THE MAGAZINE THAT FEEDS MINDS

HOW IT WORKS

SCIENCE ENVIRONMENT TECH … TORY SPACE

INSIDE

AGE OF THE DINOSAURS
AN A-Z GUIDE TO THESE PREHISTORIC BEASTS

ELIMINATING SPACE JUNK
Meet the satellites set to clean up Earth's orbit

YOUR IMMUNE SYSTEM
How do our soldier cells get around the body?

21ST-CENTURY
COMBAT VEHICLES
INSIDE THE WORLD'S MOST POWERFUL & INTELLIGENT WAR MACHINES

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- NEUTRINOS
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- HEARING AIDS
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- WATER ON MARS

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Why is this watery habitat such a haven for wildlife?

TOUCHSCREENS EXPLAINED
The technology that lets us interact with our devices

ELECTRIC GUITARS
How these instruments create their unique sound

MEGA PLANETS
THE SECRETS OF GAS GIANTS REVEALED

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ISSUE 056
IMAGINE PUBLISHING

5 TOP FACTS:
Combustion Engine

The Beginning
The 4 stroke cycle engine was invented in 1870 by the German engineer Otto.

High Speed
The German engineer Daimler built the first high speed petrol engine in 1887.

Speed
Inside the cylinder the piston and connecting rod rise and fall some 6000 times a minute at speeds of 500km/hr or more.

Engine Types
In the early days of automobiles three types of engines were available, petrol, steam and electric.

Fuelling
In the early days people would buy petrol in the form of a 10 gallon can and pour it into the tank with the aid of a funnel.

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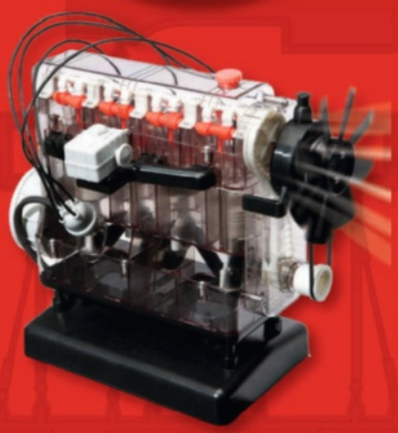


A42509
Combustion Engine

- **Lights imitate spark**
- **Moving pistons**
- **Motorised fan**
- **Light imitates combustion**
- **Thrust Control**
- **Revolving Turbine**

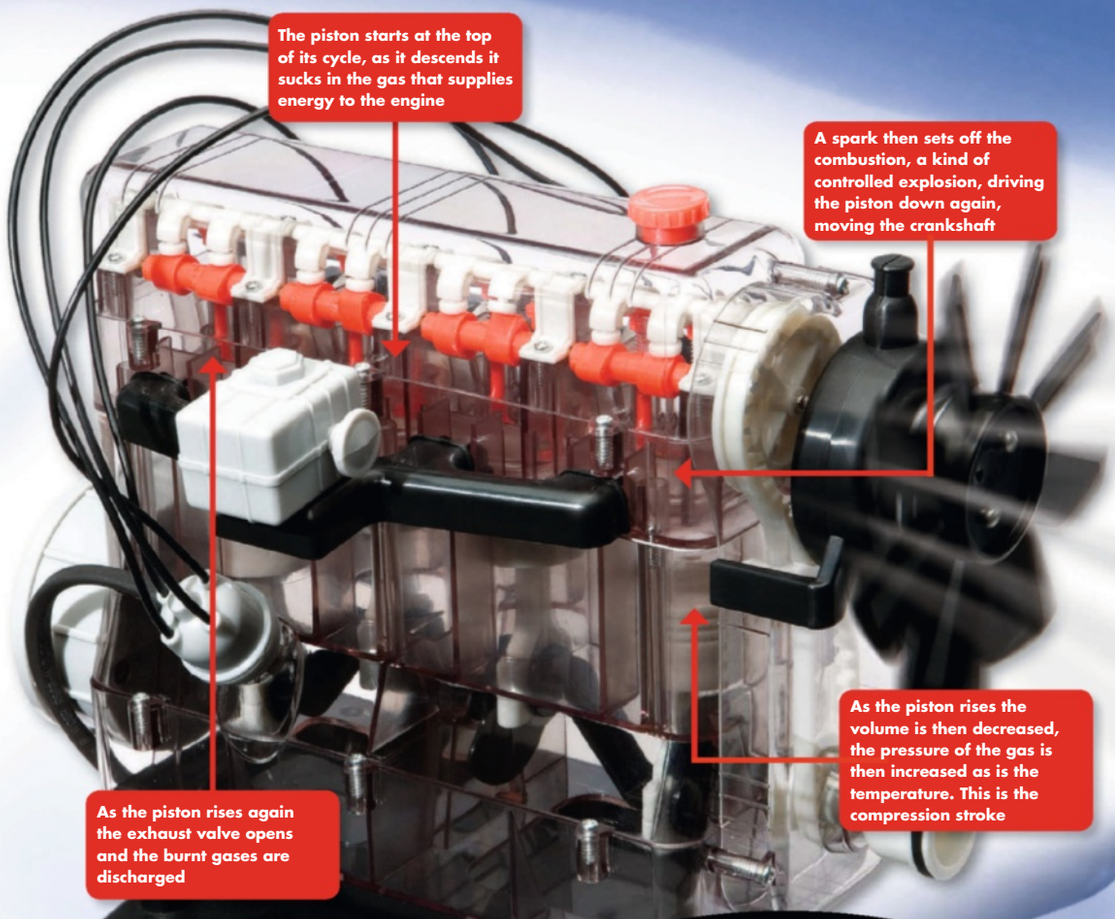
Discover how a combustion engine works by building your very own working model. Using the simplified instructions, piece together over 100 parts to build an engine with movement and lights.

This fantastic engine is a marvellous and fun way to learn all about how an internal combustion engine works.

First the engine 'starts up' and then it runs 'firing' to show how the combusting fuel and air drives the pistons down to make the crankshaft turn.

Scan this QR code with your smartphone to find out more!

HOW IT WORKS



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ISSUE 56

WELCOME

The magazine that feeds minds!

Page 68
Learn how these amazing prehistoric beasts lived and what drove them extinct in our A-Z guide

It's a well-known fact that many of our greatest engineering feats have been born out of warfare. While weapons, of course, play a big part in the life of a combat vehicle, equally important are its defensive capabilities, its advanced computing tech and how it gets around – and it's these latter technologies which often trickle down into the civilian world. By taking a peek inside some of today's most cutting-edge war machines this month, we are getting a glimpse into the future of everyday transport. And let's face it, fighter jets, attack helicopters and battle tanks are just plain cool.

Also effortlessly cool are dinosaurs. They capture our imagination more than any other animal that has ever roamed Earth. In a special feature we celebrate all things dino, from their anatomy and how they communicated to what the movies got wrong. Enjoy the issue.

Adam Millward
Deputy Editor

Meet the team...

Marcus
Senior Designer
Humans will be spoilt for choice in where they live in the future. Covered in this issue is the possibility of living underwater for people sick of land.

Erlingur
Sub Editor
I'm fascinated by dinosaurs. Even though I know the Velociraptors in *Jurassic Park* aren't entirely realistic, I still want one as a pet.

Jackie
Research Editor
There are so many tiny organisms beyond what we can see; it's amazing to think that something only a few micrometres long can be alive.

Helen
Senior Art Editor
The epic scale and depth of the Grand Canyon never fails to impress. Discover the powerful natural forces behind its formation on page 24.

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

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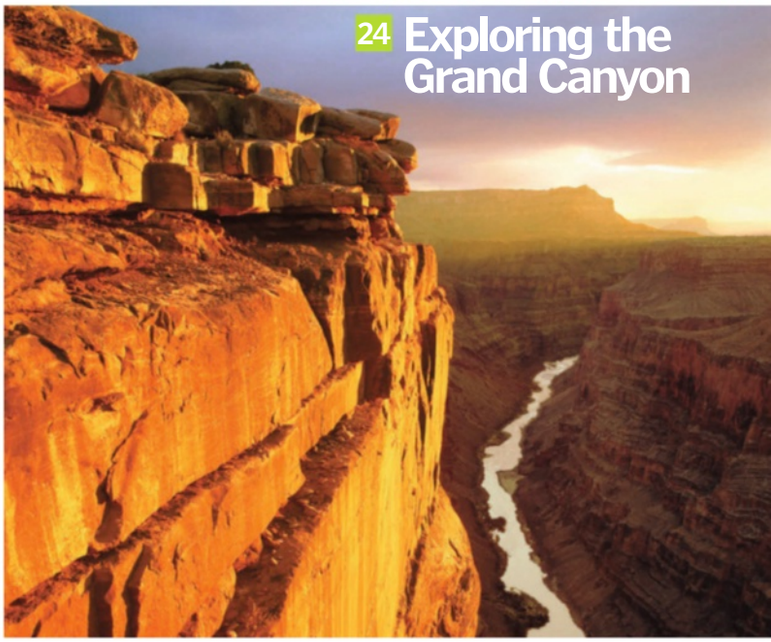
From fighter jets to battle tanks and attack helicopters, we reveal the engineering under the hood of today's deadliest war machines...



Meet the experts...

Luis Villazon
Underwater buildings
Luis dives into this month's Technology feature to guide us through the construction process behind aquatic dwellings, which are springing up under the sea.

Rob Jones
Age of the dinosaurs
Rob takes us back to the prehistoric era to uncover the anatomy of famous dinos as well as looking at how palaeontology reveals their secrets today.

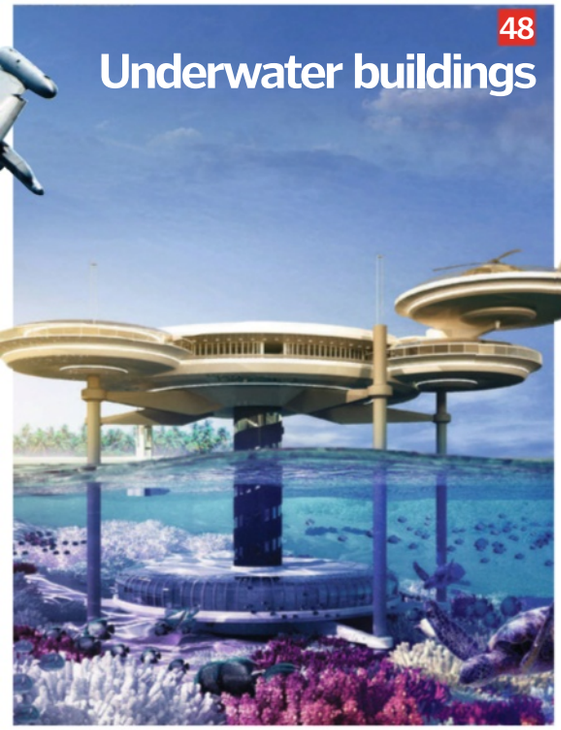
Giles Sparrow
Mega planets
Space expert Giles is back to reveal the origins and mysteries of the biggest planets in our Solar System and how we go about studying gas giants.

Vivienne Raper
Grand Canyon
Vivienne takes us on a tour of one of the best-known natural wonders, explaining its unique ecosystem and how natural forces carved it out.

Laura Mears
Tiniest life on Earth
They might be only a few nanometres in size, but Laura puts micro-organisms under the microscope to reveal why they're so adept at survival.

How can space junk be cleared from orbit using cleaner bots? Find out on page 41

REGULARS



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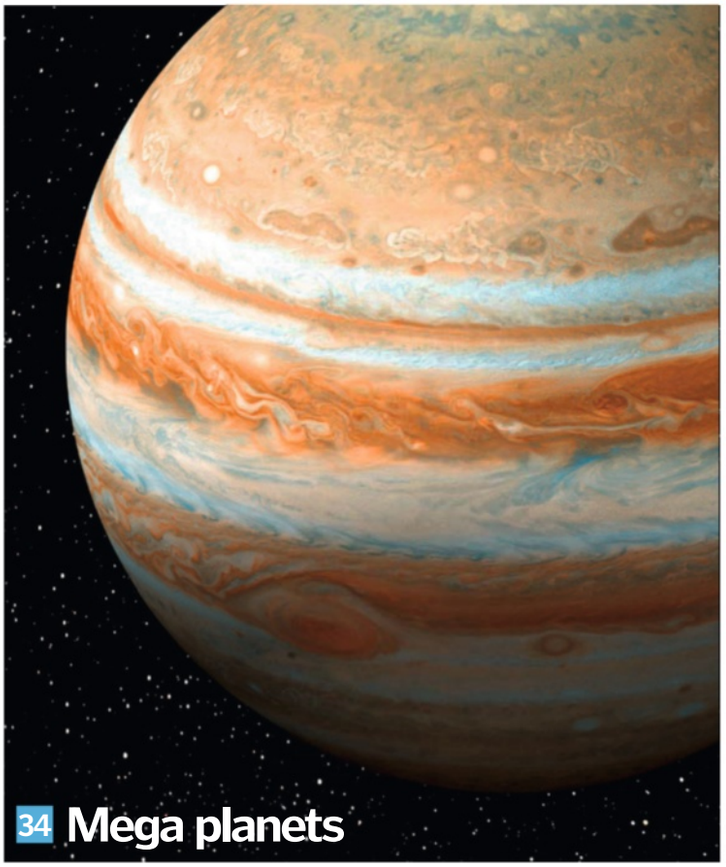

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56 Electric guitars

GLOBAL EYE

Showcasing the incredible world we live in

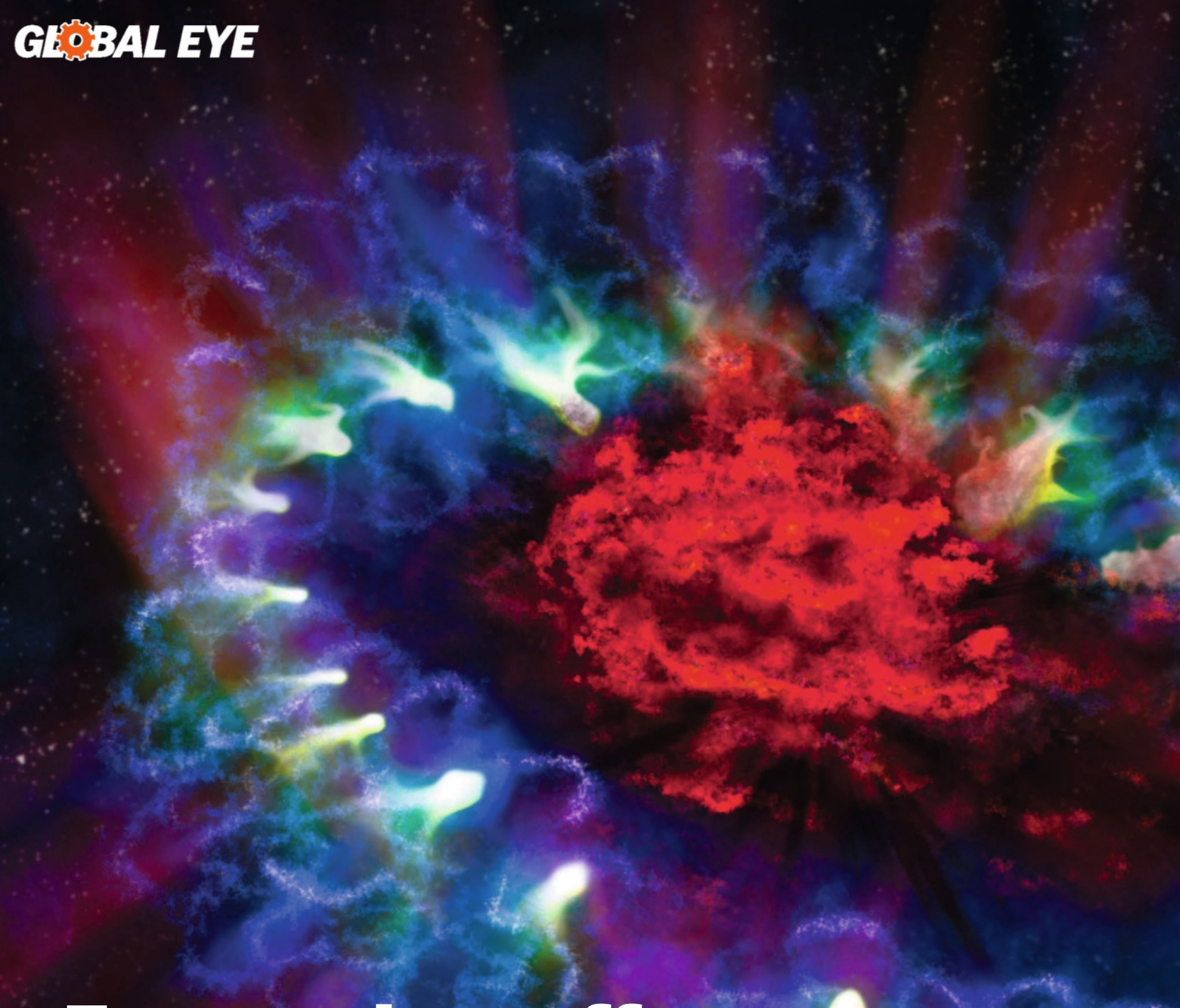
New super-sub set to take plunge

The latest state-of-the-art Astute-class submarine prepares for tests at sea

With two sister vessels already in service, the third Astute-class sub – HMS Artful – is due to commence sea trials imminently. With a displacement of 7,400 tons and at 97 metres (318 feet) long, the nuclear-powered attack submarine is an impressive sight to behold, but what really makes this the most advanced sub ever built for the Royal Navy is the tech inside. Its nuclear power source is great enough to power a city the size of Southampton, UK, and means it never has to be refuelled. And because all its oxygen and fresh water are extracted from the ocean, an Astute-class sub can go round the world without surfacing once. The sonar equipment is so sensitive that it can detect a ship leaving New York harbour from the English Channel.

A total of seven Astute-class submarines are planned, with HMS Artful due to enter service by 2015. Such a major project as this requires an equally impressive construction facility. At 51 metres (167 feet) high and 260 metres (853 feet) long, the Devonshire Dock Hall in Cumbria (pictured here) is one of Europe's largest shipbuilding sites.

The forward-end construction of the fifth Astute-class submarine, Anson, lining up alongside its sisters, Artful and Audacious. HMS Astute and HMS Ambush are already in service in the Royal Navy © BAE Systems



Ex-star dust offers clues to galaxy origins

Earth's biggest telescope lends weight to long-held theory that supernovas produce the building blocks of galaxies

Recent images by the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile have captured unprecedented levels of fresh dust at the heart of a supernova. While dust might not sound like the most exciting of finds, it is these tiny particles that are thought to go on to form planets and stars, so establishing their origins is a major breakthrough.

"Supernovas have long been thought to be the creators [of cosmic dust]," explains Remy Indebetouw from the National Radio Astronomy Observatory. "But catching one in the act is far from easy. And even when we do spot a supernova cloaked in a dusty plume, there's the old chicken-egg problem: how do we know that the cloud wasn't there first?"

Aiming to bust the dust mystery once and for all, an international team of researchers used the super-powerful ALMA radio telescope to study the 1987A supernova – the closest to be observed since 1604 – located some 168,000 light years from Earth. The results were conclusive, as Indebetouw continues: "We found a remarkably large dust mass concentrated in the central part of the ejecta. And all of that matter – the red area… at the centre of the picture – was there in the core of the star before it exploded. That's the exciting thing."

The main ALMA array comprises 66 antennas working together to gather super-detailed images

The massive helium balloon will have a volume of about 1.1mn m^3 (40mn ft^3)

Space tourism beyond planes

We've all heard about SpaceShipTwo aiming to take its first commercial passengers off Earth in 2014, but planes aren't the only vehicles heading out of this world – soon we'll also be able to get an astronaut's view of our planet by balloon. World View's high-altitude helium balloon will venture to around 30 kilometres (19 miles) above the surface carrying eight people (six passengers and two crew) in a pressurised gondola below. The voyage will not only offer spectacular views of the planet's curved edges and the cosmos beyond, but also allow those on board to experience a few seconds of weightlessness during a short period of rapid descent. World View is currently accepting reservations for the slated 2016 maiden flight.

Lightning can shape mountains

It's always been assumed that mountains take hundreds of thousands of years to erode, but new research suggests the process can be much quicker in a stormy climate. In fact, scientists studying the Drakensberg Mountains in South Africa believe up to ten cubic metres (350 cubic feet) of rock can be demolished by a single lightning strike. The damage is caused when the electricity hits the mountain and rapidly vaporises water underground. As the vapour seeks to escape, nothing can stand in its way – not even tons of rock. When hit by lightning, minerals in the rock have their magnetic field reversed, making previous strikes detectable with a compass.

The king of beasts' secrets revealed

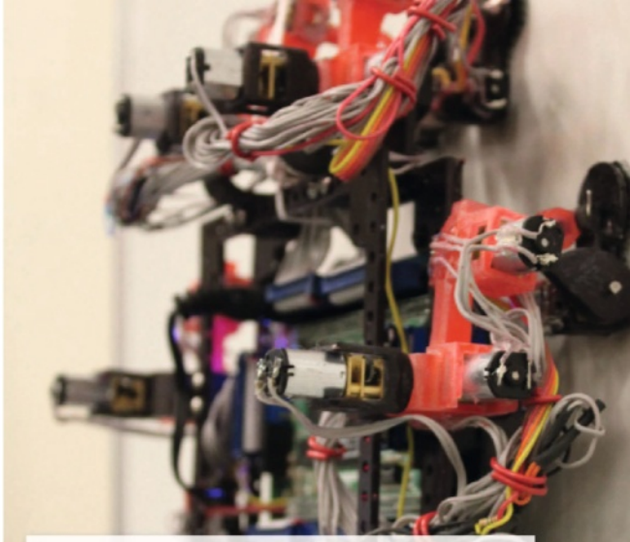
The latest edition of **World of Animals** is packed with amazing wildlife stories from all over the globe, but the star of the show is the mighty lion. In issue 3's main feature, you'll follow in the paw prints of Africa's biggest cats and learn about every aspect of their lives, from how they hunt and rear cubs to the strict social order of the pride. You'll also discover why humans and animals are more alike than sometimes assumed, in an article that explores 50 traits we have in common. You can buy **World of Animals** at all good newsagents or digitally via iTunes. For even more animal action, go to **animalanswers.co.uk**.

GLOBAL EYE

10 COOL THINGS WE LEARNED THIS MONTH

Earth has put on weight

After tracking the movements of several satellites orbiting Earth – which are determined by our planet's gravitational pull and ultimately its mass – a GPS expert has suggested the world could be up to 0.008 per cent heavier than currently estimated. Ben Harris from the University of Texas, USA, suspects the most likely explanation for this deficit is a disc of invisible dark matter, up to 70,000 kilometres (43,500 miles) across, hugging the equator. If his calculations prove accurate the secrets of elusive dark matter – believed to constitute up to 80 per cent of the universe yet so hard to pin down – could soon be illuminated.

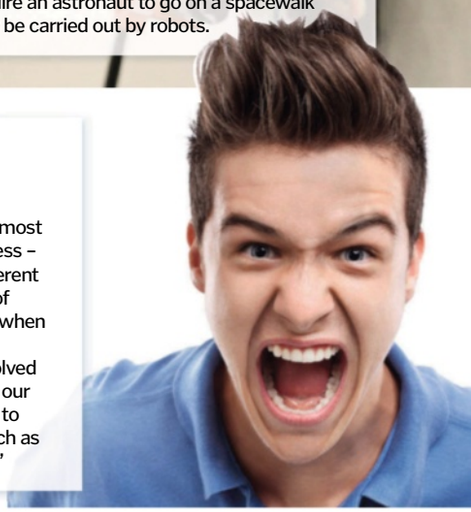


Robot geckos are training for space

The ESA and Simon Fraser University in Canada have demonstrated how gecko-inspired robots are perfectly suited to life in space. By imitating the micro hairs found on a real gecko's foot, the impressive grip of Abigaille crawling robots (pictured) has been known for some time. This latest research has shown that the gecko bot loses none of its sticking power when subjected to the vacuum and temperatures encountered off Earth. Thus, maintenance jobs on satellites and space stations that currently require an astronaut to go on a spacewalk could one day be carried out by robots.

Our emotions can be mapped in the body

A study into human emotion has revealed that our most basic feelings – from anger to sadness and happiness – create distinct sensations, experienced across different areas of the body. The findings support a number of everyday expressions, from feeling 'warm all over' when happy to 'weak at the knees' when in love. Lauri Nummenmaa from Aalto University in Finland, involved with the study, explains: "Emotions adjust not only our mental, but also our bodily states. They prepare us to react swiftly to dangers [and] the opportunities such as pleasurable social interactions in the environment."



A cure for tone deafness is in sight

Being able to distinguish musical notes with what is known as 'absolute pitch', like legendary musicians such as Mozart, has long been a talent you either have or you don't. However, a study into how mood-stabilising drugs affect our ability to learn suggests we might be able to develop a pill to hone not only this skill but many others too. Participants took either valproic acid (VPA), which contains an inhibitor changing how the brain reacts to stimuli, or a placebo, before being given a music lesson. Test results revealed that, on average, those given VPA identified pitch far more accurately than the control group. If chemicals are able to reorganise neural pathways that are usually firmly established during childhood, this could open up possibilities in not only adult learning but psychiatric treatment as well.

The ultimate sunroof has arrived

Solar energy is increasingly being used to power buildings and supply energy to our cities, but soon it could be directly fuelling our cars. At the latest Consumer Electronics Show (CES) held in early January in Las Vegas, Ford revealed its C-MAX Solar Energi Concept which boasts a solar panel on its roof. It will reportedly be able to harvest the same power as a four-hour battery charge and travel a distance of 34 kilometres (21 miles). The car still features a conventional electricity port to supplement the rooftop cells, which would be charged using a special Fresnel lens that can adjust with the Sun's movement to maximise its energy.

Bacteria can stop deserts in their tracks

As a result of intensive farming, the deserts of northern China have been expanding for decades, forcing thousands to relocate. But now there is a new secret weapon against the creeping sand – cyanobacteria. The trick to reversing desertification is to rebind the top layer of soil so it's not so prone to drying out and blowing away in the wind. Planting tough species of grass helps a little, but still allows sand and dust through the gaps. After an eight-year trial, researchers from the Chinese Academy of Science have found spraying cyanobacteria onto the dunes greatly improves soil integrity. The micro-organisms photosynthesise sunlight and form a sticky mat that holds loose earth together, encouraging more plants to take root as well as absorbing carbon dioxide.

Human hunters move like sharks

Working with the Hadza tribe of Tanzania – one of the last big game hunters to forage on foot – a new anthropological study has shown we seek food in a similar way to creatures like sharks and bees. The Hadza hunters were given watches with GPS to track their route, which flagged up a familiar pattern in nature known as the Lévy walk; this involves several small movements in one area, before embarking on a longer distance to a new area. This pattern has not only been observed when humans are searching for food in the wilderness, but also when walking around towns or even attractions like theme parks, as well as in many animals' hunting-gathering behaviour.

Zebra stripes work like an optical illusion

Several theories have been put forward as to why zebras have evolved their distinctive black and white markings – and the latest research suggests the stripes work as an optical illusion to dazzle and confuse their enemies. The variation in stripe thickness and direction across the animal's body – particularly when zebras are moving in large herds – fool the built-in motion detection mechanisms of any onlookers. By way of comparison to similar optical illusions the researchers offered the example of a barbershop pole, where the painted stripe appears to move upwards as the pole spins. Often buying individuals the valuable seconds needed to escape, this defence method is apparently effective not only on predators like big cats but works to confuse tiny biting insects as well.

Colonists take one step closer to Mars

In one of the most ambitious space missions ever devised, 200,000 people applied for a one-way ticket to the Red Planet. Now they have been whittled down to a long list of just over 1,000. Mars One is seeking to establish a human colony (illustrated below) on our celestial neighbour by 2023, with prior missions dropping off the living habitat and supplies.

All 1,058 applicants are over 18, with most (297) hailing from the USA. This group will now undergo "rigorous simulations, many in team settings, with a focus on testing physical and emotional capabilities", according to the programme's chief medical officer, Norbert Kraft, in order to select 40 candidates for training that begins in 2018.

