THE MAGAZINE THAT FEEDS MINDS

# HOW IT WORKS

SCIENCE ENVIRONMENT TECHNO

INSIDE

DINO GIANT
HOW DID THE MASSIVE APATOSAURUS LIVE?

WHY DO WE GET FLU?
How winter's worst bug invades our bodies

MOTORBIKE PHYSICS
What forces are at play when a rider corners?

BIRDS OF PREY EXPLAINED
Why these avian assassins are built for the kill

OVER 2,000 TIMES BIGGER THAN OUR SUN

OUR SUN

# HYPER GIANT STARS

DISCOVER HOW THE BIGGEST STARS IN THE UNIVERSE EVOLVE

227 AMAZING IMAGES & CUTAWAYS

LEARN ABOUT HELICOPTERS
MEET THE MOST ADVANCED WINGLESS AIRCRAFT EVER

+ REVEALED

- ECO CARS
- SEA SLUGS
- PYROMETERS
- MAX PLANCK
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- TERRARIUMS
- DIVING BELLS
- WAX FIGURES
- METRONOMES

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ISSUE 053

## 5 TOP FACTS: Quad Bikes

**ATV**
ATV stands for All-Terrain-Vehicle,a machine capable of traversing all kinds of difficult terrain.

**Reliable**
The British Army has used them for a number of years as reconnaissance and supply machines.

**Duties**
The ATV's are often used to carry ECM equipment, due to its weight, helping to protect patrols from I.E.Ds.

**Features**
Both fast and manoeuvrable the ATV's are perfectly suited to the fluid modern battlefield.

**Transportable**
Able to fit in the back of the Merlin helicopter the machines are air portable to remote locations and can operate independently.

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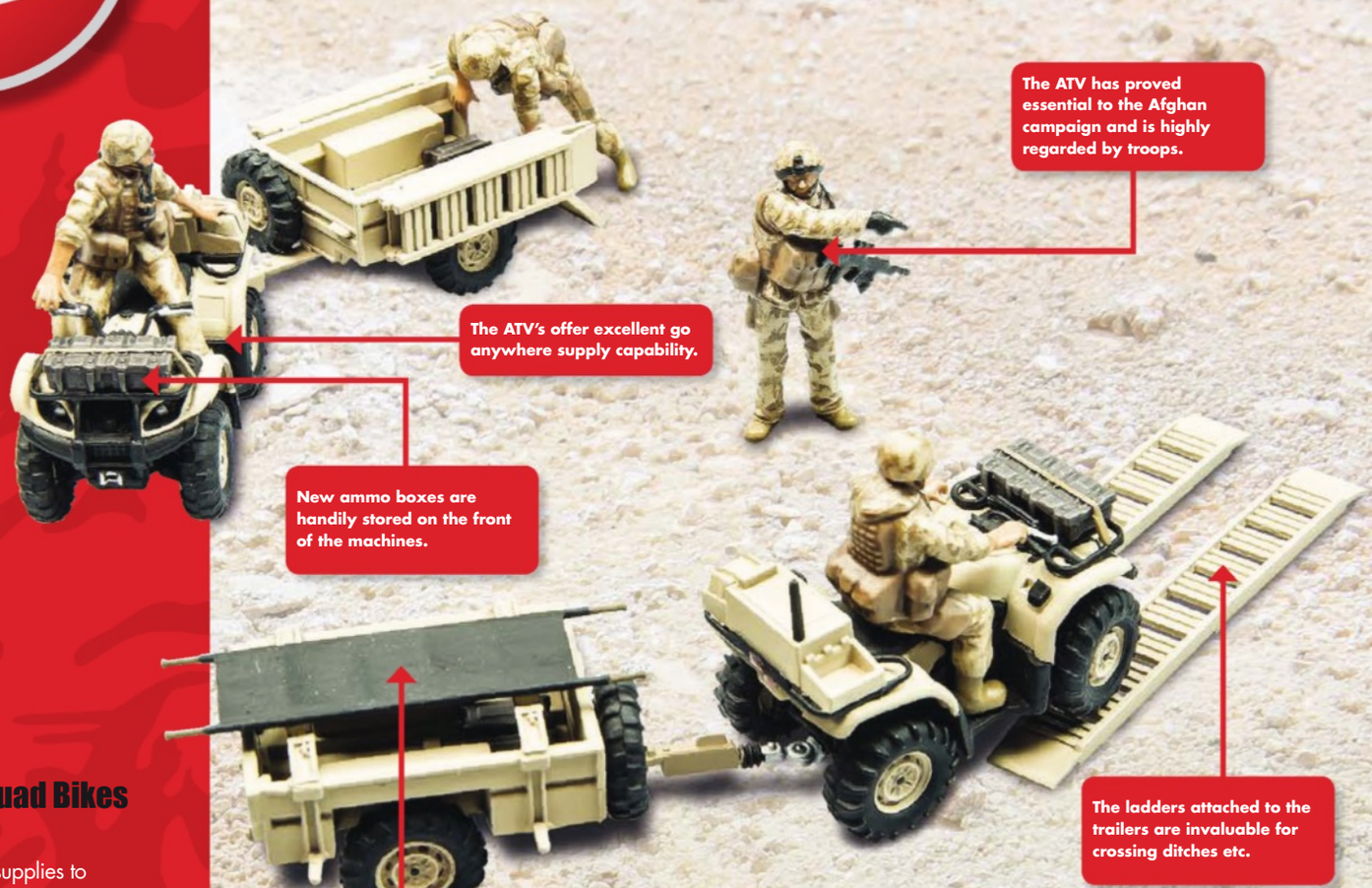
# HOW IT WORKS




## A04701
## British Forces Quad Bikes and Crew

Delivering vital combat supplies to troops on the ground, quad bikes and trailers are providing sterling service on frontline operations.

This latest batch of Afghanistan-bound ATVs and trailers will deliver food, water and ammunition to the front line, in difficult to access areas or where larger vehicles are not suitable, effectively running alongside those who are on dismounted operations.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ISSUE 53

# WELCOME

The magazine that feeds minds!

**Page 22**
Find out why birds of prey like the white-tailed eagle are perfectly built for the hunt

Let's face it, nuclear power certainly doesn't have the best of reputations – especially in the light of events like Fukushima. But by the same token, we can't pretend that our current methods of producing power are much better; indeed, many scientists assert that burning fossil fuels has caused far more environmental damage and claimed more lives through pollution than nuclear power ever has. And, of course, they won't last for ever. This issue we discover how the latest technology in the nuclear field is making this power source safer, greener and more efficient than it has ever been. Elsewhere we get up close with some of the most cutting-edge helicopters currently in the skies, looking at the engineering of fine examples like the superfast Eurocopter X3 and the super-deadly Apache.

Enjoy the issue.

**Adam Millward**
Deputy Editor

## Meet the team...

**Marcus**
**Designer**
Hypergiants caught my eye this issue and learning all about how big they really are and how they form has been fascinating.

**Helen**
**Senior Art Editor**
I loved finding out about birds of prey this month; you'll be blown away by the excellent illustration which reveals how an eagle hunts!

**Jackie**
**Research Editor**
Scientists are getting closer to making nuclear fusion a viable power source. Find out how it measures up against fission now.

**Dave**
**Editor-in-Chief**
I never knew the Brontosaurus dinosaur had been proven to be the Apatosaurus, so it was great to learn more about this giant beast.

## 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

## Get in touch

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What are these enormous stars made of and why are they known for living fast and dying young?

62 Amazing helicopters



## Meet the experts...

**Giles Sparrow**
**Hypergiants**
**HIW** regular space writer Giles is back this month to shine a light on the secrets of the brightest stars in the universe, revealing how they evolve.

**Dave Roos**
**Deep-sea mining**
Dave takes the plunge to reveal how specially adapted machines are able to dig up precious metals in the depths of the ocean.

**Aneel Bhangu**
**Life-saving robots**
Meet the robots which are helping human doctors perform complex surgery in the operating theatre and see what role they play.

**Alex Cheung**
**Nuclear power**
This month Alex takes a closer look at the huge strides in nuclear energy, making this power source safer, greener and more efficient.

**Laura Mears**
**Wax figures**
Laura is back this issue to reveal the step-by-step process behind the construction of eerily lifelike models made out of wax.

How are modern eco cars like the Nissan Leaf evolving? Find out on page 70

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Socotra's endemic dragon blood tree has been named after its blood-red sap

# 'Lost world' seen in new light

## Mystery island in the Indian Ocean confirmed to play host to many rare species of flora and fauna, up to 20 million years old

Looking more like a weird alien landscape from a blockbuster sci-fi film than a small landmass in the Indian Ocean, the mysterious island of Socotra is truly a real-life lost world.

Positioned approximately 250 kilometres (155 miles) from Somalia and 340 kilometres (210 miles) from the coast of Yemen, Socotra has long been known to exist. However, after extensive study by numerous research teams, it has been revealed that many of its hundreds of native species not only exist nowhere else in the world but also date from a time period where humans were but a distant dream. Indeed, scientists have revealed that some of the island's exotic species, such as the dragon blood tree (Dracaena cinnabari) – so-named due to its blood-red sap, date to over 20 million years old, while others such as the desert rose (Adenium obesum) grow in forms long-since unseen elsewhere on our planet.

Interestingly, according to excavations conducted in 2008, Socotra was first occupied by a prehistoric Oldowan stone-tool using culture, with crude tools discovered dating from over a million years ago. Due to this early occupation and because of the island's ancient and rare inhabitants, Socotra is a designated UNESCO World Heritage Site.

*"Scientists have revealed that some of the island's exotic species, such as the dragon blood tree, date to over 20 million years old"*

Some of Socotra's exotic plants date to over 20 million years old

The island of Socotra as seen from space – it is located off the coast of Somalia

# Black hole is sleeping

The reason why our galaxy's supermassive black hole, Sagittarius A*, is dormant has been one of the great unanswered questions, but new evidence suggests the black hole is a 'sleeping dragon', which erupted 2 million years ago and will do so again. According to the study, which was published recently in the *Astrophysical Journal*, the explosion would have been so intense that it lit up a molecular cloud system 200,000 light years away. Lead author Professor Joss Bland-Hawthorn commented: "Since 1996, we've been aware of an odd glow from the Magellanic Stream, but didn't understand the cause. Then this year, it finally dawned on me that it must be the mark, the fossil record, of a huge outburst of energy from the supermassive black hole at the centre of our galaxy. Now we know when this sleeping dragon, 4 million times the mass of the Sun, awoke and breathed fire with 100 million times the power it has today."

According to the study, Sagittarius A* erupted with great energy 2 million years ago

## Go wild about World of Animals

**World of Animals** is a new monthly magazine from the makers of **How It Works** that takes a unique look at Earth's wonderful wildlife. With breathtaking photos, captivating stories and stunning illustrations, each issue offers the safari of a lifetime. On sale 28 November, the first issue includes an in-depth look at gorillas and an exposé of 50 creatures close to extinction. **World of Animals** launches alongside digital editions for iOS and Android and will also have a brand-new website: **animalanswers.co.uk**. Be sure to share your thoughts on both Facebook and Twitter (@WorldAnimalsMag).

A traditional manned F-16 in flight. The unmanned variants have been renamed QF-16s




The MQ-1B Predator is one of the most advanced UAVs today, but is used more for combat than training

# F-16 jets to take off without pilots

## Defence contractor Boeing confirms retired F-16 fighter jets are being turned into UAVs

It has been confirmed that Boeing is retrofitting retired F-16 fighter jets with the necessary autopilot systems to allow them to fly unmanned.

The vehicles – the first of which made its maiden flight in the last week of September – can take off and fly through the skies and even perform complex manoeuvres such as barrel rolls and 180-degree split-S turns, all without a human pilot on board.

Prior to the F-16s being retrofitted they had sat dormant in military storage facilities throughout the United States, however Boeing now hopes the planes can undergo a renaissance, acting as automated drones for real-life pilots to train with.

Speaking on the successful flight, Ryan Inman, commander of the US Air Force's 82nd Aerial Targets Squadron said: "It was a little different to see it without anyone in it, but it was a great flight all the way around".

Meanwhile, Paul Cejas, the project's chief engineer, confirmed that the F-16 "flew great [and] made a beautiful landing – probably one of the best landings I've ever seen."

Moving forward, Boeing also confirmed that the six F-16s had been rebranded as QF-16s and that the US military would be using them in live-fire flight tests imminently.

*"The modified aircraft can even perform complex manoeuvres such as barrel rolls and 180-degree split-S turns all without a pilot"*

## This day in history 07/11/13: How It Works issue 53 goes on sale, but what else

**335 CE**
**No pain, no grain**
Athanasius, 20th bishop of Alexandria, Egypt, is banished to Trier on a charge that he prevented a grain fleet from sailing to Constantinople.

**1619**
**Bohemian rhapsody**
Elizabeth of Scotland and England is crowned Queen of Bohemia.

**1665**
**New edition**
*The London Gazette*, the oldest surviving journal today, is published for the first time.

**1775**
**No to slavery**
John Murray, the Royal Governor of the colony of Virginia, starts the first mass emancipation of slaves in North America.

# Turning point for Alzheimer's

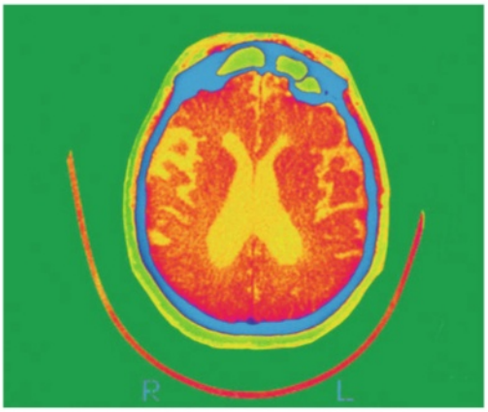
There have been two recent breakthroughs in Alzheimer's research, which could spell the end for the neurodegenerative condition.

The first comes in the form of a chemical, which, when tested on mice, was able to stop brain cells dying in those with prion disease. The scientists from the Medical Research Council Toxicology Unit at the University of Leicester, UK, believe that this chemical could be adapted to halt other serious neurological conditions including Alzheimer's.

Although we are some way off a 'cure' for human patients, Professor Roger Morris of King's College London sees it as a big step in the right direction: "I'm very excited. It's the first proof in any living animal that you can delay neurodegeneration. The world won't change tomorrow, but this is a landmark study."

Another study has made great strides in detecting the early signs of the disorder. Conducted by Birmingham City University – collaborating with Lanzhou University, China – researchers scanned the brains of patients with amnestic mild cognitive impairment (aMCI), which four times out of five will progress into Alzheimer's disease.

The scans revealed that a considerable loss of grey matter in the brain's left hemisphere consistently indicated a higher chance of developing Alzheimer's. Professor Mike Jackson, who played a major role in the research, believes such scans could serve as "alarm bells for doctors". This is a significant discovery because the earlier that Alzheimer's is spotted, the more can be done to limit its damaging effects in the long term.




# Jupiter and Saturn get diamond rain

Calculations using new atmospheric data have suggested two of the Solar System's gas giants might regularly experience showers of diamonds. US scientists have suggested that methane high in the atmosphere is transformed into soot during thunderstorms on Saturn and Jupiter. These clouds of soot provide the carbon that eventually turns into diamonds on its descent to the surface. It's estimated that the majority of the diamond 'hail' is about a centimetre (0.04 inches) across in size and that the stones probably melt when the heat and pressure grow too much near the core.

Although diamond precipitation has previously been thought feasible on other planets like Neptune, this is the first time Saturn and Jupiter have been considered to share similar meteorological traits. One of the scientists who proposed the notion, Dr Kevin Baines of the Jet Propulsion Laboratory, said: "The bottom line is that 1,000 tons of diamonds a year are being created on Saturn. People ask me – how can you really tell? It all boils down to chemistry. And we think we're pretty certain."


Could sightings of a mysterious primate actually have been a species of bear?

# Yeti mystery may finally be solved

After DNA-testing samples of supposed 'yeti' hair a British scientist believes he has unearthed the secret of the mythical beast, suggesting it is, in fact, a type of bear.

There have been reported sightings of an unusual primate, or 'Abominable Snowman' creature, for centuries in the Himalayan mountains, as well as many other regions around the globe.

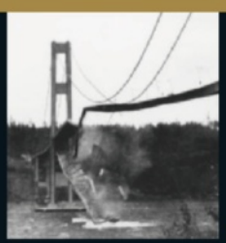
Hoping to clear up the mystery once and for all, geneticist Bryan Sykes – a professor from Oxford University – collected hair samples from the Himalayas in order to scrutinise their genes. The results matched up with the DNA of an ancient species of polar bear and Sykes thinks that yetis could be some form of polar-brown bear hybrid. Commenting on the research, Sykes said: "Bigfootologists and other enthusiasts seem to think that they've been rejected by science. Science doesn't accept or reject anything, all it does is examine the evidence and that is what I'm doing."



## happened on this day in history?

**1885**
**On track**
Canada's first transcontinental railway is completed.

**1940**
**Bridge collapses**
The original Tacoma Narrows Bridge in Washington, USA, collapses in a windstorm.



**1996**
**Off to Mars**
American space agency NASA launches the Mars Global Surveyor spacecraft.

**2012**
**Quake**
An earthquake off the Pacific coast of Guatemala kills over 50 people.

GLOBAL EYE

# 10 COOL THINGS WE LEARNED THIS MONTH

## Lightsabers might not be sci-fi after all

As far as weapons go, they don't get much cooler than the Jedi's sword of light, but the *Star Wars* prop has never had any scientific grounding – until now. US scientists have recently demonstrated that it's possible to give photons of light that elusive quality every good weapon needs: mass. They achieved this by filling a vacuum chamber with rubidium atoms, which were then cooled to just above absolute zero. When two distinct photons were introduced to the chamber, the cool temperature slowed their speed and brought them together – so much so that they left the chamber behaving like a molecule.

## Sun-powered house is seeking a new owner

The UK's very first 100 per cent solar-powered house, which is allegedly self-sustaining with no need for any external utilities, has come on to the market. Based in Leicestershire, the Solar House gathers all the energy it needs (both thermal and electric) from hybrid panels on the roof, which is then transferred to a network of pipes in the foundations where it's stored for use in the winter months. The building also boasts a number of other zero-carbon features including triple-glazed windows and tanks for collecting rainwater.

## Blooming plants are a lot older than we thought

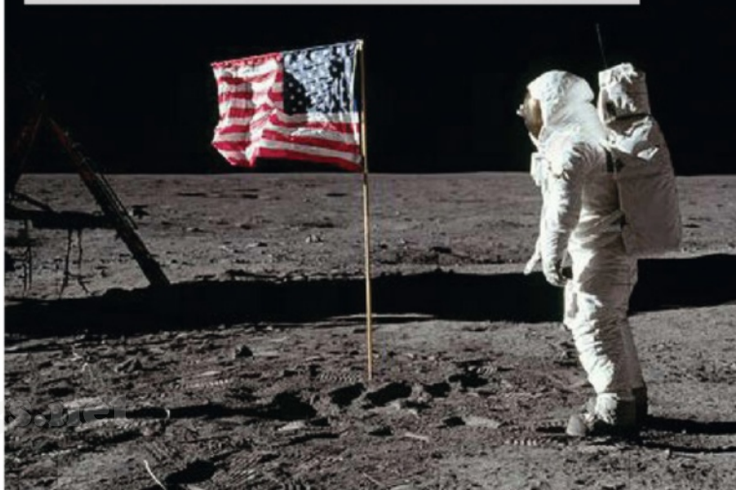
Fossilised remains of pollen have been unearthed in Switzerland dating from the Mid-Triassic period around 240 million years ago, suggesting flowering plants (angiosperms) have been around a lot longer than believed. Until now, the oldest pollen has dated to the Early Cretaceous – about 140 million years ago. Scientists used confocal laser scanning microscopy, which can analyse a sample at various depths to provide ultra-hi-res imaging, and detected six separate types of pollen. This discovery tallies up with similar evidence found in sediment from the Barents Sea, north of Russia.

## 90% of us aren't morning people

Ever wondered why that friend of yours is so bright and chirpy in the morning when everyone else is groggy and short-tempered? Well, it may all be down to the way our brains are structured. Researchers from RWTH Aachen University, Germany, suggest that only ten per cent of us can be classified as true 'morning people', while conversely 20 per cent of us are 'night owls', being most active at night. The team used diffusion tensor imaging (DTI) to study the brains of both types of people and found differences in the white matter that they claim might explain higher rates of depression and a feeling of 'chronic jetlag' among those who often stay up late.

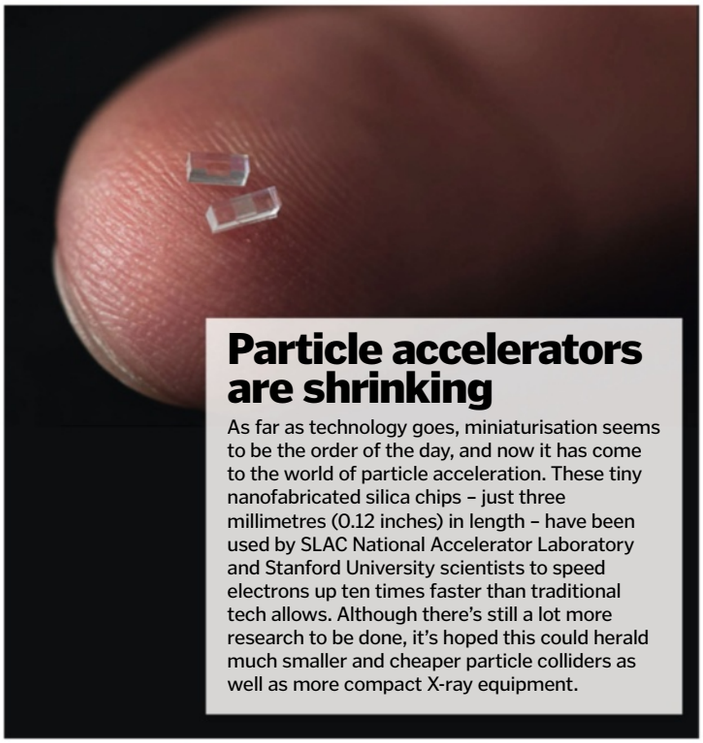
## NASA is 55 years old

On 1 October, the world's most famous space agency, the National Aeronautics and Space Administration, saw in its 55th birthday, though celebrations were somewhat marred by a US government shutdown. However, no one can take away from NASA's many achievements, from sending a probe outside our Solar System and landing man on the Moon to everyday technologies like UV-protected sunglasses. But NASA is far from contemplating retirement, putting out a to-do list that includes capturing an asteroid and sending astronauts to Mars by the 2030s.



## Beavers' butts smell of vanilla

Always assumed the extract that flavours your cakes, ice cream and perfume comes from vanilla pods? Well, not always. In fact, for decades many food and cosmetic manufacturers have been using a chemical compound called castoreum to get that popular scent and flavouring. And castoreum is a natural secretion that beavers use to mark their territory produced in castor sacs located in the rodent's rear! It's considered a perfectly safe additive, so is totally above board, but is only used in very small quantities because it is both time and labour-intensive to extract.

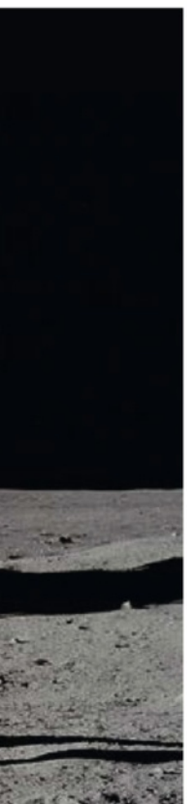


## Particle accelerators are shrinking

As far as technology goes, miniaturisation seems to be the order of the day, and now it has come to the world of particle acceleration. These tiny nanofabricated silica chips – just three millimetres (0.12 inches) in length – have been used by SLAC National Accelerator Laboratory and Stanford University scientists to speed electrons up ten times faster than traditional tech allows. Although there's still a lot more research to be done, it's hoped this could herald much smaller and cheaper particle colliders as well as more compact X-ray equipment.

## Exoplanets have cloudy days too

Data from NASA's Spitzer and Kepler telescopes has been combined to create the first cloud map of a planet outside our Solar System. Located approximately 1,000 light years away, Kepler-7b is a gaseous world similar to Jupiter (which is inset below). The clouds, which appear to be much more stable than the ones we're familiar with on Earth, were first detected when Kepler observed a bright spot on the exoplanet's western hemisphere. Spitzer was then brought in for a closer look of the atmosphere and it's now believed the spot is light from Kepler-7b's nearby star bouncing off the cloud tops.



## MIT's no fool when it comes to pyrite

Pyrite, or fool's gold, is a material brimming with potential, with possible uses in solar cells and more. But first, we need to better understand its structure and why it corrodes so easily. Researchers at MIT have made great strides by studying the mineral's surface properties in detail. Using scanning tunnelling spectroscopy and new software, the scientists discovered that the electron structure varies wildly at the surface to the bulk of the material, affecting its reactivity and conductivity. We can now look at ways to treat the surface to address this discrepancy.

## We're behind global warming

It's been controversial for decades, but a new Intergovernmental Panel on Climate Change report has concluded it's 95 per cent sure that humans are responsible for the world heating up since 1950. As well as an increase in the average air and sea temperature, this has resulted in a reduction of snow/ice, a spike in greenhouse gases ($CO_2$ is up 40 per cent since the pre-industrial era) and the rising of our oceans. If these trends continue, effects on flora and fauna could be devastating. The report suggests that the only solution is to 'put a price on carbon'.

# HYPER GIANT STARS

**Born with the mass of dozens of Suns, hypergiants are enormous stars that live fast, burn brilliantly and die young**


Imagine a star so big that if it replaced the Sun, it could engulf the Solar System as far out as the orbit of Saturn. Or one that produces as much energy in one second as our Sun does in a hundred days. These might sound unreal, but both stars exist – they're two examples of hypergiants, the most extreme stars in the universe.

Hypergiants are stars that burn with the brilliance of millions of Suns. Though born from the same clouds of interstellar hydrogen gas as normal stars, their enormous mass (tens or even hundreds of times that of the Sun) creates tremendous internal pressures that heat their interiors and accelerate the rate of the nuclear fusion reactions in their core.

So while a star like the Sun can sustain itself on a relatively small amount of hydrogen 'fuel' for a period of up to 10 billion years, a hypergiant with perhaps a hundred times the available fuel will squander it in a million years or less, blazing away as a brilliant but comparatively short-lived cosmic beacon.

Like all stars, the physical characteristics of hypergiants depend on the delicate balance between the outward 'radiation pressure' from energy escaping their cores, and the inward pull of gravity from their enormous mass. As a result, hypergiants usually change their appearance through their lifetimes. Astronomers on Earth detect these differences through measuring the range of different luminosities and colours from star to star (even though hypergiants live and die quickly on a cosmic timescale, they certainly don't change quickly enough for us to see them evolve significantly over the course of a human lifetime). By plotting these properties for various stars on a Hertzsprung-Russell diagram, they can work out the relationships between them, and the likely paths by which one type of star changes into another.

Hypergiants, it's clear, spend most of their short lives as brilliant blue stars – with temperatures of perhaps 50,000 degrees Celsius (90,000 degrees Fahrenheit), compared to the Sun's 5,500 degrees Celsius (9,930 degrees Fahrenheit). But many later evolve towards the

# 5 TOP FACTS
## HYPERGIANTS

**1 Big babies**
As hypergiants burn through all of their fuel so fast, most of them can still be found relatively close to their birthplace, embedded in starbirth nebulas.

**2 Rewriting the rulebook**
Hypergiants are so rare that they weren't included in the standard system of luminosity classes – astronomers had to add a 'Class 0' brighter than the brightest 'Class I' supergiants.

**3 Black hole progenitors**
Because their cores alone may have the mass of five or more Suns, hypergiants are the most likely stars to leave black holes in their wake when they turn supernova.

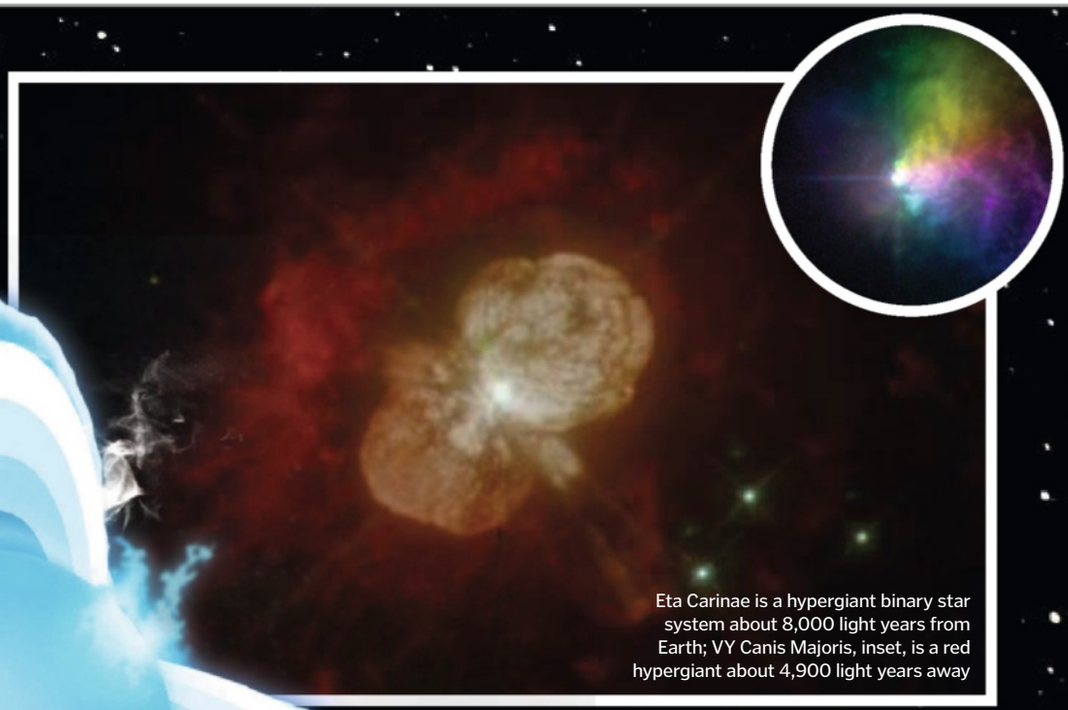
**4 Classification confusion**
Because of the confusion surrounding the various different types of hypergiant, there are some astronomers who prefer to avoid using the word in the first place.

**5 King of the hypergiants**
There are several candidates for the largest known star, but some estimates suggest the red hypergiant Westerlund 1-26 has a monster diameter equivalent to 2,500 Suns.

**DID YOU KNOW?** *In 2012 astronomers found 'light echoes' – light from Eta Carinae's 1843 outburst reflected off distant nebulas*

# Inside a hypergiant

**What are the main layers that make up a super-bright blue hypergiant?**



Eta Carinae is a hypergiant binary star system about 8,000 light years from Earth; VY Canis Majoris, inset, is a red hypergiant about 4,900 light years away

**Core region**
In a massive blue hypergiant like this, the star's core may be shining by fusion of carbon to produce heavier elements.

**Outer shell**
In the outermost fusion shell, hydrogen nuclei are being fused to create helium – the same reaction that generated energy in the star's core for most of its life.

**Hydrogen envelope**
A deep layer of hydrogen gas (not shown to scale) plays no part in fusion. The star's enormous gravity ensures that it remains fairly compact despite the outward pressure of radiation.

**Photosphere**
This layer marks the point at which the hypergiant's interior becomes transparent, allowing light to escape. In a blue hypergiant, this may heat the surface to tens of thousands of degrees Celsius.

**Inner shells**
A shell around the core generates energy by fusion of helium nuclei to create carbon that sinks to the core. The star may develop a series of onion-like fusion layers with heavier elements nearer to the core.

**Outer atmosphere**
Hypergiants are frequently surrounded by an extensive atmosphere or corona that may be several times the size of the star. The visible surface and corona may even blur into one another, making the star appear fuzzy.

cooler red end of the colour range, with surface temperatures of perhaps just 3,000 degrees Celsius (5,430 degrees Fahrenheit).

Because a star's surface temperature depends on the amount of energy escaping through each square metre of its surface, there's a direct link between a star's luminosity, colour and size; ie a cool, red star of a certain brightness must be significantly larger than a hot, blue star of the same brightness. The term 'hypergiant' describes a star's luminosity rather than its physical size, so blue hypergiants can actually be smaller than the standard red giants formed by normal Sun-like stars towards the end of their lives, despite being many times brighter. Rare red hypergiants, however, are the biggest stars in the universe. Perhaps the most famous is Mu Cephei in the northern constellation of Cepheus. Known as the Garnet Star on account of its deep red colour, it is large enough to engulf over a billion Suns within it.

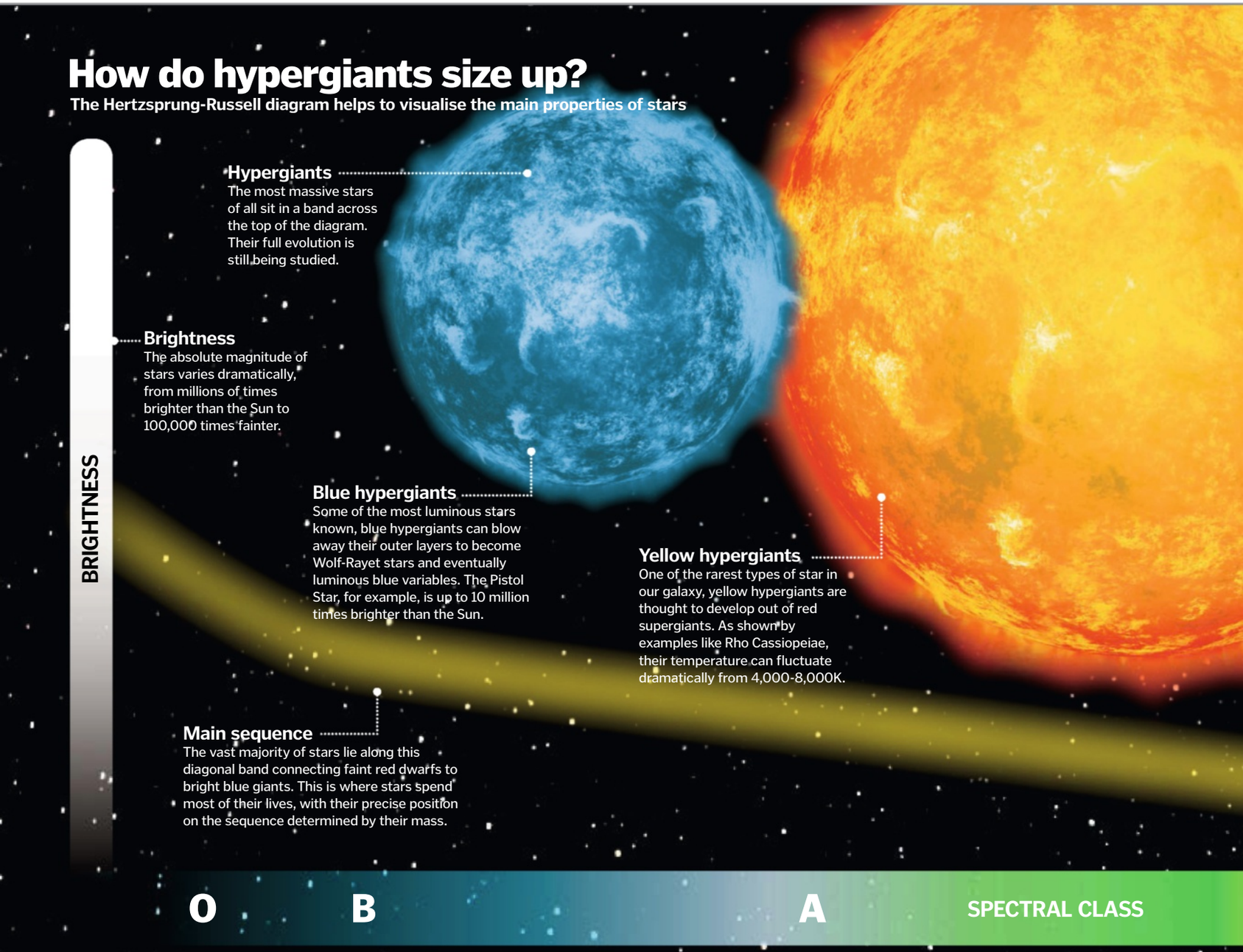
The extremes which hypergiants display stem ultimately from their enormous mass. Like all stars, they spend their 'main sequence' life shining through the fusion of hydrogen (the lightest element) into helium (the next lightest) in their cores. But while normal stars fuse hydrogen through relatively long-winded, inefficient chain reactions that rely on random collisions of atomic nuclei, the enormous pressures in a hypergiant's core allow it to use a much faster and more efficient set of reactions called the carbon-nitrogen-oxygen (CNO) cycle.

The rate of reactions in the hypergiant's core generates an enormous outward radiation pressure that swells the star's outer layers. During the main-sequence phase, the inward pull of gravity stabilises the star at few tens of solar diameters – enormous but still compact enough for its surface to remain searing hot and blue-white in colour. Once the core's supply of hydrogen is exhausted, it starts to burn fuel from surrounding shells in an attempt to keep shining. Perhaps surprisingly, this increases the hypergiant's luminosity still further, and the additional pressure of escaping radiation causes the star's outer ▶

"The collapse of a hypergiant can produce a supernova explosion that can briefly outshine an entire galaxy"

## How do hypergiants size up?

**The Hertzsprung-Russell diagram helps to visualise the main properties of stars**




surface to swell and cool, transforming it into a yellow, orange or red hypergiant depending on exactly where the balance is reached.

However, many hypergiants never quite reach this stage, staying hot and relatively compact throughout their short lifetime. They do this by blowing away their outer layers on a stellar wind similar to, but much more powerful than, our Sun's own solar wind. So-called 'Wolf-Rayet' stars can shed perhaps a solar mass of material every 100,000 years, exposing their even hotter interior layers.

Towards the end of its life, such a star may become unstable, evolving into a luminous blue variable – or LBV – star which is prone to sudden outbursts. LBVs are often surrounded by clouds of gas ejected from previous eruptions – perhaps the most famous example is Eta Carinae, a double-star system containing a blue LBV of around 100 solar masses, orbited by a blue supergiant of about 30 solar masses. In the early-1840s, a major outburst saw Eta Carinae brighten from its usual position on the borders of naked-eye visibility, to become the second-brightest star in the sky. Today, the system is still surrounded by a cloud of gas and dust ejected from that explosion.

There are many aspects of hypergiant evolution that astronomers still don't fully understand, but one thing that is certain is their fate. Lower-mass stars like our Sun have relatively sedate deaths, in which a short-lived 'second wind' of helium fusion is followed by instability that hurls off the star's outer layers to form a planetary nebula with the burnt-out stellar core: a white dwarf at its centre.

But supergiant and hypergiant stars can keep burning elements to produce heavier ones right up until they reach iron – the first element whose fusion absorbs more energy than it releases. At this point, the star's central power supply is abruptly cut off, and its outer layers collapse inwards before rebounding off the core. The resulting shockwave ignites a tremendous burst of nuclear fusion in the star's upper layers, producing a supernova explosion that dwarfs even the brightest hypergiant – and may even briefly outshine an entire galaxy.

**AMAZING VIDEO!** SCAN THE QR CODE FOR A QUICK LINK

**A tour of some of the biggest stars in space**

www.howitworksdaily.com

**DID YOU KNOW?** *R136a1 lies in a tight knot of stars once thought to be a single star with over 1,000 times the mass of the Sun*

**Red hypergiants**
Other high-mass stars follow a more conventional evolutionary path, brightening and swelling to become the largest stars in the universe. VY Canis Majoris, for instance, is estimated to measure 1,800-2,100 solar radii and has an effective temperature of 3,000K.

**Our Sun (not to scale)**

**Spectral class**
Astronomers classify stars according to various features of their spectra, in a range that generally indicates their colour and surface temperature.

F G K M

## 5 famous hypergiants

**1 Garnet Star**
This naked-eye star in Cepheus is one of the reddest stars in the sky and one of the largest stars in our galaxy.

**2 VY Canis Majoris**
This red hypergiant in the constellation of Canis Major may be the largest known star, with some estimates putting its diameter larger than Saturn's orbit around the Sun.

**3 S Doradus**
One of the most luminous stars, this blue variable in the Large Magellanic Cloud (a satellite galaxy of the Milky Way) is stable for long periods between sporadic outbursts.

**4 Pistol Star**
Hidden behind dense star clouds near the centre of the Milky Way, this blue hypergiant is surrounded by a nebula of material thrown off during outbursts a few thousand years previously.

**5 Eta Carinae**
This binary star system, embedded in the twin-lobed Homunculus Nebula, may possibly erupt soon into a spectacular supernova.

In some cases, the shockwave from the explosion can ignite clouds of material ejected from the star thousands of years before, creating an exceptionally bright supernova explosion known as a hypernova.

Hypergiants are the live-fast, die-young rock stars of the cosmos, but recently astronomers have discovered what may be the biggest, baddest star of them all. Catalogued as R136a1, this is a monster 8.7 million times more luminous than the Sun, and with roughly 256 times its mass. R136a1 lies at the heart of the Tarantula Nebula, an enormous star-forming region in the Large Magellanic Cloud, a satellite galaxy of the Milky Way. Discovered in 2010, this distant star tests the limits of how big a star can get without blowing itself apart. It is also undergoing mass loss at a tremendous rate and is thought to have shed more than 50 solar masses of material during its million-year lifespan. When this cosmic giant ends its life, it could detonate in a rare 'pair-instability' supernova, outshining normal supernovas by a factor of 50 and becoming the brightest star in Earth's skies for several months.

When this will happen is anybody's guess – Eta Carinae is often suggested as the bright star that is most likely to go supernova in the near future, but pair-instability supernovas do not give the same kind of advance warnings as their fainter cousins, so in theory such an outburst might well happen at any time...

