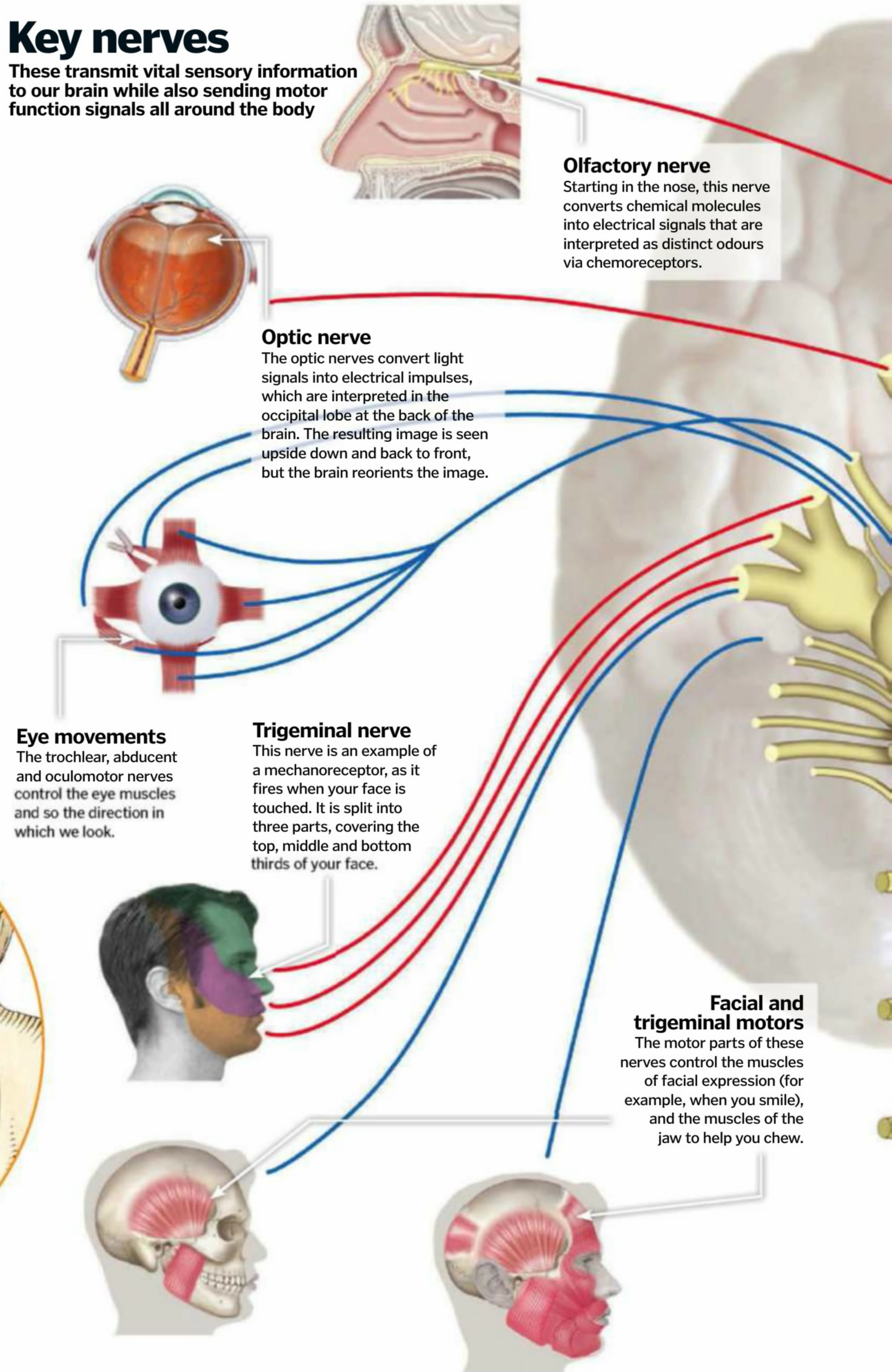
When sensory nerve endings fire, information passes through nerve fibres to the spinal cord.

3. Motor neurons feed back

The signals trigger motor neurons that initiate their own impulses that feed back to the muscle, telling it to move the body part.

Key nerves

These transmit vital sensory information to our brain while also sending motor function signals all around the body



Olfactory nerve

Starting in the nose, this nerve converts chemical molecules into electrical signals that are interpreted as distinct odours via chemoreceptors.

Optic nerve

The optic nerves convert light signals into electrical impulses, which are interpreted in the occipital lobe at the back of the brain. The resulting image is seen upside down and back to front, but the brain reorients the image.

Eye movements

The trochlear, abducent and oculomotor nerves control the eye muscles and so the direction in which we look.

Trigeminal nerve

This nerve is an example of a mechanoreceptor, as it fires when your face is touched. It is split into three parts, covering the top, middle and bottom thirds of your face.

Facial and trigeminal motors

The motor parts of these nerves control the muscles of facial expression (for example, when you smile), and the muscles of the jaw to help you chew.

A matter of taste

1 There are about 9,000 taste buds on the tongue and throat. These convert chemicals found in saliva into electrical signals, split into five tastes: sweet, salt, sour, bitter and umami.

Smell vs sight

2 Odours offer better memory recall than visual cues, as smell is tied to emotion. Looking at an old photograph can trigger memory, but a smell can evoke how you felt at the time.

Sensitive skin

3 Human skin contains over half a million sensory receptors. These are of the highest concentration in the fingertips, the ends of the toes and lips, where they're most needed.

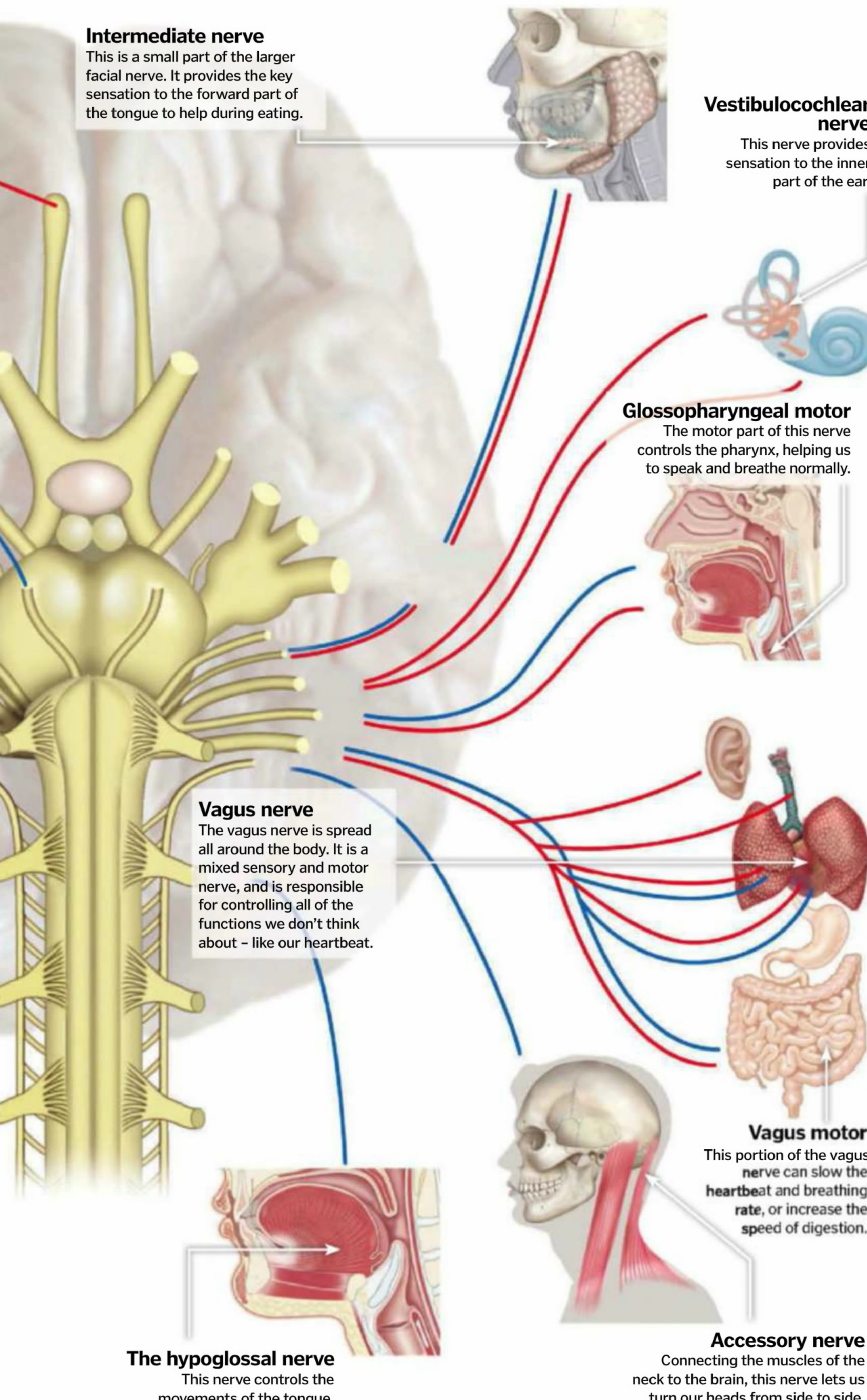
Upside down

4 The images formed in the occipital cortex are upside down, before the brain flips them. However babies start by seeing upside down, until the brain learns to adapt.

Staying steady

5 Ears do more than detect sound. The fluid and fine hairs in the inner ear maintain balance. If you spin round and stop, this fluid is still moving which is why we get dizzy.

DID YOU KNOW? The three smallest bones in the human body – the hammer, anvil and stirrup – are located in the middle ear



Crossed senses

Synaesthesia is a fascinating, if yet completely understood, condition. In some people, two or more of the five senses become completely linked so when a single sensation is triggered, all the linked sensations are activated too. For example, the letter 'A' might always appear red, or seeing the number '1' might trigger the taste of apples. Sights take on smells, a conversation can take on tastes and music can feel textured.

People with synaesthesia certainly don't consider it to be a disorder or a disease. In fact, many do not think what they sense is unusual, and they couldn't imagine living without it. It often runs in families and may be more common than we think. More information about the condition is available from the UK Synaesthesia Association (www.uksynaesthesia.com).

5	5	5	5	5
5	5	5	5	5
5	5	5	2	5
5	5	5	2	5
5	5	5	2	2
5	5	5	5	5

Non-synaesthetes struggle to identify a triangle of 2s among a field of number 5s.

5	5	5	5	5
5	5	5	5	5
5	5	5	2	5
5	5	5	2	5
5	5	5	2	2
5	5	5	5	5

But a synaesthete who sees 2s as red and 5s as green can quickly pick out the triangle.

A patient's sense of proprioception is being put to the test here



Is there really a 'sixth sense'?

Our sense of balance and the position of our bodies in space are sensations we rarely think about and so are sometimes thought of as a 'sixth sense'. There is a whole science behind them though, and they are collectively called proprioception. There are nerves located throughout the musculoskeletal system (for example, within your muscles, tendons, ligaments and joints) whose job it is to send information on balance and posture back to the brain. The brain then interprets this information rapidly and sends instructions back to the muscles to allow for fine adjustments in balance. Since you don't have to think about it and you can't switch it off, you don't know how vital these systems are until they're damaged. Sadly some medical conditions, including strokes, can affect our sense of proprioception, making it difficult to stand, walk, talk and move our limbs.

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HEROES OF... SCIENCE

HISTORY'S MOST
INFLUENTIAL
SCIENTISTS

Alfred Nobel

After exploding into the history books, this Swede sought to leave an academic legacy



Few scientists have left a legacy more noble than Alfred Nobel. This Swedish chemist not only invented dynamite, but also urged other scientists to explore new avenues of study by establishing the world's most prestigious accolade for intellectual achievement: the Nobel prize.

Since the award was founded in 1901, the greatest minds have been rewarded for their services to the advancement of science and other arts. This peer-assessed award, Nobel hoped, would inspire people to push the boundaries for the benefit of humanity. Past winners include such geniuses as Albert Einstein, Marie Curie and Alexander Fleming.

The big idea

Nobel's work with nitroglycerin led him to experiment with different additives to stabilise the oily liquid. One of Nobel's early 'big ideas' was the invention of a functioning detonator, which he designed first as a simple wooden plug and developed into the patented blasting cap, which was fitted with a small primary charge that could be detonated by a strong shock. While the detonators were groundbreaking, it was Alfred's chemistry that really put him on the map.

To make nitroglycerin safer, Nobel spent years developing the formula; several labs and factories were blown up in the process! Before long he discovered that by adding a very fine inert silica powder called diatomaceous earth, or kieselguhr, the oily nitroglycerin liquid could be transformed into a safer, malleable paste. When shaped into rods, this paste could be inserted into drilling holes and detonated in order to blast rock for mining. And the name of this material? Dynamite.



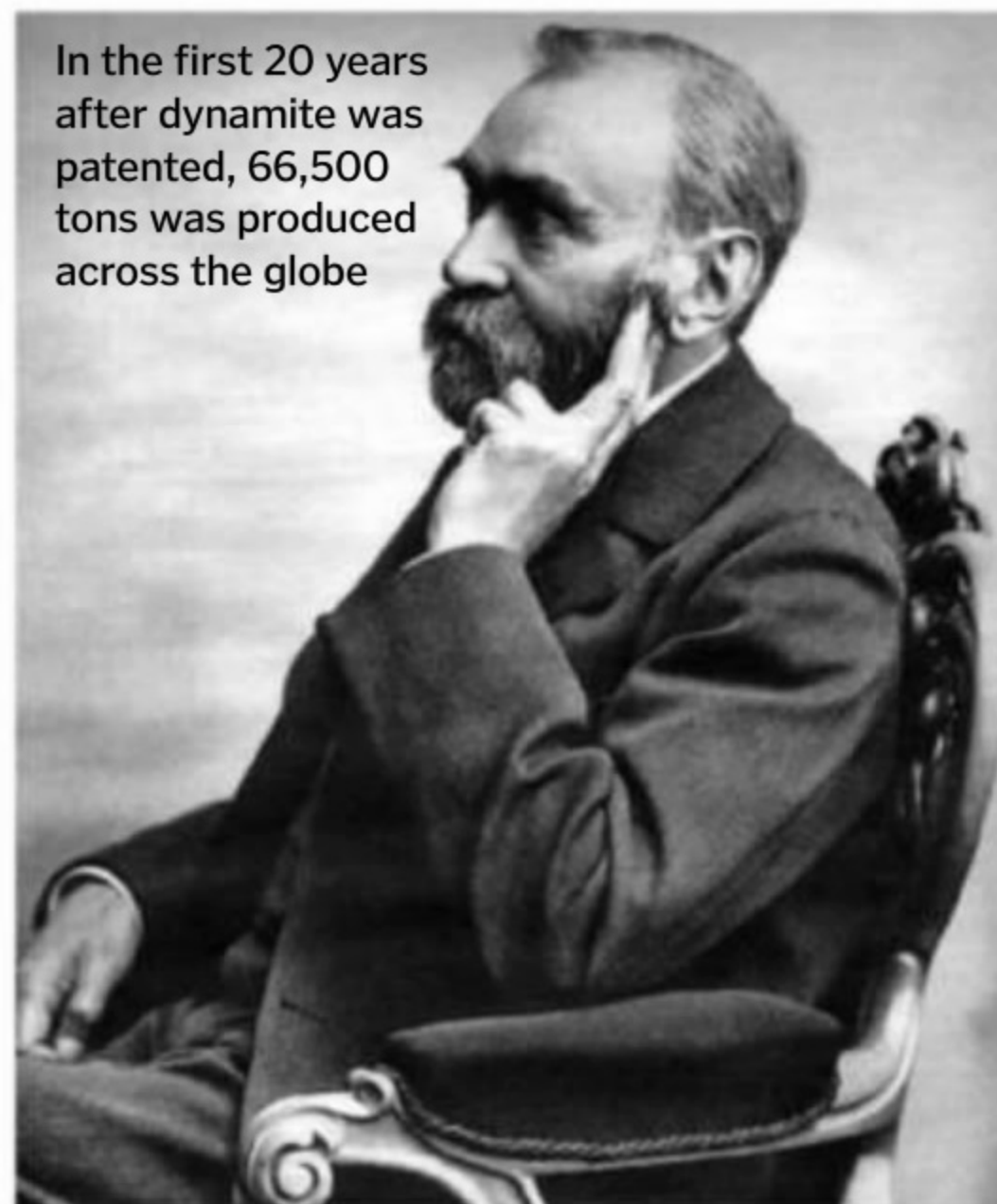
Alfred Bernhard Nobel was born in Stockholm, Sweden, on 21 October 1833 to Immanuel and Andriette. His mechanical engineer father enjoyed varying degrees of success with a number of inventing and manufacturing business ventures. In 1837, however, Immanuel left in search of better fortune in Russia. By 1842 he had established a profitable business producing equipment for the Russian military, and so the rest of the Nobel family moved out to join him.

Together with his three brothers – Robert, Ludwig and Emil – Alfred was home-educated by private tutors. Taking a cue from his entrepreneurial father, who also designed and made mines, Alfred developed a talent for chemistry – and explosives in particular. In 1850 Alfred travelled to Paris to study chemistry under French professor Théophile-Jules Pelouze, who had been carrying out experiments using concentrated nitric acid to develop explosive materials in his laboratory.

On his return to Russia Nobel began working in his father's factory manufacturing military equipment for the Crimean War. Once the conflict was over in 1856, however, the company struggled to turn a profit and, by 1859, the firm had gone bust, forcing the Nobels to return to Sweden. Alfred's two elder brothers, Robert and Ludwig, remained in Russia with hopes of salvaging what was left of the business.

Alfred, meanwhile, started experimenting with explosives in his father's lab. By 1862 he had set up a small factory in which he began to manufacture an exciting but highly volatile explosive called nitroglycerin, which had recently been invented by another of Pelouze's

In the first 20 years after dynamite was patented, 66,500 tons was produced across the globe



students: Ascanio Sobrero. While Nobel recognised the industrial potential of this explosive, the use of nitroglycerin was just not practical due to its unstable nature. The challenge was to find a way to control nitroglycerin so it could be safely handled.

Nobel spent many years perfecting the formula for his explosives, as well as inventing and developing detonation devices. Eventually his research led him to discover a way to make nitroglycerin stable and practical for the construction and mining industries. This development was the invention of dynamite (see 'The big idea' boxout), for which Nobel obtained the patent in 1867. With a commercial product on his hands, Nobel became a wealthy man at the heart of a brand-new industry. He

A life's work

The explosive timeline of the inventor of dynamite

1833

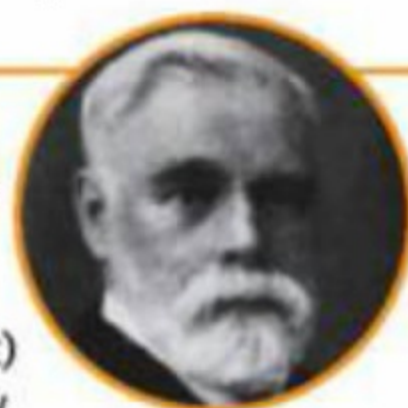
Alfred Bernhard Nobel is born in Stockholm, Sweden, on 21 October.



1837

Nobel's father (right) moves away

from the family to Finland and then St Petersburg to start up a mechanical workshop. The business goes bankrupt in 1856.

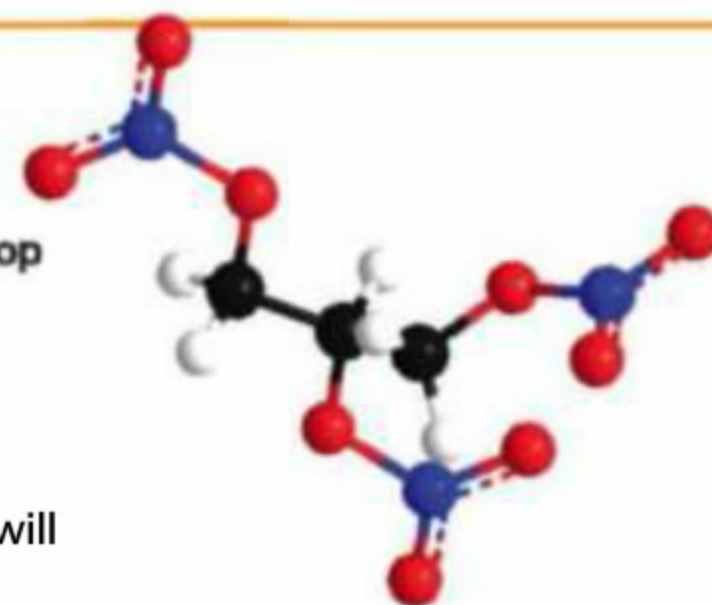


1850

After being reunited with his father in Russia, Nobel travels to France. In Paris he is employed in the laboratory of chemist TJ Pelouze.

1862

In a quest to develop new products for his father's shop, Nobel embarks on the research into nitroglycerin that will lead to dynamite.





Nobel was also interested in other aspects of chemistry, including the manufacture of synthetic rubber, leather, artificial silk and more

“He bequeathed much of his wealth to the establishment of an annual prize that he hoped would stimulate scientific progress”

established some 16 factories for producing explosives in almost as many countries.

Nobel died aged 63 of a heart attack at his home in San Remo, Italy. Without the help of a lawyer, a year before his death Nobel had signed his last will and testament. In it he bequeathed much of his wealth to the establishment of an annual prize that he hoped would stimulate scientific progress. In this document he wrote: ‘The whole of my remaining realisable estate shall be dealt with in the following way: the capital, invested in safe securities by my executors, shall constitute a fund, the interest on which shall be annually distributed in the form of prizes to those who, during the preceding year, shall have conferred the greatest benefit on mankind.’

In their footsteps...

Ragnar Sohlman

Swedish chemical engineer Ragnar Sohlman became Nobel's personal assistant when he moved to San Remo in 1883. Together with civil engineer Rudolf Lilljequist, Sohlman was appointed executor of Nobel's will. He fought both family and awarding bodies contesting the will to ensure the Nobel prize was set up. Sohlman was also creator of the Nobel Foundation and became its executive director from 1929-1946.

Albert Einstein

Without a doubt one of the most renowned Nobel laureates since the award was set up is Albert Einstein, who received the Nobel Prize in Physics in 1921. In 1905 he had published four pioneering papers: on the photoelectric effect, Brownian motion, the special theory of relativity and equivalence of matter and energy ($E=mc^2$). Einstein famously commented on the irony that a man credited with developing devastating explosives used to wage war had created a prize for peace.

Top 5 facts: Alfred Nobel

1 Factory tragedy

In 1964, two years after the invention of Nobel's first detonator, in an unrelated incident, his younger brother, Emil (along with several others), was killed when one of Nobel's factories exploded.

2 Lived to work

While Alfred was a workaholic and never married nor had children, at one point he did place a newspaper advert seeking a secretary and household supervisor. For two years from 1876 Alfred employed the Austrian Countess Bertha Kinsky.

3 The richest hobo

When Nobel died in Italy, it became apparent that he had not been registered as a resident of any country since the move to Russia when he was nine, earning him the nickname ‘the richest vagabond in Europe’.

4 Controversial will

Neither Nobel's family nor the prize-awarding bodies would co-operate with the terms of the will. The Royal Swedish Academy of Sciences claimed there were insufficient instructions about awarding the prizes.

5 Dynamite diamonds

While dynamite may originally have been developed with military applications in mind, organisations like the South African De Beers diamond-mining company were soon inspired to find ways to make use of these explosive charges for blasting rock in its mines.

1863

Nobel patents nitroglycerin (a volatile blasting oil) for use as an industrial explosive as well as a blasting cap detonator to set off explosions.

1864

Nobel's brother Emil dies while carrying out nitroglycerin experiments.

1866

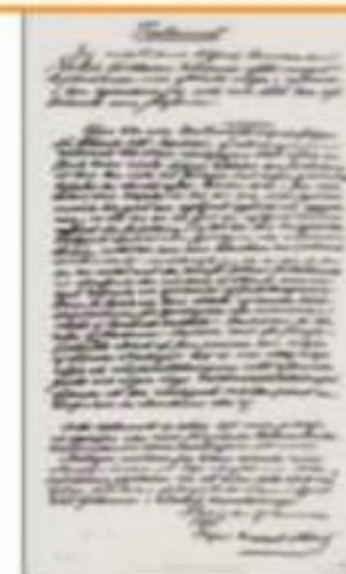
Keen to make handling nitroglycerin safer, Nobel finds the oil can be stabilised by adding diatomaceous earth – and dynamite is born.

1871

After being granted a patent for dynamite in 1867, Nobel sets up the British Dynamite Company (later renamed Nobel's Explosives Company).

1895

Nobel's last will is signed at the Swedish-Norwegian Club in Paris.



1896

Nobel dies at home in San Remo, Italy, on 10 December.





“Unlike fleas, head lice can’t jump and travel by crawling from hair to hair”

How cheese is made

Whether it’s parmesan or cheddar, all you need are three key ingredients: milk, bacteria and enzymes



The key to cheesemaking is getting the milk protein (casein) to stick together and form a solid. Casein clumps are usually kept separate by a coating of negative charges, which need to be disrupted – either by souring the milk or by adding enzymes (often in the form of rennet) to induce curdling.

Varying the type of bacteria added, the temperature and the amount of water changes the texture and flavour of the final cheese. For example, mozzarella is melted and pressed to give it a stretchy texture, while Swiss cheese is ripened at higher temperatures to induce fermentation, making bubbles of carbon dioxide that result in a holey finished product.



2. Acidification

Bacteria are added to the milk to turn the milk sugar (lactose) into lactic acid; this is what gives cheese its sharp flavour.

3. Coagulation

The enzyme rennet is then added to separate the milk into solid curds (fat, sugar and protein) and liquid whey (which is mostly water).

4. Cutting and salting

The curds are ‘cut’ to help remove excess liquid, then salted to enhance flavour and preserve the cheese.



1. Pasteurisation

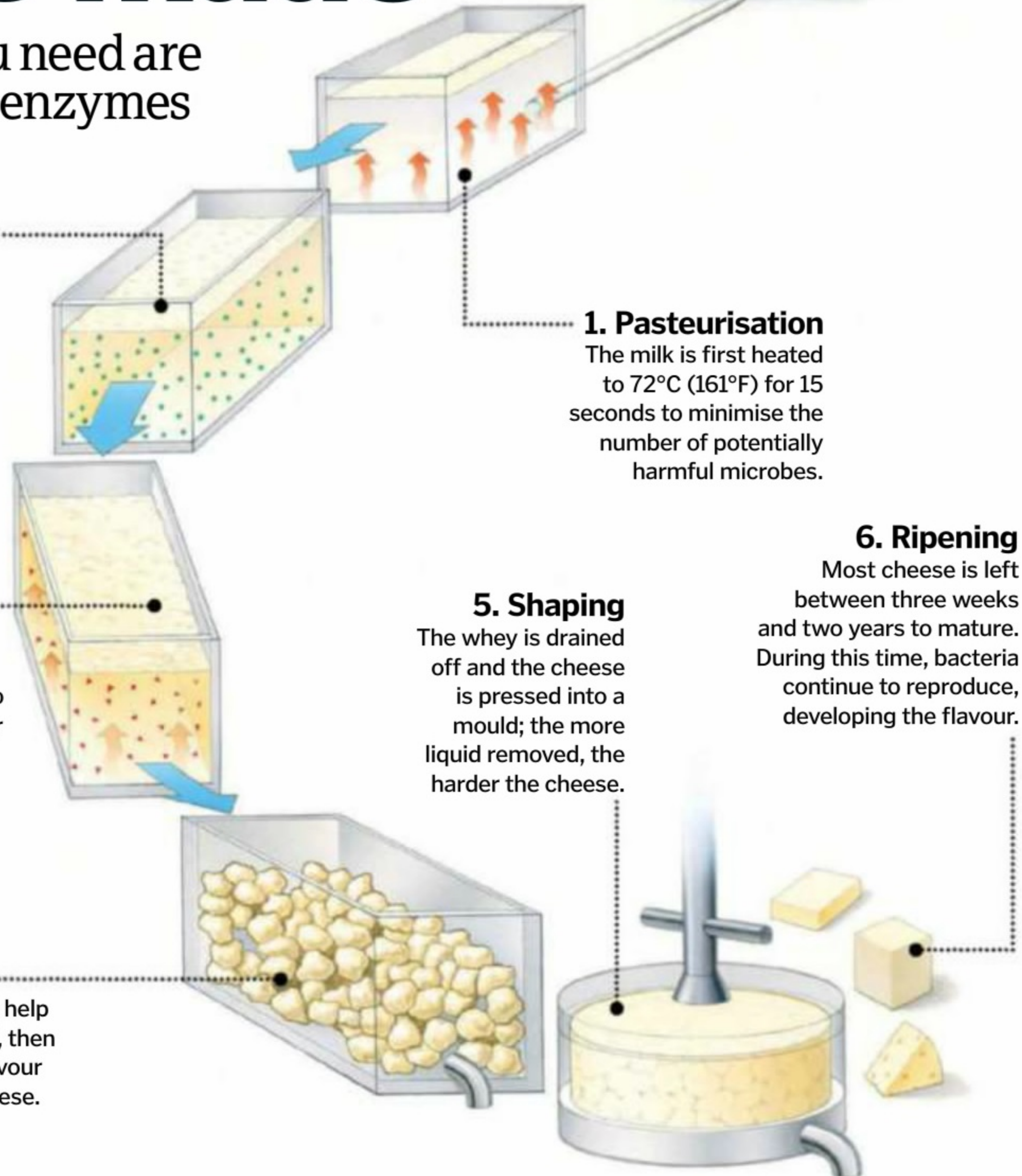
The milk is first heated to 72°C (161°F) for 15 seconds to minimise the number of potentially harmful microbes.

5. Shaping

The whey is drained off and the cheese is pressed into a mould; the more liquid removed, the harder the cheese.

6. Ripening

Most cheese is left between three weeks and two years to mature. During this time, bacteria continue to reproduce, developing the flavour.



The biology of head lice

How do these tiny insects feed, reproduce and spread?