You can't cook chips in microgravity

After a throwaway comment by a Russian ISS cosmonaut who had a craving for 'fried potatoes', Greek scientists set about looking into the feasibility of cooking chips in space. The test involved putting the potato snack into a modified centrifuge prior to cooking, with the spinning motion re-creating the effects of hypergravity. The chips supposedly proved a success at a force of three g – three times the gravity of Earth – akin to that on Jupiter. But there are serious doubts whether frying and boiling can ever work properly in environments with less gravity than Earth – or practically none at all like on the ISS – due to fundamental differences in the way liquids behave under these conditions.

21ST-CENTURY COMBAT VEHICLES

THE MODERN BATTLEFIELD IS A HIGH-TECH, HIGH-STAKES RACE FOR MAXIMUM FIREPOWER

The 20th century witnessed the greatest escalation in deadly force in history. The fate of nations has rested in the hands of ingenious engineers dreaming up bigger and badder war machines.

Ever since World War I, battle tanks have played a pivotal strategic role in large-scale warfare, both during invasions and in defence of high-value ground. The main job of a tank squadron is to take out other tanks. In a fire fight, the tank with the thickest skin and the most armour-piercing firepower wins. When it comes to battlefield supremacy, the British-made Challenger 2 is a true beast.

With a battle weight of some 63 tons (139,000 pounds), the Challenger 2 is surprisingly nimble, reaching top road speeds of 59 kilometres (37 miles) per hour. But its real talent is blowing stuff up. One blast from the Challenger 2's 120-millimetre (4.7-inch) main gun will level a lesser tank, while its own crew is protected by next-generation armour. The explosive reactive tiles built into its front and flanks respond to a rocket-launched grenade attack by repelling enemy rounds in the opposite direction.

Tanks are excellent at holding ground in a warzone, but if you want a truly versatile fighting machine, nothing beats an attack helicopter. The current chopper of choice for the US Marines is the AH-1Z Viper, codenamed 'Zulu'. The four-bladed Viper reaches top air speeds of 410 kilometres (255 miles) per hour, perfect for rocketing behind enemy lines for a late-night rescue mission. And its firepower – including Hellfire air-to-ground missiles – provides critical close-air support for a ground invasion.

The Viper isn't all strength and speed though; it's also smart. Using a host of sensors and radar equipment, the onboard computers can distinguish between friend and foe, target and track multiple guided missiles, as well as transmit air reconnaissance data to ground troops. Even the Viper's pilot helmets are smart, featuring heads-up displays in the visors that overlay flight routes and enemy targets directly onto the landscape below.

While the Zulu may be a new kid on the block, even more senior attack helicopters can be ▶

332.9m

BIGGEST EVER WARSHIP

With a flight deck over 330m (1,080ft) long and a displacement of 102,000 tons, the Nimitz aircraft carrier is the largest warship built to date. It can accommodate a crew of 6,000 and over 80 planes.

DID YOU KNOW? *The HMS Ambush sub replaces periscopes with advanced sensors connected by 100km (62mi) of cabling*

Weapons
As well as a 27mm (1in) Mauser cannon and short-range missiles, the arsenal of this fighter jet includes some of the deadliest weapons around, such as the ramjet-propelled Meteor missile.

Countermeasures
The Typhoon's Defensive Aids Sub System (DASS) boasts numerous flares and decoys to throw off incoming missiles.

Powerplant
The twin EJ200 turbofans are 74cm (29in) in diameter and each provide 90kN of thrust. Offering a top speed of Mach 2, the same jet engine is used to power the Bloodhound SSC supersonic car.

Airframe
The shell of the Eurofighter Typhoon is made with composite materials that aim for strength, lightness and stealth. 70 per cent of the structure is made from blends of carbon fibre and only 15 per cent comprised of metal.

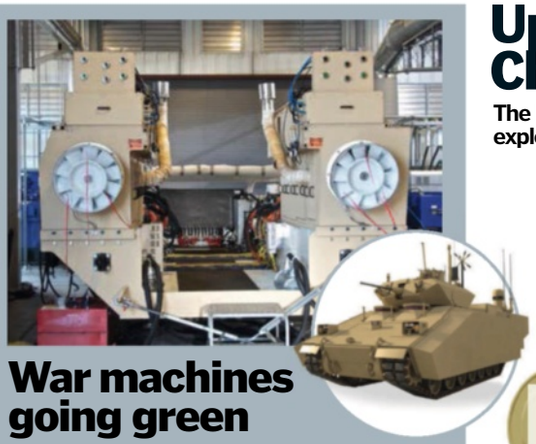
"The Typhoon is only 15 per cent metal, making it all but invisible to radar"

taught new tricks, as demonstrated by the latest reincarnation of the Apache (see page 18). But for all the power of tanks and speed of helicopters, the ultimate modern war machine has to be the fighter jet. Dominance in the air generally translates into dominance on the ground. Radar-eluding jets can penetrate deep into enemy territory and fire laser-guided missiles to destroy a target in seconds. One of the most advanced models in service is the Eurofighter Typhoon.

At a cost of £126 million ($208 million) per plane, the Typhoon is designed to be an all-in-one soldier of the skies. It can perform reconnaissance with its scanning radar, take out enemy aircraft in a close-range dogfight and drop heavy payload bombs on long-range targets – all on the same mission. The Typhoon is only 15 per cent metal, making it all but invisible to radar, and its intentionally 'unstable' delta-wing design provides maximum agility at subsonic speeds and peak performance during supersonic flight.

Of course, the war machines of the future may not even need people on board. Unmanned drones have already proven deadly accurate in locating and destroying key enemy targets. An MQ-9 Reaper drone can deliver laser-guided missiles and air-to-ground Hellfire missiles, all with the push of a button far away. It's not hard to imagine tomorrow's battles being played out by swarms of remote-controlled war bots.


The Challenger 2's Chobham armour is reported to be twice as strong as steel

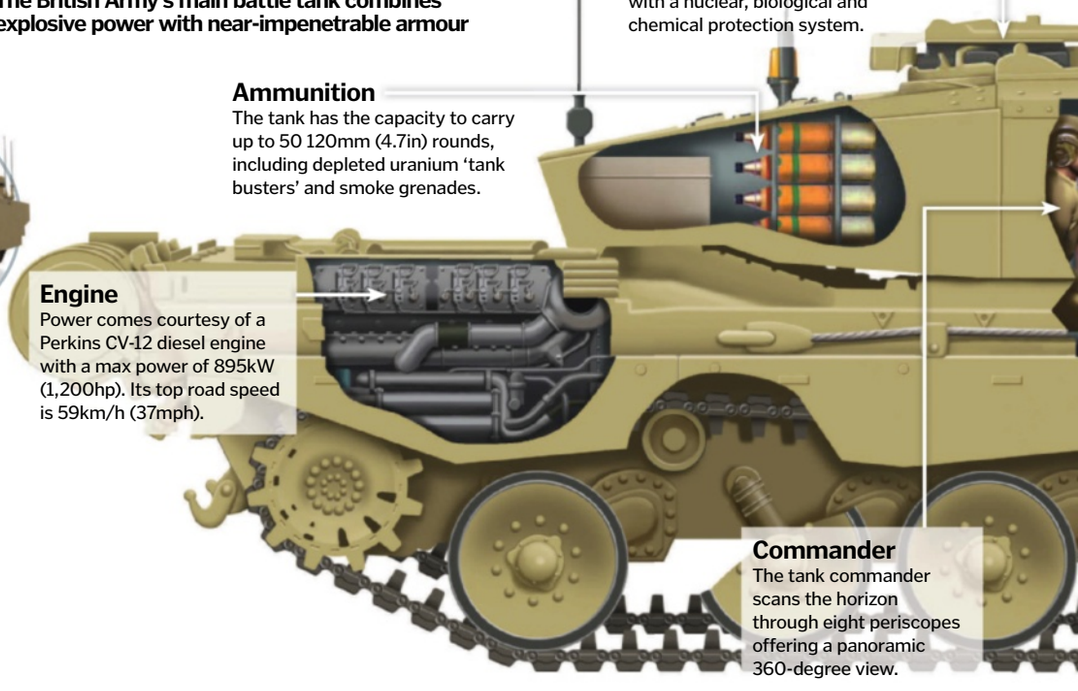


War machines going green

The BAE Ground Combat Vehicle (GCV) is the Prius of the tank world. Powered by a hybrid-electric propulsion system, the GCV offers the US Army more than savings at the petrol pump. The lightweight engine frees up weight that can be added to the tank's armour. Energy stored in the propulsion system allows for maximum power at startup. The hybrid engine also produces 1,100 kilowatts of exportable electricity – enough to power the advanced onboard computers and portable battle gadgets. Less fuel consumption also means fewer supply lines, which are a frequent target for roadside bomb attacks.

Up close with the Challenger 2

The British Army's main battle tank combines explosive power with near-impenetrable armour



Turret
The Challenger 2's turret rotates a full 360 degrees and is equipped with a nuclear, biological and chemical protection system.

Ammunition
The tank has the capacity to carry up to 50 120mm (4.7in) rounds, including depleted uranium 'tank busters' and smoke grenades.

Engine
Power comes courtesy of a Perkins CV-12 diesel engine with a max power of 895kW (1,200hp). Its top road speed is 59km/h (37mph).

Commander
The tank commander scans the horizon through eight periscopes offering a panoramic 360-degree view.

1916 The British Mark I tank debuts at Flers-Courcelette armed with two 57mm (2.2in) naval guns.

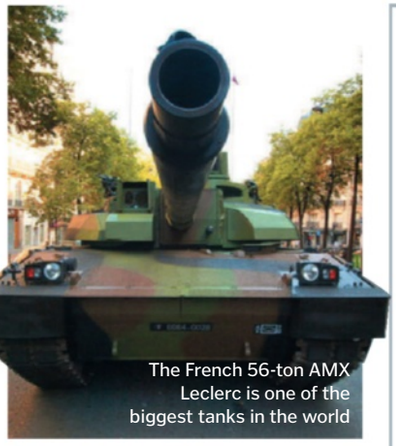
1922 The USS Langley was converted from a battleship to become the USA's first aircraft carrier.

1938 The RAF's iconic, elliptical-winged Spitfire was pivotal in 1940's Battle of Britain.

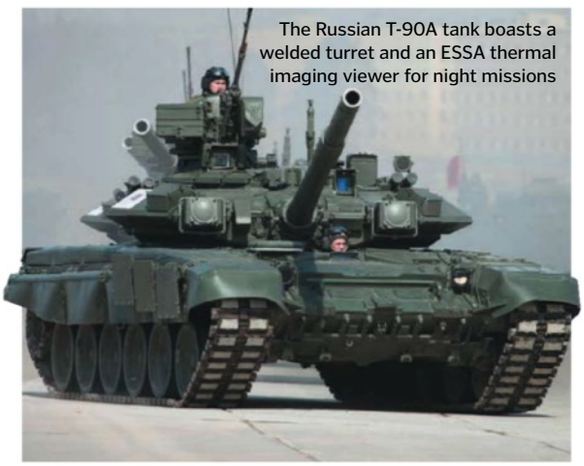
1981 The Bradley Fighting Vehicle was a fast all-terrain tank with massive firepower.

2007 The unmanned, remote-controlled MQ-9 Reaper is capable of pinpointing targets half a world away.

DID YOU KNOW? *Both cockpits in the two-person AH-1Z Viper contain identical instruments, so it can be flown by both pilots*



The French 56-ton AMX Leclerc is one of the biggest tanks in the world



The Russian T-90A tank boasts a welded turret and an ESSA thermal imaging viewer for night missions

What is it like to work inside a battle tank?

Tank driving instructor Sgt Arron Anderton tells us all about the experience of operating a Challenger 2

What does it feel like to drive the Challenger 2?
Sgt Arron Anderton: The Challenger 2 is a complex piece of equipment but once trained it is not that difficult to drive. It can take some time to get used to its size when you first start driving it, [but] once you gain more experience it can become quite fun to drive. The Challenger 2 has exceptional cross-country capability but due to the driver's restricted vision they need to read the ground up to 50 metres [164 feet] away so they can make adjustments to the direction and speed. The Challenger 2 is quite easy to handle at high speeds but is more difficult to negotiate around tight corners. The tank is [manoeuvred] by two steering levers located on either side of the driver.

What is the hardest part about driving a tank like the Challenger 2?
AA: The hardest part of driving the Challenger 2 is judging the size of the vehicle's width on public roads and driving it in confined spaces. The driving position is located in the centre of the vehicle which is different to standard cars and lorries and does take some time to get used to.

How does it feel in the tank when the main gun is fired and when you come under fire?
AA: When you are sat inside a Challenger 2 during 'live' firing of the weapons systems you tend to become oblivious to the firing of the chain gun or the bang from the 120mm [4.7in] main armament gun. The vehicle does shake a little but this adds to the adrenaline when you're scanning for targets and ensuring you engage the targets in time. Coming under small-arms (ie rifles and machine guns) fire can sound like hailstones on a tin roof, it does give you a sense of invulnerability!

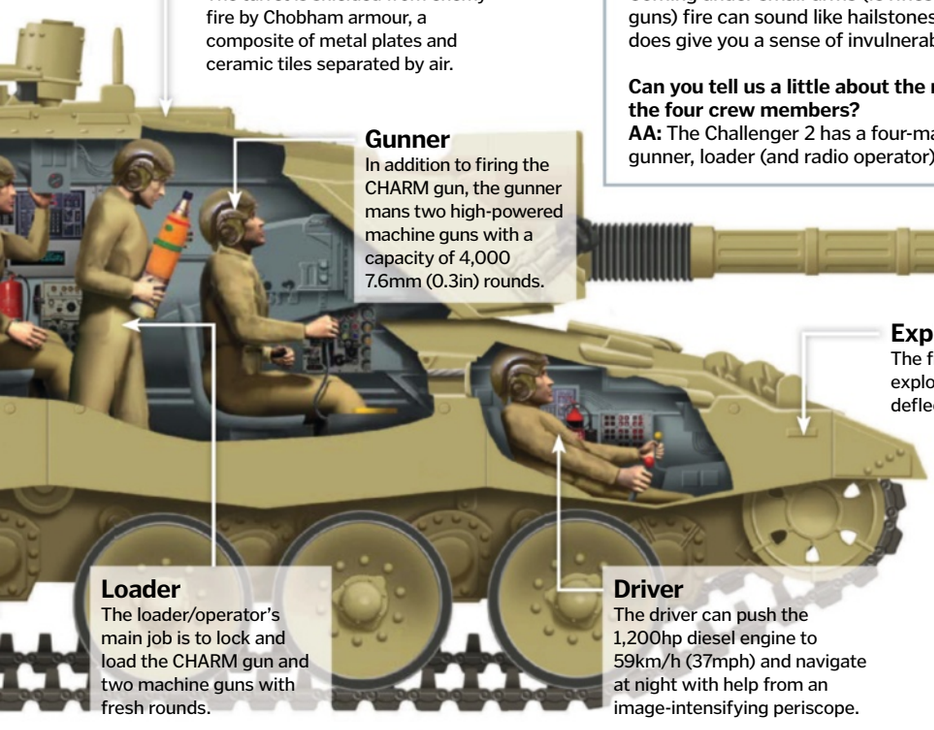
Can you tell us a little about the roles of each of the four crew members?
AA: The Challenger 2 has a four-man crew: a driver, gunner, loader (and radio operator) and commander. The driver steers the vehicle and carries out all the daily and major maintenance and running repairs. He also assists the REME (vehicle mechanics) with major repairs.

The gunner maintains the weapons systems and engages the targets identified by the commander and the crew. The loader loads the main armament and the 7.62mm [0.3in] chain gun. They have secondary duties of assisting the commander with operating the radio. The commander is in overall [charge] of the vehicle and all crew members. They navigate, send and receive radio messages and prioritise targets to be engaged by the gunner.

Due to working and living in a confined space, the camaraderie has to be second to none. As you can imagine working, living, eating, sleeping in a confined space for extended periods presents some problems – the smell can be eye-watering!

What equipment does the crew rely on to navigate in the field?
AA: Combat navigation is fitted to the vehicle and personal GPS. Additionally, good old-fashioned maps still form an integral part of navigation around the battlefield; the commander needs to be an expert in this form of navigation.

What roles do tanks assume in a warzone?
AA: A tank is a highly sophisticated fighting machine. It has the characteristics of firepower, protection, mobility and sustainability – it is also designed to operate in a CBRN [chemical, biological, radiological and nuclear] environment. It is used in all phases of battle (the advance to contact, the attack, the defence and withdrawal). It will invariably operate in an all arms environment, ie with infantry, artillery and air support. Due to its night-vision ability it can fight a 24-hour battle. Although it will normally operate in open spaces it can, with intimate infantry support, operate in built-up areas. For example, in recent years it proved highly successful in the Iraq conflict.



Thick skin
The turret is shielded from enemy fire by Chobham armour, a composite of metal plates and ceramic tiles separated by air.

Gunner
In addition to firing the CHARM gun, the gunner mans two high-powered machine guns with a capacity of 4,000 7.6mm (0.3in) rounds.

Exploding armour
The front and sides are covered with explosive plates that ignite on contact to deflect the force of enemy rounds.

L30 CHARM gun
Challenger 2's main weapon fires 120mm (4.7in) projectiles including armour-piercing, high-explosive squash head (HESH) rounds.

Loader
The loader/operator's main job is to lock and load the CHARM gun and two machine guns with fresh rounds.

Driver
The driver can push the 1,200hp diesel engine to 59km/h (37mph) and navigate at night with help from an image-intensifying periscope.

How long does it take to train the Challenger 2 crew members?


Driver 6 weeks


Loader 2 weeks


Gunner 6 weeks


Commander 5 months

"Microwave bombs aim to disable the electrical systems of buildings with a fuse-frying pulse of radio waves"

Engineering of the AH-1Z Viper

What makes the Zulu helicopter among the most advanced vehicles on Earth today?

Helmet
State-of-the-art 'Top Owl' helmet-mounted sight and display (HMS/D) units offer a binocular display with a 40-degree field of view and easier comms.

Avionics
A third-gen forward-looking infrared (FLIR) sensor offers one of the most accurate weapons sights on any modern helicopter whether day, night or in adverse weather. It can track multiple out-of-sight targets simultaneously.

Engines
Combined with the main rotor system, the two T700-GE-401 engines power the AH-1Z, giving it a cruise speed of just under 300km/h (186mph).

Rotor blades
The four blades are made of composite materials which can better withstand bullets. They can also be folded to better fit on aircraft carriers.

Wing stubs
Although not needed for flight, these mini-wings offer valuable space for mounting weapons and radar tech.

Challenger 2

- Crew: 4
- Armour: 5/5
- Cost: £4mn ($6.6mn)

Max speed
The tank can hit 59km/h (37mph) on roads.

Power
1,200bhp Perkins-Condor CV12.

Bell AH-1Z Zulu

- Crew: 2
- Armour: 2/5
- Cost: £18.8mn ($31mn)

Max speed
During a dive the Zulu can reach 411km/h (255mph).

Power
Two T700-GE-401 turboshaft engines.

Eurofighter Typhoon

- Crew: 1
- Armour: 1/5
- Cost: £126mn ($208mn)

Power
A pair of EJ200 turbojet engines.

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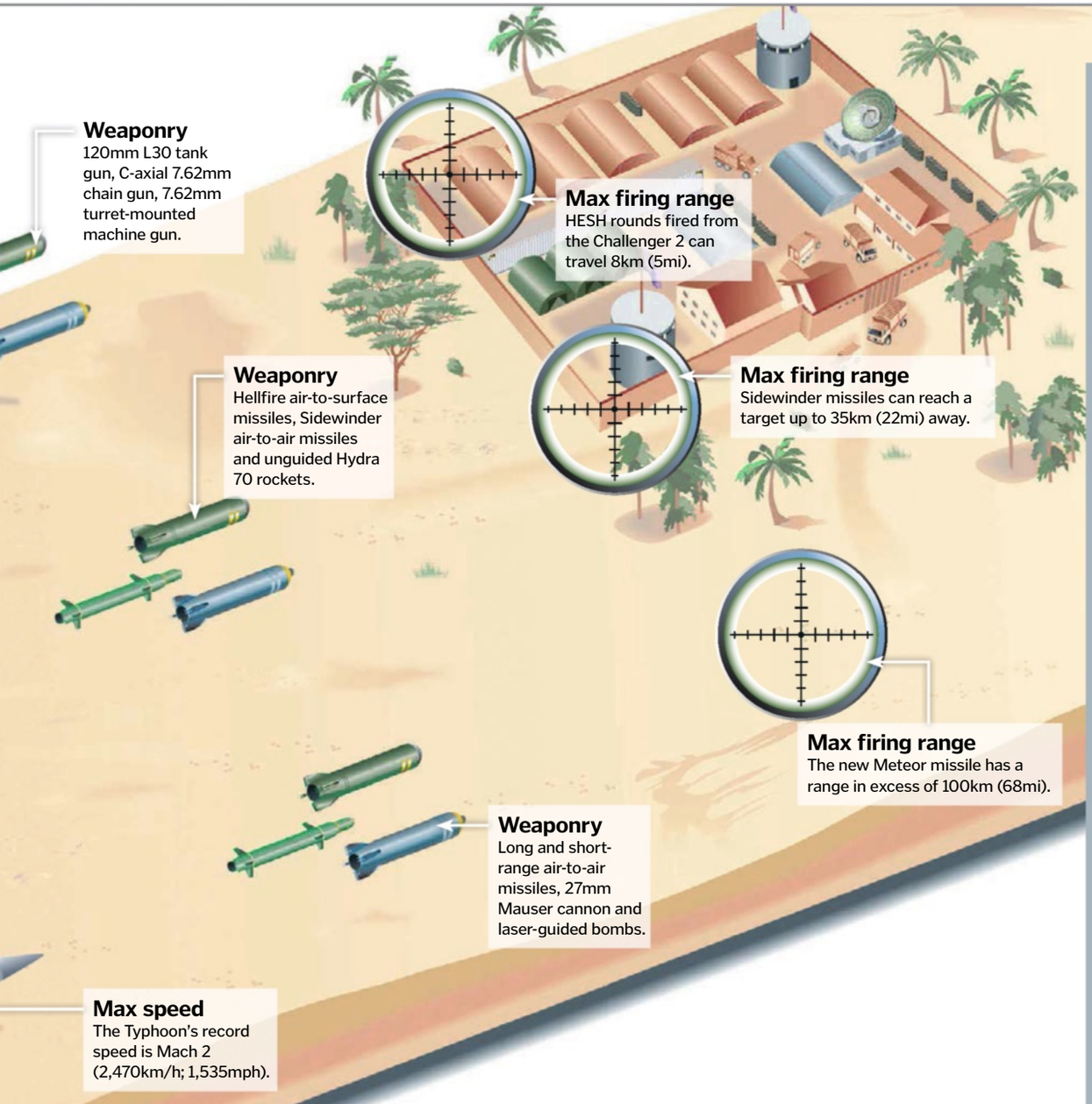
DID YOU KNOW? *The AH-64D Apache Longbow can prioritise up to 128 threats in less than a minute*



Weaponry
120mm L30 tank gun, C-axial 7.62mm chain gun, 7.62mm turret-mounted machine gun.

Max firing range
HESH rounds fired from the Challenger 2 can travel 8km (5mi).

Weaponry
Hellfire air-to-surface missiles, Sidewinder air-to-air missiles and unguided Hydra 70 rockets.

Max firing range
Sidewinder missiles can reach a target up to 35km (22mi) away.

Max firing range
The new Meteor missile has a range in excess of 100km (68mi).

Weaponry
Long and short-range air-to-air missiles, 27mm Mauser cannon and laser-guided bombs.

Max speed
The Typhoon's record speed is Mach 2 (2,470km/h; 1,535mph).

Laser-based weapons are already being fitted to today's combat vehicles

Next-gen weapons

The Challenger 2's main gun is essentially a bigger, meaner version of the same rifled-cannon technology that has been blasting oversized rounds for nearly a century. The weapons of the future are more subtle, but immensely more strategic. Take the Passive Attack Weapon developed by the Pentagon to safely eradicate a store of deadly bioagents. Dropped from an aeroplane, the 450-kilogram (990-pound) bomb explodes in mid-air, raining down thousands of steel and tungsten rods that can penetrate canisters of chemical weapons.

Microwave bombs made by Boeing for the US Air Force aim to disable the electrical systems of target buildings with a fuse-frying pulse of radio waves. The US Navy has been testing 32-megajoule rail guns that use magnetic fields to launch armour-piercing projectiles 185 kilometres (115 miles) without an ounce of gunpowder. And what would the future of weapons be without lasers? The US Navy is actively testing its solid-state Free Electron Laser with hopes of creating a weapon capable of melting through 610 metres (2,000 feet) of steel per second!

Ready for battle!

1 HMS Ambush

The Royal Navy's newest nuclear submarine boasts sonar sensitive enough to detect craft about 5,630km (3,500mi) away. Built for over £1bn ($1.6bn), the Ambush carries a payload of 38 Tomahawk cruise missiles.

2 B-2 Spirit

The iconic batwing stealth aircraft is the USAF's flagship strike bomber. Able to fly 18,520km (11,508mi) with only one aerial refuelling, it can deliver 20 tons of bombs deep into enemy territory.

3 USS Zumwalt

This 'all-electric' US Navy destroyer generates all the power it needs. The ship's sharp-angled hull lowers its radar profile and its payload includes two 155mm (6.1in) guns capable of striking a target 154km (96mi) away.

4 Assault Breacher Vehicle

The US Army's mine-clearing tank's signature move is firing a rocket that unfurls 100m (328ft) of sausage-like tubing packed with a ton of C4 explosives, clearing an area the size of a football pitch of hidden mines.

5 ATF Dingo

A German armoured mobility vehicle used to transport troops, the Dingo is reinforced to withstand land mines, gunfire and many other heavy weapons. The top-mounted weapons station can be fired by a gunner directly, or via remote control using a monitor inside the cabin.

"The Apache's resilience in combat has also made it one of the foremost war machines of the age"

Evolution of the Apache

The AH-1Z Zulu might be newer, but there is arguably another attack helicopter more renowned for its deadliness: the AH-64 Apache. A barbarous hybrid of power, penetration and liquid speed, the Apache excels in ravaging enemy lines and installations, laying waste to the strongest of battlements with high-explosive missiles and rockets, while gunning down any attackers with its 30-millimetre (1.2-inch) chain gun. As history has shown, with the Apache successfully deployed in the Gulf, Balkan, Iraq and Afghanistan conflicts among many others, these abilities have been proven time and again, with its 14-plus operators worldwide using it in all manner of roles.

Interestingly though, despite the Apache's mighty arsenal of offensive weapons, the real reason it is such a feared opponent is the advanced nature of its combat systems and electronics. For example, its avionic and sensor suite includes a target acquisition and designation system (TADS), pilot night-vision system (PNVS), GPS navigation, passive infrared countermeasure system, ground-fire acquisition system (GFAS) and, most cutting-edge of all, an integrated helmet and display sighting system (IHADSS). A bit like a military take on Google Glass, this latter piece of technology augments the pilots' control in a number of ways (see 'Apache anatomy' for more). Combined these technologies enable this incredible helicopter to operate in the harshest environments with ease, while always ensuring it hits its target.

The Apache's resilience in combat has also made it one of the foremost war machines of the age, with the helicopter made to demanding build and crashworthiness standards. Indeed, during the Gulf War many Apaches were repeatedly hit by small-arms fire and rocket-propelled grenades, but only one of them went down and even then both of its pilots survived. Similarly more recently in Afghanistan, many Apaches were hit in Operation Anaconda (2002), but none were brought down by the enemy, with the helicopter's toughened airframe, along with features such as a self-sealing fuel system, seeing off all incoming fire.

Maybe the most telling aspect to the Apache's prowess on the battlefield, however, is its enduring legacy – one which is still playing out, even after 28 years fighting on the frontline. Indeed, this technical leader of attack helicopters continues to be improved all the time, with additional operators such as India, South Korea and Indonesia looking to take up the Apache in the near future. Additional technological enhancements, such as an upgraded transmission with split-torque face gears for more power output and an improved all-digital communications system look set to keep this helicopter at the top of its class for some time yet.

Apache anatomy

Get up close and personal with the tech of this ever-evolving frontline veteran

The USA currently operates 669 Apache attack helicopters, with that number set to rise over the next decade

Rotor blades

The Apache has a four-blade main rotor and a four-blade tail rotor, which grant a maximum rate of climb of 889m (2,915ft) per minute. It also boasts superb manoeuvrability for a helicopter, easily capable of complex, low-altitude operations.