## Monster problems

The rarity of hypergiants poses problems for astronomers trying to join the dots between the handful of examples they have to study – for instance, they're still not sure of the link between Wolf-Rayet stars and LBVs. They also believe that an entire class of 'yellow hypergiants' has significantly lower masses than their hypergiant cousins and are, in fact, more closely related to red supergiants.

Even the existence of the 256-solar mass monster R136a1 poses a problem, since up until its discovery, astronomers assumed 150 solar masses was the biggest a star could get without tearing itself apart. Still, by searching for answers to questions about these stars, astronomers are building on knowledge of the processes that affect smaller stars like our Sun.

"The largest shield volcano on Earth – Mauna Loa in Hawaii – is smaller than the largest caldera on Olympus Mons"

When placed next to two of the Earth's tallest mountains, you can see just how big Mars's Olympus Mons really is

**Olympus Mons**
At about 22km (13.7mi) tall, Olympus Mons is two and a half times taller than Mount Everest, and over double Mauna Kea's height too.

**Mount Everest**
Mount Everest is the highest peak on Earth above sea level at 8,848m (29,029ft), though mountains in the rest of the Solar System are measured from their bases.

# Giant space mountains

## Everest has nothing on mighty peaks elsewhere in the Solar System…

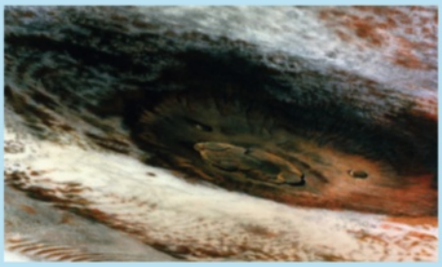
We marvel at Mount Everest, the highest peak on Earth at 8,848 metres (29,029 feet). Yet in comparison to some of the other mountains found in our Solar System, it's positively puny. Since its discovery in 1971, Olympus Mons has held the title of tallest mountain in the Solar System. It is a shield volcano located in the western hemisphere of Mars, and has a height of about 22 kilometres (13.7 miles) when measured from base to summit. Olympus Mons looks a lot like the volcanoes that make up Hawaii. It's asymmetrical, has a low profile and is probably built up from thousands of basaltic lava flows.

In 2011, a mountain on 4 Vesta – an asteroid designated as a minor planet – was named as a potential challenger to Olympus Mons. Since Vesta is one of the largest asteroids in the Solar System, it makes sense that it would have one of the tallest mountains. Thought to be an impact crater, Rheasilvia is the most prominent feature on the rocky body. The central peak in Rheasilvia has also been measured at 22 kilometres (13.7 miles) from its base. First spotted by the Hubble Space Telescope in 1997, the crater was more closely examined by NASA's Dawn space probe. Given the margin of error for measuring space mountains, Olympus Mons still officially holds the designation of tallest mountain in the Solar System.

The third-highest mountain is one of the most unusual. Found on Iapetus, Saturn's third-largest natural satellite, it doesn't even have a name of its own beyond 'equatorial ridge of Iapetus'. But it is an incredibly dramatic feature, dividing the moon at its equator and giving it a walnut-like appearance. The ridge contains numerous isolated peaks along its 1,500 kilometres (930 miles), some of them estimated at more than 20,000 metres (65,617 feet). We don't yet know how the ridge formed or why it's located along the moon's equator.

## Calderas on Olympus Mons

Olympus Mons has a complex of calderas and caldera segments at its peak – cauldron-like depressions that form when a volcano's roof collapses after an eruption. Each one indicates a separate eruption in the history of the volcano. Olympus Mons' largest caldera is 80 kilometres (50 miles) wide and was probably a lava lake. By comparison, the largest shield volcano on Earth – Mauna Loa in Hawaii – is smaller than the largest caldera on Olympus Mons!



# 5.5km

## BIGGEST MOON MOUNTAIN

Our Moon has some peaks of its own, the tallest of which is Mons Huygens at about 5,500 metres. It is the result of the Imbrium impact, when a huge object struck the Moon and left a massive crater as well as mountains.

**DID YOU KNOW?** *Olympus Mons is so big and shallow that if you stood on Mars you could never see its entire profile*

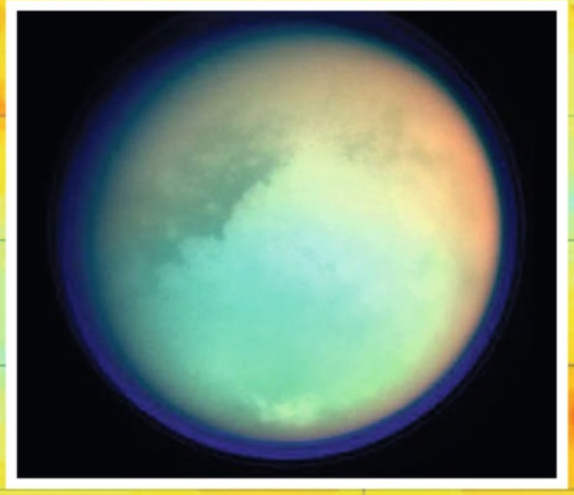
**Base area**
At nearly 700km (435mi) across Olympus Mons' width is just as impressive as its height. This diagram shows how it would sit if it were placed in France.


**Mauna Kea**
If measured from its base, Hawaii's Mauna Kea is over 10,000m (32,800ft) – taller than Mount Everest.

## The real Mount Doom?

Titan, Saturn's largest moon, is home to a mountain range named Doom Mons. This range is in the southern hemisphere of the moon and stands out on the mostly smooth surface. It may be the largest mountain range on Titan, estimated at 1.5 kilometres (0.9 miles) tall.

The International Astronomical Union's naming convention for mountains on Titan is to name them after mountains in JRR Tolkien's works, although Doom Mons has an unknown origin. It is located near Sotra Patera, a cryovolcano that is over 30 kilometres (20 miles) across.



A topographical map of Titan put together using data from the Cassini probe. Doom Mons is located in the red region on the right; inset, Titan

## How do space peaks form?

**1 Volcanic activity**
Large volcanic mountains often form from fluid lava flows, and may be larger than terrestrial volcanoes due to a lack of tectonic plates on the particular body.

**2 Tectonics**
These mountains form due to the movement of plates in the crust, caused by compressive forces within the planet or moon.

**3 Impact**
Large projectiles like asteroids striking a planet or moon can leave more than craters; they can also fault and fracture the surface to create new mountains.

"Treadmills, cycling machines and resistance equipment enable them to limit muscle atrophy"

# ISS medical treatment

## How is illness prevented and treated when you're out in space?

The human body is adapted to account for the effects of gravity. Muscles and bones respond to impact and resistance, and the circulatory system compensates so bodily fluids don't accumulate in the legs and feet. When gravity is removed, the changes to the body are dramatic.

To compensate for the lack of gravity on the International Space Station (ISS), the crew members have access to an array of specially designed exercise equipment. Treadmills, cycling machines and resistance equipment enable them to limit muscle atrophy. This prevents long-term problems associated with muscle wasting in low gravity and allows the fitness of the crew to be monitored.

The lack of gravity also affects the circulatory system. Fluid redistributes to the upper body, causing the tissues in the head and face to swell. This leads to symptoms similar to the common cold and can place pressure on the optic nerve, distorting vision. Abnormal heart rhythms have been reported on several occasions, so the ISS is equipped with a defibrillator.

Astronaut Sunita Williams works out on the TVIS treadmill on board the ISS

In microgravity, microbes float about in the air, making infection a real danger. Recent studies also suggest that bacteria adapt to space in ways that aren't familiar on Earth, posing an extra threat. On top of that, the immune system itself finds it more difficult to function. In order to protect the crew, the air is filtered and monitored for contamination.

Unfortunately, space crews do get ill, and 75 per cent of astronauts require medication while in space; the ISS carries medication for a range of illnesses. If the medical problem cannot be treated on board, the station is close enough that crew members can be returned to Earth for more specialist treatment.

## Keeping healthy on the ISS

**A tour of the main facilities on the station that keep astronauts fighting fit**

**Blood/saliva testing**
Saliva testing kits and an on-board blood-testing machine help the crew spot any infections early.

**Radiation detector**
A neutron particle detector allows crew members to monitor neutron radiation levels.

**Resistive exercise device**
Exercise equipment allows the crew to build up their muscle strength.

**Treadmill**
The Treadmill with Vibration Isolation Stablilisation (TVIS) had special tech to reduce vibrations that could disrupt nearby scientific experiments. It has recently been replaced with a new model.

**Veloergometer**
Another machine designed for exercise, this provides both aerobic and cardiovascular conditioning.

**Air sampler**
Microbes float in the air in zero gravity, so an air sampler is used to keep a close eye on contamination.

**Defibrillator**
The space station is equipped with emergency medical equipment to restart the heart in the event of a cardiac arrest.

## Common ISS injuries

**1 Space adaptation syndrome (SAS)**
Like motion sickness, it is a reaction of the vestibular balance system to the disorientation of microgravity.

**2 Nervous system and sensory organs**
Body fluids gather in the head during weightlessness, increasing the pressure on the back of the eyeballs and pushing on the optic nerve. This can result in distortion of vision. Fluid accumulation also leads to nasal congestion, altering smell and taste.

**3 Digestive system**
Loss of appetite is common and astronauts often complain that food tastes unusual. This is thought to be the result of nasal congestion, much like getting a cold.

**4 Skin**
In microgravity the skin undergoes a process similar to ageing, becoming thinner and more fragile. Draughts from the ventilation systems can also dry out the skin, making it more liable to cuts and irritation.

**5 General trauma**
Living on a space station poses many hazards, including chemical and electrical burns, exposure to toxic substances and physical trauma. During the Space Shuttle Program (1981-98), 141 injuries were reported.

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"Earth's core is molten, so our planet's magnetic field is induced by a circulating electric current at the core"

# Earth's magnetic field

## Just where did our protective magnetosphere come from?

Before we can understand how Earth's magnetic field works, we need to first have a basic understanding of magnetism. Magnetic fields are formed when electric charges move through magnetic materials like iron.

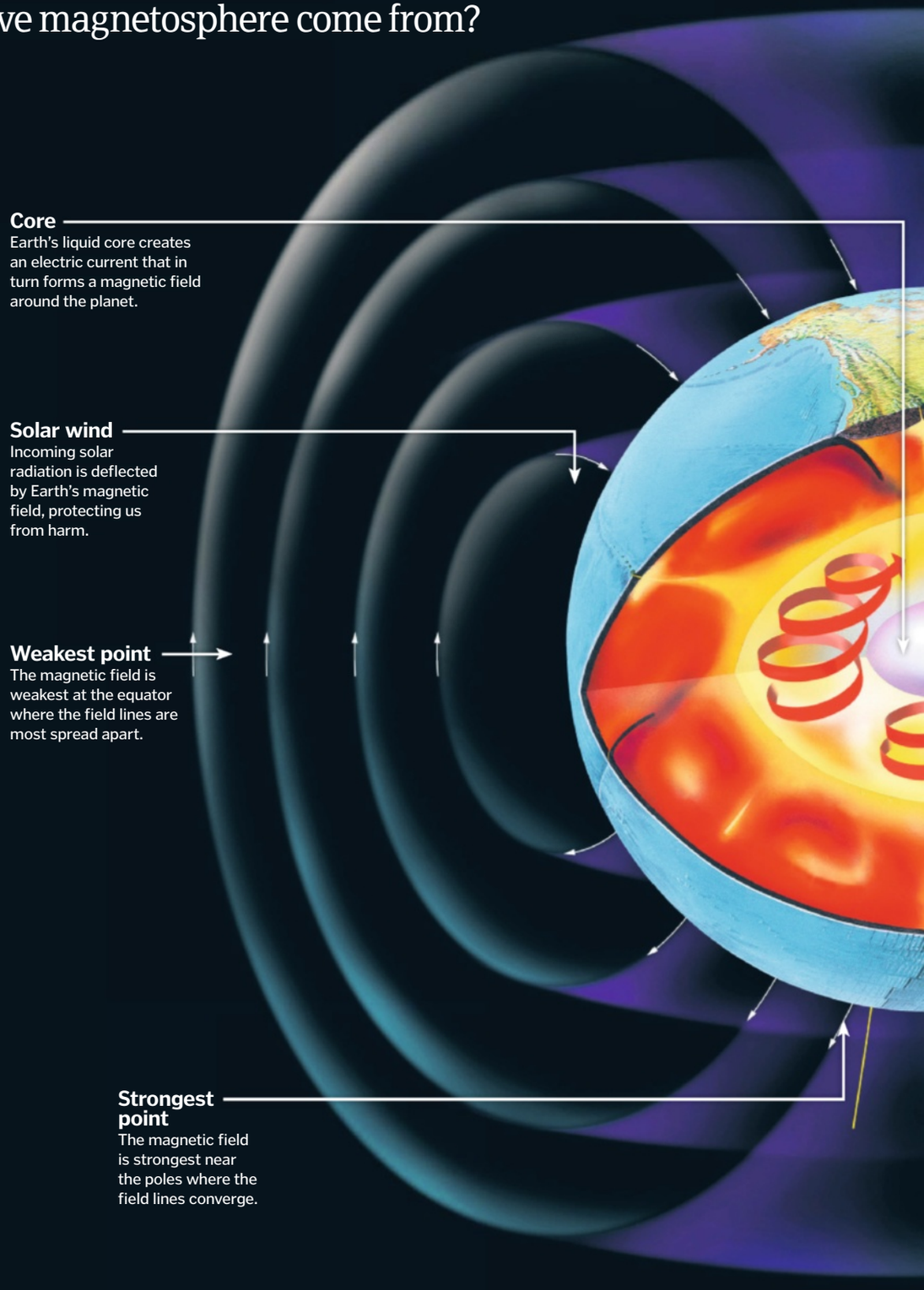
Any magnetised material is dipolar, which means it has a north and south pole, and the magnetic field lines run from north to south. The magnetic field lines at the north pole swing back round to the south pole, creating an external magnetic field outside the material that can influence other things that get too close.

You're probably familiar with a bar magnet, and in essence Earth's magnetic field is very similar to that; imagine a giant bar magnet running through the core of Earth from pole to pole and you'll get the picture. However, Earth's core is molten, so our planet's magnetic field is induced by a circulating electric current at the core. One of the outcomes of this is that, on rare occasions, Earth's magnetic field can flip. This is believed to happen once every 200,000 years on average.

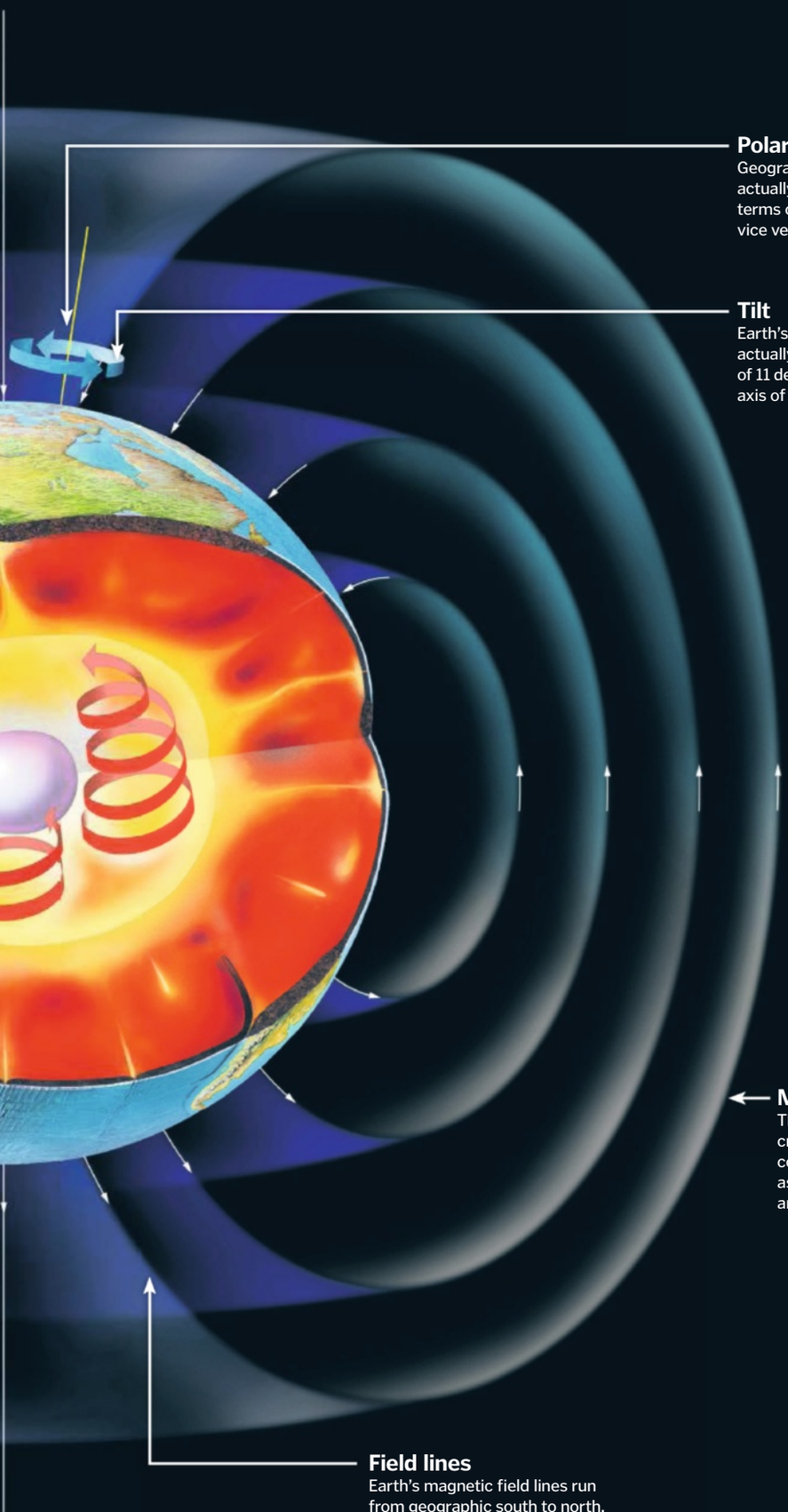
Taking the 'bar magnet' through Earth analogy further, it just so happens that the south pole of Earth's magnetism is at the geographic north pole, and the north pole is at the geographic south pole. When someone refers to 'magnetic north', they're actually referring to the south pole of Earth.

Earth's magnetic field is also not perfectly aligned with the rotation of the planet, instead being tilted at an angle of 11 degrees. It's also not stationary; the magnetic poles are constantly moving, and indeed the south magnetic pole (at geographic north) has drifted up to 1,100 kilometres (684 miles) across the Canadian Arctic over the past four centuries.

Interestingly, though, despite the size of Earth, the magnetic field is weaker than a fridge magnet. However, that's still enough to protect us from harmful radiation from the Sun and elsewhere in the galaxy, and helps our planet retain its atmosphere.



DID YOU KNOW? *The last geomagnetic reversal of Earth's magnetic field is believed to have occurred 41,000 years ago*




## Origin of the magnetic field

As already mentioned in the main text, Earth's magnetic field is the result of moving electric field in the liquid molten iron core. Compared to the surface, the magnetic field at the core is about 50 times stronger.

It's likely that Earth has had a magnetic field for pretty much the entirety of its 4.5 billion-year lifetime. However, when Earth first formed, it's likely that the entire core was liquid; at the moment, only the outer core is liquid, with the inner core being solid due to the intense pressure. This means that Earth's early magnetism was likely stronger than it is now. Exactly how much stronger we can't be sure, but it's believed this strong magnetic field helped Earth retain an atmosphere early in its life, in the opposite way that Mars has lost its atmosphere as its magnetic field has dissipated.

## Future of the magnetic field

Earth's magnetic field is weakening, but the exact reason why is poorly understood. However, this is no cause for concern; records suggest it decreases and increases in intensity relatively frequently. Since German mathematician Carl Friedrich Gauss first measured its strength in 1845, it has dropped about ten per cent.

If the magnetic field drops significantly further, there is a chance the magnetic field could flip. Contrary to popular belief, however, this will not signify the end of the world. The magnetic field has been known to flip many times over the last billion years, and life has survived. Therefore it's unlikely another flip would cause any devastating effects.

The only true danger is if the magnetic field were to disappear completely. As long as Earth has a liquid core, though, it will continue to have a magnetic field. Unless you're still around in a few billion years when such an event could occur, you haven't got much to worry about.

# BIRDS OF PREY

## The fastest, the strongest, the most agile – meet the planet's most adept aerial assassins and learn how they survive

Some are manoeuvrable dog-fighting specialists, while others soar high above the ground like stealth bombers. They attack in the air, on the ground and in water. All of them are apex predators, adapted for life at the top of the food chain.

Birds of prey, also known as raptors, may look like feathered dinosaurs, but they aren't any more related to them than any other bird. The physical resemblance comes from their shared carnivorous lifestyle. Most belong to one of two families: the Accipitrids include eagles, hawks, buzzards, kites, harriers and true vultures, while the Falconids consist of falcons, kestrels and falconets. There are also two families of owls and a few species, such as the osprey and secretary bird, that are in families of their own.

Raptors hunt in two main ways. The large Accipitrids and ospreys float high above the ground while they scan for possible targets using their extremely acute vision. They will then dive-bomb or circle around to strike silently and suddenly. Eagles prefer to snatch prey and keep flying in order to minimise the time they spend vulnerable on the ground. Sea eagles, such as the bald eagle, use this technique to catch fish swimming close to the surface. Ospreys, which hunt in freshwater as well as the sea, can spot fish under the surface while flying as high as 40 metres (130 feet) above the water. They drop feet first, and will completely submerge in pursuit of the kill. Uniquely among raptors, ospreys have nostrils they can close to keep water out.

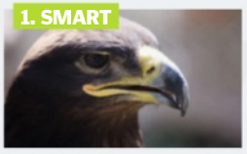
Falcons and hawks hunt other birds in the air. The peregrine falcon attacks pigeons and water birds from high above, dive-bombing – or stooping – from 4.8 kilometres (three miles) up so that they accelerate to over 320 kilometres (200 miles) per hour. At this speed the increased air pressure is enough to burst their lungs, but peregrines have small bones in their nostrils called tubercles that divert most of the airflow to the sides.

While the peregrine is technically the fastest animal in the world, falling isn't the same thing as flying. The fastest in level flight may be the Eurasian hobby, which actually chases down speedy swallows and swifts.

Species that can't compete in speed rely on their superior agility, like the forest falcons. These sit patiently in dense forest areas, using their extremely sensitive hearing to listen for birds flying nearby. When one passes close

### EXTINCT MEGA-EAGLE

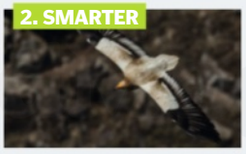
THE HAAST'S EAGLE LIVED IN NEW ZEALAND UNTIL IT WAS DRIVEN EXTINCT IN THE 15TH CENTURY. IT WEIGHED 15KG (33LB) AND HAD A 3M (9.8FT) WINGSPAN!



**1. SMART**

### Golden eagle

Golden eagles in Israel have been known to snatch tortoises and drop them onto rocks from a height in order to crack open their shells.



**2. SMARTER**

### Egyptian vulture

These birds can't pick up smooth ostrich eggs, so it has learnt to drops stones on them from above to shatter the shell.

**3. SMARTEST**

### Bateleur eagle

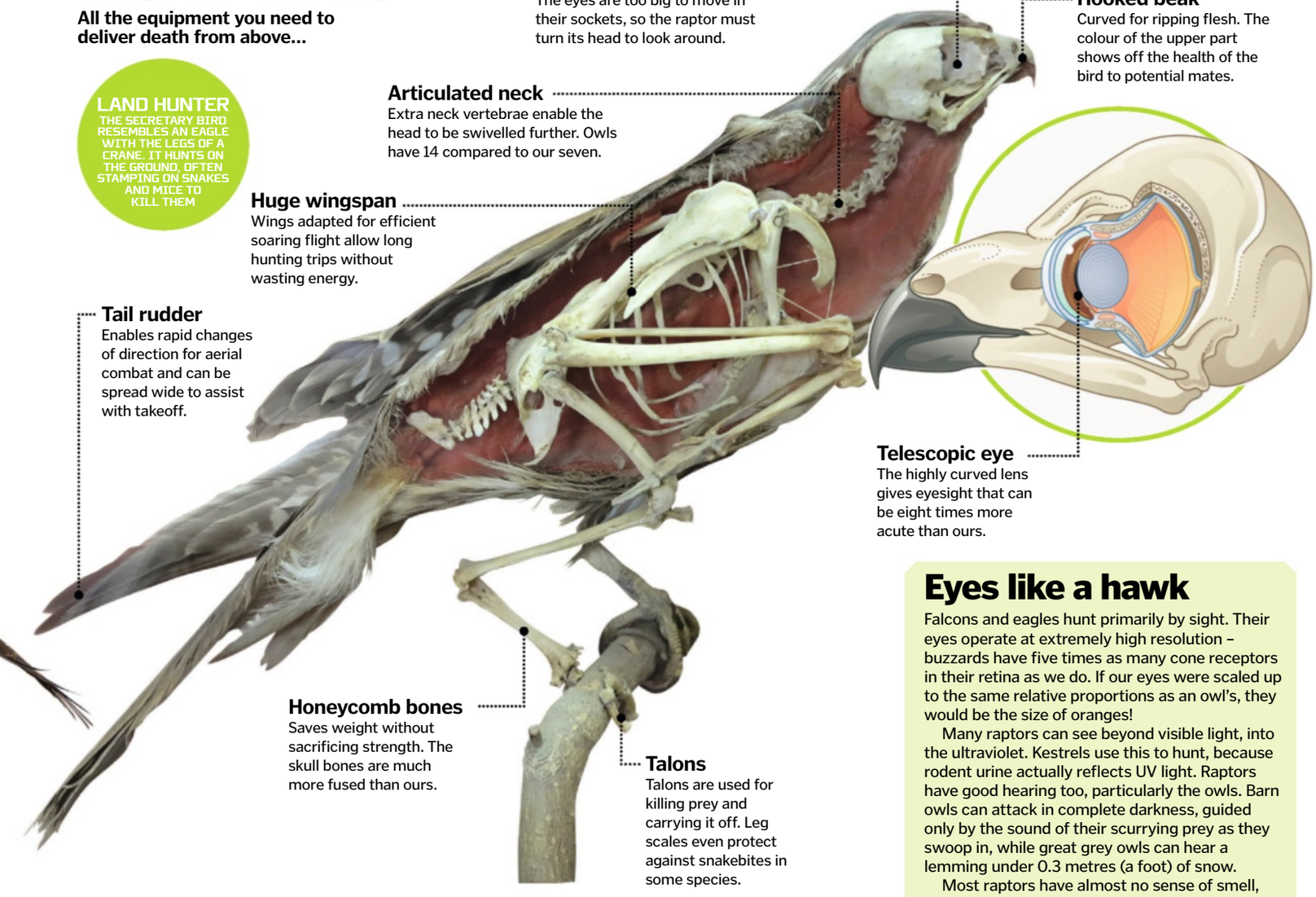
The African bateleur eagle goes one step further and sneakily throws stones at burrows, in the process scaring animals out of their safe shelters.

**DID YOU KNOW?** *The feathers of a bird of prey weigh more than its entire skeleton!*

# Built for the kill

**All the equipment you need to deliver death from above...**

**LAND HUNTER**
THE SECRETARY BIRD RESEMBLES AN EAGLE WITH THE LEGS OF A CRANE. IT HUNTS ON THE GROUND, OFTEN STAMPING ON SNAKES AND MICE TO KILL THEM



### Fixed vision
The eyes are too big to move in their sockets, so the raptor must turn its head to look around.

### Hooked beak
Curved for ripping flesh. The colour of the upper part shows off the health of the bird to potential mates.

### Articulated neck
Extra neck vertebrae enable the head to be swivelled further. Owls have 14 compared to our seven.

### Huge wingspan
Wings adapted for efficient soaring flight allow long hunting trips without wasting energy.

### Tail rudder
Enables rapid changes of direction for aerial combat and can be spread wide to assist with takeoff.

### Telescopic eye
The highly curved lens gives eyesight that can be eight times more acute than ours.

### Honeycomb bones
Saves weight without sacrificing strength. The skull bones are much more fused than ours.

### Talons
Talons are used for killing prey and carrying it off. Leg scales even protect against snakebites in some species.

## Eyes like a hawk

Falcons and eagles hunt primarily by sight. Their eyes operate at extremely high resolution – buzzards have five times as many cone receptors in their retina as we do. If our eyes were scaled up to the same relative proportions as an owl's, they would be the size of oranges!

Many raptors can see beyond visible light, into the ultraviolet. Kestrels use this to hunt, because rodent urine actually reflects UV light. Raptors have good hearing too, particularly the owls. Barn owls can attack in complete darkness, guided only by the sound of their scurrying prey as they swoop in, while great grey owls can hear a lemming under 0.3 metres (a foot) of snow.

Most raptors have almost no sense of smell, but New World vultures are an exception. The scent of rotting meat has been added to gas supplies in North America because Turkey vultures will detect leaks in pipelines by circling high above the spot.

enough they will launch into a short and dangerous slalom run through the branches to catch the bird before it escapes.

Falcons use their beak as a weapon, and some even have a tooth on the upper beak that they use to snap the spine of their prey. For most other raptor species, though, the beak is only used for tearing chunks of flesh from an already downed victim. To kill, they rely on their talons. The exact shape of these depends on the type of animal they hunt: owls have short, heavily muscled toes to squeeze the breath from mice and small mammals, with thin, straight talons to hold them still; while eagles and buzzards have longer, curved talons on the backwards-facing toe and the first forward-facing toe for a powerful pincer grip. The osprey can even rotate its talons so that two toes face forward and two back to hold on to wriggling fish.

*"The shape of the talons depends on the type of animal they hunt"*

## ON THE MAP


**Famous birds of prey around the world**

1. Golden eagle
2. Madagascar fish eagle
3. Galápagos hawk
4. Philippine hawk-eagle
5. Bald eagle
6. Great grey owl

"Bald eagles take four or five years to reach sexual maturity, and usually lay only one or two eggs per season"

Vultures and condors have the weakest talons of any raptor, because their diet consists almost entirely of carrion. Vultures have bald heads to make it easy for them to plunge their entire head into the carcass of a large animal without the blood getting on their feathers.

Judging which is the biggest bird of prey isn't easy. The Andean condor has the largest wingspan at up to 3.5 metres (11.5 feet) and the Philippine eagle the longest body at over one metre (three feet), while the heaviest is Steller's sea eagle in north-east Asia, which can weigh up to nine kilograms (20 pounds).

Because they have no predators, raptors tend to live a long time. Golden eagles last for 25 years in the wild and up to 46 years in captivity, and the Philippine eagle can survive for up to 60 years in the wild! But a long lifespan goes hand-in-hand with a slow rate of reproduction. Bald eagles take four to five years to reach sexual maturity, and usually lay only one or two eggs per season. Even when more than one egg hatches, in many raptor species the strongest chick will kill the others in the nest. This makes many raptors very vulnerable to population crashes from hunting or habitat loss. Around 120,000 Amur falcons are illegally killed by hunters every year in India as they migrate from eastern Asia to South Africa, for example.

There are success stories too though. Red kites have been reintroduced to the UK and Ireland, and peregrine falcons are no longer endangered in Britain now that organochlorine pesticides have been banned.

## Home sweet home

Falcons take over abandoned nests of other birds rather than building their own, but other raptors build wide platforms called eyries, or aeries. These are normally high up with a commanding view of the countryside. A golden eagle can see a hare from a mile away, and a sheep from 4.8 kilometres (three miles), so it can search a wide area without ever leaving its nest. Raptors add to their nest each breeding season and can become very big. A bald eagle's nest is strong enough to support a man and can weigh two tons!

## On the hunt

**How to catch a rabbit from hundreds of metres up**

**On the lookout**
Large raptors need huge ranges to find enough food. A golden eagle can patrol an area of 200km² (77mi²).

**SUSHI SPECIALIST**
OSPREYS ARE THE ONLY RAPTORS THAT LIVE EXCLUSIVELY ON FISH. BACKWARDS-FACING SCALES ON THEIR TALONS ACT AS BARBS TO HELP GRIP THEIR SLIPPERY CATCH

**Stealth mode**
Light plumage on their underside makes them hard to see against the bright sky.

**VEGGIE RAPTOR**
THE PALM-NUT VULTURE GETS MOST OF ITS FOOD FROM THE FRUIT OF THE OIL PALM. IT WILL ALSO OCCASIONALLY EAT CRABS AND INSECTS, THOUGH

**Eye protection**
As it strikes, the raptor closes its third eyelid – or nictitating membrane – to protect the eyes.

**Dust off**
Staying on the ground is dangerous. Raptors will immediately carry off anything that weighs less than them.

**Claws of death**
Small prey die by asphyxiation – squeezed so tightly they cannot breathe. Raptors often start eating before their prey is dead.

**DID YOU KNOW?** *The smallest bird of prey is the white-fronted falconet. It weighs just 35g (1.2oz) – the same as a sparrow!*

### Soaring
Large raptors need to stay aloft for long periods while they search for prey. To save energy, they make use of natural updrafts. In wide-open areas, the Sun heats the ground, which warms the air next to it. Hot air rises, creating a thermal. Another source of lift comes from cliffs and peaks, where the wind is deflected upwards.

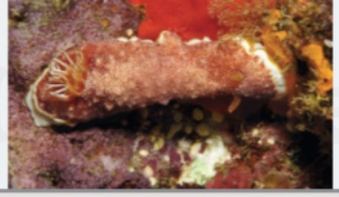
### Gliding run
The raptor glides from one updraft to another, always scanning the terrain for movement.

### Hovering
Kites and buzzards prefer to hover low, near to gaps in ground cover, and drop on anything that moves.

### Divebomber
Eagles and buzzards make their attack run from downwind and swoop in at a shallow angle. This minimises the speed lost if they miss their target and allows them to gain altitude again easily. Smaller hawks and falcons aim for maximum speed, with their wings tucked back to increase their freefall speed to over 240km/h (150mph).

**What can Chromodoris reticulata dispose of?**

**A** Its head **B** Its penis **C** Its tail



**Answer:**
In early-2013, researchers discovered that Chromodoris reticulata can not only detach its penis, but also grow a replacement. Even before this news, we knew sea slugs were complex as far as reproduction goes, as many are hermaphrodites.

**DID YOU KNOW?** *Sea slug species range in size from just a few millimetres to over 30 centimetres (12 inches) long*

# How sea slugs develop

## They come in all manner of colours and shapes, but how do these marine creatures change when they're growing up?

'Sea slug' has become something of a catch-all term for a number of different species of marine animals, though probably the most familiar is a kind of gastropod called the nudibranchs. The reason these snails are 'nude', so to speak, is because they lose their shells at the larval stage just a few days after they hatch. The loss of this defence has meant nudibranchs have had to evolve some ingenious ways to survive.

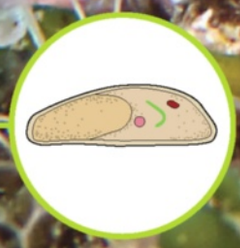
As well as acquiring a psychedelic range of patterns and colours to deter predators, many also gain a secret weapon from their food. By eating prey like sea anenomes, which naturally contain stinging cells called nematocysts, the sea slug can repurpose them for itself, storing them in fleshy appendages on its back called cerata. Follow the step-by-step below to see how a nudibranch goes from egg to young sea slug.

### 1. Egg
Sea slugs typically lay their eggs and live on hydroids, which themselves are one life stage of a predatory colonial invertebrate related to jellyfish.

### 2. Hatched veliger
On hatching, a tiny snail (just a few hundred micrometres long) emerges called a veliger. Via swimming and crawling, it seeks its own hydroid to settle on.

### 3. Losing the shell
It only resembles a snail for a few days. After that, it loses its larval shell in a process called detorsion, where the shell, mantle and several major organs twist around the body.

### 4. Radula emerges
After a week, it develops the means to eat. The radula is an organ covered in thousands of tiny razor-sharp teeth, or denticles, for gnawing into the hydroid.



### 5. Rhinophores grow
Lastly sensory organs called rhinophore buds emerge on the creature's head, which detect chemicals. These can be retracted if it is attacked.

© Thinkstock; Alamy

"The layers of calcium have formed a number of terraces, topped with shallow pools"

# Pamukkale Travertines

## Discover the science behind how these stunning limestone pools formed

It might look like some extravagant bathing complex carved into the rock, but this series of stepped pools in south-west Turkey is 100 per cent natural.

Pamukkale, which translates as 'cotton castle' due to its white colour, is the site of extensive geothermal activity, with a natural fault deep underground leading to many hot springs. As the heated water emerges near the top of the monolith, which rises 200 metres (660 feet) above the surrounding Curuksu Plain, it pours over the cliffs much like any other waterfall. However, once it reaches less steep terrain, dissolved minerals – principally calcium carbonate – begin to precipitate out.

Over many years – we're talking as far back as 2.5 million years – the layers of calcium have formed a number of terraces (known as travertines), topped with shallow pools as the spring water continuously flows out. Interspersed between these pools are what looks like petrified cascades of glistening rock.

Essentially this process occurs because of a disparity between the carbon dioxide-rich geothermal water and the air (which contains less than one per cent $CO_2$). As the carbon dioxide rapidly 'degases' – ie is expelled – from the water to balance out this contrast, a unique form of limestone, also called travertine, is deposited onto the base rock.

Although initially quite soft, this limestone hardens over time, and it's actually a popular building material around the Mediterranean. The fewer impurities, the whiter the travertine looks; less pure examples appear yellowish or brown. Pamukkale was made a UNESCO World Heritage Site in 1988 and was popular with the Ancient Greeks and Romans two millennia ago, who believed the hot springs to have restorative powers.

**1. WEIRD**

**Mammoth Cave, USA**

The Mammoth-Flint Ridge Cave System is the longest in the world. It passes through different levels of limestone.

**2. WEIRDER**

**Stone Forest, China**

Thought to be over 270 million years old, many of these tall limestone stacks look like trees, hence the name.

**3. WEIRDEST**

**White Desert, Egypt**

Home to a number of mushroom-shaped chalk structures carved over centuries by weathering and sandstorms.

**DID YOU KNOW?** *Ancient Greeks built a spa town at the top of the Pamukkale site called Hierapolis*

These stepped pools in south-west Turkey are completely natural

## Taking the waters

From the UK to Japan and North America, for thousands of years many have sworn by the health benefits of bathing in and drinking geothermal water. Indeed, Ancient Greek Hippocrates talks about such treatment in the fifth century BCE and the practice has since acquired its own name: balneotherapy.

Its proponents claim that the mineral-rich waters are capable of easing the symptoms of many illnesses, from skin conditions to respiratory illnesses such as asthma and joint problems (arthritis, for example). Interestingly, they also argue that such therapy is more cost effective and has fewer negative effects on the body than many drugs used today.

However, scientific research to date has failed to prove definitively if balneotherapy works or not. That said, most studies suggest that it is not harmful, so at worst it could serve as a placebo, or at best as a complementary therapy alongside other treatments.

"They function in a similar way to the hair cells of the human ear, which detect vibrations in the cochlea"

# How fish sense danger

Discover how fish use special cells to hunt and avoid being hunted

A line of specially adapted cells, called a lateral line, runs down each side of a fish. They function in a similar way to the hair cells of the human ear, which detect vibrations in the fluid of the cochlea.

Each sensory cell of the lateral line has tiny hair-like projections called cilia, which stick upwards into a protective jelly-like cap.

As water moves past them they bend; this mechanical disruption opens tiny channels in the cell membrane, allowing ions to move in. The cell then releases neurotransmitters, activating sensory neurons and alerting fish to the potential presence of prey or a predator in the near vicinity.

## Lateral line biology

**A close-up look at the cells that help fish survive**




# Cyclone vs anticyclone

What causes these spinning systems of air and how do they differ?

Cyclones and anticyclones are generated when areas of high and low air pressure collide. These are created by differences in temperature and humidity.

Air temperature affects the molecules' kinetic energy. The higher the temperature, the more the molecules move and collide. Humidity, on the other hand, affects the air itself. The atmosphere's main constituents – diatomic oxygen and nitrogen – are heavy compared to water vapour. The water in humid air replaces some of the heavier molecules, making it lighter than dry air, and therefore of a lower pressure.

An anticyclone is a region of high atmospheric pressure. The air descends through the system, spreading out sideways as it makes contact with the ground. The compressed air causes a rise in temperature – hence why anticyclones are associated with summer weather and dry winter days.

In contrast, a cyclone is centred around a region of low pressure. Inward spinning winds draw air upwards into the system – as it rises, water vapour cools and condenses, resulting in cloudy weather and storms.

Hurricanes and cyclones form as a result of rapid shifts in air pressure and temperature

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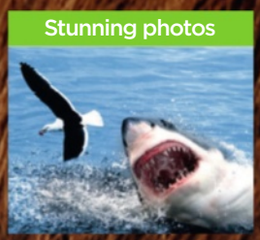



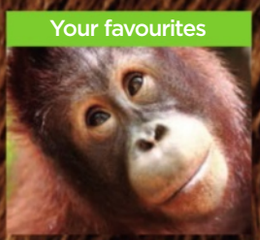




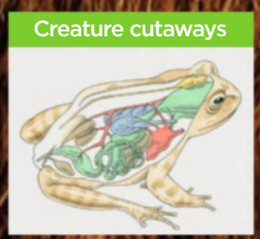



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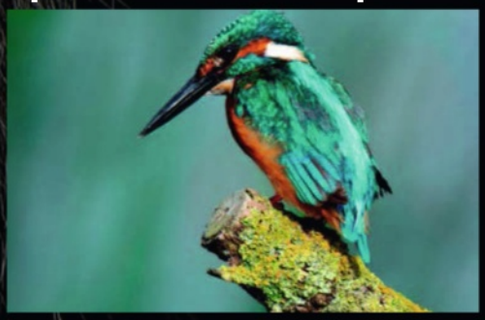

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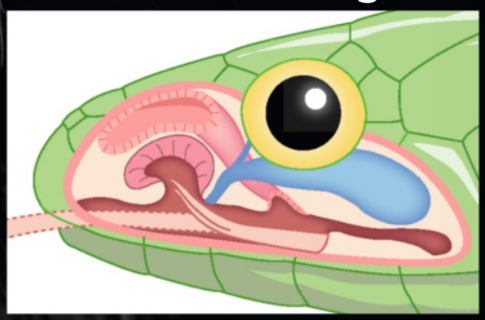

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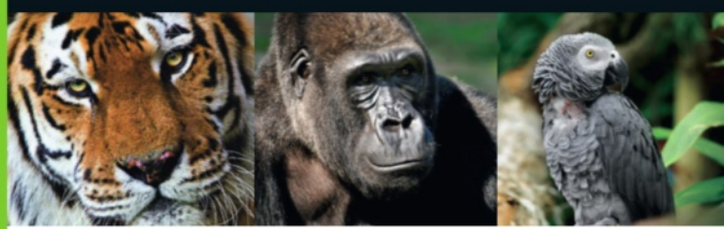

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## Which of these products has contained powdered baobab?