Lice feed about six times a day, using biting mouthparts to pierce the scalp. They inject small quantities of saliva into the wound, with an anticoagulant to prevent blood clots from forming. Proteins in the saliva, and in their faeces, are the cause of the itching associated with infestation; the immune system recognises them as foreign and initiates an inflammatory response.

Unlike fleas, head lice can’t jump and travel by crawling from hair to hair. Transmission occurs by direct head-to-head contact or by transfer on shared towels, brushes, etc. It is also a myth that lice prefer clean hair; they are not fussy as long as they have access to blood and somewhere to lay their eggs.

Born to bite

Nymphs are equipped with biting mouthparts and so can begin feeding immediately.

Hatching

After a week the egg hatches and an immature louse, or nymph, emerges.

Egg

Lice stick their eggs to the hair shaft with protein glue.

Moulting

The nymph sheds its exoskeleton three times as it matures.

All grown up

Adult lice are 2.5-3mm (about 0.1in) long, flat and wingless. They are pale grey to brownish red in colour.

Reproduction

Head lice reproduce sexually and the male louse often dies after mating.

Laying

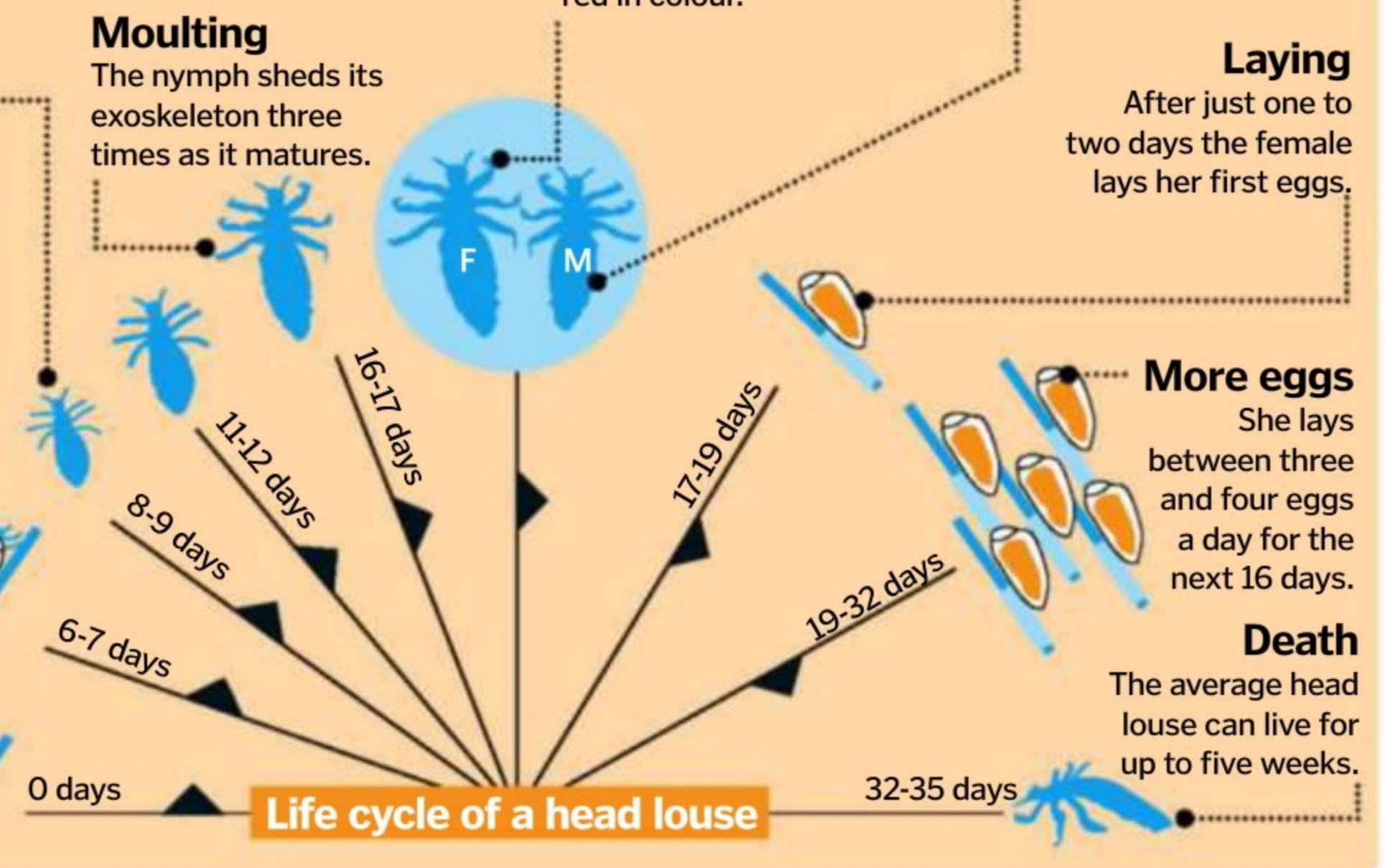
After just one to two days the female lays her first eggs.

More eggs

She lays between three and four eggs a day for the next 16 days.

Death

The average head louse can live for up to five weeks.



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Every year the bicycles used in the Tour de France are enhanced by new and improved technology

Cutting-edge racing bikes

Pro cyclists use clever engineering and new materials to leave their rivals in the dust...



In bicycle racing, one thing will never change: the more power you put into the system, the more speed you get out. But over the past 50 years, the technology and design of racing bikes has undergone radical changes, and the future promises even lighter, faster and more efficient machines.

Take, for example, the Dogma 2 designed by Italian bicycle manufacturer Pinarello – the bike on which British cyclist Sir Bradley Wiggins won the 2012 Tour de France. At first glance, this is a bicycle like any other that has been built in the past 120 years. There are two rubber tyres, handlebars, a tubular frame, pedals and a chain-and-sprocket mechanism that powers the rear wheel. But the Dogma 2 has about as much in common with your average bike as a Ferrari does with a Fiat.

The first critical difference between the Dogma 2 and the majority of bikes on the market today is that it is purely for racing. Racing bikes are not designed for comfort nor style, and certainly not for affordability. They are built to be aerodynamically flawless,

feather light and astoundingly efficient about transferring muscle power to speed.

Let's start with weight. Think about the last time you lifted a mountain bike to stow it on the roof rack of your car. Those things can be heavy and bulky. In contrast, the Dogma 2 frame weighs just 920 grams (two pounds)!

That's because nearly every serious racing bike is made from carbon fibre, a super-light material with an impressive strength-to-weight ratio. The carbon fibre used in the Dogma 2 is called 60HM1K, which means it can withstand a hefty 60 tons of force per square centimetre.

Then there's the aerodynamics of the Dogma 2. Every single part of this machine is modified to reduce drag. The fat rims and flattened spokes of the tyres cut effortlessly through the air; vertical frame parts are triangular in cross-section with the point facing forward; and even seemingly aesthetic flares have been engineered for speed and efficiency.

For example, the forks on the Dogma 2 – the part of the frame that attaches to the front wheel – are wavy, which looks undeniably cool. ▶

What is a Retül fitting?

For serious cyclists, a professional bike fitting is absolutely critical. The right frame geometry makes each pedal stroke more efficient, shaving precious seconds from time trials and reducing repetitive stress on the body. Retül is a bike-fitting technology that uses 3D motion capture to record real-time data about a rider's body position on the bike. After doing a physical assessment of the rider, the fitter places LED markers on the rider's wrist, elbow, shoulder, hip, knee, ankle, heel and toe. The Retül motion capture system tracks the movement of each sensor. Armed with accurate data about the rider's knee and ankle angles, and the position of the knee throughout the pedalling cycle, the fitter can adjust the Retül Müve stationary bike to maximise the efficiency and safety of each power stroke. Using Retül software, the fitter can then match the Müve bike measurements to order a perfectly attuned bike frame.

The Retül Müve bike used to gather data during a fitting



Triangle required

1 According to Union Cycliste Internationale (UCI) rules, all racing bikes must be constructed around a central triangle made by the top tube, down tube and seat tube.

Disposable frames

2 Due to the incredible stress that's placed on professional racing bikes, most competitive riders have to replace their carbon-fibre frames every three or so months.

No pain, no gain

3 It might come as a surprise, but if a rider wants to double their speed, they must exert not just two times – but eight times – the physical effort. No wonder it's so tiring!

Sticky start

4 As part of its 'marginal gains' campaign, the 2012 Olympics British cycling team sprayed their tyres with an alcohol solution pre-race to increase stickiness for a standing start.

On-board computers

5 To train for races and improve performance, competitive riders use bikes mounted with computer sensors that measure pedal speed and the effort exerted by the rider.

DID YOU KNOW? Recumbent bikes are the fastest bicycles on flat ground, but were banned from competitions in 1934



Racing bike anatomy

Professional racing bikes are lighter, smaller and custom-made to suit the rider and the event

Saddle

To decrease overall weight of the bike, all nonessential items are sacrificed, including a comfortable saddle cushion.

Frame

High-end racing bike frames are almost entirely carbon-fibre construction tailored to precise measurements of the rider.

Stem

On racing bikes, the handlebars are mounted directly on a shortened stem that improves handling and makes it easier to swap handlebars after a crash.

Gear shifter

Small pivoting switches on the brake handles alter the tension of the cable when the gear is changed, in turn moving the derailleurs.

Handlebars

Racing bike handlebars ergonomically fit the natural shape and angle of the rider's hands.

Wheel

Racing rims are a composite of aluminium and carbon fibre with tyre pressure pumped up to 9.8kg/cm² (140psi) for road bikes and up to 15.5kg/cm² (220psi) for track events.

Pedal

Racing pedals have only two pieces – the footplate and the crank arm – positioning the pedal much closer to the bike.

Derailleurs

Though some bikes are getting wireless derailleurs, most still are controlled manually via cables linked to the gear shifter.





“One of the massive advantages of carbon fibre is how the material can be layered and then shaped”



Sebastian Wigmore rode to victory at the 2012 Tour de France on a Pinarello Dogma 2

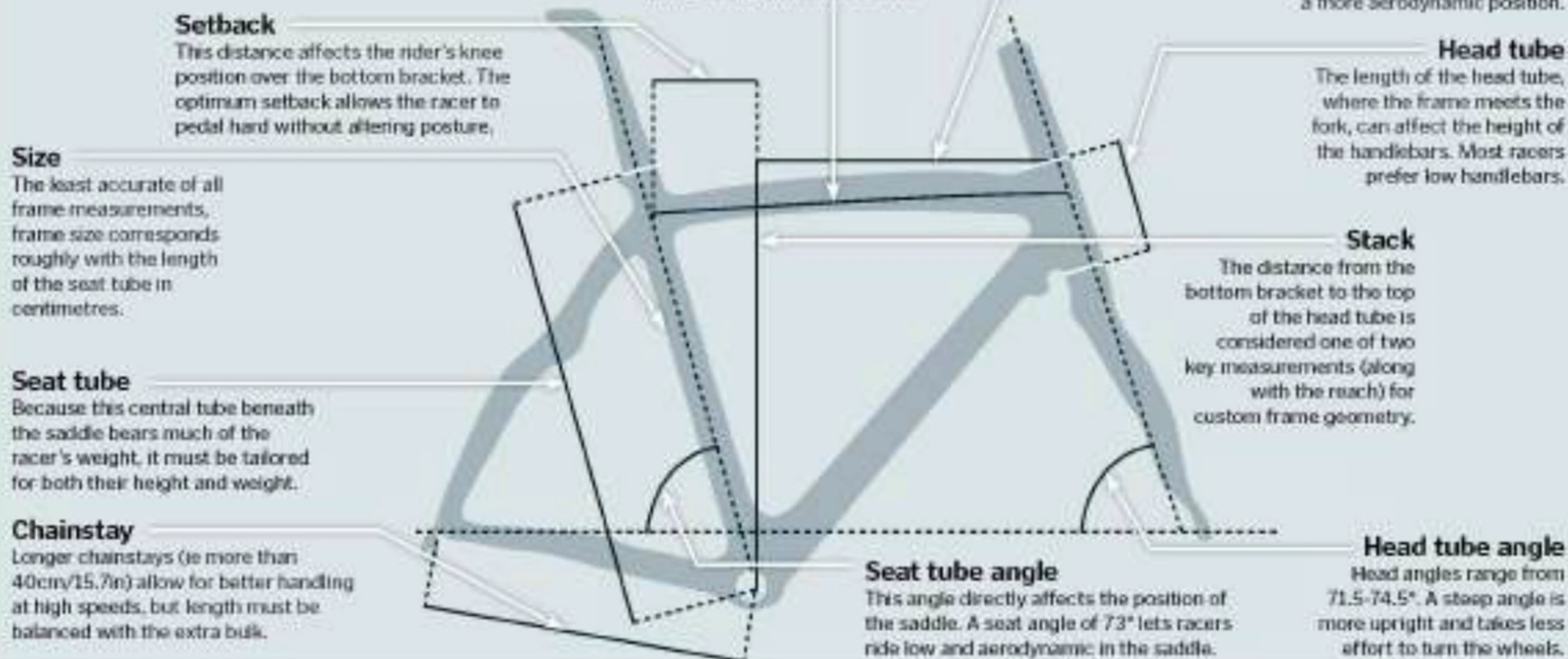
► But the undulating width of the tubing works to absorb vibrational frequencies from the front wheel, making for a smoother, faster ride. All cables for braking and shifting are also routed internally, further minimising the profile.

One of the massive advantages of carbon fibre – beyond its strength and weight – is how the material can be layered and then shaped to achieve even the most ambitious engineering goals. For instance, all racing bikes mount the chainset – the powertrain of the bike – on the right side. This creates an imbalance in the forces exerted on the right and left sides of the frame while pedalling.

Pinarello responded to that imbalance by creating an ‘asymmetrical’ frame for both the original 2009 Dogma and its sequel. Carbon-fibre frames are constructed by layering multiple sheets of carbon-fibre fabric to provide customised structural rigidity and wall thickness. A close look at the right side of the

Frame geometry

Every component of a racing bicycle can be resized or reinforced to work with the rider



Bicycle evolution

We pick out some of the big cycling innovations of the 20th century...

1903

Three-speed hub
Invented by British company Sturmey-Archer, this switchable internal gear mechanism is built into the wheel hub.

1910

Derailleur
The first commercial derailleur uses pedal switches to change across four gears.

1930

Quick-release hub
Italian cyclist Tullio Campagnolo invents a simple mechanism for changing wheels.



1932

Recumbent
Considered a novelty today, the first French recumbent bikes break the mile and kilometre speed records.

1940

Cambio Corsa
Campagnolo makes a two-gear shifter that employs fork-like levers to move the chain back and forth.



DID YOU KNOW? The Dogma 2 frame is embedded with nanoparticles that absorb the force of a crash without snapping the frame

The chainset in focus

Often referred to as the crankset in the USA, the chainset is the highly efficient drivetrain on a modern racing bike. By pedalling, the rider applies torque to two front chainrings that pull a chain around ten or

more rear sprockets, or 'gears'. The teeth on each sprocket are carefully spaced in order to allow rear derailleurs to slip the chain from sprocket to sprocket in a fraction of a second while on the move.

Cogset

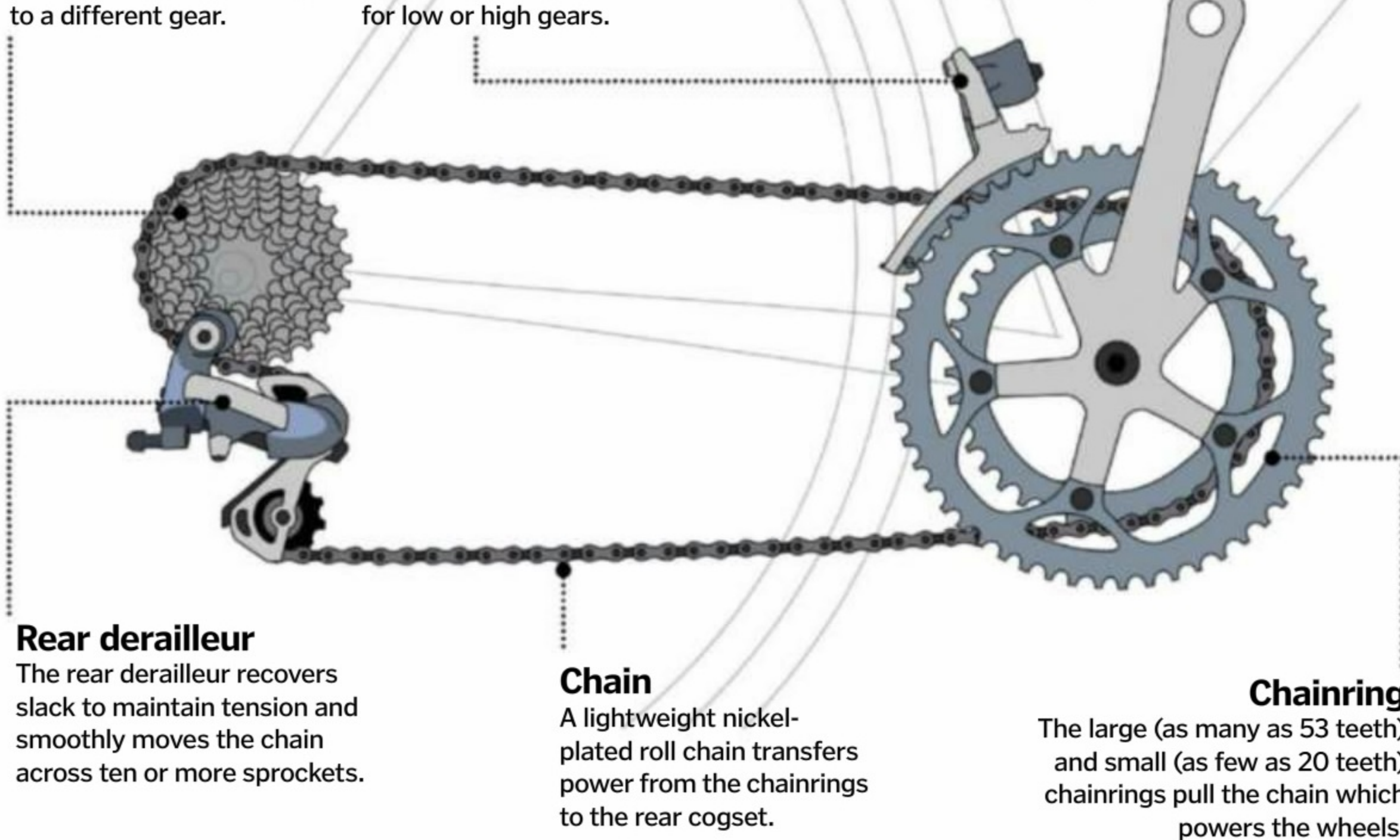
This rear assembly consists of ten or more sprockets of varying sizes, each corresponding to a different gear.

Front derailleur

The front derailleur switches back and forth from the large to small chainrings to provide the right tension for low or high gears.

Crank arm

An aluminium or carbon-fibre crank arm transfers force from the pedals into torque that rotates the chainring.



Rear derailleur

The rear derailleur recovers slack to maintain tension and smoothly moves the chain across ten or more sprockets.

Chain

A lightweight nickel-plated roll chain transfers power from the chainrings to the rear cogset.

Chainring

The large (as many as 53 teeth) and small (as few as 20 teeth) chainrings pull the chain which powers the wheels.

Dogma frame reveals slightly thicker tube walls to balance pedalling stress across the entire frame. The result is a bike that responds with maximum efficiency to pedalling forces.

Interestingly one of the subtlest innovations in modern racing bikes is also one of the most technologically brilliant. Many professional gear-shifting systems are now entirely wireless. Yes, that's right – not a single cable.

The mechanism on a bike responsible for moving the chain from sprocket to sprocket is called a derailleur (French for derailer). Bikes have both a front and back derailleur. The front one sits above and behind the right pedal, moving the chain from one large sprocket to a much smaller one. The rear derailleur, on the other hand, slips the chain on and off up to 11

different sprockets which are mounted in the centre of the rear wheel.

Until recently, riders changed gears by adjusting the tension of cables that ran from the handlebars to the derailleurs. But even the best shifting systems experience wear on the metal cables that can affect shifting speed.

In a wireless shifting system like the Campagnolo Electronic Power Shift, ergonomic light-touch triggers are built into the handlebars and brake levers. A tiny radio inside the handlebars transmits each shift command wirelessly to the derailleurs, which seamlessly move the chain using small electronic motors. A mechanical derailleur can downshift a maximum of five sprockets at a time and upshift only three, while an

Wheels up close

As with the rest of a professional racing bike, the wheels and tyres are designed to be as lightweight and aerodynamic as possible while maximising speed and efficiency. Modern wheels have larger rims for improved aerodynamics, fewer spokes (or even no spokes), and spokes are flat rather than cylindrical.

The entire wheel (ie rim, spokes and axle hub) weighs less than 800 grams (1.8 pounds). Tyres are still rubber, but the interior tubes are inflated to as much as 15.5 kilograms per square centimetre (220 pounds per square inch), granting razor-thin contact with the road along a path as narrow as five millimetres (0.2 inches).

Rim

The fat rims on modern racing wheels reduce drag, as does their tapered triangular cross-section.

Spoke

To reduce drag, racing wheels only have 16 spokes and they are 'bladed', or flattened, to cut through the air.



Hub

The wheel rotates freely around the axle using lightly oiled ceramic ball bearings housed in the hub.

electronic shifting system can downshift or upshift all 11 sprockets at once.

Bike manufacturers are already developing on-board computers and sensors to create the first fully automatic electronic shifting system. Imagine a racing bike that can anticipate an upcoming gradient and automatically shift gear. Wireless braking can't be far behind.

All of these innovations don't come cheap, of course. A fully equipped Dogma 2 with wireless shifting and high-end wheels will run to £8,700 (\$13,200). And if that's not mind-boggling by itself, just think, a professional rider can go through a new bike every three months.



1951

New derailleur

Campagnolo revolutionises bike racing with the Gran Sport derailleur – the first to use cables to switch gears.

1964

SunTour Grand Prix

A 'slant parallelogram' derailleur becomes the model for all future chainset designs.

1980s

Aerodynamics

The first racing bikes are designed and engineered for maximum aerodynamics in Germany and the UK.

1984

Clipless pedal

LOOK releases the first widely adopted clipless pedal for locking in and releasing racing shoes.



1992

Lotus SuperBike

Brit Chris Boardman wins gold at the Barcelona Summer Olympics with a space-age monocoque carbon-fibre bike.

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Answer:

Skilled drivers can actually change gear in a manual car without using the clutch pedal, by matching the engine revs to the RPM required for each gear. Get it wrong though and the gearbox will be damaged so it's best to leave this to the professionals!

DID YOU KNOW? Clutch brakes can also be used to stop the drive from an electric motor or even in the winding of a clock

Clutch brake engineering

Looks may deceive, but this metal ring can play a vital role in engaging a vehicle's transmission



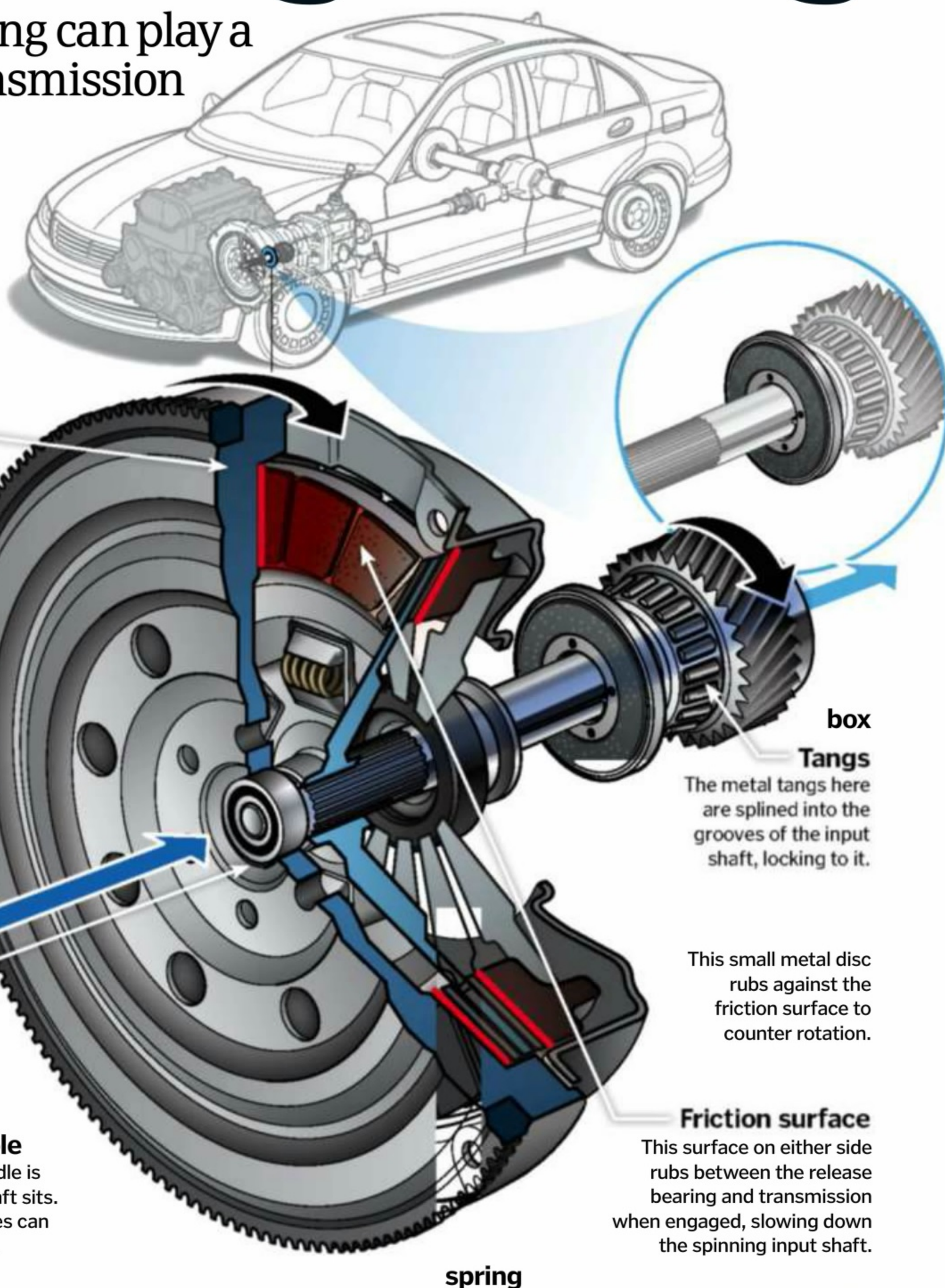
Transmissions play a fundamental role in the process of getting a vehicle to move. A car's transmission is connected to the engine and serves to 'transmit' the power generated there to the wheels that drive the vehicle. Within this transmission, gears are used to reduce the number of revolutions of a crankshaft, ensuring more effective use of the engine's torque.

When a car is in neutral, power from the engine is driving the transmission input shaft, in turn rotating some parts in the transmission on idle. However, once first gear is selected to go forwards or reverse to go backwards, the clutch is depressed, disengaging the input shaft from the engine. Due to inertia, the input shaft could still spin for some time however, meaning certain parts of the transmission will be spinning too fast to interlock with the gears.

A clutch brake works by fixing to the input shaft on a manual gearbox, acting as a source of friction between the release bearing and transmission bearing retainer cap, effectively reducing the input shaft's rate of rotation and slowing the spinning inside the gearbox. This allows for the gears to 'mesh' effectively without any significant grinding or clashing. Indeed, clutch brakes are instrumental in avoiding excessive wear of those all-important inner transmission components.

There are three common types of clutch brake found in vehicles: a one-piece clutch brake, a two-piece 'hinged' clutch brake and a torque-limiting clutch brake. The one-piece variety can only be installed with the transmission removed from the vehicle, so it can go over the circular input shaft. Its thick plate provides a good friction surface to slow the input shaft when it's spinning.

A two-piece hinged clutch brake, on the other hand, can be installed with the transmission in place, simply by hinging and then fixing around the input shaft. Finally, a torque-limiting clutch brake is commonly used for more heavy-duty applications and features a hub with washers that slip under a certain amount of torque, ensuring the smooth engagement of gears in the transmission.



Flywheel

Power from engine

Input shaft hole
The hole in the middle is where the input shaft sits. Hinged clutch brakes can simply clip round it.

box
Tangs

The metal tangs here are splined into the grooves of the input shaft, locking to it.

This small metal disc rubs against the friction surface to counter rotation.

Friction surface

This surface on either side rubs between the release bearing and transmission when engaged, slowing down the spinning input shaft.

spring

Lost in transmission

Many different types of transmission can be found in vehicles today; the most common is manual. Usually found on commercial vehicles, the driver here must manually select and then engage the appropriate gear using a shifter/stick and clutch pedal. With the clutch pedal depressed and the clutch disengaged from the engine, ensuring no power is transferred to the wheels, the driver selects a gear by moving the gear shifter into position, before releasing the clutch pedal and engaging power to the wheels once more. This process is completed within seconds, ensuring very little momentum is lost while on the move.

Automatic transmission changes the gears itself without any input from the driver, making for a very smooth driving experience. This transmission is more commonly found in family vehicles.

With a semi-automatic, the driver may up-shift or down-shift a gear manually, but without the need for a clutch pedal. This is because electronic gear and torque sensors engage or disengage the clutch in tandem with the manual gear selection. Some manufacturers have developed their own versions of automatic transmission with a manual override, such as Audi's Tiptronic or Porsche's Doppelkupplung (PDK) gearboxes.