Weaponry

The arsenal carried by the Apache is devastating, with missiles such as the AGM-114 Hellfire and AIM-92 Stinger partnered with a bounty of 70mm (2.8in) Hydra 70 rockets and the ever-reliable 30mm (1.2in) M230 chain gun with 1,200 rounds.

Powerplant

The Apache is powered by two GE T700 turboshaft engines, each with high-mounted exhausts on either side of the fuselage. This powerplant grants a top speed of 293km/h (182mph).

Human-machine interface

The integrated helmet and display sighting system (IHADSS) allows advanced features such as syncing the helicopter's M230 chain gun with the pilot's head movements, so the gun can be aimed with the turn of the head.

Tandem control

The crew of the Apache sits in tandem, with one pilot sitting above and behind the other. Both pilots can fly the gunship and both can operate all weapons systems – critical when fighting in today's complex warzones.

Controls

With laser, infrared and thermal tracking systems, including a target acquisition night-vision sensor, as well as a threat prioritisation system, the Apache is ideal for covert and low-visibility operations.

5 TOP FACTS
AERIAL ASSASSINS

1 F-35 Lightning II
The F-35 Lightning II is one of the most advanced fighter jets ever, capable of ground attack, reconnaissance and air defence missions. It also features cutting-edge stealth capabilities.

2 Sukhoi T-50
The fifth-gen Sukhoi T-50 is Russia's most state-of-the-art combat plane. Armed with air-to-air, air-to-surface and air-to-ship missiles, the T-50 can pack a punch too.

3 Chengdu J-20
Reports claim this Chinese stealth fighter is the most advanced piece of aerial military equipment in the East. It appears to be an F-22/F-35 hybrid and armed to the teeth.

4 F-22 Raptor
The most established fighter jet in the world since its introduction in 2005. 182 operational aircraft give the US Air Force unparalleled dog-fighting capabilities.

5 F-16 Fighting Falcon
An older fighter jet but still remains in widespread use due to its excellent handling and combat prowess. The F-16 is an excellent all-round, short-range, multi-role fighter.

DID YOU KNOW? *Stryker AFVs can be adapted for many roles, including engineering support, medical treatment and firing mortars*

Stryker in focus

Check out some of the key features packed into these top-rate AFVs

Machine gun
A .50-calibre machine gun that can be manned or controlled from within the Stryker proves a lethal tool against infantry and light armoured vehicles.

Diesel engine
A heavy-duty 261kW (350hp) Caterpillar JP-8 diesel engine grants the Stryker its mobile power, allowing the 16-ton vehicle to surpass 97km/h (60mph) with ease.

Tough shell
The Stryker is built around a toughened steel skeleton and has a spall liner. 14.5mm (0.6in)-thick armour plate kits can be fitted to its chassis for even more protection.

All-wheel drive
Depending on terrain, thanks to the Stryker's advanced Allison transmission, the driver can switch between four and eight-wheel drive operation modes.

The Stryker boasts an unmatched combination of survivability, mobility and lethality

Electronics
The Stryker comes with a Force XXI Battle Command Brigade and Below (FBCB2) digital comms system that allows communication between vehicles and a remote weapons system (pictured) to fire from the safety of the cabin.

Room to spare
Along with a two-man crew, the Stryker can carry up to nine fully equipped soldiers in its rear compartment, plus a wide selection of vital equipment and provisions.

Armoured fighters on wheels

Sure, if you want the heaviest armour or most destructive firepower on the battlefield, then you call in a tank. But tanks tend to be decidedly one note in the theatre of war and cumbersome when posed with any obstacle outside their immediate remit – ie blowing things into last week with a massive cannon! As a result, today national militaries are calling upon a different class of war machine more and more. The armoured fighting vehicle (AFV) is a cool combo of personnel carrier, tank and military jeep which can undertake almost any mission due to its unparalleled flexibility.

While a tank is great at crossing rough terrain with its caterpillar track, that system's inherent limitations along with the machine's gross weight restrict its agility and speed massively. Examples like the Challenger 2 struggle to get past 60 kilometres (37 miles) per hour and possess next to no agility. On the other hand, the armoured fighting vehicle delivers a shielded vehicle that easily blows through 100 kilometres (60 miles) per hour, is capable of traversing cross-country terrain with ease, can sport a wide variety of cannons, machine guns and missiles, and is able to transport nine fully equipped soldiers on top of that – all without so much as breaking a sweat.

Of this new wave of vehicles, the Stryker family of AFVs made by General Dynamics Land Systems is one of the most advanced and prolific. The wide range of formats the Stryker comes in really highlights why they are not only usurping more and more of the roles historically assigned to tanks but executing them far more effectively.

For example, the Stryker family members include vehicles equipped for anti-tank operations, medical evacuation missions, fire support and reconnaissance, infantry deployments and direct-fire assaults, to name just a few! Strykers offer these bespoke abilities with an agility, speed and cost-effectiveness unheard of in the tank world.

You might start to wonder if the armoured fighting vehicle will make the tank obsolete, but this is unlikely. Sometimes only the biggest and heaviest armoured machine is capable of breaking down an enemy's front door, but moving forward into the 21st century, there's no doubt the use of multipurpose vehicles like the Stryker will rise. In almost every arena, speed and adaptability can be the difference between success and failure. Nowhere is that more true than in modern warfare, and the still-evolving armoured fighting vehicle delivers both with consummate ease.

Awesome amphibians

With flexibility being key to success in the realm of modern combat, one vehicle firmly on the up is the amphibious assault vehicle – essentially an armoured personnel carrier and landing boat hybrid. They enable troops to be deployed remotely from the ocean, transported under bulletproof protection to shore and then distributed over enemy terrain, without any slow and dangerously exposed vehicle changes, quickly getting soldiers to where they need to be.

Arguably the most successful amphibious assault vehicle in production today is the AAV-P7/A1, a tracked amphibious landing vehicle produced by US Combat Systems (now part of BAE Systems). It delivers a 26-ton armoured personnel carrier with 45-millimetre (1.8-inch) armour plating, a roof-mounted Mk 19 automatic grenade launcher, a .50-calibre machine gun and room for 21 soldiers in its cavernous rear compartment. Perhaps most impressive though, the AAV-P7/A1 can cruise up to 37 kilometres (23 miles) through choppy waters before hitting land and still has enough steam to operate for some 480 kilometres (300 miles) on terra firma.

"How many chains the hydrocarbon is broken down into determines what the crude oil is eventually used for"

Petrol vs diesel

These two fuels power millions of vehicles every day but how do they differ in their properties and refinement process?

Petrol and diesel are burned in combustion engines to power all manner of vehicles. Although both these fuels are made from crude oil extracted from deep inside the Earth and used for the same purposes, their properties vary greatly.

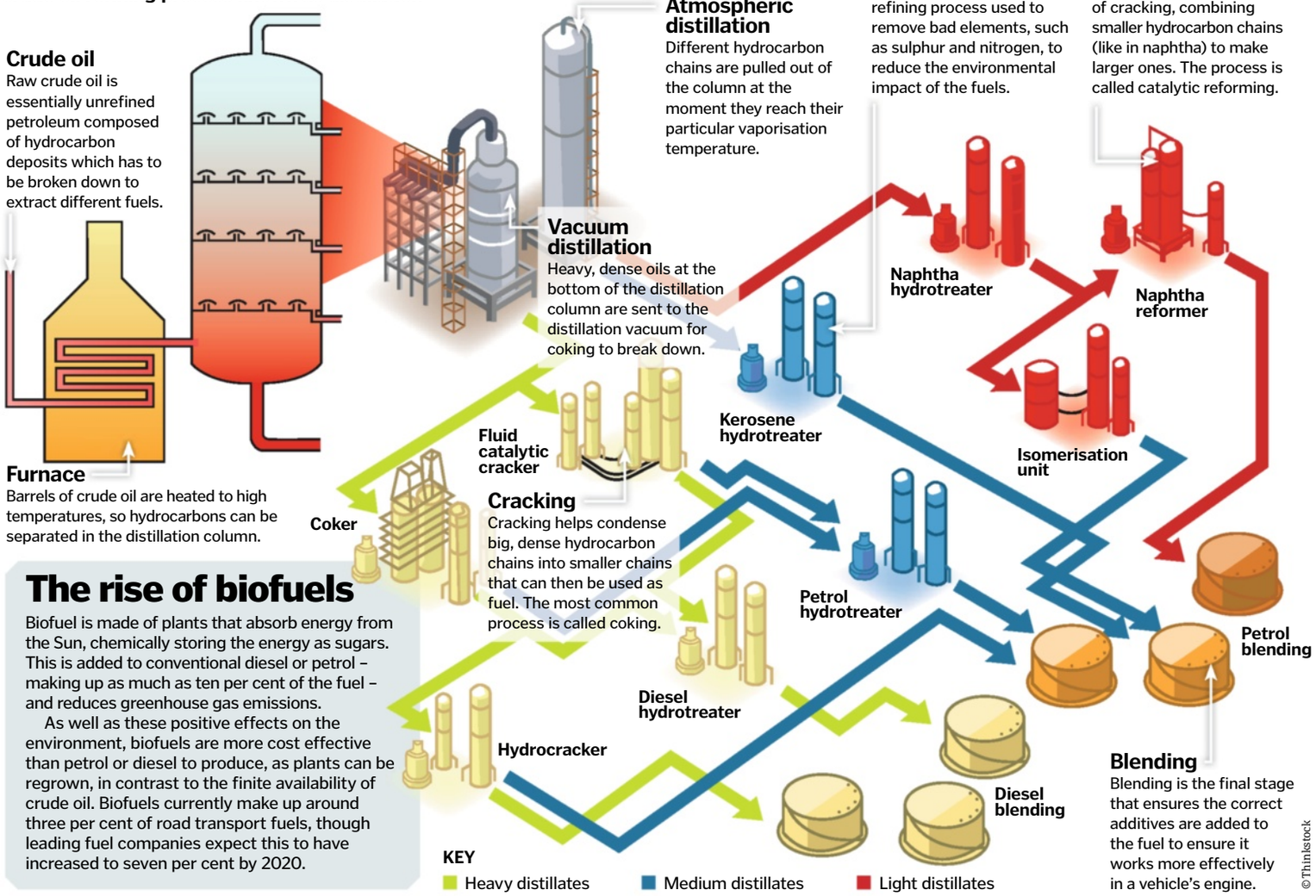
Crude oil contains a mixture of different hydrocarbon chains that need to be broken down to produce fuel. How many chains the hydrocarbon is broken down into determines what the oil is eventually used for.

Petrol (or gasoline) has a chain length of between four and 12 hydrocarbons and so takes longer to extract through the process of distillation. As diesel is produced by greater chain lengths of hydrocarbons, it is easier to refine as the crude oil doesn't need to be broken down so much. That said, diesel often needs to be cleaned of more pollutants to ensure vehicle emissions remain as low as possible.

Diesel has a higher energy content in megajoules per litre (roughly 36.9) compared to petrol (around 33.7) as it is denser. Also, the combustion process in a diesel vehicle's engine is considered more efficient as no spark is needed to ignite the fuel. This means a diesel engine has lower fuel consumption and produces less CO_2 than petrol. In contrast, petrol is cleaner (contains fewer pollutants) after it has been distilled and is lighter, so is easier for fuel companies to transport.

Fuel production line

Petrol and diesel are two end products of a more complex crude oil refining process known as distillation



The rise of biofuels

Biofuel is made of plants that absorb energy from the Sun, chemically storing the energy as sugars. This is added to conventional diesel or petrol – making up as much as ten per cent of the fuel – and reduces greenhouse gas emissions.

As well as these positive effects on the environment, biofuels are more cost effective than petrol or diesel to produce, as plants can be regrown, in contrast to the finite availability of crude oil. Biofuels currently make up around three per cent of road transport fuels, though leading fuel companies expect this to have increased to seven per cent by 2020.

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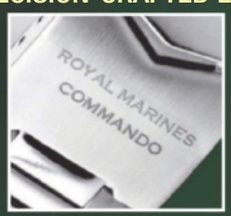

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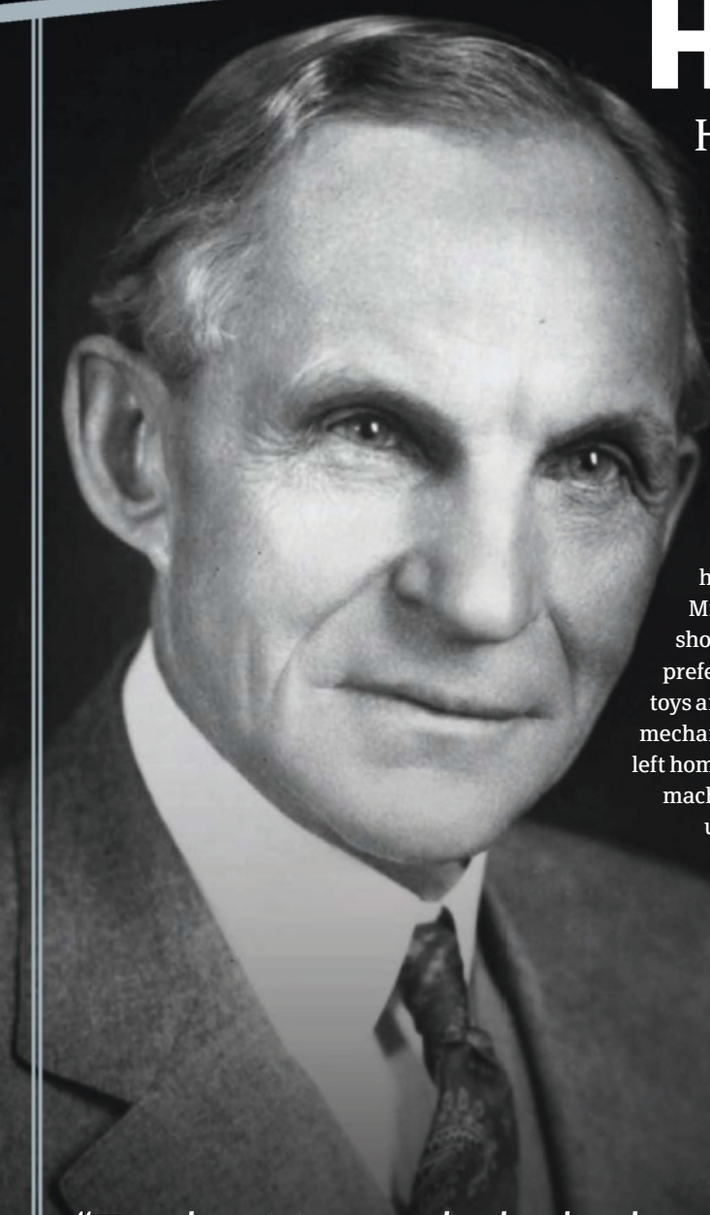
Henry Ford

How Ford's model of mass production transported the automobile from exclusive toy of the rich to everyday vehicle for the masses



"Ford set to work designing simple, low-cost cars that were easy to maintain, operate and handle on rough roads"

Henry Ford did not invent the car, nor did he invent the assembly line. What he did do, however, was develop the first large-scale moving assembly line, leading to the mass production and meteoric rise of the everyday automobile.

Ford's beginnings were fairly humble. He was born on a farm in Michigan in 1863, but as a child he showed little interest in farming, preferring to spend his time dismantling toys and watches to study their inner mechanisms. While still a teenager, Ford left home in 1879 to become an apprentice machinist in Detroit, and in 1891 he took up a job as an engineer at the Edison Illuminating Company.

He soon had enough time and money to invest in his own project to develop a horseless carriage. In 1896, he completed his first self-propelled vehicle: the Quadricycle. Gasoline-powered with a simple frame and four bicycle-like wheels, it was steered with a tiller. Its top speed was a then-impressive 32 kilometres (20 miles) per hour. The Quadricycle's success led to interest from investors, who helped him establish his own car-manufacturing company in 1899. However, both this and another company of his failed to take off.

Determined not to give up though, Ford concentrated his efforts on developing an 80-horsepower racing car, called the '999'. This car was raced to victory by Barney Oldfield in the Manufacturer's Challenge Cup in October 1902. Interest in Ford was quickly rekindled, and in 1903 the Ford Motor Company was formed. Ford set to work designing simple, low-cost cars 'for the great multitude'. In 1908, he introduced the Model T – a simple, affordable motorcar that was easy to operate, maintain and handle on rough roads.

The car became so popular at the time that they were selling faster than they could be manufactured, so the company had to devise a new way to meet the growing demand. The solution came in the form of a moving assembly line. Rather than one worker assembling an entire component, they were each allocated one or two parts to put together, which was then passed on to the next person in line until it was completed. This made the process extremely efficient, and by 1914, the total time for the production of a single Model T had dropped from 12 hours to just 26 minutes and 30 seconds. As a result, the cost of the car also fell from $850 to as little as $260. Ford expanded sales and manufacturing overseas, and by the early-Twenties, half of the cars in the world were Model Ts.

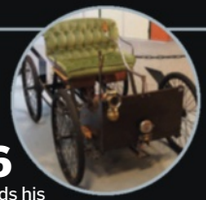
A life's work

The major milestones in Henry Ford's journey to international fame

1863
Henry Ford is born on a farm in Michigan to parents William and Mary.

1879
Henry moves to Detroit, Michigan, to begin his apprenticeship as a machinist.

1891
He is hired by Edison Illuminating Company as an engineer, where his passion for automobiles is encouraged by Thomas Edison.



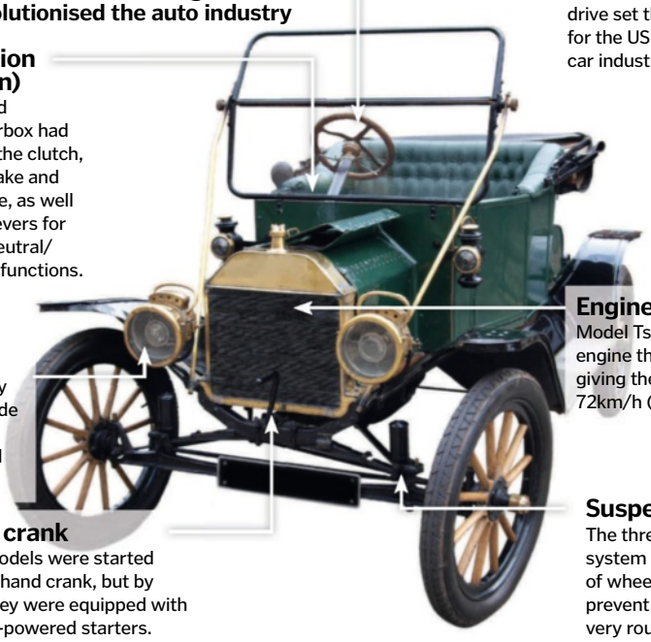
1896
Henry builds his first self-propelled vehicle, the Quadricycle, which reaches a top speed of 32km/h (20mph).

The '999', Henry Ford's victorious race car from 1902 in which he beat the world speed record

Ford sitting in his first automobile, the Quadricycle

Exploring the Model T

The simple design of Ford's best-selling car secured its success and revolutionised the auto industry



Steering wheel
The Model T's left-hand drive set the standard for the US and European car industries.

Transmission (not shown)
The two-speed planetary gearbox had one pedal for the clutch, one for the brake and one for reverse, as well as two hand levers for throttle and neutral/ parking brake functions.

Engine
Model Ts had a four-cylinder engine that produced 20bhp, giving the car a top speed of 72km/h (45mph).

Headlights
These were originally acetylene lamps made of brass, but in 1915 new cars were fitted with electric lights.

Suspension
The three-point suspension system allowed for plenty of wheel movement, to prevent damage on the very rough early roads.

Hand crank
Early models were started using a hand crank, but by 1920 they were equipped with battery-powered starters.

However, sales of the Model T gradually declined, overtaken instead by General Motors' more comfortable and more powerful Chevrolet. Other models were developed, but none saw the same level of success as the Model T. In 1932, at age 69, Ford introduced his last great innovation – the lightweight, inexpensive V8 engine. But even this wasn't enough to reclaim his lead in the US market, so by 1936, Ford Motor Company had been outdistanced by both General Motors and Chrysler Corporation. Still, Ford's assembly line became the standard model of production of the 20th century, accelerating the growth of a middle class and giving the freedom of mobility to millions.

Moving with the times

The moving assembly line completely changed the face of manufacturing. The minimal and repetitive motions of each worker sped up efficiency. Minimal training was required, meaning Ford could employ unskilled workers, many of whom were immigrants. However, this also meant that the work was incredibly boring, and the turnover at the company was so high that Ford had to hire 53,000 people a year to keep a constant workforce of 14,000 at the plant. To overcome this, in 1914 Ford more than doubled its wage rate to $5 a day to reduce the high employee turnover – an amount that was unheard of for unskilled work. Now that the factory workers were able to afford the cars they were making, the job became that much more desirable, which led to Ford being able to secure its position as the leading car manufacturer in the world at the time.

Top 5 facts: Henry Ford

1 A WWI pacifist
Henry Ford strongly opposed World War I and funded a Peace Ship that set sail to Europe with the aim of kick-starting peace negotiations. This mission was soon aborted though.

2 Anti-semitic
Despite being one of the country's largest employers of black and migrant workers, Ford was anti-semitic and published a number of texts in which he blamed Jews for manipulation of the market.

3 Ventures in aviation
Ford also designed and manufactured aeroplanes, including one which would become the first successful US airliner. The plane's maiden flight took place in 1926 and it carried 12 passengers.

4 Monochrome manufacturing
Until the development of the assembly line, Ford cars were only available in one colour, with Ford famously saying: "Any customer can have a car painted any colour that he wants, so long as it's black".

5 Driving on ice
In 1904, Ford broke the land-speed record driving his '999' racing car across a frozen lake. He reached a top speed of 146km/h (91mph).

1902
Ford's 80bhp '999' racer wins the Manufacturer's Challenge Cup.

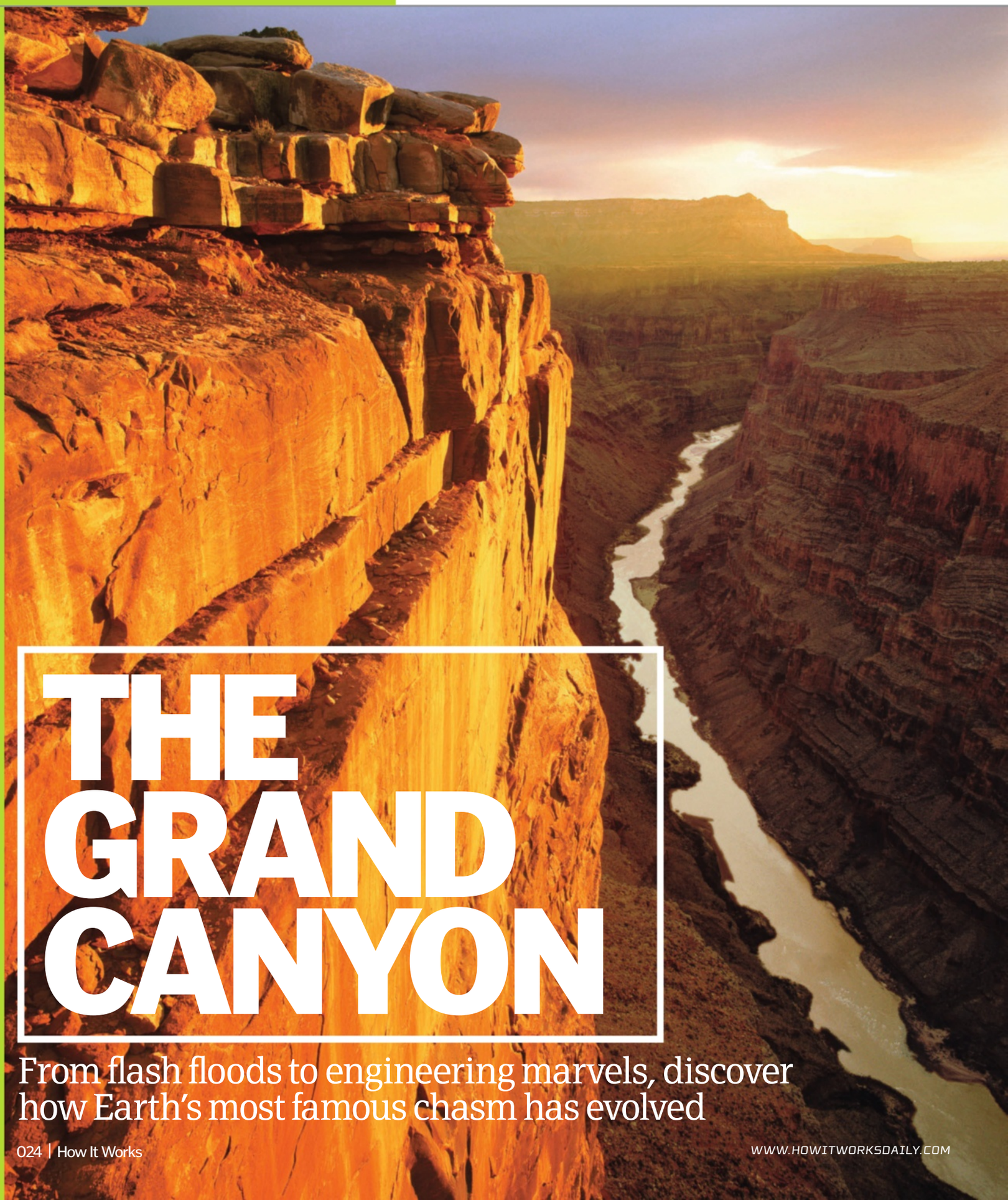
1903
The Ford Motor Company is founded with the help of several investors.

FORD MOTOR CO. DETROIT. MICH.

1908
The Model T goes into production and becomes the biggest-selling car in the world.

1914
Ford announces that it will more than double its workers' wages to $5 a day.

1932
At age 69, Ford develops the compact and low-cost V8 engine, which outperforms all other competitors.



THE GRAND CANYON

From flash floods to engineering marvels, discover how Earth's most famous chasm has evolved

5 TOP FACTS
GRAND CANYON LANDMARKS

1 Havasu Falls
The turquoise waters of Havasu Creek plunge 30m (100ft) over red rocks, creating the canyon's most striking waterfall. The spectacular colour comes from dissolved magnesium.

2 Lava Falls
Among Earth's best-known rapids, boats drop some 4m (13ft) in churning waters. The Colorado River is constricted by debris at the falls and rushes through the narrow channel.

3 Angel's Window
This mammoth natural arch is high on the North Rim and offers views over the Colorado River. The wedge-shaped hole was created by wind and water eroding weaker rocks.

4 Desert View Watchtower
This fake ruined tower and curio shop gives sweeping views of the canyon. Finished in 1932 in the early days of tourism, it is modelled after Native American watchtowers.

5 Lee's Ferry
The only place for 1,120km (700mi) where you can drive down to the Colorado River. Native Americans, miners and pioneers made ferry crossings here from 1872 to 1928.

DID YOU KNOW? *Flash floods can tear through narrow canyons at speeds exceeding 7m/s (23ft/s) – faster than most cyclists!*

The Grand Canyon on the Colorado Plateau in south-west USA is among our planet's most spectacular natural wonders. The proportions of this colourful crevice in the Earth are mind-boggling, reaching as deep as 1.6 kilometres (one mile) – easily enough to fit four stacked Empire State Buildings. It stretches an average 16 kilometres (ten miles) from rim to rim – equivalent to the length of 176 football fields.

You'd expect a canyon this big to take millions of years and a geological cataclysm to form. But surprisingly, the Grand Canyon was created by the Colorado River steadily cutting into the Colorado Plateau. Scientists believe this erosional process began 5 or 6 million years ago – which is a blink in geological time.

Stare into the canyon and you can see countless rock layers. Their striking colours are due to rainwater washing minerals down the cliffs. The canyon's dramatic step-stair profile is caused by wind and water eroding weaker rock layers. Some rocks, like shale, are easily worn away while others, such as granite, are much more robust.