**A** Cheddar cheese **B** Pepsi cola **C** Umami beans

**Answer:**
Interestingly, the powdery white interior of select baobabs was used in the limited-release Japanese drink, Pepsi Baobab. PepsiCo described the taste as 'liberating and refreshing'.

**DID YOU KNOW?** *Six of the nine species of baobab grow on the island of Madagascar*

# Mighty baobabs

## Why do these African trees have such fat trunks?

Baobabs are a series of tree species from the genus Adansonia that are famed for their peculiarly large trunks. The trees, six species of which grow exclusively on the island nation of Madagascar, vary in height, bark colour and foliage. However, they can be typically identified due to their location and distinct shape, with some boasting diameters of 11 metres (36 feet).

The reason for the overly large trunks lies with their ecosystem's environmental factors, with the deserts of Africa and forests and scrubland of Madagascar undergoing extended periods of drought annually.

Indeed, baobab trunks are so massive that large examples can store up to 120,000 litres (32,000 gallons) at any one time, allowing the tree to store a huge supply of water throughout the year, no matter how dry it gets.

## 5 types of baobab

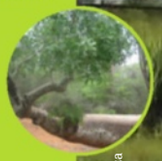
**1 Adansonia digitata**
The most widely spread of all the baobab species, digitata can be found across the hot, dry savannahs of sub-Saharan Africa.

**2 Adansonia rubrostipa**
Nicknamed the 'Fony Baobab', rubrostipa is a baobab genus within the family Malvaceae. It grows in west Madagascar.

**3 Adansonia madagascariensis**
Capable of growing to enormous proportions, this species grows typically in Madagascar's dry deciduous forests.

**4 Adansonia grandidieri**
Capable of reaching 30m (98ft) in height, these baobabs grow solely in Madagascar and have spectacular white flowers.

**5 Adansonia za**
Another of Madagascar's baobabs, Adansonia za has a brownish-rose bark and relatively fat trunks. Their seeds consist of 11 per cent oil content.



A fully grown example of the Adansonia grandidieri baobab

"Plants may go in for chemical warfare, with leaves that are unpalatable or even poisonous"

Cacti are infamous for their spiky exterior that defends their water stores

# Plant defences explained

## The plant kingdom has evolved some canny ways to see off a variety of threats

Leaves are vital to the survival of plants. They catch the sunlight that plants use to power food production from oxygen and water in the process called photosynthesis. Stems hold the leaves in a position that maximises the light they catch, much like an array of green solar panels. Anything that damages the leaves or stems reduces the amount of sunlight the plant can collect, slowing its growth and impacting on the plant's overall health.

Oddly, too much sunlight can damage plants too. Chlorophyll, the green chemical which reacts with sunlight in photosynthesis, is easily damaged by high intensities of direct sunlight. Plant cells therefore contain chemicals which act like sunblock, letting in just the right amount of light for photosynthesis. Plants that always grow in shady woods don't need sunblock, but they may die if we replant them into sunny gardens. Drought also damages plant growth, because the leaves of a wilted plant are not best arranged to catch the Sun – so getting enough water is essential.

However, the main threat to plant photosynthesis is from animals that eat the leaves or stems. Plants therefore invest a lot of energy in keeping grazers away. Some plants use different kinds of armour. Their leaves might have a tough, waxy coat that makes leaves difficult to eat, or a beard of hairs to stop insects settling on them. Other defences might include their stems and leaves, which may have spines or prickles that make it uncomfortable to eat the leaves or even get too close.

Many plants also go in for chemical warfare, with chemicals in their leaves that are unpalatable or even poisonous to grazing animals. A few species can also cheat; they don't produce poisons themselves but instead look like other plants that animals know are toxic, and so avoid getting eaten by proxy.

## 5 TOP FACTS
USEFUL PLANTS

**1 Tasty tannins**
Many chemicals that evolved to discourage animals from grazing plant leaves are useful to humans. For example, we rather like the bitter taste of tannins, which we brew in tea.

**2 Willow for headaches**
Willow trees produce salicylic acid to stop insects burrowing into their bark. Humans extract this to cure headaches and it is now used as the active ingredient in aspirin.

**3 Fatal foxgloves**
Foxglove plants contain digitalis, a poison causing abdominal pain, nausea and death. Animals avoid it, but we use it as a drug to regulate dangerously fast heartbeats.

**4 Jungle medicine**
South American natives used an extract from the sap of Cinchona trees as a cure for malaria. Quinine extracted from the tree is still a major weapon against this disease.

**5 Rubber repair**
Insects won't burrow into rubber trees because their sap tastes bitter. The exuded sap also hardens to repair any insect damage. We extract the sap to make rubber.

**DID YOU KNOW?** *Bracken isn't to be messed with: young leaves contain cyanide, while older ones can cause cancer and blindness*

# Chemical warfare

Plants use thousands of different poisons and distasteful chemicals to stop animals eating their leaves. Many are derived from the lignins used to harden cell walls, or tannins which may help regulate plant growth. The grain of Indian millet is an important food in tropical countries, but its leaves contain a chemical called dhurrin. When an animal tries to eat its leaves, the plant releases enzymes which break down the dhurrin, which in turn release cyanide – one of the deadliest compounds known.

Plants like poison ivy (pictured below) release chemicals which cause a painful skin rash in any animal brushing against them. The sap of the African blister bush sensitises the skin to sunlight, so animals suffer painful sunburn.

Some plants can warn neighbours of attack too. When an animal grazes certain African acacias, they produce poisons and ethylene gas. The ethylene triggers all the acacias within the surrounding 45 metres (150 feet) to produce poisons, in case the animal attacks them too.

# Stinging nettle up close

**We zoom in to the painful defensive weapon used by this common weed**

**Stinging hairs**
The leaves and stems of common nettle are covered in stinging hairs – glass-like tubes made of silicate.

**Bulbous cap**
The bulbous cap of the hair has a fragile fracture zone beneath it, and readily snaps off at the lightest touch.

**Hypodermic needle**
Without its cap, the hair's sharp tip acts like a hypodermic syringe, penetrating the animal's skin and injecting its contents.

**Irritant injection**
Irritant liquids including acetylcholine, formic acid and histamine are injected into the animal – and, as we know, that hurts!

# Six types of plant protection in focus

**1 Prickly leaves**
Tough, prickly-edged leaves like holly discourage grazing animals, but it takes energy to produce them. Leaves higher on the plant have no prickles, but, if an animal tries to eat them, it grows replacement leaves with prickles.

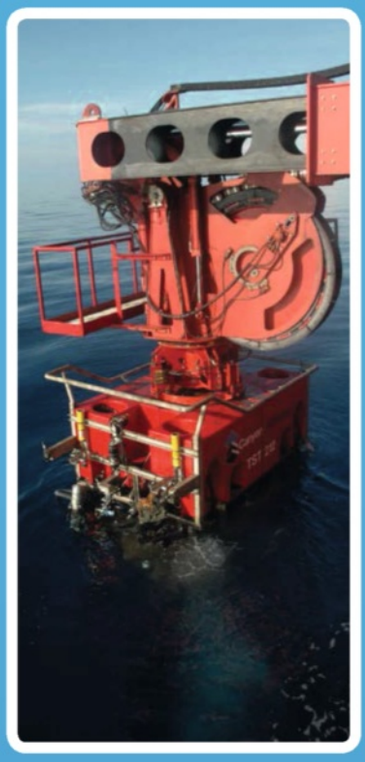
**2 Spines**
Many plants have spiny leaves. In cacti, the stem is green and photosynthetic, and its leaves are reduced to very tough, sharp spines. These have evolved to stop animals biting into the swollen stems to steal the stored water.

**3 Thorns**
Thorns are short, highly modified side stems, which make it uncomfortable for animals trying to eat the plant. But in plants like the blackberry, the thorn's job is to attach to surrounding vegetation so the plant can scramble over it.

**4 Silica blades**
Humans sometimes put broken glass on top of walls to repel climbers – and many meadow grasses use the same technique. The edges of their leaves are protected by a line of microscopic, sharp blades of silica.

**5 Camouflage**
It is difficult to hide leaves which are green and exposed to the Sun, but in the desert, some plants have leaves that look just like pebbles, helping to disguise them from animals seeking food and moisture.

**6 Insect guardians**
Some acacia bushes have glands that secrete nectar to attract ants, and hollow thorns in which ants can nest. The ants want these resources for themselves, so they mount a ferocious attack on any intruders.



# DEEP-SEA MINING

## Massive remote-controlled machines are poised to brave extreme elements to launch an underwater gold rush

Man landed on the Moon in 1969, but it would be nearly another decade before we discovered a remarkably alien world right here on Earth. In 1977, a group of geologists sent an unmanned submersible vehicle thousands of metres down to the seafloor off the coast of the Galápagos Islands. They were searching for proof of plate tectonics, the theory that the Earth's crust not only shifted, but was perpetually consumed and reborn at volcanically active seams.

What they found at the bottom of the ocean would revolutionise both geology and biology. In the middle of a vast, featureless desert they discovered otherworldly rock towers, some measuring 30 metres (98 feet) in height, each of them teeming with previously unseen life forms, including snails the size of a fist, tubeworms measuring three metres (9.8 feet) long, paper-white crabs, purple octopi and swarms of shrimp. The fuel for this explosion of life was the boiling-hot fluid spewing from the top of each tower. Rich with minerals, it supported thriving colonies of bacteria, which in turn provided nutrients to increasingly more complex deep-sea life.

Geologists labelled these deepwater seams 'hydrothermal vents', and thousands more would be located atop every undersea fault line from the Pacific's 'Ring of Fire' to the Mid-Atlantic Ridge. When scientists analysed samples of rock taken from hydrothermal vents, they found unique chemical and mineral properties. The large rock towers were mostly pyrite – an iron sulphide – and other sulphide-dominant rocks. Trapped in these sulphides were high quantities of metallic elements like copper, zinc, and even gold and silver.

Why exactly are hydrothermal vents so packed with valuable minerals? It has to do with heat and pressure. The pressure on the deep ocean floor is 160 times greater than at sea level. This forces seawater downward through cracks and seams in the floor. In volcanically active areas, that water comes into contact with shallow reservoirs of magma, heating it to hundreds of degrees and triggering chemical reactions that strip the seawater of oxygen, magnesium and other elements.

As the super-heated seawater percolates toward the surface, its acidity leeches minerals like copper, zinc and iron from surrounding rock. When the hot, mineral-laced water flows out into the deep ocean, it meets surrounding seawater that's oxygen-rich and nearly freezing cold. The clash of these two extremes triggers another series of chemical reactions in which valuable minerals precipitate out of solution and solidify to form metal-rich towers.

The mining industry has known about this deep-sea treasure for decades, but the cost and technical difficulty of digging a mile deep has been daunting. Previous efforts to harvest manganese nodules – potato-sized nickel balls, copper and rare minerals – from the deep ocean floor proved financially disastrous.

## 5 TOP FACTS
MARINE MINING

**Gold rush**
1 If deep-sea mining companies could retrieve all of the gold believed to exist in seabed deposits, it's estimated that it would be worth in the region of £94 trillion ($150 trillion).

**A Roman industry**
2 Ancient Rome mined volcanic deposits on Cyprus for copper ore. Seafloor massive sulphide (SMS) deposits are deep-water examples of this same phenomenon.

**Saltwater diamonds**
3 The diamond giant De Beers mines the shallow ocean floors (90-140m/295-460ft) off South Africa, where the Orange River deposits diamond-rich silt into the sea.

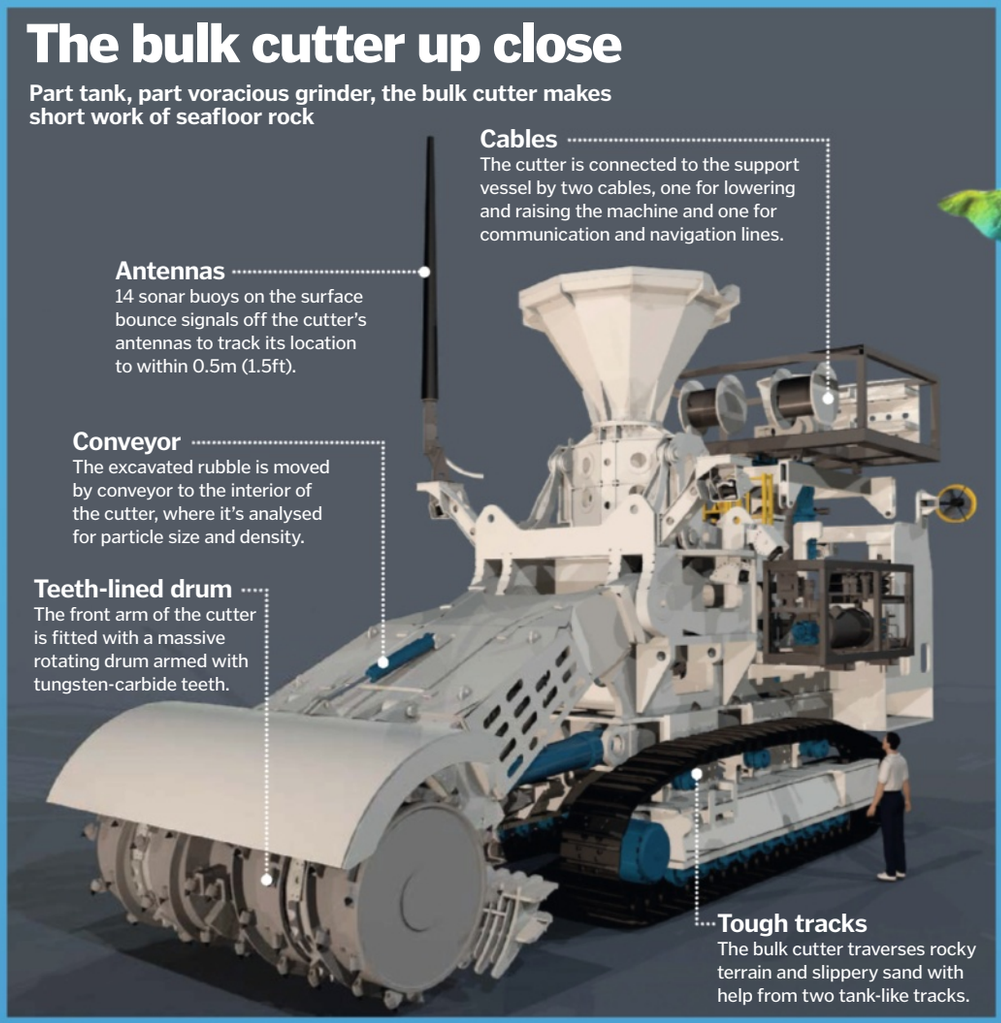
**Vent colonies**
4 Scientists debate the impact of mining on deep-sea life around hydrothermal vents. As long as new vents are available, some argue that these lifeforms will still thrive.

**Mining for good**
5 Deep-sea mining is a potential source of revenue for developing nations. Even operations in international waters must share profits with developing countries.

**DID YOU KNOW?** *Geologists estimate that seabed mineral deposits have enough ore to give everyone on Earth 4kg (9lb) of gold*

# The bulk cutter up close

**Part tank, part voracious grinder, the bulk cutter makes short work of seafloor rock**



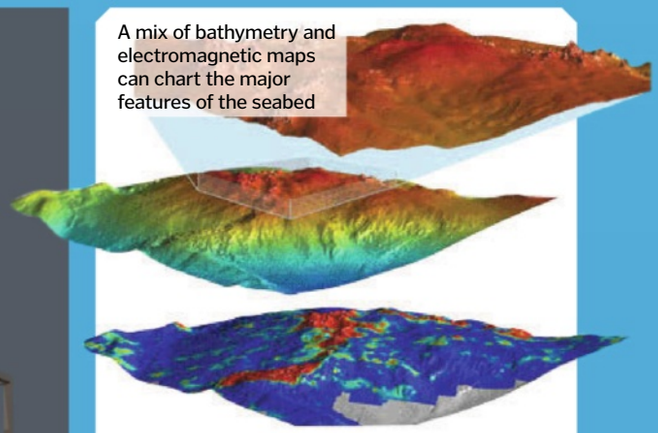
**Cables**
The cutter is connected to the support vessel by two cables, one for lowering and raising the machine and one for communication and navigation lines.

**Antennas**
14 sonar buoys on the surface bounce signals off the cutter's antennas to track its location to within 0.5m (1.5ft).

**Conveyor**
The excavated rubble is moved by conveyor to the interior of the cutter, where it's analysed for particle size and density.

**Teeth-lined drum**
The front arm of the cutter is fitted with a massive rotating drum armed with tungsten-carbide teeth.

**Tough tracks**
The bulk cutter traverses rocky terrain and slippery sand with help from two tank-like tracks.



A mix of bathymetry and electromagnetic maps can chart the major features of the seabed

## Mapping minerals

The map of global seafloor mineral deposits looks exactly like an outline of the planet's tectonic plates. When two plates converge or diverge under the sea, mineral-rich fluids escape through the seams in the Earth's crust. On land, these geothermal vents might look like gurgling mud pots or geysers. On the seafloor, the minerals inside the blazing hot fluids cool and precipitate into rocky deposits called seafloor massive sulphides rich with zinc, copper, silver, gold and other rare elements. These deep-sea mineral fields ring the coastal waters of the Pacific and line the Mid-Atlantic Ridge. The hottest spot for potential deep-sea mining exploration is the western South Pacific near the coasts of Papua New Guinea and Australia. The majority of the seafloor is considered beyond the jurisdiction of individual nations, and is therefore controlled by the International Seabed Authority, which has so far issued 17 exploratory permits to private companies and governments including China, Russia, India and France.

But a hot market for minerals and heavy investment in seafloor mining technology has set the stage for a deepwater gold rush. Nautilus Minerals, a seafloor mining company based in Toronto, Canada, wants to be the first in the water. With help from UK heavy machinery manufacturer Soil Machine Dynamics (SMD), Nautilus has built massive robotic cutters and excavators to pulverise mineral-rich seafloor deposits, pump the debris to the surface and sift out the treasure. The target site is an outcropping of vents off the coast of Papua New Guinea believed to contain enough copper, gold, silver and zinc to fetch £1.8 billion ($2.9 billion) on the open market.

*"Trapped in these sulphides were high quantities of metallic elements like copper, zinc, and even gold and silver"*

Nautilus's highly specialised mining machines are 300-ton beasts that combine the brute force of terrestrial continuous mining equipment with high-end technology like HD video cameras and 3D sonar that allows them to be operated remotely at depths of 1.6 kilometres (one mile). The company will employ three vehicles – known as seafloor production tools – each with its own critical mission: the auxiliary cutter, the bulk cutter and the collecting machine.

The business end of the auxiliary cutter is a cluster of four rotating drums fitted with a total of 200 tungsten-carbide teeth. Mounted on a long boom, the spinning teeth are tasked with chewing up mineral deposits on steep or uneven gradients, including those towering hydrothermal vents.

The bulk cutter is 14.2 metres (46.6 feet) long by 4.2 metres (13.8 feet) wide and leads with a rotating cylinder studded with 7.6-centimetre (three-inch) teeth. The bulk cutter shreds rock on seafloor contours and flat benches carved out by the auxiliary cutter. Both the bulk and auxiliary cutters grind the rock to diameters smaller than five centimetres (two inches).

The collecting machine is like a monstrous wet/dry vacuum, sucking up a slurry of pulverised rock, silt and seawater with a long adjustable arm capped with a spinning, sifting nose. The collecting machine draws the material into its body, where sensors can measure the slurry's density, flow rate, temperature and pressure.

The next stop is the 120-ton subsea pump built by GE, designed exclusively for mining jobs that require the high-flow transport of rocky slurry and mud. The massive ten-chamber pump is suspended by cables from the support vessel floating a mile up. In fact, each of the seafloor vehicles is also connected

"Seafloor mining holds tremendous promise, but still has to overcome a number of difficult challenges"

to the support ship by cables that carry communication, power and navigation lines.

The pump forces the rock-studded material up a 30-centimetre (12-inch) rigid rubber pipe reinforced with steel and Kevlar. On the support vessel, the slurry is fed into a dewatering plant, where liquids are filtered and spun out to leave dry, rocky debris. The plan is to have barges ferry the material 50 kilometres (31 miles) to a storage facility in the Papua New Guinea port of Rabaul, after which the minerals can be extracted and concentrated into marketable ore.

Seafloor mining holds tremendous promise, but still has to overcome a number of difficult challenges. The first is obtaining the rights to mine the deep ocean. In the case of Nautilus, the company signed a 20-year mining lease with Papua New Guinea, one of few nations that actually owns mineable seafloor deposits. Most hydrothermal vents exist in international waters, where they are regulated by the UN-sanctioned International Seabed Authority, which is slower to sell exploration rights.

The second obstacle is increasing pressure from environmental groups and marine biologists, who worry about the impact of mining on the little-understood plants and animals that thrive in the extreme environments of the vents. Seafloor mining will certainly destroy some of those habitats, but will the sealife be able to successfully relocate to undisturbed vents? This and many other questions remain to be answered.

In the meantime, Nautilus and a handful of other international players are preparing to take their mining machines to the high seas, in order to hunt the depths for a treasure bounty the likes of which has never been seen.

## Mining conditions in the depths

The conditions of life thousands of metres below the ocean surface are otherworldly. Pressure is so intense that the fluids seeping from deep-sea vents are neither liquid nor gas, but something in between – not to mention those fluids are highly corrosive, acidic and searing at temperatures over 315 degrees Celsius (600 degrees Fahrenheit). At a short distance from the hydrothermal vents, the temperature of surrounding deep-sea waters is close to freezing. These brutal conditions pose tremendous technical challenges to mining operations, including the construction of robotic machinery that can operate in such temperature and pressure extremes, not unlike landing a mining rig on a passing asteroid.

## Mining out the facts

**We speak to John Elias from Nautilus Minerals about the major challenges that deep-sea mining presents**

**What are you searching for under the ocean that we can't get on land?**
Nautilus Minerals is the first company to explore the ocean floor for polymetallic seafloor massive sulphide (SMS), which contains appreciable amounts of copper, gold, silver and zinc. They are formed predominately along tectonic fault lines where hot magma containing high concentrations of dissolved minerals seeps out of the earth and mixes with cold seawater, which causes the minerals to precipitate and form these deposits on the ocean floor. Compared to land-based porphyry copper mines, SMS deposits contain copper in concentrations that are ten times higher. For example, Solwara 1, Nautilus's maiden project, has an average copper concentration of about seven per cent copper, while land-based copper mines average about 0.6 per cent.

**How do you find a site to dig underwater?**
Nautilus has employed a number of techniques for identifying prospective sites. One is mapping bathymetry by sonar, to look for areas of recent or current volcanic activity. Another is sampling and measuring the properties of the water column, looking for large-scale ash plumes that result from volcanic activity that is typically associated with seafloor massive sulphide mineralisation. We also traverse over the seafloor in areas where we found ash and metal anomalies in the water column to locate seabed expressions of the mineralisation. This is using a remotely operated vehicle (ROV) that takes small samples of rock. Lastly, we use geophysics and drilling activity to estimate the actual resource of metal contained at the most promising SMS discoveries. There is practically no impact on the environment from these exploration activities, apart from the presence of a ship. Even the drilling is a much lower impact than land, because we do not need to clear access tracks to get the drill rig in.

**How does sea-mining differ from on land?**
Nautilus developed a seafloor production system composed of seafloor production tools (SPTs), the riser and lifting system (RALS) and the production support vessel. There are a number of aspects that differentiate Nautilus's mining methodology from its land-based counterparts. Unlike land-based mines, the system Nautilus developed features an infrastructure (the SPTs, the RALS and the vessel) that can be relocated from one mining site to another. No roads have to be built to reach the deposit and no communities need to be relocated. The high grades combined with a relatively small amount of overburden ensure seafloor SMS deposits like Solwara 1 will have a smaller physical footprint than its land-based counterparts. Mineral deposits on land are increasingly of lower grade, which means more waste is being created per ton of metal produced.


## Ocean mining in action

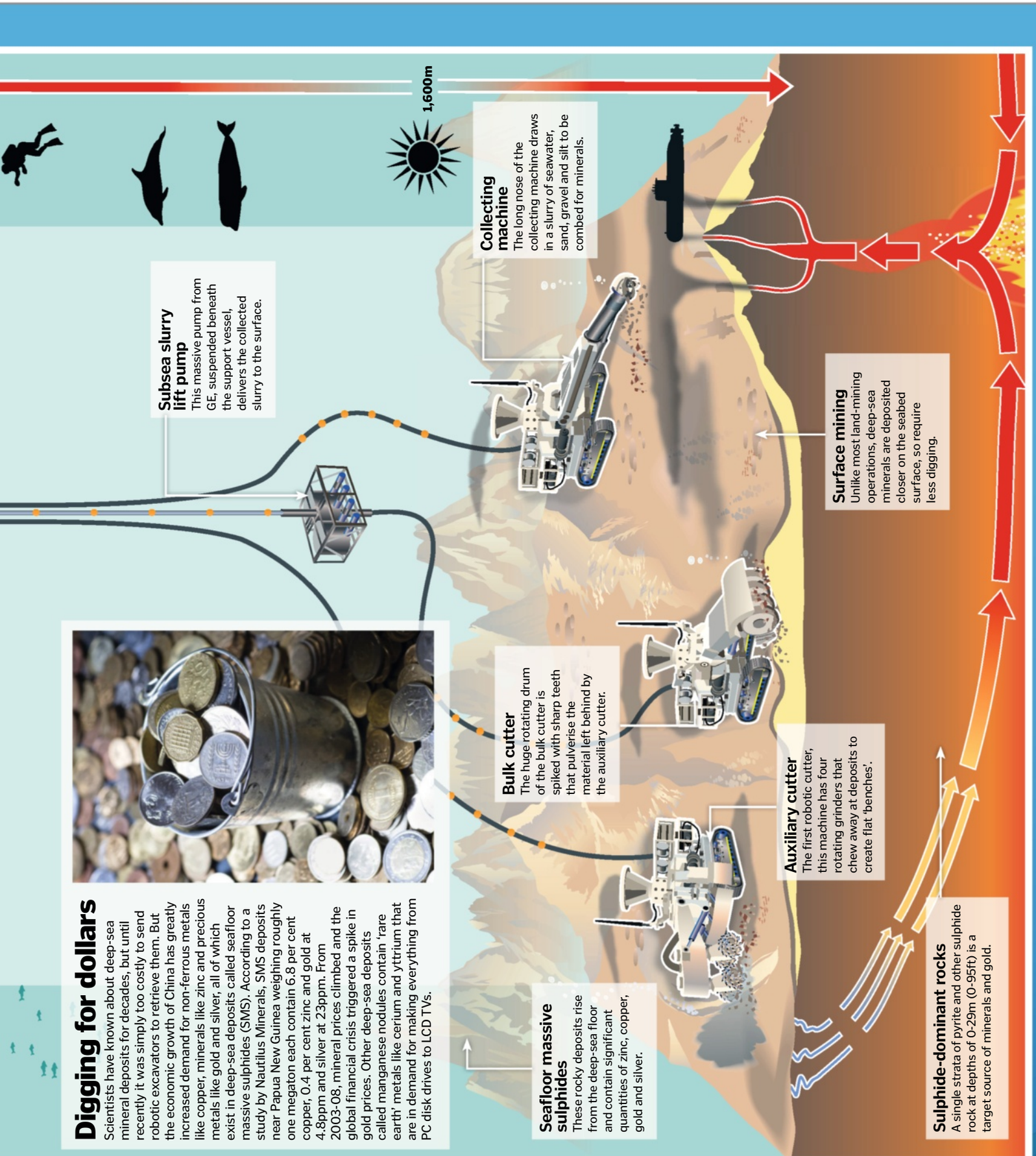
**This is the system that Nautilus Minerals will use to extract valuable minerals from the seabed**

# 27bn

## FIELDS OF MANGANESE NODULES

Geologists debate how these rock clusters form, but estimate that the eastern Pacific seafloor holds more than 27 billion tons of the nodules rich in manganese (29 per cent), as well as nickel (1.3 per cent), copper (1.1 per cent) and other metals.

**DID YOU KNOW?** *At 1,600m (5,250ft) below the ocean surface, the pressure is 160 times greater than at sea level*




## Digging for dollars

Scientists have known about deep-sea mineral deposits for decades, but until recently it was simply too costly to send robotic excavators to retrieve them. But the economic growth of China has greatly increased demand for non-ferrous metals like copper, minerals like zinc and precious metals like gold and silver, all of which exist in deep-sea deposits called seafloor massive sulphides (SMS). According to a study by Nautilus Minerals, SMS deposits near Papua New Guinea weighing roughly one megaton each contain 6.8 per cent copper, 0.4 per cent zinc and gold at 4.8ppm and silver at 23ppm. From 2003-08, mineral prices climbed and the global financial crisis triggered a spike in gold prices. Other deep-sea deposits called manganese nodules contain 'rare earth' metals like cerium and yttrium that are in demand for making everything from PC disk drives to LCD TVs.

"Pyrometers use electromagnetic radiation to determine the temperature from a distance"

# Inside a pyrometer

## The tool that's tough enough to measure superhot objects

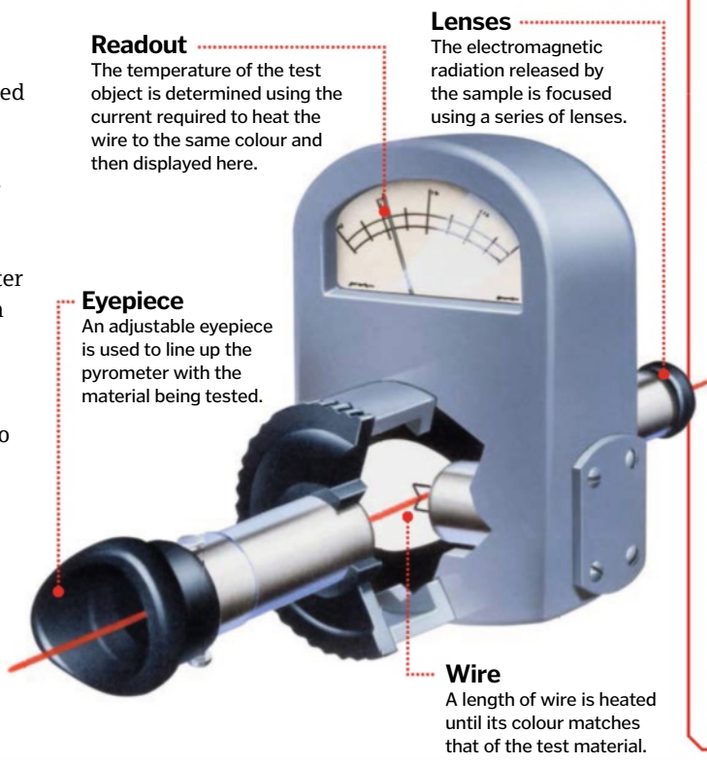
To measure the temperature of objects hot enough to melt traditional thermometers, a pyrometer is often used. These specialist thermometers use the electromagnetic radiation released by hot objects to determine their temperature from a distance.

As objects heat up they release infrared and visible light, which can be used to determine their temperature. An optical pyrometer contains a metal wire, which can be heated using a variable electrical current; as the wire is heated, it changes colour. By matching the colour of the wire to the colour of the object being tested, an approximate temperature can be deduced.

A more accurate reading can be obtained by focusing the electromagnetic radiation on temperature-sensitive electrical components. The components produce a variable current, depending on the heat level.

### Optical pyrometer up close

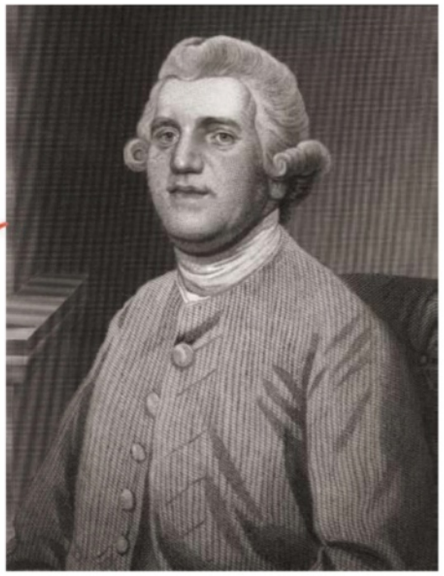
**This simple piece of kit can safely calculate the temperature of scorching-hot objects**

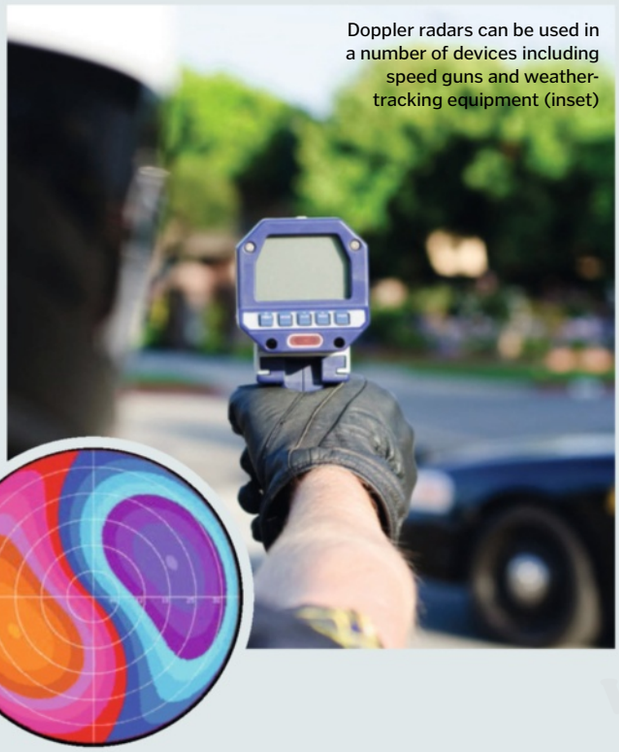



### Origins in the pottery trade

Founder of the Wedgwood pottery company, Josiah Wedgwood, invented the pyrometer in the 18th century to measure the temperature of his kilns. Clay changes colour depending on the temperature at which it is fired. Wedgwood made a series of pieces of clay, fired at known temperatures, ranging in colour from buff (low temperature) to red (high temperature).

Using these as a guide, he was then able to determine the temperature of the kiln by comparing the colour of the clay to his predetermined reference scale. Wedgwood was elected to the Royal Society in 1783 in recognition of his scientific achievements.





Doppler radars can be used in a number of devices including speed guns and weather-tracking equipment (inset)

# Doppler radars

## Learn about the technology that tracks the motion of objects using echoes and the Doppler effect

Radar equipment produces electromagnetic waves, such as microwaves or radio waves. The waves hit the target and are reflected back towards the detector. In a similar way to echolocation in bats, the time it takes for the wave to reflect back can be used to determine the distance.

By sending out waves of a known frequency, the radar can also be used to determine the velocity of the target. When a police car drives past, the siren sounds high-pitched as it heads towards you, and rapidly changes to a lower pitch once it has zoomed past – this is known as the Doppler effect. If the radar target is moving towards the detector the frequency of the waves arriving at the detector is increased, and if the target is moving away, the frequency is decreased, allowing its velocity to be calculated.

Doppler radar has a variety of applications. The police use handheld radar guns to determine the speed of passing vehicles, while military planes contain pulse radars for targeting. Large-scale Doppler radar is also used to scan the atmosphere to follow aircraft, or to track and predict the weather.

**AMAZING VIDEO!** SCAN THE QR CODE FOR A QUICK LINK

**See a wax ET come to life at Madame Tussauds**

www.howitworksdaily.com

**DID YOU KNOW?** *The Madame Tussauds studios produce between 40 and 50 wax figures each year*

# Building wax figures

## Discover how lifelike models are made step by step

Wax figures have been around since the Middle Ages and are made from a combination of beeswax and Japan wax. To construct a wax figure, first a clay model is made – this model is used to generate a mould. The wax mixture melts at low temperatures and a layer of molten wax is poured into the mould. Once set, the wax remains soft enough to be carved, but durable enough to create a lasting, detailed statue. Heated metal tools can be used to chase away any seams or imperfections in the surface, and to melt sockets in the face for the eyes and teeth. The softness of the set wax also allows individual hairs to be embedded – one of the most time-consuming parts of the process. Finally, layers of oil-based paint are used to create realistic skin colour and texture.

Wax sculptors spend months creating their super-lifelike models

## A spotlight on Madame Tussaud

Marie Tussaud was a French sculptor, born in 1761. Her mother worked as a housekeeper for wax sculptor Dr Philippe Curtius, and under his tuition, Tussaud learnt the craft. During the French Revolution, Tussaud made death masks of some of the most infamous victims of the guillotine. Tussaud then travelled to England, and in 1835, she opened her first permanent exhibition on Baker Street in London. It originally had 400 figures, including a popular Chamber of Horrors exhibit still loved today. After Tussaud's death in 1850, her grandson, Joseph Randall, commissioned the move to Marylebone Road.

### 1. Clay model

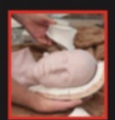
To capture a true likeness, wax sculptors use a combination of photographs, video footage and body measurements. First a steel and aluminium skeleton is constructed and a rough outline of the musculature is created using chicken wire and newspaper. The body is then positioned, before being covered in clay and sculpted.

### 2. Make a mould

Moulds for wax figures are made from different materials. For the head, a plaster mould is often used. For the body, steel supports and hessian sacking are added to the plaster to support the additional weight of the mould. For hands, meanwhile, the moulds can be made of dental alginate.

### 3. Cast the wax

The plaster mould for the head is filled with molten wax. Wax contracts as it solidifies, so the clay sculptures and resulting moulds are made two per cent larger than the size required. For the hands, a flexible plastic known as 'elvex' is sometimes added to the wax to prevent the digits snapping. The body is cast in resin and fibreglass.

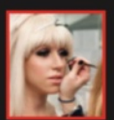


### 4. Add the hair

After the wax figure is removed from the mould, any seams are melted away, and further detail is carefully added to the face and hands. Each individual hair is hand poked into the wax figure's head using a fine fork-ended needle; this stage can take up to six weeks to complete.

### 5. Eyes

Next up is a feature that really transforms the model from inanimate mannequin to realistic human double: the eyes. The glass eyes are carefully painted with watercolours, using silk thread to build up the patterning on the iris. Teeth are constructed using dental acrylic, with a silicone mould taken from the subject's mouth.



### 6. Paint the skin

Like skin, wax is translucent, providing the perfect base. Skin colour is built up using oil-based paint. The paint is stippled onto the wax to create a realistic texture. The artists take into account the pose of the statue, as well as the display lighting, to create realistic shadows across the figure.

"Typically, terrariums are used to grow plants that can only exist in tropical climates"

# Terrariums explained

Discover how these fish tank-like devices are used to grow tropical plants

Terrariums are a special type of enclosure with a glass case that specialise in re-creating a foreign habitat very different to the room they are located in. Typically they are used to grow plants that can only exist in tropical climates such as croton or selaginella, with a series of lighting, water and circulation systems artificially imitating their native habitat.

Animals can be kept in terrariums too, with turtles being one of the most common inhabitants. However, their prime modus operandi is for botanical or decorative purposes, akin to a fish tank in modern homes and offices. It's worth noting, as can be seen in the 'Get to know your habitats' boxout, terrariums differ from other similar enclosures like insectariums and formicariums.

Indeed, a terrarium's focus on plants and flowers makes it in many ways more akin to a botanical garden's tropical glasshouse than an aquarium, with facilities like the Eden Project in the UK and the Biosphere 2 in Arizona sharing much of its technology, albeit on a far larger and more complex scale. For a closer look at the key components that make up a modern domestic terrarium, check out the main image.

## Anatomy of a terrarium

**What technology enables us to re-create tropical forests within a small glass sphere?**

**Lighting**
A series of LED lights is mounted within the lid to replicate necessary levels of illumination and heat for the plants to grow effectively.

**Misting module**
To ensure that the artificial water cycle of the terrarium is well distributed, a misting module in installed.

**Tank**
Terrarium tanks are similar in construction to aquariums, consisting of a base, glass tank and lid. Sizes vary, though most are no more than 100cm (39.3in) tall.

**Planting tray**
The compost for the terrarium's plants is placed on top of a special capilliary mat that draws water from the system's reserves while preventing saturation.

**Fans**
A fan network attached to an internal carbon filter ensures a supply of fresh air throughout the bowl.

**Base**
The terrarium's power supply, fans and water reservoir are located within the base. Support struts extend from the base to maintain stability on flat surfaces.

### Win a biOrb AIR!

Reef One has kindly donated a biOrb AIR for us to give away to one lucky reader. For a chance to win your very own terrarium, just visit **www.howitworksdaily.com**, search for 'biOrb AIR' and enter the draw.

## Get to know your habitats...

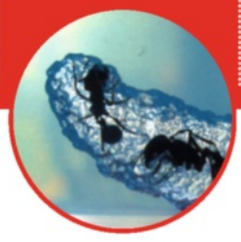
**Aquarium**
An aquarium is a simulation of a water habitat, like a river or lake. It can be fresh or salt water and contains marine creatures.

**Insectarium**
An insectarium is a special type of simulated dry habitat that caters solely to insects and arachnids such as the tarantula.