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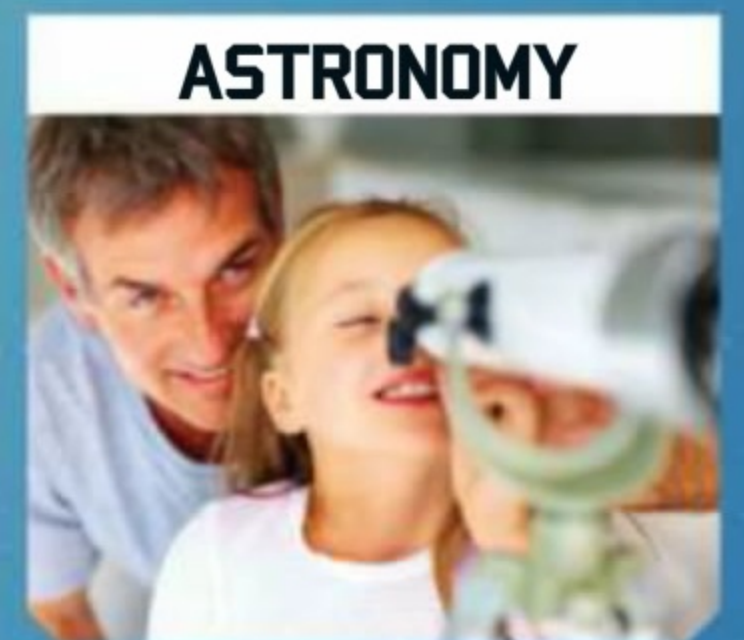
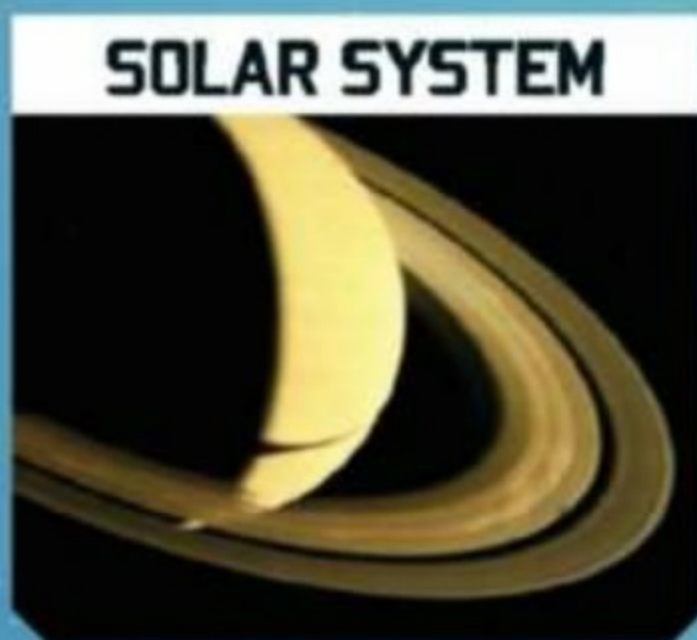


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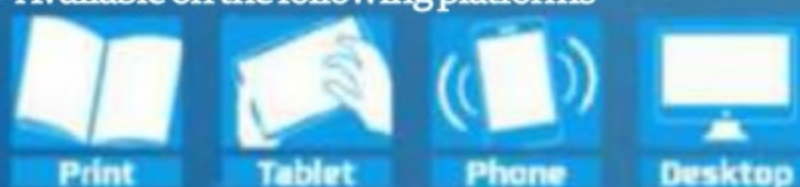


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1. OLD

Early oar

Ancient Egyptian life was centred around the Nile, so rowing came naturally to them. Cedar wood oars were used to both propel and steer the riverboats.



2. TRADITIONAL

Square top

Usually carved from spruce or ash wood, these heavy oars have large, long blades that are ideally suited for a slow cruise around the lake.



3. SPEEDY

Carbon fibre

Designed to maximise thrust, these lightweight tapered blades made of carbon fibre feature a large surface area and no-slip aerodynamics.

DID YOU KNOW? In an eight-person shell, synchronising the backward shift between strokes is key to maximising velocity

The physics of rowing

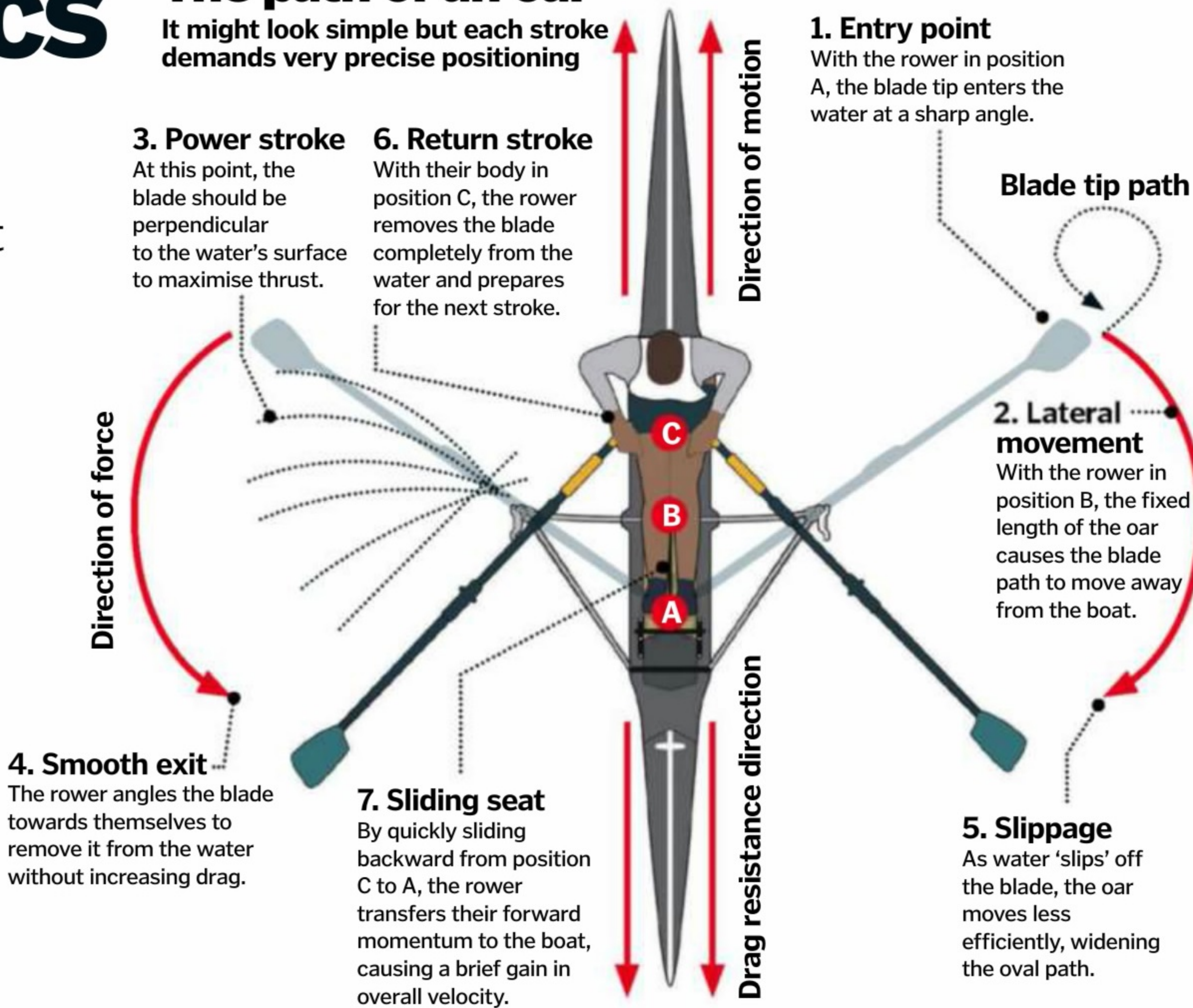
Modern oars maximise thrust and minimise drag to aid muscle-powered propulsion



A racing hull is propelled through the water using the action/reaction principle of Newton's third law of motion. The oar blade applies force to a mass of water, producing an equal but opposite force that moves the boat forward. In a fluid, the velocity of the boat is equal to the thrust of the rowers minus the drag of the water. Lightweight racing shells are highly aerodynamic, reducing drag considerably. To maximise thrust, pro rowers use oars designed to reduce slippage in the water. The path of an oar blade is a tight oval – not the arc most of us assume. The ideal blade design doesn't slip from side to side, but uses all its energy to move the most water possible. Modern racing blades are also tapered like jet plane wings, effectively causing the water to 'stick' to the blade's surface.

The path of an oar

It might look simple but each stroke demands very precise positioning



Vapour-recovery systems explained

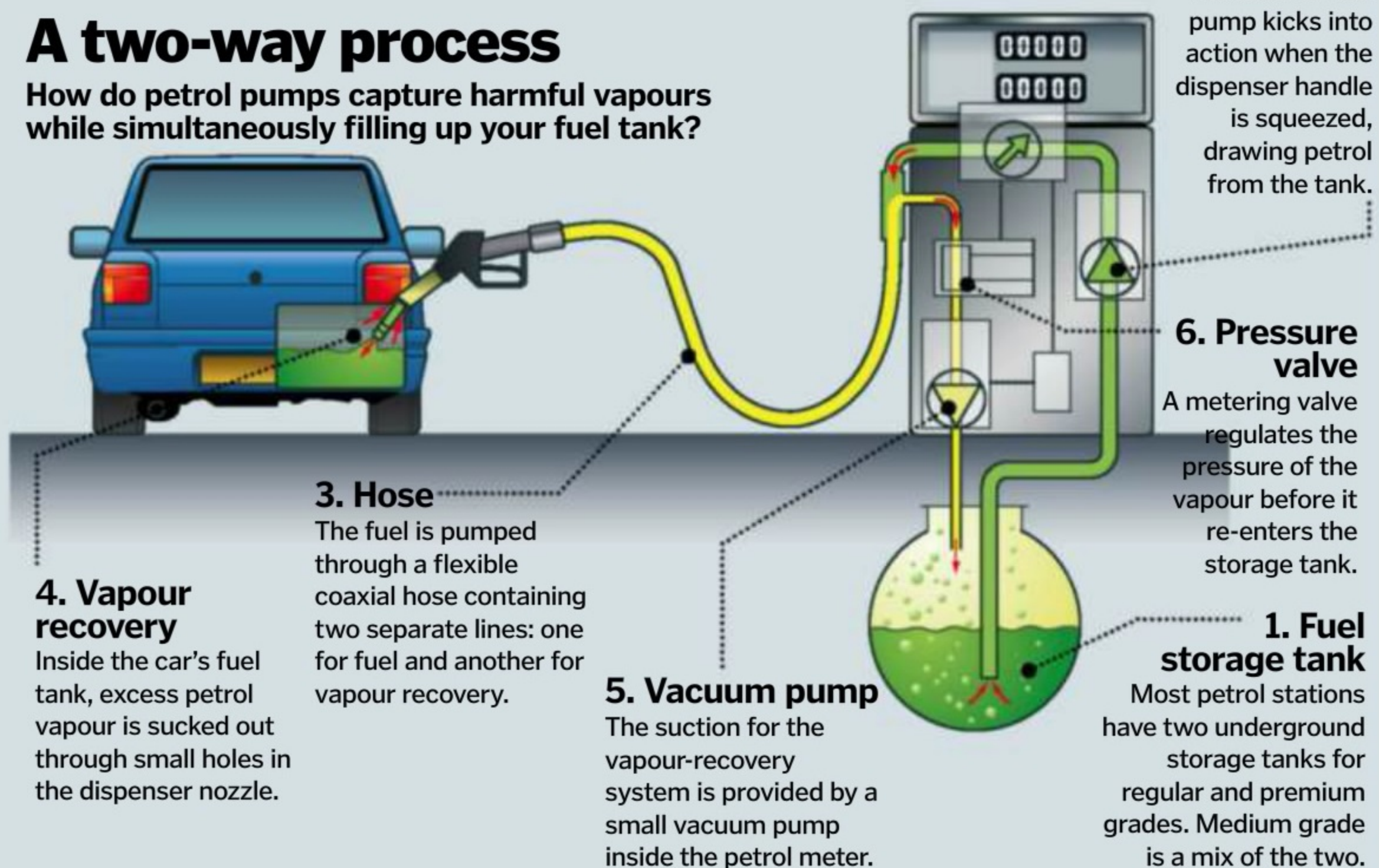
Protecting the environment from extra fumes starts at the petrol pump...



Automobiles are one of the leading causes of air pollution and noxious smog. Not only is car exhaust a toxic source of hydrocarbons, but so are the petrol fumes that escape while refuelling. Starting in the Nineties, all petrol stations were required to install vapour-recovery systems in their pumps. The idea is simple: use a vacuum pump to draw fumes back into the underground petrol storage tank. The trick is installing two separate lines inside the pump hose: one line deposits liquid fuel into the vehicle's tank and the other sucks away excess vapour via small holes near the tip of the dispenser. Some dispensers are also equipped with an extra rubber boot that creates a tighter seal around the tank opening. Vapour recovery works in tandem with automatic shut-off valves to prevent spills, leaks and air pollution.

A two-way process

How do petrol pumps capture harmful vapours while simultaneously filling up your fuel tank?






“Commonly used for troop support and ground attacks, it can loiter for long periods at low altitudes”

On board the Warthog

Why is the A-10 Thunderbolt fighter jet still in use today and just as popular as it was four decades ago when it first took off?

 The A-10 Thunderbolt is a single-seat, close-air support fighter jet that also goes by the names Warthog and Tankbuster. Development for the aircraft began in 1967 and its first flight was in 1972. There are several reasons why the A-10 has proved popular enough to weather 40-plus years of advancing military tech – chief among them its combat versatility and high survival rate.

The A-10 boasts a short takeoff and landing capacity with a range of nearly 1,300 kilometres (800 miles). Commonly used for troop support and ground attacks, it can loiter for long periods at low speeds and altitudes below 300 metres (985 feet) and it’s capable of soaking up as much damage as it can dish out. Indeed, the A-10 can take direct hits from armour-piercing and explosive shells, has multiple redundancies for its flight systems and, most incredibly, it can return to base on one engine, one tail stabiliser, one elevator and even having lost half a wing! As a result, it’s well known among US Air Force pilots for its ‘get home’ effectiveness.

Modern A-10s have been upgraded from the original 1972 blueprint, of course. Navigation and targeting systems have been dramatically

improved. Pilots can now wear night-vision goggles for low-light ops, plus a host of electronic countermeasures and smart-bomb capacity have been installed.

A-10 Thunderbolt II tech

We’ve pulled apart the Warthog to see what makes it such a hardy aircraft

Canopy

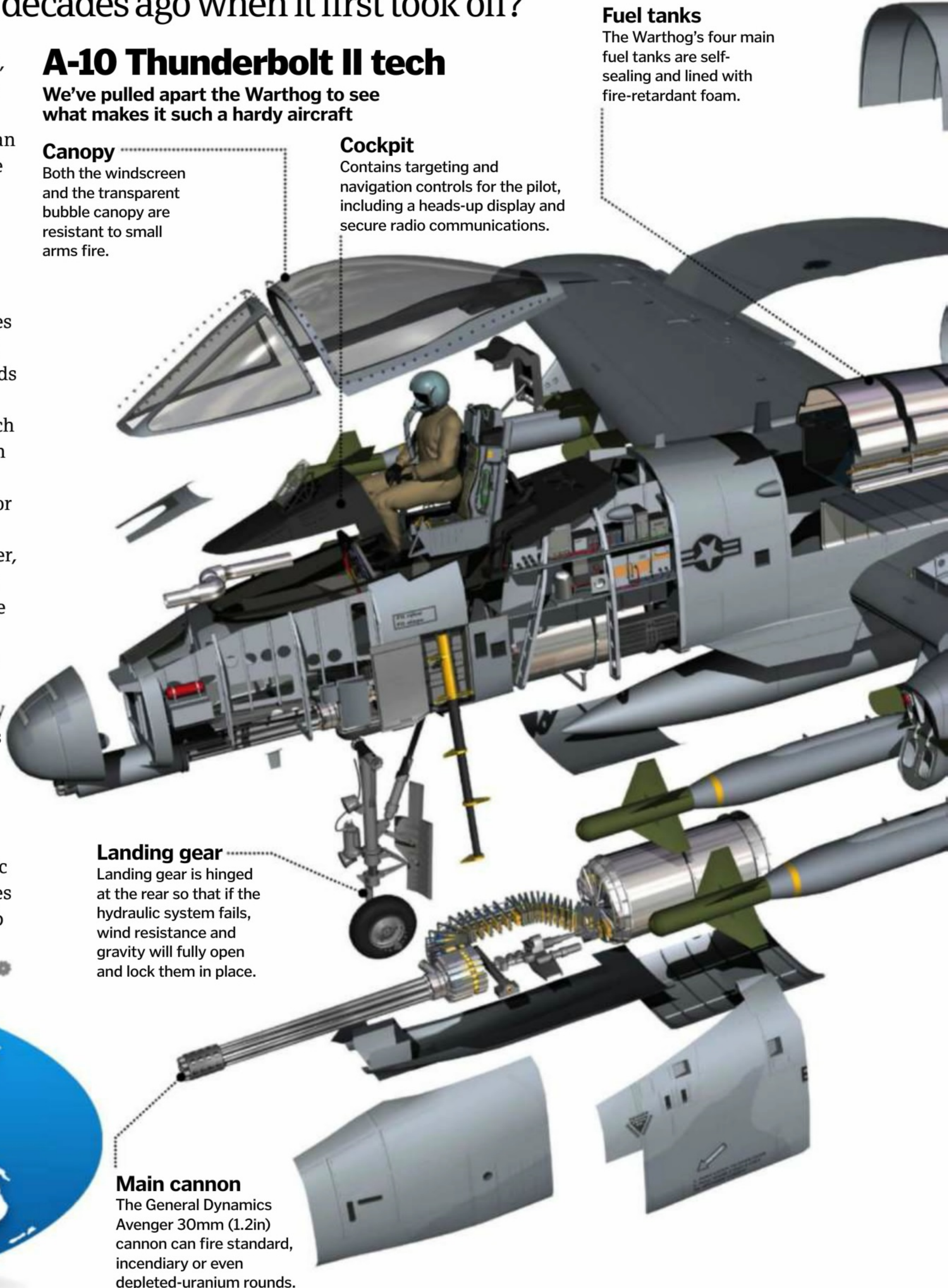
Both the windscreen and the transparent bubble canopy are resistant to small arms fire.

Cockpit

Contains targeting and navigation controls for the pilot, including a heads-up display and secure radio communications.

Fuel tanks

The Warthog’s four main fuel tanks are self-sealing and lined with fire-retardant foam.



Landing gear

Landing gear is hinged at the rear so that if the hydraulic system fails, wind resistance and gravity will fully open and lock them in place.

Main cannon

The General Dynamics Avenger 30mm (1.2in) cannon can fire standard, incendiary or even depleted-uranium rounds.



ON THE MAP

A-10s in service

- 1 Balkans
- 2 Florida, USA
- 3 Afghanistan
- 4 Iraq
- 5 Libya
- 6 South Korea



DID YOU KNOW? The A-10 is so versatile that one has been converted to serve as a weather research platform

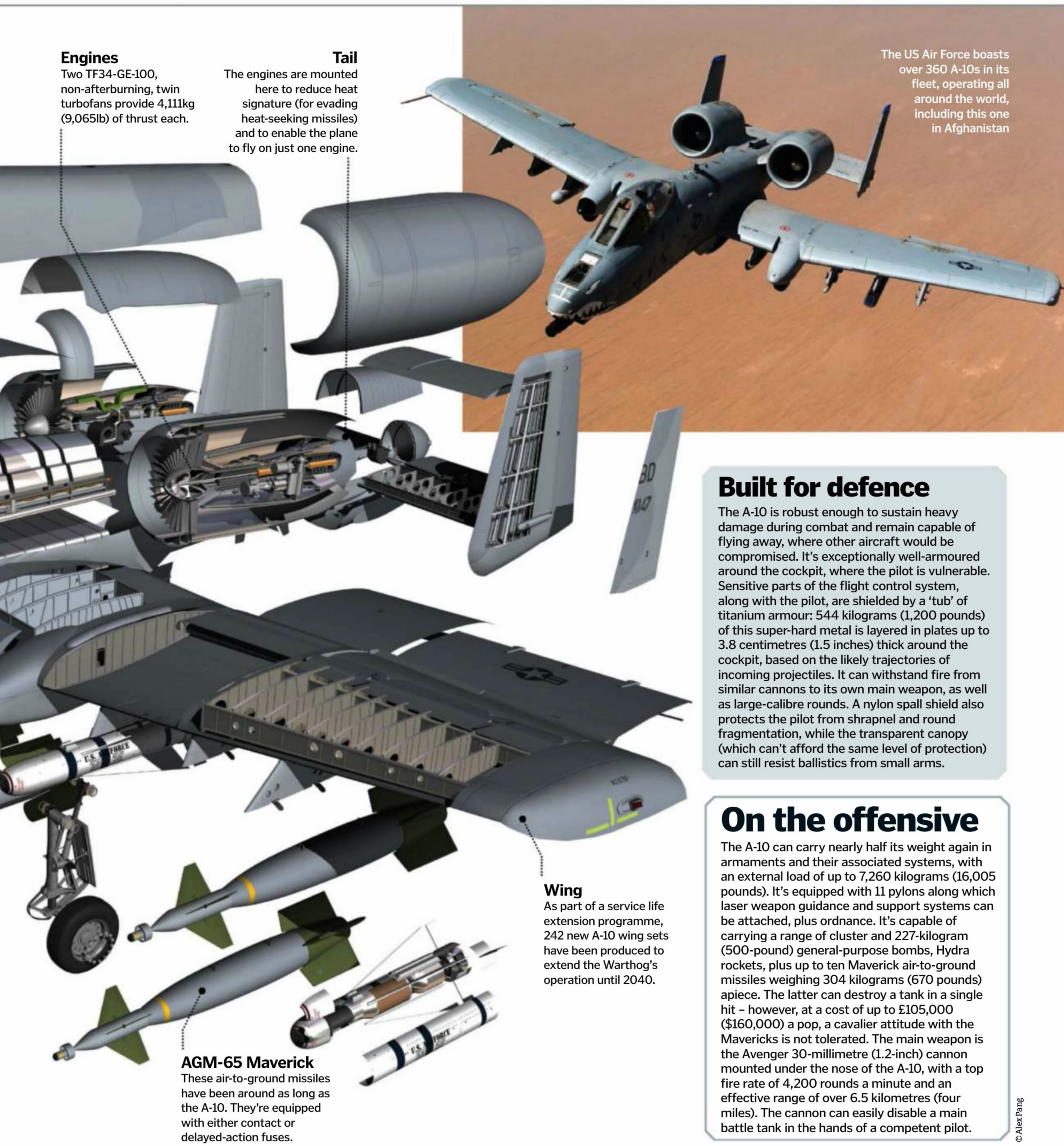
Engines

Two TF34-GE-100, non-afterburning, twin turbofans provide 4,111kg (9,065lb) of thrust each.

Tail

The engines are mounted here to reduce heat signature (for evading heat-seeking missiles) and to enable the plane to fly on just one engine.

The US Air Force boasts over 360 A-10s in its fleet, operating all around the world, including this one in Afghanistan



Built for defence

The A-10 is robust enough to sustain heavy damage during combat and remain capable of flying away, where other aircraft would be compromised. It's exceptionally well-armoured around the cockpit, where the pilot is vulnerable. Sensitive parts of the flight control system, along with the pilot, are shielded by a 'tub' of titanium armour: 544 kilograms (1,200 pounds) of this super-hard metal is layered in plates up to 3.8 centimetres (1.5 inches) thick around the cockpit, based on the likely trajectories of incoming projectiles. It can withstand fire from similar cannons to its own main weapon, as well as large-calibre rounds. A nylon spall shield also protects the pilot from shrapnel and round fragmentation, while the transparent canopy (which can't afford the same level of protection) can still resist ballistics from small arms.

On the offensive

The A-10 can carry nearly half its weight again in armaments and their associated systems, with an external load of up to 7,260 kilograms (16,005 pounds). It's equipped with 11 pylons along which laser weapon guidance and support systems can be attached, plus ordnance. It's capable of carrying a range of cluster and 227-kilogram (500-pound) general-purpose bombs, Hydra rockets, plus up to ten Maverick air-to-ground missiles weighing 304 kilograms (670 pounds) apiece. The latter can destroy a tank in a single hit - however, at a cost of up to £105,000 (\$160,000) a pop, a cavalier attitude with the Mavericks is not tolerated. The main weapon is the Avenger 30-millimetre (1.2-inch) cannon mounted under the nose of the A-10, with a top fire rate of 4,200 rounds a minute and an effective range of over 6.5 kilometres (four miles). The cannon can easily disable a main battle tank in the hands of a competent pilot.

Wing

As part of a service life extension programme, 242 new A-10 wing sets have been produced to extend the Warthog's operation until 2040.

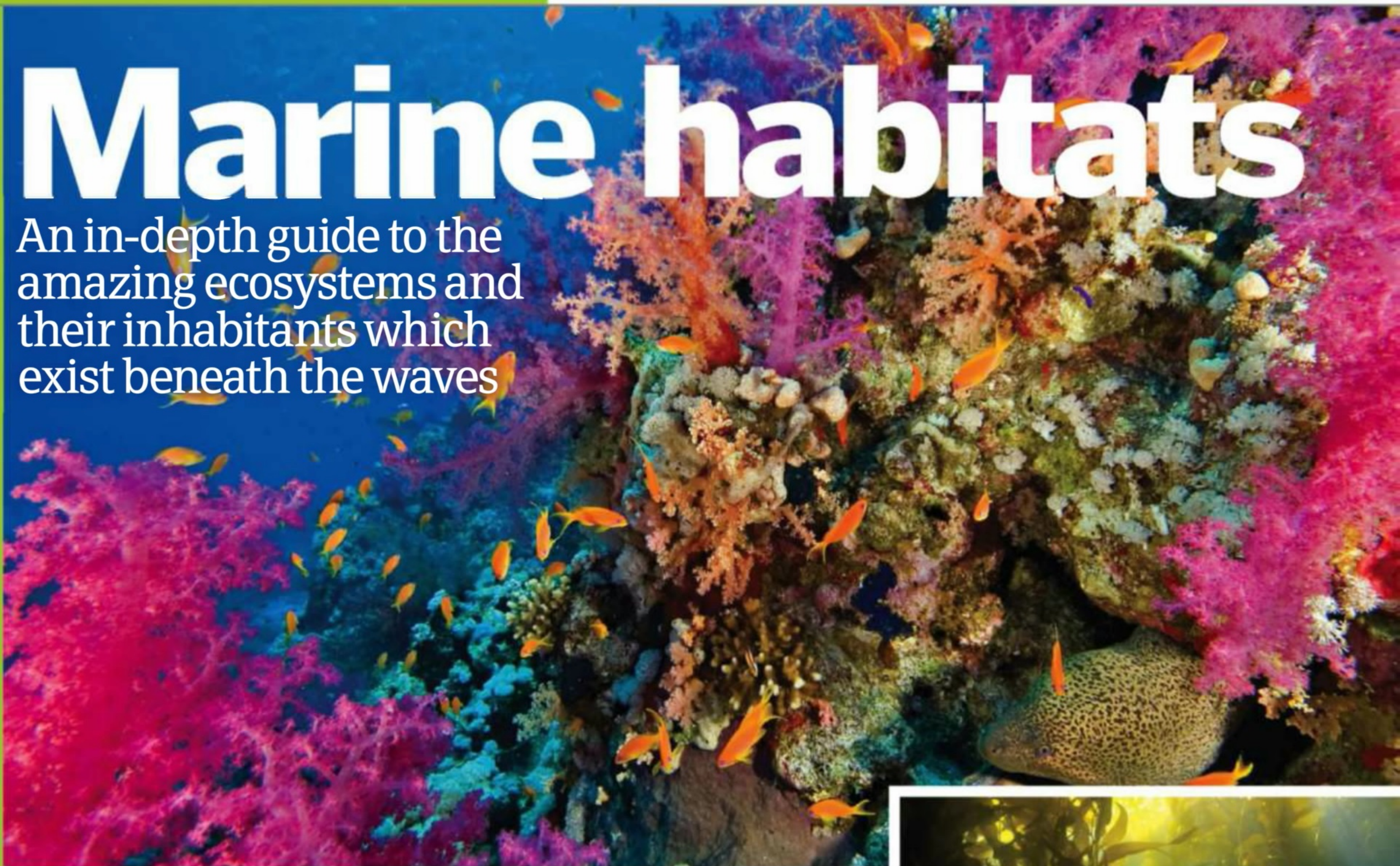
AGM-65 Maverick

These air-to-ground missiles have been around as long as the A-10. They're equipped with either contact or delayed-action fuses.



Marine habitats

An in-depth guide to the amazing ecosystems and their inhabitants which exist beneath the waves



Earth's oceans support thousands of unique habitats. Each species has a niche and is adapted for the physical and chemical properties of its home in the water column (a pelagic habitat) or on the seabed (a benthic habitat). Sunlight is a major governing factor and most species-rich areas are in shallow waters where light is plentiful. Likewise temperature is another key regulator of life in the sea. This is due to its strong influence over the rate of chemical reactions, which affects the growth, reproductive success and general activity of any creatures whose body temperature is the same as the water around them. Each ocean habitat is also affected by many other factors such as salinity, pressure and nutrients to name but a few.

The rocky shore is the first frontier between land and sea. It's known as the littoral zone and is a high-energy environment, battered by waves. Organisms living here have to be hardy, as the waves take their toll and the tide floods in and out twice a day, leaving rockpools to bake in the Sun. Yet despite these hard conditions, the littoral zone is full of life.

The upper tidal reaches are favoured by tough species such as barnacles, limpets and periwinkles. These shell-dwellers hunker down when the tide goes out and re-emerge as the water returns. The middle and lower-shore habitats support the species that are a little less adapted for the absence of water. Algae grow in cracks and crevices with plenty of available light for photosynthesis. Mussels, sea snails and chitons make the middle shore their home, whereas crabs, oysters, anemones, urchins, starfish, kelp and even young fish can be found on the lower shore and in the shallows beyond.

On the sandy beaches that often accompany rocky coastal habitats, the power of crashing waves erodes the shoreline and deposits fine gravel and silt. This creates a porous habitat that is perfectly suited to species of worms that live within the sandy material, as well as flatfish that have evolved to blend in.

Estuaries also shoulder the boundary between land and sea. Characterised by tidal water that fluctuates in salinity, estuaries play host to species that are perfectly adapted to these rapid chemical transitions. Animals like



A giant kelp forest off the rocky island of Catalina, CA

oysters and some crabs can regulate their osmotic properties (the way that their bodies handle saltwater and freshwater) to deal with the daily salinity changes, whereas other creatures prefer to head out with the tides to stay in the salty realm. Other animals such as glass eels actually live in estuarine environments and change their salinity preferences throughout their life cycle.