The canyon rocks are older than the canyon itself. The limestone cliffs directly below the rim formed 270 million years ago. As much as 1.6 kilometre (one mile) of younger rocks covered them, but were worn away over millennia. Remnants of these younger rocks exist near the Grand Canyon; Red Butte, for example, was protected from erosion by a cap of hard lava.

The canyon's importance is not limited to its geology. Elevation ranges from 760 metres (2,000 feet) at the bottom to over 2,440 metres (8,000 feet) on the North Rim, creating vast differences in temperature and rainfall.

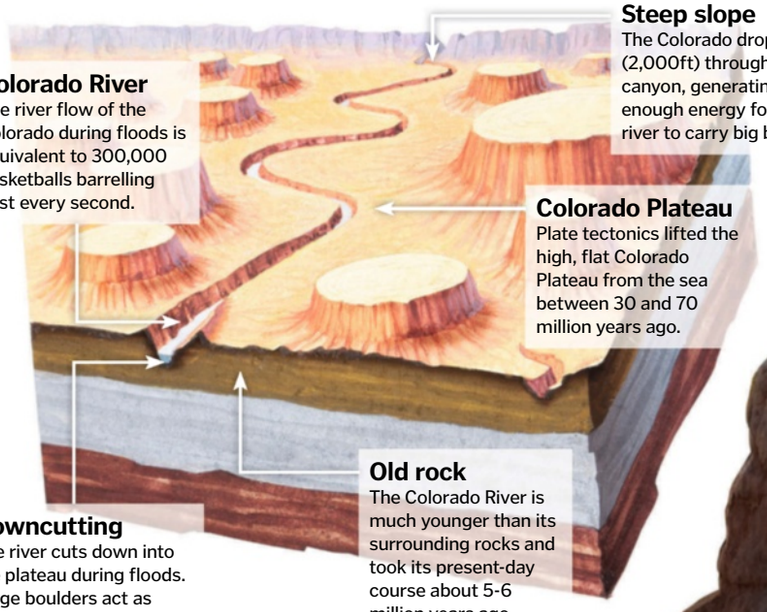
The highest temperatures are at the canyon bottom. Temperatures rise by around ten degrees Celsius per kilometre (29 degrees Fahrenheit per mile) descended. Bright Angel Ranger Station, the coolest and wettest weather station, is less than 13 kilometres (eight miles) from Phantom Ranch, the hottest and driest. The coolest temperature recorded was -30 degrees Celsius (-22 degrees Fahrenheit) on the North Rim, while the warmest temperature clocked in at 49 degrees Celsius (120 degrees Fahrenheit) at Phantom Ranch.

Beyond temperature, precipitation radically varies across the site. Lee's Ferry is the driest station in the park, with only 15.5 centimetres (6.1 inches) of rainfall on average per year. Compare this to the North Rim, which receives 3.6 metres (12 feet) of snow annually.

LONG DRIVE
It takes five hours to drive between the South and North Rim Villages, as the canyon is in the way!

The arid climate often results in flash flooding. In late summer, clouds build in the clear skies. Ground heating creates updraughts of warm air that climb several kilometres; if the air is moist, violent thunderstorms ensue. The parched ground cannot absorb the rainfall, meaning a wall of water up to 15 metres (50 feet) deep can sweep down creeks and dry channels, collecting debris.

Canyon in the making
What did the Grand Canyon look like in its early days?



Steep slope
The Colorado drops 610m (2,000ft) through the canyon, generating enough energy for the river to carry big boulders.

Colorado River
The river flow of the Colorado during floods is equivalent to 300,000 basketballs barrelling past every second.

Colorado Plateau
Plate tectonics lifted the high, flat Colorado Plateau from the sea between 30 and 70 million years ago.

Old rock
The Colorado River is much younger than its surrounding rocks and took its present-day course about 5-6 million years ago.

Downcutting
The river cuts down into the plateau during floods. Large boulders act as chisels, chipping down through the riverbed.

Rock layers exposed

Glimpse in the Grand Canyon and you'll spy countless layers of different coloured rocks. They form a geological history spanning almost 2 billion years.

The inner canyon rocks formed approximately 1.8 billion years ago during a collision of the Earth's crustal plates. The intense heat and pressure resulted in the creation of dark garnet-studded metamorphic rocks and volcanic rocks.

On top are layers of sedimentary rocks, laid down in climates ranging from sandy deserts to shallow seas. Many contain fossil sponges, bacteria or armoured fish. The youngest rocks are about 270 million years old – any younger overlying rocks have since been eroded away.

"The varied conditions mean the canyon supports a range of wildlife"

The Colorado River erodes exposed rock walls during floods. The river averages 91 metres (300 feet) wide and 12 metres (40 feet) deep, with a volume equal to 15,000 basketballs rolling past per second, though in the last ice age, volumes may have reached a million basketballs.

The varied conditions mean the canyon supports a huge range of wildlife. Five of the seven North American habitats are found here, including hot desert, desert steppe, open woodland, fir and spruce forest. Such diversity is akin to travelling between Canada and Mexico!

The Grand Canyon National Park is home to over 1,500 plant, 89 mammal, 47 reptile, nine amphibian and 17 fish species. Among them is the California condor, the biggest North American land bird. It roosts inside the canyon's red limestone cliffs and has a wingspan of up to three metres (9.8 feet).

VARIED HEAT
Temperatures can be simultaneously 21°C (70°F) on the North Rim and a sweltering 38°C (100°F) at the Colorado River below.

On the surface, coyotes are at the top of the food chain, able to sprint at up to 65 kilometres (40 miles) an hour after their prey. The park is also refuge to species such as mountain lions, while there are a dozen plants found only in the borders of this unique national park.

Humans have lived in the canyon for over 10,000 years too. They include hunter-gatherers who created rock art and nomads who built semi-permanent villages on canyon terraces.

Today, the canyon receives about 5 million visitors a year and is greatly affected by us. The Glen Canyon Dam blocks the Colorado River 24 kilometres (15 miles) upriver of the canyon. The dam traps 90 per cent of the canyon's annual sediment supply in Lake Powell – the USA's second-largest reservoir. It controls the release of water to generate hydroelectric power, eliminating the enormous spring floods that eroded the plateau.

But the dam has also endangered archaeological resources and reduced fish populations. Among them is the humpback chub, an endangered 4-million-year-old fish.

The canyon is deepening at around 0.1mm (0.004in) annually, but the rate is slowing. The Colorado River has eroded its steep slopes and has less power to cut through hard crystalline volcanic rocks. A few million years in the future, erosion may have deepened it somewhat, but it could have grown too wide to see across.

Grander canyons

The Grand Canyon is not actually our planet's biggest. Tibet's Yarlung Tsangpo Grand Canyon is considered to be one of the world's deepest. It stretches over 5,300 metres (17,400 feet) top-to-bottom in some places – which is more than three times the depth of America's Grand Canyon.

Tsangpo is also among Earth's longest and most inaccessible canyons. In 2002, a seven-person team were the first to successfully kayak the upper gorge. They used satellite images to navigate as there were no maps available.

Another candidate for the deepest gorge is Kali Gandaki Gorge in Nepal 1. Among the shallower canyons is Peru's Colca Canyon 2, which is over twice as deep as the Grand Canyon.

Earth's widest canyon is Australia's Capertee Valley. Copper Canyon in Mexico 3, meanwhile, is a series of canyons that together are more than 100 times longer than the Grand Canyon.

But some of Earth's biggest canyons are hidden, as they lie beneath the sea. For instance, Zhemchug Canyon in the Bering Sea is 60 per cent deeper than the Grand Canyon. And mammoth canyons are still being discovered, like Greenland's Grand Canyon, which was carved by rivers some 4 million years ago, before Greenland was buried by ice.

Off Earth, Valles Marineris on Mars 4 trumps the Grand Canyon on all counts including length, width, depth and age; if it were placed on Earth, it would stretch from Los Angeles to New York.

Life on the edge

Discover how the Grand Canyon's plants and animals adapt to this rugged terrain

Coyote
These clever, adaptable animals will eat almost anything, including fruit, grass, carrion and rabbits, hence why they thrive in this terrain.

THE STATS
GRAND CANYON

LENGTH **433km**

1.6km AVERAGE DEPTH

4.2tn m³ TOTAL VOLUME

29km MAX WIDTH

180m NARROWEST POINT

>6mn yrs AGE

DID YOU KNOW? *Sightseeing plane crashes are the main cause of death around the Grand Canyon, with 65 fatal flights recorded*

Walking on air...

The Skywalk is an engineering masterpiece that took four years and $30mn (£18.2mn) to build. This glass-bottomed platform protrudes 21m (70ft) from the canyon rim, offering a stunning view – though not one for vertigo sufferers!

Finished in 2007, the Skywalk was assembled on the West Rim. It took two days to roll it over the canyon, using the same rod-and-plate method as used for the Egyptian pyramids.

Floating 1,200m (4,000ft) above the Colorado, the U-shaped Skywalk is supported by beams anchored deep within the red limestone bedrock, which act as counterweights.

The Skywalk has had 2 million visitors. Each of the walkway's glass panel units can withstand the weight of 800 people, but only 120 visitors are allowed on at a time.

California condor
New World vultures with strong beaks to break dead animal bones. Their bald heads help them keep clean when rooting inside carcasses.

Utah juniper
These bushy trees have an extensive root system to access moisture in the dry environment. They can live for 700 years.

Common raven
Their stocky bodies and water-rich diet of carrion, eggs and plants helps them regulate their body temperature in desert heat.

Barrel cactus
Their barrel-shaped stems are pleated like an accordion and swell to hold water. Curved spines also help to shade the plant.

Mountain cottontail
Limited food and scarce shelter may explain why these rabbits are solitary. They are named for their fluffy cotton-ball tails.

Margarita flowers
A drought-tolerant plant found in shallow and dry soil. It has narrow leaves to minimise water loss.

Beaver-tail cactus
A small prickly pear that grows to around 60cm (2ft) tall. Like all cacti, it stores water in its fleshy stems.

Mountain lion
Human activity forced these big cats to retreat to the rugged uninhabited Grand Canyon. They can measure up to 2.4m (8ft) from nose to tail.

World of Animals

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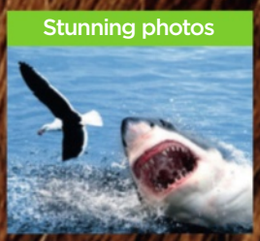

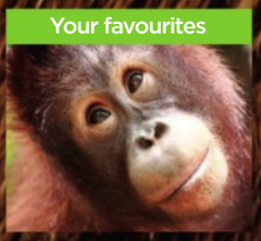

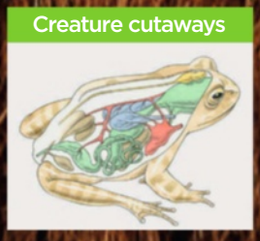

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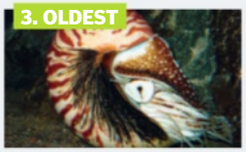
1. OLD

Coelacanth
Although previously thought to be extinct, two species of coelacanth have remained virtually unchanged for 300 million years.

2. OLDER

Crinoid
Ancient relatives of starfish, crinoids dominated the seas some 450 million years ago and still, in fact, exist in the oceans today.



3. OLDEST

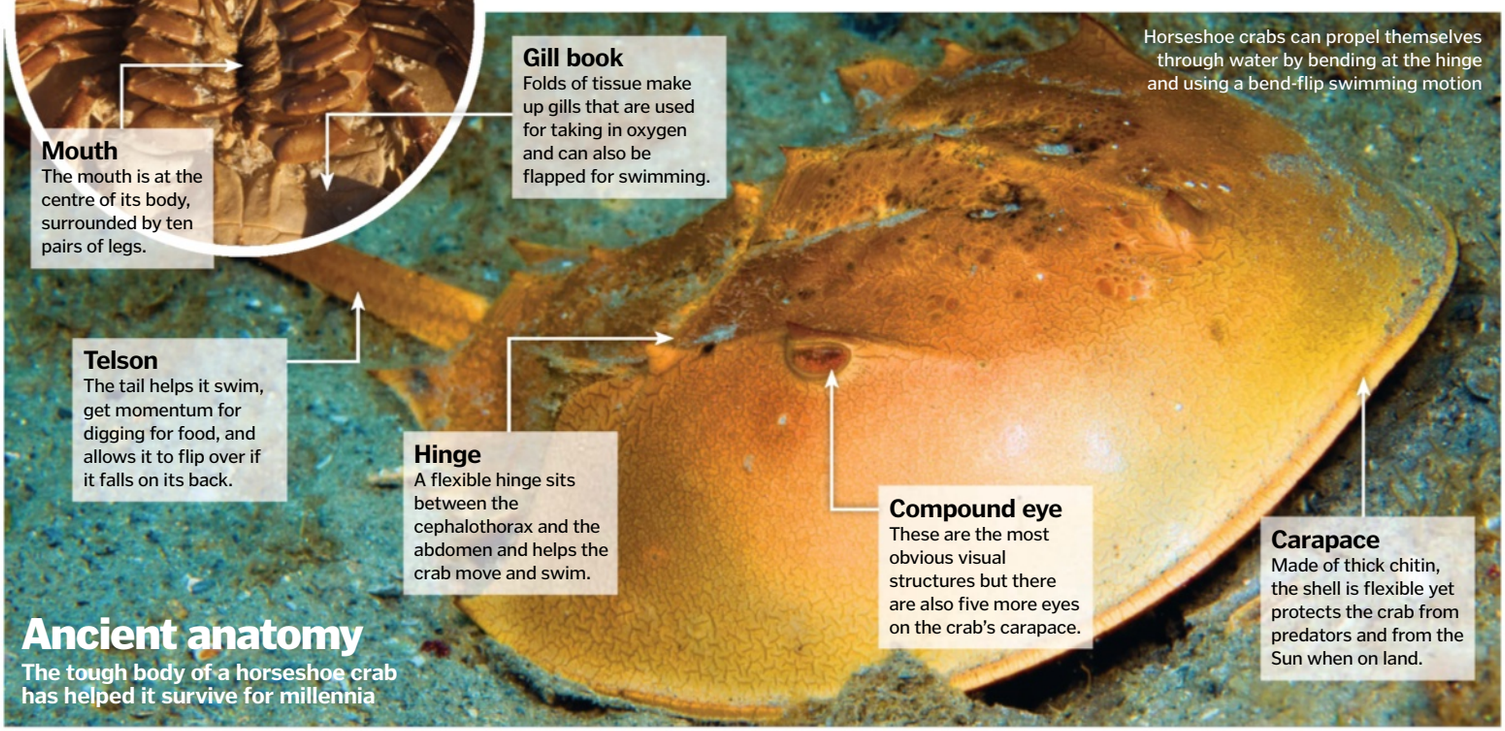
Nautiloid
Members of the nautiloid group – a type of cephalopod – appeared in the fossil record 500 million years ago and have changed very little since.

DID YOU KNOW? *Sea snakes begin shedding their skin by rubbing their lips on rocks or coral to loosen skin on the head*

Horseshoe crabs

The 400-million-year survival story of a modern fossil

The four species of horseshoe crab look like heavily armoured crustaceans, but are more closely related to spiders and scorpions, as ancient members of the subphylum Cheliceriformes. The fossil record dates the origins of the horseshoe crab to over 400 million years ago, and the species has remained relatively unchanged for 250 million years, earning them a place in the select group of 'living fossils'. The largest spawning ground is on the beaches of Delaware Bay, USA. They live on the seafloor feeding on bivalves and worms then make their way to the beaches each summer to spawn.



Jointed legs
Horseshoe crabs have three types of legs used for different things, such as walking and grasping females during mating.

Feeding pincers
Known as chelicerae, these pincers grab food such as worms and pass it to the mouth.

Gill book
Folds of tissue make up gills that are used for taking in oxygen and can also be flapped for swimming.

Mouth
The mouth is at the centre of its body, surrounded by ten pairs of legs.

Horseshoe crabs can propel themselves through water by bending at the hinge and using a bend-flip swimming motion

Telson
The tail helps it swim, get momentum for digging for food, and allows it to flip over if it falls on its back.

Hinge
A flexible hinge sits between the cephalothorax and the abdomen and helps the crab move and swim.

Compound eye
These are the most obvious visual structures but there are also five more eyes on the crab's carapace.

Carapace
Made of thick chitin, the shell is flexible yet protects the crab from predators and from the Sun when on land.

Ancient anatomy
The tough body of a horseshoe crab has helped it survive for millennia

Sea snake biology

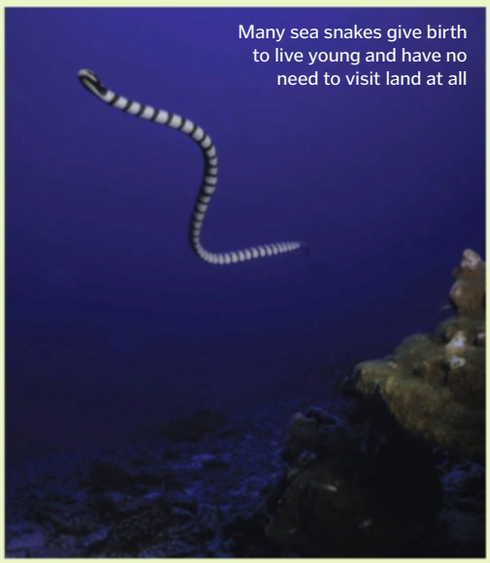
How these serpents have adapted to life in the big blue

Sea snakes can be found in all types of warm-water bodies, from mangroves and estuaries to coral reefs and the ocean. There are over 60 known species, all descended from lizards. Although sharing characteristics with their terrestrial cousins, sea snakes have adapted to a watery lifestyle. Tails are flattened for swimming, scales are reduced or even absent for streamlining and nostrils can be closed to stop water getting in.

All sea snakes breathe air, but some species are able to stay underwater on a single breath for hours at a time. These reptiles can absorb gases through their skin while underwater and also slow down their metabolic rate in order to stay submerged for longer.

A sea snake's skin is shed the same as terrestrial snakes, but around every two to six weeks. This removes any marine parasites and reduces the risk of disease.

Sea snakes feed on fish, eggs and eels, and with very sharp eyesight these slithery swimmers are ambush hunters. Like land snakes, most sea snakes possess fangs and venom, but the toxins are tailored for killing fish and not usually dangerous to humans.



Many sea snakes give birth to live young and have no need to visit land at all

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5 TOP FACTS
HIGH-UP FARMING

Inca Empire
1 The Inca civilisation of South America was largely built off the back of terrace farming, with great cities such as Machu Picchu supported by the food they produced.

Hanging Gardens
2 The legendary Hanging Gardens of Babylon are often depicted in art as terraces, with a series of staggered layers supporting tropical vegetation and animals.

Rice mania
3 Terrace farming is used to grow a variety of crops around the world. These include olives and wheat, however the most common by far is rice in China and South-east Asia.

Andes origin
4 Terrace farming has been used for many centuries but is thought to have been developed originally by the Wari peoples of the Andes mountains in South America.

Making a comeback
5 A large restoration programme is currently underway in Peru, South America, aiming to revive terraces which have long fallen out of use.

DID YOU KNOW? *The rice terraces of the Philippine Cordilleras are a UNESCO World Heritage Site*

Farming on mountains

How does terrace farming help us work around natural gradients?

Terrace farming is an ancient technique used to both cultivate crops and maintain a hilly terrain's soil health, with the system ensuring moisture and minerals remain locked within the land. As such, farmers in arid, steep or high-rainfall regions can increase their crop yields and prevent damaging erosion.

A terrace system consists of multiple tiers of planting beds, each stepped above another on the side of a hill or mountain. Each area is supported against the incline by a wall – typically a dry-stone structure, which ensures the soil remains level and packed with minerals by limiting runoff. Alternatively, in dry regions, the walls also help to maintain what limited moisture there is.

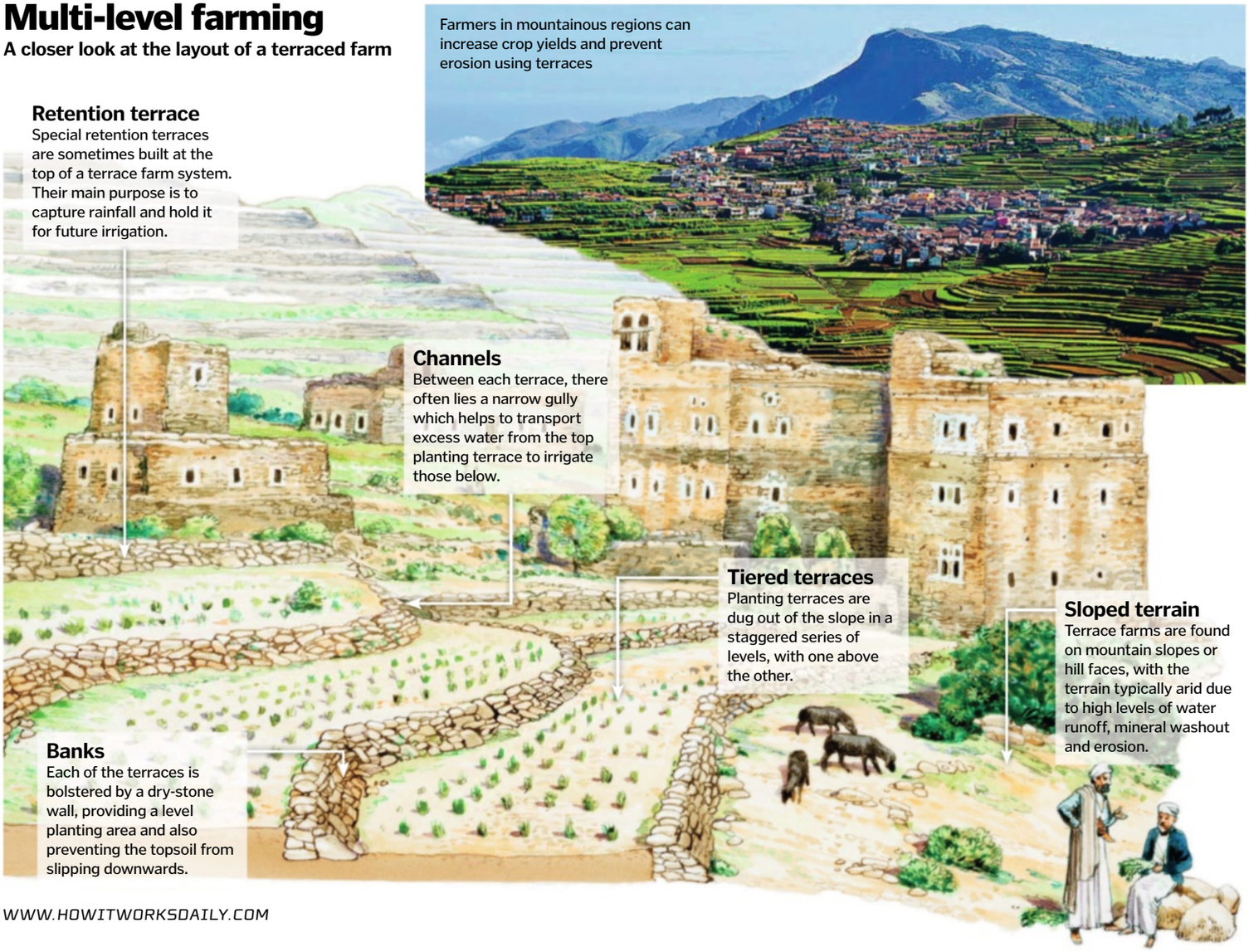
There are two main types of terrace. The first are retention terraces, used in low-rainfall areas and designed to capture as much runoff water as possible, which is then used to irrigate crops or distributed to lower terraces. The second type is the graded terrace, which is built at a slight gradient and designed to intercept and divert runoff water into protected waterways, preventing it from washing out other levels. In most terrace farms, a combination of these will be used.

The terrace system also allows for some controlled irrigation of crops within the planting areas. This is achieved through shallow channels that let captured water gradually trickle down through the stepped tiers by the power of gravity.

Hotspots for terrace farming

Multi-level farming

A closer look at the layout of a terraced farm



"If one element is removed or damaged, it could result in a huge shift in the ecosystem's dynamics"

Life on coral reefs

Take a closer look at these highly productive ecosystems to see how they support dazzling biodiversity in delicate balance

Coral reefs are dubbed as the rainforests of the ocean, and it's not hard to see why. Thriving in warm, clear water, reefs provide food and protection for a huge range of species, from small fauna right up to apex predators. It's an environment where each plant and animal relies on the presence and function of its neighbours for survival. If one element is removed or damaged, it could result in a huge shift in the ecosystem's dynamics, leading to the decline of the reef.

A reef begins with the settling of stony coral polyps, which get their name from the rigid calcium carbonate skeleton that they secrete. They eventually develop into large reef-forming colonies, cemented together by species such as coralline algae and encrusting invertebrates. Vibrant soft corals, sponges and anemones find their way into the mix, with the nooks and crannies provided by the stony corals serving as excellent places to live. Plenty of species of worm will enjoy this habitat too, closely followed by scavengers and predators such as starfish and sea urchins.

As the reef begins to attract more and more species, the promise of food increases, making the area an evermore attractive place to live. Molluscs such as dazzling sea slugs, squid, octopuses and clams will arrive to live in the coralline crevices, as will crustaceans such as crabs, lobsters and shrimp. Some shrimp have an extra draw for the reef too, such as cleaner shrimp that operate 'cleaning stations' where they nibble off the parasites of larger animals.

Hundreds of fish species live permanently on the reef, but others will arrive solely to cash in on the buffet. Sharks and large shoals of fish cruise the habitat looking for tasty morsels, and their leftovers provide meals for other smaller reef dwellers. Other marine travellers such as sea turtles will drop in and make the most of the surplus of food during long journeys.

Why are reefs under threat?

Coral reefs are facing a host of issues threatening their survival. Overfishing can break the food chain and leave a window for opportunistic species to take hold. Pollution and sedimentation is clogging the clean, clear water corals need to thrive and global sea surface temperatures are rising, causing coral bleaching to occur; a process where the corals expel their single-celled symbiotic algae in response to thermal stress. Ocean acidification is also posing a threat to the calcium carbonate structure that forms the backbone of the habitat.

Among other schemes to protect our planet's reef habitats, the introduction of new Marine Protected Areas (MPAs) hopes to reduce the stresses of overfishing and destructive fishing practices. This will make the overall reef stronger and more resilient, giving it a better chance to battle other threats such as sedimentation from land runoff.

5 TOP FACTS
REEF KILLERS

1 Tiger shark
This shark species is a voracious predator and scavenger. They have excellent senses of sight and smell and seem to eat anything and everything they come across.

2 Moray eel
A key reef predator, moray eels hide in crevices and lie in wait for their next meal. They have two strong sets of jaws: one for grabbing and another for eating their prey.

3 Crown-of-thorns starfish
This starfish has a huge appetite for coral. It feeds by extending its stomach over the polyps to liquefy and digest the tissue, leaving only skeletons behind.

4 Blue-ringed octopus
Found on western Pacific reefs, this tiny octopus measures only 20cm (8in). It's highly poisonous and uses toxins to immobilise and devour its prey.

5 Reef stonefish
As a master of camouflage, the stonefish resembles an algae-encrusted rock. That is until it ambushes its victim by brandishing spines laced with deadly toxins.

DID YOU KNOW? *While covering less than one per cent of ocean floor, coral reefs support 25 per cent of all known marine life*

Cold-water corals

Many associate coral reefs with the warm, clear water of the tropics, but corals can also be found as deep as 2,000 metres (6,562 feet) and at temperatures of 4°C (39°F). These cold-water corals are found living on elevated outcrops such as seamounts and ridges deep in the ocean, and the corals like to live in a strong flow of water. One of the main differences between cold-water corals and their tropical counterparts is that there is no symbiotic, photosynthetic algae living within the cold-water coral tissue. This means sunlight isn't essential for their survival, as they survive by catching particles of food such as plankton from their surroundings.

Reef dwellers

Meet the major animal groups found in tropical coral reefs around the world

Primary production
Plankton is sparse on coral reefs. Single-celled algae living within the coral tissue form the base of the food web, producing up to 90 per cent of the coral's energy through photosynthesis.

Top predators
Some species of sharks and rays live on or near coral reefs to take advantage of the bounteous food choices. The massive manta ray feeds on small fish and crustaceans.

Schools of fish
Fish are essential inhabitants and visitors to coral reefs. Small fish make the reef their permanent home, while other larger schools drop by for a meal.