**Vivarium**
Similar to a terrarium, albeit designed more for animals, vivariums are typically home to a wide variety of flora and reptiles.

**Paludarium**
An artificial habitat that re-creates swamp or rainforest habitats. It features aspects of both aquariums and terrariums.

**Formicarium**
Similar to the insectarium, the formicarium is an artificial habitat that re-creates conditions for ant colonies.



**Riparium**
A riparium is a very particular type of paludarium – one in which the contained water sources have a circulating current.

1. CLASSIC

**ErgoSof**
The ErgoSof PenAgain features the classic rocket shape and a comfortable soft-touch coating. The index finger cradle reduces grip-related stress.

2. PENCIL

**Rockyt Writer**
This ergonomic pencil for kids makes writing fun. Designed for the smaller hand, the Rockyt Writer comes with five refills and dual built-in erasers.

3. COMING SOON!

**ErgoSleek**
Coming soon to GBA Pens is the polished aluminium and chrome ErgoSleek PenAgain, which provides a weightier feel and a dash of elegance.

## SPECIAL PROMOTION

# How the PenAgain works

### Discover how the comfortable 'no grip' design reduces stress on the hands and fingers

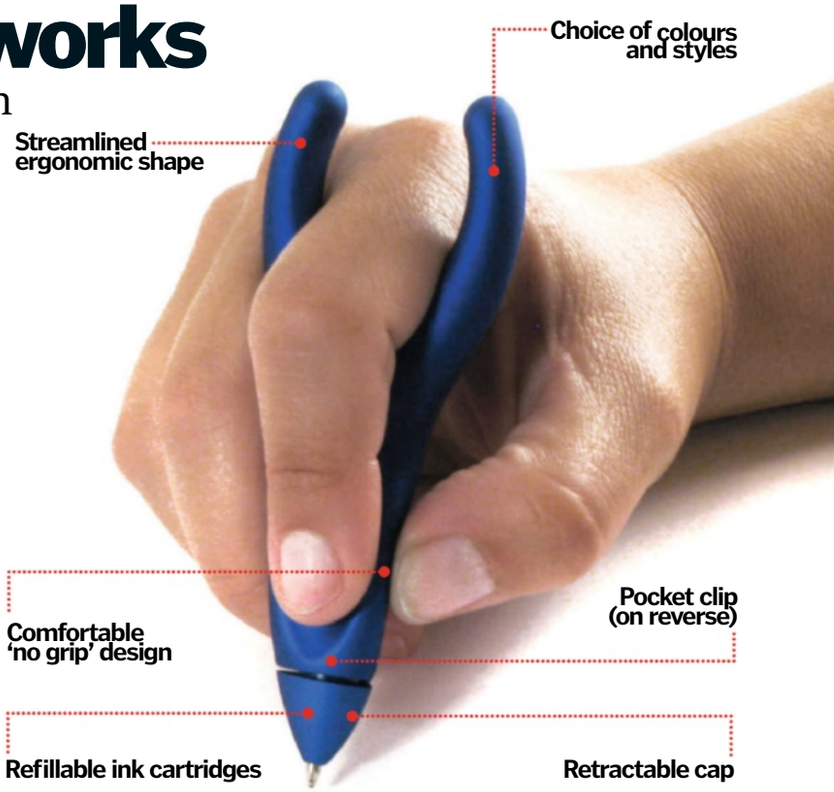
With a patented wishbone-shaped design, the PenAgain is an innovative writing implement hailed as the biggest innovation in the writing industry since the ballpoint pen replaced quill and ink.

Influenced by the shape of the human hand, the PenAgain's tripod design is thought to improve the hand's posture and encourages a comfortable writing position. This is intended to increase writing motion efficiency and lessen grip-related hand stress, making it ideal for those who spend a lot of time writing or who suffer from hand cramp and other joint disorders or complaints.

While a standard ballpoint relies on a strong grip, the PenAgain features a distinctive index finger cradle, designed to use the weight of your hand to achieve the pressure to apply ink to paper. While using the PenAgain will initially feel strange, that's entirely natural as your hand 'unlearns' a lifetime of poor writing habits. When using a PenAgain, you should resist the urge to grip the pen with your fingers; just relax your hand and let gravity hold it. Before long, you'll feel the tension of writing melt away.

**Learn more**

GBA Pen Company is the sole UK distributor for the PenAgain brand. To get your hands on your own PenAgain, call 01245 225758 or visit **www.gbapen.co.uk** and quote 'Penagain13' when ordering (on the phone or online) for ten per cent off the price.



"Joysticks are used to control the movements of the robotic arms"

# Robotic surgery

Medical technology in the operating theatre has come on leaps and bounds, but it still needs a helping hand from humans...

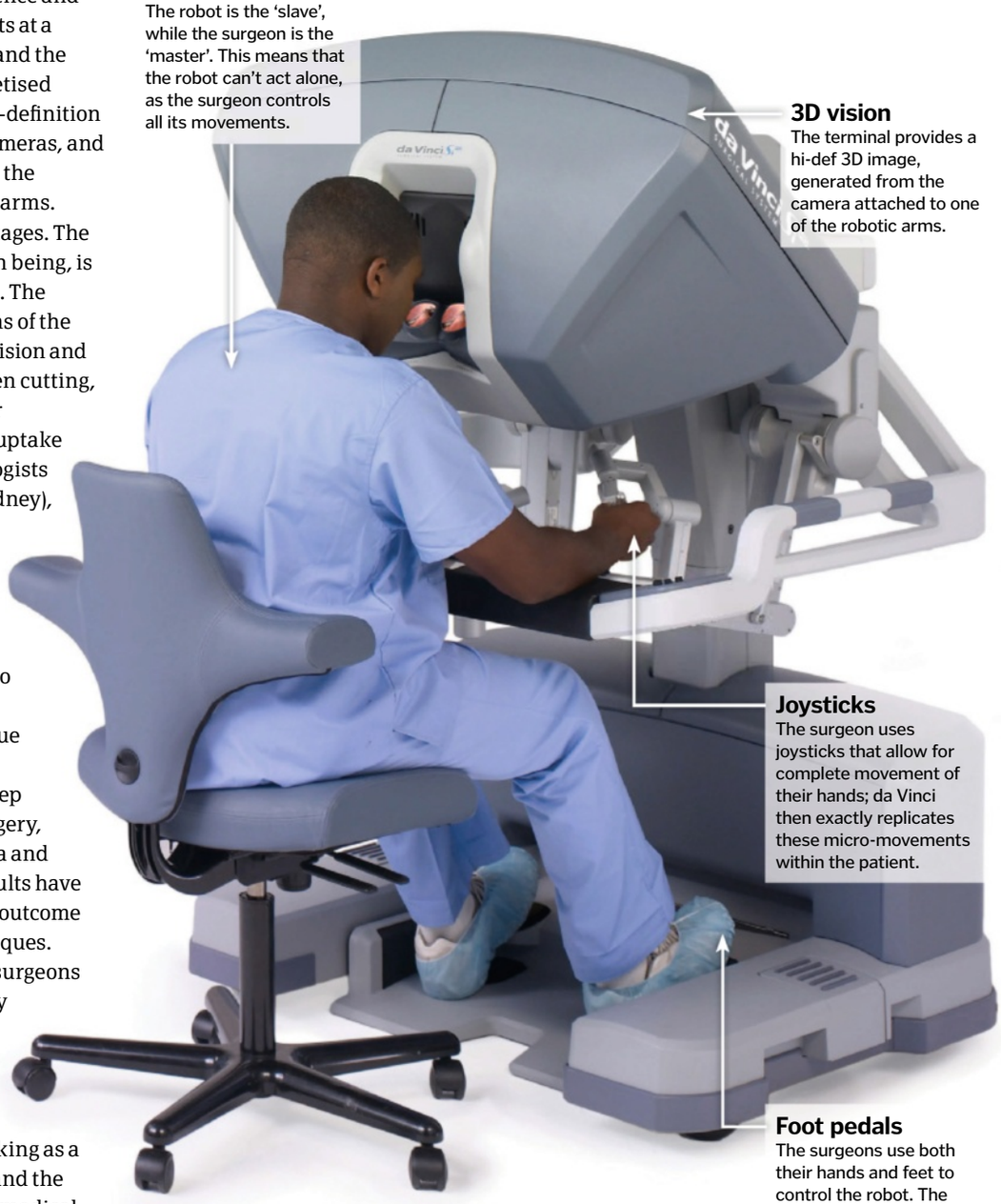
Robotic surgery allows for control and precision previously unknown to surgeons. Contrary to popular belief, the robot does not operate on the patient alone. It is a 'slave' to a human 'master', meaning it is not a true robot (these have intelligence and react automatically). The surgeon sits at a console next to the operating table and the robot is placed around the anaesthetised patient. The surgeon looks at a high-definition 3D image provided by the robot's cameras, and special joysticks are used to control the ultra-fine movements of the robotic arms.

This brings many exciting advantages. The camera, previously held by a human being, is now held perfectly still by the robot. The movements and angles that the arms of the machine provide allow for fine precision and less damage to adjacent tissues when cutting, leading to reduced pain and a faster recovery. This has led to very rapid uptake by some specialists, including urologists (who operate on the bladder and kidney), gynaecologists (who operate on the uterus and ovaries) and heart surgeons. As with most technologies, there are downsides to using robots in operations. They are expensive, large, cumbersome to move into place, and remove the important tactile feeling of real tissue between the surgeon's fingers.

Robotic surgery is considered a step forward from standard keyhole surgery, where the surgeon holds the camera and operating arms. However, early results have shown that there are practically no outcome differences between the two techniques. Combined with higher costs, some surgeons think this means robots are actually inferior to current techniques. This has led to the development of on-going trials, comparing robotic to standard keyhole surgery. Surgeons around the world are working as a single, giant team to deliver these, and the results will determine the future of medical robots for generations to come.

## da Vinci in action

**This state-of-the-art surgical system works as part of a big team to deliver high-precision surgery. Find out what role it plays now...**



**DID YOU KNOW?** *Surgical robots are incredibly expensive, with current versions costing around £900,000 ($1.45mn) each*

**Robotic arms**
The ends of the robot's arms, which include a camera and operating instruments, are placed in the operating site at the start of the procedure.

**Internal view**
The camera is projected onto several screens around the operating theatre, so the team knows exactly what the surgeon is doing.

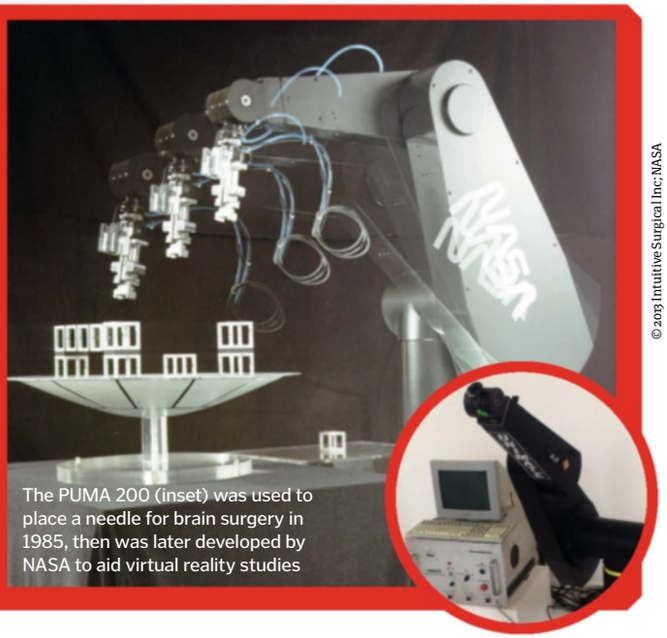
**Surgical team**
Someone always remains 'scrubbed up', so that they are sterile and ready to move any parts of the patient or robot.

## Fluorescence imaging

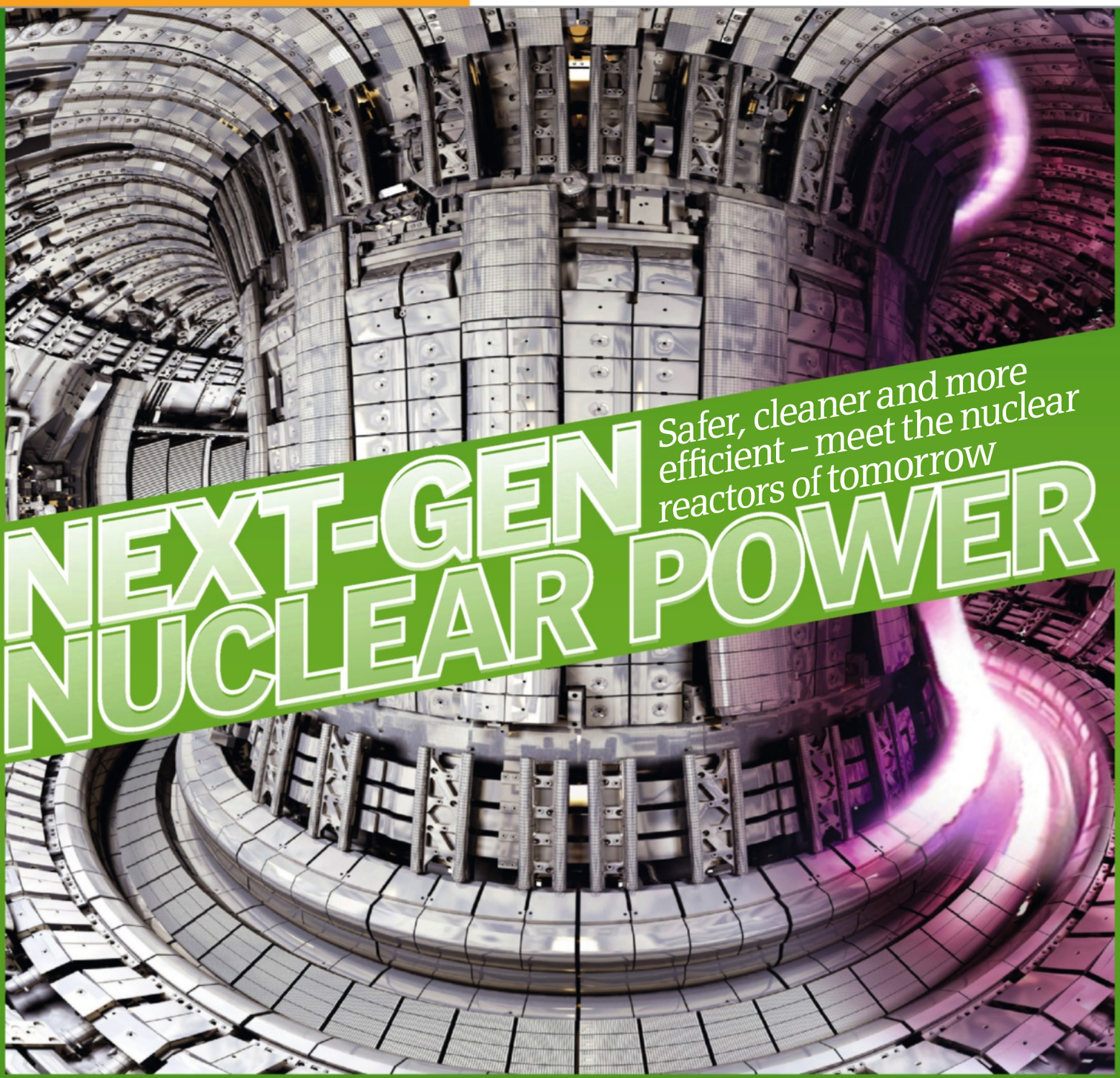
Fluorescence imaging is still in the experimental stages, and is right at the cutting edge of technological science. Indocyanine green (ICG) is a dye that was initially developed for photography and is now used clinically. It is injected into the patient's bloodstream, and has been adapted so that it sticks to cancer cells – for example, within the bowels. At the time of surgery, the doctor inserts a camera into the patient's body (either using their hands or a robot), and the dye is excited by light at a precisely matching wavelength. This creates bright green fluorescence, distinguishing cancerous from normal tissue and allowing the surgeon to make precise incisions.

## The evolution of robotic surgery

The current robots in use, like the da Vinci Surgical System, are second generation. The first generation, like the Unimation PUMA developed in the Eighties, had very limited movements and could only carry out specific tasks. The second generation brought a range of fine and varied actions, which surgeons rapidly adapted to. These new-and-improved robots were pioneered and driven forward by North American health systems. Uptake has been slower in Britain due to health budgets, at a time when other treatments have an even bigger impact on patient outcome. There is excitement over development of the third generation of robot, which promises to be more compact, faster and to be packing in even more cutting-edge technology. The future may see telesurgery, where the surgeon in one place (eg a hospital) performs robotic surgery on a patient elsewhere (eg an injured soldier on a battlefield).



The PUMA 200 (inset) was used to place a needle for brain surgery in 1985, then was later developed by NASA to aid virtual reality studies



# NEXT-GEN NUCLEAR POWER

## Safer, cleaner and more efficient – meet the nuclear reactors of tomorrow

As energy demands soar, nuclear energy could hold the key to meeting our world's needs, carbon-free. From fusion reactors to the next generation of fission plants, the nuclear reactors of tomorrow are getting ready to take on the challenge.

Like traditional fossil fuel plants, nuclear fission plants turn water into steam, driving turbines to generate electricity. But instead of burning coal or gas, a nuclear reactor creates heat by splitting atoms.

Inside, atomic nuclei (usually uranium) are bombarded with neutrons, causing them to become unstable and split, releasing neutrons and energy. Some neutrons go on to trigger further reactions, creating a self-sustaining chain reaction with the potential to release colossal amounts of energy. If the neutrons are moving too fast however, they're less likely to be absorbed by the atomic nuclei, so a 'moderator' – often water – is added in order to keep their speed in check.

The radioactive elements produced by fission reactions make nuclear reactors more vulnerable to overheating than a fossil fuel plant. "When you switch a coal-fired plant off, the heat dissipates very, very quickly," explains Malcolm Joyce, professor of Nuclear Engineering at Lancaster University, UK. At the heart of a nuclear reactor however, the decay of radioactive isotopes continues to generate heat for weeks and months after shutdown. Nuclear accidents arise when a malfunction or an

# 5 TOP FACTS
## NUCLEAR ENERGY

**1 Fission in nature**
Nuclear fission chain reactions once occurred naturally in uranium deposits in Gabon. This is the only place scientists have observed evidence for natural nuclear reactors.

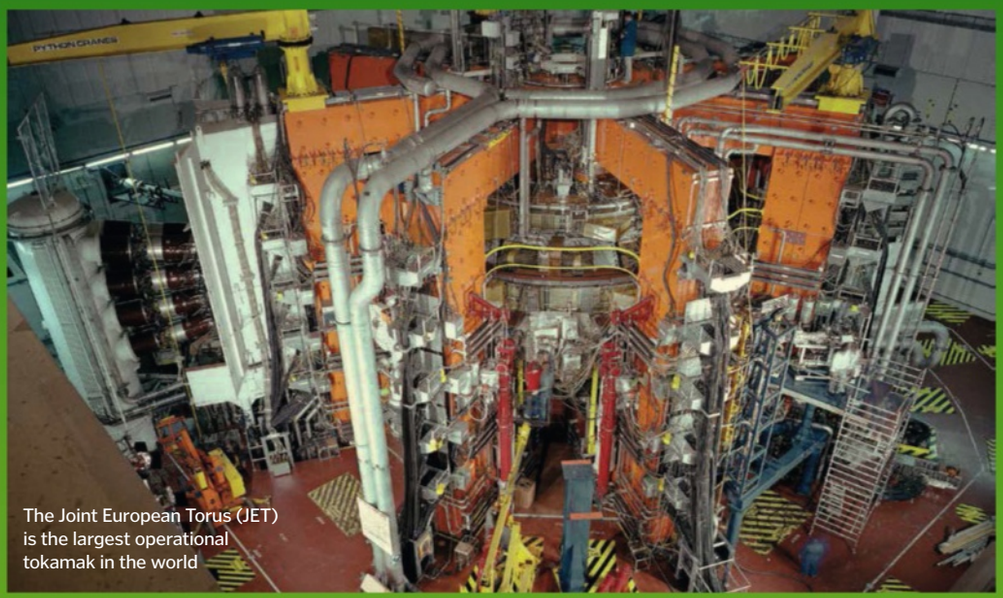
**2 $CO_2$ savings**
If the energy produced by the world's nuclear fission plants was generated from coal plants instead, these would release 2 billion tons of carbon dioxide into the atmosphere.

**3 Enriching uranium**
The uranium-235 that fuels most nuclear plants makes up only 0.7 per cent of natural uranium reserves. This percentage can be increased by a process called enrichment.

**4 Made of stars**
From helium to iron, almost every element on Earth was created by nuclear fusion reactions at the heart of stars, which essentially fuse lighter elements into heavier ones.

**5 Underwater power**
On-board fission reactors provide nuclear submarines with an almost limitless supply of energy, enabling them to go for up to ten years without refuelling.

**DID YOU KNOW?** *Inside a fusion reactor, half a gram of fuel releases as much energy as burning 11 tons of coal!*

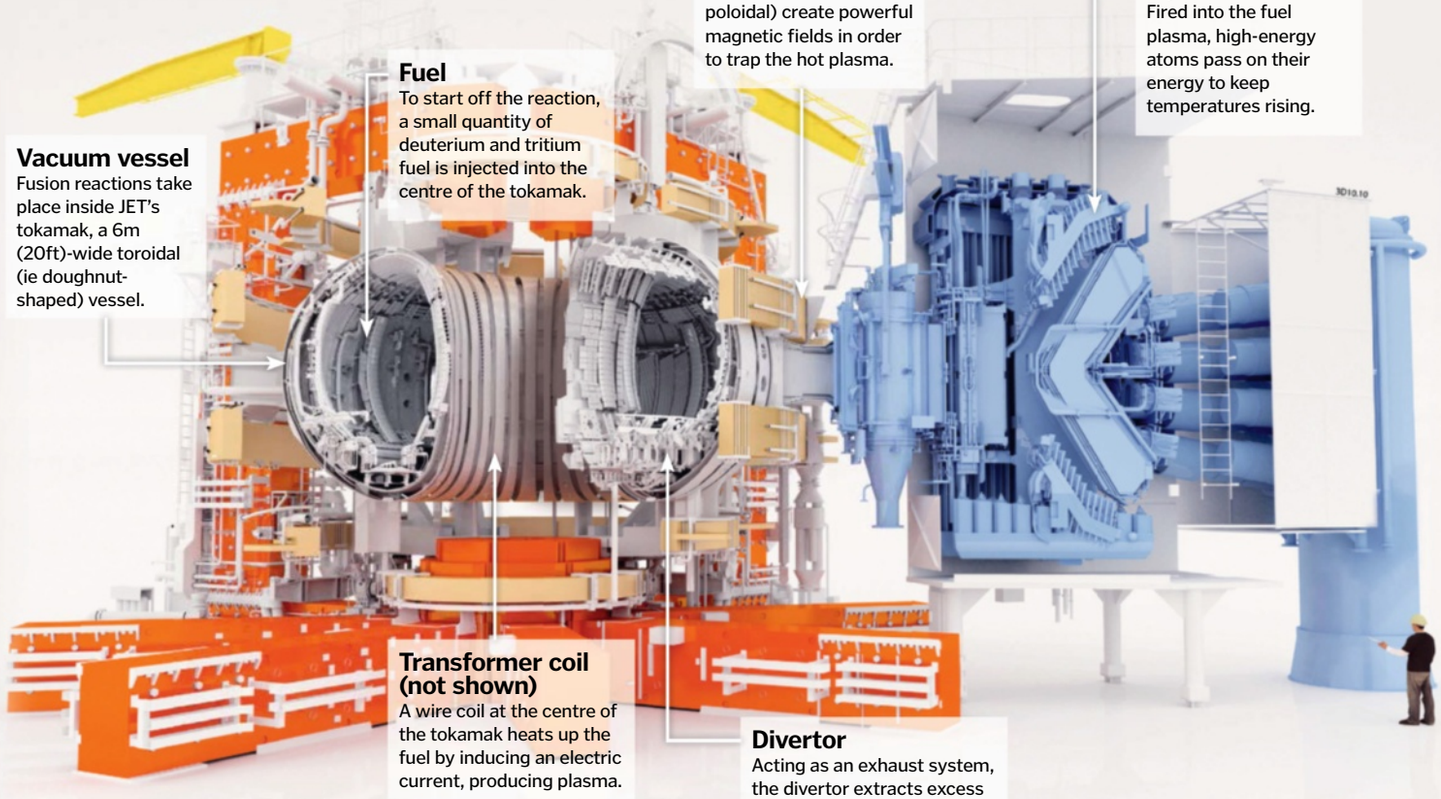

The Joint European Torus (JET) is the largest operational tokamak in the world

# What are tokamaks?

A tokamak is a device with a unique mission: producing the tremendous temperature and pressure conditions needed for nuclear fusion to take place. Developed in the Soviet Union in the 1960s, it consists of a doughnut-shaped vessel surrounded by powerful magnets. Deuterium and tritium fuel inside the tokamak are heated to 150 million degrees Celsius (270 million degrees Fahrenheit) – ten times hotter than the Sun's core! These extreme temperatures cause the fuel's atoms to separate into ions and electrons, forming a cloud of charged particles known as plasma. To maintain the fuel's temperature, it cannot be allowed to touch the cooler walls of the tokamak – besides, at this temperature the plasma would simply melt through any solid material known to man. Instead, two sets of magnets create an invisible cage, confining the fuel and suspending it safely away from the tokamak's walls.

# How does JET work?

**Find out how the Joint European Torus keeps a check on plasma that reaches up to 150mn˚C**



**Outer magnets**
Two sets of magnetic coils (toroidal and poloidal) create powerful magnetic fields in order to trap the hot plasma.

**Neutral beam injection**
Fired into the fuel plasma, high-energy atoms pass on their energy to keep temperatures rising.

**Fuel**
To start off the reaction, a small quantity of deuterium and tritium fuel is injected into the centre of the tokamak.

**Vacuum vessel**
Fusion reactions take place inside JET's tokamak, a 6m (20ft)-wide toroidal (ie doughnut-shaped) vessel.

**Transformer coil (not shown)**
A wire coil at the centre of the tokamak heats up the fuel by inducing an electric current, producing plasma.

**Divertor**
Acting as an exhaust system, the divertor extracts excess heat, helium ash and other impurities from the plasma.

JET has been researching fusion power since the Eighties

"Planning for worst-case scenarios, newer reactors beef up their safety with extra cooling systems"

external disruption affects cooling systems, causing the reactor core to overheat or even melt down, releasing radioactive material from its core. "Instances of overheating are actually really rare," says Joyce. But although the vast majority of nuclear reactors have operated without incident for decades, accidents at Three Mile Island, Chernobyl, and most recently Fukushima provide painful reminders of how things can go wrong. "At Three Mile Island reactors overheated because of a very gradual loss of coolant," explains Joyce. While at Fukushima, the tsunami took out back-up generators, bringing cooling systems to a halt.

Like most nuclear power stations in operation today, these disaster-struck plants were generation II reactors – part of the first wave of commercial reactors built back in the Seventies and Eighties. Most of our current fleet are pressurised water reactors (PWRs). These plants, however, typically extract only one per cent of the energy available from their uranium fuel. Further, they are modelled on early reactors which were conceived to produce weapons-grade plutonium, making nuclear proliferation a threat. Faced with these concerns, engineers have gone back to the drawing board to design brand-new reactors that will make nuclear fission power safer but also much more efficient.

Built from the Nineties onwards, generation III reactors, such as the European Pressurised Reactor (EPR) or the Economic Simplified Boiling Water Reactor (ESBWR), incorporate state-of-the-art safety features. "There's a big emphasis on what's called passive cooling these days," says Joyce. Whereas earlier plants rely on electrically powered pumping systems to circulate coolant, passive systems ingeniously take electricity out of the equation – for example, using gravity to flush the reactor with water stored in tanks above it.

Planning for worst-case scenarios, newer reactors beef up their safety with extra cooling systems. "Instead of having one or two systems, as was the case in earlier reactors, in the EPR

## The safest reactor in the world

**Find out how the Economic Simplified Boiling Water Reactor's passive systems can cool its core for up to 72 hours without power**

**Gravity-driven cooling**
Water from these surrounding pools drains into the reactor core to maintain water levels.

**Safety relief valve**
Steam is released from the reactor core and condensed in the suppression pool, relieving pressure inside the core.

**Control rods**
Automatically inserted into the reactor if a coolant pipe leaks or breaks, these absorb neutrons and shut down the reactor.

## NUCLEAR POWER THROUGH HISTORY

**1938**
Otto Hahn, Lise Meitner and Otto Frisch bombard uranium with neutrons, in the process discovering nuclear fission.

**1939**
Hans Bethe works out the basic nuclear processes by which hydrogen is fused into helium inside stars.

**1942**
Enrico Fermi produces the first nuclear fission chain reaction using the Chicago Pile-1 reactor.

**1951**
The Experimental Breeder reactor is the first nuclear reactor to produce electricity, powering four light bulbs.

**1956**
The world's first commercial nuclear fission plant, with an initial capacity of 50MW, opens in Calder Hall, England.

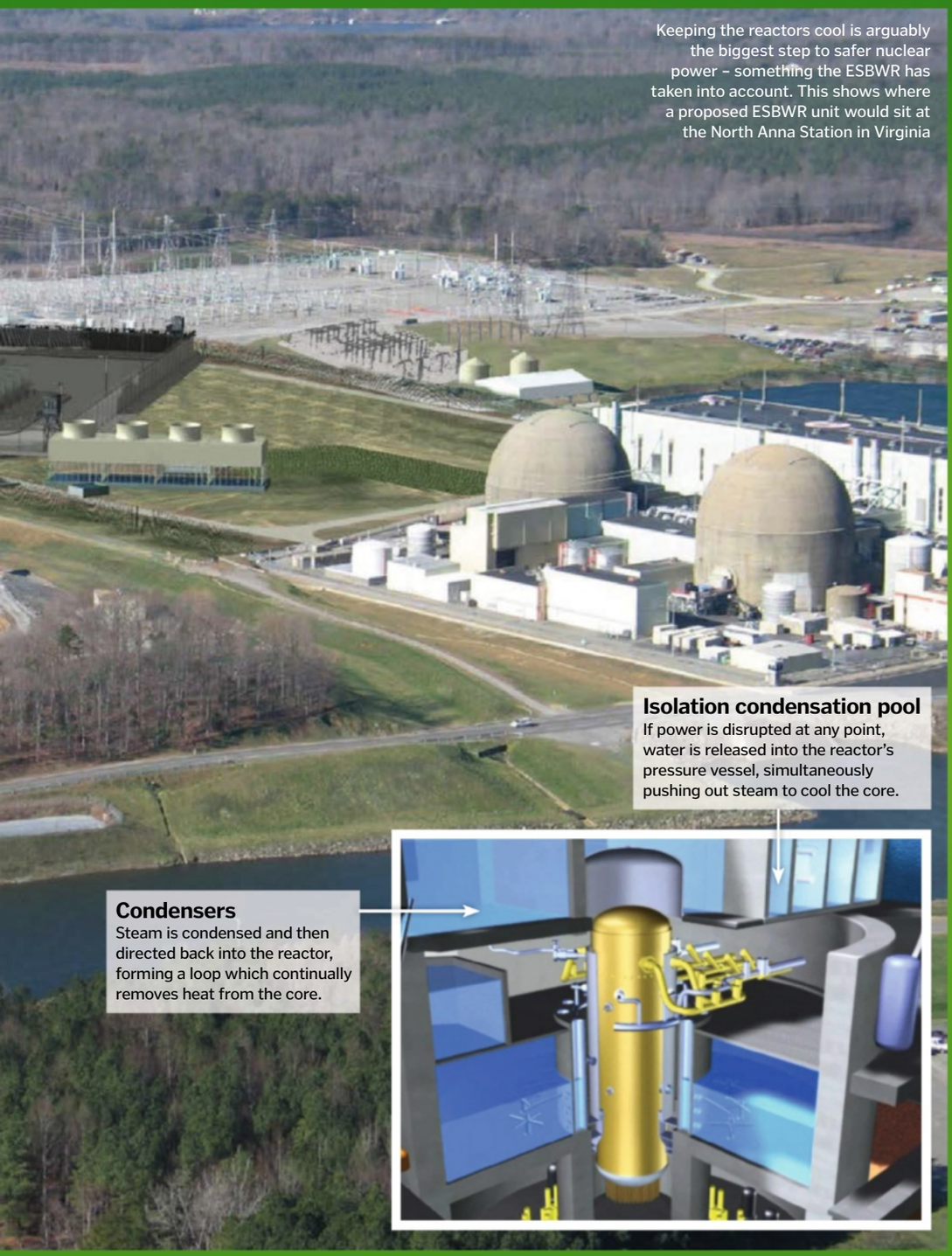
RECORD BREAKERS
BIGGEST USER

# 75%

## FRANCE'S NUCLEAR ELECTRICITY

France generates a larger proportion of its electricity from nuclear power than any other country. It currently has 58 nuclear fission plants in operation and derives 75 per cent of its power from them.

**DID YOU KNOW?** *With 437 plants in operation worldwide, nuclear power currently meets 13 per cent of global electricity needs*



Keeping the reactors cool is arguably the biggest step to safer nuclear power – something the ESBWR has taken into account. This shows where a proposed ESBWR unit would sit at the North Anna Station in Virginia

**Isolation condensation pool**
If power is disrupted at any point, water is released into the reactor's pressure vessel, simultaneously pushing out steam to cool the core.

**Condensers**
Steam is condensed and then directed back into the reactor, forming a loop which continually removes heat from the core.

## Safety matters

Nuclear plant safety boils down to one simple premise: keeping the reactor cool no matter what. Modern reactors centre their research and development processes around these considerations, armed with systems that will pick up the slack even when the usual cooling equipment fails. Older plants such as Fukushima's rely on active cooling systems, with electrically powered pumps circulating water coolant, and sometimes requiring human intervention. The latest systems, however, spring into action autonomously and are designed to work even during a power outage, using gravity, air flow or pressure to do the hard work instead. Rethinking how reactors work also allows a raft of new safety measures. Inside a molten salt reactor, for instance, salt mixed with the fuel expands if the reactor begins to overheat, slowing reactions. As the fuel cools, the salt solidifies, trapping radioactive materials. New fuel sources are also being researched, eg thorium is readily available to mine, but much less radioactive than uranium.

Monazite is a key ore containing thorium, a radioactive fuel that could prove to be both cheaper and safer than uranium

**1958**
Scientists at the Kurchatov Institute in Moscow develop the tokamak, the dominant concept in fusion research.

**1986**
Runaway reactions at the Chernobyl power station cause the worst nuclear accident in history.

**1997**
The Joint European Torus (JET) sets the current record for fusion energy, achieving 16MW of power.

**2005**
Construction of the first European Pressurised Reactor begins in Finland, expected to begin operating after 2014.

**2011**
A severe earthquake and tsunami cause overheating and explosions at the Fukushima plant in Japan.

**2030s**
Construction of the first generation IV fission reactors is due to begin.

"A key focus of critical future research is identifying materials that can deal with heightened temperatures"

there are four independent cooling systems," Joyce tells us. So if one fails, the other three can still cool the reactor effectively.

Fast-forward to 2030 and nuclear power supporters hope that generation IV reactors will be at the helm of a 'nuclear renaissance'. Co-ordinating efforts, the Generation IV International Forum has picked the six most promising designs to focus research on. Tweaking coolants, fuels as well as completely rethinking how reactors work, these six contenders aspire to re-invent nuclear power.

Combined with passive safety systems, new features will make generation IV reactors safer than ever. New coolants such as molten salts allow for lower pressures inside the reactors, minimising the risk of radioactive material ever leaking out. Like the PWR, some designs use the same substance to both cool and moderate the chain reaction.

Essentially this means that in the absence of coolant the reaction is no longer moderated – "the reactor effectively switches itself off", notes Joyce. Other reactors, meanwhile, will use fuel pellets encased in layers of protective coating, which can contain radioactive contamination in the event of an accident.

For nuclear power to take on a bigger share of the world's future energy production, keeping costs down is a must too. One way to boost efficiency is to run reactors at much higher temperatures. A standard PWR, operating at around 300 degrees Celsius (570 degrees Fahrenheit) has an efficiency of 32 per cent, but gen IV reactors will operate at up to 1,000 degrees Celsius (1,832 degrees Fahrenheit). "The aim is to get up to efficiencies of 60 per cent or thereabouts," says Joyce. To make this possible, a key focus of critical future research is identifying materials that can deal with heightened temperatures.

Three of the generation IV designs are labelled as 'fast reactors', conceived to run without moderators. The higher-energy neutrons in a fast reactor can be used to make new fuel by 'recycling' existing waste to recover usable energy. They could also be used to destroy long-lived waste from other reactors and plutonium from dismantled weapons.

As a result of these combined modifications, generation IV reactors will be safer, produce less long-lived waste and squeeze more energy out of their fuel than their predecessors, paving the way for greener and cheaper nuclear power.

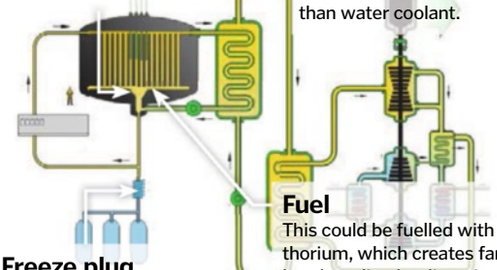
But nuclear fission isn't the only way to tap into the awesome power of the atom. Since the 1940s, scientists worldwide have been attempting to harness nuclear fusion – the same reaction that powers the heart of stars like our very own Sun.

"Nuclear fusion reactions release a very, very large amount of energy," says Dr Duarte Borba

## Reactor rivals

**The race is on for gen IV reactors to prove their worth, but six contenders must first undergo extensive feasibility studies to identify issues and optimise their designs. Researchers hope to build demo plants in the 2020s, moving on to commercial plants in the 2030s. Check out two of the options...**

### Molten Salt Reactor



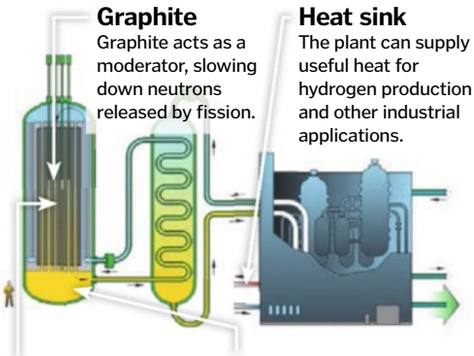
**Liquid fuel**
Liquid fuel flows through the core and expands in case of overheating.

**Coolant**
Molten fluoride salts act as a coolant and can take much higher temperatures than water coolant.

**Fuel**
This could be fuelled with thorium, which creates far less long-lived radioactive waste than uranium.

**Freeze plug**
If power is lost, this plug melts and the fuel is captured and cooled in drainage tanks.

### Very High Temperature Reactor



**Graphite**
Graphite acts as a moderator, slowing down neutrons released by fission.

**Heat sink**
The plant can supply useful heat for hydrogen production and other industrial applications.

**Core**
Temperatures in the reactor core will reach up to 1,000˚C (1,832˚F), maximising efficiency.

**Helium coolant**
Helium gas is chemically inert, with a limited tendency to become radioactive when exposed to neutrons.

A senior advisor for the EFDA, Dr Duarte Borba is looking to step up JET's global collaboration efforts

## What's going on at the INL?

The USA's Idaho National Laboratory (INL) is at the cutting edge of nuclear and energy research. Its scientists are working on the Next Generation Nuclear Plant, which will harness the waste heat produced by its fission reactor, using it for hydrogen production or other industrial processes. But INL's influence stretches well beyond planet Earth. Indeed, the Mars rover Curiosity gets its power from a nuclear 'battery' assembled and tested by INL. The system is fuelled by plutonium-238, which gives off heat as it undergoes radioactive decay. The battery then converts this heat into electricity, supplying the rover with 110 watts of power day and night.