In warmer climates, estuarine water is often colonised by mangrove swamps, which are ecosystems with another unique set of salinity adaptations. Mangrove trees, of which there are many types, have long, twisting roots that can filter seawater. The leaves can also excrete salt,

How is the fine sand near coral reefs produced?

A Waves B Fish eating coral C Old sandcastles



Answer:

The diet of the reef-dwelling parrotfish (pictured left) consists mainly of the algae within coral polyps. The fish rip off coral chunks and grind it up with teeth in their throats. Excess coral is then excreted as fine sand – yes, it's essentially fish poo!

DID YOU KNOW? At Earth's deepest point, the pressure is 11,318 tons/m² – about the same as trying to hold up 48 jumbo jets!



ON THE MAP

Ocean ecosystems

- 1** Mangrove swamps: southern Florida
- 2** Kelp forests: Monterey Peninsula, California
- 3** Seagrass beds: Shark Bay, Western Australia
- 4** Lowest point on Earth: Challenger Deep
- 5** Artificial reef (made of 25 tanks): Gulf of Thailand
- 6** Hydrothermal vent fields, Mid-Atlantic Ridge



making them ideally adapted for living in brackish water. The large mangrove roots hold the shoreline together and resist erosion as well as protecting the shore from wind and wave energy. This provides shelter for animals and other plants, and mangroves are important nursery grounds and essential food sources for birds, crustaceans and fish, along with large marine mammals such as manatees.

Seagrass beds are often found growing near mangrove ecosystems in estuaries, bays, inlets or lagoons. Seagrasses are one of the few groups of flowering plants in the sea and they need clear, shallow water to grow. These underwater lawns are home to animals such as seahorses and pipefish that rely on the shelter and nutrients from the grass, but as fragile ecosystems, seagrass beds are under threat. Pollution, competition from invasive species and increased sediment in the water are endangering the longevity of these habitats.

Moving farther out from the coast, the shallow offshore waters of the continental shelf

are known as the sublittoral zone. Light is still plentiful in the water column here, which means that productivity is high. Conditions are ideal for plant and algal growth, and so can support some of the ocean's most diverse yet delicate ecosystems: coral reefs.

Reefs form when coral larvae in the water column attach to rocks and other substrates and start to grow. The coral is made up of calcium-carbonate skeletons that house coral polyps. These polyps in turn contain tiny photosynthetic plant cells called zooxanthellae, which lend coral its vibrant colour. The coral needs a specific set of physical and chemical parameters to survive, which is why reefs are so fragile. Lots of light and a relatively constant temperature of around 20 degrees Celsius (68 degrees Fahrenheit) are essential. Because of this, increasing global temperatures are threatening the existence of reefs across the planet. If the temperature of the water gets too high, bleaching can occur which is when the coral ejects the zooxanthellae algae. This causes the coral to turn white, and without the zooxanthellae to photosynthesise, the coral ▶



Man-made reefs

Man-made reefs are areas of the seafloor that are colonised by marine species as a result of the reef's placement by humans. Reefs can be created in order to promote biodiversity in an area, or to compensate for overuse of a habitat. Other artificial reefs are less deliberate, as organisms colonise things such as shipwrecks or oil platforms. The reefs can bring life to otherwise barren areas, providing a substrate for many species to flourish. The ocean floor can be a very challenging place to live, and so once lifted into the water column, organisms are exposed to ocean currents big and small, which bring with them food (plankton) as well as other essential nutrients that enable life to thrive.

Once the reef is in place, the colonisation process will begin almost instantly. The first arrivals will be encrusting species such as barnacles and tubeworms. The larvae of these critters land on the reef by chance; after being spawned, they hitch a ride on the currents and are swept away to find a new home. Then come the hydroids, closely followed by sea urchins and scallops. As diversity increases, so does the deliciousness of the reef for other predators, which are then drawn to the area for food. After a few years, the reef will be bursting at the seams with life, which in turn attracts more new arrivals. Examples of man-made reefs include sunken aircraft carriers, art sculptures, tanks and even memorial gardens where a person's ashes can be encased in a 'reef ball' and laid to rest.

Life in the mudflats

Coastal mudflats are large intertidal expanses of silt and sediment, usually found at the mouth of an estuary or in other sheltered environments. Mudflats are highly productive and are teeming with important biological species and processes. The top layer of mud, which gives the flats their characteristic brown colour is rich in oxygen, but the lower layers are black and anoxic, and these support a different type of microbial ecosystem based on chemical reactions. Species diversity is usually low, but numbers of these animals are very high and the oxygenated mud generally harbours lugworms, cockles, mussels and some types of algae, among many others. Intertidal mudflats also provide a nursery ground for many creatures, eg salmon, which take advantage of the sheltered waters to feed and mature before leaving for the open ocean. Similarly migratory birds and coast-based mammals also depend on the mudflats for their calorie-rich food stores.



Seamount ecology

Seamounts are underwater mountains that rise from the ocean floor. They appear near tectonic boundaries or hotspots and are formed as lava seeps out of the Earth and cools in the water to form a conical structure. When the mountain gets large enough it will breach the surface – the Hawaiian islands formed this way, for example.

Seamounts are oases of life in the open ocean as their conical shape provides a safe haven for deep-sea corals, sponges, worms, crustaceans and fish. The mountain soars high off the seabed, so strong currents run over it, providing plankton for filter-feeding species and promoting the upwelling of nutrients to support thousands of animals – many unique to these habitats. Fish are drawn to this bounty of food, and themselves attract larger predators like sharks and tuna. Seamounts are also thought to be navigational aids for migrating ocean dwellers like whales.



“Another strange yet beautiful adaptation of animals in deeper habitats is bioluminescence”

will die. Without the coral, the ecosystem it once supported will eventually decline and the thousands of species living there will need to find a new home.

In the clear, near-shore habitats that have cooler temperatures, giant kelp forests make the most of the sub-littoral light. Instead of roots, kelp has finger-like holdfasts that grip on to rocks on the ocean floor. The cool, oxygen- and nutrient-laden water provides an environment where the kelp can thrive. And, in turn, the expansive forests provide food and shelter for fish, seals, jellyfish and sea otters, among others.

As the continental slope begins to increase, the ever-deeper water provides new niches to fill. The epipelagic zone is the upper sunlit layer of the open ocean and this habitat bears a stark contrast to the species-rich environments of the littoral and sublittoral zones. Many large, ocean-going species are found here, such as cetaceans like whales and dolphins, invertebrates such as jellyfish and large fish

such as bluefin tuna and marlin, but they are few and far between. These animals are specially adapted to living in this vast expanse of water, with streamlined bodies, powerful muscles and clever camouflage.

Deeper still, the seabed continues to drop through the bathyal and bathypelagic zones and then levels off at the abyssal plain and abyssopelagic zone. Marine biologists know very little about the life that survives at and below these depths. What we do know is it's icy cold, pitch black and the staggering pressure would crush any air in the swim bladders of regular fish.

But deep-sea varieties have bodies that are made mostly of water. Muscles are more gelatinous with less protein, meaning a slower pace of life is essential. Helpfully this saves energy in a deep-sea organism, as food is often scarce. Another strange yet beautiful adaptation of animals in deeper habitats is bioluminescence. In the case of the anglerfish it is used to lure prey; others use their flashing lights to attract a

mate or confuse predators. However animals also have to rely on the heightening of other senses, such as smell or vibration to find a meal – or not become one.

The abyssal plains and their alien-like inhabitants are interrupted by mountainous scores through the seabed in the form of oceanic ridges. Ridges are hotspots of tectonic activity, and also boast one of the most interesting marine habitats: hydrothermal vents. Hundreds of clam, mussel, shrimp, tubeworm and snail species populate the large chimneys that spew out magma-heated, mineral-rich waters from the Earth's crust. Chemicals dissolved in the vent waters form the basis of the food chain in lieu of sunlight.

These environments are totally different to those found in shallower waters hundreds of metres above. They are a prime example of how marine life is capable of flourishing under some of the most extreme conditions, and proof that the creatures which live in the ocean truly are masters of adaptation.

From surface to seabed

Explore the types of ocean ecosystem and see how their inhabitants have adapted to them



Epipelagic zone

Coral reef

Bright coral species live in shallow water with plenty of light so symbiotic zooxanthellae algae can easily photosynthesise.

Pelagic species
Animals which live in the open ocean have streamlined bodies, powerful swimming muscles and often camouflaged bodies to afford them protection.

Open ocean
The sunlit top layer of the open ocean offers minimal nutrients and so is often called the 'marine desert'.

Sandy habitats
Animals which live here are masters of camouflage, such as rays and other flatfish that blend into the background to hide from predators.

Plankton

1 Phytoplankton (algae) and zooplankton (tiny animals) provide food for many animals. Larvae drift in the zooplankton to distribute species, while phytoplankton is the base of all marine food webs.

Carnivores

2 Carnivores keep the food web in check and regulate the populations of their prey. Without top predators, an opportunistic species could take over an ecosystem.

Bacteria

3 These microscopic decomposers are as vital as any bigger animal. They convert dead organic matter back into nutrients that are then made available to plants.

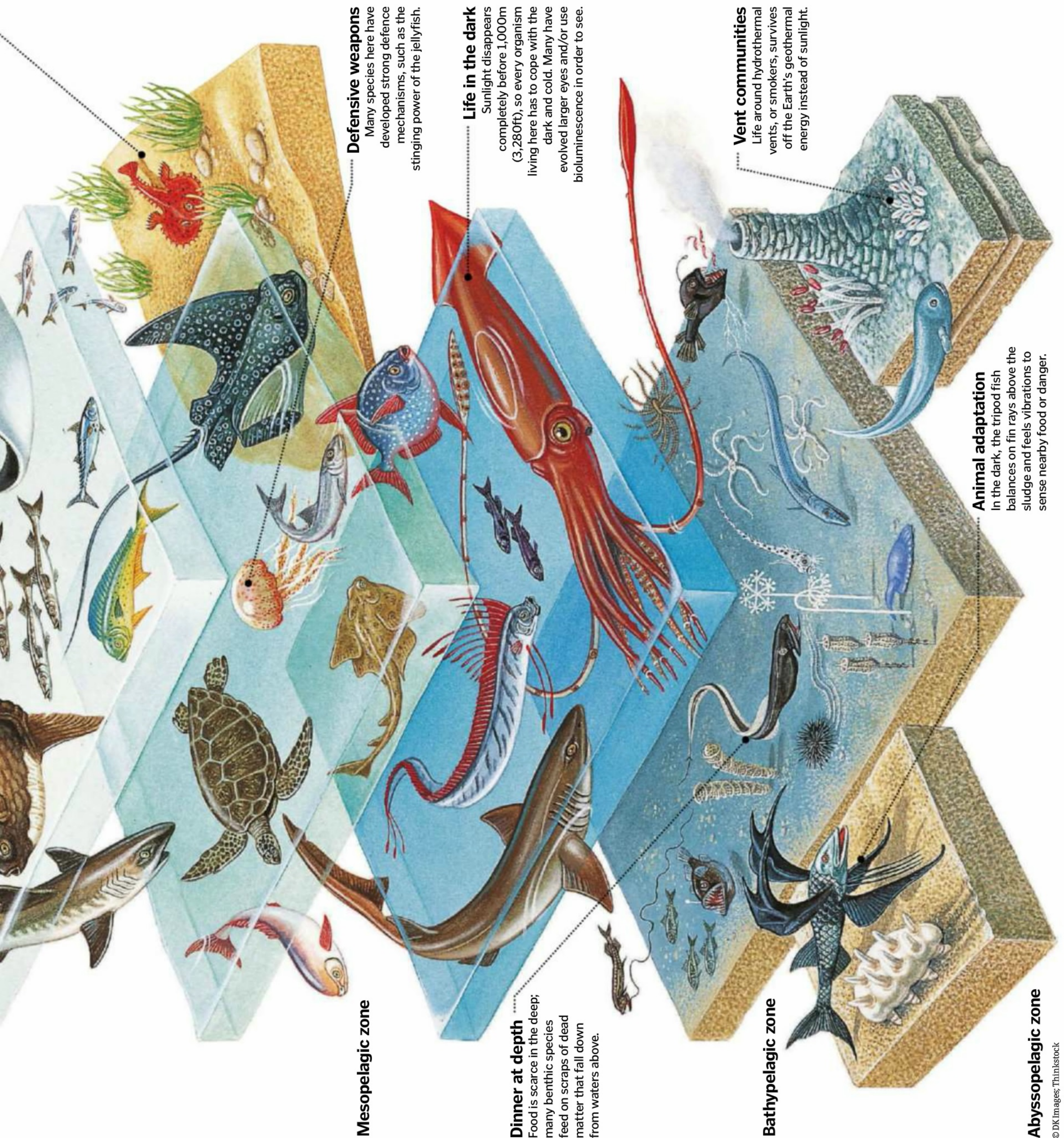
Plants

4 As well as microscopic algae, larger algal species as well as marine plants are crucial. They get energy from the Sun and photosynthesise to provide an entire ecosystem with food.

Herbivores

5 Usually animals such as small fish graze on plants and algae. They are prey for carnivores that then feed the apex predators. A few mammals like manatees are herbivores too.

DID YOU KNOW? Giant kelp that forms huge forests in shallow, sunlit waters can grow up to 30cm [12in] per day



Defensive weapons
Many species here have developed strong defence mechanisms, such as the stinging power of the jellyfish.

Life in the dark
Sunlight disappears completely before 1,000m (3,280ft), so every organism living here has to cope with the dark and cold. Many have evolved larger eyes and/or use bioluminescence in order to see.

Vent communities
Life around hydrothermal vents, or smokers, survives off the Earth's geothermal energy instead of sunlight.

Animal adaptation
In the dark, the tripod fish balances on fin rays above the sludge and feels vibrations to sense nearby food or danger.

Mesopelagic zone

Dinner at depth
Food is scarce in the deep; many benthic species feed on scraps of dead matter that fall down from waters above.

Bathypelagic zone

Abyssopelagic zone



“Thermoreceptors on their noses enable them to pinpoint where blood flows closest to the prey’s skin”

Geode geology

They may look unassuming on the outside, but these rocks are hiding treasure within...

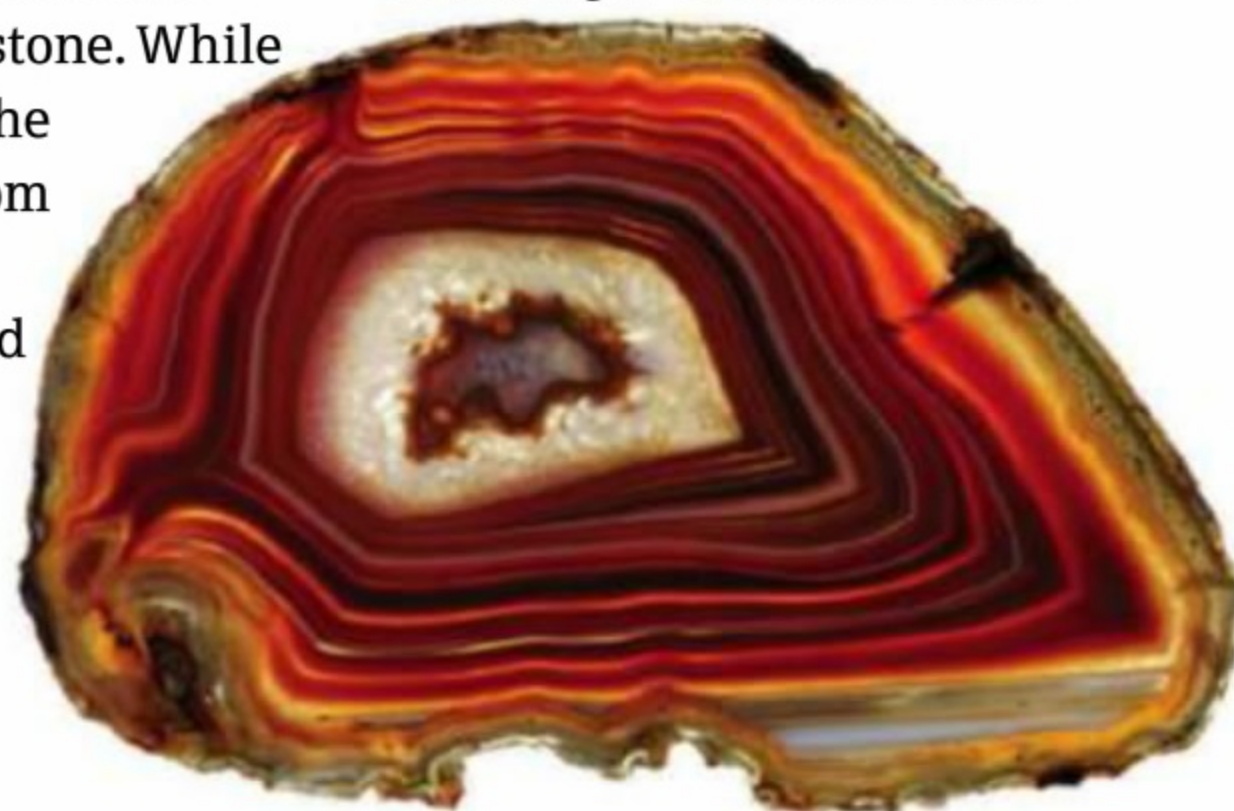


Geodes are the perfect embodiment of the expression: it’s what’s on the inside that counts. Although there’s some dispute over the finer details of how these crystalline structures develop, there are currently two environments known to support them: sedimentary rock (eg limestone) and volcanic rock (eg basalt).

For both, the process starts with a hole encased in the rock, but where this cavity comes from differs. In igneous rock, gas bubbles in the magma become trapped as it turns to stone. While in sedimentary rock the cavity might result from concretions (accumulations of hard minerals) disintegrating, or even organic matter, like a dead animal or plant root, rotting away to leave a void.

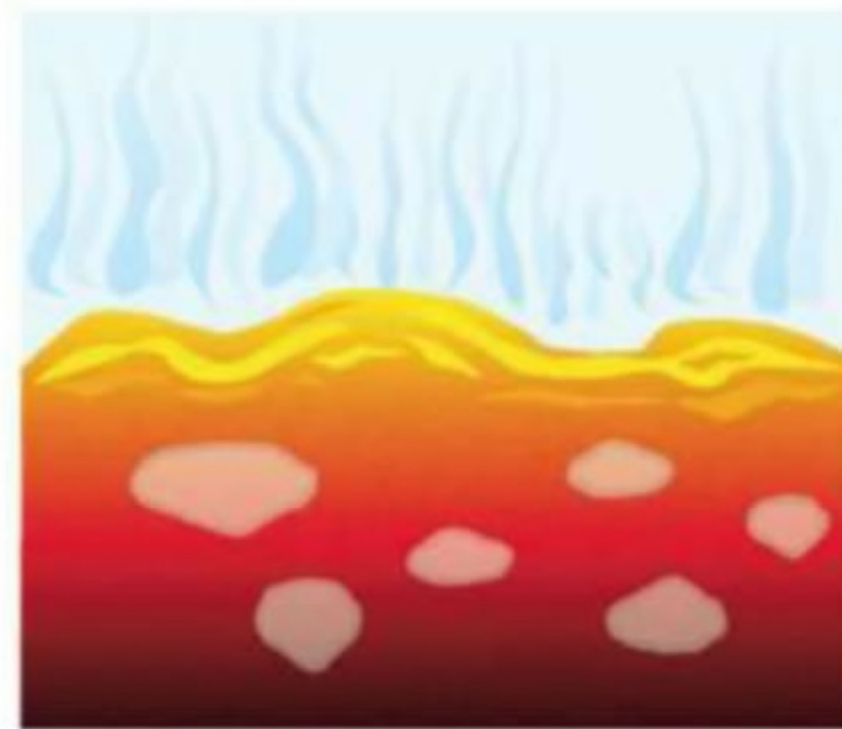
Groundwater containing tiny traces of minerals passes through the rock, including through this hollow, and over millennia a layer of gel-like silica is left lining the cavity, which then hardens into a solid shell of quartz-based chalcedony as it dries out.

Over time, more and more water permeates the cavity and all manner of minerals – like agate, amethyst and jasper – precipitate out, forming inwardly pointing crystals. If the hole becomes completely filled, it’s no longer called a geode but a nodule.



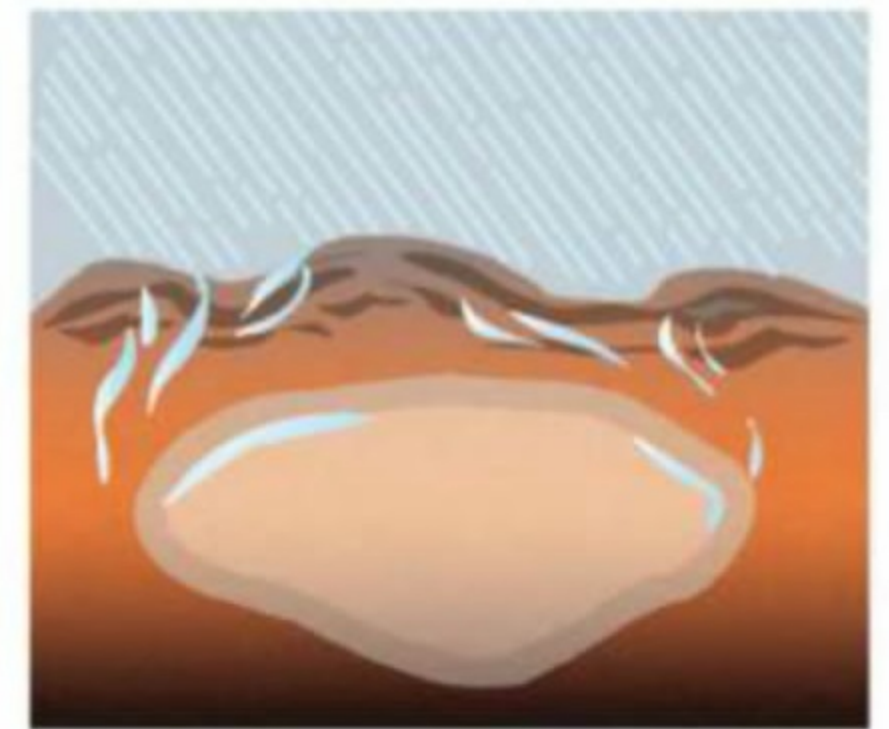
Volcanic geode formation

See how one of these colourful crystal structures develops over many years



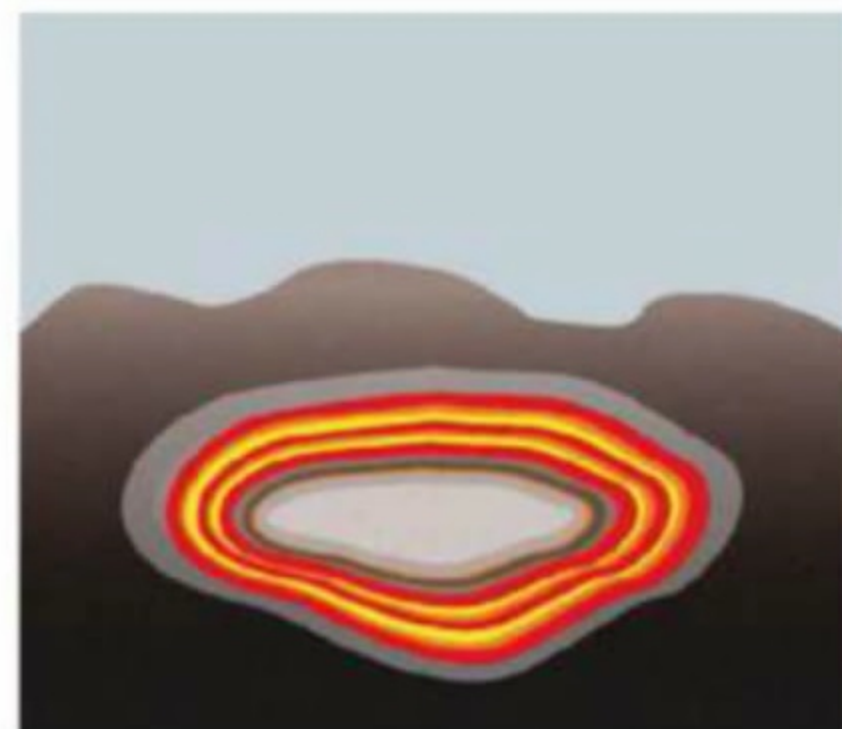
1. Bubble

Volcanoes and tectonic activity push magma towards Earth’s surface. As the lava solidifies into sheets of igneous rock like basalt, gaseous bubbles are trapped, leaving variously sized cavities.



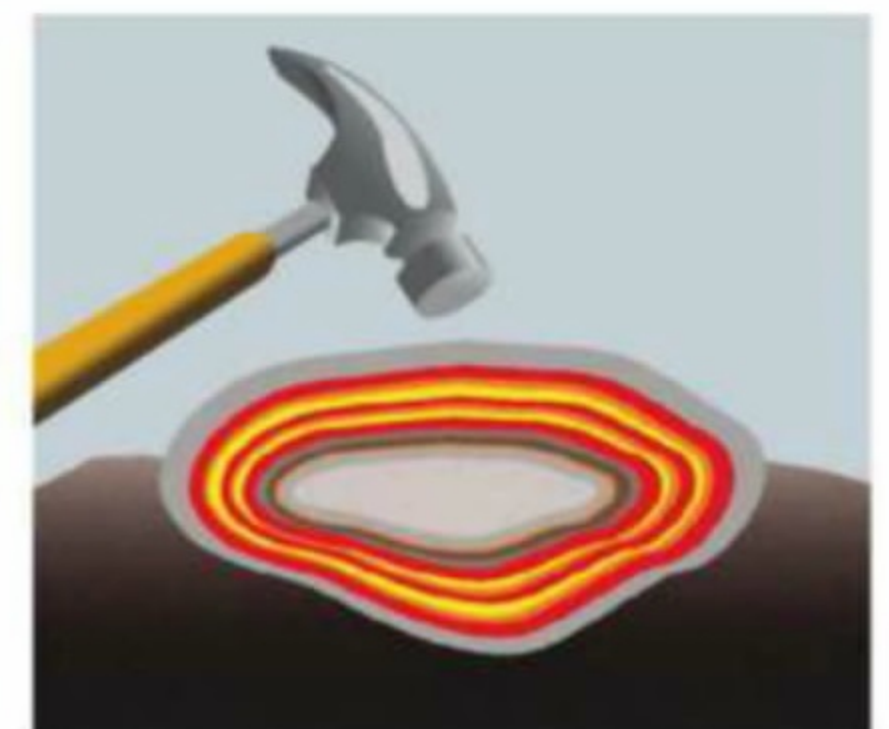
2. Mineral-rich water

Groundwater seeps through the rock, absorbing minerals like silicates as it goes. As it passes through the hollow, it deposits tiny traces on the sides that build up to form a layer of chalcedony.



3. Layer by layer

This process repeats, precipitating new crystals, which can vary greatly in type, size and colour, depending on impurities as well as regional geological conditions like temperature and pressure.



4. Exposure

Whether a result of weathering or more dramatic tectonic activity, the rock layer can break up, exposing the geodes within. Gem collectors look out for their telltale egg-like shape and then break them open.

How do vampire bats survive?

Discover how these flying mammals get by on a diet consisting solely of blood

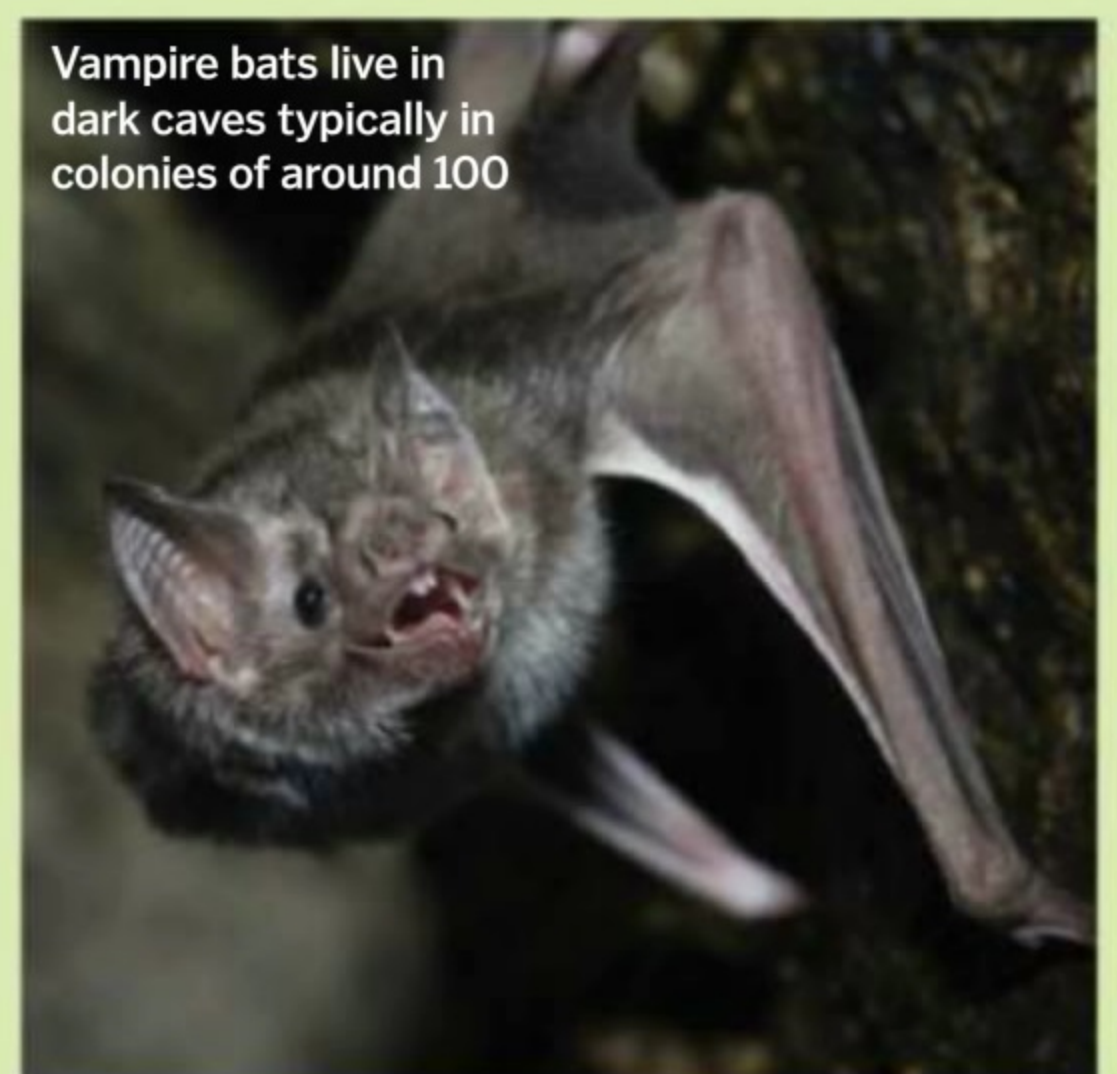


In the realm of books and movies, vampires are big business, but the natural world can boast the real thing. Found across the tropical forests of South America through to Mexico, much like its fictional counterpart, the vampire bat sleeps during the day – usually in dark caves – and only ventures out at night to feed.