Octopuses
The rocky reef crevices provide excellent sites for octopuses to lie in wait for prey such as crabs and fish, as well as to hide from their enemies.

Molluscan inhabitants
The largest mollusc on a reef is the giant clam. These huge creatures can reach 1.2m (4ft) in length and accommodate algae in their tissue to supplement their diet.

Primary consumers
In a food web, primary consumers are grazing herbivores. On the reef these include small fish, starfish, crabs, urchins and even turtles that nibble on coral and algae.

Cone snails
These predatory snails are highly venomous and prey on and paralyse fish, worms and other molluscs before eating them.

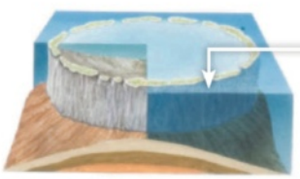
Mutual relationships
Every niche is inhabited on a reef, with many symbiotic relationships. The anemone provides the clownfish with shelter and food, while the fish cleans the anemone and circulates water.

Atoll reef formation

How do these mid-ocean reefs develop over time?

Coral ring
This type of coral reef begins as a fringing reef surrounding an island in the middle of the ocean, far away from land.

Vertical growth
Over time the coral grows upwards, building upon itself. Subsidence causes the island in the middle to sink, and the fringing reef becomes a barrier reef.



Central lagoon
As the island slips beneath the water over time, the coral continues to grow. This results in a circular reef surrounding a deep lagoon known as an atoll.

MEGA PLANETS

How do the gas giants differ from rocky worlds like Earth?

Imagine a planet with a storm large enough to swallow Earth, so light that it could float if you could find an ocean big enough, or one wracked by wind speeds of almost double the speed of sound. Believe it or not, these awesome-sounding worlds aren't the stuff of science-fiction novels – they're the reality of the Solar System's biggest planets: the gas giants.

Our Solar System divides neatly into two main parts. In the compact and relatively warm inner region, the planets – Mercury, Venus, Earth and Mars – are all broadly Earth-like in composition. Beyond Mars, separating inner and outer Solar Systems, lies a broad ring of smaller rocky bodies – scattered fragments that never got to form a planet, known as the Asteroid Belt.

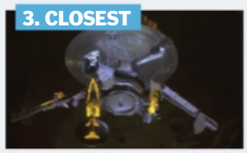
The outer Solar System itself, meanwhile, is a vast and largely empty region of space which is filled with lurking monsters in the form of four giant planets. These, in order from the Sun, are Saturn, Jupiter, Uranus and Neptune.

Each of these worlds is on a scale far beyond our everyday experience of the rocky planets. To give you some idea of the difference, Jupiter is big enough to fit our planet inside it over 1,300 times, and Saturn is only a little smaller. Uranus and Neptune, meanwhile, are near-twins just half the size of their inner neighbours, but still large enough to eat Earth for breakfast. What's more, these planets are physically very different from our world and its immediate neighbours; instead of being predominantly made up of dense, rocky materials with perhaps a thin layer of gas and water, these titans work the other way, being gas (or at least, gas turned to liquid under enormous pressure) nearly all the way through – hence why they're called 'gas giants'.

Each giant has a thick outer atmosphere overlying a huge internal 'mantle' of chemicals

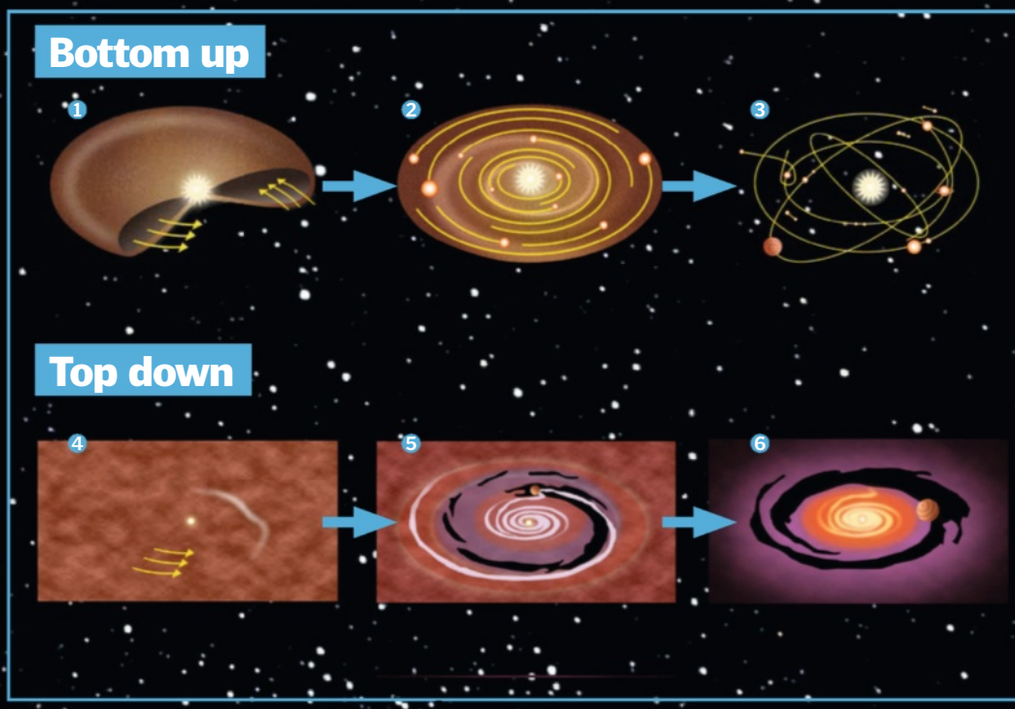
Voyagers 1 & 2
The two probes flew past Jupiter at distances of 206,700 and 570,000km (128,440 and 354,180mi) from the cloud tops in March and July 1979.

Pioneer 11
This earlier probe flew on a kamikaze mission through Jupiter's dangerous radiation belts, at 43,000km (26,720mi) from the surface in 1974.



Galileo probe
In 1995, Galileo released a probe that plunged into Jupiter's atmosphere, sending back signals for the first 600km (373mi) of its descent.

DID YOU KNOW? *It's believed several moons of Jupiter and Saturn might make suitable habitats for alien life*



How do gas giants develop?

There are two main schools of thought as to how gas giants form. In the 'bottom up' model, solid bodies come together, or accrete, in the outer Solar System 1 in much the same way they do closer to the Sun, creating rocky bodies called planetesimals that move through the surrounding disc of gas.

As they grow large enough to generate their own substantial gravity, some planetesimals start to pull in the lighter gas and ice from their surroundings 2, eventually building up a huge envelope.

After enough time has passed, the gas giants become so big that they 'scatter' all the other material from their surroundings, while any gas that is not absorbed is blown out across space 3.

In the 'top down' model, the giant planets start out as denser regions within the overall gas cloud 4 that begin to collapse under their own gravity.

As these collapsing 'protoplanets' pull in more material from their surroundings, they naturally start to rotate, forming whirlpools that draw evermore dust and gas in 5.

Eventually the protoplanets clear out their region of space, leaving a ball of gas that continues to collapse until it becomes a stable planet 6.

Jupiter

Equatorial diameter: 11.2 x Earth

Distance from Sun: 778mn km (484mn mi)

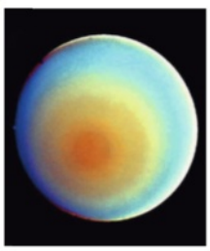
Info: Jupiter is the king of the planets, large enough to swallow up all the others with room to spare. Its gravity has a big influence on the motion of all other planets in the Solar System.

Saturn

Equatorial diameter: 9.4 x Earth

Distance from Sun: 1.43bn km (886mn mi)

Info: Saturn is the second-largest planet, and the least dense, famed for its brilliant system of rings (though in fact all the giant planets have ring systems of one kind or another).

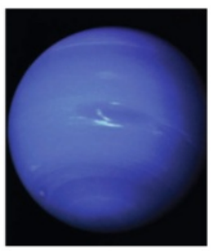


Uranus

Equatorial diameter: 4.0 x Earth

Distance from Sun: 2.9bn km (1.8bn mi)

Info: Uranus is a world that orbits on its side, rolling around the Sun every 84 years. It is surrounded by a system of narrow, dark rings that give it a target-like appearance.



Neptune

Equatorial diameter: 3.9 x Earth

Distance from Sun: 4.5bn km (2.8bn mi)

Info: Neptune is the outermost major planet – a near-twin in size to Uranus, but with much more violent weather systems. These produce huge dark storms in its atmosphere.

that transform their state from gas to liquid and even stranger states of matter deep inside the planet under pressure from above. The solid core of the world is Earth-sized at most, and puny in comparison to the enormous envelope of surrounding gas. Despite what seems to us like a tenuous composition, a giant can hold itself together through the sheer force of its enormous gravity (Jupiter's, for example, is two and a half times Earth's at its cloud tops).

The upper atmospheres of the gas giants play host to violent weather systems – huge storms and hurricane-force winds powered not only by heat from the Sun, but also by energy from within the planet itself. At least three of the giants have their own internal 'power plant', driven by the slow gravitational collapse of their cores and the sifting of dense particles towards the lower layers while lighter ones drift upwards – a process that can generate considerably more energy than sunlight alone in the cold depths of the Solar System. The only giant not known to have an internal energy source of this kind is Uranus, so it's something of a mystery why its weather is so extreme.

Despite their size, the giants also spin rapidly on their axis, giving them considerably shorter days than Earth's – Jupiter and Saturn spin in ▶

Giant stats for giant planets

2,100km/h
Highest wind speeds recorded on Neptune, the outermost planet of the Solar System

62
Number of moons orbiting Saturn

318x
Jupiter's mass in terms of Earth

-224°C
Coldest recorded temperature on Uranus

165
Length of Neptune's orbit around the Sun in Earth years

1,321
Number of Earths that could fit inside Jupiter

"Jupiter and Saturn's rotation is so fast that each planet bulges out noticeably around its equator"

9.9 and 10.7 hours, respectively, and Uranus and Neptune in 17.2 and 16.1 hours. The speed of their rotation helps wrap weather systems around each planet to form distinctive cloud bands. In the case of Jupiter and Saturn, the rotation is so fast that each planet bulges out noticeably around its equator, where it can barely hold itself together.

So where did these giant planets come from and why are they so different from Earth and its rocky neighbours? The difference is best explained by a prominent division in the early Solar System – a 'snow line' beyond which volatile chemicals (those which boil at relatively low temperatures) could survive without being boiled away and blown out into interstellar space by the fierce radiation of the young Sun. As our newborn star cleared such materials from the inner Solar System, leaving only rocky fragments to form the Earth-like planets, it left a huge ring of lightweight gas and icy chemicals orbiting beyond. There are two leading theories to explain what happened next – see boxout on page 35.)

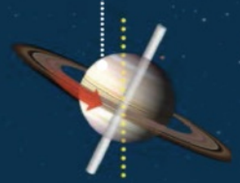
Each of the four Solar System giants has its own unique features. Jupiter is the largest and also the most colourful, its surface wracked by giant storms, the most famous of which is undoubtedly the Great Red Spot – centuries old and large enough to swallow Earth twice over. It also has a huge magnetic field, thought to be created by a vast sea of electrically conducting 'liquid metallic hydrogen' created as normal (ie molecular) liquid hydrogen that breaks down under pressure near the core.

Though rightly famed for its spectacular system of rings, the body of Saturn itself looks surprisingly bland at first glance, but looks can be deceiving. The sixth planet is thought to be internally very similar to Jupiter, and can certainly produce equally violent weather – but its lower gravity means that its upper layers of gas are not so compressed, lending the planet as a whole a density less than water. This combines with reduced radiation from the Sun to produce a cool upper atmosphere in which ammonia can condense and form a planet-wide creamy haze that largely hides the violent weather systems beneath from view.

Uranus and Neptune are distinctly different from the inner giants – not only in their smaller size and distinctive colours (blues and greens rather than creams and browns), but also for their internal composition. While Jupiter and Saturn are more than 90 per cent hydrogen, the inner layers of Uranus and Neptune are mostly

Explore the ringed titan

Saturn is the second-largest planet in the Solar System and a spectacular example of a 'typical' gas giant



Axis inclination
Saturn's axis is tilted 26.7°. One rotation lasts 10 hours and 39 minutes.

Encke division
A small gap that separates the A ring into two parts.

F ring
The farthest visible ring.

A ring
Saturn's outer ring.

Cassini division
5,000km (3,100mi) wide, it is located between the A and B rings.

B ring
Saturn's brightest and widest ring.

C ring
Saturn's only transparent ring.

500km (310mi)

14,600km (9,100mi)

25,500km (15,800mi)

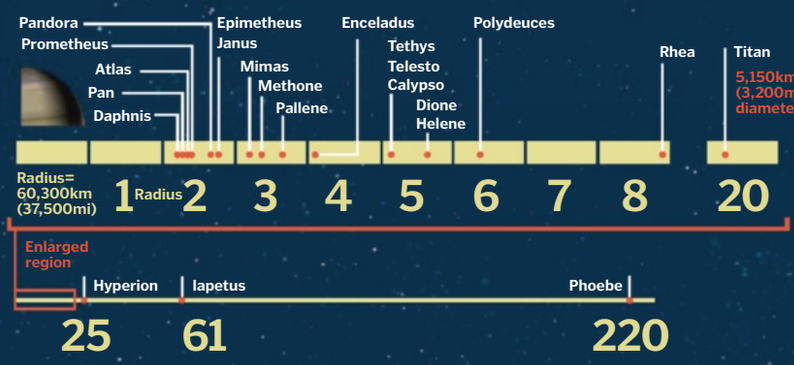
17,500km (10,900mi)

8,500km (5,300mi)

Ring thickness
Although Saturn's rings are very wide, their thickness is sometimes less than 10m (33ft).

Satellite system

Saturn, like all the gas giants, has a big family of moons – more than 60 at the last count (their distance from Saturn shown below). Many developed out of debris left behind as the planet formed, and these include large, complex worlds. Others are merely asteroids or comets captured by Saturn's gravity.



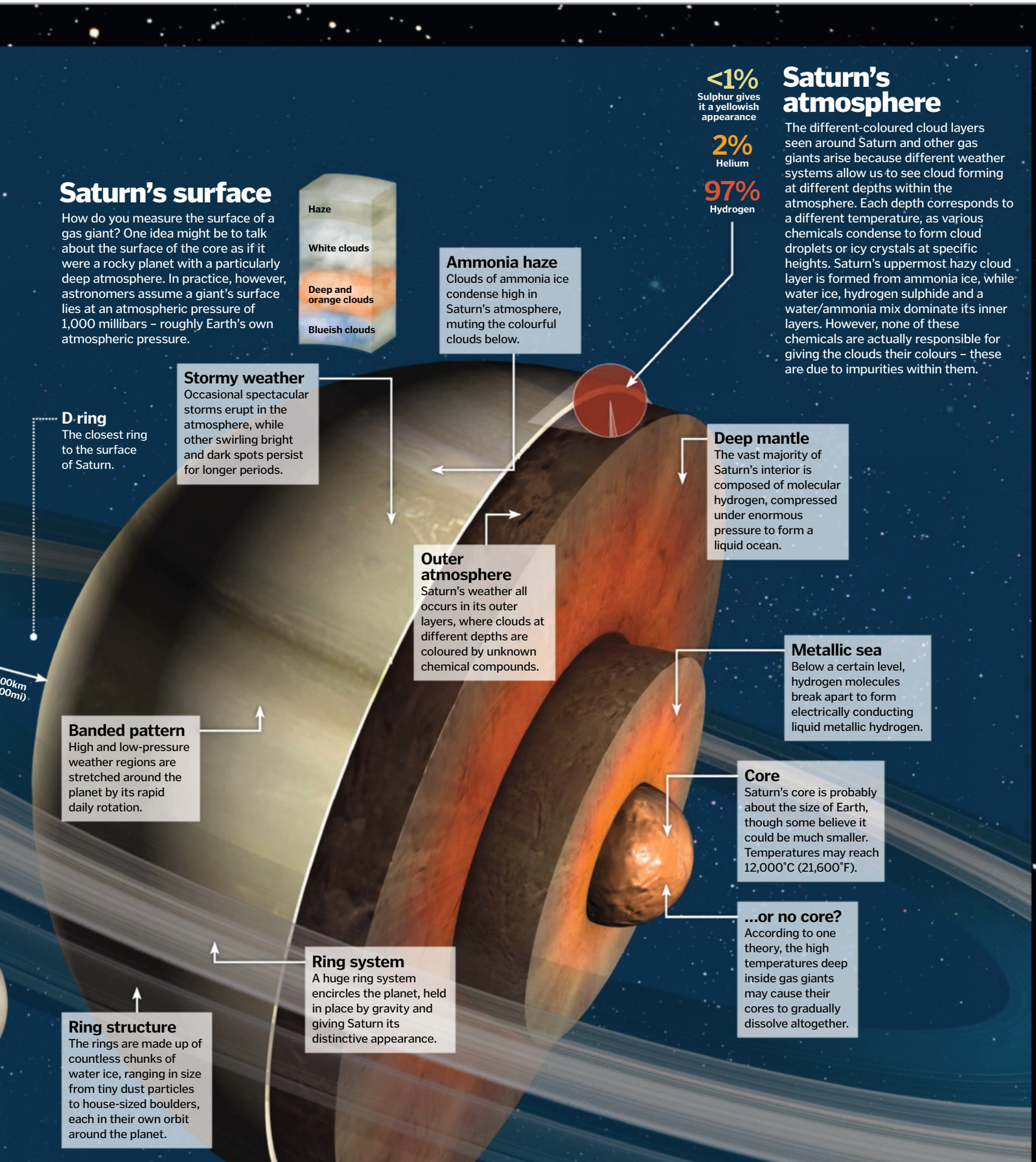
RECORD BREAKERS
LARGEST PLANET

2.037x

KING OF THE GAS GIANTS

First spotted in 2011 1,044 light years away, HAT-P-32b is the largest planet by diameter so far discovered with a radius 2.037 times that of Jupiter. Having said that, it's been inflated so much its mass is actually less than Jupiter's.

DID YOU KNOW? *NASA used the powerful gravity of the giant planets to slingshot the two Voyager probes between them*



Saturn's surface

How do you measure the surface of a gas giant? One idea might be to talk about the surface of the core as if it were a rocky planet with a particularly deep atmosphere. In practice, however, astronomers assume a giant's surface lies at an atmospheric pressure of 1,000 millibars – roughly Earth's own atmospheric pressure.

Saturn's atmosphere

The different-coloured cloud layers seen around Saturn and other gas giants arise because different weather systems allow us to see cloud forming at different depths within the atmosphere. Each depth corresponds to a different temperature, as various chemicals condense to form cloud droplets or icy crystals at specific heights. Saturn's uppermost hazy cloud layer is formed from ammonia ice, while water ice, hydrogen sulphide and a water/ammonia mix dominate its inner layers. However, none of these chemicals are actually responsible for giving the clouds their colours – these are due to impurities within them.

Ammonia haze
Clouds of ammonia ice condense high in Saturn's atmosphere, muting the colourful clouds below.

Stormy weather
Occasional spectacular storms erupt in the atmosphere, while other swirling bright and dark spots persist for longer periods.

D ring
The closest ring to the surface of Saturn.

Deep mantle
The vast majority of Saturn's interior is composed of molecular hydrogen, compressed under enormous pressure to form a liquid ocean.

Outer atmosphere
Saturn's weather all occurs in its outer layers, where clouds at different depths are coloured by unknown chemical compounds.

Metallic sea
Below a certain level, hydrogen molecules break apart to form electrically conducting liquid metallic hydrogen.

Banded pattern
High and low-pressure weather regions are stretched around the planet by its rapid daily rotation.

Core
Saturn's core is probably about the size of Earth, though some believe it could be much smaller. Temperatures may reach 12,000˚C (21,600˚F).

...or no core?
According to one theory, the high temperatures deep inside gas giants may cause their cores to gradually dissolve altogether.

Ring system
A huge ring system encircles the planet, held in place by gravity and giving Saturn its distinctive appearance.

Ring structure
The rings are made up of countless chunks of water ice, ranging in size from tiny dust particles to house-sized boulders, each in their own orbit around the planet.

"Uranus is a frustrating puzzle – it orbits the Sun tipped over at an angle of 98 degrees from 'upright'"

composed of chemical compounds such as ammonia, methane and water (all 'ices' in the terminology of planetary science). Beneath the surface layers of Uranus and Neptune, the ices condense to give the planets 'slushy' interiors – for this reason, they are sometimes called 'ice giants' rather than true gas giants.

Uranus is a frustrating puzzle – it orbits the Sun tipped over at an angle of 98 degrees from 'upright', perhaps as the result of some huge impact early in its history. This gives the planet extreme seasons throughout its 84-Earth-year orbit of the Sun: when Voyager 2 (the only space probe so far to explore these outermost worlds) flew past in 1986, one pole was in the middle of a 42-year permanent summer, the other lost in the long cold night of midwinter. At the time, the planet was something of a disappointment since it did not appear to show any weather systems, but a few years later, Hubble Space Telescope images showed signs that Uranus's weather had 'woken up'. It's now thought that, at their most extreme, the seasons help suppress Uranus's normal weather patterns (and perhaps even conceal evidence of its internal energy source).

If Uranus is disappointingly quiet, however, then the Voyager probe found Neptune is surprisingly active for a world with a temperature around -200 degrees Celsius (-328 degrees Fahrenheit). Winds of over 2,000 kilometres (1,240 miles) per hour whip weather systems around the planet and an internal energy source pumps out more than two and a half times as much energy as Neptune receives from the Sun. This may be connected to changes in Neptune's unique chemistry deep within its interior, where methane molecules decompose and the carbon they release is compressed to form tiny diamond crystals that rain down onto the core.

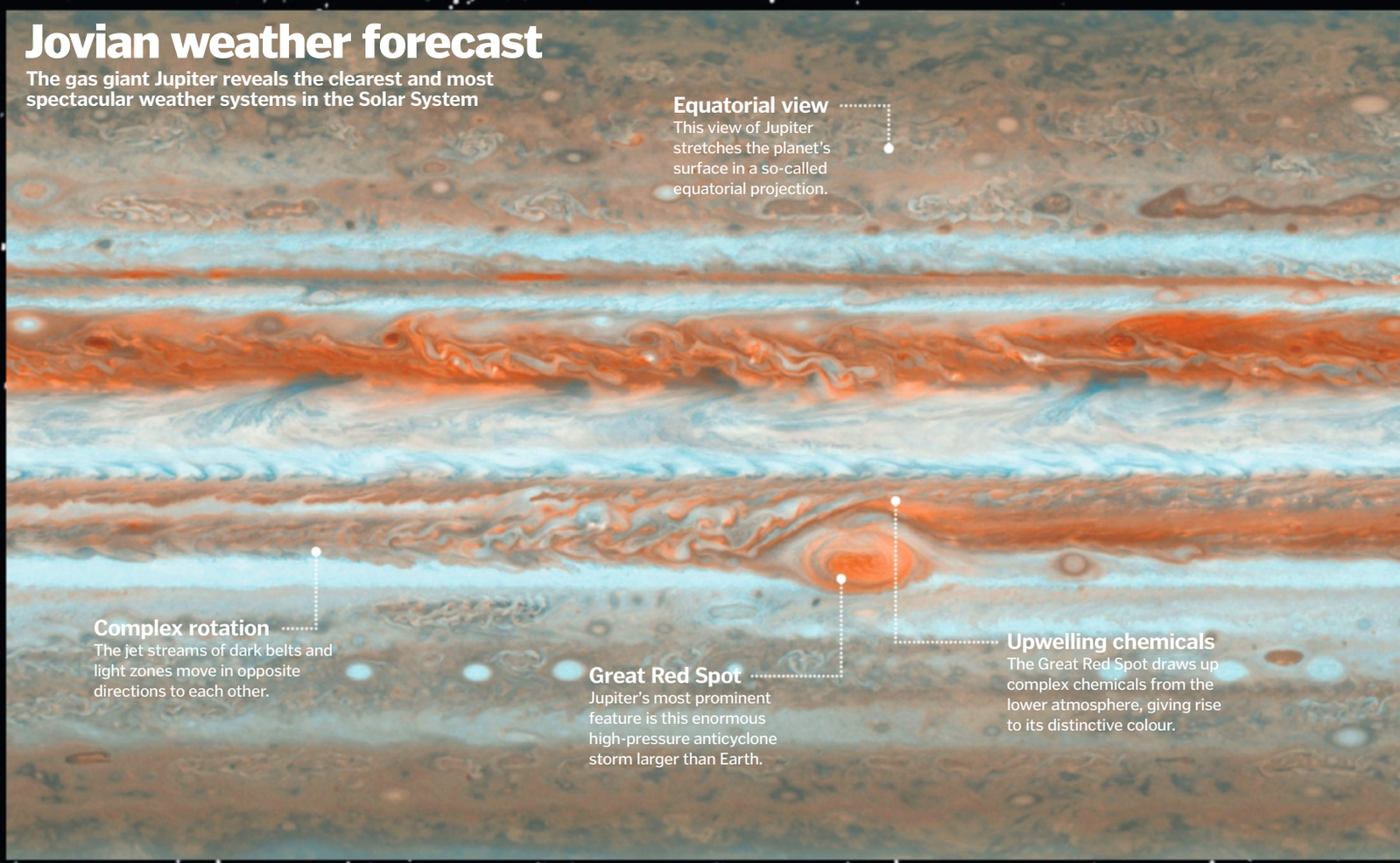
The four gas giants of our own Solar System are amazing and unique worlds in their own right, with enough secrets and unsolved mysteries to keep researchers busy for decades to come. But as if that weren't enough, over the past two decades, astronomers have found themselves with hundreds of other gas giants

Juno is looking to solve some of Jupiter's greatest mysteries

to study, thanks to the discovery of planets orbiting other stars. The vast majority of extrasolar planets found so far have been giants – not because they are innately more common than rocky planets, but simply because they are the most obvious for our current detection methods. Although we are obviously limited in our knowledge of these distant alien worlds, they have already thrown up some major surprises (see 'Hot Jupiters'), and one thing is for certain – we have much more to learn about these monster planets.

Jovian weather forecast

The gas giant Jupiter reveals the clearest and most spectacular weather systems in the Solar System



KEY DATES
GIANT MILESTONES

1700s
James Pound estimates Jupiter's diameter, confirming it as the largest in the Solar System.

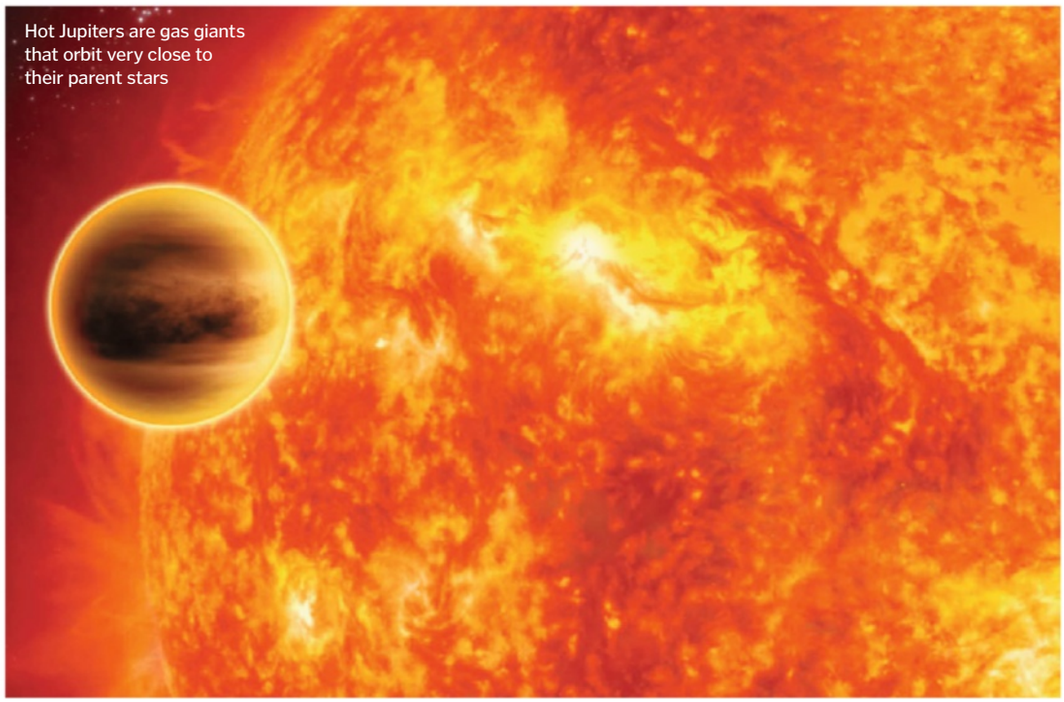
1831
Heinrich Schwabe observes Jupiter's Great Red Spot. A century later it is accepted as a gas giant.