## Which releases the most radiation?

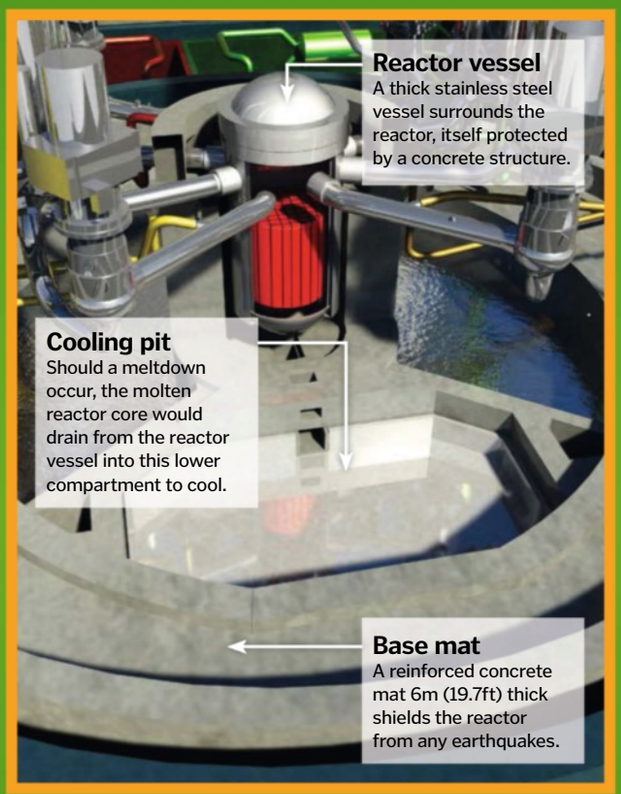
**A** Fission reactor **B** Coal plant **C** Wind farm

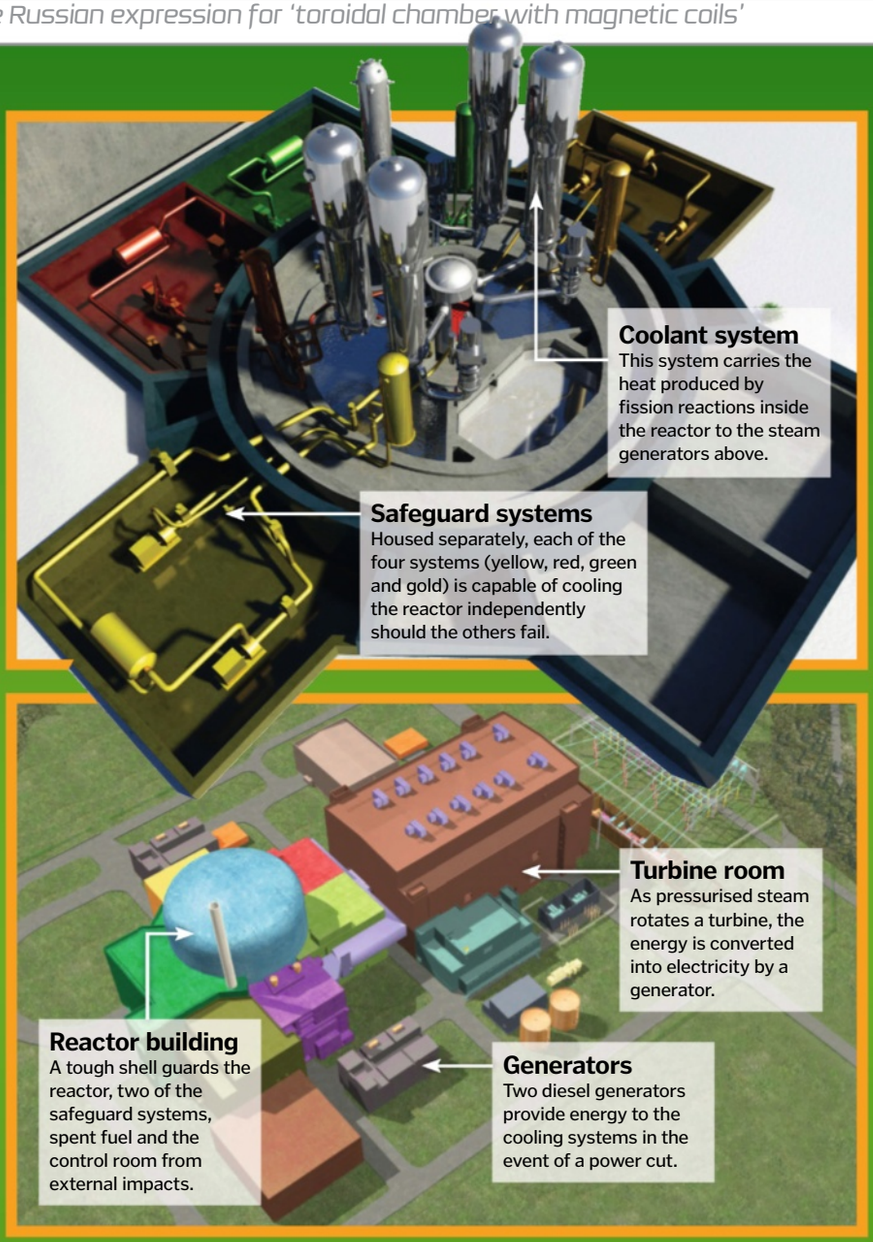
**Answer:**
Coal contains small amounts of radioactive elements uranium and thorium. Burning coal concentrates and releases these elements into the environment – but the overall increase in radiation exposure for nearby residents remains very low.

**DID YOU KNOW?** *The word tokamak is short for the Russian expression for 'toroidal chamber with magnetic coils'*

## Tour of the EPR

Produced by French company Areva, the European Pressurised Reactor (EPR) is a generation III+ pressurised water reactor, currently under construction in France, Finland and two sites in China. With an electrical production capacity of more than 1,650 megawatts, it will be one of the most powerful reactors on Earth. Designed to withstand everything from earthquakes to plane crashes, the EPR will be safer than its predecessors, but also cheaper and more efficient. For each unit of electricity it produces, it will use 15 per cent less uranium than gen II reactors currently in use, and produce ten per cent less long-lived radioactive elements too.




of JET (the Joint European Torus), the world's largest nuclear fusion reactor based in Oxfordshire, UK. The reaction occurs when tritium and deuterium (isotopes of hydrogen) nuclei combine to produce helium nuclei and a neutron. Deuterium occurs naturally in seawater while tritium can be obtained by processing lithium, abundant in our planet's crust. Indeed, "There's an almost unlimited supply of fusion fuels," Borba tells us.

Like fission, fusion energy could supply abundant energy minus the carbon dioxide emissions. The process is inherently safer than nuclear fission, with reactions ceasing within minutes in case of incident and no danger of meltdown. What's more, the small amount of radioactive waste produced has a lifetime of 50-100 years rather than thousands. Fusion's benefits are numerous, but it comes with one considerable drawback: it's incredibly tricky to create the right conditions for fusion to occur. Positively charged deuterium and tritium nuclei repel each other, so to force them together, the fuel needs to be tightly confined and heated to ultra-high temperatures, which Borba notes "is very difficult to achieve".

Inside a fusion reactor, at temperatures of around 150 million degrees Celsius (270 million degrees Fahrenheit), the fuel's atoms break apart to create plasma. The most successful approach to handling this scalding soup of charged particles is to trap it using a powerful magnetic field at the heart of a device called a tokamak. Prevented from touching the sides of the vessel, the fuel can then reach the perfect combination of pressure and temperature conditions for fusion to occur. Using this approach, JET has proven that nuclear fusion can be produced here on Earth, but the challenge now is scaling up the reactor and making it more efficient. Producing magnetic fields and heating the fuel gobbles up a lot of energy, but for the technology to be commercially viable, future reactors will need to generate far more energy than they use up. Currently, JET just about breaks even. "The key technologies are there, it's just a matter of integrating them at a larger scale," says Borba. This is the task assigned to JET's successor, ITER, currently being built in France.

Bigger and more efficient, fusion scientists hope that ITER will produce 500 megawatts of power with an input of just 50 megawatts, paving the way for commercial fusion power. "We're quite optimistic that within 20 or 30 years we'll be in a position to build a fusion power plant," concludes Borba.

"A seasonal flu jab is developed every year, to match the flu that is circulating in the population"

# Inside the flu

## We reveal how this common winter bug stays one step ahead of our immune system

The influenza virus infects a staggering 5 million people worldwide every single year, travelling from person to person in airborne droplets, and causing chills, fever, sore throat, runny nose, headaches and muscle pain.

The flu virus changes gradually by a process known as antigenic drift. As the virus replicates, single nucleotide errors occur in the viral genome, causing minute changes to the proteins that coat the outside of the virus. The immune system recognises these proteins to detect and destroy the infection, so as they change, the ability of the body to recognise the virus decreases, preventing people from building up immunity.

Not only does the virus make continual, subtle changes to its genome and proteins, but it also occasionally develops huge mutations. If a host becomes infected by more than one strain of flu virus, and the two meet inside a single cell, there is a chance that their genomes will mix together, consequently producing new, mutant flu virus. This is a rather rare occurrence, but can form dangerous new strains of flu – the swine flu (H1N1) pandemic of 2009 was found to contain genetic information from four different viruses: one human, one avian and two swine influenza.

This is one of the reasons that a universal vaccine against all types of flu is such a challenge. Currently, a seasonal flu jab is developed every year, to match the flu that is circulating in the population. Each subsequent year, the virus has usually changed sufficiently that the vaccine is no longer effective.

However new research suggests that some cells of the immune system can recognise proteins from the core of the virus. These are essential to viral function, and mutate far more slowly, so developing a vaccine against these important proteins could help T-cells to develop long-term immunity to the bug.

The flu virus mutates each year so it's hard for the body to build up immunity

## Get to know your ABCs...

### Influenza A

The natural hosts of influenza A are wild water birds. Transfer to domestic poultry exposes humans to the virus and can result in cross-species infection. The H1N1 Spanish flu of 1918 and the H5N1 bird flu of 2004 were influenza A.

### Influenza B

Influenza B prefers a human host and is less common. It mutates slowly, enabling most to build up immunity, but it doesn't last for ever. It rarely infects other species, preventing the creation of the new, mutant strains that cause pandemics.

### Influenza C

This produces only mild disease, and most adults have been infected at some point in their life. It infects humans and pigs, but is far less common than influenza A and B. It can cause local epidemics, but does not lead to pandemic flu.

## The virus in focus

**Take a closer look at the anatomy that makes up a single flu virion**

# KEY DATES
## FLU OUTBREAKS

**1918**
Spanish flu, H1N1, infected 500 million people worldwide, and killed an estimated 50 million. It spread to the Arctic.

**1957**
Asian flu, H2N2, spread throughout China then across the globe, killing over a million people.

**1968**
Hong Kong flu, H3N2, shared genetic info with the virus that caused the Asian flu pandemic of 1957.

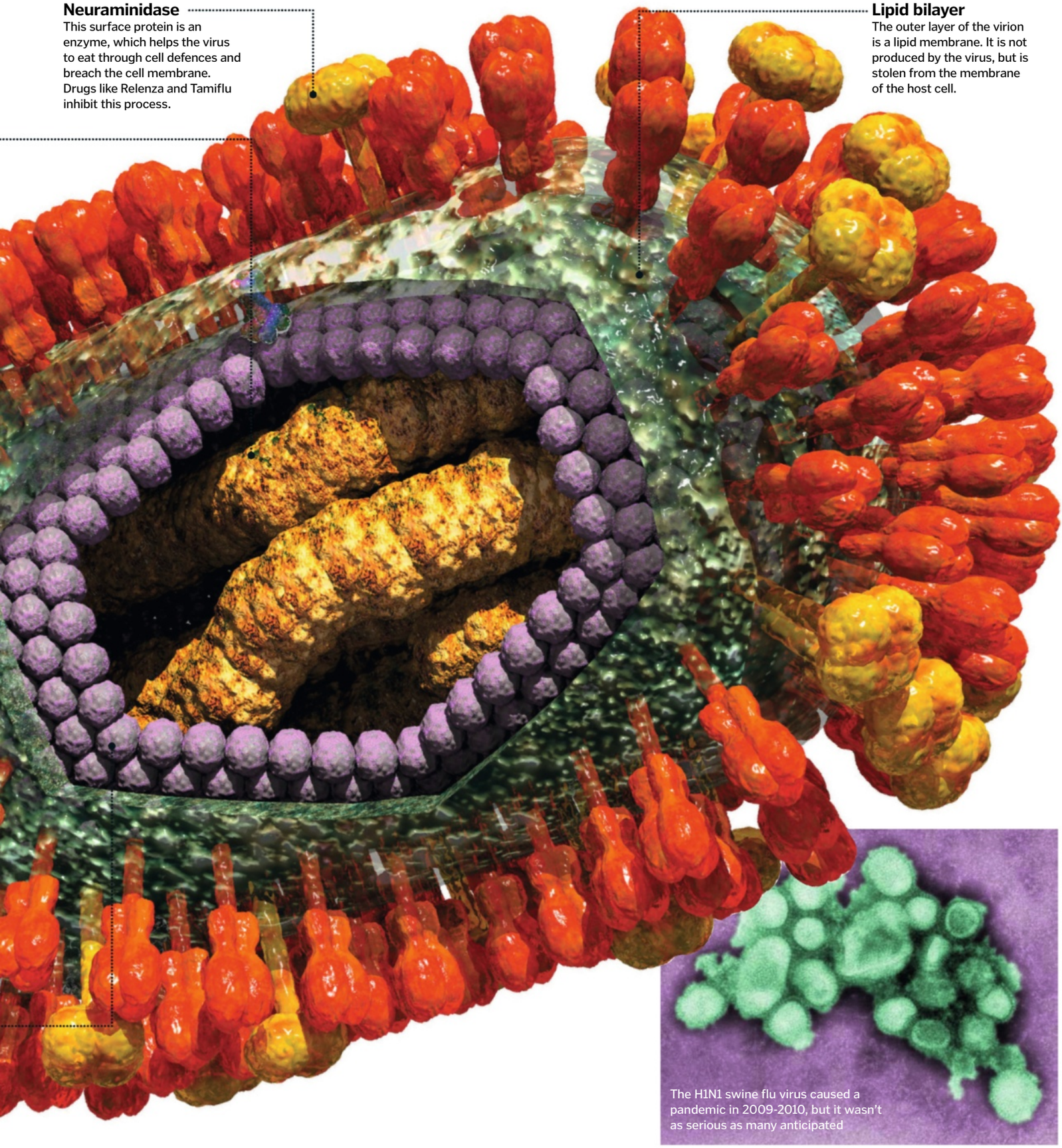
**1977**
Russian flu, H1N1, affected mostly children as most adults had been exposed to a similar virus before.

**2009**
The pandemic flu of 2009 was a new strain of the H1N1 virus. It killed 18,000 people worldwide.

**DID YOU KNOW?** *Influenza A viruses are named after the two major proteins that cover their outer membrane*

**Neuraminidase**
This surface protein is an enzyme, which helps the virus to eat through cell defences and breach the cell membrane. Drugs like Relenza and Tamiflu inhibit this process.

**Lipid bilayer**
The outer layer of the virion is a lipid membrane. It is not produced by the virus, but is stolen from the membrane of the host cell.





The H1N1 swine flu virus caused a pandemic in 2009-2010, but it wasn't as serious as many anticipated

"The interaction of the magnetic field with the winding currents generates a usable force within the motor"

# Electric motors

## How do these widespread devices transform electrical energy into motion?

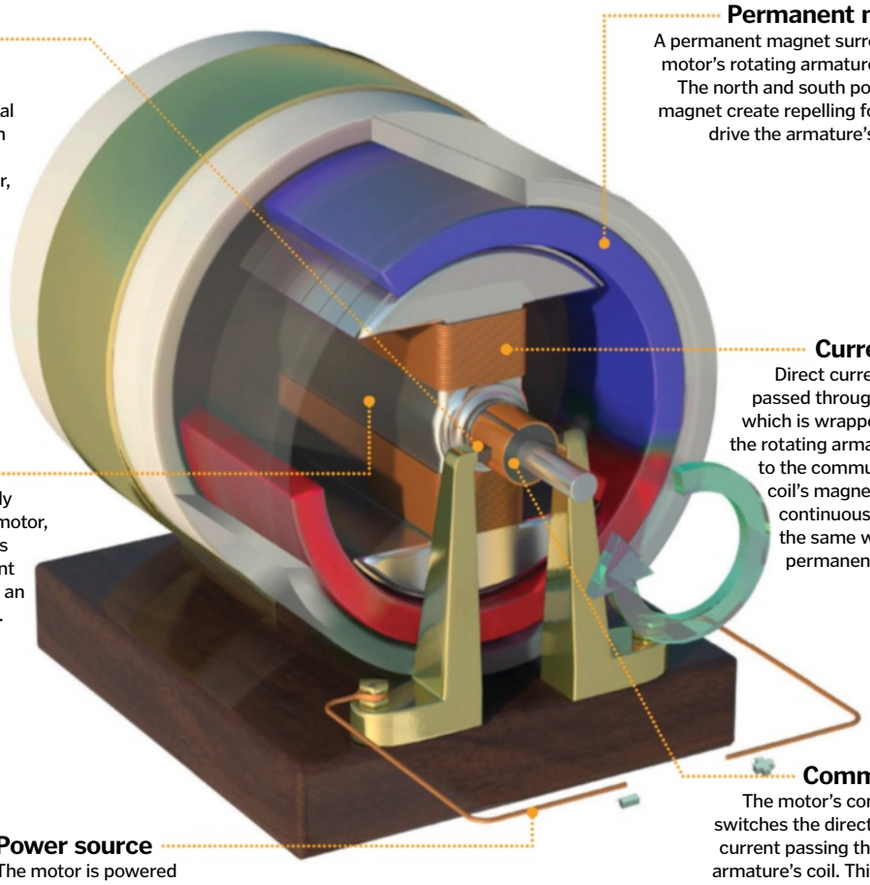
Electric motors are devices that, in simple terms, convert electricity – as delivered from one or more power sources – into mechanical energy through electromagnetism. This ability to generate workable mechanical power grants the electric motor broad appeal, driving all sorts of machines from cars to the hands of clocks.

The mechanical energy generated by electric motors is a result of the torque from the interaction of conductors carrying current and a magnetic field. The exact positioning of the conductors and the magnetic field differ depending on the type of motor – of which there are many (AC, DC, induction, etc) – but the principle remains the same: the interaction of the magnetic field with the winding currents generates a usable force within the motor.

As can be seen in the illustration, a basic electric motor consists of six key parts. The wire winding surrounding the motor's central armature is supplied with current, forcing unpaired electrons to align in the metal, merging their force and creating a coherent magnetic field. With the armature and windings now acting as an electromagnet, the surrounding permanent magnet – with its intrinsic north and south poles – forces the armature to spin at speed, with that kinetic energy harnessed for mechanical work.

## DC motor cutaway

**We highlight the core components of a direct-current electric motor**



**Brush**
The brushes (often made of carbon) maintain an electrical connection between the energy source and the commutator, while allowing the latter to rotate.

**Permanent magnet**
A permanent magnet surrounds the motor's rotating armature and coil. The north and south poles of this magnet create repelling forces that drive the armature's rotation.

**Current coil**
Direct current (DC) is passed through the coil, which is wrapped around the rotating armature. Due to the commutator, the coil's magnetic field is continuously pushed the same way by the permanent magnet.

**Armature**
The active, physically moving part of the motor, the armature rotates within the permanent magnet to generate an electromotive force.

**Commutator**
The motor's commutator switches the direction of the current passing through the armature's coil. This flips the coil's electromagnetic field every half-turn to ensure a constant spin direction.

**Power source**
The motor is powered by an energy source – typically a large battery array or generator.

## Top five electric motor uses

**1 Cars**
From the movement of simple components such as windscreen wipers, right through to the propulsion of all-electric vehicles like the Toyota Prius, electric motors are used to some extent in every automobile on Earth.

**2 Appliances**
It's amazing how many electric motors can be found in your very own home, with everything from food processors and electric whisks to vacuum cleaners relying on them.

**3 Toys**
Electric motors are now so cheap to make that they can even be incorporated into children's toys. Remote-control cars, animatronic models and action figures are all brought to life with them.

**4 Gadgets**
Electric toothbrushes, ceiling fans and automated window-cleaning robots are but a few of the increasingly diverse range of gadgets that incorporate electric motors.

**5 Watches**
The vast majority of quartz wristwatches, plus many analogue clocks, are powered by electric stepper motors, which regulate the movement of the hands.

"When the nerve is compressed it causes numbness, tingling and pins and needles"

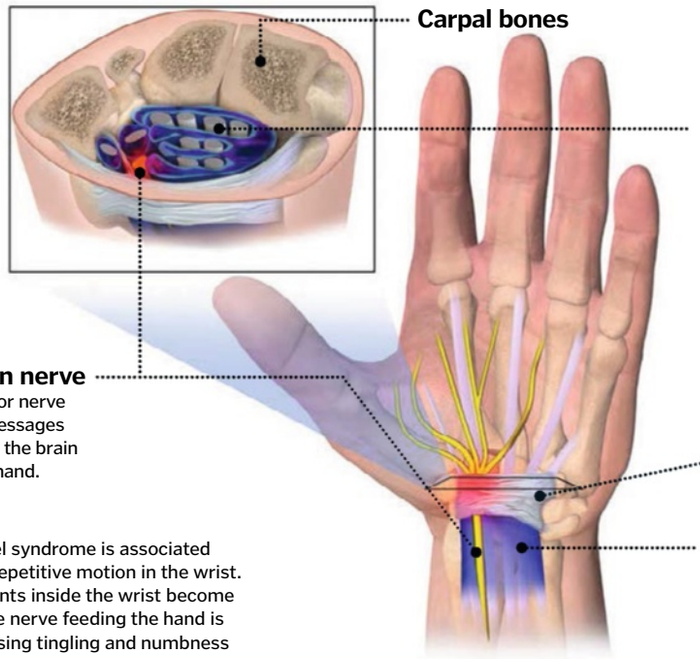
# Carpal tunnel syndrome

What is it about the anatomy of the wrist that leads to tingling and numbness?

The tendons and nerves of the human wrist travel through a narrow tunnel. The carpal bones form an arch, covered on the underside of the wrist by the tough carpal ligament.

This stiff tunnel has no room to expand, so if the ligaments become inflamed they can compress the median nerve. The median nerve carries sensory information from the thumb, index finger, middle finger and half of the ring finger, so when the nerve is compressed it causes numbness, tingling and pins and needles in a specific pattern across the hand.

The pain is often worse at night because the wrists are held flexed during sleep, compressing the nerve even further. Treatment can be as simple as immobilising the joint at night-time. In more serious cases though, steroids may be used to reduce inflammation, and as a last resort, the carpal ligament can also be cut to release the pressure.




Carpal tunnel syndrome is associated with heavy repetitive motion in the wrist. If the ligaments inside the wrist become inflamed, the nerve feeding the hand is crushed causing tingling and numbness

# The biology of warts

What causes these growths on the skin and can anything get rid of them?

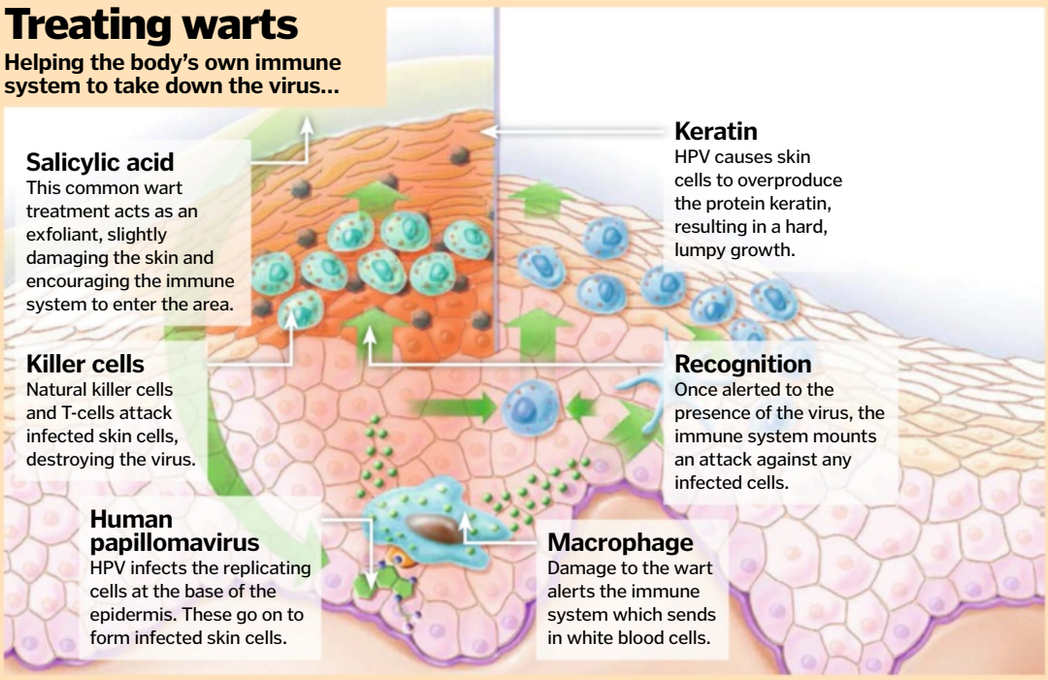
The human papillomavirus (HPV) infects the replicating cells at the base of the skin. This leads to overproduction of the tough protein, keratin. As the keratin builds up, it causes a rough growth to form.

Virus particles are shed as the cells of the skin flake off and can survive for very long periods of time without a host, making transmission from person to person very easy.

HPV is very good at hiding from the immune system and can persist in the skin for years. Alerting the immune system to the presence of the virus can help to treat infection. Traditional treatments, including salicylic acid and freezing via cryotherapy, aim to damage the wart so that the immune system will be called in to assist with repairs. It then becomes alerted to the presence of the virus and is able to mount an attack.

## Treating warts

**Helping the body's own immune system to take down the virus...**

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RECORD BREAKERS
DATED DENTISTRY

# 6,500

## OLDEST FILLING EVER DISCOVERED

A cracked tooth from around 6,500 years ago found in Slovenia appears to have been repaired using beeswax. Researchers are now conducting trials to find out how effective this would have been at reducing pain of a cavity.

**DID YOU KNOW?** *Some people have a genetic variation that means they do not produce underarm odour at all*

# How 72-hour deodorants work

Discover the chemistry that helps us combat body odour for up to days at a time

Deodorants prevent the odour associated with sweating, either by masking it, or by killing the bacteria responsible. To make the effects last longer, the active ingredients are sometimes encased within microcapsules. As the capsules take up water from sweat they burst, releasing deodorising chemicals. By including capsules of a variety of sizes, each requiring a different amount of water to burst, the duration can be extended.

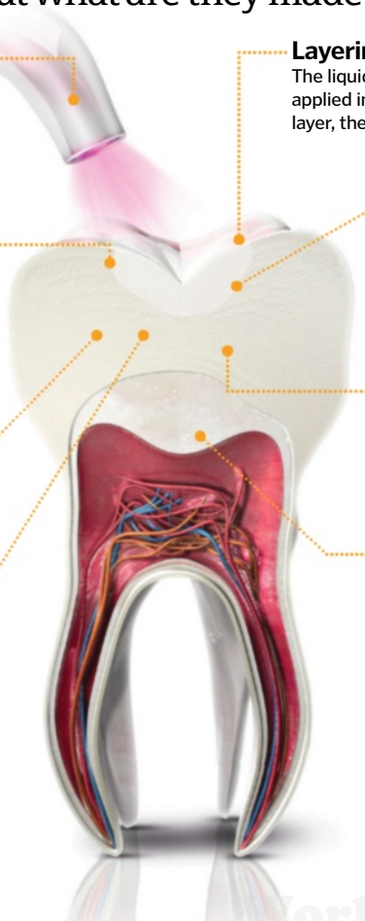
Most deodorants also contain antiperspirants, which prevent sweating from occurring at all. These are usually aluminium-based compounds. The aluminium is taken up by the cells that line the openings of the ducts that carry sweat to the surface of the skin.

As the aluminium moves into the cells, it takes water with it, causing the cells to swell and closing off the ducts. Depending on the type of aluminium compound used, the effect will last for different lengths of time.

Antiperspirants cause cells to swell and the ducts to close up, preventing sweating altogether

# Modern fillings

Composite resins are replacing traditional metal fillings, but what are they made of?



**Curing**
A light is used to trigger a chemical reaction within the resin, causing the material to harden.

**Layering**
The liquid composite resin is applied in layers. After each layer, the composite is cured.

**Composite resin**
Dental composites are made from a resin matrix containing inorganic materials, like silica, for durability.

**Finishing touches**
A piece of carbon paper is used to test whether the bite lines up properly, and the filling is smoothed down accordingly.

**Acid**
A controlled amount of acid is applied to the drilled tooth to generate micro-holes for the filling to bind to.

**Primer**
A priming agent is brushed onto the prepared tooth surface to enable the filling to adhere properly.

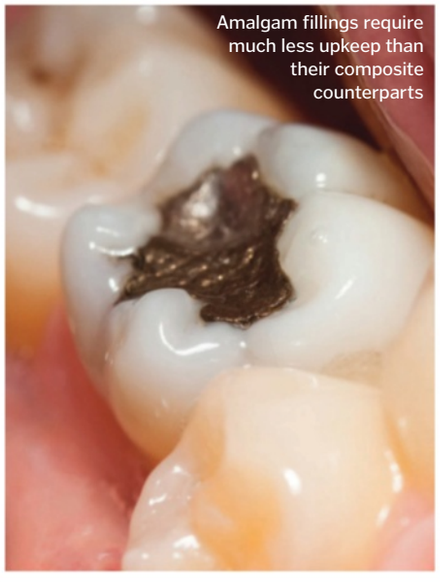
**Base**
In deeper fillings, a cement base made from glass ionomer or zinc phosphate is added to insulate the nerve from temperature changes.

**Decay**
The decayed portion of the tooth is removed using a high-speed drill; this generates a solid platform for the filling to stick to.

## Is metal bad?

Traditional silver-coloured 'amalgam' fillings are made from mixed metals, and are often comprised of around 50 per cent mercury. Historical evidence suggests that this type of filling has been in use since around 650 CE, and despite the advances in composite materials, the amalgam filling is still in use to this day.

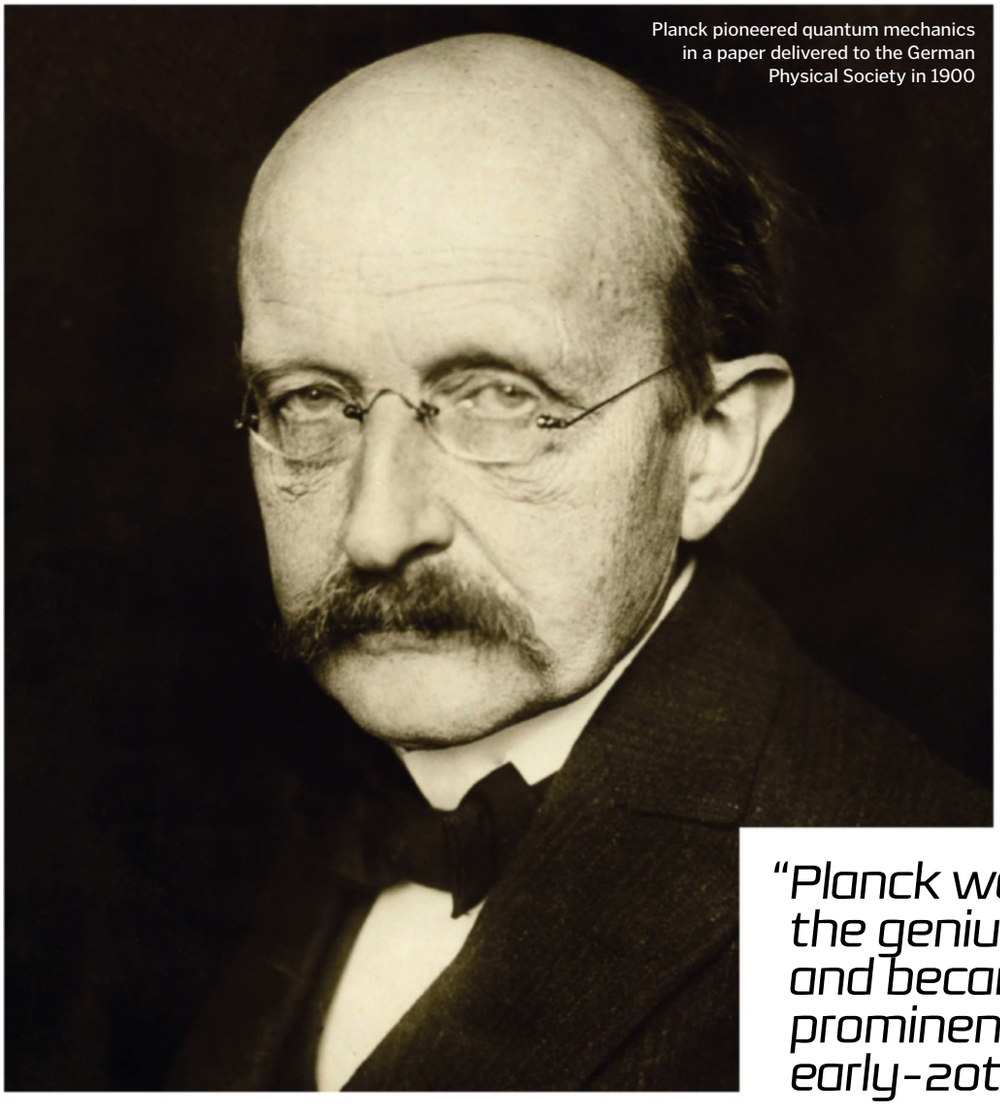
There has been much controversy over the biological safety of amalgam fillings though, and concerns have been raised regarding mercury released into the body, as well as into the environment. However, as it stands, no causal link between health complaints and amalgam fillings has been proven. In fact, they still provide some advantages over composite fillings, and require significantly less repair and replacement.



Amalgam fillings require much less upkeep than their composite counterparts

# Max Planck

## The father of quantum physics, Max Planck was one of the foremost theoretical physicists of the 20th century whose work ushered in a new era of science



Planck pioneered quantum mechanics in a paper delivered to the German Physical Society in 1900

If you had to choose two scientists of the 20th century whose work most affected its course and discoveries, the first would no doubt be Albert Einstein, but the second could be Max Planck. Einstein's theory of relativity revolutionised how humans perceived and understood space and time, while theoretical physicist Planck's development of quantum theory, with his probing work into atomic and subatomic processes, radically transformed how physics was understood and directly led to many other discoveries and inventions that still have a widespread impact today.

Easily Max Planck's most important discovery was his realisation that the energy of electromagnetic waves is contained within indivisible 'quanta' packets that have to be radiated or absorbed as a whole. This is commonly referred to as Planck's black-body radiation law and, as can be seen in detail within 'The big idea' boxout explanation, it is both simple and incredibly enlightening. However, when Planck delivered his research for the first time in 1900, it was anything but, with its suggestions seemingly conflicting directly with all of classical physics. Indeed, even Planck himself did not fully believe his law was correct, only reluctantly deducing it through a cold sense of logic.

His remarkable discovery was not recognised either by the existing scientific establishment, with recognition only coming after Einstein himself adopted the idea of quanta and later introduced the follow-on theory of wave-

*"Planck was suddenly seen as the genius he had always been and became one of the most prominent scientists of the early-20th century"*

## A life's work

**Events that sculpted the life of one of the 20th century's leading physicists**

**1858**
He is born Max Karl Ernst Ludwig Planck in Kiel, the Duchy of Holstein in the German Confederation.

**1864**
Experiences war first hand as Prussian and Austrian troops march through Kiel during the Second Schleswig War.

**1878**
After graduating early from the Maximilians school in Munich, he travels to Berlin to study, passing his exams with flying colours.

**1880**
Planck presents his habilitation thesis entitled Equilibrium States Of Isotropic Bodies At Different Temperatures and becomes a private lecturer in Munich.

**1885**
Planck is appointed associate professor of theoretical physics at the University of Kiel.

## In their footsteps...

### Max von Laue

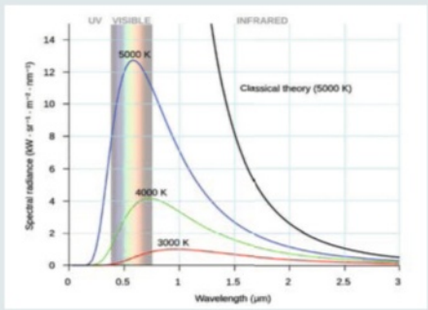
Max Theodor Felix von Laue was a student under Max Planck and later Nobel prize winner, receiving the prestigious award for his discovery of the diffraction of X-rays by crystals. For four decades he was one of the foremost scientists in Germany and spent much of his later years re-organising Germany's broken scientific institutions post-WWII.

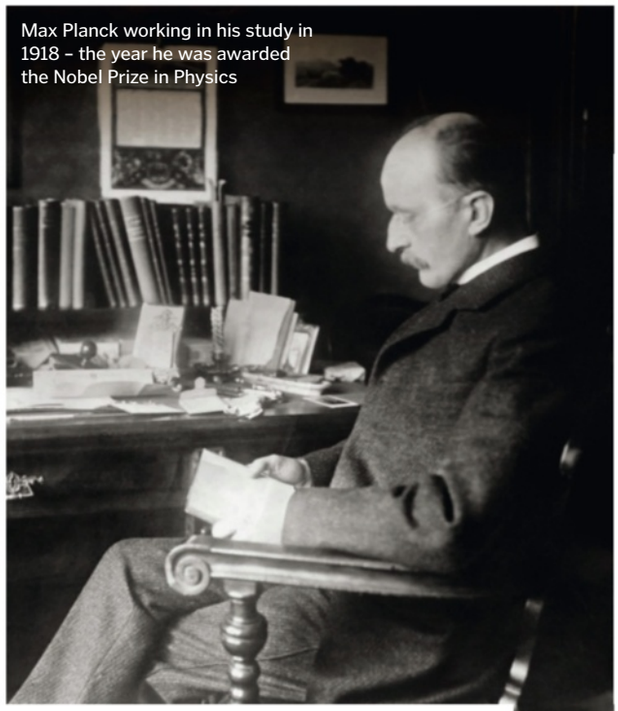
### Gustav Ludwig Hertz

A German experimental physicist and another Nobel prize winner, Gustav Ludwig Hertz was one of Max Planck's earliest students, later going on to win the prestigious physics accolade for his experiments into inelastic electron collisions in gases. Indeed, Hertz had one of the longest careers of any of Planck's students, dying aged 88 in 1975.

## The big idea

Planck's law is a mathematical relationship formula created in 1900 by Max Planck to explain the spectral-energy distribution of radiation emitted by an idealised black-body phenomenon. Key was Planck's assumption that sources of radiation are atoms in a state of oscillation and that the vibrational energy of each atomic oscillator may have a series of discrete values but never any fixed value between. This discovery, along with the ground-breaking work of Albert Einstein, led directly to the end of the age of classical physics and ushered in the era of quantum theory.



Max Planck working in his study in 1918 – the year he was awarded the Nobel Prize in Physics

particle duality in 1909. Following this, Planck was suddenly seen as the genius he had always been and became one of the most prominent scientists of the early-20th century, attending among numerous others, the celebrated Solvay Conference in Brussels in 1911.

Indeed, famously it was due to Planck's input at the conference that Henri Poincaré – the most famous mathematical physicist of the 19th century – could provide mathematical proof that Planck's radiation law required the existence of quanta and, as a knock-on effect, converted many of Europe's top scientists to this new quantum theory.

And so quantum theory was born, and over the following decades it was built upon and expanded by some of the most well-known scientists of all time. From Einstein to Niels Bohr, Erwin Schrödinger to Paul Dirac, Planck – as the father of quantum theory – had given them an entirely new way to look at and understand the processes of the physical world – one which they would go on to explore in much more detail through the nuclear age.

## Top 5 facts: Max Planck

**1 Name change**
Max Planck was born Karl Ernst Ludwig Marx Planck, but by the age of ten he began signing his name as simply 'Max'. He would continue to use this for the rest of his life, largely abandoning his other forenames.

**2 Special theory**
Max Planck was one of the first physicists to understand the importance of Albert Einstein's theory of relativity, using his influence to promote the young Einstein's seminal work and expand upon it.

**3 Manifesto**
Max Planck was one of the German scientists who signed the Manifesto of the Ninety-Three, a 1914 proclamation that supported the German military actions in the early period of World War I. He later regretted signing the declaration.

**4 Highest authority**
After World War I Planck was considered the highest scientific authority in the whole of Germany and consequently held positions at Berlin University, the Prussian Academy of Sciences and the German Physical Society.

**5 Resistant**
During WWII Planck was one of very few scientists to remain in Nazi-led Germany, advocating a 'persevere and continue working' motto.

**1892**
After years of lecturing, Planck is made full professor at the prestigious University of Berlin.

**1900**
Planck outlines for the first time his famous black-body radiation law to the German Physical Society.

**1918**
Max Planck receives the Nobel Prize in Physics for his groundbreaking work on quantum theory.

**1928**
The German Physical Society creates the Max Planck medal and enshrines it as the highest accolade that they can bestow.

**1947**
Max dies at the age of 89 in his last home situated in Göttingen, Germany.

A single AH-64D Apache costs over £18mn ($30mn) to build

# AMAZING HELICOPTERS

## Meet some of the world's most cutting-edge helicopters and find out why they are so well adapted to a range of roles

Since the first modern-era helicopters took flight a little over 100 years ago, this form of aircraft has been overshadowed by the high-speed planes of the jet age. For decades, speed and altitude ruled the roost both in the military – think of the insane Mach 3+ speeds attainable by the SR-71 Blackbird – but also in commerce, with cargo, weaponry and, most importantly, people transported by aeroplanes rather than their slower, more ungainly cousins. However, today, in 2013, things are changing...

Now, more than ever before, in specialist high-level applications, helicopters are being favoured over their faster winged counterparts. A combination of advanced technological upgrades, new base designs and a global landscape that is increasingly in a state of flux means that the versatility offered by the one-time black sheep of the family is now being warmly embraced. Helicopter manufacturers worldwide are doubling down on their existing technology and future research in a hope to win the inevitable next big contract.

Take the mainstay of the US Air Force, the intimidating AH-64 Apache, as an example. This gunship has diced with death for almost 30 years, seeing active combat service in numerous wars. However, as of October 2013, far from the Apache being steered towards retirement, the fifth iteration has just been approved, boasting a series of bleeding-edge technological systems and improvements.

Nicknamed the AH-64E Guardian, this helicopter now features improved digital connectivity, a joint tactical radio system, a

## 5 TOP FACTS
### CHOPPER TRIVIA

**Aerial screw**
1 Arguably the first helicopter as we understand them today was devised by famous Italian polymath Leonardo da Vinci in the form of his 'aerial screw' sketched back in the 1480s.

**Name origins**
2 The word 'helicopter' was coined by French inventor Gustave de Ponton d'Amécourt in 1861. In the 20th century, this was built on with the slang 'chopper'.

**First flight**
3 However, the first manned flight in a helicopter didn't come until two French brothers, Jacques and Louis Breguet, flew in their Gyroplane No 1 in 1907.

**Mass production**
4 Mass production of helicopters began in 1942 with the introduction of Igor Sikorsky's R-4. The R-4 had a maximum speed of 121 kilometres (75 miles) per hour.

**Turbine age**
5 The age of the turbine-powered helicopter began in 1951 with the introduction of the Kaman K-225. A twin-turbine model followed three years later.

**DID YOU KNOW?** *The longest distance travelled without landing in a helicopter is 3,561km (2,213mi)*

The 8,382kW (11,240hp) delivered by the Mil Mi-26's engines makes it the most powerful helicopter ever made

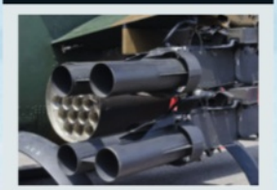
### The statistics...