Their most common unwitting ‘donors’ are large herbivores like horses and cows, though human attacks are not unheard of. Most of the time, victims will rarely notice as the bats only consume about a tablespoon of blood per sitting; this said, they are often accused of spreading rabies. Contrary to popular belief,

they don’t actually ‘suck’ the blood either, but rather nip the skin with their sharp teeth and then lap at the blood that flows out.

Like all bats they use echolocation to get around, but they have also evolved some unique ways to hunt. For one thing they have special thermoreceptors on their noses, which – via infrared radiation – enable them to pinpoint where blood flows closest to the prey’s skin, while an anticoagulant in their saliva stops blood clotting before they’ve had their fill. Vampires are also unusual within the bat family for their ability to walk, climb and even hop along the ground – ideal for stealthily approaching slumbering victims.



Vampire bats live in dark caves typically in colonies of around 100

© Thinkstock



1. OLD

Lucy

Lucy is probably the most famous fossil of a human ancestor in the world. Almost 40 per cent of her 3.2-million-year-old skeleton is intact.



2. OLDER

Archaeopteryx

Archaeopteryx is arguably Earth's oldest bird. It lived around 150 million years ago and had a dinosaur's teeth and tail so it's seen as a transitional species.



3. OLDEST

Trilobite

The earliest arthropod trilobites first appeared 521 million years ago in the Early Cambrian era. They have been found in Africa, Europe and North America.

DID YOU KNOW? The FBI seized the world's largest skeleton of a T-rex dinosaur [Sue] during a 1992 legal dispute

Fossil formation

How do fossils record the history of life on Earth?

In August 1990, a volunteer palaeontologist called Susan Hendrickson discovered a fossilised spine and leg bone sticking out of a cliff in South Dakota, USA. She was to unearth the biggest and most intact skeleton of a Tyrannosaurus rex ever found. The T-rex – nicknamed Sue – was once a vicious carnivore more than 3.5 metres (12 feet) tall.

Fossils like Sue are physical evidence of the history of life on Earth. They include footprints, animal tracks, dinosaur skeletons, impressions left by plant leaves and even tiny ridges built by bacteria. Few living creatures become fossils though – most rot away completely or are eaten when they die.

Hendrickson didn't find Sue entirely by chance – she searched in the right place. Exposed at the cliff face were rocks 65-67 million years old, formed when

dinosaurs were roaming the Earth. Significantly younger or older rocks wouldn't contain T-rex fossils. This rock layer – sometimes called the Hell Creek Formation – comprises sandstones, mudstones and clays. Like most rocks that contain fossils, it would have formed underwater. The Hell Creek Formation specifically is made from ancient sand, silt and clay deposited on a warm and moist river delta.

Fossils also reveal the positions of ancient seas or other bodies of water. Ammonites, for example, were ocean molluscs whose fossilised shells could reach two metres (6.6 feet) across. Ammonites can be found in the mountains near Kremmling, Colorado – thousands of kilometres from the ocean today, but their presence confirms Colorado was largely covered by sea when they lived about 70 million years ago.

Wood to rock

Petrified forests are woodlands that have turned to stone. In the Petrified Forest National Park in Arizona, you can find petrified logs from conifers, tree ferns and ginkgos that grew around 215 million years ago, when some of the earliest dinosaurs were alive. Among the park's coolest features is Agate Bridge, a natural arch made from a fossilised conifer 34 metres (100 feet) long.

Petrified forests begin forming when trees are buried rapidly beneath river sediments or volcanic ash. This deprives them of oxygen (and so bacteria), which stops them rotting. Petrification happens if these trees soak in mineral-rich water for a long time. The minerals seep into the wood and eventually replace it, turning the tree to stone. Petrified trees are usually made of clear quartz, but can be brightly coloured by metals like iron and copper.

A fossil in the making

The process that turns a deceased dino to stone

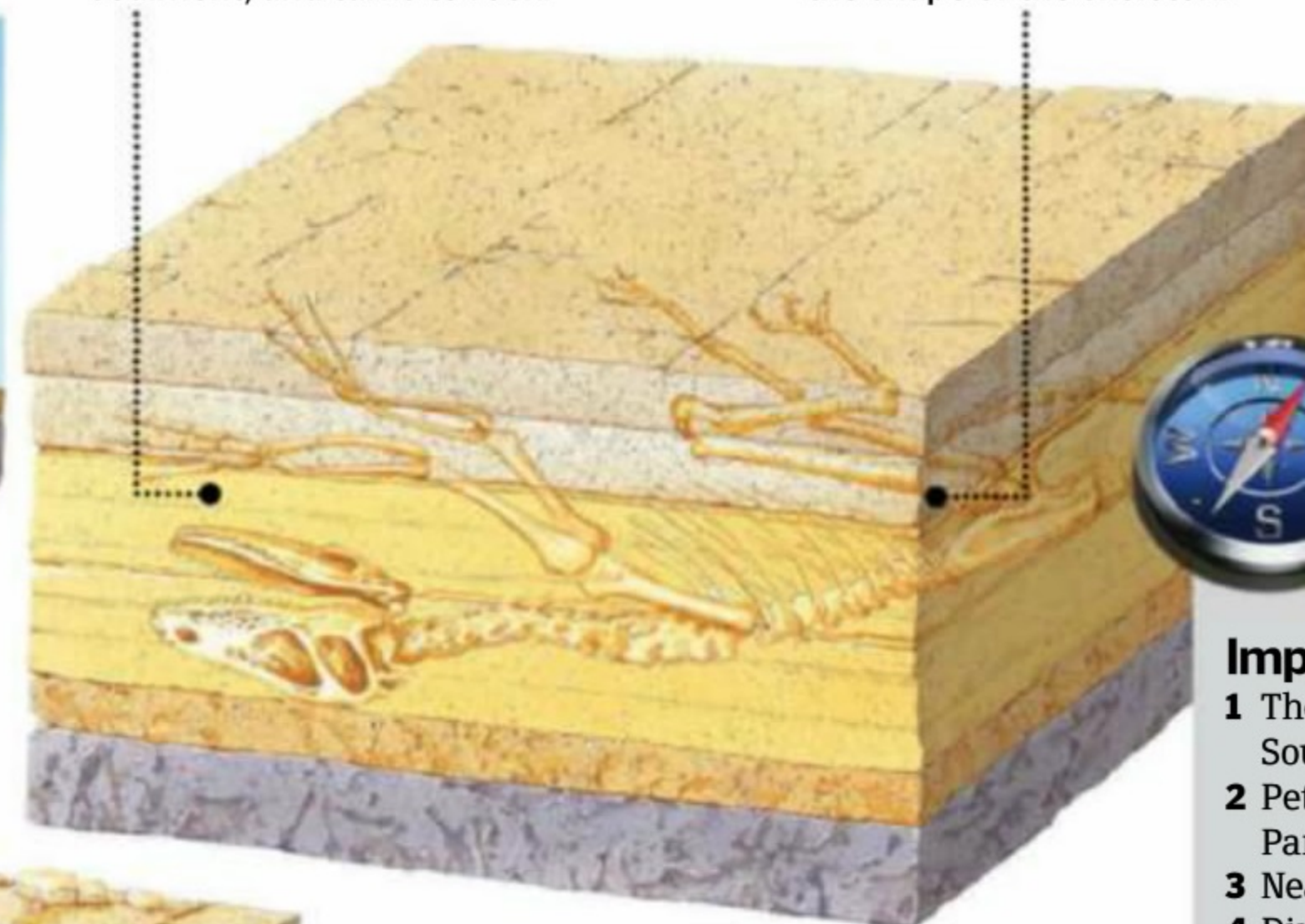


1. Creature buried

A dead animal falls to the sea-/riverbed and is buried by sediment. This prevents its skeleton rotting away due to a lack of oxygen.

2. Sediment compressed

The sediment containing the skeleton is compressed by the weight of overlying sediment, and turns to rock.

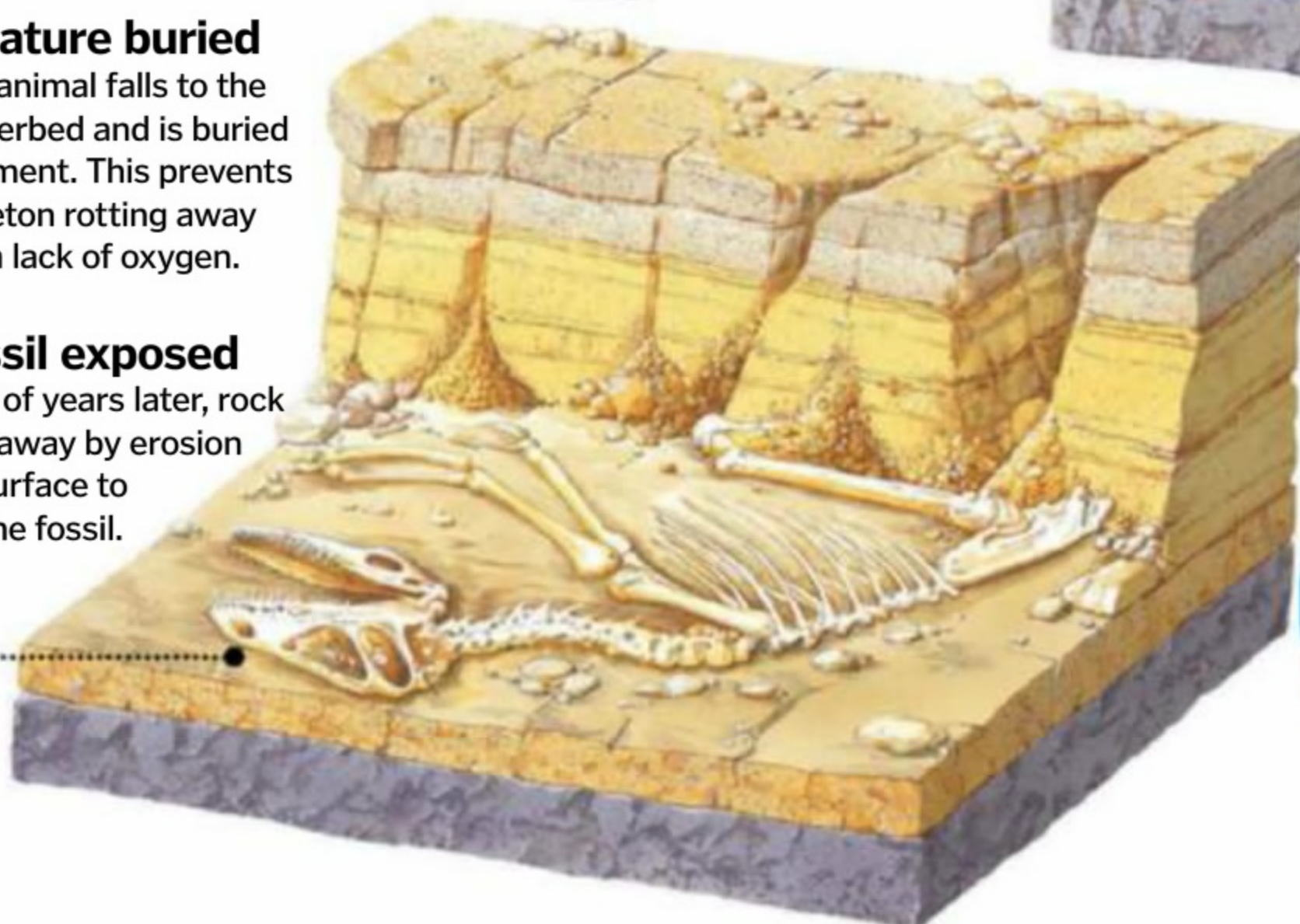


3. Fossil forms

Groundwater dissolves the bones, leaving a cavity. The water deposits minerals, forming a fossil the shape of the skeleton.

4. Fossil exposed

Millions of years later, rock is worn away by erosion at the surface to reveal the fossil.



ON THE MAP

Important fossil sites

- 1 The Cradle of Humankind, South Africa
- 2 Petrified Forest National Park, Arizona, USA
- 3 Neander Valley, Germany
- 4 Dinosaur Cove, Victoria, Australia
- 5 Mammoth Site, South Dakota, USA



Anatomy of the pig

Often maligned in popular culture and language, hogs are much smarter and cleaner than you might at first think...

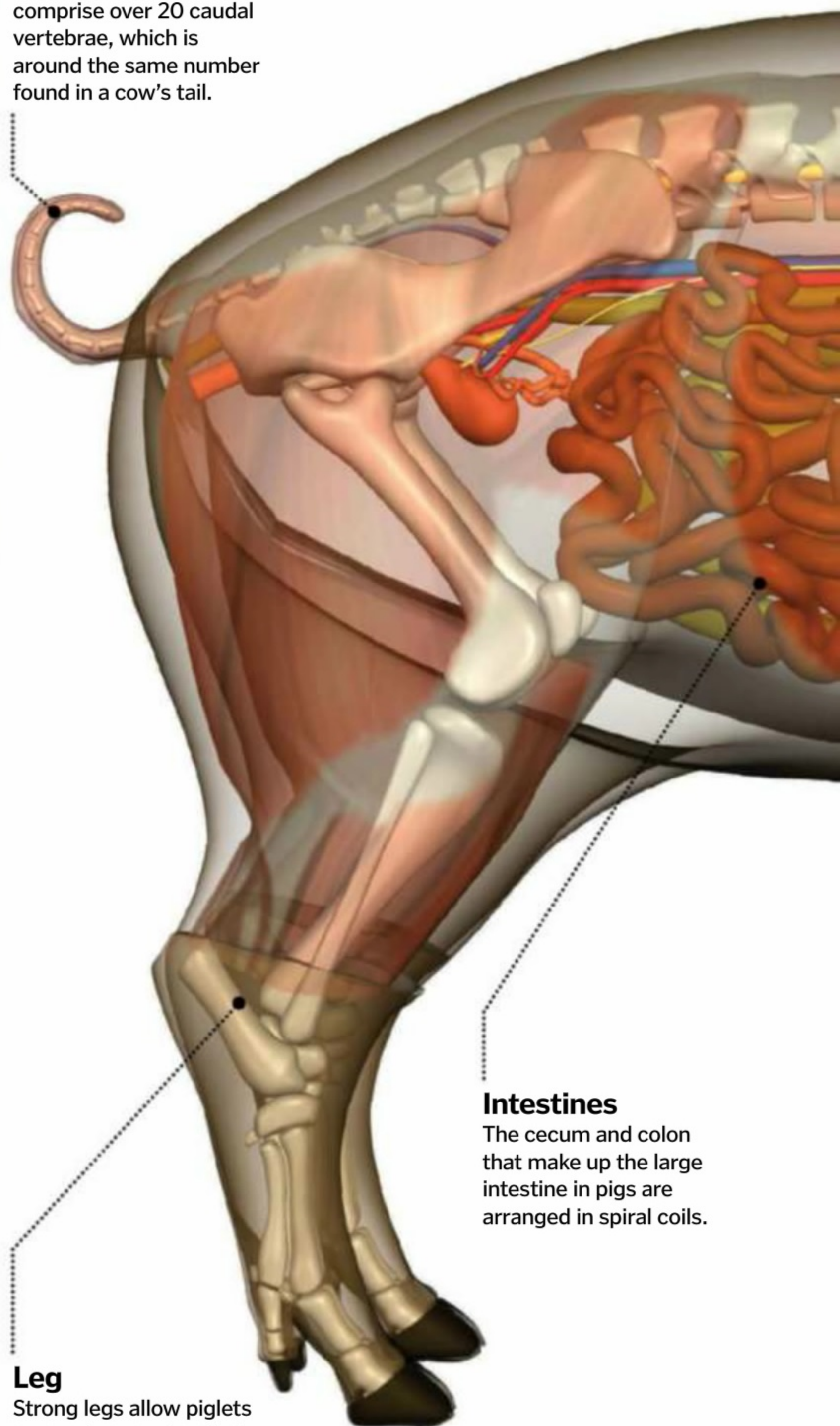


Piggy physiology

What is special about the anatomical make up of the pig?

Tail

A pig's short tail can comprise over 20 caudal vertebrae, which is around the same number found in a cow's tail.



Intestines

The cecum and colon that make up the large intestine in pigs are arranged in spiral coils.

Leg

Strong legs allow piglets to stand soon after birth. As adults they use that strength to dig for food.



It seems unfair that the English language has amassed so many derogatory sayings about pigs, because under the skin they're a lot like us. Indeed, the hearts of some breeds are similar enough in weight, internal structure and the rate at which blood is pumped through to have potential for human heart transplants. Pigs are also impressive learners. In a study published in 2009 scientists showed a reflection of food to pigs who had previously seen mirrors and compared their responses with a group that hadn't. The former were much less likely to think the food was behind the glass.

Pigs and other members of the Suidae family, which includes wild boars and warthogs, have a strong skeleton that allows them to be sturdy defenders of their territories and offspring. They also have a very good sense of smell that compensates for poor eyesight. A hog's snout, together with its even-toed trotters

and short, muscular limbs, is perfectly adapted for sniffing out and uncovering food buried in the soil of the forests and grasslands in which the species evolved.

Wild pigs will consume grubs, amphibians and small birds as well as forage for roots, leaves, nuts, fruit and fungi. To chew on this omnivorous diet they have canine, incisor and molar teeth, just as we do. The pig's digestive system, meanwhile, features anatomical differences from ours (a spiral colon, for example), but works the same way: food is broken down in a one-chambered stomach and intestines and then passes through to the colon for excretion.

Contrary to the myth, pigs keep bodily waste away from food and don't wallow in it. They do like a mud bath because they don't perspire. Wet mud keeps them cool as heat is given off by evaporation – a technique also used by elephants. 'Sweating like a pig' then is one saying that definitely does pigs a disservice. ❁

Jamón ibérico de bellota is arguably one of the tastiest meats on Earth, but it comes at a premium. Cut from free-range, acorn-fed Spanish pigs, it is cured for two years or more before it's sold.

DID YOU KNOW? Extinct entelodonts might be nicknamed 'hell pigs' but are only distantly related to modern porkers

Spine

Projections on the strong lumbar vertebrae broaden the abdomen and are attached to muscles that support the internal organs.

Skin

Although the structure of a pig's skin is similar to our own, they have very few sweat glands. To cool down they bathe in mud; this also serves as a kind of sunscreen.

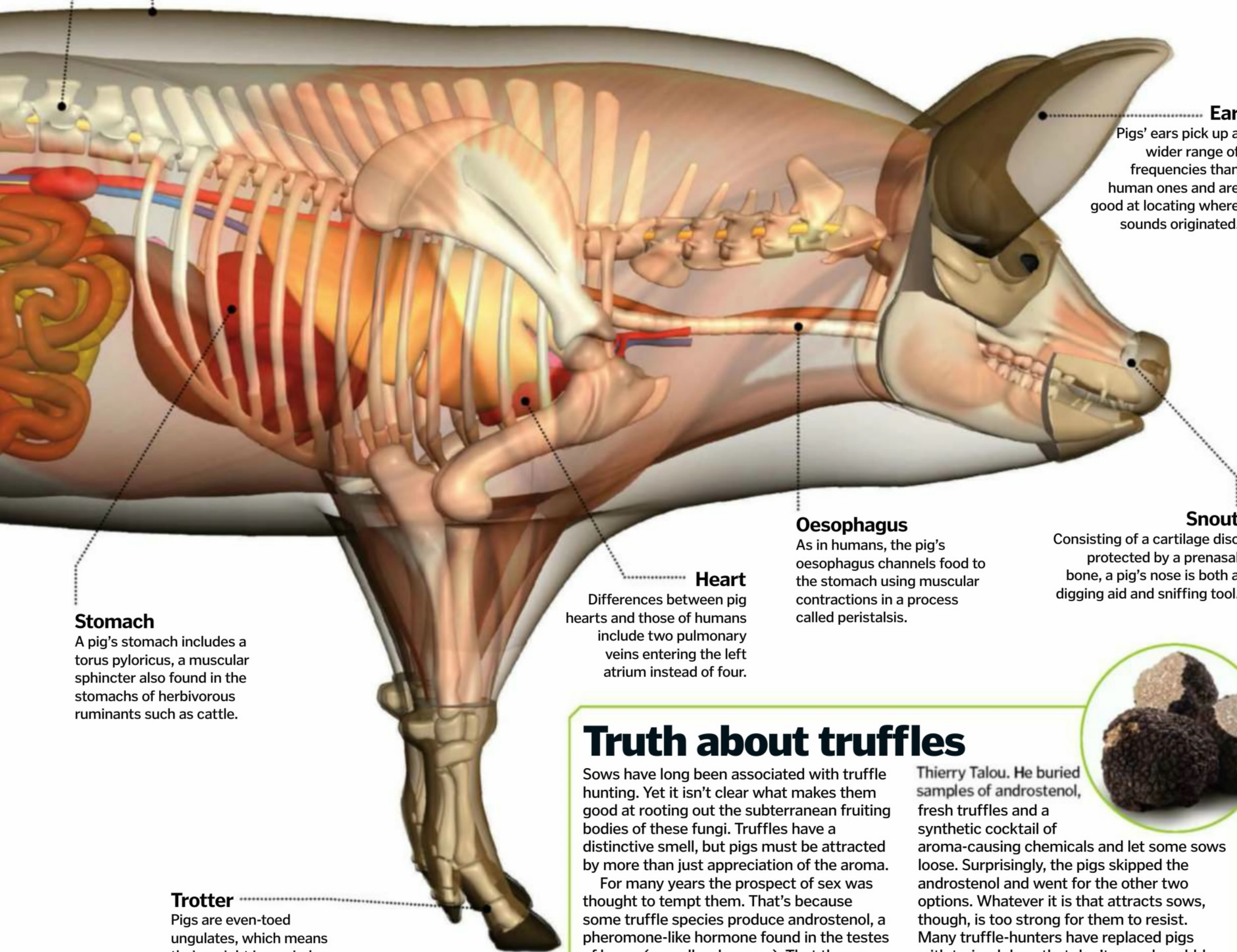
Pork's unwanted passengers

Once you realise what might be lurking inside your pork chops you might be inclined to turn up your oven. Pigs can be infected by common roundworms in the genus *Trichinella*. Transmission to humans can occur through eating meat that isn't cooked at a high enough temperature to kill the larvae. Ingestion results in trichinosis, with symptoms including dizziness and stomach ache. Among pig parasites, though, pork tapeworm (*Taenia solium*) is more concerning.

The larvae of this tapeworm also enter the human body through undercooked meat. Once inside, they migrate to the tissues, causing cysticercosis. The symptoms can be minor if they infect only muscles, but can include loss of vision or weakness if larvae reach the eyes or the spine. The infection can be more serious still if worms reach the brain and form cysts, causing neurocysticercosis; in these cases, victims can fall into a coma or even die suddenly.



Tapeworms are nasty parasites that set up home in the intestines



Stomach

A pig's stomach includes a torus pyloricus, a muscular sphincter also found in the stomachs of herbivorous ruminants such as cattle.

Heart

Differences between pig hearts and those of humans include two pulmonary veins entering the left atrium instead of four.

Oesophagus

As in humans, the pig's oesophagus channels food to the stomach using muscular contractions in a process called peristalsis.

Ear

Pigs' ears pick up a wider range of frequencies than human ones and are good at locating where sounds originated.

Snout

Consisting of a cartilage disc protected by a prenasal bone, a pig's nose is both a digging aid and sniffing tool.

Trotter

Pigs are even-toed ungulates, which means their weight is carried on the third and fourth toes of their cloven hooves.

Truth about truffles

Sows have long been associated with truffle hunting. Yet it isn't clear what makes them good at rooting out the subterranean fruiting bodies of these fungi. Truffles have a distinctive smell, but pigs must be attracted by more than just appreciation of the aroma.

For many years the prospect of sex was thought to tempt them. That's because some truffle species produce androstenol, a pheromone-like hormone found in the testes of boars (as well as humans). That theory, however, was undermined by French chemist

Thierry Talou. He buried samples of androstenol, fresh truffles and a synthetic cocktail of aroma-causing chemicals and let some sows loose. Surprisingly, the pigs skipped the androstenol and went for the other two options. Whatever it is that attracts sows, though, is too strong for them to resist. Many truffle-hunters have replaced pigs with trained dogs that don't eagerly gobble up the fungal delicacies they find.





Ancient Greek theatres

We discover how these massive amphitheatres were built and used



With the invention of tragedies in the late-sixth century BCE, comedies in the fifth century BCE and the satyr play tragicomedies around the first century BCE, the Ancient Greeks had to build a huge number of impressive theatres to do their plays justice. As the centuries went on – and the popularity of the theatre grew and grew – the buildings had to expand and adapt to meet the demand. Indeed, many of these semicircular amphitheatres could seat well over 10,000 people and were used frequently during religious festivals such as the Dionysia, a major celebration centred around the god Dionysus.

While the theatres of the Ancient Greeks began as simple clearings with a smattering of wooden benches for the audience to sit on, before long they had grown into full-blown sanctuary-like facilities. These included large banks of stone seats, a vast orchestra and acting area, a complex backstage network of rooms, entrances and trapdoors, as well as a wide selection of ornate and decorative scenic backdrops. These features, along with the Ancient Greeks' love for festivals, led theatres to take a central role in cementing and spreading Greek culture – something the Romans would later adopt for themselves.

Theatres were made primarily out of stone, often with the amphitheatre's seats placed into the side of a hill for extra support, while traditional construction methods for civic buildings and temples were transferred for the production of colonnades, scenery and entranceways. Interestingly, the greatest technical feat in constructing many of these theatres were the excellent acoustics, with the shape and angle of the seating arrangement and materials (limestone was a popular choice, for instance) serving as acoustic traps. These would filter out low-frequency sounds like spectator chatter and enhance the high frequencies of the performers' voices.

Tour of the theatre

Take a guided tour of the theatrical building at the heart of Ancient Greek entertainment

Kerkis

The koilon was composed of a series of wedge-shaped seating blocks (kerkides) arranged in a semicircle. These were divided by various walkways and stairs.

Thyroma

These structures were stone pillars into which vertical grooves were cut. The grooves received the painted background panels and held them in place.

Episkenion

The upper storey of the skene. Accessed by a ramp or stairwells, it provided an additional acting/singing space.

Prohedria

This was the general term used for any stone seating within the theatre – but is sometimes used to specifically describe the honorific seats in front of the orchestra.

Analemmata

Often the theatre's koilon was built into a hillside, which acted as a natural brace. However, the outer edges could be left exposed and so were secured by analemmata – ie retaining walls.





1. BIG

Theatre of Delphi

Located behind the Temple of Apollo in the Sanctuary of Delphi, this theatre has 35 rows of seats for spectators.



2. BIGGER

Odeon of Herodes Atticus

With a capacity of 5,000, the Odeon is located on the Acropolis in Athens, Greece, and is still used for performances today.



3. BIGGEST

Theatre of Epidaurus

Built in the fourth century BCE and able to seat 15,000, this theatre is one of the largest classical examples in the world.

DID YOU KNOW? Members of Ancient Greek acting guilds were referred to as 'technitai'

Pinakes

Pinakes were the painted wooden panels used as changeable backdrops to indicate where the action was taking place. They were inserted into the skene's slotted thyromata.

Skene

This background structure was used by the actors and theatre workers to change costumes, assemble props and operate any mechanical apparatus. It would often resemble a Greek temple.

Diazoma

Midway up the koilon a semicircular walkway, known as the diazoma, split the amphitheatre's seating area in two.

The role of masks

The wearing of masks in a theatre setting was not invented by the Ancient Greeks but was a key part of all their productions. For one thing, masks were closely connected to Ancient Greek religion, with many of their gods – who famously liked to meddle in the affairs of humans – depicted in each performance. The masks worn by the actors therefore both allowed them to transform into a deity visually, as well as venerate them in a form of ritual performance; indeed, records indicate many masks were burned after each show as a sacrifice.

Secondly, masks enabled each actor to be better seen by the audience, with exaggerated features such as noses and mouths, as well as facial expressions, more easily transmitted at a distance. The hiding of the face also enabled each actor to play multiple roles – especially female characters, as women were banned from acting within the theatre at this time.

One of the most common deity masks worn was that of Dionysus, who among other hedonistic roles – such as the god of wine and revelry – was also the god of the theatre.

Parodos

Both actors and audience members could enter through parodoi into the theatre proper. Typically, entrances were located either side of the skene.

Thymele

This was an altar-like structure used by the leader of the chorus to direct the other singers, much like a conductor. It was located at the centre of the orchestra.

Koilon

The koilon was the theatre's seating area, though it was sometimes used to describe the theatre as a whole too.

Klimakes

Located at either side of the kerkides were klimakes, narrow stone steps that led from the bottom of the koilon to the top. They were the primary means of reaching the epitheatron.

Epitheatron

Any seating above the diazoma was part of the epitheatron. Seats here cost less than those below the diazoma.