1973
Pioneer 10 flies within 130,360km (81,000mi) of Jupiter, sending back the first close-up photographs.

1995
Michel Mayor and Didier Queloz (right) discover 51 Pegasi B, or 'Bellerophon' – the first 'hot Jupiter'.

2004
The Cassini spacecraft enters Saturn's orbit. It's the longest-lasting and most successful gas giant probe.

DID YOU KNOW? *Jupiter's gravity disrupts the orbits of comets, and may even help protect Earth from impacts*

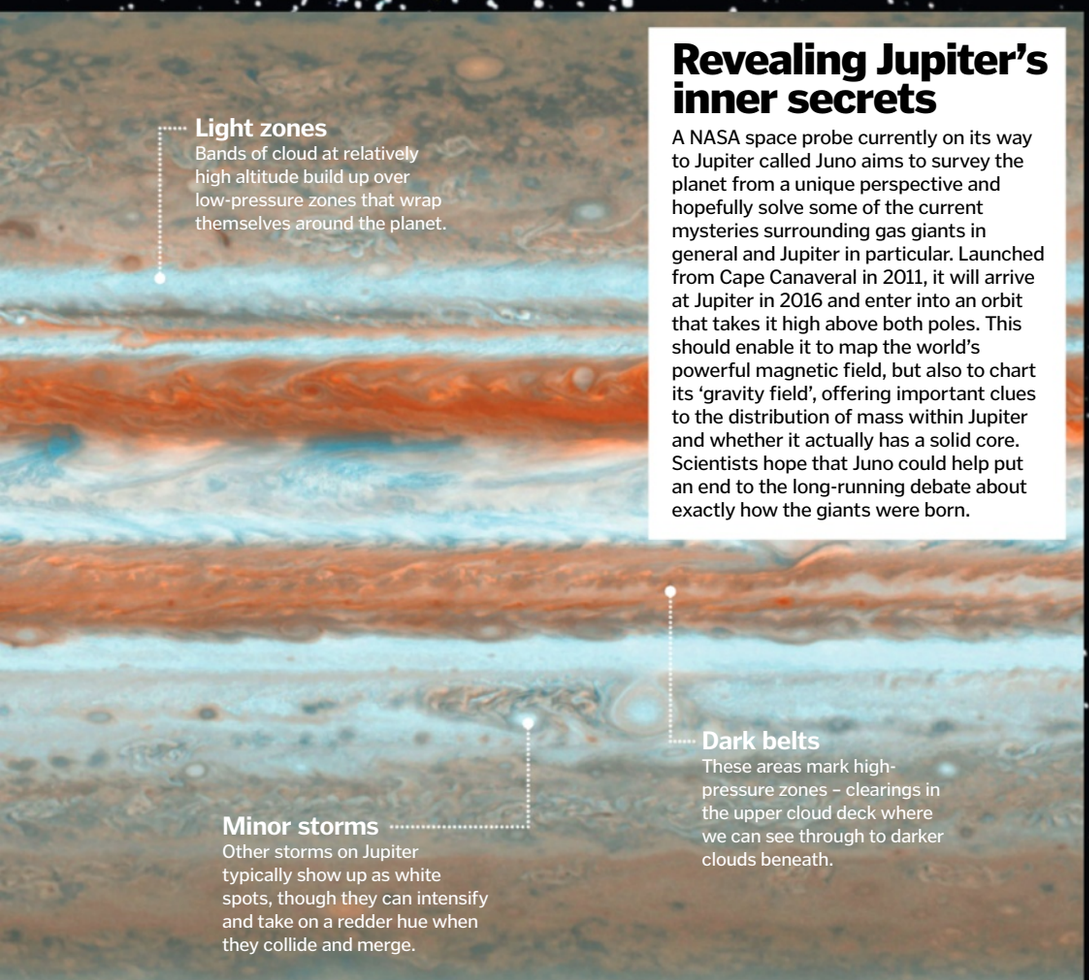


Hot Jupiters are gas giants that orbit very close to their parent stars

Hot Jupiters

Among the most puzzling of the new types of giant planet to have been discovered orbiting stars beyond our Solar System are the 'hot Jupiters' – gas giants with the mass of Jupiter or more that sit very close to their stars – sometimes completing an orbit in just a few days or even hours. In some cases, these planets are actually evaporating in the heat, leaving wakes of gas trailing behind them as they move.

According to our understanding of the way that gas giants form, the material needed to create them was never present this close to their stars, so instead they must have started much farther out, and then migrated inwards on a spiral path. Computer models suggest that something like this also happened to Jupiter early in the history of our own Solar System, but that it was 'saved' and restored to its current position by interaction with Saturn, before it could wreak havoc on the inner planets. Other planetary systems may not have been so lucky, and there's even some evidence of stars that have recently swallowed their unfortunate planets altogether.



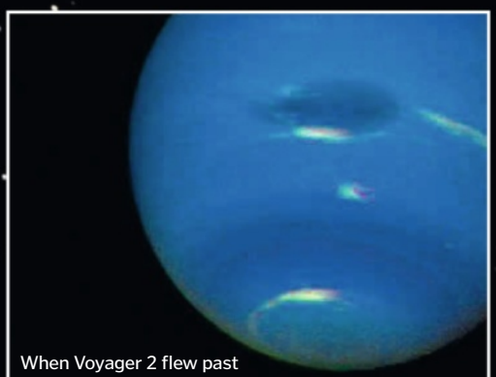
Light zones
Bands of cloud at relatively high altitude build up over low-pressure zones that wrap themselves around the planet.

Minor storms
Other storms on Jupiter typically show up as white spots, though they can intensify and take on a redder hue when they collide and merge.

Dark belts
These areas mark high-pressure zones – clearings in the upper cloud deck where we can see through to darker clouds beneath.

Revealing Jupiter's inner secrets

A NASA space probe currently on its way to Jupiter called Juno aims to survey the planet from a unique perspective and hopefully solve some of the current mysteries surrounding gas giants in general and Jupiter in particular. Launched from Cape Canaveral in 2011, it will arrive at Jupiter in 2016 and enter into an orbit that takes it high above both poles. This should enable it to map the world's powerful magnetic field, but also to chart its 'gravity field', offering important clues to the distribution of mass within Jupiter and whether it actually has a solid core. Scientists hope that Juno could help put an end to the long-running debate about exactly how the giants were born.



When Voyager 2 flew past Neptune in 1989, it found the planet dominated by an enormous storm that was named the Great Dark Spot. However, unlike Jupiter's Great Red Spot, this proved to be a temporary phenomenon

Unlike the broad, bright rings of Saturn, with their countless ringlets, Uranus's ring system is composed of just 13 narrow, dark ringlets that are thought to be largely composed of methane ice

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THE STATS
SPACE RUBBISH

500,000 PIECES OF DEBRIS BIGGER THAN A MARBLE

40% JUNK MADE UP OF SATELLITE OR SPACECRAFT BREAK-UPS

30hrs NOTICE REQUIRED TO PLAN AND EXECUTE DEBRIS AVOIDANCE

56yrs OLDEST PIECE OF SPACE JUNK IN ORBIT

13,000 WEEKLY 'CLOSE CALLS'

8km/sec TOP SPEED OF MOST SPACE JUNK

DID YOU KNOW? *Being hit by a coin-sized piece of space debris is akin to being hit by a bowling ball at 483km/h (300mph)!*

Cleaning up space junk

How one aerospace company plans to rid Earth's orbit of dangerous debris

Space junk is a growing problem for satellites in Earth orbit. Currently there are more than 500,000 pieces of debris ranging in size from a marble to a car being tracked, each of which can be travelling at up to 28,000 kilometres (17,500 miles) per hour. These could have devastating effects if they came into contact with a satellite.

Thankfully, Earth orbit is huge, so the chances of a collision happening are quite slim, but not unprecedented. For example, in 2009 a Russian satellite collided with a US satellite, creating over 2,000 new pieces of space junk. As we add more objects into Earth orbit, collisions such as this will inevitably become more and more common.

To deal with space debris, a number of solutions have been suggested, including using lasers to push junk back into the atmosphere where it will burn up. However, a company called Swiss Space Systems (S3) has suggested a more innovative and affordable way of dealing with the larger chunks of debris.

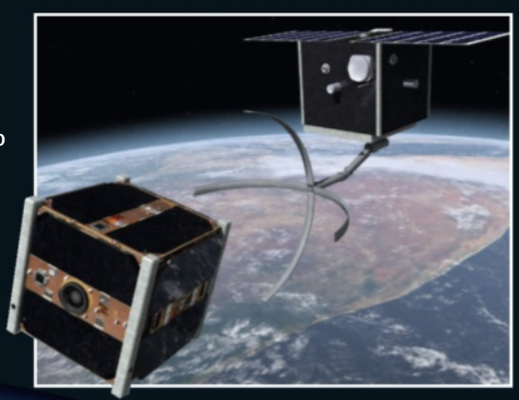
They plan to send up a satellite known as CleanSpace One into orbit on a demonstration mission in 2018. The 30-kilogram (66-pound) satellite will launch on a small spaceplane, also in development by S3. Once it reaches orbit, the satellite will use a four-pronged robotic arm to grab a piece of debris and then, using its onboard thrusters, CleanSpace One will bring it down to a lower altitude and release it to burn up in our atmosphere.

This first mission will cost some £9.7 million ($16 million) and, if successful, the same technology could well be used by satellite operators around the globe in the future to help clean up regions of Earth's orbit.

Real-life Gravity

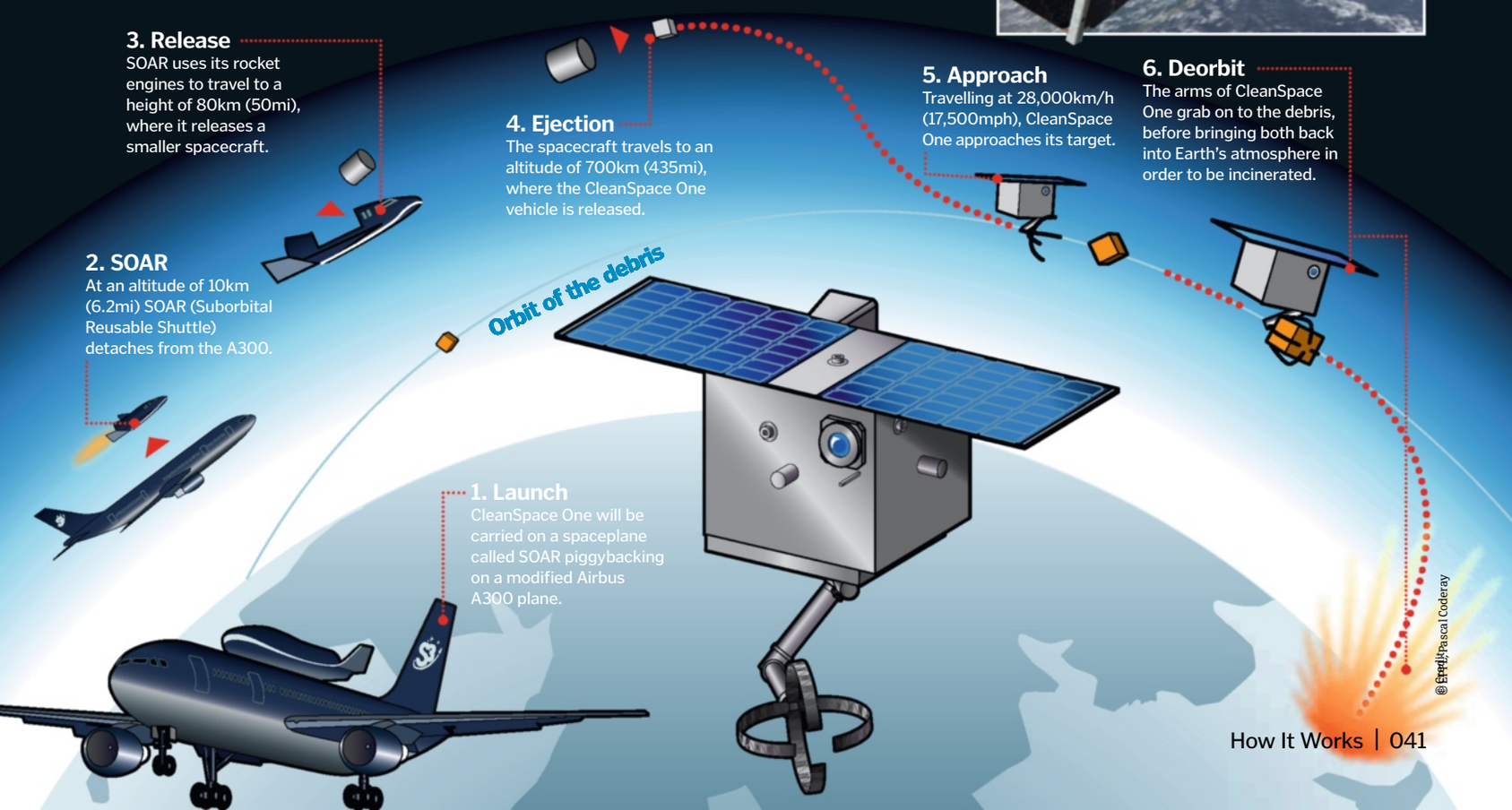
If you've seen the 2013 movie *Gravity*, you might already be aware of the dangers of space junk. In the film, a Russian satellite is blown up by a missile, starting a chain reaction as the debris from the satellite hits other satellites, creating even more debris in the process.

Although the effects were exaggerated in the movie, this is an entirely possible scenario known as the Kessler syndrome. NASA scientist Donald Kessler in 1978 proposed that as the number of objects in orbit increases, the chances of a chain reaction of collisions becomes an ever-likelier threat, hence the urgency to clean up.



CleanSpace One's mission

A step-by-step look at how this spacecraft will remove debris from orbit



"Quark stars are a hypothetical stellar remnant that might be somewhere between a black hole and neutron star"

Quark star debate

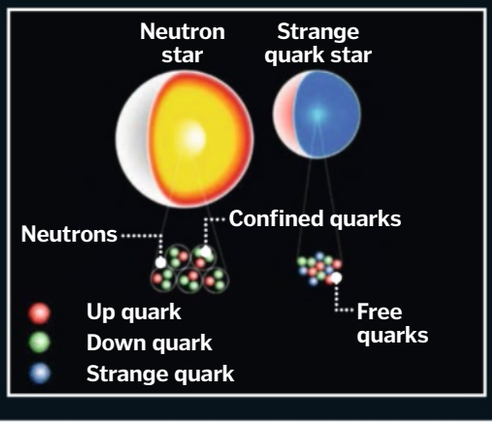
Strange stellar remnants are spurring discussion among astronomers, but how do quarks differ from other stars?

When a massive star goes supernova, it usually goes one of two ways. It can become a stellar remnant known as a neutron star, or it can collapse into a black hole. Quark stars are a hypothetical stellar remnant that might be somewhere in the middle – not massive enough to be a black hole, but too massive to remain a neutron star.

Quark stars are also known as strange stars because they comprise strange matter – a form of matter in which the quarks, or basic particles, aren't organised into protons and neutrons like matter on Earth. There are 'up' quarks and 'down' quarks, but as yet there's no logic determined to them. Scientists theorise that if you compress these quarks hard enough, some of them will become heavier and then turn into 'strange' quarks.

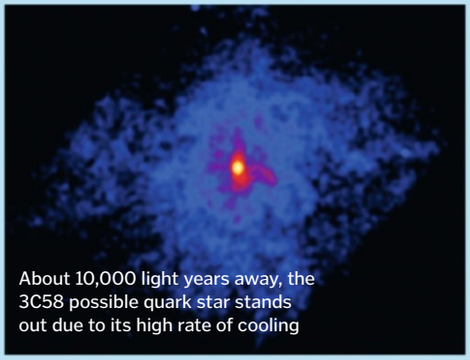
Quark stars may be born when a neutron star can't withstand the forces of the pressure necessary to keep it from collapsing. This pressure breaks the neutrons down into quarks, some of which become strange quarks. Since quark stars are theoretical and have just a few found candidates thus far, like XTE J1739-285, the debate about them is just getting started.

There is also the electroweak star, so dense and pressured that the energy at the core would 'burn' strange matter



Candidate quarks

Statistically there can't be many quark stars in our galaxy, based on current theories about them. But we've found a few potential contenders – mostly neutron stars that appear to be overly dense. RX J1856.5-3754 was once considered to be a possible quark star, based on Chandra X-ray Observatory and Hubble Space Telescope observations, but it's recently been excluded from the list. One candidate still in the running is XTE J1739-285, an incredibly fast-spinning star once considered a neutron star. Others include PSR B0943+10, a relatively old pulsar with unusual changes in its X-ray emissions, and the 3C58 pulsar in the Milky Way.



About 10,000 light years away, the 3C58 possible quark star stands out due to its high rate of cooling

A spherical halo of neutrinos around a spiral galaxy

Origins of neutrinos

These minuscule particles are prevalent throughout the universe, but where do they come from?

Neutrinos are incredibly tiny, almost massless and carry no electrical charge. They're also everywhere in the universe, constantly passing through atoms at nearly the speed of light.

Neutrinos are affected only by gravity – which is very weak at subatomic levels – and weak nuclear forces. There are three different types of neutrino, known as flavours – tau, muon and electron – and each is associated with the charged particle that gives the flavour its name.

These particles are born of highly energetic events in the universe like a star going supernova, or from nuclear fusion. They may also be produced by radioactive decay. Nuclear fusion produces electron neutrinos: when two hydrogen atom protons merge, they form deuterium. This process releases both an anti-electron and an electron neutrino. Many believe that the majority of neutrinos were produced during the Big Bang; these neutrinos are mostly stationary, while the ones produced as a result of supernovas are very active.

These particles are very difficult to detect, but do interact with atoms to generate energy. Neutrino detectors can comprise large pools of water or ice, with super-sensitive sensors to pick up radiation emitted by collisions. Hard as they may be to study, they can help us better understand how the cosmos formed.

What was recently found orbiting a rogue planet?

A A moon **B** A black hole **C** A spacecraft

Answer:
The answer is a moon – or exomoon – found outside the Solar System. This satellite is part of the MOA-2011-BLG-262 exoplanet-exomoon system detected in December 2013; its host is estimated to have four times the mass of Jupiter.

DID YOU KNOW? *Estimates suggest there might be twice as many rogue planets as 'normal' planets in the Milky Way*

Rogue planets

Meet the free-floating planets that like to fly solo

Up until the late-20th century the only planets we knew of were those found in our own Solar System. Now, thanks to missions such as NASA's Kepler spacecraft, we know of hundreds more that exist in other planetary systems across the cosmos. But in the last decade, we've started to find some planets drifting freely through space, and estimates suggest that there could be millions more in our Milky Way alone.

First theorised in 1998, several rogue planets have been found since 2012. The predominant theory as to how these planets come to be 'going solo' surmises that these bodies were knocked out of a planetary system by some major event – perhaps a passing star or a nearby unbalanced young system.

Another emerging theory, however, suggests that some rogue planets could be born without a parent star in clouds of dust and gas. These planets would then form in a similar way to stars, except they would be too small to ignite fusion at their cores, so end up remaining as planets rather than developing into stars. Studies indicate free-floating planets may be able to retain some heat, although they are most likely to be cold and barren worlds.

Detecting rogue planets is a tricky business. Our usual methods of finding exoplanets, by noticing their effect on their parent star, is impossible here. Instead, scientists either try to directly image them or notice the gravitational microlensing effect a rogue planet has as it passes in front of a background star.

First sighting

One of the closest rogue planets to our Solar System, and the first to ever be confirmed in 2012, was CFBDSIR2149-0403. Found about 100 light years from us, its proximity has allowed it to be studied in detail. Observed by the European Southern Observatory's Very Large Telescope (VLT) in Chile and the Canada-France-Hawaii Telescope (CFHT) on Hawaii, astronomers have deduced it is between 50 and 120 million years old. It is thought to have a surface temperature of 400 degrees Celsius (750 degrees Fahrenheit) and a mass four to seven times that of Jupiter. Interestingly some observations have also detected water and methane in its atmosphere.

CFBDSIR2149-0403 is the faint dark blue dot in the centre of this shot

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THE STATS
SUN IN NUMBERS

4.6bn AGE (YRS)

SURFACE TEMP **5,500°C**

MASS **333,000 Earths**

DIAMETER **1,391,980km**

~220km/s VELOCITY (ORBITING CENTRE OF GALAXY)

VOLUME **1.3mn Earths**

DID YOU KNOW? *As well as the interior, helioseismology can even reveal features on the far side of the Sun like sunspots*

Listening to stars

We can learn a lot about the Sun by tuning in to the waves that travel through it

Studying the Sun isn't just about measuring radiation and visible light – there's even more going on under the surface than you may have realised. On Earth, seismology is the study of the energy waves that travel through our planet from its core. The Sun has its own version, called helioseismology after the terrestrial form, although there's no actual seismic activity on the Sun. It's more closely related to asteroseismology, the study of the frequency spectrum of pulsing stars.

Seismic waves on Earth are usually the result of a single event, such as an earthquake or a volcanic explosion. Solar waves don't have a single source; they're most likely generated by turbulence and other processes happening in the convection zone, right near the Sun's surface. Scientists describe the behaviour of these waves as being similar to a bell ringing continuously. They are visible on images of the Sun as oscillations, or the up-and-down waves, of gases. However, solar waves are typically measured by Doppler shifts – changes in the wave frequencies. These appear as spectrum lines – darker or brighter lines in an otherwise continuous spectrum. These waves resonate in the Sun and interference between them results in standing, or constant, waves.

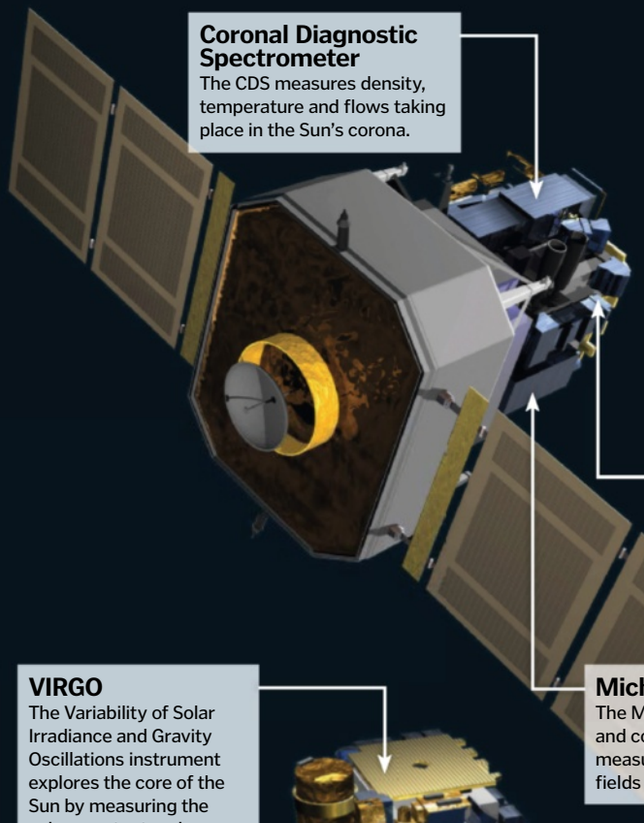
By studying and analysing these waves we can infer a lot about what's going on inside the Sun; for example, it's taught us about temperature variations, volume, density, composition and even the age of the interior. There are several ground and satellite-based instruments which use helioseismology. One is the Solar and Heliospheric Observatory (see below) and another is NASA's Solar Dynamics Observatory (SDO), which includes the Helioseismic and Magnetic Imager (HMI). The SDO has been studying the Sun since 2010 and has already made many discoveries. In 2013, data helped explain the flow of meridional circulation, which moves material within the Sun between low and high altitudes.

Solar waves

Depending on the force that drives the wave, solar waves can be classified into three different modes: acoustic (p-mode), gravity (g-mode) and surface gravity (f-mode). Acoustic waves have the force of pressure behind them and are determined by the speed of the solar sound waves. These high-frequency waves are often known as five-minute oscillations because that is the approximate length of their cycle; they are visible and take place in patches on the surface of the Sun. Gravity waves are driven by that force and have low frequency; these waves cannot be seen on the surface as they occur below the convection zone in the Sun's interior. Surface gravity waves, meanwhile, occur in the photosphere. There may be millions of overlapping modes within each type. Together this data can be analysed to make inferences about the Sun's interior and even what's occurring on the side facing away from us.

SOHO spacecraft in focus

What tools does the Solar and Heliospheric Observatory have on board to reveal the Sun's inner secrets?



Coronal Diagnostic Spectrometer
The CDS measures density, temperature and flows taking place in the Sun's corona.

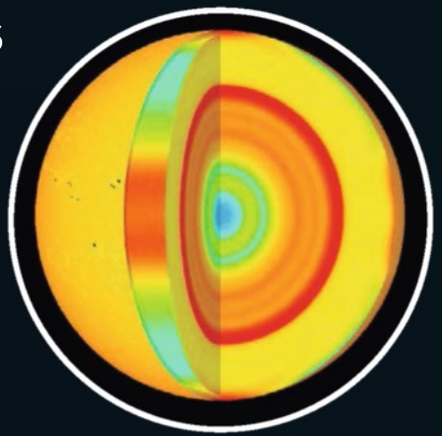
GOLF
The Global Oscillations at Low Frequencies tool studies the core by measuring variations in solar disc velocity.

Michelson Doppler Imager
The MDI studies the convection zone and coronal magnetic fields by measuring the velocity and magnetic fields in the photosphere.

VIRGO
The Variability of Solar Irradiance and Gravity Oscillations instrument explores the core of the Sun by measuring the solar constant and intensity oscillations.

UVCS
The Ultraviolet Coronagraph Spectrometer studies both the microscopic and macroscopic behaviour of the corona.

Solar Wind Anisotropies
These telescopes are tuned to a hydrogen wavelength to measure solar wind streams and solar wind mass flux. They can also map the heliosphere's density.



Scientists can study the internal structure of the Sun by listening to solar waves travelling through it

"Mariner 9 revealed deep river valleys as well as grooves, lake basins and inverted streams"

Is there water on Mars?

Learn why scientists think the Red Planet could once have been more blue

When pondering whether a planet is capable of supporting life, one of the first things scientists think about is whether water exists there. The polar caps on Mars have hinted at the presence of water since the planet was first viewed via telescope. Now we know the vast majority of the water on Mars is ice, and the rest exists as water vapour in the atmosphere and soil. The visible ice is located in the north polar ice cap, but ice is also present under the solid carbon-dioxide south polar cap and in other areas around the planet.

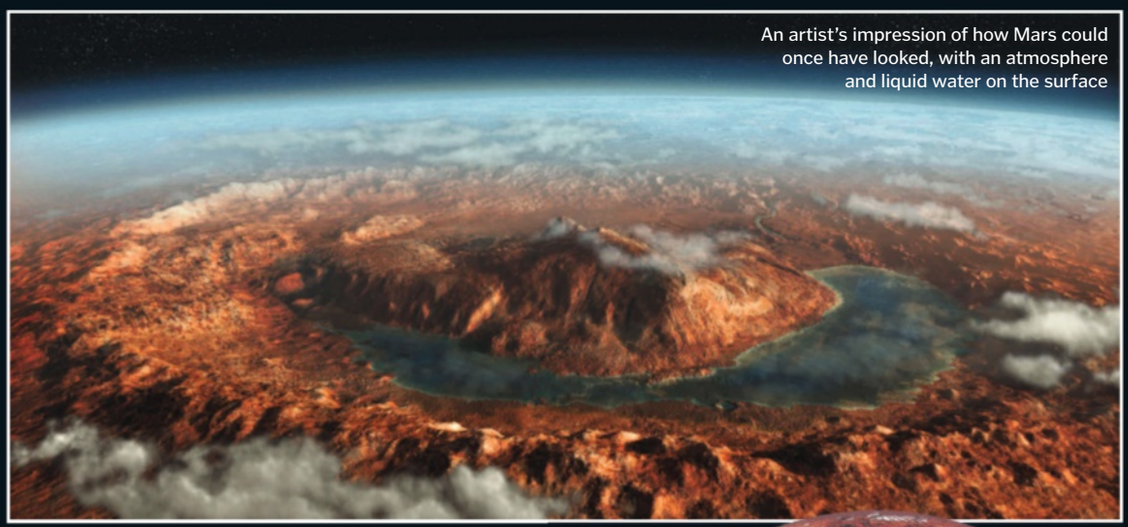
It's not believed there can be liquid water on Mars – except perhaps for brief periods of time – because the planet's average temperature and atmospheric pressure is too low to support it. However, exploration has uncovered evidence that there were once vast amounts of liquid water on our neighbour – potentially covering as much as a third of its surface. Before about 3.8 billion years ago, Mars may have been much warmer with a dense atmosphere.