**Eurocopter X3**

**Crew:** 2
**Length:** Classified
**Height:** Classified
**Weight:** Classified
**Powerplant:** 2 x Rolls-Royce Turbomeca RTM 322
**Rotors:** 1 x 5-blade main rotor / 2 x 5-blade tractor rotors
**Max speed:** 472km/h (293mph)
**Max range:** Classified
**Max altitude:** 3,810m (12,500ft)
**Armaments:** N/A

*"These upgrades vastly improve the lethality and versatility of the Apache"*

### The statistics...



**Boeing AH-64D Apache**

**Crew:** 2
**Length:** 17.7m (58.2ft)
**Height:** 4.05m (13.3ft)
**Weight:** 7,270kg (16,027lb)
**Powerplant:** GE T700-GE-701
**Rotors:** 1 x 4-blade main rotor; 1 x 4-blade tail rotor
**Max speed:** 276km/h (171mph)
**Max range:** 485km (301mi)
**Max altitude:** 6,400m (21,000ft)
**Armaments:** 1 x 30mm (1.2in) M230 Chain Gun; AIM-92 Stinger; AGM-114 Hellfire; Hydra 70mm (2.8in) rockets

brand-new set of T700-GE-701D engines, upgraded transmission system with split-torque face gears to accommodate for even more power, new composite rotor blades, updated radar system and, most impressively of all, unmanned aerial vehicle (UAV) capabilities. It's impressive stuff.

Combined, these upgrades vastly improve the lethality and versatility of the Apache, with the helicopter's cruise speed, rate of climb, payload threshold and target engagement capabilities vastly enhanced. ▶

## Fastest-ever chopper

On 7 June 2013, the Eurocopter X3 hybrid set a new world record for high-speed flight in a helicopter, racking up two runs where it exceeded 472 kilometres (293 miles) per hour. By clocking in these two runs, it officially beat the previous record holder, the Sikorsky X2. The X3's record breaking run was achieved at an altitude of 3,050 metres (10,000 feet) during a 40-minute flight over the south of France. The helicopter itself was powered by a pair of RTM 322 turboshaft engines, which generated the necessary energy to rotate the five-blade main rotor and twin propellers. Speaking on the run, pilot Hervé Jammayrac stated that: "It's no exaggeration to say that the X3 is clearly in its element at high speeds."

"These sort of capabilities demonstrate why helicopters are currently being earmarked as the vehicle of the future"

Where the Apache is pushing the boundaries of combat capabilities in helicopters, the awesome Eurocopter X3 demonstrator is transforming people's perceptions of the speeds they can attain. Flying in June 2013, the X3 racked up 472 kilometres (293 miles) per hour and, in doing so, not only smashed the existing world record for highest speed in a helicopter, but demonstrated how compound helicopters may be the future of the field.

Indeed, the reason why the X3 can post a top speed over 160 kilometres (100 miles) per hour greater than that of the Apache is due to its addition of short-span wings with tractor propellers – two of the key features that make it what is known as a compound helicopter.

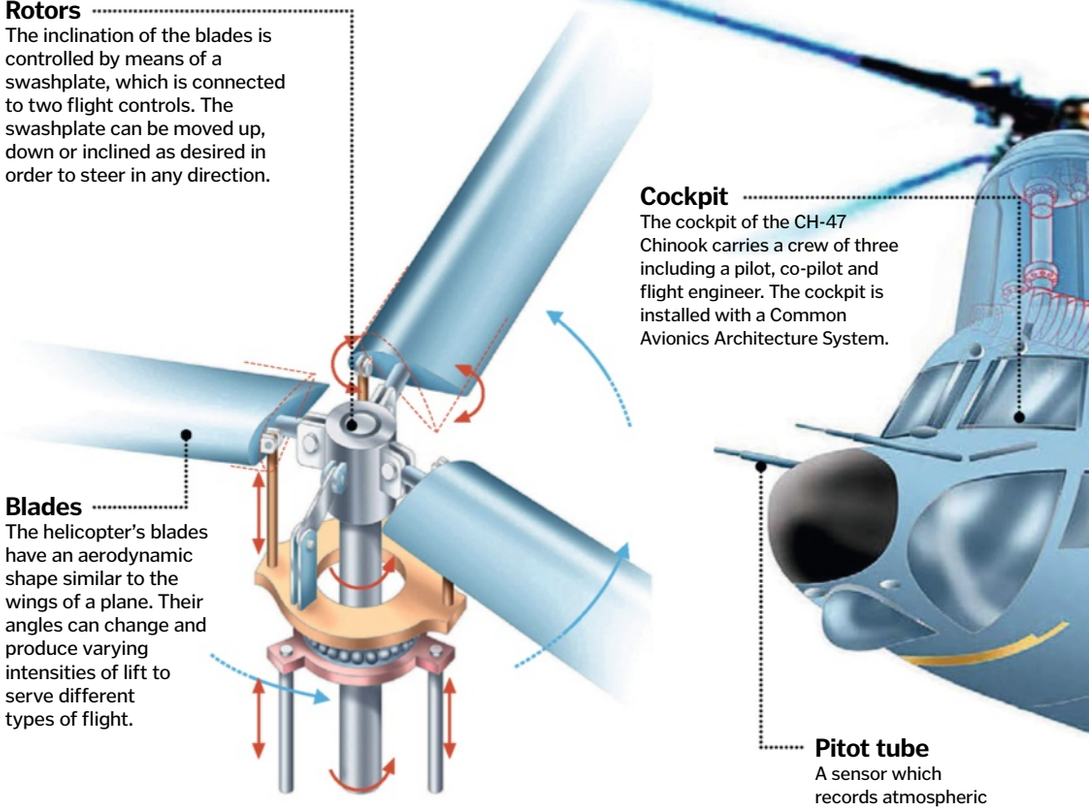
The X3 is installed with a large main rotor just like traditional helicopters, but also two forward-facing smaller propellers. Combined with the short-span wings, these three sets of rotors provide excellent levels of vertical lift as well as added quantities of forward thrust, combining the benefits of a rotorcraft with those of a propeller-driven aeroplane.

These sort of capabilities demonstrate why helicopters are currently being earmarked as the aerial vehicle of the future, with the X3 capable of landing in the tightest of spots – critical when faced with the ever-reduced space of the 21st-century urban landscape – while then also cruising internationally between countries at a pace akin to a jet airliner. As a demonstrator, the X3 is most likely not going to enter mass production itself, however the technology that it boasts is set to be incorporated into many a future helicopter.

One futuristic helicopter currently in use, where technology close to the X3's could be adopted, is the impressive Kaman K-1200 K-MAX. The K-MAX isn't slow, delivering a top speed of 185 kilometres (115 miles) per hour, but if the X3's speed could be combined with the K-1200's advanced UAV capabilities, you would have one heck of a vehicle. This is because, unlike any other helicopter listed here, the K-MAX can be operated entirely remotely and unmanned, with a secure wireless data link

## Rotors and flight

**How do dual-rotor helicopters' rotors work in tandem?**



**Rotors**
The inclination of the blades is controlled by means of a swashplate, which is connected to two flight controls. The swashplate can be moved up, down or inclined as desired in order to steer in any direction.

**Cockpit**
The cockpit of the CH-47 Chinook carries a crew of three including a pilot, co-pilot and flight engineer. The cockpit is installed with a Common Avionics Architecture System.

**Blades**
The helicopter's blades have an aerodynamic shape similar to the wings of a plane. Their angles can change and produce varying intensities of lift to serve different types of flight.

**Pitot tube**
A sensor which records atmospheric pressure and registers elevation and horizontal/vertical velocities.

**Hover**
Each of the rotor blades has the same degree of inclination. This produces a lift that corresponds to the weight of the machine, which remains suspended in the air without moving backwards or forwards.

**Forward flight**
With the swashplate pointed forward, the inclination of the blades increases. As such, the lift is in turn increased in the tail rotor meaning the entire vehicle tilts forward and advances.

**Vertical flight**
As the swashplate moves upward and the angle of the blades is increased, more lift is generated, exceeding the weight of the helicopter, so it begins to climb. To descend, the swashplate moves downward and diminishes the angle, thereby reducing lift.

**Reverse flight**
With the swashplate aimed backwards, the inclination of the blades increases the lift of the front rotor. The helicopter thus moves backwards.

**Tail rotor**
In most helicopters this helps keep the vehicle stable and can be oriented in any direction.

## Helicopter evolution

**Check out some of the best, worst and just plain weird choppers ever designed**

### 1480s
**Aerial screw**
Leonardo da Vinci sketches out what he refers to as an 'aerial screw' in his notebook. It is never built however.

### 1907
**Cornu helicopter**
French bicycle-maker Paul Cornu builds an experimental helicopter. It makes a number of short hops off the ground.

### 1924


**Oehmichen No 2**
Étienne Oehmichen sets the first recognised helicopter world record by flying his design 360m (1,181ft).

### 1942
**Sikorsky R-4**
Igor Sikorsky builds the first ever mass-produced helicopter, the R-4, with 131 units made over a two-year period.

# 97,000

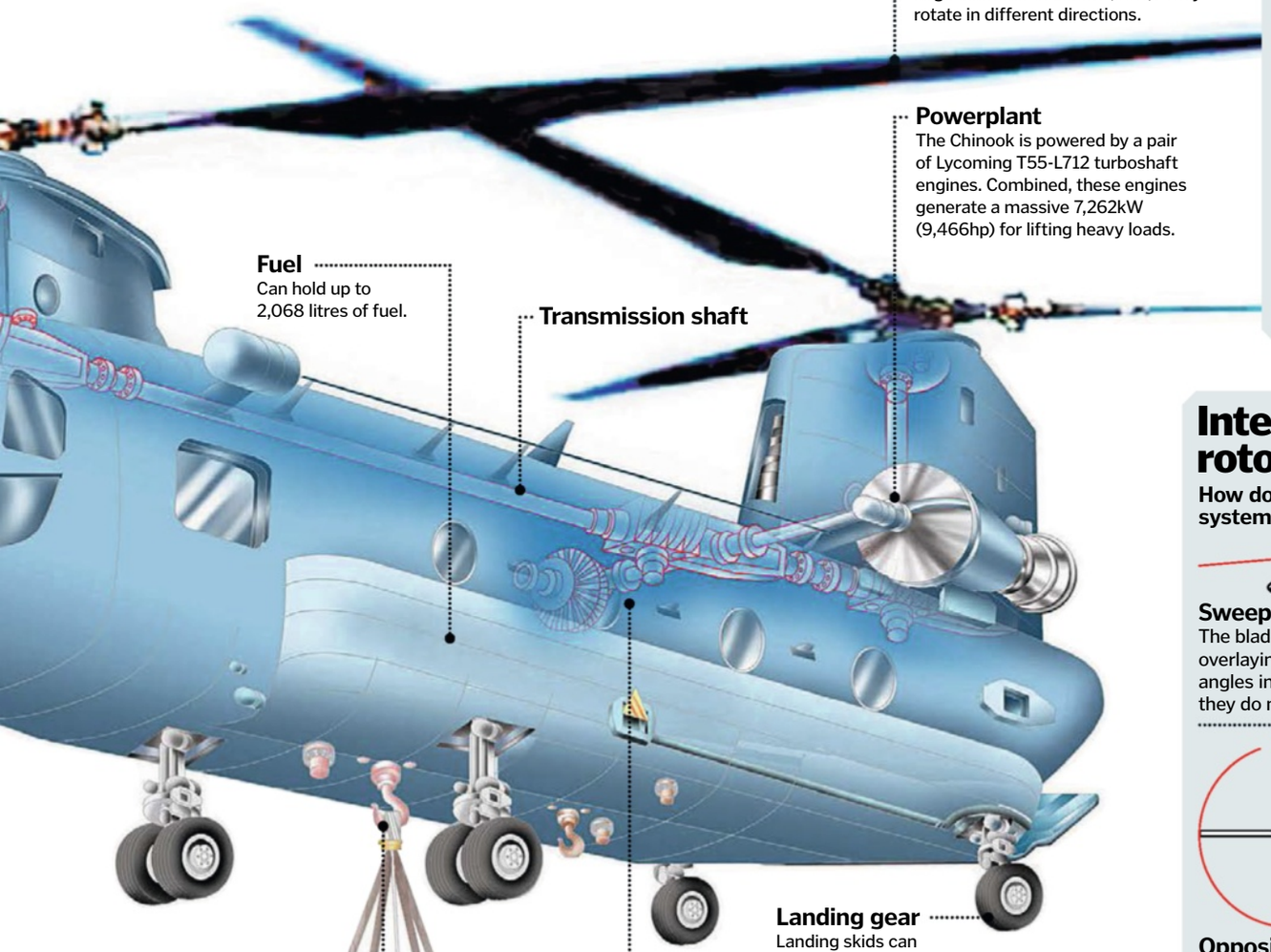
## HEAVIEST HELICOPTER EVER

The heaviest helicopter ever built, the Russian Mil V-12, had a max weight of 97,000kg (213,850lb). The helicopter was also the second biggest ever, measuring in at a whopping 37m (121.4ft).

**DID YOU KNOW?** *The highest altitude a helicopter has reached is recorded at 12,442m (40,820ft)*

# Chinook CH-47 engineering

**Check out the key components of this heavy-duty helicopter**



### Main rotors
The intermeshing system on the Chinook consists of two three-bladed main rotors, each boasting a large diameter of 18.3m (60ft). They rotate in different directions.

### Powerplant
The Chinook is powered by a pair of Lycoming T55-L712 turboshaft engines. Combined, these engines generate a massive 7,262kW (9,466hp) for lifting heavy loads.

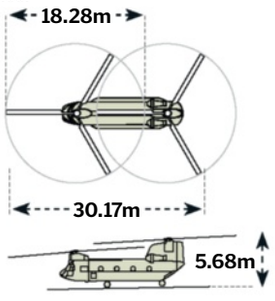
### Fuel
Can hold up to 2,068 litres of fuel.

### Transmission shaft

### Landing gear
Landing skids can replace wheels to land on snow or ice.

### Cargo hook
Can carry up to ten tons of weaponry, ammunition, combat equipment, etc.

### Storage
The Chinook's speciality, the helicopter can carry up to 55 soldiers at any one time. In terms of cargo, the Chinook can take a load weighing up to 12,700kg (28,000lb).




## The statistics...

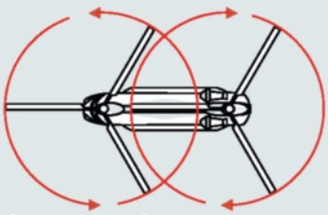
### Boeing CH-47F Chinook

**Crew:** 3
**Length:** 30.1m (98.7ft)
**Height:** 5.7 m (18.7ft)
**Weight:** 10,185kg (23,400lb)
**Powerplant:** GE T700-GE-701
**Rotors:** 2 x Lycoming T55-L712
**Max speed:** 264km/h (164mph)
**Max range:** 741km (450mi)
**Max altitude:** 5,640m (18,500ft)
**Armaments:** 3 x M240/FN MAG machine guns

# Intermeshing rotors

**How do these novel rotor systems work?**

### Sweep
The blades sweep through overlaying areas, but at different angles in a staggered fashion, so they do not come into contact.



### Opposite spin
As such, helicopters like the CH-47 Chinook do not require a tail rotor because the main rotors rotate in opposite directions. The action of one cancels out the other.

### Turning
The rudder pedals alter the inclination of the plane of rotation of the rotors in such a way that the plane of rotation of one tilts to the left and the other to the right, or vice versa, to change direction.

## 1959
### Sikorsky S-61
The S-61 betrays Sikorsky's heritage as a helicopter maker as it is marred by high mortality rate accidents.

## 1966
### Hughes YOH-6A
The YOH-6A sets a new world record for distance travelled without landing.

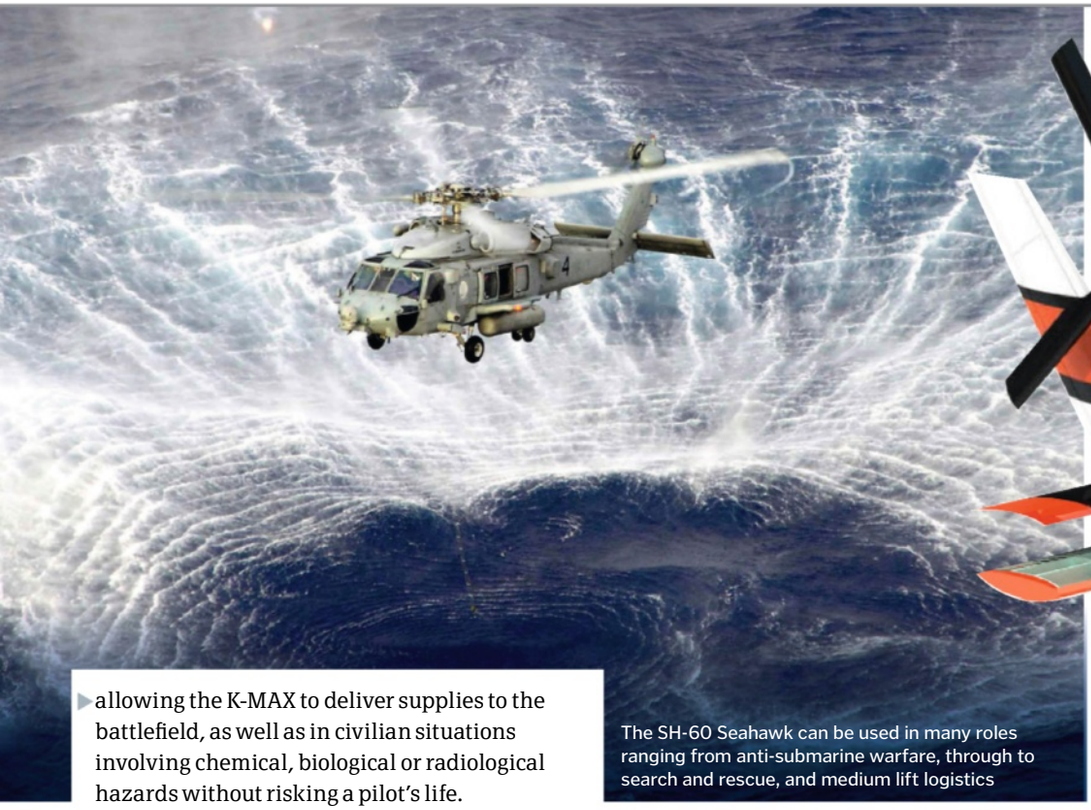
## 1972
### Aerospatiale Lama
French aviator Jean Boulet pilots an Aerospatiale Lama to a height of 12,442m (40,820ft), setting a still unbroken record.

## 1986
### Westland Lynx
English pilot John Egginton sets the first official helicopter speed record of 400km/h (249mph) in a Westland Lynx.

## 2003
### Eurocopter Tiger
The Eurocopter Tiger becomes the first all-composite helicopter to be developed in Europe, incorporating a glass cockpit.

## 2011
### E-copter
French-Australian inventor Pascal Chrétien builds the world's first manned, fully electric helicopter.

"Thanks to its excellent design, the Seahawk is one of the most widely deployable helicopters in the world"



The SH-60 Seahawk can be used in many roles ranging from anti-submarine warfare, through to search and rescue, and medium lift logistics

allowing the K-MAX to deliver supplies to the battlefield, as well as in civilian situations involving chemical, biological or radiological hazards without risking a pilot's life.

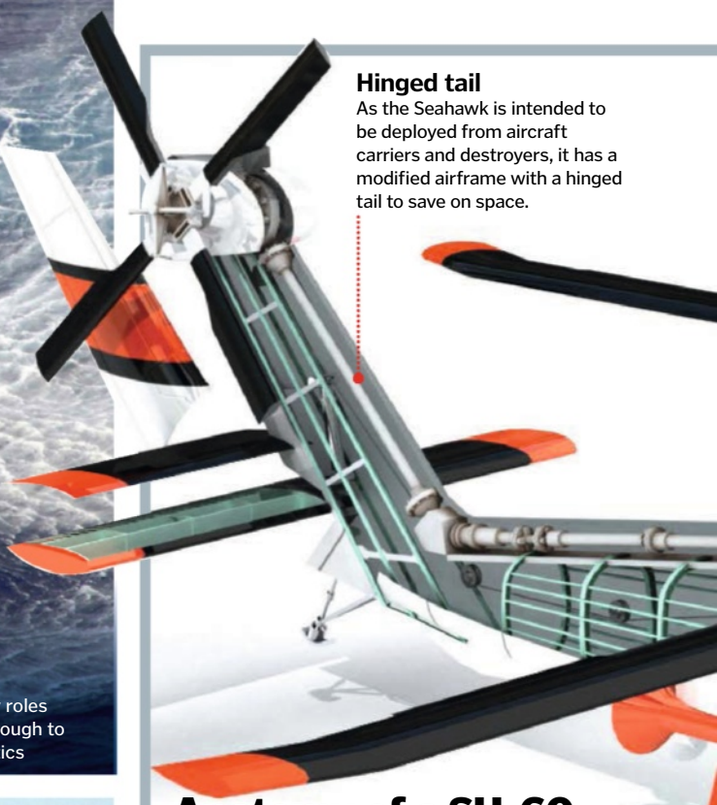
The maturity of the K-MAX's UAV tech is indeed startling. As of February this year, a pair of K-MAXes working in Afghanistan had delivered cargo over 600 unmanned missions. In total, these two helicopters have racked up over 750 unmanned flight hours and, when you consider the potential applications going forward – such as fire-fighting, civilian transportation and disaster relief – it's easy to see how the flexibility and automation it delivers is simply not deliverable by a manned aircraft or unmanned drone. For the K-MAX to live up to this multi-use ideal however, the helicopter is going to have to learn some lessons from some of the most versatile and resistant of all helicopters around, eg the Sikorsky SH-60 Seahawk and the Mil Mi-26.

For many the Seahawk is considered the most versatile of all helicopters and for good reason. It has seen a series of upgrades over the past 20 years seeing it outfitted with the necessary tech for anti-submarine warfare, anti-surface warfare, naval special warfare insertion, civilian and combat search and rescue, vertical replenishment and medical evacuation operations. In addition, thanks to its excellent design, the Seahawk is one of the most widely deployable helicopters in the world, capable of being launched from frigates, destroyers, cruisers, fast combat support ships, amphibious assault ships and aircraft carriers when used in its native ocean habitat.

The Chinook CH-47F is a carrying colossus, capable of lifting personnel carriers and jet aircraft with ease

Where the Seahawk excels in role versatility, the Mi-26 excels in hardiness and heavy-duty lifting capabilities. The largest and most powerful helicopter ever to have gone into production, the raw power generated by this flying fortress of a chopper is epic, with its twin Lotarev D-136 turboshaft engines pushing out a colossal 8,382 kilowatts (11,240 horsepower) each, and allowing the Mi-26 a maximum takeoff weight of 56,000 kilograms (123,459 pounds); that's nearly six times that of the SH-60 Seahawk and almost 20 times that of the K-MAX. This amazing lifting ability – which can also extend to transporting 90 troops at a time – has seen the helicopter's manufacturer Rostvertol recently be commissioned to produce another 22 top-spec Mi-26Ts for the Russian Air Force, while also winning a contract to upgrade the existing fleet.

However, of all the helicopters currently being granted a new lease of life in this re-birth of the field, it is the king of logistical operations – the Boeing CH-47 Chinook – which is arguably seeing most success. Despite being intended to



**Hinged tail**
As the Seahawk is intended to be deployed from aircraft carriers and destroyers, it has a modified airframe with a hinged tail to save on space.

## Anatomy of a SH-60 Seahawk helicopter

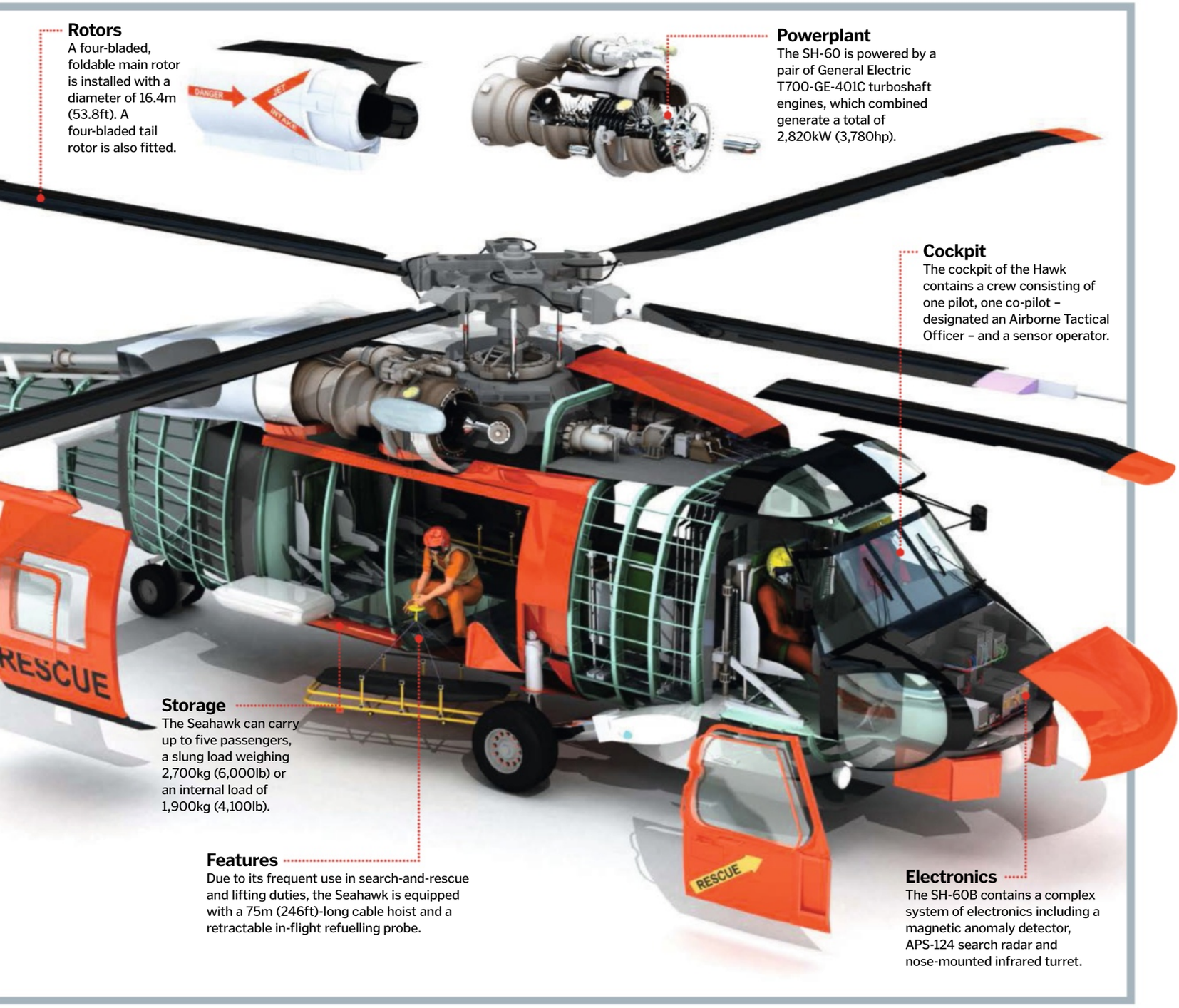
**A look at the core features of this versatile chopper built for a life at sea**

### The statistics...

**Sikorsky SH-60 Seahawk**

- **Crew:** 3-4
- **Length:** 19.8m (64.9ft)
- **Height:** 3.8m (12.3ft)
- **Weight:** 9,450kg (21,000lb)
- **Powerplant:** 2 x General Electric T700-GE-401C
- **Rotors:** 1 x 4-blade main rotor; 1 x 4-blade tail rotor
- **Max speed:** 270km/h (168mph)
- **Max range:** 600km (373mi)
- **Max altitude:** 3,580m (12,000ft)
- **Armaments:** N/A

**DID YOU KNOW?** *The world's first manned electric-powered helicopter was flown in 2011*




be replaced by the advanced tilt-rotor V-22 Osprey, so far over 1,179 Chinooks have been built. Thanks to a series of technological improvements such as the integration of a Common Avionics Architecture System (CAAS), a next-generation global positioning system (GPS) and terrain following and avoidance radars, as of 2013, Chinooks worldwide – there are 20 nations that operate them – are thriving. They combine modest military capabilities with ruggedness, heavy-duty lifting capabilities, role versatility, high-speed travel (read: 264 kilometres/164 miles per hour), stability thanks to its tandem rotors (see the boxout on page 65 for more information) and solid fuel economy.

Indeed, in many ways, the CH-47 Chinook is the best all-round helicopter on the planet, combining almost every quality aeronautical engineers look for when designing an aircraft. It also demonstrates that, while speed will always remain important in all forms of airborne vehicle, it will probably not be the most critical quality for future aircraft, with lifting power, efficiency, adaptability all more crucial to 21st-century travel. It also shows that despite being overshadowed by fixed-wing aircraft for decades, helicopters are continuing to up their game, bringing innovation and hi-tech engineering to the aviation world.

"The harder a tyre is pressed into the ground, the more grip it enjoys"

# The physics of cornering

## It may look precarious, but leaning into a corner on a motorbike actually offers more grip

As bikes only have two wheels, they don't simply turn through corners in the way a four-wheeled vehicle does. Instead, they effectively carve through the turns, leaning from side to side and using the full outer radius of their tyres to maintain contact with the road.

When a biker leans into a corner at pace, a number of extra forces come into play to help the bike maintain grip. Firstly, camber thrust is created, which means a point on the outer surface of a leaned, rotating tyre that would normally follow an elliptical path when in contact with the ground is forced to follow a straighter path. Meanwhile, as the bike tracks round a bend, the cornering causes a centrifugal force to press the tyres into the road, ensuring grip is maintained.

The harder a tyre is pressed into the ground, the more grip the tyre enjoys, and thanks to centrifugal force and camber thrust acting against the tyres here, more weight is essentially put on the vehicle when leaning over. A bike therefore technically has more grip through a corner than it does when vertical in a straight line, despite the same amount of tyre surface area being in contact with the road.


# Emergency brakes explained

## Discover the tech that can prevent a rear-end smash – even if a driver is caught unawares

The Bosch predictive emergency braking system constantly scans the road ahead for hazards

A predictive emergency braking system automatically helps bring a car to a halt when it becomes apparent the driver hasn't reacted to an obstacle in front.

The technology employs a radar working alongside a car's electronic stability program (ESP), with the radar at the front of the car emitting waves that bounce off vehicles ahead. When the distance to the car in front dramatically shortens, the waves bounce back quicker. When this happens at speeds over 29 kilometres (18 miles) per hour, the system warns the driver visually and via audio.

At the same time, the ESP prepares for emergency braking, ensuring full stopping power is granted valuable hundredths-of-a-second sooner. If the driver fails to react to the warning signals, the system automatically initiates braking itself, sending a message to the engine control unit that then activates the brake pads. If the driver then presses the brake pedal, the system provides extra stopping power while constantly calculating the pressure needed to avoid contact with the obstacle. If the driver isn't providing sufficient force of the brake discs on the brake pads, the system tops up the estimated deficit.

At speeds below 29 kilometres (18 miles) per hour, the emergency braking system again notifies the driver of the hazard, meanwhile preparing the braking system for an emergency stop. If the driver fails to react in time, the ESP initiates full automatic braking within seconds to halt the vehicle as fast as possible.

**Which of these animals makes its own diving bell?**

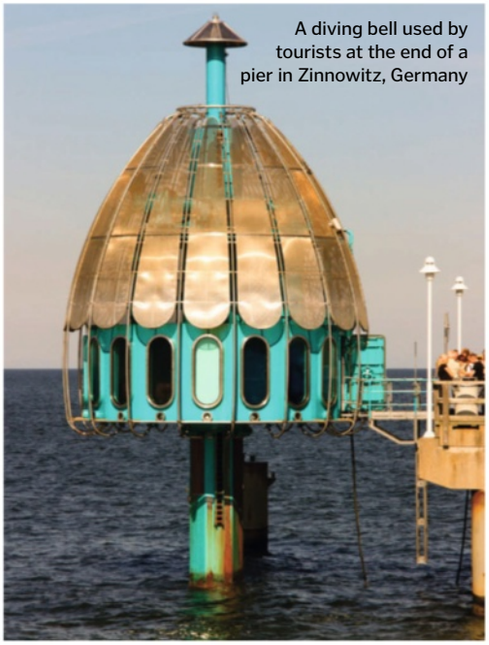
**A Sea snake B Water spider C Chimpanzee**

**Answer:**
The water spider (Argyroneta aquatica), also known as the diving bell spider, constructs a silk diving bell and fills it with air trapped in the fine hairs on its legs. It's the only spider that's known to spend its whole life underwater.

**DID YOU KNOW?** *Dry bells are used in submarine rescue missions; they form an airtight seal with the hatch to let crew escape*

# Diving bells

## The pressurised compartment of these amazing sea vehicles allows divers to exit underwater



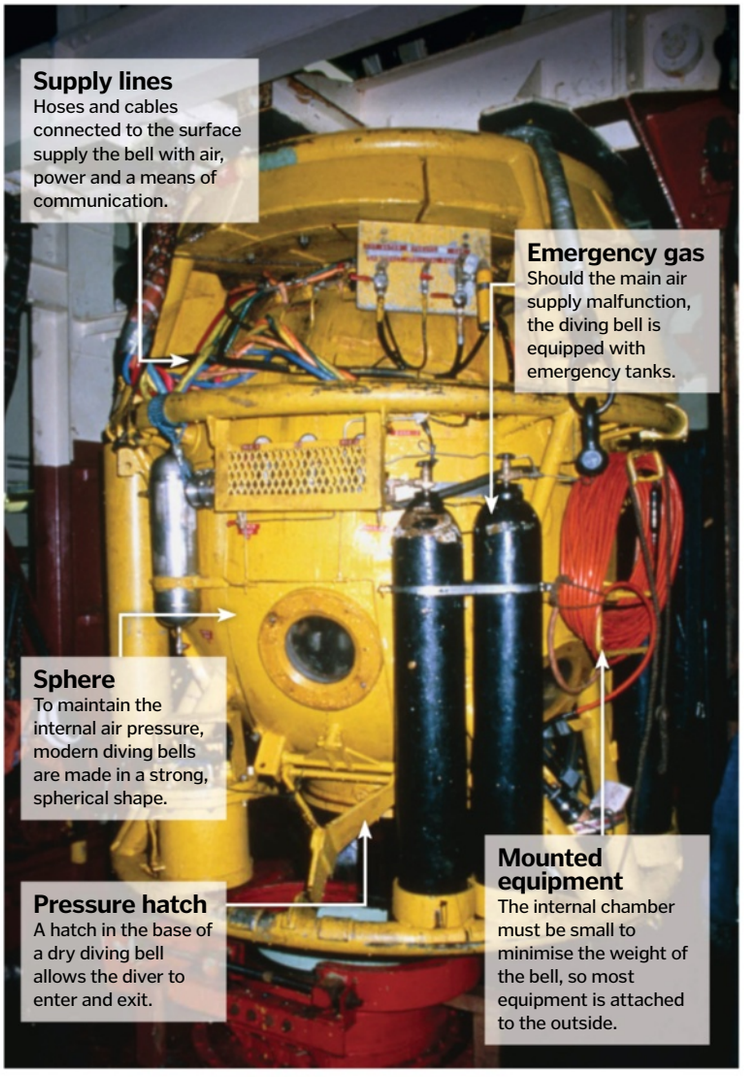
A diving bell used by tourists at the end of a pier in Zinnowitz, Germany

The diving bell is one of the earliest diving chambers, which dates back to the fourth century BCE. The traditional wet bell consists of a chamber, open at the bottom, which is attached by a hose to an air supply on the surface.

It functions in a similar way to a moon pool, with the air inside the diving bell pressurised by the weight of the seawater above. The pressure of the air is equal to the pressure of the water, preventing water from entering the diving bell, and allowing divers to enter and exit through the bottom.

As the bell descends and the pressure increases, the air inside is compressed, so a continual supply of fresh air is pumped in from the surface. A ballast helps to counteract the buoyancy of the air and keeps the bell steady, preventing any air from leaking out.

A modern dry bell is also pressurised, but is closed at the bottom by a hatch. The hatch opens inwards and is kept closed by the air pressure inside, allowing divers to come and go. Alongside the air supply, cables to the surface also provide power for lighting, tools and communication equipment.



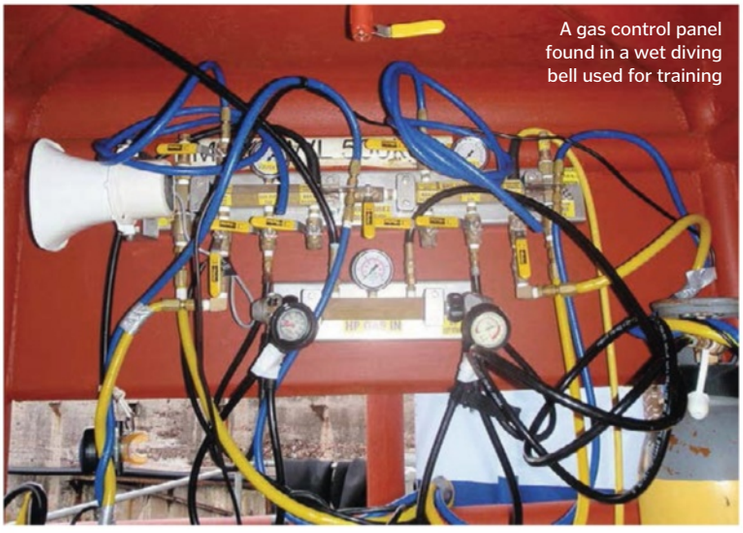
**Supply lines**
Hoses and cables connected to the surface supply the bell with air, power and a means of communication.

**Emergency gas**
Should the main air supply malfunction, the diving bell is equipped with emergency tanks.

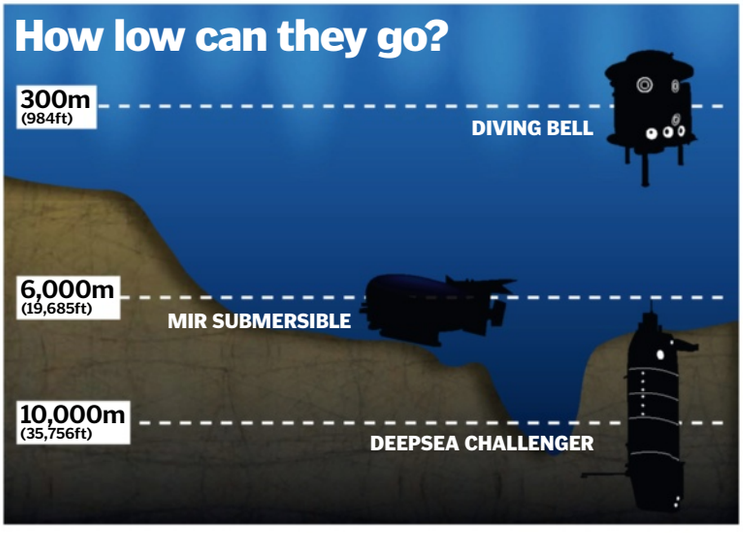
**Sphere**
To maintain the internal air pressure, modern diving bells are made in a strong, spherical shape.

**Pressure hatch**
A hatch in the base of a dry diving bell allows the diver to enter and exit.

**Mounted equipment**
The internal chamber must be small to minimise the weight of the bell, so most equipment is attached to the outside.



A gas control panel found in a wet diving bell used for training



"The Leaf can be charged from flat to 80 per cent capacity in 30 minutes"

# Eco cars evolved

## See how modern electric cars are stepping up a gear...

Battery electric vehicles (BEVs) have been around for longer than you would expect. The first examples of cars powered by electricity were in the early-19th century, and were commonplace until the internal combustion engine took over. The first examples were very basic and couldn't be recharged. However, the modern-day BEV has evolved a lot since back then and has overcome technical difficulties that made them previously unsuitable for our roads.

Charging time has always been a big issue among the motoring community where BEVs are concerned. Previous examples of BEVs have usually had charging times of around 8-12 hours from UK sockets. This time has been dramatically reduced by new technologies explored by manufacturers like Nissan with the Leaf. Indeed, the Leaf can be charged from flat to 80 per cent capacity in around 30 minutes from a special charging port.

Nissan has also applied some very creative theories to improve the overall efficiency of the Leaf. For example, the front LED lights are designed to deflect airflow away from the wing mirrors. This reduces aerodynamic drag acting on the car, so that less power is needed to propel the vehicle forwards.

Whereas existing BEVs have had issues with large battery packs taking up cabin space, the Nissan engineers have developed theirs to free up space. This is achieved by having the thin 24-kilowatt-hour battery pack underneath the floor. This also has the added benefits of improving handling and structural rigidity.

Modern BEVs are becoming increasingly technologically advanced, with the Leaf having a dedicated app for smartphones. This can be used to start a charging session, activate climate control and to check estimated driving range information without leaving your sofa.

## Inside the new Nissan Leaf

**Take a look at the cutting-edge technology powering the 2013 Nissan Leaf electric car**


**Battery cells**
A total of 192 cells that are similar to your mobile phone batteries give a range of up to 200km (124mi).




**Battery pack**
The battery pack and controller unit weighs 300kg (660lb), so is positioned as low as possible to improve handling.

**Regenerative brakes**
The electric motor can absorb the energy usually lost as heat in braking and put it back into the batteries.

## Eco car timeline

**We track the rise of electric-powered vehicles from their conception to today**

**1830s**
**First electric carriage**
Scotsman Robert Anderson builds and drives a basic (non-rechargeable) electric carriage.

**1897**
**Electric cabs**
The Pope Manufacturing Company becomes the first large-scale electric car maker, filling the NYC streets with electric taxis.

**1899**
**Speed record**
The French-built 'La Jamais Contente' becomes the first electric car to reach 100km/h (62mph).

**1920s**
**Internal combustion engine**
By the end of the Twenties, the electric car is surpassed by combustion engines.

# 328.6

## ELECTRIC CAR LAND SPEED RECORD

In June 2013, former science minister Lord Drayson set the electric land speed record for an electric car at 328.604 kilometres (204.185 miles) per hour at Elvington Airfield in Yorkshire, UK.