Proskenion

The proskenion was the platform/stage directly in front of the skene. It typically included a colonnade and wide open acting space located in front of the prohedria.

"As casting technology and familiarity with the new medium improved, bronze work became more complex"

Chinese bronze-casting furnaces

Inside the furnace

Versions of this ingenious metal-casting furnace design are still used to this day

The innovation that led to some of the finest bronze work ever produced

Neolithic people were familiar with copper, but the mineral was rare and tricky to work with. The discovery that copper could be combined with tin to make a stronger and more easily manipulated material heralded a whole new era: the Bronze age.

In early furnaces, a large ceramic pot held the molten metal over a coal fire and air from a pair of bellows was pumped in via an opening. As the bronze melted, it sank to the bottom of the vessel while impurities collected on top. A ramrod was used to break and dislodge a clay plug blocking the spigot, allowing metal to pour out of the crucible into waiting moulds.

Once the metal cooled, the moulds were broken and the seam marks and flashing removed. These moulds were made in sections, so the completed bronze might be assembled from multiple individually cast elements.

Early bronzes resembled forms previously made from clay. However, as casting technology and familiarity with the new medium improved, bronze work became more complex and included everything from intricately decorated ceremonial pots to weaponry.



Tap hole
When the metal is melted the clay plug is removed, allowing molten metal to flow through the tap hole.

Crucible
A large ceramic pot made of straw-tempered clay holds the metal to be melted.

Fuel
Hot-burning charcoal is used to heat the furnace.

Tuyère
Bellows (not shown) pump air through this opening, feeding oxygen into the fire.

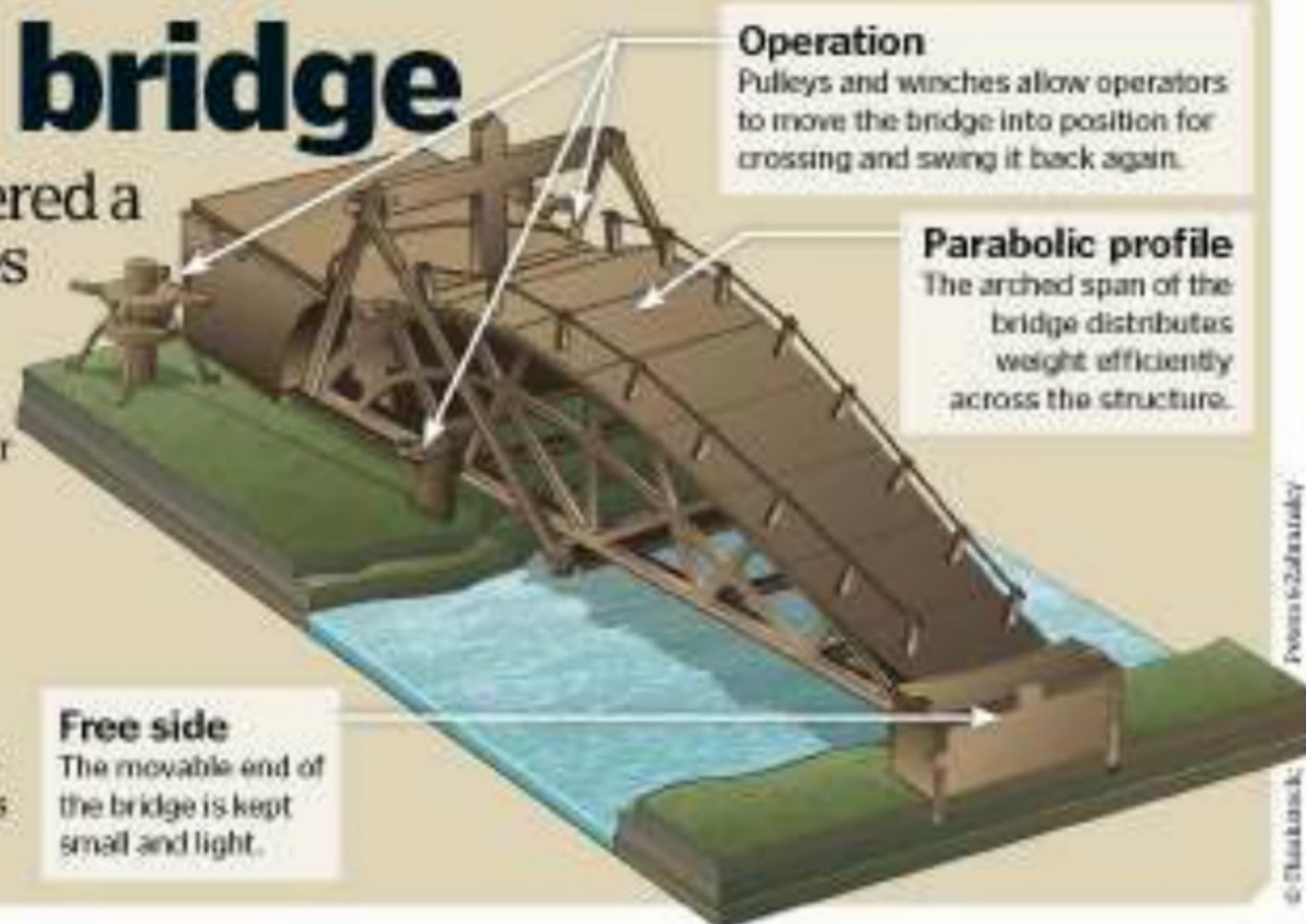
Bed plate
Some furnaces feature a platform on which to stand the crucible so it doesn't sit directly on the charcoal.

Da Vinci's swing bridge

Ponti salvatici, or 'bridges of salvation', offered a safe means of passage for marching armies

Among Leonardo da Vinci's many inventions were bridges designed to be light to carry and quick to assemble. The swing bridge would span a small waterway, allowing soldiers and supplies to pass, and then retract to stall the enemy. These bridges pivot on a pylon located on one side of the watercourse, while the smaller

end rests on the opposite bank. Modern one-sided bridges use a substantial underground anchor to support the weight of the bridge as it swings. Da Vinci addressed this by including a counterweight tank. Swing bridges are still used, although most pivot on a central axis, and their purpose is to let large ships pass rather than warfare.



Operation
Pulleys and winches allow operators to move the bridge into position for crossing and swing it back again.

Parabolic profile
The arched span of the bridge distributes weight efficiently across the structure.

Free side
The movable end of the bridge is kept small and light.



Answer:

It comes as a surprise to many, but the international distress signal doesn't actually stand for anything. The three letters were chosen because they were easy to remember and quick to transmit: 'S' is represented by three dots, while 'O' is three dashes.

DID YOU KNOW? The facsimile telegraph was invented in the 1930s and was later replaced by the digital fax machine

Electric telegraph machines explained

How did these early telecommunications devices send and receive messages?



Experienced operators could easily converse at 30 words a minute using Morse code



The advent of electricity was the seed that spawned a thousand modern technologies. One of the first to take advantage of this new form of power was the electric telegraph – a machine that could send and receive messages over hundreds of miles of wire in seconds. A number of inventors contributed to the development of this device: Hans Christian Orsted's discovery of magnetic needles deflecting in the presence of an electric current, William Sturgeon's multiturn magnet, and both Michael Faraday and Joseph Henry's advancements of electromagnetism.

One of the most important pioneers of electrical telegraphy was Samuel Morse. Morse

was actually a professor of painting and sculpture, but the idea of using electricity to communicate had inspired him. During the mid-1830s – along with his associate, Alfred Vail – he devised a cipher language using dashes, spaces and dots, which is still a part of some naval training to this day: Morse code.

With that established, he went on to invent and patent a telegraph machine in 1837. This was divided into a transmitter and a receiver. The part sending the message – the transmitter – housed a component called a portarule with a moulded typeset, dots and dashes set into it. As the type moved through the mechanism it would intermittently make and break the connection between receiver and battery. At the other end, the receiver would then use a stylus controlled by an electromagnet to print these dots and dashes onto a strip of paper.

Morse code tech

How one of the simplest and most effective telegraph devices works

5. Message

The duration that the key is held dictates how long the roller inks the paper – creating either dots or dashes to denote letters.

4. Spool

A continuous blank strip of paper reels off this spool.

3. Lever

The electromagnet attracts a nearby lever, pressing an inked roller against the paper.

2. Electromagnet

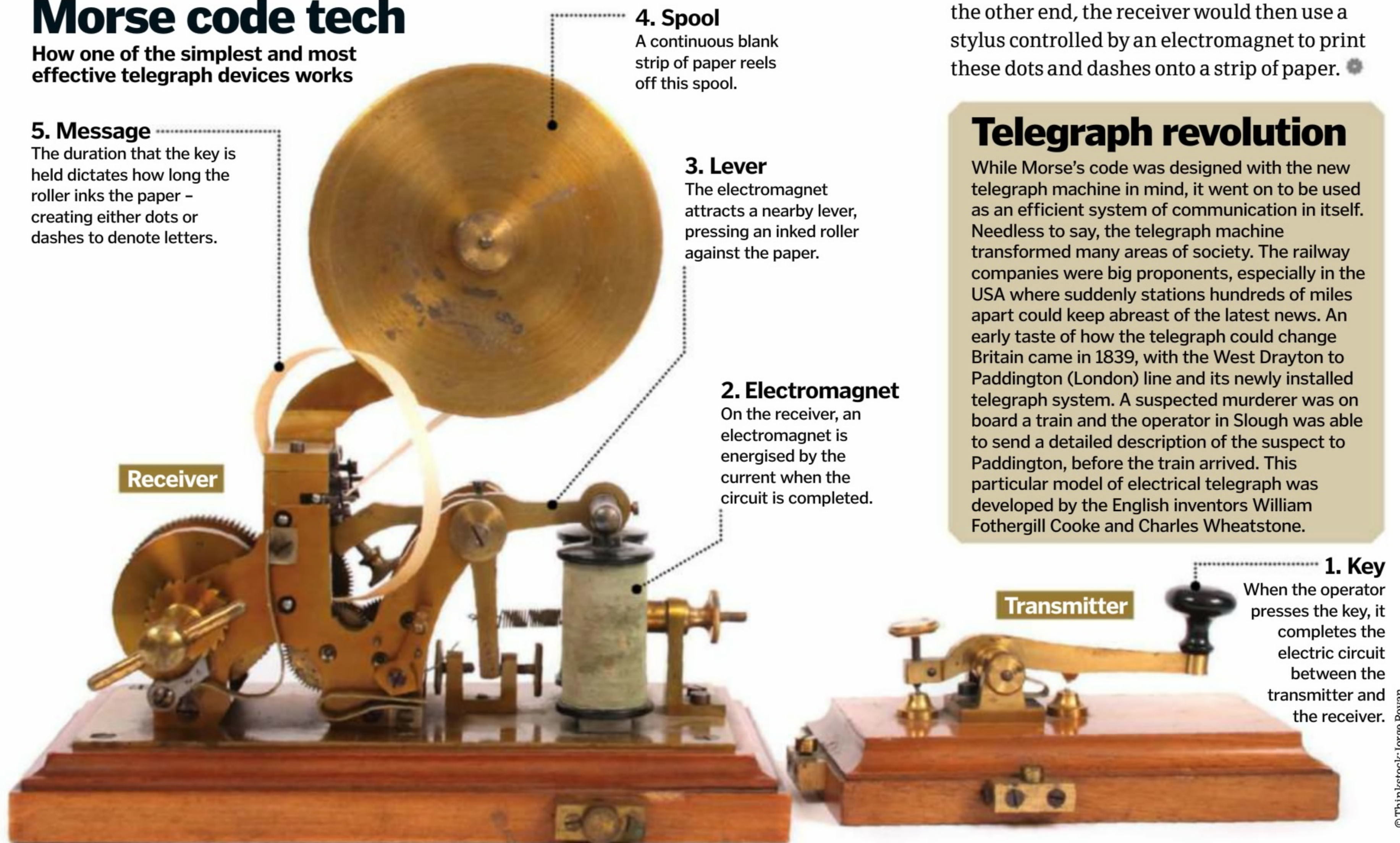
On the receiver, an electromagnet is energised by the current when the circuit is completed.

Telegraph revolution

While Morse's code was designed with the new telegraph machine in mind, it went on to be used as an efficient system of communication in itself. Needless to say, the telegraph machine transformed many areas of society. The railway companies were big proponents, especially in the USA where suddenly stations hundreds of miles apart could keep abreast of the latest news. An early taste of how the telegraph could change Britain came in 1839, with the West Drayton to Paddington (London) line and its newly installed telegraph system. A suspected murderer was on board a train and the operator in Slough was able to send a detailed description of the suspect to Paddington, before the train arrived. This particular model of electrical telegraph was developed by the English inventors William Fothergill Cooke and Charles Wheatstone.

1. Key

When the operator presses the key, it completes the electric circuit between the transmitter and the receiver.



© Thinkstock; Jorge Royan

"If the dams were breached then production in the Ruhr region would be greatly reduced"

The technology behind Operation Chastise

How It Works takes a closer look at the famous Dambuster raid of 1943



Arguably the most famous heavy bomber of World War II, the Avro-built Lancaster undertook some of the most dangerous missions in the conflict. Intended as a night bomber but often used in the day too, the Lancasters under Bomber Command flew some 156,000 sorties during the war, dropping 609,000 tons of bombs. Among these was the 'bouncing bomb' designed by British inventor Barnes Wallis for the Dambuster raid of 1943.

Wallis devised the bomb in order to destroy dams in Germany's Ruhr Valley. The dams were significant as the Ruhr region was one of the country's main industrial areas, with arms, vehicles and raw materials feeding the Nazi war machine. If the dams were breached then production in the region would be greatly reduced, aiding the Allied cause.

The weapon's design was simple yet complex. The bomb consisted of a cylindrical drum housing almost 3,000 kilograms (6,615 pounds) of high explosive that would detonate at the base of a dam with hydrostatic pistons. The real challenge was getting the bomb into position.

Multiple steel-linked torpedo nets protected the dams of the Ruhr. These would snag any incoming underwater missiles and prevent any explosion near the dams' bases. Wallis's bomb, however, was designed to skim across the surface of the water, effectively jumping over the nets and then careering into the dam.

To achieve this, the bomb needed to be dropped at a specific height and speed, with a pre-loaded backspin. This backspin was integral as it both increased bounce height on contact with the water and also reduced speed, so the Lancaster had a chance to fly clear.

Wallis's bombs were eventually put to use in Operation Chastise on 16 May 1943, in which 19 bombing aircraft and 113 attack fighters descended on the Ruhr Valley. Two major dams were breached by the bouncing bombs, causing massive flooding and significant loss of civilian life. This Allied success came at a cost though, with eight of the bombing aircraft shot down, along with 53 of the fighter planes.



The Lancaster remained in military service until 1963 when it was retired



The Möhne Dam was destroyed by a bouncing bomb



One of Wallis's bouncing bombs on display at the Imperial War Museum, London

Bomber man



Barnes Wallis was an English engineer who for much of his career worked for the British aviation firm Vickers. Upon joining the company Wallis was tasked with working on airship designs - including the

record-breaking R100 - but as WWII approached he got drafted into designing aeroplanes.

While Wallis would eventually imagine and design the bouncing bomb off the back of a paper he penned on strategic bombing, prior to this he was responsible for a number of other notable achievements including the introduction of geodetic airframes and wings, which were unparalleled in both lightness and strength.

After the war Wallis was promoted to head of the Vickers-Armstrongs R&D department where he spearheaded several projects including the now common variable-sweep wing (swing-wing).

© Martin Richards

**5 TOP FACTS:
AVRO LANCASTER B.III**

On the night of 16th May 1943, 19 Lancaster Bombers took part in the raid, with 11 returning. 53 Allied airmen were killed, with 3 taken prisoner.

The project was code-named Chastise. The dams supplied water and power to the German industrial areas so were very important targets.

The Möhne dam was attacked first and breached, with the Eder and Sorpe being attacked later. The resulting flood waters killed an estimated 1,650 people.

The bigger effect though was felt on production, with 20,000 men having to be diverted from other tasks to repair the dams and lots of farm land damaged by the flood waters.

The raid was masterminded by Barnes Wallis, responsible also for the famous bouncing bomb used in the attack.



How it works



617 Squadron was formed specially for this raid, and remains operational.

The Lancasters were specially modified by removing the mid-upper turrets to save weight.

The dams were fortified by torpedo nets and reinforced, making conventional attacks problematic.

By rotating the bomb as it fell, it enabled it to sink against the dam and cause the breach.

Two Aldis lamps in the fuselage let the crew know when their altitude was correct.



Scan this QR code with your smartphone to find out more!

AVRO LANCASTER B.III - NEW

This aircraft was flown by Wing Commander Guy Gibson, Commanding Officer No.617 Squadron. Gibson led three Lancasters to attack and breach the Eder Dam. After the raid, Gibson was awarded the Victoria Cross in recognition not just of the raid, but his leadership and valour demonstrated as master bomber on many previous sorties.

A50138 1:72 Scale

The Dambusters Avro Lancaster B.III Gift Set



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HORNBY visitor centre



“As the rack-and-pinion gears had teeth, they acted as an additional form of adhesion to the track”

Rack-and-pinion railways

How did these unique transit systems help hefty locomotives scale steeper mountain slopes than ever before?



A rack-and-pinion railway (also known as a cog railway) was one that employed a toothed track. The addition of the toothed rail – which was usually located centrally between the two running rails – enabled locomotives to traverse steep gradients over seven per cent, which remains to this day the maximum limit for standard adhesion-based railways.

Core to the operation of each rack-and-pinion system was the engagement of the locomotive’s circular gears onto the linear rack. The rack and pinion therefore was essentially a means of converting the rotational energy generated by the train’s powerplant into linear motion on the rack. As both the rack-and-pinion gears had teeth, the system also acted as an additional form of adhesion to the track, with the inter-meshing teeth holding the vehicle in place when not in motion.

Due to the primary form of power traditionally being steam, for rack-and-pinion systems to work the trains needed to be considerably adjusted. This modification stretched from the undercarriage of the train (so pinions could be installed) to the tilting of its boiler, cab and superstructure.

Tilting was necessary as steam engine boilers require water to cover the boiler tubes and firebox at all times to maintain stability – something that is nigh-on impossible to achieve if the train isn’t level. As such, cog railway locomotives would lean in towards the track to counter the terrain’s gradient.

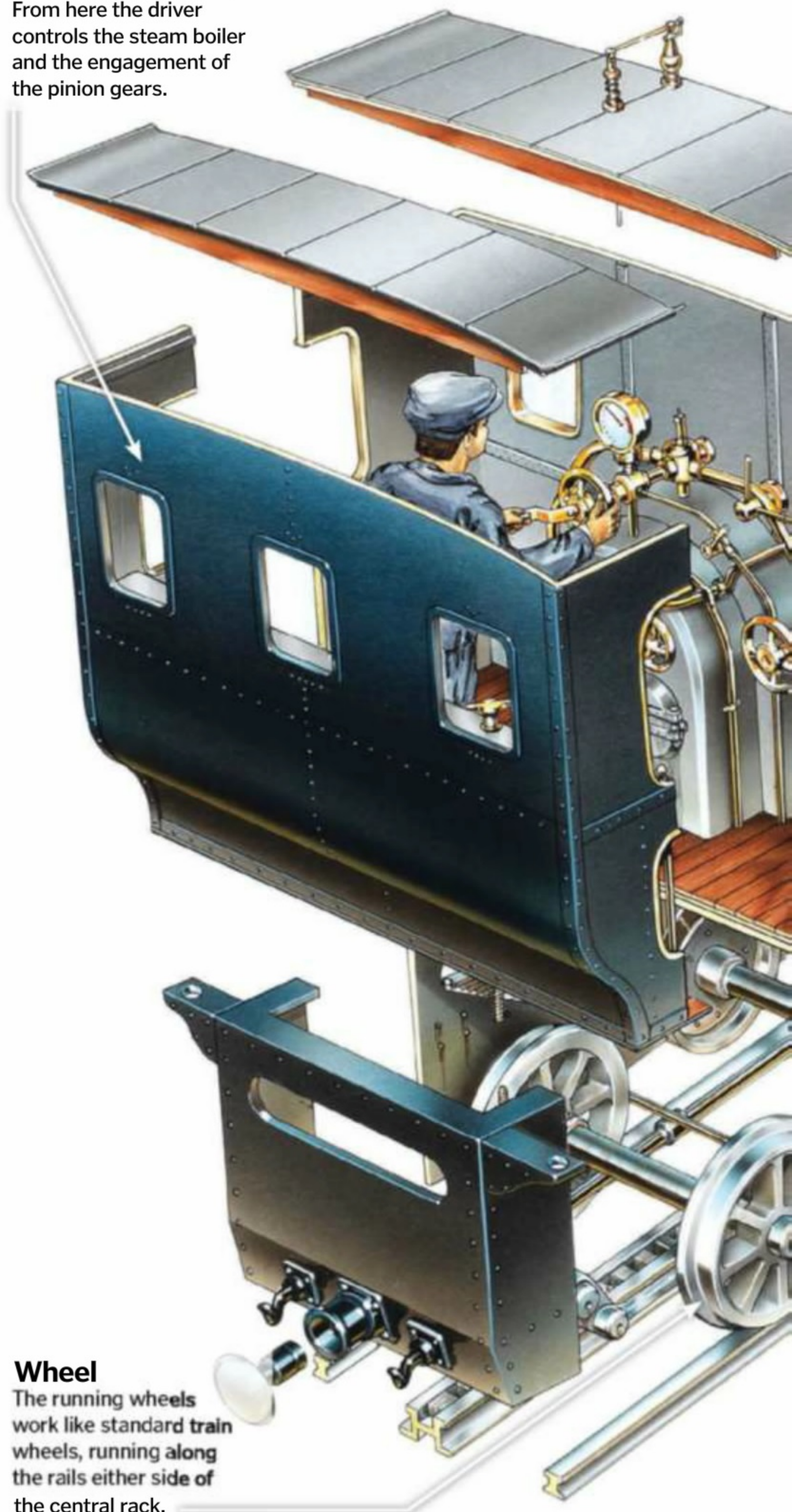
Today, while rare, rack-and-pinion systems are still in operation worldwide, albeit with a mix of steam engines and diesel/electric locomotives. One of the most famous is the Mount Washington Cog Railway, which we look at more closely in the boxout opposite. ⚙️

Rack and roll

Understand the anatomy of a rack-and-pinion locomotive now with our cutaway illustration

Cabin

To the rear of the engine and carriage is the cabin. From here the driver controls the steam boiler and the engagement of the pinion gears.



Wheel

The running wheels work like standard train wheels, running along the rails either side of the central rack.



A rack-and-pinion railway built with a Strub system in rural Italy, 1920

STEEPEST RAILWAY GRADIENT

This is the maximum gradient of the world's steepest cog railway. The Pilatus Railway runs from Alpnachstad at Lake Lucerne, Switzerland, to a terminus near the Esel summit of Mount Pilatus, climbing 1,635 metres (5,364 feet).

DID YOU KNOW? The first rack-and-pinion railway was introduced in West Yorkshire, England, in 1812

Engine

Older cog railways would use steam engines to provide the power to drive the pinion gears. As with the cab, the engine is tilted forward so it's level during operation.

Buffer

Unlike standard adhesion trains, rack-and-pinion systems don't tend to attach the carriage to the locomotive with a linkage. Instead, the carriage is simply pushed with the locomotive's buffers.

Carriage

Passengers sit in a covered wooden carriage. Due to the slow nature of the system, larger-than-standard windows are often installed that offer panoramic views.

Rail

Either side of the rack are two standard rails for the carriage and locomotive's wheels to run on. These allow for the switching of lines and access to mechanical turntables for 360-degree rotation.

Rack

In the centre of the line is the rack, a toothed rail into which the locomotive's pinions slide. This engagement between the pinion and the rack allows the train to maintain a good grip even on steep terrain.

Pinion gears

Mounted to the locomotive's undercarriage is a series of circular, teathed gears. As these rotate, driven by the engine, the teeth slot into the recesses in the rack, helping haul the train along.

Cog railway evolution

1 Marsh

Made famous by the Mount Washington Cog Railway, the Marsh system – invented by Sylvester Marsh in 1861 – used the locomotive's gear teeth like rollers, arranged in rungs between two 'L'-shaped wrought-iron rails.

2 Riggensch

The 1863-made system created by inventor Niklaus Riggensch used a ladder rack made from steel plates connected by regularly spaced rods. While effective, the fixed ladder rack was fairly complicated and expensive to build, so very few examples survive.

3 Abt

Carl Roman Abt improved the Riggensch system in 1882 by using multiple solid bars with vertical teeth machined into them that were mounted centrally between the rails. This ensured the pinions on the wheels were in constant contact with the rack.

4 Locher

Eduard Locher's 1889 system had gear teeth cut into the sides of the rails rather than the top, which were engaged by two cog wheels on the locomotive. This system could work on steeper track gradients than anything prior.

5 Strub

Invented by Emil Strub in 1896, the Strub system utilised a rolled flat-bottom rail with rack teeth machined into the head 100mm (4in) apart. Safety jaws installed on the locomotive gripped the underside of the head in order to prevent derailments.

A mechanical mountain climber

The Mount Washington Cog Railway in New Hampshire, USA, was the first rack-and-pinion railway used to climb a mountain. Completed by Sylvester Marsh in 1869, the system is the second-steepest rack railway in the world, with a top gradient of 37.4 per cent. The railway runs 4.8 kilometres (three miles) up Mount Washington's western slope, beginning at 820 metres (2,700 feet) above sea level and culminating just short of the peak at 1,917 metres (6,288 feet). The locomotive goes up at 4.5 kilometres (2.8 miles) per hour and descends at 7.4 kilometres (4.6 miles) per hour. Despite being built 144 years ago, this cog railway is still fully operational.



BRAIN DUMP

Because enquiring minds want to know...



Ask your questions

Send us your queries using one of the methods opposite and we'll get them answered

MEET THE EXPERTS

Who's answering your questions this month?

Luis Villazon



Luis has a degree in Zoology from Oxford University and another in Real-time Computing. He's been writing about science and tech since before the web. His science-fiction novel *A Jar Of Wasps* is published by Anarchy Books.

Giles Sparrow



Giles studied Astronomy at UCL and Science Communication at Imperial College, before embarking on a career in publishing. His latest book, published by Quercus, is *The Universe: In 100 Key Discoveries*.

Alexandra Cheung



With degrees from the University of Nottingham and Imperial College, Alex has worked for several scientific organisations including London's Science Museum, CERN and the Institute of Physics. She lives in Ho Chi Minh City, Vietnam.

Rik Sargent



Rik is an outreach officer at the Institute of Physics, based in London, where he works on a variety of projects aimed at bringing physics into the public realm. His favourite part of the job is travelling to outdoor events and demonstrating 'physics busking'.

Dave Roos



A freelance writer based in the USA, Dave has researched and written about every conceivable topic, from the history of baseball to the expansion of the universe. Among his many qualities are an insatiable curiosity and a passion for science.

Which is the world's tallest waterfall?

Bryan P

■ The two top contenders are Angel Falls in Venezuela and Tugela Falls in South Africa, but which one claims the title depends on the criteria. The debate is whether to award the title to the tallest single drop or to the tallest sequence of falls. Angel Falls easily wins the tallest drop contest with a breathtaking 807-metre (2,648-foot) cascade. But Tugela Falls is a series of five falls in quick succession, which taken together drop a total 948 metres (3,110 feet). When Angel Falls was originally measured in 1949, the American expedition included a second 30-metre (98-foot) plunge farther downstream. If you include the sloping rapids between these two falls, the total drop in elevation is 979 metres (3,212 feet). DR

aviator Jimmie Angel who spotted it from the air while searching for gold in the region



How does a camel turn fat into water?

Lizzie Harfield

■ When fat is metabolised to release energy, the carbon and hydrogen atoms combine with oxygen to form CO₂ and water. Fat is a mixture of hydrocarbons. Each gram of fat broken down in this way releases just over a gram of water. Surprisingly though, camels can't make use of this H₂O. The oxygen needed to break down the fat means they need to breathe more and overall they actually *lose* water via their lungs. A camel's hump enables it to store food, but water is located in all the body's tissues. Camels can withstand incredibly high levels of dehydration; they can lose 25 per cent of their body weight via sweating – half of that would be enough to cause heart failure in most animals. **LV**



Taking the hypothetical 17,000km (10,560mi) as the answer, that's equivalent to the distance from London to Sydney!

How many metres does our blood travel every week?

Sam Jones

■ We've calculated it could travel 17,000 kilometres (10,563 miles) in a week. The average adult has five litres (1.3 gallons) of blood pumping around their body. About 20 per cent of this blood is in the heart and arteries, whooshing out through the aorta at 45 centimetres (17.7 inches) per second for a person at rest. It reaches lows of just 0.5 millimetres (0.02 inches) per second as it branches out into the maze of tiny capillaries which deliver oxygen to

cells, tissues and organs. The blood picks up speed again to around 25 centimetres (9.8 inches) per second as it returns to the heart in larger veins. Using these figures, you could calculate that the average speed of blood in the body is 28 centimetres (11 inches) per second, which equals about 17,000 kilometres (10,563 miles) in a week. The reality is far more complicated as blood pressure and heart rate (linked to how active you are, among other factors) affect blood velocity dramatically. **AC**



Why were telephone boxes in Britain red?