Until the Mariner 9 spacecraft returned data about the planet in 1971, we didn't know much about its past. The probe revealed deep river valleys as well as grooves, lake basins and inverted streams. Subsequent probes and landers revealed even more evidence of past water flows through imagery as well as soil and mineral analysis. More recently, NASA's Mars Reconnaissance Orbiter spotted dark streaks that may be liquid water from melting runoff during the Red Planet's warmer months.

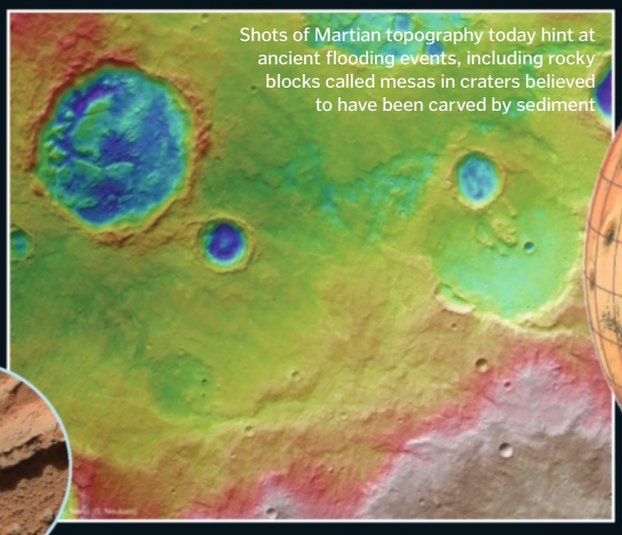
Despite numerous probes and several rovers on the surface, we've yet to solve the mystery of where all that water went. If Mars was once more Earth-like and covered in H_2O, what happened? One theory is that the planet lost its magnetic field, allowing solar wind to strip away its atmosphere. In November 2013, NASA launched the MAVEN (Mars Atmosphere and Volatile Evolution) craft, a probe tasked with finding out what happened to the atmosphere and surface water on Mars, so by the end of 2014 the answer may be within sight.

Curious discoveries

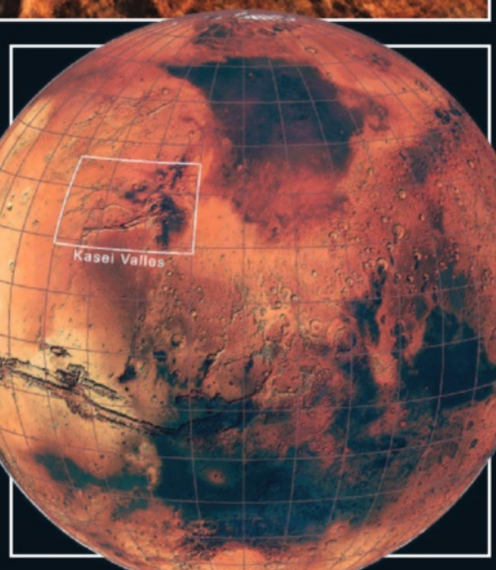
NASA's Curiosity rover landed on Mars in August 2012, with one of its mission objectives to determine the role of water on the planet. The rover's landing spot was Gale Crater, where it found evidence of clay formations, or 'mudstone'. This means there must have once been a lake in the area. The Curiosity programme's lead scientist, Michael Meyer, has also stated that an area in the crater called Yellowknife Bay likely once held salty water. The rover has discovered a massive ancient streambed where knee-deep water likely flowed for years too. As part of the same brief, Curiosity has been studying the history of rock formations in the crater, such as one nicknamed 'Darwin', to see how water may have played a role in their formation. The rover has also established that the soil on the Red Planet is currently made of about two per cent water.



An artist's impression of how Mars could once have looked, with an atmosphere and liquid water on the surface



Shots of Martian topography today hint at ancient flooding events, including rocky blocks called mesas in craters believed to have been carved by sediment



THE STATS
MARS NUMBERS

AVERAGE TEMPERATURE
-63°C

RIVER VALLEYS
40,000

1963
WATER VAPOUR CONFIRMED

3km
ESTIMATED ICE CAP THICKNESS

WATER IN SOIL
2%

AVERAGE ATMOSPHERIC PRESSURE
750Pa

DID YOU KNOW? *Currently Mars is estimated to be covered in about 5mn km³ (1.2mn mi³) of ice*

Other water worlds

Mars isn't the only place in the Solar System with H_2O. This diagram charts the distribution of water and ice, comparing the water volume of other bodies to Earth's

Key
- Water and ice
- Ice only

Earth's Moon
0.00000000002 Earths

Mercury
0.0000002 Earths

Earth
366 million trillion gallons (1.38 billion trillion litres) of water

Ceres
0.14 Earths
Located in the Asteroid Belt, the dwarf planet Ceres' mantle contains more fresh water in the form of ice than Earth, and it may also have a liquid ocean.

Europa
2.9 Earths
Europa, Jupiter's smallest Galilean moon, has one of the smoothest surfaces in the Solar System, thanks to high water-ice content. It may also feature a subsurface liquid ocean.

Mars
0.003 Earths

Callisto
27 Earths
The Jovian moon Callisto contains water ice, but likely in equal proportion to rock. Some think that a liquid ocean could exist underneath its surface.

Ganymede
36 Earths
The largest moon in the Solar System is estimated to be equal parts rock and water ice. It may also have a saltwater ocean between layers of ice.

Titan
29 Earths
Saturn's largest moon Titan is thought to be half water ice and half rocky material. Scientists theorise an ocean may be located below surface ice.

Enceladus
0.2 Earths
This Saturnian moon is small and believed to contain a high percentage of water ice. Sprays of vapour indicate subsurface water too.

Bringing the water back

The lack of liquid water on the surface of Mars is one of the major roadblocks to permanent human colonisation of the planet, but there have been discussions about how to tackle this problem. Since we know that Mars has plenty of water in the form of ice, colonists could place their bases primarily in these areas. Another possibility is creating the right conditions for water to reform. Terraforming, a process designed to create a habitable planet by altering its atmosphere, surface and other properties, would be the obvious course of action to take. If we could give Mars an atmosphere, surface temperatures would rise and theoretically we'd naturally end up with liquid water. We'd also need to be able to sustain that heat and keep the atmosphere stable. However, terraforming is still a theoretical process and comes with numerous challenges. The water issue is also just one of many when it comes to colonising the planet. That said, making Mars habitable is still very much within the realm of possibility.

Underwater buildings

With land in short supply, it's little wonder more and more architects are looking beneath the waves for inspiration...

Submarines have been around since at least the 18th century and modern nuclear subs can reach depths of over 400 metres (1,300 feet). By comparison, building a house just ten or so metres (33 feet) below the surface might seem easy by comparison, but permanent dwellings have their own set of unique challenges. Let's start at the front door. A submarine rises to the surface to let people on and off. This means the air inside the sub can be kept at normal atmospheric pressure. But a completely submerged building anchored to the seabed either needs an airlock, so the pressure can be adjusted as divers enter and exit, or it needs to keep its internal air pressure the same as the water pressure outside.

When you spend more than an hour or so breathing high-pressure air, the nitrogen in the air dissolves into the water stored in your body tissue. Without an extensive period of gradual decompression at the end of your stay, the nitrogen will come out of solution all at once and form bubbles that can cramp muscles and block blood vessels. This is a potentially lethal condition known as 'the bends'.

To avoid this risk, most undersea buildings currently being planned have a permanent access link to the surface. This allows the air pressure throughout the building to be kept at normal atmospheric levels, but it means that there is nothing balancing the huge weight of the water outside. At a depth of 20 metres (66 feet), each square metre of wall or window has more than 20 tons of weight pressing against it. This requires much thicker and stronger materials than a normal house, plus walls and roofs have to be curved to distribute the load evenly. A permanent connection to the surface also exposes the building to tidal forces.

The Underwater Room at Tanzania's Manta Resort is a single-bedroom hotel in the Zanzibar archipelago. To avoid the constant scouring of the twice-daily four-metre (13-foot) tides in the island chain, this room isn't firmly anchored to the seabed. Instead it hangs below an upper deck that floats on the surface. The effect is rather like an extreme version of a glass-bottomed boat.

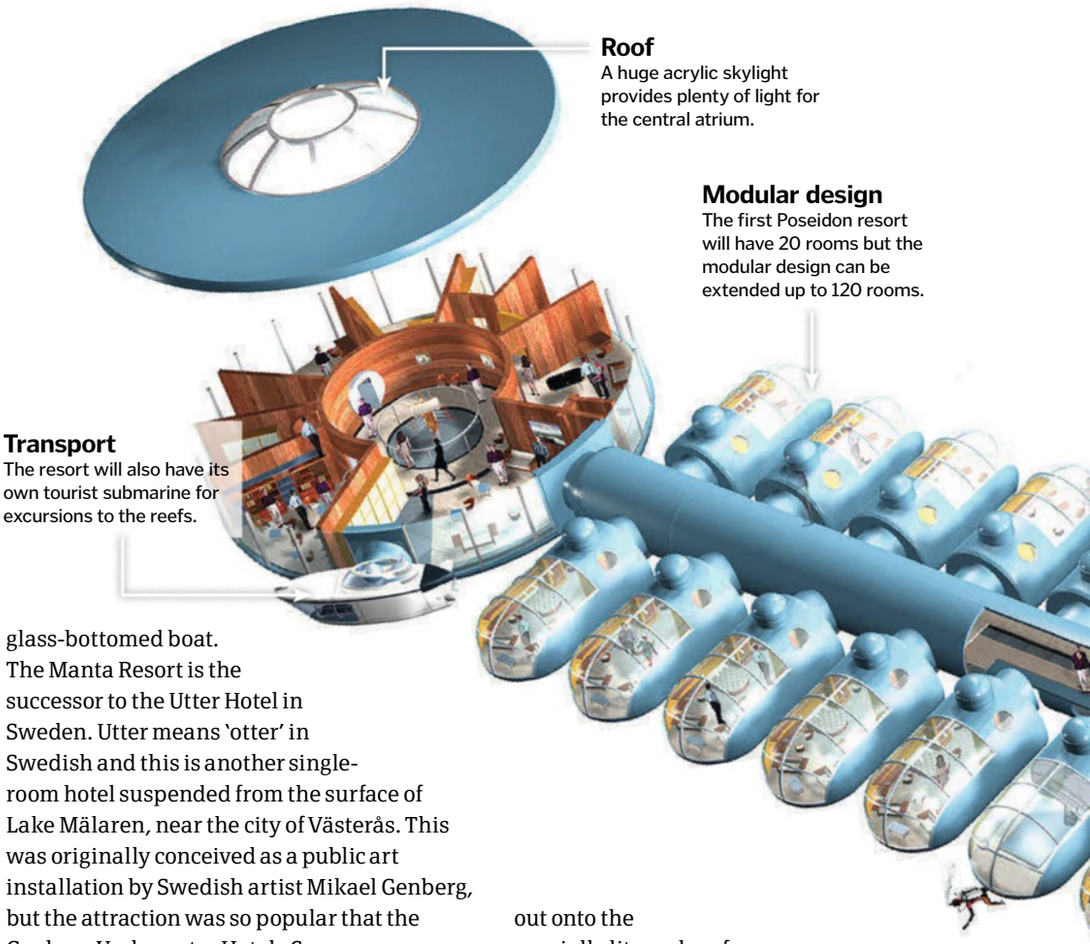
The Manta Resort is the successor to the Utter Hotel in Sweden. Utter means 'otter' in Swedish and this is another single-room hotel suspended from the surface of Lake Mälaren, near the city of Västerås. This was originally conceived as a public art installation by Swedish artist Mikael Genberg, but the attraction was so popular that the Genberg Underwater Hotels Company was formed in 2006 to bring the concept to warmer waters around the world.

More ambitious designs have floors raised entirely above the sea surface, as well as anchored below it, with the two levels connected by narrow support piles. The Water Discus Hotel is an ambitious project proposed for the Maldives that looks like a landed spaceship. The upper levels are supported high enough above the water to survive a medium-sized tsunami, while the undersea level sits ten metres (33 feet) deep with 21 bedrooms that look out onto the specially lit coral reef.

Dr Lech Rowinski chairs the Department of Theory and Ship Design at Gdansk University in Poland. He is a cofounder of Deep Ocean Technology, the company behind the Water Discus Hotel. In an exclusive interview with **How It Works**, he told us about the challenges of the project: "For us, wave action is the biggest problem, because we are necessarily limited to areas with low tidal ranges. We have the opposite design to an oil rig, where you build high above the water just to avoid the waves. In our case we have a ▶

A new Poseidon adventure

One of the marine habitats currently under construction, take a tour around the Poseidon Undersea Resort now



5 TOP FACTS
AQUATIC ABODES

1 Aquatica
An old submarine refuelling base is turned into a medical research base in *Deep Blue Sea* (1999). Surprisingly, breeding super-intelligent mutant sharks turns out to be a bad idea.

2 Broken Ridge
In the Nineties TV series *seaQuest DSV*, land resources are exhausted and underwater mining towns line the ocean floor. Broken Ridge is off the coast of Australia.

3 Tri-Oceanic Corp
In *Leviathan* (1989), undersea miners plan to spend 90 days at the bottom of the Atlantic Ocean. But then they find a contaminated shipwreck and start sprouting tentacles.

4 Deep Core
The deep-sea platform in *The Abyss* (1989) sits an alarming 2km (1.2mi) under the sea. That's peanuts compared to the aliens living in the 8km (5mi) ocean trench though.

5 Atlantis
Not just the lost city of Greek legend, but also the secret undersea lair of supervillain Karl Stromberg from the 1977 Bond movie *The Spy Who Loved Me*.

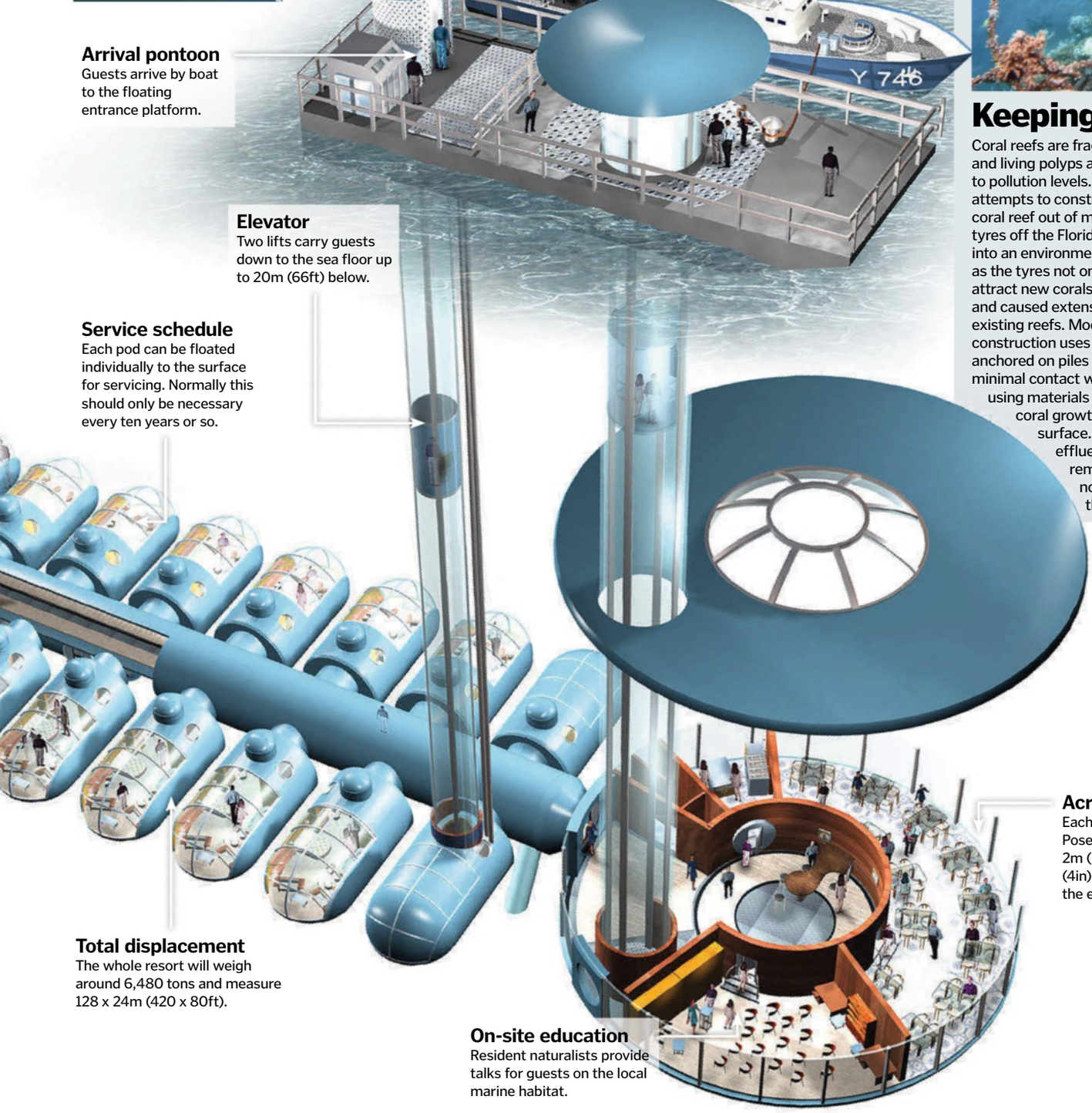
DID YOU KNOW? *To hire the entire Poseidon Undersea Resort exclusively for a week will cost $2.75mn (£1.67mn)*


The Poseidon underwater resort is located in Fiji


Artificial coral reefs have improved massively over the years and today are much more eco-friendly

Keeping green

Coral reefs are fragile structures and living polyps are very sensitive to pollution levels. In the Seventies, attempts to construct an artificial coral reef out of millions of old car tyres off the Florida coast turned into an environmental catastrophe as the tyres not only failed to attract new corals but broke loose and caused extensive damage to existing reefs. Modern undersea construction uses buildings anchored on piles so they have minimal contact with the seabed, using materials that encourage coral growth on their surface. All waste and effluent is recycled or removed in order to not contaminate the water.



Arrival pontoon
Guests arrive by boat to the floating entrance platform.

Elevator
Two lifts carry guests down to the sea floor up to 20m (66ft) below.

Service schedule
Each pod can be floated individually to the surface for servicing. Normally this should only be necessary every ten years or so.

Acrylic windows
Each curved pane in a Poseidon resort is 3 x 2m (10 x 6ft) and 10cm (4in) thick to withstand the external pressure.

Total displacement
The whole resort will weigh around 6,480 tons and measure 128 x 24m (420 x 80ft).

On-site education
Resident naturalists provide talks for guests on the local marine habitat.

"The Water Discus Hotel is designed so that the entire underwater section can rise to the surface"

substantial volume under the water so there are huge forces acting on it." Surprisingly, the solution is not to sink deep foundation piles into the bedrock. Instead the Water Discus Hotel will be anchored to the seabed using suction. It works a bit like a Wellington boot that gets stuck in deep mud, except that the mud in this particular case is a steel-walled cavity that the hotel base sits in. "It's a question of not allowing water *under* the structure," explains Dr Rowinski: "You have a cavity – it doesn't need to be water-tight, but with very limited flow. Pumping the water out isn't required because it is a dynamic system. One moment you have lower pressure at the bottom of the wave and another moment you have higher pressure, so you only need a small overall force keeping the base of the hotel in the cavity."

The walls of underwater buildings are made from steel, using shipbuilding techniques, but the large windows are made from acrylic plastic. It flexes slightly to avoid stress fractures, but more importantly it has a refractive index very similar to water, so it doesn't interfere with the view. It is also the reason underwater hotels are sited no deeper than 30 metres (98 feet) below the surface. "It's a question of visibility," says Dr Rowinski: "We need to provide some colour for objects in the water and if you want colour you need shallow water."

But even ten metres (33 feet) of water presents a significant problem in the event of an emergency evacuation. Ironically, fire safety is actually a major consideration in an aquatic building because even a small fire can quickly consume the available breathable air. The Water Discus Hotel is designed so that the entire underwater section can rise to the surface. Dr Rowinski explains: "We designed the ballast tanks above the water level so you can raise the structure easily, without the aid of any mechanical equipment. It rises under its own buoyancy. It would take at least 15 minutes to rise, but we think this is actually too fast, so we aim for half an hour. This is for organisation of the evacuation – to allow people to move without panicking."

And if you happen to be concerned about the risk of hurricanes or tropical storms, an underwater holiday might actually be the safest destination for you. "I think the hotel will be more resistant to weather than buildings on land," concludes Dr Rowinski: "In the Maldives, very high waves during tsunamis are very likely so it's safer to be in the underwater compartment than on the shore."


This underwater suite is part of a luxury hotel in the Maldives

Ocean homes

While a week-long luxury holiday or research trip might be enough for most of us, if you want something more permanent, there are now a few companies that will build you a permanent undersea residence. US Submarine Structures LLC is currently constructing two-bedroom circular houses that can be anchored to the seabed of your choice. The 'H_2OME' project can cope with depths between ten and 20 metres (33-66 feet) and is connected to the surface via a lift in the central pillar. This means the air inside the house is the same pressure as the surface, so there is no need for airlocks or lengthy decompression procedures when you leave. The panoramic acrylic windows extend around the house, offering views from every room. Each habitat features over 460 square metres (5,000 square feet) of living space, complete with luxury furnishings and décor inspired by five-star hotels and superyachts.

Evolution of undersea habitats

1962

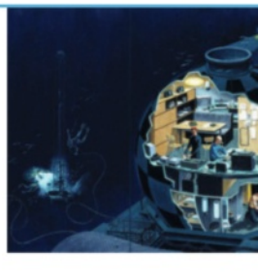
Conshelf I
Designed by Jacques Cousteau, the Continental Shelf Station is the first inhabited underwater building. Two 'oceanauts' spend a week in this 5 x 2.5m (16.4 x 8.2ft) cylinder.

1964

SEALAB I
Built by the US Navy to study techniques to reduce decompression sickness after diving for extended periods. It spends 11 days at 58m (190ft) depth.

1965

Conshelf III
The last of Cousteau's underwater habitats (right). At 100m (328ft) below the surface – ten times deeper than Conshelf I – it is self-sufficient for three weeks.



THE STATS
WATER DISCUS HOTEL SPECS

ROOMS **21**

1,000m² FLOOR AREA

DEPTH **10m**

DIAMETER 49m

2017 COMPLETION DATE

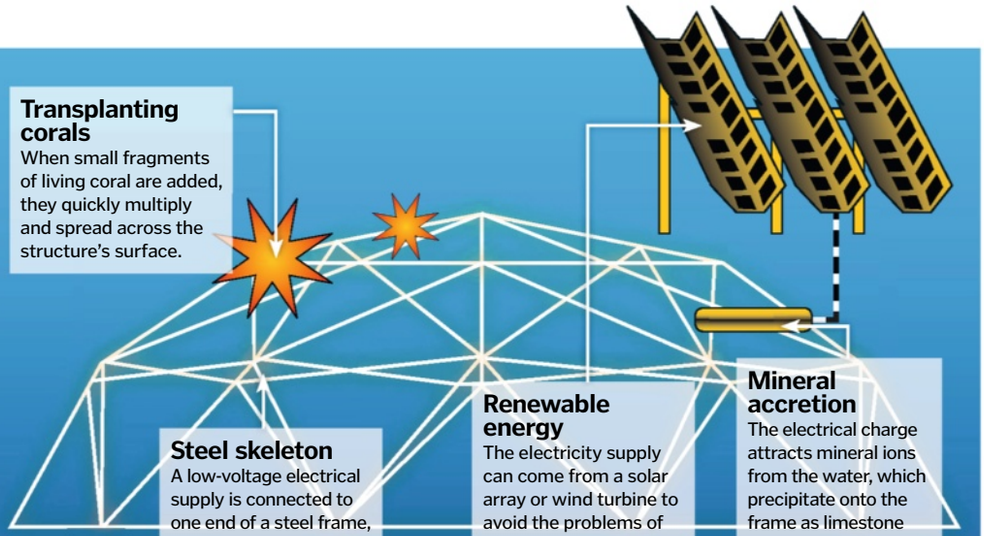
$50-120mn ESTIMATED COST

DID YOU KNOW? *In 1966, a Soviet amateur diving club built a series of underwater habitats (The Ichthyander Project) in the Black Sea*

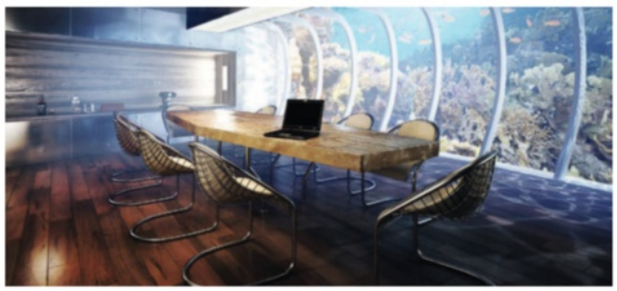
Make a living building

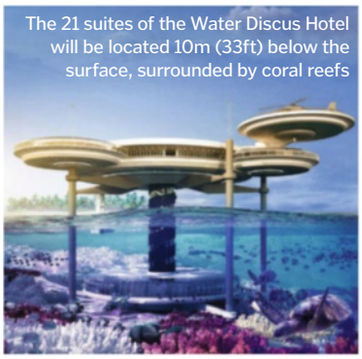
A coral reef is made mostly from calcium carbonate (limestone). The coral polyps living there absorb mineral ions from the seawater and deposit it as solid rock around their bodies to form an exoskeleton. Biorock harnesses these same mineral ions but uses electricity instead of living corals to precipitate them as solid rock. The electrically charged ions can be attracted onto a metal surface by running an opposite charge through the metal. This only needs a low voltage, harmless to marine life and by varying the current you can adjust the mineral formation.

In theory, Biorock could let us 'grow' a building (see diagram). Although it uses more energy to produce than ordinary concrete, it is three times stronger and can take any shape. The layer grows at up to five centimetres (two inches) a year and damage from storms or collisions can heal itself, provided the power stays on. And far from harming marine life, corals attached to Biorock actually grow faster and tolerate worse sea conditions than corals on natural reefs.




We may soon literally sleep with the fishes in marine H_2OMEs currently under development




The 21 suites of the Water Discus Hotel will be located 10m (33ft) below the surface, surrounded by coral reefs

1968

Helgoland
The first underwater habitat built for cold waters, Helgoland is a 14 x 7m (46 x 23ft) cylinder that operates in the North and Baltic seas.

1969

Tektite
This 15m (49ft)-deep research habitat comprises two metal cylinders on a rectangular platform with a flexible tunnel connecting them.

1970

Hydrolab
Over 15 years, Hydrolab hosts 180 separate missions. Four scientists can live for weeks at a time in the 6m (20ft) cylinder (right).

1986

Aquarius
Still in use today, it weighs 73 tons and can be deployed in water up to 37m (120ft) deep. It has six bunks, a shower and a Wi-Fi connection.

2005

Ithaa
This restaurant in the Maldives (right) sits 5m (16.4ft) below the surface. Diners enjoy 180-degree panoramic views while they eat.