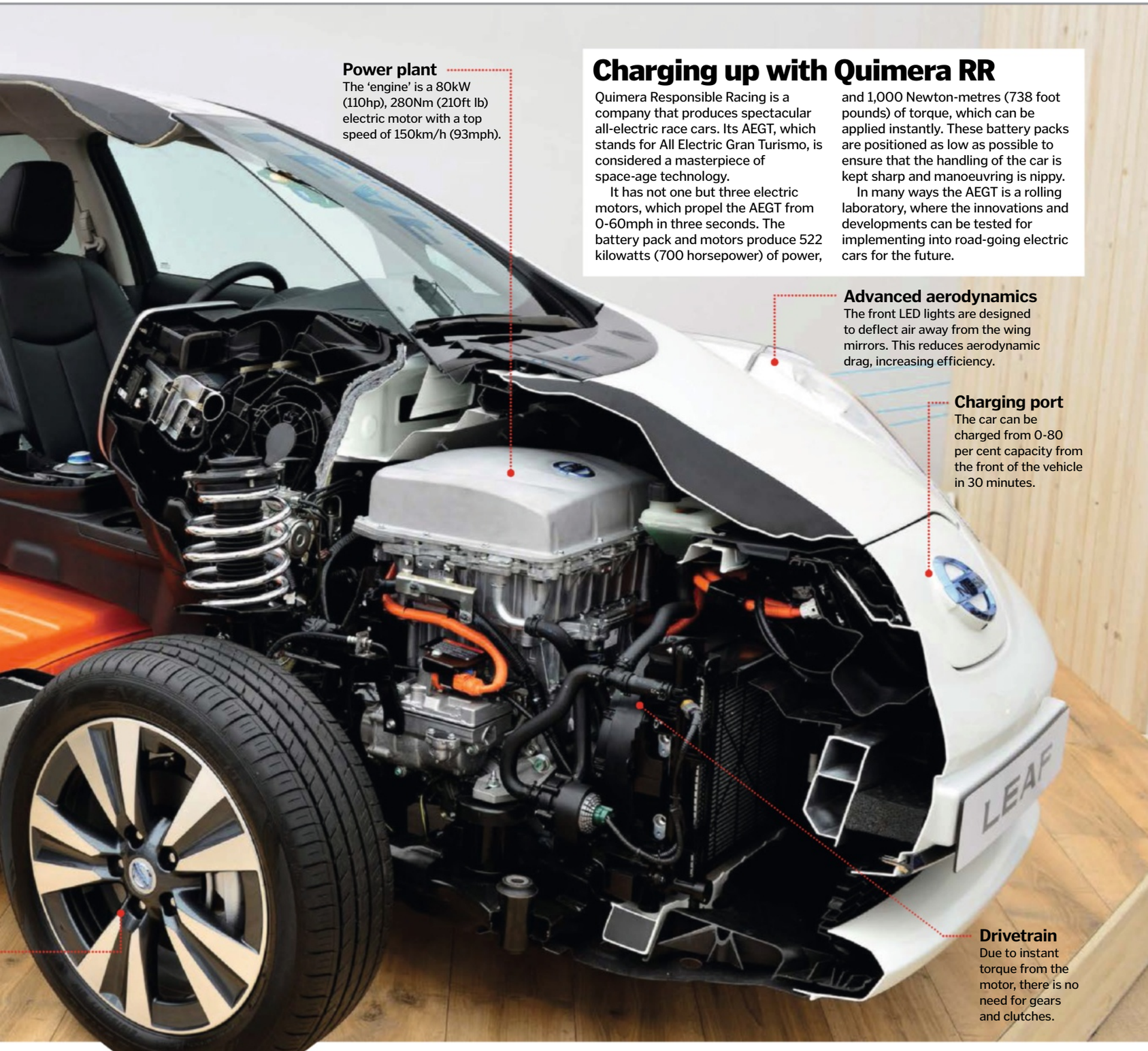
**DID YOU KNOW?** *The first US speeding ticket was given to an electric car 'hurtling' at 19km/h (12mph) in a 13km/h (8mph) zone*

## Charging up with Quimera RR

Quimera Responsible Racing is a company that produces spectacular all-electric race cars. Its AEGT, which stands for All Electric Gran Turismo, is considered a masterpiece of space-age technology.

It has not one but three electric motors, which propel the AEGT from 0-60mph in three seconds. The battery pack and motors produce 522 kilowatts (700 horsepower) of power, and 1,000 Newton-metres (738 foot pounds) of torque, which can be applied instantly. These battery packs are positioned as low as possible to ensure that the handling of the car is kept sharp and manoeuvring is nippy.

In many ways the AEGT is a rolling laboratory, where the innovations and developments can be tested for implementing into road-going electric cars for the future.




**Power plant**
The 'engine' is a 80kW (110hp), 280Nm (210ft lb) electric motor with a top speed of 150km/h (93mph).

**Advanced aerodynamics**
The front LED lights are designed to deflect air away from the wing mirrors. This reduces aerodynamic drag, increasing efficiency.

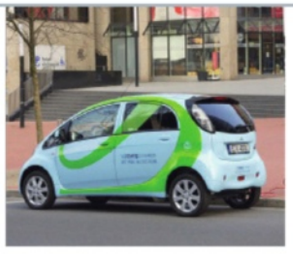
**Charging port**
The car can be charged from 0-80 per cent capacity from the front of the vehicle in 30 minutes.

**Drivetrain**
Due to instant torque from the motor, there is no need for gears and clutches.

### 1966
**GM Electrovan**
This has been credited as being the first-ever hydrogen fuel cell car produced.

### 2004
**Electric sports car**
Tesla Motors begins development of the Roadster, which has been sold in over 31 countries to date.

### 2010
**Mass production**
The Mitsubishi i-MiEV becomes the first EV to sell more than 10,000 units.



### 2013+
**The future**
Eco cars are primed to compete with combustion engine cars, with extended ranges and faster charging times.


# Meet the real Brontosaurus

## One of the largest animals to ever exist on Earth, the Apatosaurus towered metres over its Jurassic rivals

Four times heavier than an African elephant, five times longer than your car and almost six times the height of a full-grown human, Apatosaurus was one of the largest dinosaurs of the Jurassic period and one of most gigantic to ever walk the Earth.

As is typical with large dinosaurs of this period, Apatosaurus (once mistakenly known as Brontosaurus) was a herbivore, consuming vast quantities of foliage and grasses over the lands that now form modern-day North America. Interestingly, despite its size, its name is derived from the Greek 'apate' and 'saurus', which translate as 'deception lizard' – a name bestowed by its original discoverer, American palaeontologist Othniel Charles Marsh.

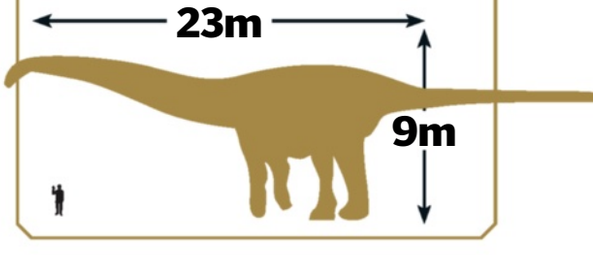
Prior to the 1970s, Apatosaurus, along with many other sauropods, were considered largely aquatic creatures that relied on being partially submerged in swamps and lakes to remain stable – a view seemingly confirmed by their colossal bulk. However, recent evidence has demonstrated that through a combination of massive limb bones and a series of weight-reducing internal air sacs located throughout the neck and spine, Apatosaurus's home was, in fact, entirely land-based, only spending time at water sources to drink.

Speaking of drinking, the Apatosaurus required gallons of water per day to remain healthy, while it also needed to process vast amounts of food, spending a large proportion of each day grazing. It did this with few predators, as only the largest carnivorous dinosaurs had any chance of bringing down an Apatosaurus, largely thanks to its size. It also had a deadly weapon in its tail, which was capable of being swung at great velocity at any foes.

Despite its defensive prowess, however, the Apatosaurus could not battle off extinction, with it falling to a medium-sized extinction event around 150 million years ago.

### Apatosaurus vs human

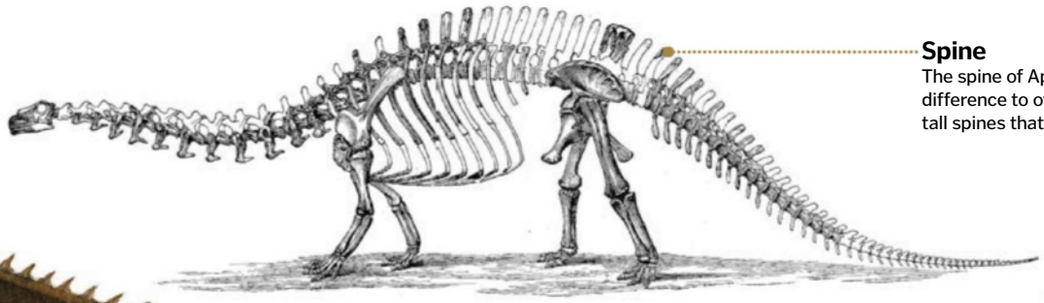
**How would this enormous dinosaur have sized up to a person?**



# THE STATS
## APATOSAURUS

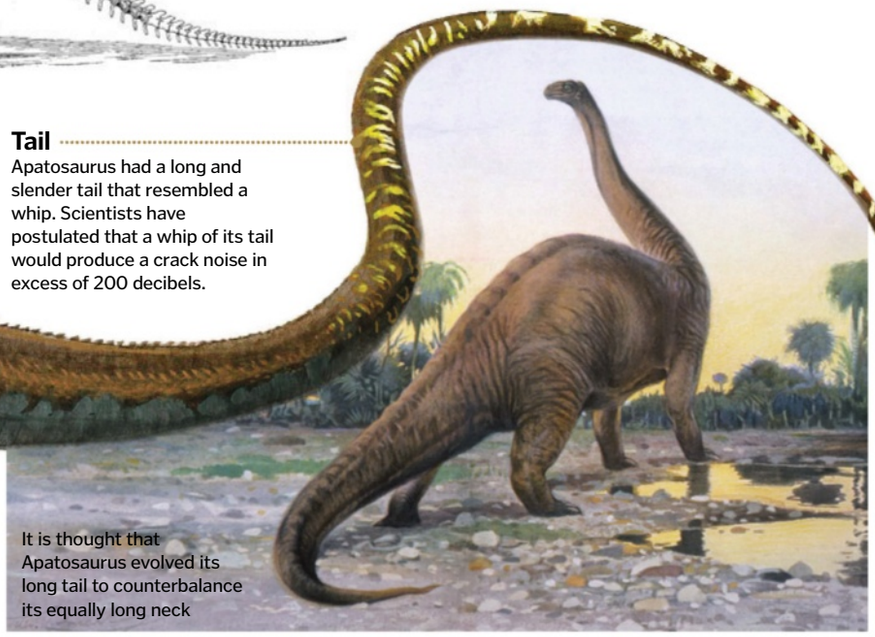
HEIGHT 9m | WEIGHT 30,000kg | TIMEFRAME 154-150MYA
LENGTH 23m | LIFE EXPECTANCY Up to 100yrs | DISCOVERED 1877

**DID YOU KNOW?** *Apatosaurus skeleton fragments have been found in Wyoming, Colorado, Oklahoma and Utah*



**Spine**
The spine of Apatosaurus was interesting in its difference to other sauropods, possessing incredibly tall spines that made up half its total height.

**Tail**
Apatosaurus had a long and slender tail that resembled a whip. Scientists have postulated that a whip of its tail would produce a crack noise in excess of 200 decibels.



It is thought that Apatosaurus evolved its long tail to counterbalance its equally long neck

**Legs**
The limb bones of Apatosaurus were incredibly sturdy and strong, capable of supporting its huge mass. It had a single claw on each forelimb and three on each hindlimb.

## The bone wars

During the beginning of the golden age of modern palaeontology, two prominent American palaeontologists, Edward Cope and Othniel Marsh, had a falling out over excavated dinosaur remains, with the men then proceeding to attempt to beat each other to unearth and describe new species of dinosaur. In this rush to become the foremost palaeontogist of the age, Marsh described first in 1877 and then later in 1879 two supposedly separate species of dinosaur. He named the first one Apatosaurus and called the second one Brontosaurus.

Following this, the name of Brontosaurus became world famous, with a complete skeleton mounted and displayed in the Peabody Museum, Yale, under the Marsh title in 1905. However, Marsh in his haste had made a terrible mistake. The Brontosaurus was actually just a fully-grown Apatosaurus and, since the Apatosaurus had been described first in 1877, its name took precedent, with 'Brontosaurus' made officially redundant in the early-20th century. Interestingly, however, as the Brontosaurus name had become firmly fixed in the public consciousness, it remained far more popular and is still in use to this day to the chagrin of many dinosaur experts.

A photograph of Othniel Marsh taken between 1865 and 1880

## Stamp scandal

In 1989, the US Post Office decided to release a special edition set of four stamps depicting famous dinosaurs. These included a Tyrannosaurus, Stegosaurus, Pteranodon and, interestingly, a Brontosaurus.

The latter was included despite the fact that, as noted in 'The bone wars' boxout, the name 'Brontosaurus' had been made officially redundant in the early-20th century.

The fallout from this was massive, with many palaeontologists and dinosaur enthusiasts accusing the US Post Office of promoting 'scientific illiteracy' and re-opened a bone war-style feud between others. Indeed, even the celebrated palaeontologist Stephen Jay Gould got involved, writing a famous defence of the Brontosaurus name in his *Natural History* magazine piece 'Bully for Brontosaurus'.

"Some of the most famous structures of this kind include the pyramids of Egypt and the cairns of Ireland"

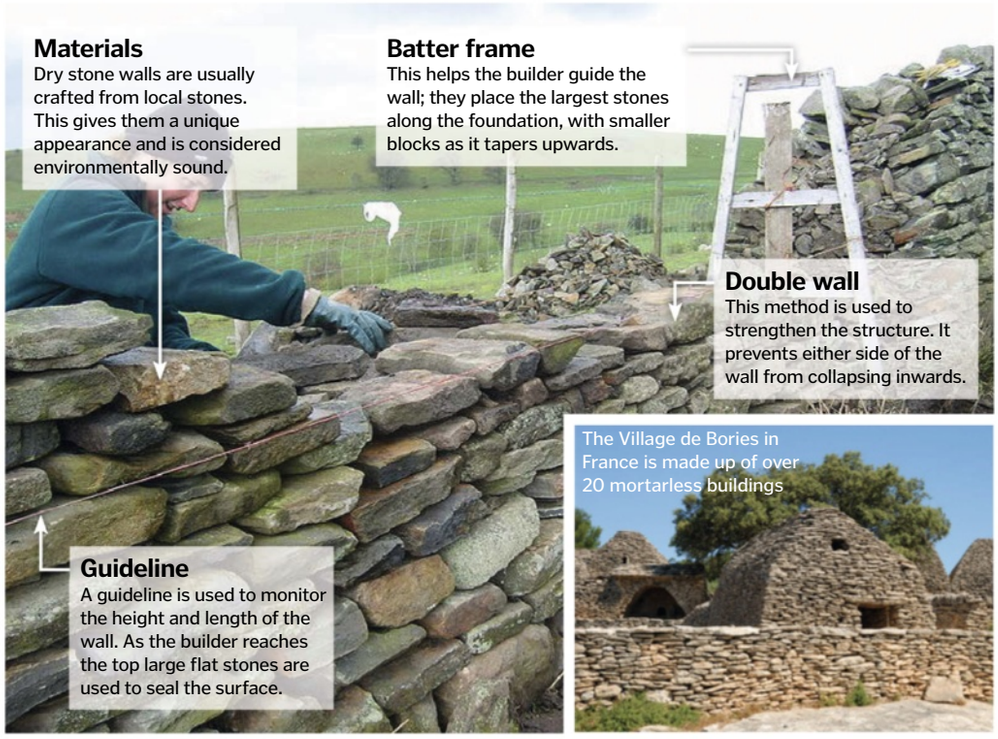
# How dry stone walls are built

## This clever form of masonry dates back centuries and has been used to make all manner of structures without any cement, relying instead on craftsmanship and gravity

Dry stone walls form the architectural backbone of history. They are comprised of a series of interlocking stones carefully stacked and balanced together without the aid of any mortar.

There are various methods adopted during construction, but most are made of regular blocks assembled using wooden frames and measuring lines. Today, dry stone walls are commonly seen in the countryside, where they are used to divide land and crops. However, dry stone walling was also used in the ancient world; indeed, the practice was used in the construction of many prehistoric monuments, Roman bridges and early churches.

On the other hand, its methodology has even been used to create works of modern art. Some of the most famous structures of this kind include the pyramids of Egypt and the cairns of prehistoric Ireland. Perhaps the most elegant use of dry stone walling can be seen at Machu Picchu in Peru, where the Incan civilisation created a magnificent city constructed of polished, dry stone walls.



**Materials**
Dry stone walls are usually crafted from local stones. This gives them a unique appearance and is considered environmentally sound.

**Batter frame**
This helps the builder guide the wall; they place the largest stones along the foundation, with smaller blocks as it tapers upwards.

**Double wall**
This method is used to strengthen the structure. It prevents either side of the wall from collapsing inwards.

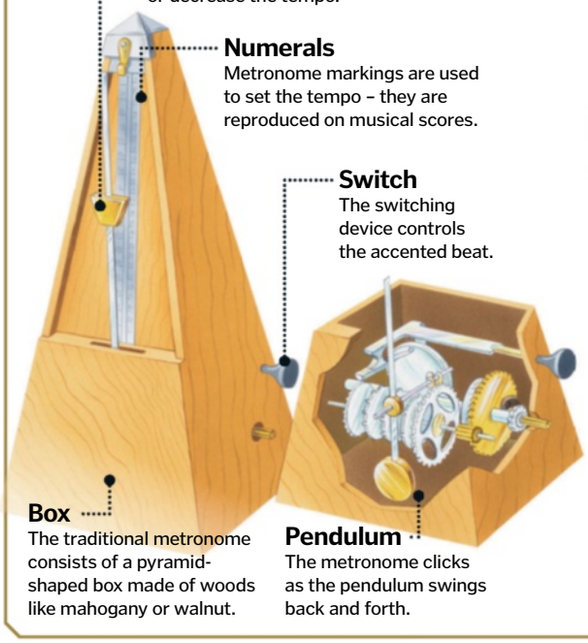
**Guideline**
A guideline is used to monitor the height and length of the wall. As the builder reaches the top large flat stones are used to seal the surface.



The Village de Bories in France is made up of over 20 mortarless buildings

# Inside metronomes

## Learn all about these time-keeping instruments that help musicians to keep the beat




The earliest notable scientific experiments with pendulums were conducted by Galileo Galilei in 1602. In 1696, Étienne Loulié adopted his theories and designed the first metronome – an instrument that is still used by musicians today. Received with great enthusiasm, by 1812, Dietrich Nikolaus Winkel was manufacturing 'Maelzel's Metronomes', a device that is still in use.

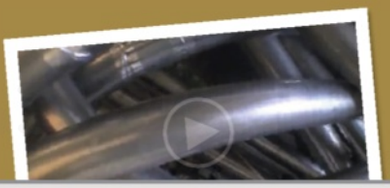
A metronome produces a systematic series of clicks or beats that can be measured over minutes. Traditional metronomes were designed with a slim pendulum, weighted and attached to a wooden frame; the pendulum counts a series of rhythmic beats. Today, metronomes are highly advanced and are more likely to be electronic or digital formats. The beats they produce can help a musician assimilate the timing or 'tempo' of a piece of music. The metronome can also be used by composers to mark variances on a written score.

There has been much debate about the use of the metronome. Some musicians believe that it is unnatural for a player to work to an exact tempo. In fact, many notable composers, including Wagner and Brahms, have criticised the metronome, believing that it denies the player a natural form of expression. Those against the tool claim that musicians using one produce a dull 'metronomic' sound.

**AMAZING VIDEO!** SCAN THE QR CODE FOR A QUICK LINK

**Stanford Hospital's pneumatic tubes in action**

www.howitworksdaily.com



**DID YOU KNOW?** *The Central Telegram Office would send 5 million letters by pneumatic tube a year to London's post offices*

# What were pneumatic tube systems used for?

## Discover how these unusual machines transported messages in a flash

Pneumatic tube systems were a novel form of transportation popular in the late 19th and early 20th century, in which cylindrical containers were transported through a network of metal tubes via compressed air or by partial vacuum.

The systems were developed as an alternative form of courier for objects, letters and even – for a short, experimental time – people, with banks, post offices, telegraph exchanges and offices all connecting themselves via an intra or extranet of tubes.

The most common use for pneumatic tubes was in post offices and telegraph exchanges, with large city-based postal centres connected to local branches by miles upon miles of tubing. These systems greatly sped up the delivery of physical mail, reducing the need for human postal workers to cross large areas of a city, only making the final short connection between local branch and target destination on foot. The same largely became true for banks, with money, deposits and even withdrawals actioned via pneumatic tube.

Indeed, the uptake of pneumatic tube systems was so great that in the latter decades of the 19th century it was even attempted to extend the principle to carry people, with projects such as the 1869 Beach Pneumatic Transit Company in New York building hundreds of metres of subway-style tube networks. While these systems worked, the upscaling in size largely eradicated the efficiency and speed of smaller, post-sized networks, leaving them to be abandoned in favour of traditional rail networks.

### Down but not out

Despite pneumatic tube systems garnering widespread popularity and usage through late-19th and early-20th-century cities worldwide, the advent of the digital computer, internet and World Wide Web meant that by the turn of the 21st century, they were almost all redundant. After all, no pneumatic tube system could run a message from London to New York in a matter of seconds like an email can.

However, despite email's dominance, pneumatic tube systems are still used today in select areas – foremost of which is in the medical sphere. Many large hospitals and medical research laboratories have extensive pneumatic tube networks, allowing drugs, tools, blood packs and biological samples to be rapidly transited around typically large and warren-like facilities. To gain a better understanding of how these amazing systems work, be sure to take a look at the video link above.

## Telegraph exchange step-by-step

**Follow the journey of a telegraph and find out the role pneumatic tubes played**

### 1. Telegraph in

Telegraphs would enter the exchange from their point of origin – ie another post office branch – via manual mail or pneumatic tube delivery.

### 2. Sorting

The telegraph would be sorted, with its destination logged by human operators.

### 3. Re-routing

The telegraph would then be re-routed in the exchange, being sent to the relevant dispatch area via an intranet of internal pneumatic tubes.

### 4. Telegraph out

Once at the dispatch area, the telegraph was sent out by pneumatic tube. This network was extensive in major cities, transporting the telegraph over hundreds of metres.

### 5. Receipt

The sent telegraph would arrive at its destination's local office or exchange, with the communiqué delivered in person to the recipient.

A secretary collects capsules of documents at a typewriter factory in Hull, UK, in 1954

A tube used to transport airmail between a post office and the airport in the Thirties

© Corbis; Getty

"Most famous for its series of frescoes which cover the walls and vaults of the upper and lower churches"

# The Basilica of San Francesco d'Assisi

## Home of the Franciscan Order, the basilica is an architectural marvel and pilgrimage centre which draws Christians from all over the world

The great basilica church of Assisi was constructed in honour of St Francis immediately after his canonisation in 1228. Designed by one of St Francis's first followers, both upper and lower churches originally followed a simple aisleless cruciform plan, although chapels were subsequently added to allow further space for friars and pilgrims to worship. Attached to the basilica is the Sacro Convento, the 'sacred convent' which is the spiritual home of the Franciscan order.

Built from local stone and brick, the basilica was constructed on a hillside, over St Francis's burial place. The difficulties the site presented resulted in the construction of a massive church on two levels supported by internal buttressing. Employing both the Romanesque and Gothic architectural styles, the lower church is a simple basement structure, while the upper church is a taller and more elegant construction. Lit by tall Gothic lancet windows, the upper church contains some of the best examples of 13th-century stained glass in Italy.

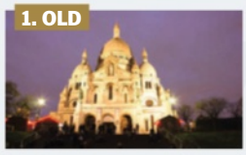
The basilica is perhaps most famous, however, for its unrivalled series of frescoes which cover the walls and vaults of both upper and lower churches. Mostly dating from the 13th and 14th centuries, they include work by the young Giotto and other Italian masters. Portraying the life of Christ, saints and other religious scenes, the most famous images consist of a cycle of paintings which portray the life of St Francis.

In 1818 St Francis's tomb was rediscovered beneath the floor of the lower church. To ensure that pilgrims could access the saint's relics and pray in their presence, a crypt chapel was excavated by order of Pope Pius VII. Originally designed in a neo-Classical style, it was given its present severe neo-Romanesque face-lift in the early-20th century when a number of Francis's original followers were re-buried in the crypt close to the saint's tomb. Together the basilica and monastery were declared a UNESCO World Heritage Site in 2000.

### The day the basilica trembled

On 26 September 1997, two earthquakes measuring 5.5 and 6.1 magnitude hit the Assisi region. While the basilica received some minor structural damage, it was not until an aftershock shook the church that the vaulting at the crossing and the west end of the nave of the upper basilica collapsed destroying frescos by Giotto. Tragically, two friars and two specialists who were inspecting the earthquake damage at the time were killed in the disaster. The upper church was then closed for the following two years. After the building was structurally secured, the vaulting in the church was rebuilt. Although the frescos have yet to be restored, approximately 80 per cent of the original painting fragments have been recovered and will eventually be replaced in their original position. Costing about £31 million ($50 million), the restoration was complete in time for the Vatican's Holy Year celebrations in the year 2000.

Vaulting in the upper church was rebuilt after earthquake damage



**1. OLD**

### Sacré-Cœur, Paris

Built between 1875 and 1914, the church dominates north Paris. It's famous for its adoration of the Blessed Sacrament.

**2. OLDER**

### San Francesco d'Assisi

Constructed between 1228 and 1253 over St Francis's burial place, the basilica in Assisi is famous for the tomb of the saint.

**3. OLDEST**

### St Peter's Basilica, Vatican

Started in the fourth century CE and finished in 1626, it covers the grave of St Peter.

**DID YOU KNOW?** *The basilica is also the burial place of Giovanna of Italy, the last queen of Bulgaria, who died in 2000*

# A simple church for a simple saint

**The basilica of St Francis is a pilgrim church which also serves as a monastery**

## The statistics...

### *Basilica of San Francesco d'Assisi*

**Architect:** Brother Elias Bombadone, OFM

**Years of construction:** 1228-1253

**Type of building/purpose:** Papal minor basilica and friary church

**Location:** Assisi, Umbria, Italy

**Full length:** 80m (260ft)

**Full width:** 50m (160ft)

**Cost of construction:** More than £50mn (in modern terms)

### Campanile

The basilica's low bell tower stands on the north side of the nave. It has 12 arched bell openings which mirror the twelve apostles of Christ.

### Fresco decorations

The whole of the interior of the upper basilica is covered in fresco decoration painted by Giotto and others. Most of the decoration illustrates the life of St Francis.

### Upper basilica

A four-bay nave, transept and apsidal choir, the upper basilica is used daily by the friars who live in the convent attached to the basilica.

### Lower basilica

Entered by a magnificent columned portico, the lower basilica is decorated with frescos and contains a number of side chapels for pilgrims.



### Piazza

In front of the church is a long rectangular piazza in which pilgrims can gather before entering the upper or lower basilicas.

### Crypt

Built in the early-19th century after St Francis's tomb had been discovered, the crypt chapel allows pilgrims to access the saint's relics.

### Earthquake damage

In the 1997 earthquake, the vaulting at the crossing and the west end of the nave of the upper basilica collapsed.

### Tomb of St Francis

Rediscovered in 1818, the ancient stone coffin, which contains the saint's body, stands at the centre of the crypt, secured safely behind the main altar.

## Who was Francis of Assisi?

One of the most venerated religious figures in history, Francis was the son of a wealthy cloth merchant. Born Giovanni di Pietro di Bernardone in 1181, but renamed 'Francesco' by his father, Francis's early life was unexceptional. Receiving a vision in 1204, he renounced his worldly lifestyle and embraced poverty. Founding the order of Friars Minor with the pope's approval, he preached on the streets and travelled to Egypt attempting to convert the Sultan. Francis later increasingly withdrew from the world and focused on prayer. He died on 3 October 1226. On 16 July 1228, Francis was declared a saint by Pope Gregory IX and on the following day the pope laid the first stone of the basilica in Assisi.

# BRAIN DUMP

Because enquiring minds need to know...

## Want answers?

Send your questions to...

How It Works magazine @HowItWorksmag

howitworks@imagine-publishing.co.uk

## When is a species classed as endangered?

**Ron Farrell**

■ The International Union for the Conservation of Nature (IUCN) maintains a 'Red List' of the world's endangered species. There are seven categories that range from Least Concern, through to Near Threatened, Vulnerable, Endangered, Critically Endangered, Extinct in the Wild and finally Extinct. Endangered species face a 'very high risk of extinction in the near future'. This takes into account the number of animals left, as well as their rate of decline and geographical distribution. Just under 64,000 of the 2 million-plus known species are assessed each year. Currently 5,766 species are classed as endangered and 3,947 as critically endangered. **LV**

Nearly 4,000 species, including the orangutan, are currently classed as critically endangered

## Meet the experts...

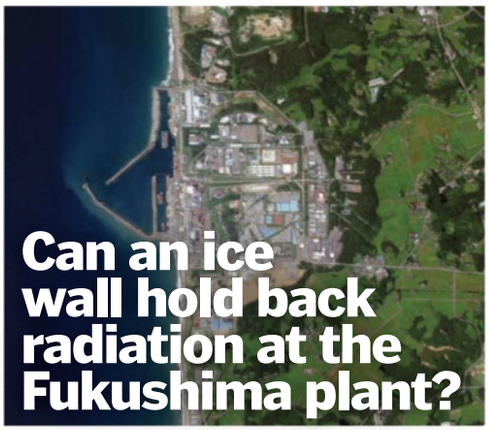
**Luis Villazon**
Luis has a degree in zoology and another in real-time computing. He's been writing about science and technology since before the web. His science-fiction novel, *A Jar Of Wasps,* is published by Anarchy Books.

**Giles Sparrow**
Giles studied Astronomy at UCL and Science Communication at Imperial College, before embarking on a career in space writing. His latest book, published by Quercus, is *The Universe: In 100 Key Discoveries.*

**Rik Sargent**
Rik is a science communicator who has a background in physics and public engagement. Pastimes include baking cakes, experimenting with sound, plus the science and art of brewing coffee.

**Alexandra Cheung**
With degrees from the University of Nottingham and Imperial College, Alex has worked at many a prestigious institution including CERN, London's Science Museum and the Institute of Physics.

**Dave Roos**
A freelance writer based in the USA, Dave has written about every conceivable topic, from the history of baseball to the expansion of the universe. He has an insatiable curiosity for all things science and tech.



## Can an ice wall hold back radiation at the Fukushima plant?

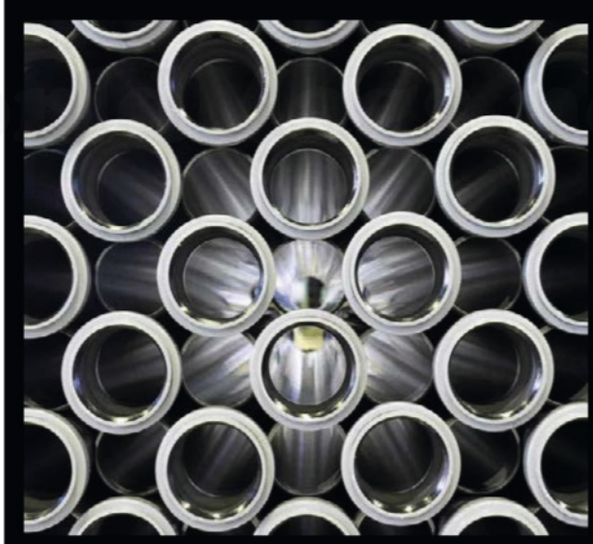
**Tony Dalton**

Experts believe that Fukushima's underground ice wall will contain radioactive water. Since the meltdown, groundwater flowing through the site has been carrying radioactive material into the sea. The Japanese government has decided to seal off the area with a three-metre (ten-foot)-thick ice wall, created by pumping a cooling liquid through underground pipes. This will both hold water and stop further groundwater entering the site. Similar walls have been used to isolate mines, but this is the first one built around a nuclear plant. A demonstration, albeit on a smaller scale, has shown that an ice wall can hold in radioactive water, so most nuclear experts are confident that it will prevent contaminated water from seeping out of the site. However, maintaining the wall will be hugely expensive, so it is at best a temporary measure. **AC**

## How is Bubble Wrap manufactured?

**Shauna Newton**

Bubble Wrap is made by heat-sealing two sheets of thin plastic – one that's flat and another that's been dimpled with bubbles – and trapping the air inside. First, polyethylene pellets are melted into thin sheets, and one sheet is wound around a metal drum with holes punched in it. Suction is applied through the holes, stretching the plastic into small raised bubbles. The bubble sheet is immediately laminated to a second sheet, trapping a cushion of air inside. **DR**



## What is it that makes stainless steel stainless?

**Rohan Malik**

Stainless steel contains at least 13 per cent chromium (by weight), which helps it to resist rust and staining. Chromium in steel combines with oxygen in the atmosphere, forming a thin film of chromium oxide that protects the steel from further exposure to oxygen – the main cause of corrosion in steel. Steel and chromium oxide molecules are a similar size, allowing them to bond very strongly together and in the process attach the film firmly to the surface. Stainless steel is not completely stain-proof, however, and is most notably exposed as unprotected in environments with low oxygen, high salinity or poor circulation. **RS**

## Is Voyager 1 really in interstellar space now?

**Anton Speed**

Almost certainly – after a 35-year journey out of the Solar System, Voyager 1 seems to have finally left the heliosphere (the region dominated by particles flowing out from the Sun in the solar wind). Scientists think it achieved this landmark around August 2012, when its detectors began to pick up increasing numbers of cosmic rays – actually high-speed particles from distant stars and galaxies.

This indicates that it has almost certainly crossed the heliopause – the boundary between the heliosphere and the interstellar medium – and is now drifting through a turbulent region just beyond the Sun's protective bubble. However, some scientists want to wait and see how conditions settle down beyond this bubble before admitting that the boundary has been crossed. **GS**

## How do people walk over hot coals?

**Hannah C**

Firewalking is possible thanks to the low thermal capacity and conductivity of burning coals, and the performer's quick steps. Burning wood has a low heat capacity compared to the water that makes up our bodies, so although firewalkers step on coals at a sizzling 550 degrees Celsius (1,000 degrees Fahrenheit), the amount of thermal energy the coals hold is small. Wood and ash are also excellent heat insulators. In the split second during which an experienced firewalker's feet are in contact with the coals, the amount of heat energy absorbed by the skin isn't large enough to cause serious damage. **AC**

# 5-SECOND FACTS

### Contact lenses are 125 years old

The first successful contact lenses were tested out in 1888 by German ophthalmologist Adolf Fick. Made of glass, they covered the front of the eye. It wasn't until the invention of smaller, softer, gas-permeable lenses in the Seventies that contacts hit the mainstream.

### Karate belt roots lay in swimming

Judo was the first martial art to award a 'black belt', introduced by its founder Jigoro Kano, who was inspired by Japan's high school swimming, where advanced students wore black ribbons. The other colours were introduced as a motivation tool for Westerners by Mikinosuke Kawaishi, and was so successful that other styles followed.

**What's the most common illness on Earth?** Find out on page 82

# BRAIN DUMP

## Want answers?

Send your questions to...

How It Works magazine @HowItWorksmag

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## 5-SECOND FACTS

### Triceratops was the last dino standing

The last dinosaur was probably Triceratops. Fossil bones have been found from right before the asteroid impact that signalled the end of the dinosaurs 65 MYA. Isolated dinosaur bones have been found in more recent strata than this, but never a full skeleton and the dating evidence for these is controversial.

### Chillies trick your brain into thinking they are hot

Hot chilli peppers like habaneros and jalapeños contain a chemical called capsaicin that tricks your brain into thinking your lips are on fire. Chillies have evolved to repel mammals, which destroy their precious seeds. When you eat or touch chilli seeds, the capsaicin activates the same pain receptors in your brain that indicate extreme heat.

## What's the most common disease in the world?

**Sophie W**

The most widespread infectious disease in humans worldwide is the common cold, with the rhinovirus being the main cause. The common cold has been with us since antiquity, has no cure, and is the number one reason adults miss work and children miss school; with adults catching a cold on average two to three times a year, and children 6-12 times a year. The most common non-contagious disease is gum disease, also known as gingivitis and periodontal disease. It is estimated that half the world's adult population has gum disease, and that most people will have some degree of it at least once in their life. It occurs when a buildup of plaque and tartar begins to irritate and inflame your gums. The best method of prevention is brushing teeth twice a day, flossing and regularly visiting the dentist. **RS**

## Does truth serum really exist? How does it work?

**Faye**

For nearly a century, psychiatrists have experimented with sedatives like sodium amytal and sodium pentothal, so-called 'truth serums' that lower inhibitions and uncover a subject's true motives. The truth is that they are wildly imprecise, and like polygraph tests, inadmissible in court as evidence. It all began in 1915, when an American obstetrician administered sodium amytal as pain relief during labour and discovered that patients seemingly lost the ability to censor themselves. Truth serum was then used as a police tool and by US military psychiatrists to weed out soldiers faking shell-shock during WWII. By modern scientific standards, however, none of these applications were successful. Subjects drugged by truth serum are extremely vulnerable to suggestion, and reveal as much blithering nonsense as truth. **DR**

## What's the difference between lunar and solar calendars?

**Gary Kendrick**

Solar calendars are based on the year – the period of time Earth takes to orbit the Sun, and therefore the time the Sun takes to return to its position in the sky relative to the background stars, equivalent to approximately 365.25 days. Lunar calendars, meanwhile, are based on the lunar month – the period of time between successive new moons or full moons, when Earth, the Moon and the Sun are aligned with each other. A lunar month is equivalent to 29.53 days. The Moon takes just 27.32 days to orbit the Earth; the extra time is needed for the Moon to 'catch up' with the relative position of the Sun in the sky. **GS**

# Who came up with horsepower as a form of measurement?

**Ed McCallister**

Horsepower measures the rate at which work is done, and was first used by Scottish engineer James Watt in the late-18th century to measure the power of steam engines against draft horses, which was useful when engines began to replace horses. One horsepower (1hp) equals 746 watts, which is the same power you would need to lift a 15,000-kilogram (33,070-pound) mass one foot in a minute. Today, horsepower is associated with car engines, with higher horsepower generally denoting a faster vehicle. However, tractors also need a high horsepower in order to push or pull heavy loads. **RS**

## Why is olive oil so good for you?

**Tracey Forrester**

Olive oil's health benefits are mostly down to its high monounsaturated fatty acid (MUFA) content. Dairy or meat products contain saturated fats which lead to 'bad' cholesterol that can build up on artery walls.

MUFAs, on the other hand, promote 'good' cholesterol which counters this effect. Swapping butter or other fats for olive oil could therefore reduce your risk of heart disease. Olive oil also has high levels of vitamin E and other antioxidants, which are believed to help protect cells from damage caused by free radicals (unstable atoms or molecules). This could in turn ward off serious illnesses like cancer. **AC**

## How do lungfish survive?

**Sammy Downer**

Many fish can supplement their oxygen intake by gulping air into their swim bladder, but this is just a simple sac surrounded by blood vessels. The six lungfish species have lungs that are divided into lots of subcompartments to increase the internal surface area and help them absorb oxygen. Most lungfish's gills have atrophied, and they actually require air to survive – only the more primitive Queensland lungfish in Australia still retains the ability to breathe in water. **LV**

## Why do we laugh?

**Robert Philipson**

Laughter has evolved primarily as a social cue, a way to communicate social bonding and relieve social anxiety. Scientists studying laughter – called gelotologists – found that people laugh at almost anything. Laughter is used as a 'punctuation mark' to communicate good-natured friendship. This may have evolved in our primate ancestors to signal a lack of aggression. You are 30 times as likely to laugh in a group than by yourself, and the funniest situations involve incongruity or surprise. Laughter is also a powerful medicine, triggering the release of dopamine and endorphins, as well as raising heart rates and respiration. **DR**

**Why are there so many islands in Scandinavia?** Find out on page 84

# BRAIN DUMP

## Why does Scandinavia have so many islands?

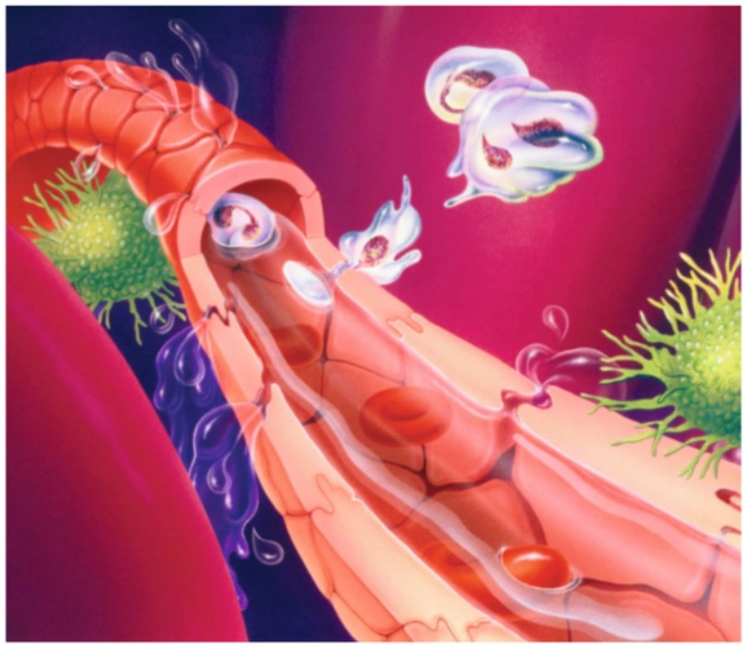
**Jack Fromer**

The multitude of islands dotted along Scandinavia's coastline were created by glaciation. During the last ice age, Scandinavia was smothered by an ice sheet up to three kilometres (1.9 miles) thick. Advancing glaciers scoured the landscape, carving deep valleys (fjords) but also leaving mountains of debris. The crushing weight of the ice warped the Earth's crust downward, pushing coastal areas underwater. Since the ice melted some 19,000 years ago, the region has been slowly bouncing back to its former altitude, rising by a few millimetres each year. As submerged land is lifted, elevated areas jut out of the sea to form islands. **AC**

## 5-SECOND FACTS

### Stilts have been used for over 2,500 years

There are paintings and other remains from Ancient Greece that show stilts were already in use before 500 BCE. Stilts may have originally been invented as a way to travel rapidly over uneven ground, and were still widely used by shepherds in French regions such as Gascony until the early-20th century.