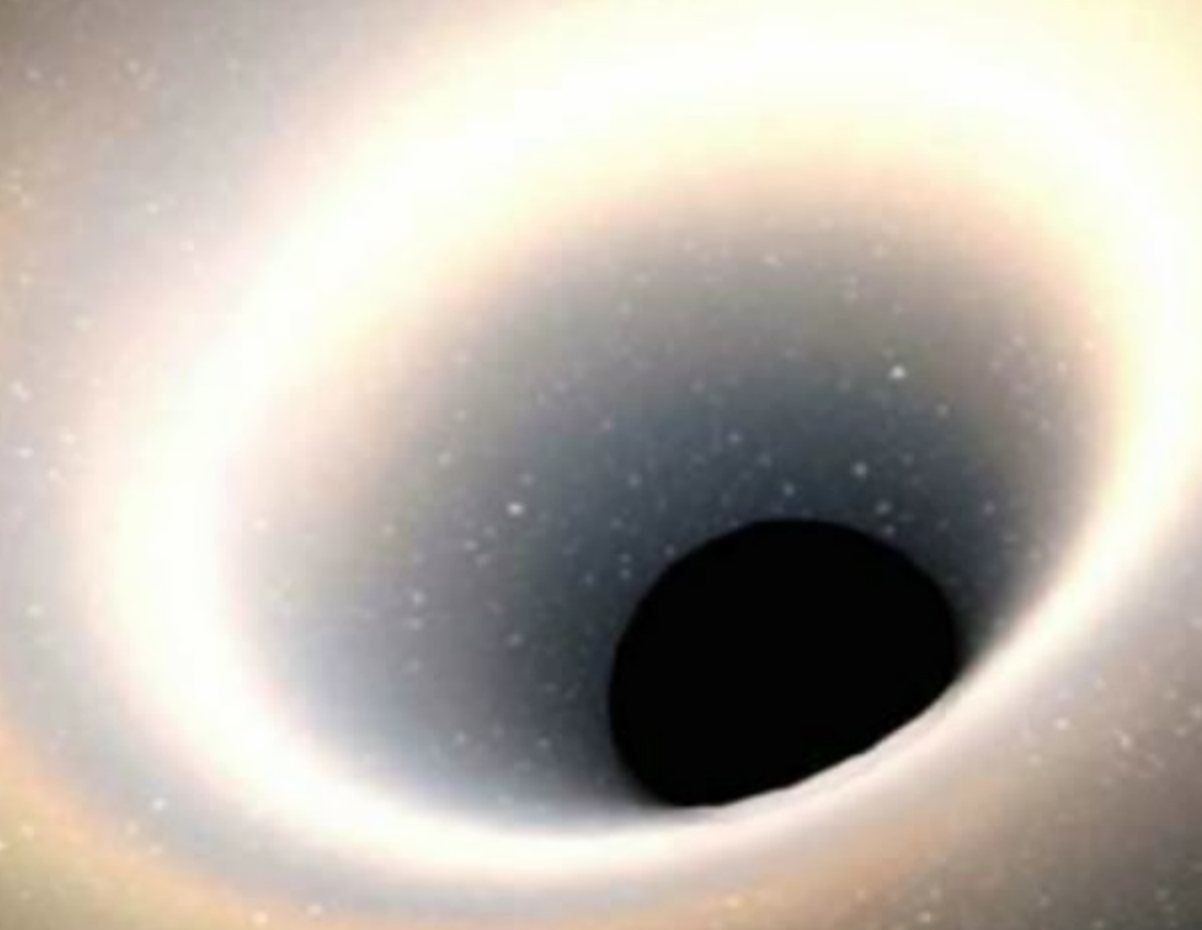
Sally Pole

■ It is likely this was done to match the red postboxes that had been around for 50 years prior. Phone boxes were manufactured by the Post Office, and while the designer, Sir Giles Gilbert Scott, had suggested painting them silver with a green-blue interior, he was overruled and red was chosen. The first iconic K2 British telephone boxes were introduced to the public in 1926. Postboxes weren't always painted red either; they were originally green, but were soon changed to red to make them easier to spot. **RS**

Could transport through wormholes be possible?

Seth Kent

■ While wormholes are theoretically feasible according to the laws of physics, there's no evidence that they exist. Tubes that provide shortcuts between different parts of the universe is a nice idea, but the concept presents a number of problems in practice. Even if they did exist they'd probably be very tiny, thread-like connections so in order to pass through you'd find yourself stretched out, or 'spaghettified', into a narrow stream of atoms. Keeping a wormhole open for practical travel would need some kind of antigravity force – and while that's also a theoretical possibility, it might be easier to find another form of high-speed travel, or indeed just to take the scenic route. **GS**



Why are the Elgin Marbles so controversial? Find out on page 84

BRAIN DUMP

Because enquiring minds want to know...

What is a dopplergram?

Find out on page 85

Want answers?

Send us your questions using one of the methods opposite and we'll get them answered

What makes a volcano extinct?

Steve McAllistair

■ For a volcano to be labelled extinct, it would have to show no activity in 10,000 years and no possibility of future eruption. However volcanologists have been known to argue over the precise definition because the traditional classifications of volcanic activity – active, dormant and extinct – are not based on a scientific consensus. An active volcano is generally described as a volcano that has erupted in recorded human history, or is

believed to have erupted in the past 10,000 years (since the last ice age). The oldest recorded volcanic eruption occurred in central Turkey in 6,200 BCE. A dormant volcano is one that hasn't erupted in the past 10,000 years, but still has access to a magma source or is located in a seismically active region. While an 'extinct' volcano may not erupt during humanity's time on Earth, it's harder to bet on the geologic time scale. DR

What is the difference between superglue and normal PVA?

Harun Tokin

■ Superglue and PVA glue both use polymerisation for adhesion. Polymerisation is a chemical reaction, where the sharing of electrons allows some types of molecule to join together, forming long chains called polymers. Superglue contains a compound called ethyl 2-cyanoacrylate, which reacts with water to cure (ie turn from a liquid into a solid). Usually there is a very thin layer of water present on most surfaces – condensed water vapour from the air – making superglue effective on almost any type of surface. PVA (polyvinyl acetate) glue is water-based, and is commonly used for sticking wood together. Water in PVA intertwines the fibres of wood with the polyvinyl acetate, eventually evaporating and leaving behind a bond stronger than the material itself.

RS



What are the Elgin Marbles and why are they so controversial?

Rebecca Mills

■ The Elgin Marbles is the common name for a massive collection of Ancient Greek sculpture which has been on display in the British Museum since the early-1800s. The collection includes 75 metres (247 feet) of the original 160-metre (524-foot) frieze from the Parthenon temple in Athens (below). The frieze is the highly decorative section above the columns in classical Greek architecture. The collection is controversial because its namesake – the seventh Earl of Elgin – removed the treasures from Greece with the permission of the Ottomans, who occupied Greece from the mid-15th century until 1821. For decades, the Greeks have called for the priceless artefacts' return, but the British Museum defends its ownership as legitimate. DR



Cinder, or scoria, cones like this are the most common type of volcano on Earth

Why aren't mongooses more afraid of snakes?

Tom

■ Mongooses have thick coats that protect them from short-fanged snakes and they are extremely agile. But the main reason is that they are highly resistant to snake venom. One of the main constituents of the venom is a toxin that mimics the shape of the neurotransmitter acetylcholine. If you are bitten, the venom attaches to the receptor sites on your nerve cells and blocks the normal action of acetylcholine. This causes numbness and paralysis. Mongooses have a different molecular shape to their receptor site so that acetylcholine still binds to it correctly but snake venom does not. **LV**



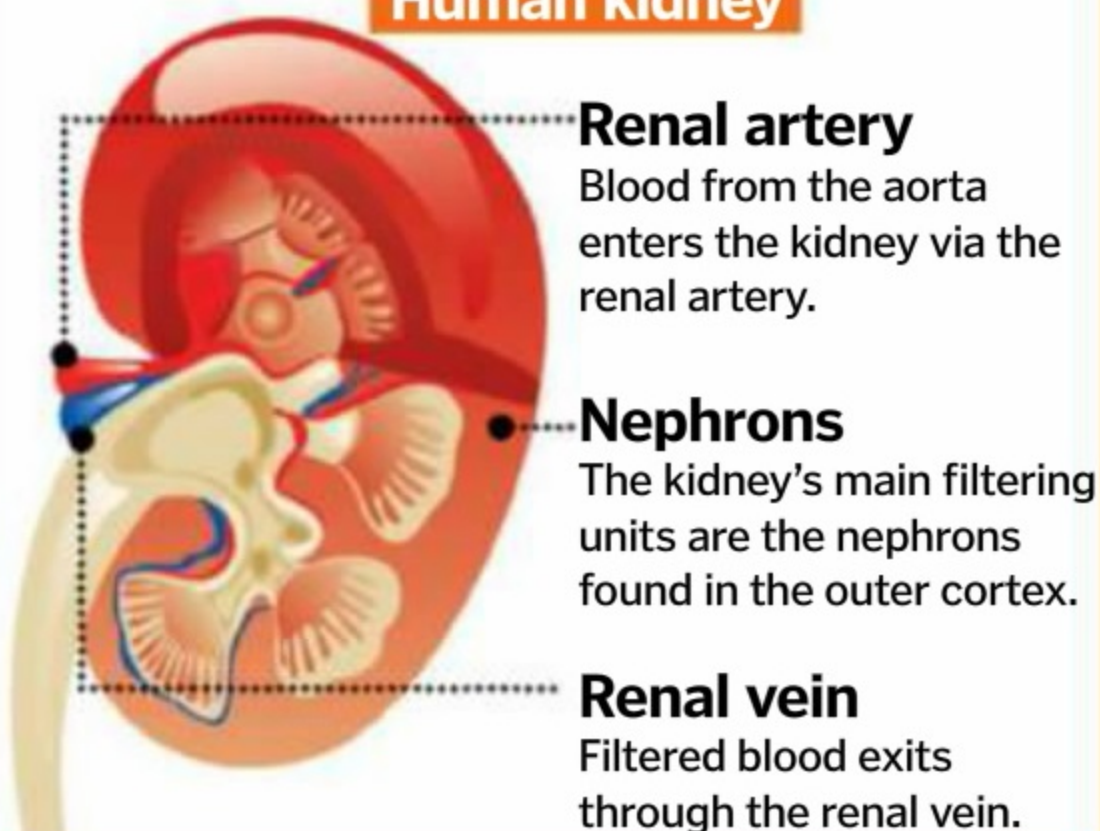
Mongooses live predominantly in Africa and feed on everything from insects and birds through to lizards, worms and frogs

Why did we evolve to drink fresh water rather than seawater?

Simon Dieterich

■ In order to function, we – along with our fellow vertebrates – depend on a precise concentration of salt in our blood: 0.9 per cent. Our kidneys regulate this balance, excreting any excess salt in urine. Drink seawater and your kidneys struggle to produce enough urine to flush out the salt, leading to rapid dehydration. Marine animals have evolved different solutions to this problem. Fish get rid of salt through their gills. Seals and whales have extremely efficient kidneys, producing very salty urine. And most sea mammals simply avoid swallowing salt water, getting fresh water from their prey instead. These adaptations, however, come at a cost: it takes a lot of energy to fuel super-efficient kidneys, for example. It seems the evolutionary trade-offs involved in adapting to salt water weren't worth it for us. **AC**

Human kidney



When was a second officially timed and who classified it?

Matt Spechley



■ Al-Biruni, an 11th-century Persian scholar (left), was the first to use seconds to measure time, dividing a day into hours, minutes and seconds, but also thirds (one-sixth of a second) and fourths (one-sixth of a third). As such a second was first defined as one-86,400th of an average solar day. With the advent of ultra-accurate atomic clocks, scientists Louis Essen and William Markowitz converted the second into atomic time, using the frequency of radiation emitted by the caesium-133 atom as a yardstick. This established the standard measure of a second, officially adopted in 1967 and now used worldwide. **AC**

What is a dopplergram?

Jordan Chapman

■ A dopplergram is a map that shows the way in which different parts of an object that's producing light are moving towards or away from us. They're most commonly used for mapping the surface of the Sun. The idea is to measure the way the Doppler effect alters the wavelength of light waves or other radiation coming from different parts of the surface; when the source of waves is moving away from us, the wavelength is stretched, or 'red shifted', and when it's moving towards us, it's compressed, or 'blue shifted'. By measuring the red and blue shifts on different parts of the Sun's surface, we can tell which ones are moving towards or away from Earth, revealing patterns of granulation caused by currents of moving hot gas emanating from our star. **GS**



Can diamonds be melted? Find out on page 86

BRAIN DUMP

Because enquiring minds want to know...

Can anyone own the Moon?

Find out on page 87

Want answers?

Send us your questions using one of the methods opposite and we'll get them answered

Chimpanzee brains are quite similar to ours in some ways, but the wiring is very different

How do human and chimp brains differ?

Josh

■ The average weight of a chimpanzee brain is 384 grams (13.5 ounces); our brains are three and a half times heavier. That's only part of the story though, because different species have different brain structures. Rodents' brain cells, for example, are much less efficiently packed and for a rat to have the same number of brain cells as us, it would need a brain at least 35 times

larger than ours. However it seems that chimps are close enough relatives that they have similar brain structures so they do actually have about three and a half times fewer brain cells than us – at roughly 49 billion. Chimps have less brain dedicated to white matter in the temporal cortex, which means they have fewer neural connections and so a lesser ability to process data. **LV**

Why do radio waves travel at the speed of light and not sound?

Gail Bradbury

■ Radio waves are a form of electromagnetic radiation – the same phenomenon as light, X-rays and various other types of radiation, but with much longer wavelengths. As such, they travel at the speed of light (ie 300,000 kilometres/186,000 miles per second) – a lot faster than the 340 metres (1,125 feet) per second that sound itself moves through the air. It's easy to be fooled by the fact that when you hear the word 'radio', you usually think of voices or music, but radio waves aren't sounds themselves – just the medium used to broadcast an electronic signal from the studio to your hi-fi, which the speaker then turns back into the vibrations in the air which we hear. **GS**

Radio waves can be diffracted by large structures like mountains and buildings



Does the island of Monte Cristo exist?

Jan Carter

■ Yes it does. French writer Alexandre Dumas visited the tiny, uninhabited island of Montecristo in 1842 and was inspired to use the craggy, windswept rock as the setting for part of his novel *The Count Of Monte Cristo*. With an area of only 10.4 square kilometres (four square miles), Montecristo is the smallest in a string of islands off the coast of Italy forming the Tuscan Archipelago. During its long history, the island was briefly occupied by monks and hermits, then overrun in the 1550s by pirates rumoured to have buried treasure in its many caves. Today, Montecristo is a protected nature reserve, although an infestation of black rats threatens many of its native species and its viability as a tourist destination. **DR**



Is it possible to melt diamonds into a liquid?

Thomas Austen

■ Yes. Kind of. If you heat diamond in the open air, it will start to burn at around 700 degrees Celsius (1,292 degrees Fahrenheit), reacting with oxygen to produce carbon dioxide gas. Heating diamond in the absence of oxygen, meanwhile, will see it transform into graphite – a more stable form of carbon – long before turning into liquid. Despite this, scientists found a way to melt diamond. Using super-strong magnetic fields, they fired small plates at 34 kilometres (21 miles) per second towards tiny pieces of the mineral, subjecting them to 10 million times normal atmospheric pressure. The diamonds melted, then re-solidified when the pressure dropped, leading some scientists to suspect there could be seas of liquid diamond on Neptune and Uranus, due to their atmospheres generating intense pressure and containing carbon. **RS**



The trick to liquefying a diamond is to put it under huge pressure



If I freeze food can no bacteria affect it?

Samantha Knight

■ No. Freezing preserves food by stalling the reproduction and growth of bacteria and other micro-organisms. Most disease-causing bacteria have evolved to thrive at temperatures close to that of the human body. The average household freezer maintains a frosty -18 degrees Celsius (0 degrees Fahrenheit) or below: in these conditions there is no liquid water available and the enzymes bacteria rely on cannot function.

Freezing therefore protects food from decay until you're ready to use it. As water inside bacteria expands to form ice crystals it kills some of the micro-organisms, though most are tough enough to survive the ordeal. They simply remain dormant, springing back into action when you take your dinner out of the freezer. You can limit their reproduction by thawing your food in the fridge or microwave rather than leaving it out at room temperature. **AC**

Who can lay claim to the Moon?



Sarah Kane

■ According to the 1967 United Nations Outer Space Treaty, 'Outer Space, including the Moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means.' This treaty has been ratified by 62 countries, including the world's leading space powers, and was intended to apply to commercial and private operations

as well. In contrast, the 1979 International Moon Treaty, drawn up specifically to prevent private claims to lunar real estate, has only been ratified by a handful of nations. Rest assured, though, that any private operator who did try to stake part of the Moon would certainly at least have to plant a flag there – rather than just setting up a website and claiming to own it! **GS**

Could Concorde ever have pulled off a barrel roll?

Gail Bradbury

■ Yes, apparently. A barrel roll is a manoeuvre whereby an aeroplane makes a complete corkscrew-like rotation around its horizontal line of travel, while maintaining a roughly constant direction. An important consideration before performing any type of aerial acrobatics is the amount of g-force that will be exerted on the aircraft. G-force isn't strictly a force – it's a measure of acceleration per unit mass, with one unit of g taking the value of 9.8 metres (32.2 feet) per square second per kilogram of mass (the same acceleration produced by gravity at Earth's surface). When going around a tight corner in a car, you can feel the g-force pushing you sideways. Concorde – like most commercial aircraft – was built to withstand around 2.5 g. Barrel rolls exert approximately 1-1.5 g on an aeroplane when done correctly. Pilots Jean Franchi and Brian Walpole reportedly performed barrel rolls in Concorde during test flights, but never with passengers on board. **RS**



Hunting en masse increases the odds of success for lions



Why do lions hunt in packs but tigers alone?

Dan Mullins

■ It's down to the different prey types and landscapes in which they hunt. Lions stalk the open savannah in Africa, preying on the zebra, antelope and wildebeest that live in herds. With hundreds of pairs of eyes and ears listening out for danger there are very few places for a hunter to hide. A group can hunt more effectively by stalking the herd from several directions at once,

encircling it. Tigers, meanwhile, live in dense jungle where lines of sight are short and it's much easier to lie in wait for an ambush or creep up within pouncing distance without being seen. Indeed, a group of tigers hunting together would just increase the likelihood of spooking their prey and, unlike some cats, tigers don't have the stamina for a prolonged chase, so they normally abandon an attack if they are spotted too early. **LV**

THE KNOWLEDGE

FOR CONNOISSEURS OF KIT AND SAVANTS OF STUFF

The ultimate convertible ultrabook

Toshiba Satellite U920T-108

Price: £899/\$1,455

Get it from: www.toshiba.co.uk

Operating systems don't tend to have much of an impact on the physical design of a laptop. Windows 7, for example, didn't have manufacturers scurrying around to build a new type of machine around its features. The same can't be said of Windows 8, though, which is pre-installed on the Toshiba Satellite U920T-108 and whose touchscreen functionality is pretty much the reason this laptop exists.

The U920T is a third-generation mobile Core 3 CPU-based machine with four gigabytes of RAM, CPU-integrated graphics and a 128-gigabyte hard disk drive. It's a 'convertible ultrabook', which means two things: the U920T has had to adhere to a strict set of hardware and performance criteria as laid down by Intel, and an excellent sliding mechanism that transforms it from a slim laptop into a 31.8-centimetre (12.5-inch) touchscreen tablet.

Tablet-mode U920T isn't quite as elegant as dedicated tablet devices and nowhere near as light, but it does offer a premium amount of display real estate. Nudge the screen upwards and it slips back to reveal the keyboard and into laptop mode for more typing-intensive tasks.

The mechanism is a genuine pleasure to play with; the screen glides back and forth over its runners yet still feels secure. A proper field test with hundreds of tablet/laptop mode changes might reveal otherwise, but based on our initial impressions, it feels like it will comfortably last the lifetime of the machine. We're still to be won over by Windows 8 itself, but this is by far one of the most attractive devices currently supporting the touchy-feely operating system.

Verdict: 

The statistics...

Screen size:

31.8cm (12.5in)

CPU:

Intel Core i3-3217U

Battery life:

Up to 4 hours

Weight:

From 1.5kg (3.3lb)

Operating system:

Windows 8, 64-bit

Aspect ratio: 16:9

Gorilla Glass

The toughened glass screen is both scratch resistant and has an anti-fingerprint coating.

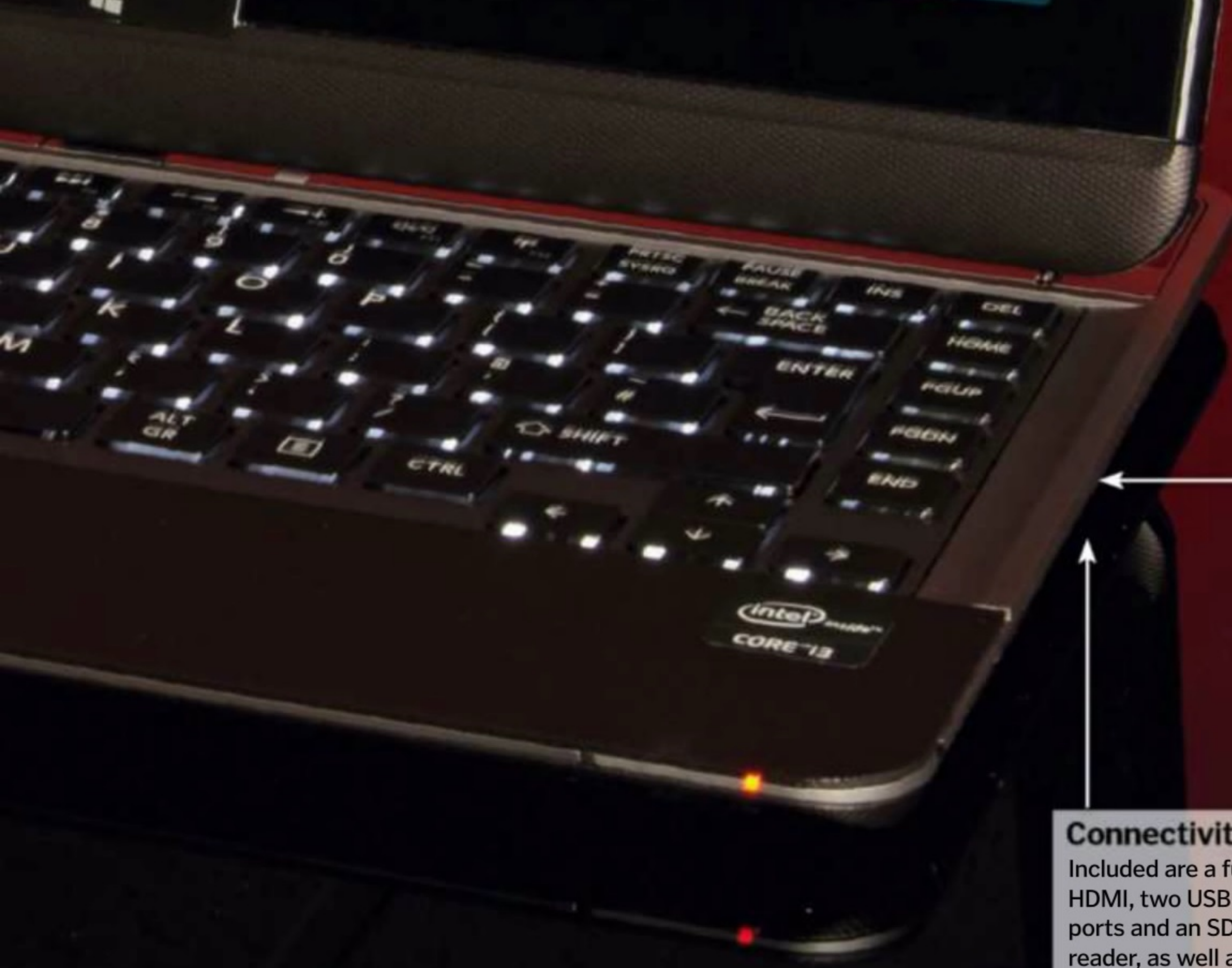
Front camera

Two cameras are integrated into the U920T: a 1MP camera in the front and a 3MP model at the back.

Keyboard

Totally hidden while in tablet mode, the keyboard is backlit ready for use in laptop mode.

Sliding hinge
Allows the U920T's screen to fold to close like a laptop, or slide down to become a tablet.



Slimline body
As per ultrabook standards, the U920T is of a class of thin laptops no more than 21mm (0.8in) thick.

Connectivity
Included are a full-size HDMI, two USB 3.0 ports and an SD card reader, as well as standard connectivity.

BITE-SIZE REVIEWS

Your essential guide to the other awesome stuff we like this month



Land Explorer binoculars

Price: £129.99/\$TBC

Get it from:

www.originator-tech.com

To those not in the know, Originator-Tech's Land Explorer binoculars are quite a boxy-looking pair of compacts that morph into a convenient package. But via a little Bluetooth magic, they're a very convenient sightseeing and navigation tool. By downloading the free app on to your smartphone or tablet device and syncing it with the Land Explorer, you can discover where a landmark is or what it's called simply by pointing the binoculars in the right direction. Target information can be shared with friends immediately too, which would make the Land Explorer a novel, if rule-bending, way of completing an orienteering course.

Verdict: ★★★★★



Pong iPhone 5 case

Price: £47.99/\$59.99

Get it from:

www.pongresearch.co.uk

It looks like just another plastic phone case, but Pong boasts a few twists. By embedding an antenna system that couples with the smartphone's own antenna, it can optimise signal strength and squeeze a little extra juice out of the battery too. Plus, it reduces wireless radiation exposure by up to 91 per cent below the internationally accepted safety limit. There's also hard independent proof that the Pong case at the very least is an effective wireless radiation shield. So if that peace of mind is worth the asking price, this should make the Pong iPhone 5 case a no-brainer.

Verdict: ★★★★★

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HOW IT WORKS

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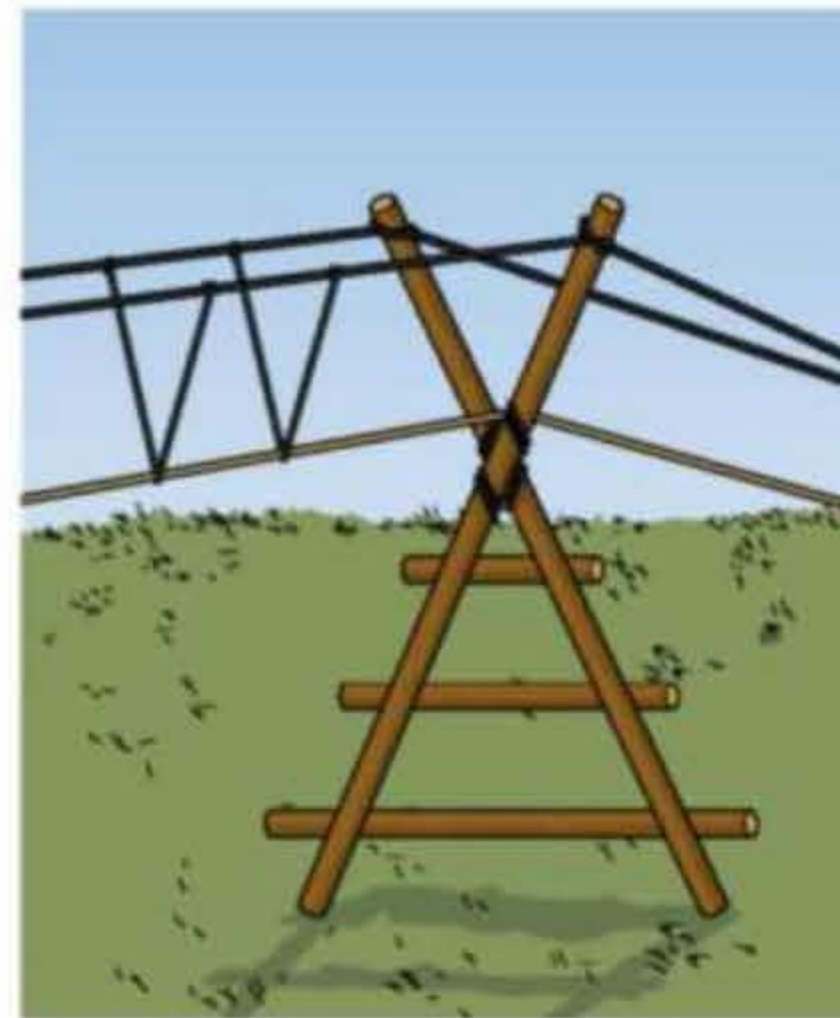
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Build a rope bridge

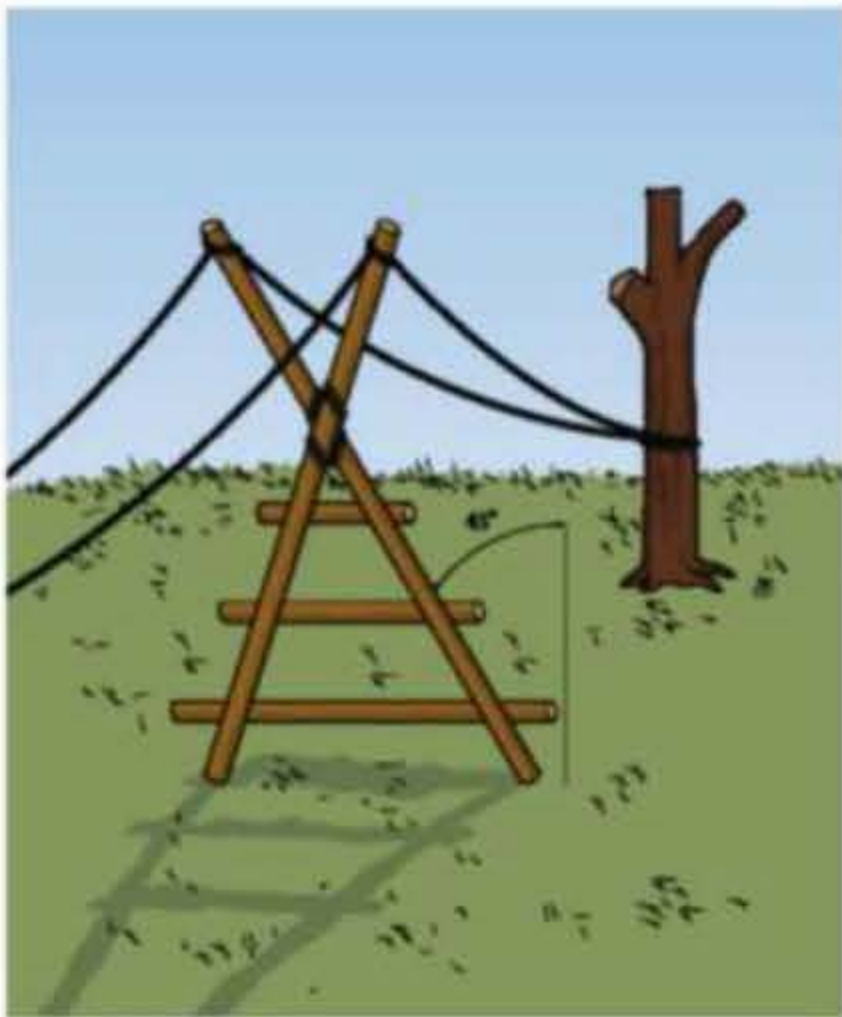
If you're in need of a reliable means of crossing a deep gorge or fast-flowing river, you can use our simple five-step guide to bridge the gap



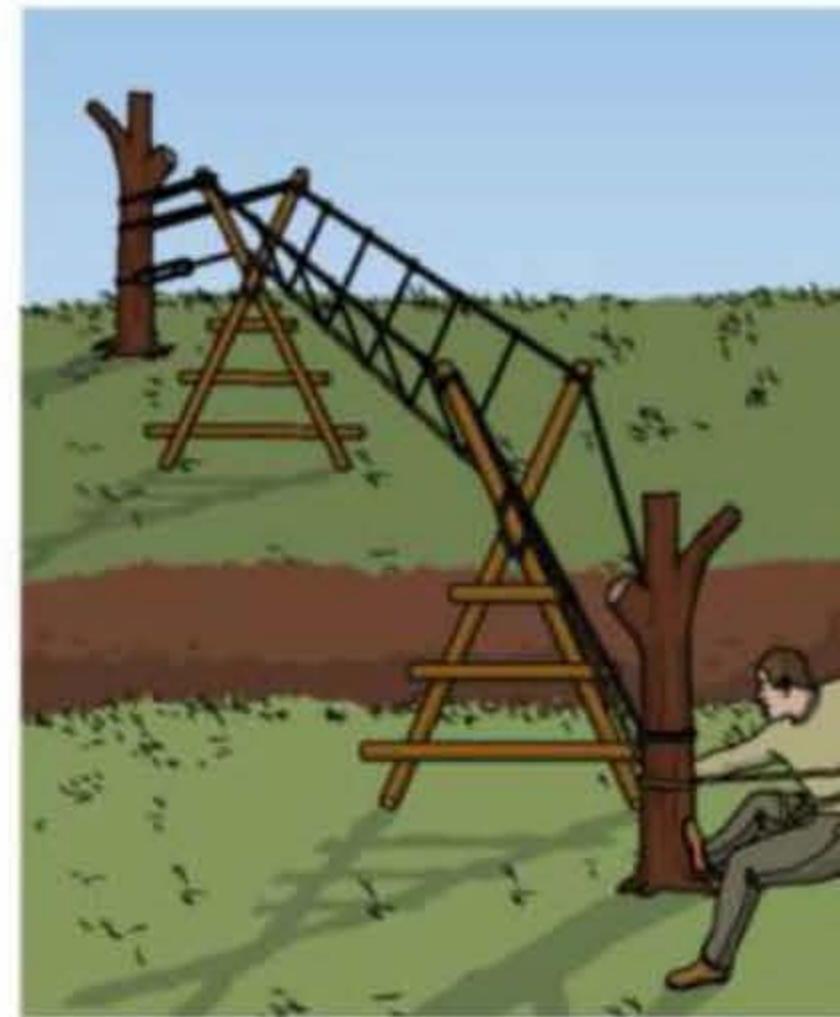
1 Make the trestles
The first job is to build the bridge's trestles – the wooden supports at either end that will hold the two handrails and footrope. These are made by crossing two long wooden poles/spars (as shown) and binding them with rope – best achieved with a square lashing (pictured). Across the bottom half of this 'X' frame, brace it with a few extra spars, again secured with rope, to increase the trestle's sturdiness.