## What is septic shock?

**Charlotte D**

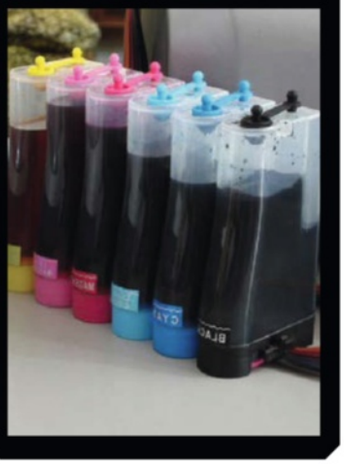
Septic shock is a life-threatening medical condition in which a widespread infection causes a dangerous drop in blood pressure. It begins with a bacterial infection, typically in an elderly patient, an infant or someone with a compromised immune system.

As the infection spreads, the body's immune system releases powerful chemicals into the bloodstream, causing widespread inflammation called sepsis. Sepsis is thought to cause tiny blood clots that block the flow of oxygen to vital organs, leading to organ failure and the sharp drop in blood pressure that triggers septic shock. Septic shock is a leading killer in hospital intensive care units. Common treatments for this condition include broad-spectrum antibiotics and oxygen. **DR**

## Why are printer inks not primary colours?

**Lewis Willoughby**

Suppose they used red, green and blue ink instead. Which colours would you mix to make yellow? You couldn't do it. Mixing red and green *light* gives yellow because you are adding together photons of different wavelengths. But with ink, you start with white ambient light and reflect it off the pigment molecules, which absorb some of the photons. So you are *subtracting* wavelengths, rather than adding them. The printer ink colours of cyan, magenta and yellow are used because they each absorb one of the primary colours – yellow ink absorbs blue light, and reflects red and green, for example. **LV**



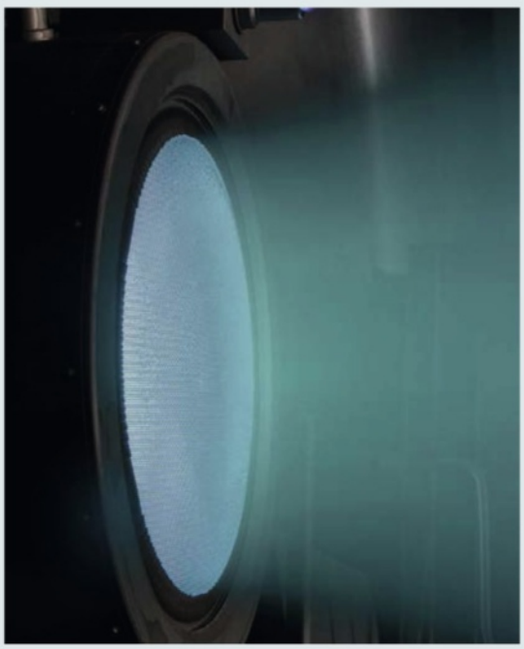
# What will replace the ISS once it's decommissioned?

**Jake**

The simple answer, unfortunately is that nobody knows – but a few people have some interesting ideas! The International Space Station is supposed to remain in operation until at least 2020, and there are proposals to extend its working life beyond that to around 2028, after which it will be deliberately de-orbited into the ocean. NASA's medium-term goals are geared to exploring deeper space, with a return to the Moon and manned exploration of an asteroid on the cards before the long-awaited mission to Mars. But whatever shape space exploration is in by that time, we'll presumably still need some kind of waystation in low Earth orbit (LEO), so who will provide it? China is developing its own space station, so it's possible they might spearhead another international effort. Another exciting possibility is that commercial space companies, some of whom are already responsible for ferrying supplies to the ISS, could develop and launch their own space stations with NASA's support. **GS**

# How does NASA's Evolutionary Xenon Thruster (NEXT) work?

**Duncan Vale**



NEXT is a solar-electric engine, commonly known as an 'ion engine'. Like all engines of this type, it uses electricity harvested by solar cells to ionise atoms of a propellant (in this case the unreactive gas xenon). The ionisation process uses a strong electric field to strip away electrons from the xenon atoms, leaving them with an overall positive charge. The electrons are then expelled from the thruster by repulsion from a positively charged 'accelerator grid'. As gas escapes from the rear, the thruster is pushed forward by a balancing force. The forces involved are tiny compared to those produced in conventional rockets, but the process is extremely efficient and the thrust can be sustained for years rather than minutes. **GS**


# Why are some fungi deadly?

**Jill Brown**

Many fungi have evolved toxins to stop animals eating them. These often advertise their toxicity with bright colours or a specific smell – the fly agaric toadstool is red with white spots, for example. Harmless mushrooms have evolved to mimic poisonous species to gain the deterrent effect without the effort of synthesising toxins. Some species are probably poisonous purely as an accident of their metabolism. Fungi digest plant matter into various chemicals, but can't necessarily get rid of all the by-products, so they just build up in their tissues. But the most dangerous toadstools belong to the genus Amanita, which includes the death cap. These produce amatoxins, which stop your cells from making the DNA-like substance, mRNA. This causes the cellular machinery to grind to a halt, resulting in liver failure. In severe cases it is fatal, unless you receive a liver transplant. **LV**

## Latest Brain Dump lands

A new edition of Imagine Publishing's digital science magazine **Brain Dump** is now up for grabs, offering some eye-opening insights into the fields of nature, science, astronomy and more. In the latest mag you'll find out why dogs see in black and white, how microwaves cook our food so quickly, plus why we sometimes get a stitch when we exercise. Issue 6 of **Brain Dump** is packed with loads of trivia that's written in easy-to-digest snippets for those who are short on time and always on the move. So for the answers to those questions and many more check out the latest issue on iTunes, Google Play or ask your own questions at **www.facebook.com/BraindumpMag** or Twitter @BrainDumpMag.

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# REVIEWS

## All the latest gear and gadgets


Ryobi's jigsaw is much easier to handle than a standard saw


Avoid hitting the mains with the Bosch PMD Multi-detector

# DIY essentials

## Get handy around the house with top tools

We've all been there – standing in a pile of wood pieces, staring at the instructions and realising you need more than just a cheap hex key. Whether you're assembling furniture, putting up a shelf or doing general repairs, you need the right tool for the job. Some are better than others though, and here we select a few of the essentials that ensure your DIY is both easy and safe.

**Checklist**

- ✔ Moisture detector
- ✔ Drill
- ✔ Jigsaw
- ✔ Miner's light
- ✔ Stud detector
- ✔ Tool belt

### 1 Tool belt

**JCB Drill Holster & Pouch with Belt**
**£24.98/$N/A**
**www.diy.com**
A more convenient way to carry your tools around, this JCB belt comes with a number of different pouches designed for various tools and components. It's incredibly sturdy, so even the heaviest drill won't rip the dedicated drill holster, and the electrician's pouch has room for all your screwdrivers and testing equipment that won't fit in the roomy nail pouch. You can even add pouches to the belt for a sturdier hammer loop or to carry your mobile phone around.
**Verdict:** ●●●●●

### 2 Moisture detector

**Stanley Moisture Meter**
**£41.98/$N/A**
**www.diy.com**
A must-have device for carpentry or painting, moisture detectors can determine whether wood or walls are suitable for use – especially if you're in an older and possibly damp room. The Stanley moisture meter is a light and handy device that accurately measures surfaces for how much water content they have. The cover for the probes swings back, meaning you won't lose it and risk damaging the probes, and it also lets you test the batteries to make sure you don't run out of power.
**Verdict:** ●●●●○

### 3 Stud detector

**Bosch PMD Multi-detector**
**£67.98/$N/A**
**www.diy.com**
One of the most important things to do before drilling is to make sure you're not going to burst a water pipe or electrocute yourself by piercing the mains. Unguided drilling can be dangerous and expensive, and this multi-detector from Bosch does a bit more than your normal stud detector. It helps you detect the location of different materials in the wall by directing you towards them, and even has a guide hole so you can mark up areas that are off limits.
**Verdict:** ●●●●○

### 4 Drill

**Makita HP330WWX2**
**£79.99/$N/A**
**www.wickes.co.uk**
What's DIY without a drill? Probably painting, but for all other tasks you need a good electric drill. The HP330 is a portable drill that not only allows you to make holes, but also put the screws into the holes you've made. The drill driver function comes alongside a hammer drill and normal drill function, selectable at the base of the chuck. The drill itself is rechargeable, coming with a removable battery pack and charger for it, allowing you to swap battery packs while you're working.
**Verdict:** ●●●●○

### 5 Jigsaw

**Ryobi EJ600**
**£49/$N/A**
**www.ryobi-direct.com**
When you need to cut out some wood or metal, you use a saw. However, using a handsaw can be time-consuming and inaccurate. This is where a good jigsaw comes in, a hand-held power saw with guides and interchangeable blades that allow you to cut along a measured line. The Ryobi is a solidly built jigsaw with a number of different settings for cutting metal as well as different thicknesses of wood. The blade is well protected, but there's enough gaps in the guide to see where you're cutting.
**Verdict:** ●●●○○

### 6 Miner's light

**Uni-Com LED Head Torch**
**£4.99/$N/A**
**www.robertdyas.co.uk**
DIY is not always done indoors or even in well-lit areas, with garages, lofts and dark cupboards often being low on illumination. Even in a well-lit room, you may have difficulty getting light into the area you're working, so a miner's light can be very handy for illuminating your surroundings. This head torch comes with five LEDs that pack a serious punch, and is also able to attach itself to magnetic surfaces if you ever need a more consistent light focused on a dark area where your head won't fit.
**Verdict:** ●●●●○

## EXTRAS

Three brilliant ways to get even more help around the house

**BOOK**

### Collins Complete DIY Manual

**Price:** £25/$N/A
**Get it from:**
www.amazon.com
This complete guide breaks down the majority of standard DIY tasks into specific sections, with chapters dedicated to planning and safety to make sure your project comes together in the best possible way.

**APP**

### Spirit Level Free

**Price:** Free
**Get it from:** iTunes
If your handy spirit level is nowhere to be found and you need to see if something is level, this handy app turns your phone into a spirit level. Thanks to the iPhone's accelerometer and magnetometer, it's a pretty accurate measuring device.

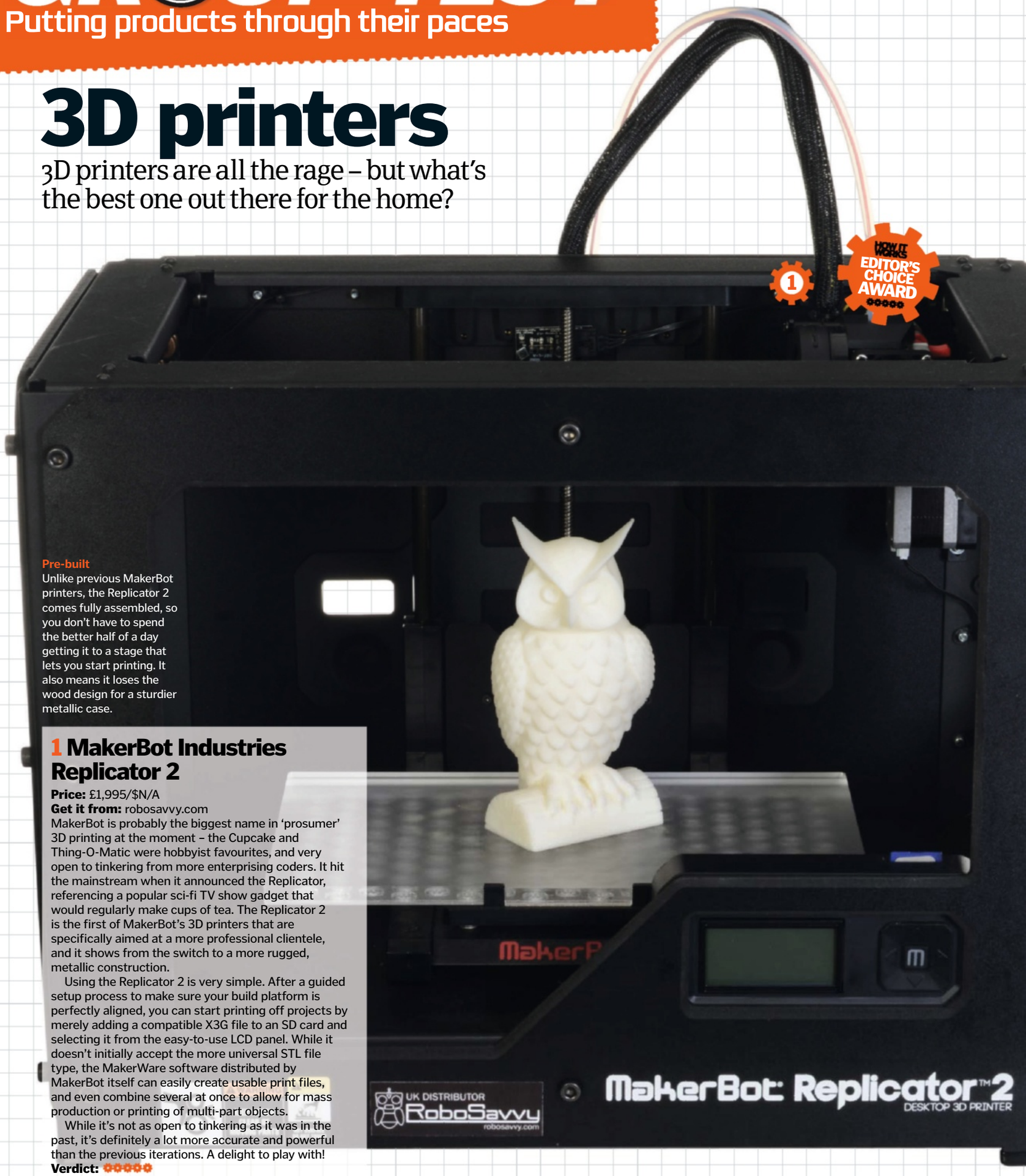
**WEBSITE**

### doityourself.com

An award-winning website with a huge community of active DIYers that can help you with almost any problem. There's also an extensive selection of tutorials on just about every subject in both written and video form.

# 3D printers

3D printers are all the rage – but what's the best one out there for the home?




**Pre-built**
Unlike previous MakerBot printers, the Replicator 2 comes fully assembled, so you don't have to spend the better half of a day getting it to a stage that lets you start printing. It also means it loses the wood design for a sturdier metallic case.

## 1 MakerBot Industries Replicator 2

**Price:** £1,995/$N/A
**Get it from:** robosavvy.com

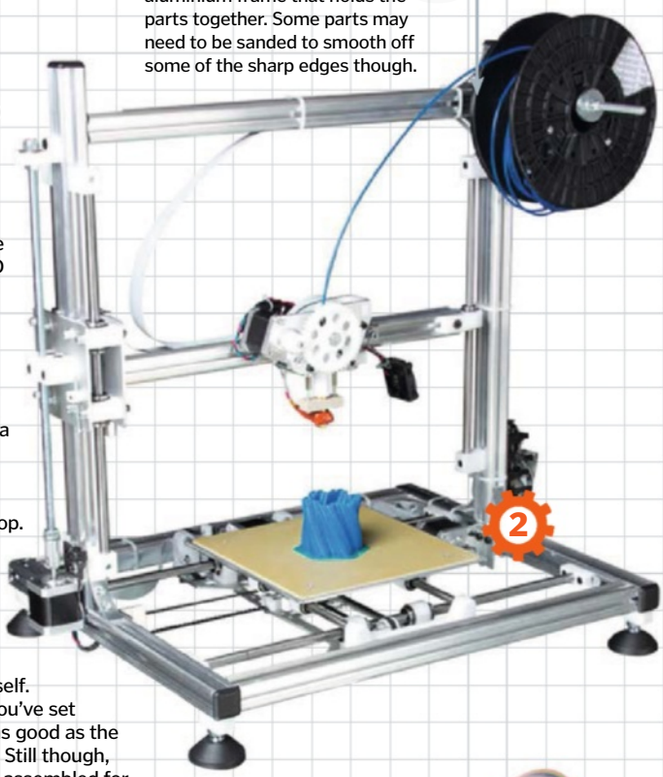
MakerBot is probably the biggest name in 'prosumer' 3D printing at the moment – the Cupcake and Thing-O-Matic were hobbyist favourites, and very open to tinkering from more enterprising coders. It hit the mainstream when it announced the Replicator, referencing a popular sci-fi TV show gadget that would regularly make cups of tea. The Replicator 2 is the first of MakerBot's 3D printers that are specifically aimed at a more professional clientele, and it shows from the switch to a more rugged, metallic construction.

Using the Replicator 2 is very simple. After a guided setup process to make sure your build platform is perfectly aligned, you can start printing off projects by merely adding a compatible X3G file to an SD card and selecting it from the easy-to-use LCD panel. While it doesn't initially accept the more universal STL file type, the MakerWare software distributed by MakerBot itself can easily create usable print files, and even combine several at once to allow for mass production or printing of multi-part objects.

While it's not as open to tinkering as it was in the past, it's definitely a lot more accurate and powerful than the previous iterations. A delight to play with!

**Verdict:** ★★★★★

**Aluminium construction**
It's not the smallest, but it's definitely light due to a minimal aluminium frame that holds the parts together. Some parts may need to be sanded to smooth off some of the sharp edges though.



## 2 Velleman K8200

**Price:** £699.99/$N/A
**Get it from:** www.maplin.co.uk
The K8200 is the cheapest product in our group test, and also the one that comes in the most pieces. While the UP! Plus 2 was one of the first 3D printers to ship prebuilt, the K8200 requires some serious patience, a steady hand and some accurate callipers to put together.

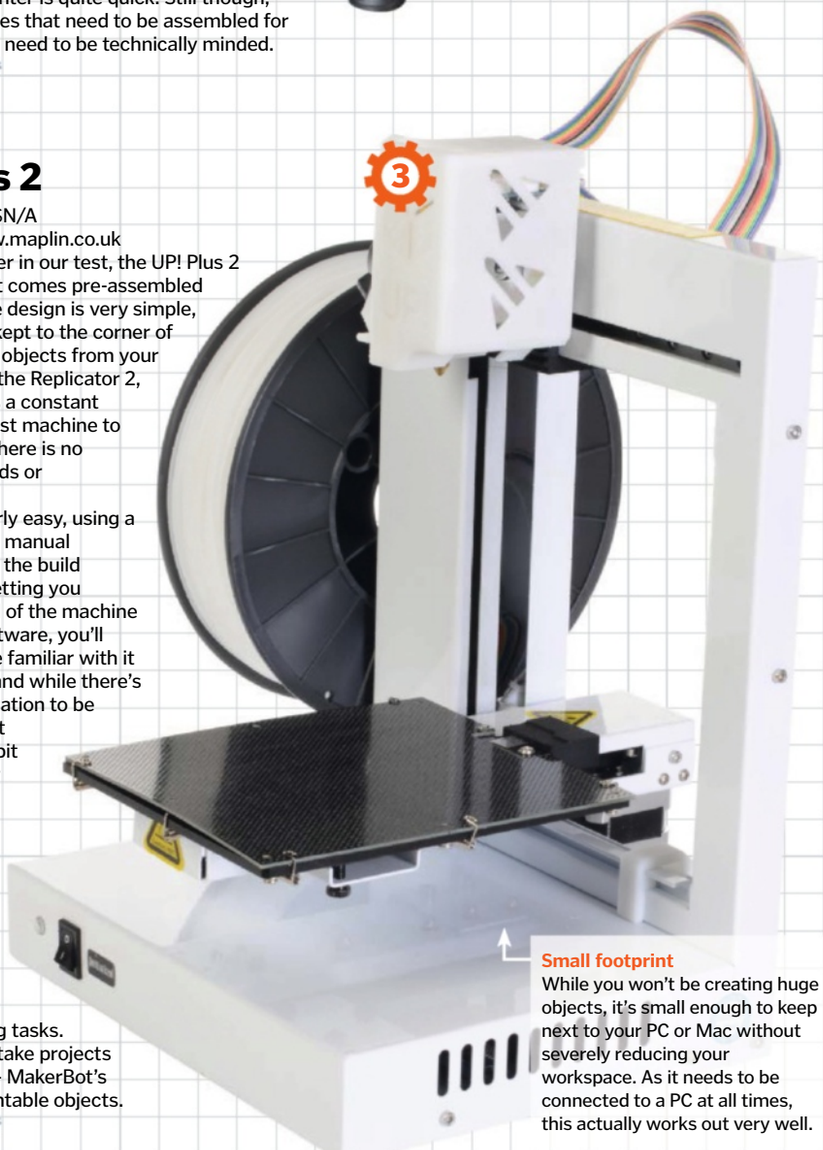
Once the assembling and calibration has been done, you can start to print objects. This is done in a two-fold process – 3D models are sliced up using the free software Slic3r, before being loaded into Repetier to then be printed via a laptop.

It's all a lot more complicated and manual than the other two printers here, especially compared to the ease of use of the MakerBot. You can at least use STL files from Thingiverse, as long as you reslice them for the K8200 itself. The objects it produces, as long as you've set up the printer exactly correctly, are as good as the others, and the printer is quite quick. Still though, there are 700 pieces that need to be assembled for this printer, so you need to be technically minded.
**Verdict:** ●●●○○

## 3 UP! Plus 2

**Price:** £1,619.99/$N/A
**Get it from:** www.maplin.co.uk
The smallest printer in our test, the UP! Plus 2 is another one that comes pre-assembled out of the box. The design is very simple, and can easily be kept to the corner of a desk for printing objects from your PC or Mac. Unlike the Replicator 2, the Plus 2 requires a constant connection to a host machine to print projects, as there is no support for SD cards or USB storage.

Setting up is fairly easy, using a piece of paper and manual alterations to level the build platform before getting you started. As control of the machine is done via the software, you'll become a lot more familiar with it than Makerware, and while there's plenty of customisation to be made on the way it builds, it can be a bit trickier to get your head around in the first place. The Plus 2 will also take STL files without any conversion, saving some time while printing and allowing for some automated printing tasks. This means it can take projects from Thingiverse – MakerBot's website for 3D printable objects.
**Verdict:** ●●●●○



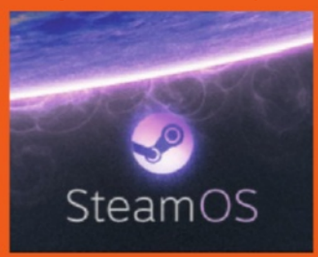
**Small footprint**
While you won't be creating huge objects, it's small enough to keep next to your PC or Mac without severely reducing your workspace. As it needs to be connected to a PC at all times, this actually works out very well.

# ON THE HORIZON

We highlight four other items to look out for in the near future

### SteamOS

Valve, the folks behind smash-hits *Half-Life*, *Left 4 Dead* and *Portal*, have been in the PC game business for years now. Steam is ubiquitous with PC gaming, and their move into the living room has been a long time coming. The company announced a new operating system to do just that, and console-like boxes will be hitting stores over the next year.




### MintBox 2

There's a small company called CompuLab that makes equally small PCs about the size of a set-top box. What's not small about its hardware, though, is the raw power some of the boxes produce, like the MintBox 2. Based on its Intense PC, it is a highly customisable little box packed with RAM, storage and an Intel i5 CPU. It can be used to power a serious media centre or a desktop computer that needs to squeeze into a small space.

### Sony NEX5 Compact Camera

The Sony NEX range of compact digital cameras are some of the best small digital cameras you can get without shelling out for an expensive DSLR. The new NEX 5 range now includes NFC connectivity to get photos to your phone quicker, while still containing the mirrorless design with interchangeable lenses.

### Nexus 5

The Nexus line of smartphones is the base on which Google develops for, meaning if you want to always be up to date, a Nexus is the way to go. Made again by LG, the next Nexus has the usual round of hardware updates, and will be the first to receive the Android 4.4 KitKat.

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# Star hop like a pro

Learn how to navigate the night sky with a telescope or pair of binoculars

### 1 Go old school

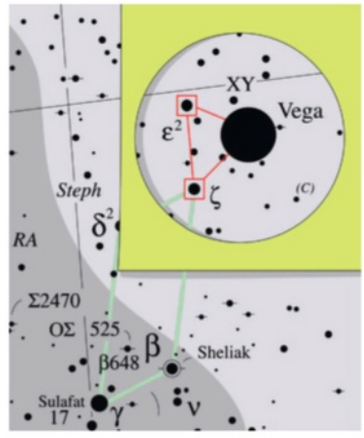
The simple solution to finding a celestial object is to use 'GoTo' systems on a modern telescope. These orientate a telescope to a desired object with almost no user input. If not available, you must star hop, ie navigate through the night sky to a target by jumping from one known celestial object to another. When using small mobile scopes this is often an essential skill. For any budding astronomer, it is a feather in the cap.

### 2 Get chart friendly

To star hop there are a few things you need, and a star chart is a must-have. As such, acquire the clearest chart available, one that shows stars and other objects clearly. Now remember, while you can probably see the chart's contents clearly when you buy it in the middle of the day, at night it will be – hopefully – pitch black. As such ensure you partner the chart with a red light torch.

### 3 Find your field

Determine the field of view (FOV) of your binoculars/telescope. This is typically written on binoculars but not telescopes. To find the FOV on telescopes divide the apparent FOV of the eyepiece (usually specified by the manufacturer) by the telescope's magnification. Remember the telescope's finder scope has a larger FOV than the main scope, so start with the lowest magnification eyepiece you have.




### 4 Try templating

It's useful to have a FOV template to use with the star chart. This can be achieved with a few square centimetres of clear plastic, a drawing compass and a felt-tip pen. Find a star on the chart, centre the view finder on it, check the stars on the edge of the FOV, then draw a circle on the plastic with the compass point on the star in the middle of the FOV. By doing this you have encircled the stars on the edge of the field.

### 5 Star hop to target

Find a bright or easily recognisable star in the middle of your scope's FOV. Note the stars at the edge of the field in the direction your target object lies in. Move the scope so the stars that were at the edge of the FOV on one side are now on the other. Repeat, finding more chart-recognisable stars in the finder in the direction of the target object. You can jump in a controlled manner across the night sky, using the chart as a map to follow your target.

### In summary...

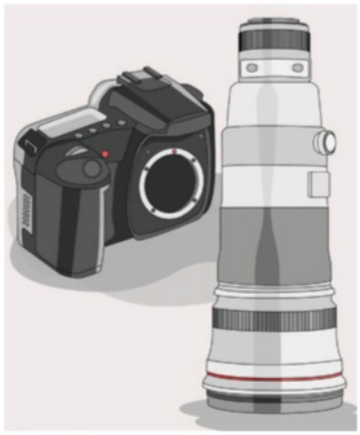
Star hopping seems difficult. However, it is deceptively simple if you break down the insanely complex night sky into small, easily navigable segments. Use a good star chart, ascertain what your piece of viewing equipment's field of view figure is, create a template, and take your time moving from one recognised celestial object to another.



**NEXT ISSUE**
- Make a Christmas pudding
- Winterproof a garden

# Photograph the Moon

## Want stunning images of our satellite? Then follow these three simple steps…



### 1 Equipment & setup

You will require a telephoto lens, as if you shoot the Moon with a standard 50mm variety the Moon will appear too small. Any telephoto lens 200mm or larger will deliver far better and larger results. Secondly, find a good position for your camera/tripod to rest upon where any movement will be totally eliminated, as even slight jolts or knocks will lead to a blurry image due to the required long exposure time.

### 2 Focus & exposure

Now we can focus on the Moon, something that should be done manually. Once the subject is in focus, input your desired exposure settings – something like aperture f/11, ISO 100, 1/25 – 1/250 should grant good results – and set your camera to self-timer mode (where the camera counts down before shooting). The latter is important as it eradicates potential camera shake induced by pushing the shoot button.

### 3 Shooting & settings

Try a couple of test shots then check your work, preferably on a larger screen than that installed on the camera. If you are not happy, try tweaking the exposure settings or taking sequential shots at different EV settings. Finally, once you have a shot that you are happy with, try tweaking it in a photo-editing program such as Photoshop – often the Moon can look spectacular in black and white or sepia colour tones.

### In summary…

Anyone can take a good picture of the Moon provided that they attempt the shot with the correct equipment, positioning and camera settings. Crucially however, patience is key to achieving a super-clear shot, with rushed attempts never turning out as desired.

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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. You may even bag an awesome prize for your efforts!

**AMAZING PRIZE FOR NEXT ISSUE'S LETTER OF THE MONTH!**

## WIN AN AWESOME SCIENCE BOOK!
Next issue's Letter of the Month winner will get a copy of *The Big Questions In Science*, a fantastic read that tackles some of the big conundrums like why we dream and if time travel is possible.

There are many theories to explain how life was created, but evolution has many advocates from the scientific world

## Letter of the Month

# Where did it all begin?

**Dear HIW,**

I would like to thank everyone involved in How It Works magazine for making all the articles enjoyable to read and very informative. I have learned a lot so far and I always look forward to your next issue.

What I love most about the magazine is the '10 things we've learned this month' articles and other little random facts. I like how detailed some of your articles are, but I do find some of them hard to follow. On these complicated and deep subjects I'd love to see a simplified version, maybe in a small box at the end of the article.

The only real criticism I have is that in many articles the writers have stated evolution to be a fact, when really it is just a theory that is yet to be proven. After years of weighing up the evidence for myself, in my opinion, I have found that there is actually more evidence to suggest that life was created.

Kind regards,
**Leanne Seddon, Wirral**

**Thanks for writing in, Leanne – we really appreciate your kind comments about the mag. Evolution is, of course, a very big can of worms to open and we always try to deal with such topics in a sensitive way, grounded in the facts, only discussing theories that have lots of evidence to back them up. That said, we understand there are a lot of different perspectives out there, so we're grateful you highlighted this issue. We hope you enjoy using your telescope to explore the wonders of space!**

## Bridging the gap

Hello,

I've been reading your excellent magazine since issue 1. It was great to see two bridges from the north-east of England in your aerial transfer bridges article in issue 51: Middlesbrough's Transporter Bridge spanning the Tees (from which my son has bungee-jumped!) and the tilting Millennium Bridge on the Newcastle-Gateshead quayside spanning the Tyne. However, I'm sorry to say that you missed a hat-trick opportunity.

A little farther up the river, just past the famous Tyne Bridge, lies the Swing Bridge which was missed from your list of bridges that move. I wondered if there are any others like it and whether you could print a picture of it? As us Geordies would say, "Howay man, it'd be champion!".

Regards,
**Derek Bousfield, Gateshead**

**Thanks for your letter, Derek. We're glad you enjoyed reading about your local landmarks – they really are incredible structures. Unfortunately we only have so much space in the magazine so we don't get to feature all the amazing things we'd like to. In fact, we were inspired to do an article on aerial transfer bridges in the first place when one of the team visited Cardiff and saw the transporter bridge at Newport while passing on the train. Newport's bridge didn't get a mention in the article either, so we hope this goes some way to redress the balance! And kudos to your son – you wouldn't catch us bungee-jumping off any bridge!**

©Thinkstock

"Would it be possible to filter out carbon dioxide and super-compress it into liquid form?"

## The future of spacecraft?

Hi HIW,

I had an idea (dangerous, I know) that it would be possible to run a spacecraft on nothing but infrared panels and an inert gas. You could use infrared panels to run the electronics. The shell would be made from a tungsten-zirconium alloy (the zirconium would be used as a replacement for titanium). The thrust would be provided by two VASIMR units on the back. VASIMR stands for Variable Specific Impulse Magnetoplasma Rocket. It produces plasma through the ionisation of gas with radio waves.

Also, I was thinking, would it be possible to do all of this and then filter out carbon dioxide and super-compress it into liquid form, then use it in the cooling system? Then, when the cooling system was full, just bottle the liquid carbon dioxide for fire extinguishers. Thanks!

**Jordan Godley (13)**

**It sounds like you've really thought this through, Jordan, and we particularly appreciate how you're also thinking about recycling with the $CO_2$ fire extinguishers! Now that NASA is finally back up and running after the US government shutdown, perhaps you'll be able to pitch your idea to them!**

## A model reader

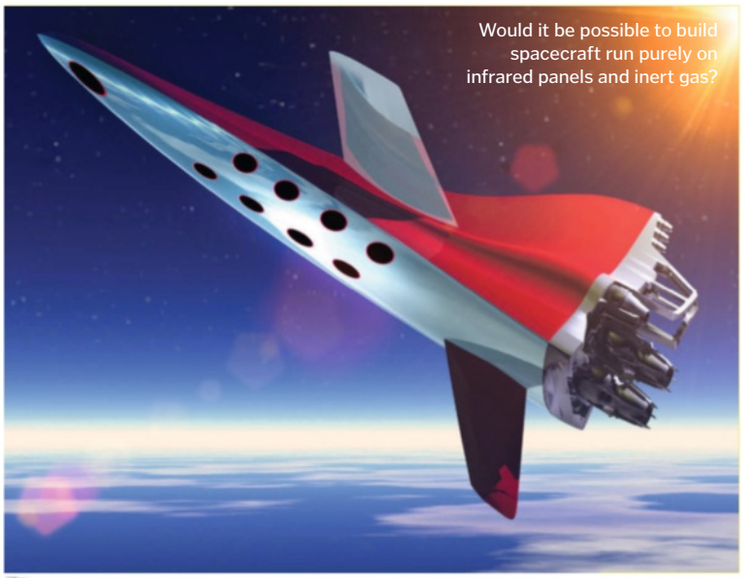
To the Editor,

I would like to know how much the 1:32 scale Ford Fiesta RS WRC model from Airfix is. Please could you let me know?

Yours sincerely,

**Q Razzaq**

**Sure thing! It costs £14.99. You can buy it from www.airfix.com/shop/cars/a03413-ford-fiesta-rs-wrc-132 or you can give them a ring on 01843 233525. Have fun building it!**



Would it be possible to build spacecraft run purely on infrared panels and inert gas?

## What's happening on... Twitter?

We love to hear from **How It Works'** dedicated followers. Here we pick a few tweets that caught our eye this month...

Smilliepimmbimms @gprpsp
Just got the new issue of **@HowItWorksmag** after fighting my 14-year-old for it

Jaz B @JSB_2000
**@HowItWorksmag** Started to read your mag at the end of a camp and soon people started flocking round the mag! Shows how awesome it is!

Martin @sociallynept
**@HowItWorksmag** – My son: How come I look at the Sun and it hurts my eyes but when I look at a photo of the Sun it doesn't?

Mary Ballard @yellowcumbrian
**@HowItWorksmag** Entered. Great #prizes. I've always loved to know how things work (wanted to be an inventor when little). My kids too

tony lannon @tonylan14
**@HowItWorksmag** loved the article about the Middlesbrough Transporter Bridge... from my hometown. I cycle over that bridge every week

Helen Porter @Lady_Laidlaw
Got mine! **@HowItWorksmag** Issue 52 is a very beautiful thing. Very well done, guys. It's a superb issue

Ollie Iron @Ollie_Iron
This month's **@HowItWorksmag** on page 20 will introduce you to the mucus glands. So at least you'll understand why it is you have a cold

Paul @Beeza68
Oi, grey mass in head. Wake up, October's HIW **@HowItWorksmag** is here. It's low in fat & chock full of learny goodness. Brain cells engage!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Issue 54 on sale 5 December 2013

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## ANSWERED NEXT ISSUE

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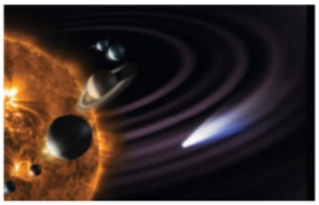
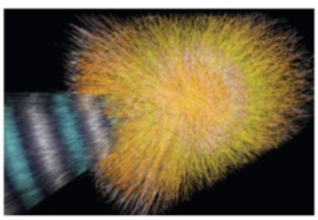


Which laws of physics govern the universe?

How is it possible for us to alter the climate?

How many ways are there to build a dam?



What happens when two particles collide?

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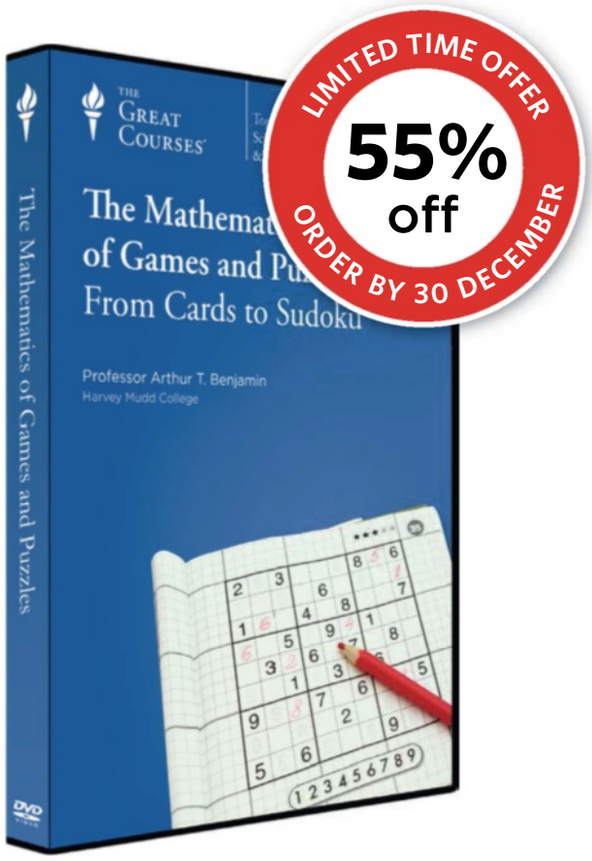


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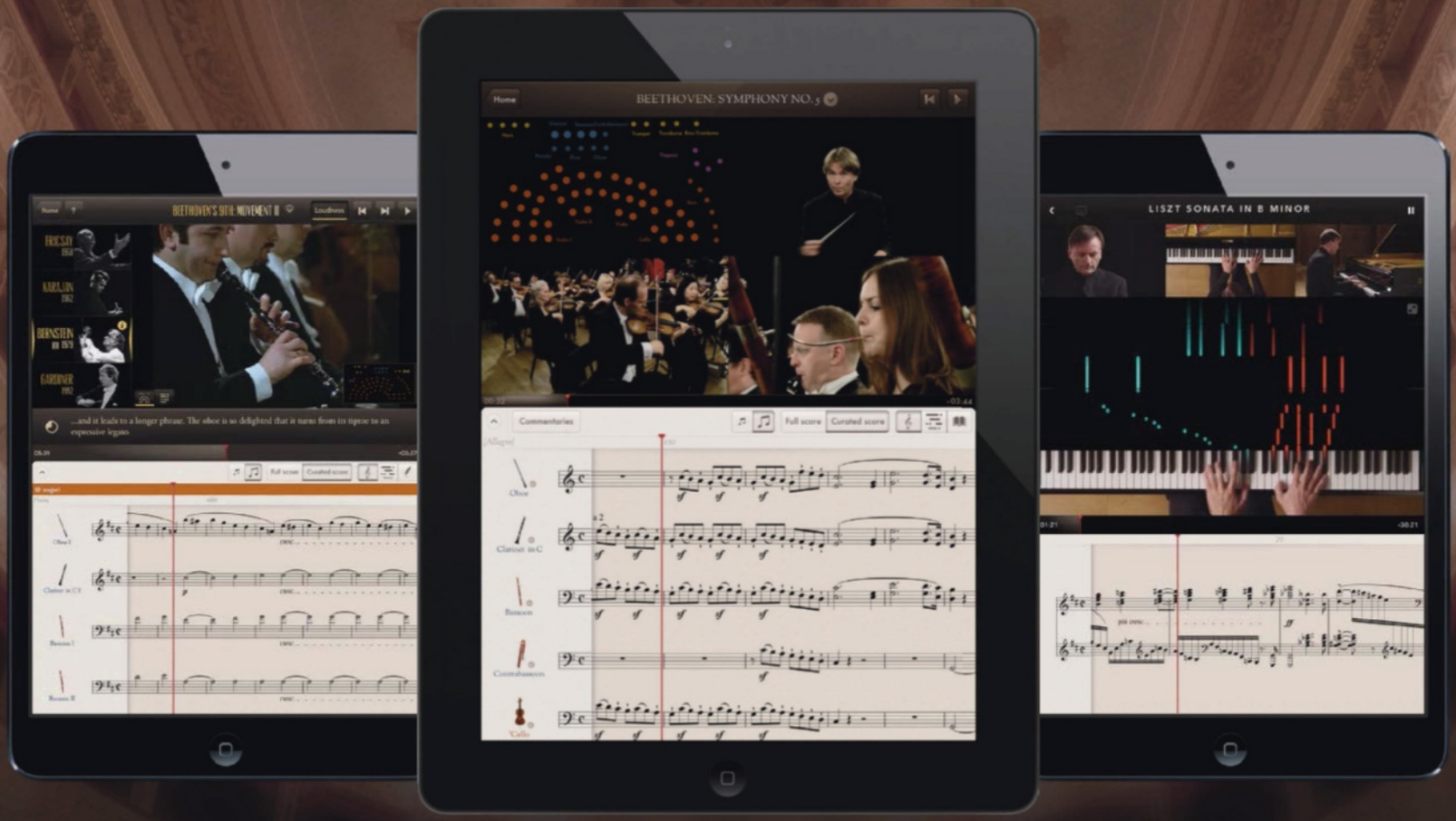


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