4 Add stringers
It's time to attach the stringer ropes; these connect the handrails to the footrope and prevent them from swaying independently. Equally space the stringers along the bridge. Tie each to one handrail with a round turn and two half hitches, then round the footrope with a clove hitch and then on to the second handrail with another round turn and two half hitches. This will create a stable 'V' shape (see picture).



2 Attach ropes
Attach the handrail ropes and footrope to the first anchor point (eg a tree). The anchor should be tied with a round turn and two half hitches (for knots guide see Learn More). The handrails will be tied to the top of the trestle with clove hitches. The footrope hangs loose over the cross-point, with an optional block and tackle placed between that and the tree. Now raise the first trestle so it leans 45 degrees away from its anchor.



5 Feel the tension
To tension the bridge elevate the trestles to about 85 degrees leaning away from each anchor. Tighten handrails by adjusting the trucker's hitch near the second anchor and tauten the footrope by manipulating the block and tackle near the first anchor; it's advisable to slip pieces of burlap, or hessian, between the footrope and each trestle's square lashing. Before jumping onto the bridge, double-check that all the knots are tight.



3 Second trestle
For the second trestle, start by positioning it under the two loose handrail ropes and footrope, ensuring it's parallel to the first trestle. Tie the handrails to the top of the second trestle's spars with clove hitches and position the assembly at a 45-degree angle towards the second tree. Pass both handrail ropes around the second anchor and then tie them with a trucker's hitch. Now lean the second trestle towards the first.

In summary...

As you can see, with a few wooden spars, a block and tackle and some heavy-duty rope, you can create your very own bridge pretty easily. The key elements to a successful rope bridge are knowing when to use the right knots, two stable anchors that won't budge when subjected to loads as they cross, and the correct tensioning of all components.

Disclaimer: Neither Imagine Publishing nor its employees can accept liability for any adverse effects experienced when carrying out these projects. Always take care when handling potentially hazardous equipment or when working with electronics and follow the manufacturer's instructions.

Learn more

Knots are vital to assembling a rope bridge. To get up to speed with your loops and hitches, check out this handy website: www.netknots.com.

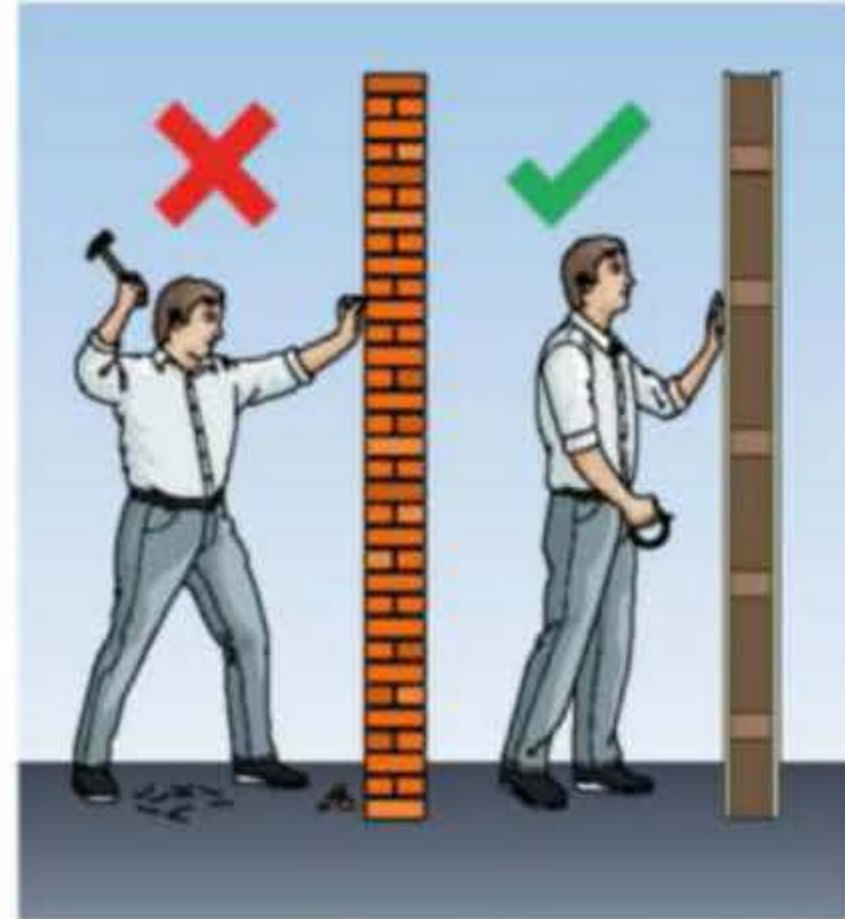
NEXT ISSUE
 - Use a telescope
 - Reattach a button

Hang a picture

Never settle for a wonky frame again – get it picture perfect every time with these tips

1 Wall type

First of all, consider the wall you're working with. If it's a masonry wall then banging nails into it could leave an insecure fitting that might see your artwork crashing down in days. If it's a cavity wall (plaster and wooden boards) then, while it's possible to hang a picture off a nail or two by hammering them into a board, it's important to check for any hidden electrical cables beforehand.



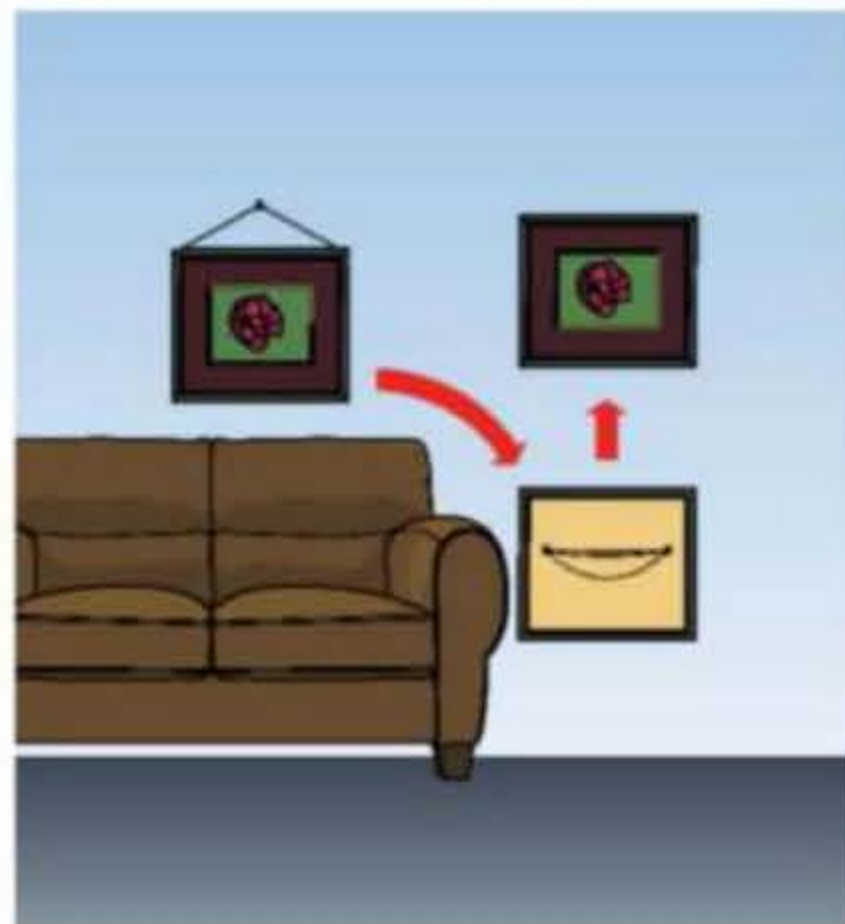
2 Plug in

If hanging on a brick/stone wall things are a bit easier. Get an electric drill and make a pilot hole. Next, insert a wall plug into the hole and test its hold by gently lowering the picture onto it. If it takes the weight, move on to step 3. If hanging on a cavity wall, prior to drilling use an electronic tester to avoid any wires, then find a wooden board by tapping the plaster before making the hole.



3 Balance and adjust

Just because you have a secure fixing doesn't mean your picture will hang straight. For top results use a water level balance to continuously adjust the picture's orientation until level. If the frame has a string hanging bar, ensure you keep all fibres hooked to the screw tip when making adjustments. Sometimes the hanger might be too slack so will need tightening.



In summary...

Don't just start banging nails into any wall without first ensuring it's both suitable and safe. While knocking nails into a masonry wall can provide a picture fixing, it's better to drill a hole and then insert a plug. Lastly, to ensure your picture is level and flush, use a spirit measure and make any necessary tweaks to the hanging mechanism.

TEST YOUR KNOWLEDGE

ENJOYED THIS ISSUE? WELL, WHY NOT TEST YOUR WELL-FED MIND WITH THIS QUICK QUIZ BASED ON THIS MONTH'S CONTENT?



- 1 What were the painted wooden panels in Ancient Greek theatres called?
- 2 What rack-and-pinion rail system is used on the Mount Washington Cog Railway?
- 3 When did the A-10 Thunderbolt II (Warthog) make its first flight?
- 4 How much larger does Earth's Moon appear in a supermoon phase?
- 5 In which year did the Danish astronomer Tycho Brahe die?
- 6 At what rate can giant kelp grow per day (in cm)?
- 7 In which US facility is the world's most powerful laser located?
- 8 What is the average temperature of a household freezer (in Celsius)?
- 9 How long ago is the Earth believed to have formed?
- 10 What is the area of Montecristo which inspired the eponymous novel (in sq km)?

ENTER ONLINE

at www.howitworksdaily.com and one lucky reader will win a model of the Lancaster B III bomber, as once used by the Dambusters – good luck!



ISSUE 46 ANSWERS

1. 8.4mph 2. 3rd century BCE 3. 62 4. 1961 5. 35.9x24mm
 6. 13 7. 2,000mm 8. 80mn 9. 2737 BCE 10. 1942



INBOX

Feed your mind. Speak your mind

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Get in touch!

We enjoy reading your letters every month. So keep us entertained by sending in your questions and views on what you like or don't like about the mag.

FANTASTIC PRIZE FOR LETTER OF THE MONTH!

WOWee ONE™

WIN A WOWEE ONE PORTABLE SPEAKER

This issue's top letter wins a WOWee One Classic portable speaker. This turns any surface into a bass amplifier using gel technology, and is compatible with all iDevices and other mobile gadgets.



Win!
A WOWee One portable speaker

To learn more about Vikings, be sure to check out our feature in issue 45

Letter of the Month

Vikings made an impact

Hi HIW

The feature 'Age of the Vikings' [in issue 45] describing cross-sea raiding parties of powerful warriors arriving in their longboats was both informative and interesting. Without doubt the legacy of the Viking era has greatly influenced our history. Yet it is interesting to muse why these ruthless opportunists felt the need to raid and pillage.

Life was harsh in Scandinavia with its short summers and long, cold winters. Vast areas of forest meant there was a shortage of farmland to support everyone. So the largely farming population often had to look for other ways to survive in this hostile environment. While the eldest sons inherited the farms, younger sons needed to seek out new livelihoods. Commodities such as wood and animal furs provided only narrow opportunities for trade. It is for these

reasons that returning longboats laden with loot would have been considered so valuable.

Best regards,
Jackie Patrick

Hi Jackie. What you say indeed rings true as often historical events are viewed with a very narrow perspective when in fact their causes and consequences are considerably more wide ranging. So while the Viking raids on Britain can be seen merely as brutal attacks for treasure, actually the causes (as you describe) and the consequences - such as the spreading of Scandinavian culture throughout the world - have greatly shaped our history. Who's to say if it's for better or for worse?



Is it just us, or do iPods always die when you get on a noisy bus/train?

Baffled by batteries

Hi,
My iPod has lost its maximum battery life over time. Why does this happen to electronic devices? I would be very grateful if you could answer this in a future issue of How It Works.

Cheers,
Robert Philipson

We have covered how batteries work in the magazine before, Robert - most recently in the big electricity cover feature that appeared in issue 44. Having said this, we haven't looked specifically into this common problem, so stay tuned for the answer in an upcoming edition.

Passive not active

To the Editor,
In your last issue [46] there was mention of hot air rising and hot water rising. In fact, 'rising' gives the wrong impression. The rising is actually passive, not active. Hot substances are (usually) less dense and so they are actually 'pushed' up by the denser cold substances beneath.

Best regards,
Philip D Welsby

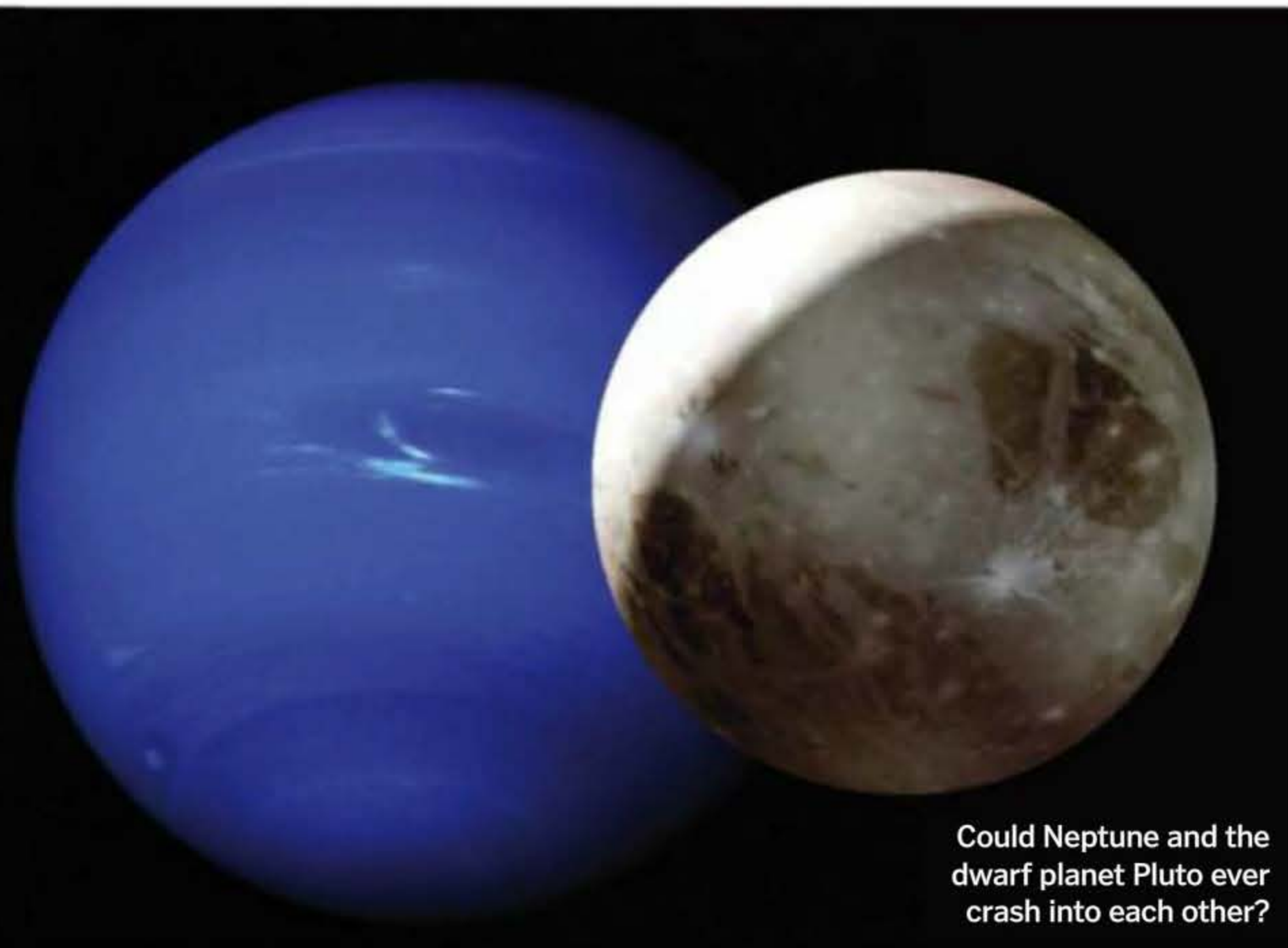
Short and sweet

Hi,
Last week I bought issue 45 of your magazine. I loved it!
Kaylee

Eyes on the prize

Hello
I'm a regular reader and have had a subscription for roughly a year. Just want to say I LOVE the magazine! It never fails to amaze me how the topics/articles relate to subjects that have come up in conversation around the time of me receiving the magazine. For example, the piece about the extinction of Neanderthals [in issue 46] came up in my A-level biology class. My teacher didn't know the reason of extinction, but I could tell him it was due to their bigger eye sockets using up a large amount of their brain capacity.
Tom Lee

Thanks very much for writing in, Tom. And yes, we have to agree that



Could Neptune and the dwarf planet Pluto ever crash into each other?

the research regarding Neanderthal eye sockets really jumped out at us last month too, which is why we wanted to include it in the '10 things we learned this month' section. It's always fascinating when a small piece of information like this comes to light through scientific research that goes on to help answer far wider-reaching questions. In this case, the simple fact that Neanderthals had slightly larger eye sockets than early humans was conceivably a primary cause of their entire species dying out. Just think, if their eyes hadn't been so large, they might still be around today!

Cooling for help

Dear Sir/Madam,
I am currently working on a humanitarian project aimed at repurposing used or abandoned vehicles to convert them into food preservation units (ie refrigerators).

I am in the last stages of my study, however, and I'm a bit lost as to how much power output an air-conditioning system produces; this is to calculate things like heat transfer and such. If there is anyone who is able to help with my enquiry, it would be hugely appreciated. Kind regards,
Ben Corkin

If anyone can help Ben with his worthy cause then please write in and we will pass on your details.

Cosmic collision?

Hi,
Neptune and Pluto's orbits crisscross. Will they one day collide and send shockwaves across the Solar System?
Finlay Hillcoat (aged 10)

The last time Pluto crossed Neptune's orbit was 11 February 1999 and this will happen again in 214 years. Importantly though, Pluto will not crash into Neptune then – nor ever. This is because, while Pluto's orbit is said to cross Neptune's for a small part of its total orbital cycle (20 years out of 248), it is actually inclined to the ecliptic by 17 degrees in comparison, while also being resonant with it; Pluto orbits the Sun twice for every three orbits of Neptune. Even at their closest, the two bodies are at least 2 billion kilometres (1.2 billion miles) apart.

"Just think, if Neanderthals' eyes hadn't been so large, they might still be around today!"

What's happening on... Twitter?

We love to hear from **How It Works'** dedicated readers and followers, with all of your queries about the magazine and the world of science, plus any topics you would like to see explained. Here we select a few of the tweets that caught our eye over the last month.

🐦 Lars Goodman @curtis_lars
@HowItWorksmag
I love your magazines!!!!

🐦 Callum Pirson @cjayp33
@HowItWorksmag
Yay! Got my first subs copy after 45 shop issues. Shame it's not as crisp/pristine as shop copies due to the way it's been handled

🐦 showshine @shusho_sho
Reading **@HowItWorksmag**
now :D

🐦 Laura @lovenailsuk
My husband got me
@HowItWorksmag today!
Absolutely brilliant. Already looking forward to the next issue. Highly recommended, guys and gals!

🐦 Bethany Williams
@xxxbethanyxxx1
@HowItWorksmag Will holding your breath when someone sneezes stop you from getting their cold?

🐦 Ryan Evans @ryanevans06
Cool, my tweet got published in this month's **@HowItWorksmag** – thanks, guys!



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Magazine team

Editor Helen Porter

helen.porter@imagine-publishing.co.uk
☎ 01202 586215

Editor in Chief Dave Harfield

Features Editor **Robert Jones**
Staff Writer **Laura Mears**
Senior Art Editor **Helen Harris**
Senior Sub Editor **Adam Millward**
Photographer **James Sheppard**
Head of Publishing **Aaron Asadi**
Head of Design **Ross Andrews**

Contributors

Aneel Bhangu, Ella Carter, Alexandra Cheung, Hannah Harris, Ben Hasler, Moe Hezwani, Ian Jackson, Ian Moores, Jonathan O'Callaghan, Katie Peat, Peters & Zabransky, Vivienne Raper, Dave Roos, Lee Sibley, Mike Simpson, Annabelle Sing, Giles Sparrow, Alasdair Stuart, The Art Agency, Luis Villazon

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Advertising

Digital or printed media packs are available on request.

Account Manager Liz Tucker

☎ 01202 586431
liz.tucker@imagine-publishing.co.uk

Senior Account Manager Lynsey Porter

☎ +44 (0)7947 364887
lynsey.porter@imagine-publishing.co.uk

Head of Sales Hang Deretz

☎ 01202 586442
hang.deretz@imagine-publishing.co.uk

International

How It Works is available for licensing. Contact the International department to discuss partnership opportunities.

Head of International Licensing Cathy Blackman

☎ +44 (0) 1202 586401
licensing@imagine-publishing.co.uk

Subscriptions

subscriptions@imagine-publishing.co.uk

For all subscription enquiries

☎ 0844 815 5944

Overseas +44 (0)1795 418680

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Head of Circulation Darren Pearce

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Production Director Jane Hawkins

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Group Finance and Commercial Director Steven Boyd

Group Creative Director Mark Kendrick

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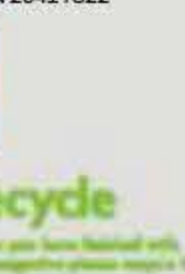
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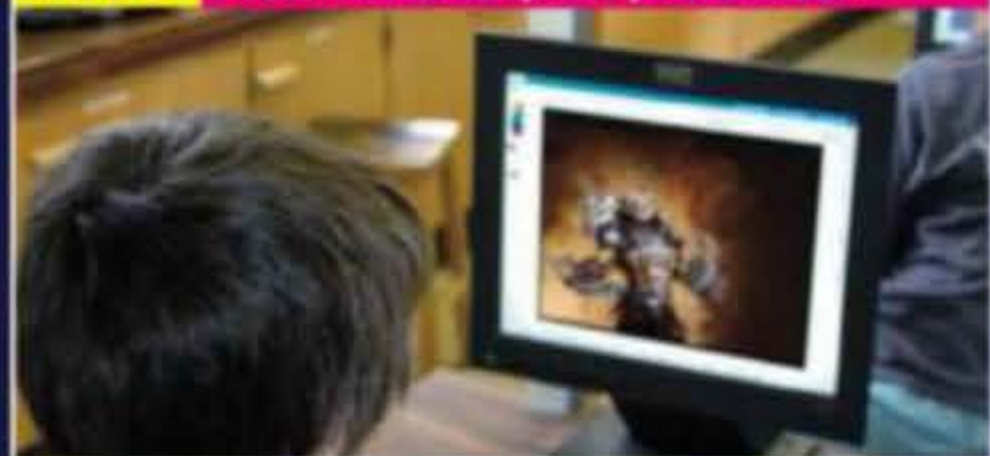
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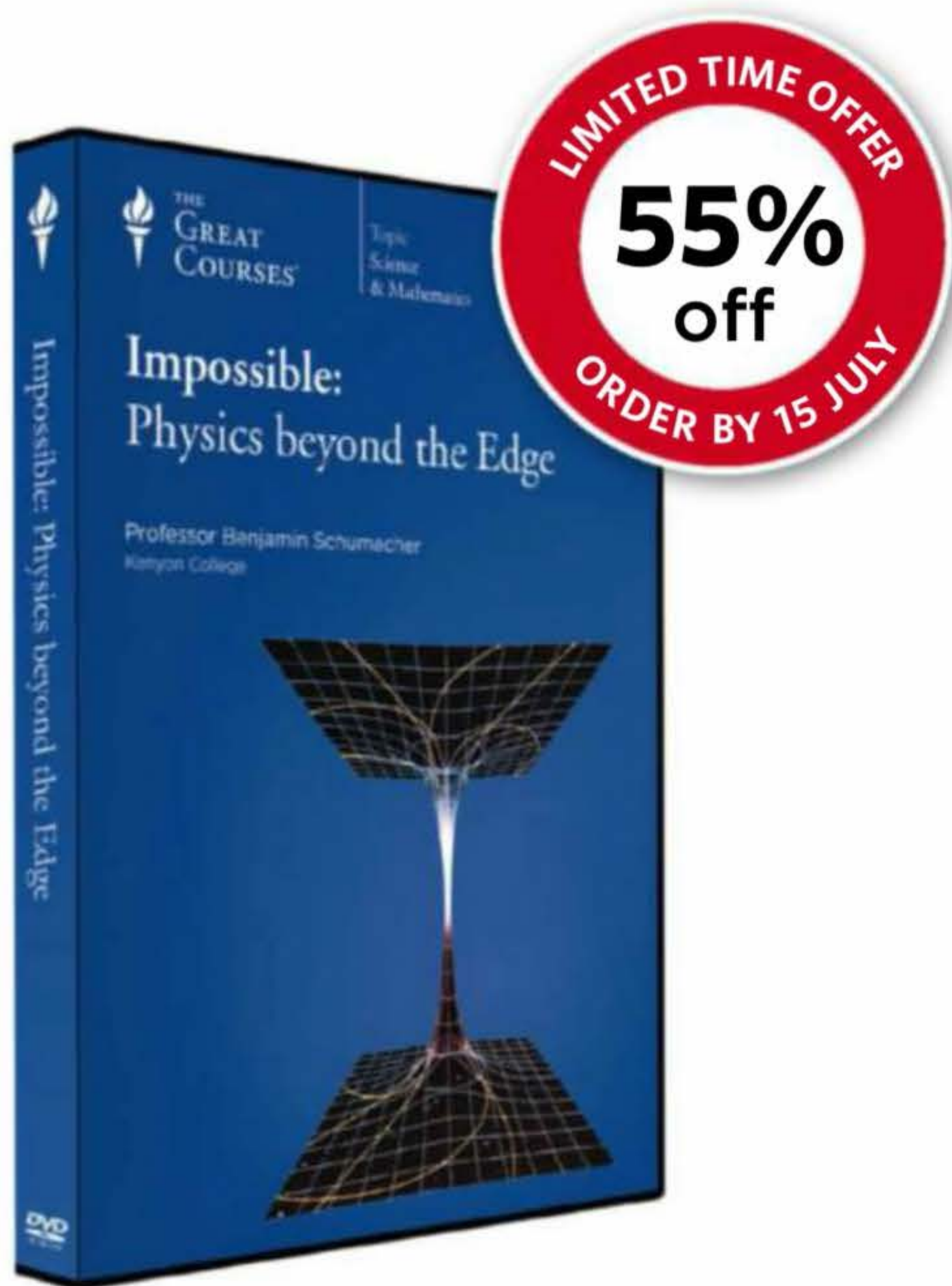


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