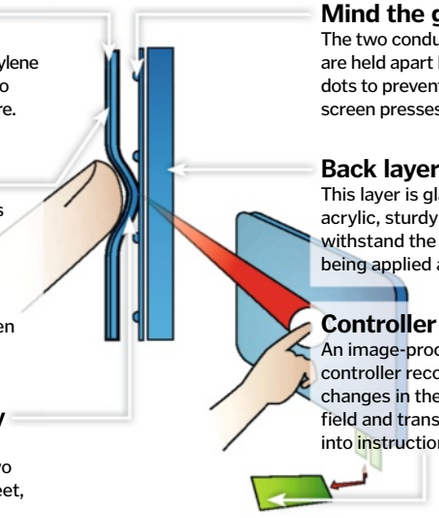
"Surge protectors generally work by isolating sensitive electronic devices from the mains supply"

Touchscreen interaction

This tactile technology comes in two main flavours – resistive and capacitive – but what are the key differences between them?

Resistive screen

Tougher, cheaper and simpler, resistive touchscreens are widely used in our everyday devices



Top layer
This is typically made of scratch-resistant polyethylene (PET) which is designed to flex slightly under pressure.

Resistance
Resistive touchscreens are made of several layers, each with a conductive indium tin oxide (ITO) coating. A current passed between these layers creates electrical resistance.

Push technology
When pressed with a finger or stylus, the two ITO coatings below meet, completing a circuit.

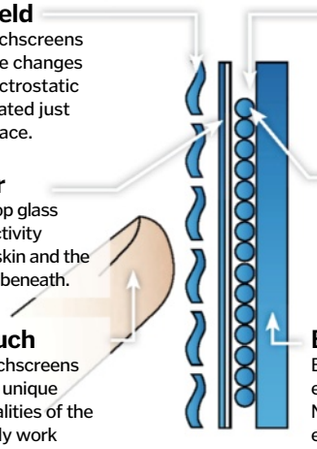
Mind the gap
The two conductive layers are held apart by spacer dots to prevent accidental screen presses.

Back layer
This layer is glass or acrylic, sturdy enough to withstand the pressure being applied at the front.

Controller
An image-processing controller recognises changes in the electrical field and translates these into instructions.

Capacitive screen

More accurate and much more versatile capacitive has to be today's touchscreen of choice



Invisible field
Capacitive touchscreens monitor minute changes in the local electrostatic field being created just above the surface.

Glass layer
Touching the top glass creates conductivity between your skin and the charged space beneath.

Human touch
Capacitive touchscreens respond to the unique conductive qualities of the skin. They rarely work with gloves (unless special capacitive ones).

Charged space
The screens are made up of spaced layers of glass coated with a fine film of indium tin oxide (ITO). A minute charge is applied to this space.

On the grid
Some touchscreens use technology where one layer is etched with a grid pattern of electrodes for even greater precision.

Behind the screens
Behind every electrode lies an embedded microcontroller. Nanosecond response times enable today's smartphones and tablets to interact almost instantly to our touch.

Surge protectors explained

Learn how these gadgets can stop your valuable devices from getting fried

Even 20 years ago, only a handful of electronic devices were connected to the mains power supply at any one time – now half our lives seem to be running off it. All that depends on drawing power at a steady rate (230 volts in the UK); any more and precious data could be lost or appliances damaged.

Surge protectors generally work by isolating sensitive electronic devices from the mains supply. If a spike occurs, they attempt to limit the voltage by blocking or grounding the excess charge, preventing it from passing to other devices.

Power spikes can happen without you even knowing it – for instance, when your air conditioning comes on or your power company is working on the lines – and a surge protector will handle most of these. However, be warned: few surge protectors can withstand nature's ultimate device killer, lightning, so during storms it's safest to unplug.

Inside a surge protector

These guardians of electronics come in many forms, but all work around common elements

1 Hot power line
The line where most of the voltage is carried, which continues to deliver power to devices even while a surge is occurring.

2 Neutral wire
One of the lines where power-spike voltage can be diverted. However most surge protectors use the safer grounding wire instead.

3 MOV
The metal oxide varistor (MOV) diverts surge voltage from the hot line to the neutral and grounding lines via a pair of semiconductors.

4 Fuse
Voltage that cannot be fully grounded by the MOV will blow this fuse to break the circuit altogether. It acts as a final fail-safe in case of a power spike.

5 Grounding wire
Linked to Earth and therefore the best place to channel excess power, it safely dissipates energy away from your electronic devices' delicate circuits and wires.

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"These compact training pools use a counter-current system to provide a continuous flow of water"

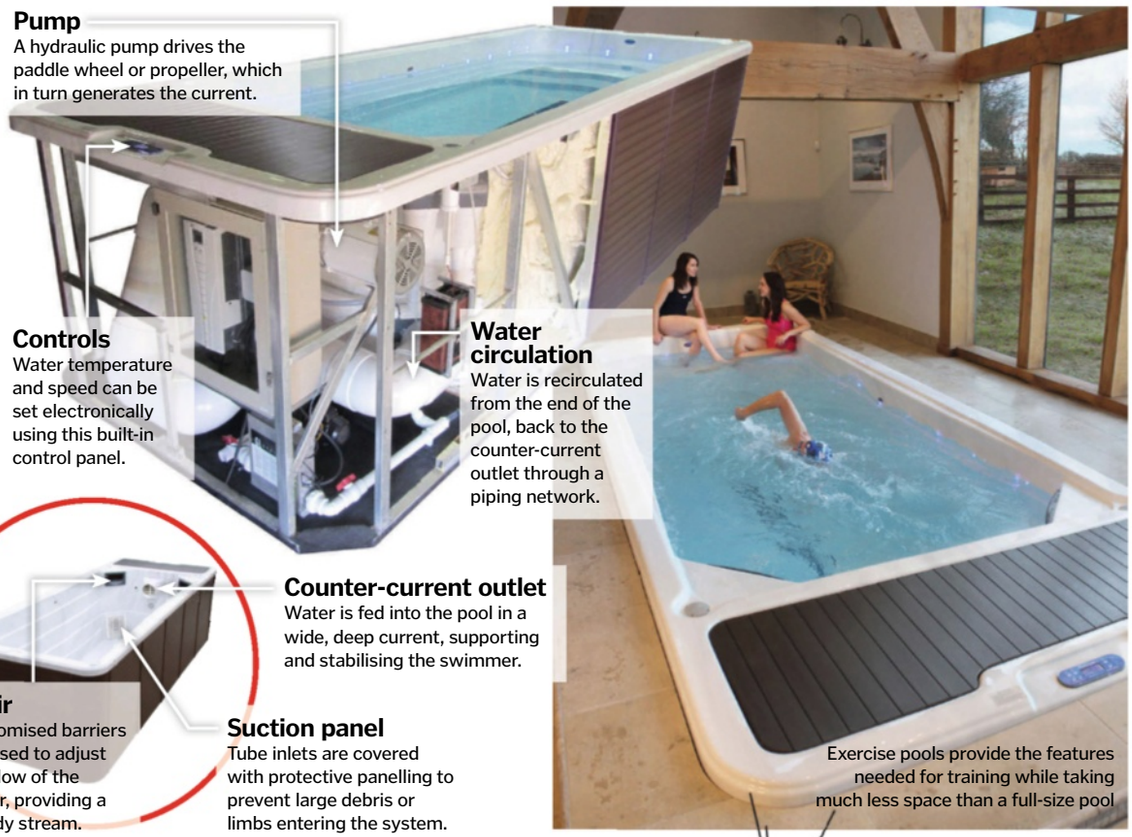
How exercise pools work

Inside the domestic swimming machines that let us swim for miles on the spot

Exercise pools are the equivalent of a treadmill for swimmers. Usually only measuring twice the length of an average person, these compact training pools allow swimmers to practise, using a counter-current system to provide a continuous flow of water to swim against.

Water is pumped using a propeller or paddle wheel and enters the pool at the front end. The speed of the current is adjustable and the water is pumped at low pressure, entering the pool in a wide stream. This minimises the bubbles and turbulence associated with the kind of jet used in Jacuzzis.

Tubes running from the back end of the pool carry water around the outside and return it to the pump, allowing the swimmer to train without the need for a full-size swimming pool or a wave machine.



Pump
A hydraulic pump drives the paddle wheel or propeller, which in turn generates the current.

Controls
Water temperature and speed can be set electronically using this built-in control panel.

Water circulation
Water is recirculated from the end of the pool, back to the counter-current outlet through a piping network.

Counter-current outlet
Water is fed into the pool in a wide, deep current, supporting and stabilising the swimmer.

Weir
Customised barriers are used to adjust the flow of the water, providing a steady stream.

Suction panel
Tube inlets are covered with protective panelling to prevent large debris or limbs entering the system.

Exercise pools provide the features needed for training while taking much less space than a full-size pool

What are jumping mines?

Discover how delay charges enable mines to detonate in the air

Bounding mines, like the German 'Bouncing Betty' and the US M16, differ from other anti-personnel mines as they explode in mid-air. When the fuse is activated, a propelling charge is fired, launching the mine out of the ground and, after a short delay, the main charge is detonated, showering its vicinity with shrapnel.

Inside an M16 mine

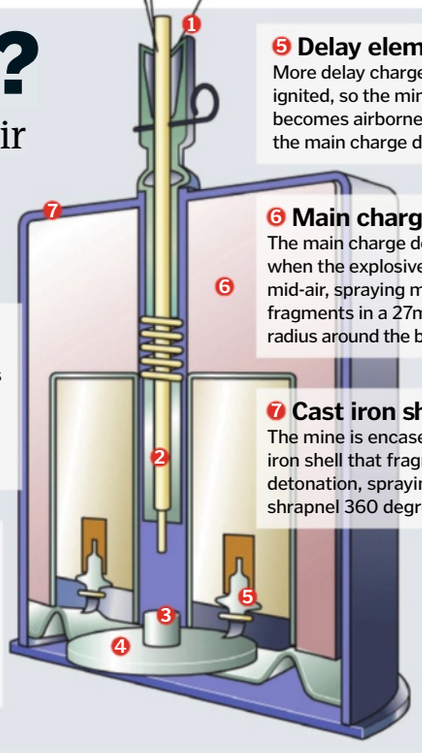
Bounding mines launch into the air before detonating to maximise their damage

1 Prongs
The three prongs of the fuse are pressure sensitive, so when stepped on or pulled by a tripwire, the firing pin is released.

2 Firing pin
The spring-loaded firing pin crushes the explosives in the percussion cap, releasing hot gas and particulates that ignite the delay charge.

3 Percussion cap
A small delay charge activated by the percussion cap acts as a timer, allowing the target to move off before it detonates.

4 Propelling charge
The propelling charge is fired, launching the mine out of its casing into the air, reaching up to 1.7m (6ft) above the ground.



5 Delay element
More delay charges are ignited, so the mine becomes airborne before the main charge detonates.

6 Main charge
The main charge detonates when the explosive is in mid-air, spraying metal fragments in a 27m (89ft) radius around the blast zone.

7 Cast iron shell
The mine is encased in an iron shell that fragments on detonation, spraying shrapnel 360 degrees.

RECORD BREAKERS
KING OF COAL

3,549mn

BIGGEST COAL PRODUCER

China mined a staggering 3,549 million tons of coal in 2012, significantly ahead of the United States, which extracted just 935 million tons. The world total was 7,831 million tons.

DID YOU KNOW? *A lot of the coal we extract for fuel today originates from the Carboniferous period 360-300mn years ago*

Exploring a coal mine

Coal fuelled the Industrial Revolution and even today is responsible for 40 per cent of the world's electricity, but how is a colliery laid out?

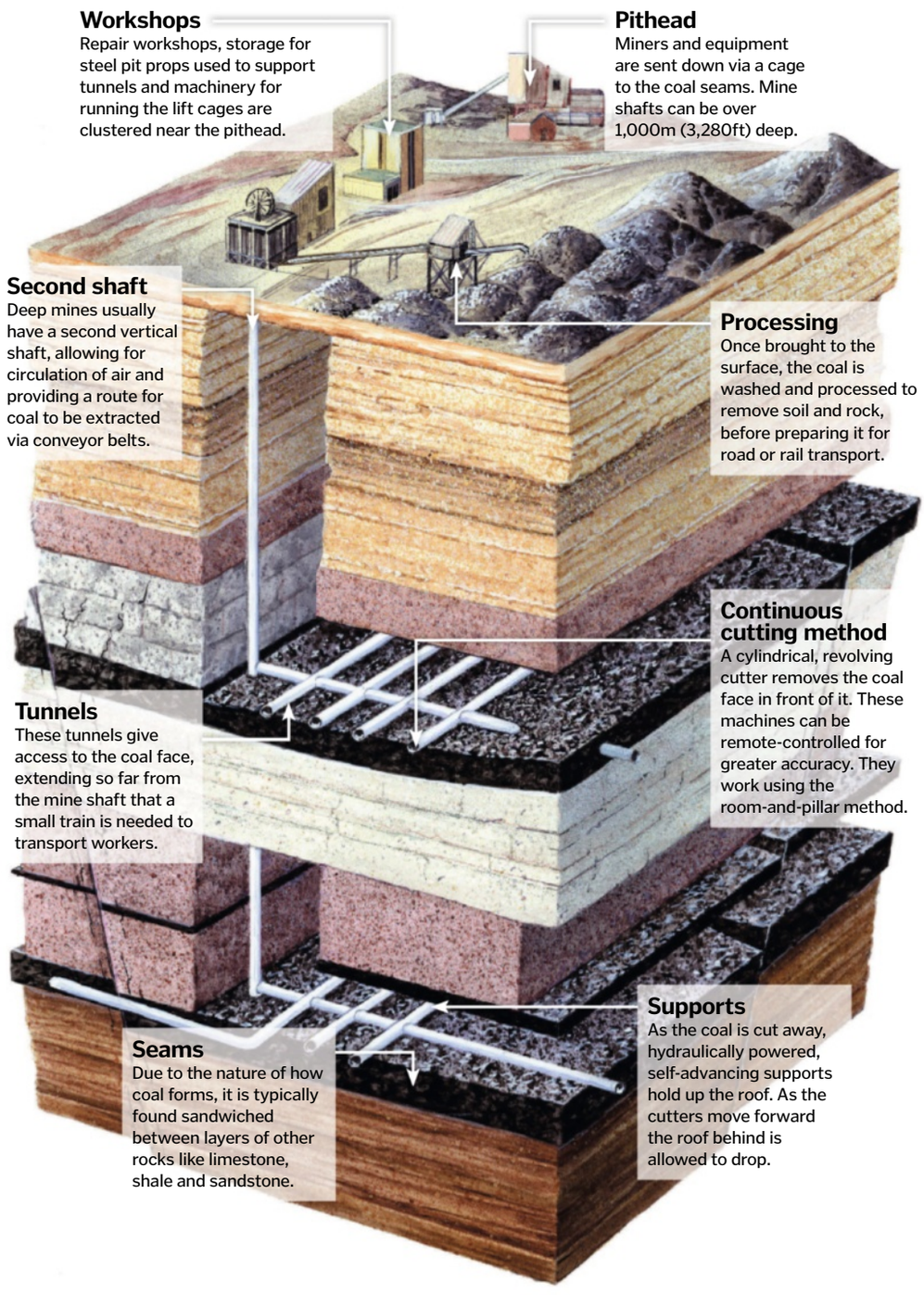
There are two basic types of coal mines, also known as collieries. The first is the opencast surface mine, which consists of a coal seam covered by an overburden layer of soil and rock. Bulldozers clear the soil and explosives are used to break up the remaining overburden. Draglines and power shovels are then brought in to remove this material, followed by the extraction of the coal. After the mine is exhausted the topsoil is returned to landscape the area.

The second type, the underground mine (shown here), can access deeper seams of coal and is far more dangerous and challenging. Originally, the coal face was dug by pick and shovel, but as time went by, explosives were used to blast away at the coal seam.

Modern mines use machines that have tungsten bits that cut into the coal face. Longwall and room-and-pillar systems are the two main methods for extracting coal. The longwall method slices horizontally into the coal face and drops the mineral onto conveyer belts. The room-and-pillar method cuts a grid-like network of tunnels in the coal seam, leaving the remaining pillars to support the roof. The longwall method can be used to finish off the pillars that are left behind by the room-and-pillar technique.

Coal mine level by level

Take a tour of the main areas that make up a colliery



Fire in the hole!

Coal seams can catch fire and burn for decades or even centuries, either due to accidental causes such as gas explosions or natural causes when there is sufficient heat and ventilation to bring about self-combustion.

Incredibly thousands of worldwide seam fires account for as much as three per cent of carbon dioxide emissions. They also belch out other toxic gases and cause subsidence and destruction to their local landscapes.

They only stop burning when they exhaust their coal reserves or are extinguished through human intervention. Deep mine fires are put out by isolating them and pumping inert gases around the area of the blaze.

Fires nearer the surface, on the other hand, can be dealt with by pumping mud and water into the ground, followed by covering the area with an impermeable layer of sediments. The extent and depth of many of these fires though means they are impossible to put out.

"The electric guitar is fundamentally the same as it was in the Fifties"

Electric guitars

What technology lends these iconic instruments their distinctive sound?

The electric guitar is probably the defining sound of 20th-century music. Like all good inventions, it solved a problem: in a band with several instruments, guitars were too quiet. In the Thirties, several guitar manufacturers developed the magnetic pick-up, which fitted underneath strings and fed an electric signal to an amplifier.

Modern guitars work in exactly the same way. Strings are made from ferromagnetic metal, usually nickel or steel. The pick-up is a bar magnet housed inside thousands of turns of wire. The vibrating strings cause fluctuations in the magnet's field, which in turn induces an alternating current in the wire. This current is the signal which is carried to the amp. Electric guitars can have a single pick-up for all the strings or one for each string.

Guitars could be heard, but the audience heard something else too: horrible howling feedback. The hollow body of the first electric guitars vibrated with sound waves from the amp, so this second problem was solved by introducing a solid body.

There is a fierce ongoing debate around who created the first solid electric guitar, but the most popular and widely sold early model was the Fender 'Broadcaster' (later called 'Telecaster'), followed in 1954 by the company's legendary 'Stratocaster'.

Manufacturers have tried making plastic, aluminium, twin-necked and headless guitars – even 'synth' guitars with MIDI (musical instrument digital interface) technology. But for the most part guitarists prefer the original; they might dabble for a while, but they always go back to the traditional six-string design.

While amps, MIDI and USB systems have all improved, providing better ways to record and enhance music, the electric guitar itself is fundamentally the same as it was in the Fifties – a testament to its well-conceived design.

Acoustic vs electric

All guitars have a body, neck and strings. Electric guitars need ferromagnetic metal strings while acoustic guitars can use strings made from nylon, bronze, brass or metal-wrapped nylon. Both acoustic and electric guitars are usually made of wood. Wood is ideal because it's relatively cheap, light and easy to shape – not to mention the fact that it also lends guitars their distinctive warm sound.

The main difference between the two types of guitar is how they produce sound. The hollow body of an acoustic guitar provides a big chamber for air to reverberate. Pluck a string and the vibration travels through the bridge into the body. The body and air inside it vibrate, creating compressed sound waves. For an electric guitar, you need an amp (or computer) to produce sound worthy of being called 'music'.

Amp up the volume

Amps boost the input signal from the guitar and drive the speaker cone. Plugged in, the weak fluctuating signal from the pick-ups passes through a series of transistors, modifying the amp's DC circuit. Next the vibrating cone generates sound waves, replicating and amplifying the sound produced by the strings.

When vacuum tube amps were replaced by solid-state amps in the Seventies, guitarists complained they sounded 'colder'. Modern amps often combine the two types for a warm but loud sound, and if your computer has a fast enough processor, you can use it as a virtual amp.

907kg

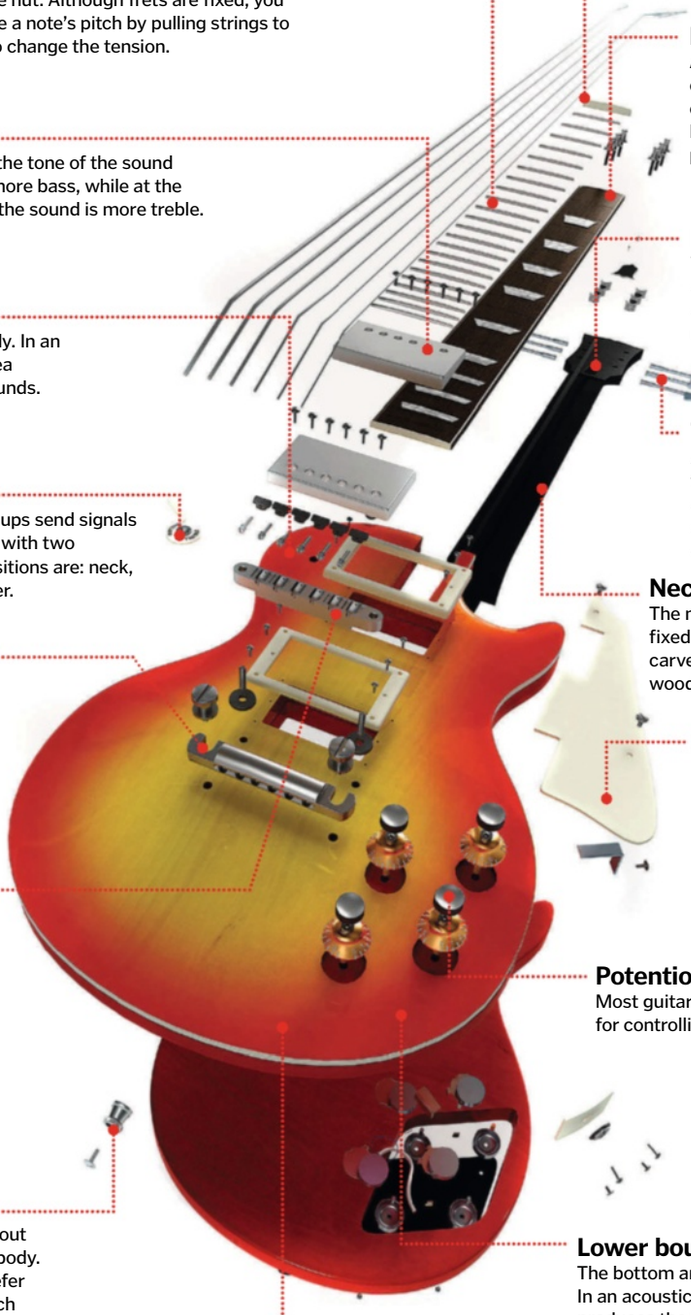
LARGEST PLAYABLE ELECTRIC GUITAR

School students in Conroe, Texas, made a 12:1 scale version of a 1967 Gibson Flying V. It stands 13.3m (43.6ft) tall, 5m (16.4ft) wide and weighs 907kg (2,000lb). It was first played in public in June 2000.

DID YOU KNOW? *Amazingly, Leo Fender – manufacturer of the famous 'Stratocaster' – couldn't play guitar*

Teardown of an electric guitar

What are the major components of these amazing instruments?



Fret
The thin, raised metal bars across the fingerboard. The distance between frets corresponds to one semitone (12 semitones make up one octave). The first fret is the one nearest the nut. Although frets are fixed, you can change a note's pitch by pulling strings to one side to change the tension.

Pick-ups
Nearest the neck, the tone of the sound picked up here is more bass, while at the bridge the tone of the sound is more treble.

Upper bout
The top area of the body. In an acoustic guitar, this area produces the treble sounds.

Pick-up selector
This selects which pick-ups send signals to the amp. For a guitar with two pick-ups, the switch positions are: neck, bridge and both together.

Saddle tailpiece
This can be adjusted to change string length and therefore tone.

Bridge
Holds the strings away from the body. The strings may terminate here or just pass over it. The height of the bridge can also be modified with screws.

Strap button
One on the upper bout and one under the body. Many guitarists prefer locking straps, which prevent them from coming adrift mid-performance.

Body
Usually kiln-dried hardwood (mahogany, ash, walnut, etc), the heavy body prevents unwanted vibrations.

Lower bout
The bottom area of the body. In an acoustic guitar, this part produces the bass sounds.

Potentiometers
Most guitars have at least two pots for controlling volume and tone.

Bridge
Holds the strings away from the body. The strings may terminate here or just pass over it. The height of the bridge can also be modified with screws.

Nut
This holds the strings in their right places and feeds them into the tuning pegs. You can lubricate the grooves in the nuts with graphite from a few swipes with a pencil.

Fingerboard
A player can press down on the strings here to change the vibrating length and therefore the pitch of the note.

Headstock
This holds the strings and can be flat or angled. The shapes are unique to each model.

Tuning pegs
Also called machine heads, these can be twisted to adjust the tension on the string, changing the pitch of the note it produces.

Neck
The neck can be adjustable or fixed, or 'straight-through' – carved from the same piece of wood as the body.

Scratchplate
This protects the finish of the body from plectrum and nail scratches. It's usually made of plastic but can be glass, wood or even fabric.

Jargon buster

Pick-up
A bar magnet wrapped in a coil of wire. Vibrations in the strings cause vibrations in the magnetic field, which induces a current in the wire.

Headstock
Aka a 'peg-head', this holds the strings under tension.

Cutaway
This indentation in the body near the neck allows the player easier access to the upper frets. There are two types: the rounded Venetian and more pointy Florentine.

Wah-wah pedal
This pedal controls the bass and treble. It's pushed down to emphasise treble and left up for bass. To get the 'wah-wah' sound, you just have to rock it up and down.

Potentiometer
A variable resistor used to adjust volume or tone. Knobs on guitars and amps are commonly called 'pots'.

Passive/active
Most electric guitars don't require electric power (only the amp) so are 'passive'. Some, however, do use power (from a battery or USB) to create effects, so are 'active'.

Licks/riffs
Licks are short musical phrases played in a solo. Riffs are short melody phrases which are repeated.

Tiniest life on Earth

Lifting the lid on the strange and wonderful creatures that inhabit a world usually out of sight...

Life on Earth is divided into three domains – archaea, bacteria and eukaryotes – and all three contain examples of microscopic life. There is also some debate as to whether a fourth domain of life should be added to encompass biological entities such as viruses (see 'What is life?').

Bacteria are prokaryotes and do not have a membrane-bound nucleus; instead, their genetic information is free in the cytoplasm. On average, they measure just a few thousandths of a millimetre in length, representing the smallest accepted life forms known to science.

Archaea are similar in structure to bacteria and were originally thought to belong to the same domain. However, they have distinct genetic differences. Archaea tend to inhabit some of the most extreme environments on the planet, and can be found in salt lakes, underground petroleum reserves and even deep-sea thermal vents (see the 'Surviving extremes' box for more information).

The final domain, the eukaryotes, includes animals, plants, fungi and protists. In contrast to bacteria and archaea, eukaryotic cells have membrane-bound organelles; their genetic information is enclosed in a nucleus, energy is produced inside the folded membranes of mitochondria and proteins are produced and packaged inside membrane stacks. This extra layer of organisation enabled the evolution of the enormous variety of single and multicellular micro-organisms that belong to this domain from humans to ants.

There are many advantages to being small. Exchange of gases and nutrients can be done by diffusion, eliminating the requirement for complicated circulatory and respiratory systems, while incoming chemical or tactile signals only have to be transmitted for short distances. A simple structure also allows for rapid replication, shortening generation times and allowing more mutations to build up over a given period, granting rapid adaptation to environmental changes.

An organism can only be so small if it is going to be able to survive on its own though. Free-living organisms must be able to transform energy from their environments – to make their own biological molecules and to assemble and organise them for growth and

0.75mm

LARGEST KNOWN BACTERIA

Thiomargarita namibiensis (aka the 'sulphur pearl') is visible to the naked eye. It contains granules of sulphur which scatter light, giving the rounded cells a pearl-like appearance.

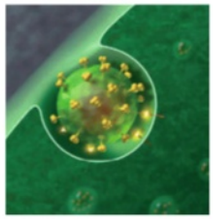
DID YOU KNOW? *Organisms don't necessarily get larger as they evolve; several small species evolved from much bigger ancestors*

This head louse is a parasite, unable to survive on its own

What is life?

The definition of life is debated, but most scientists agree on some fundamental conditions – one of the most important of which is the ability of an organism to make copies of itself. Living things are also able to transform energy from their environment, using it to maintain structural organisation – primarily for growth and reproduction.

A virus particle (or virion) does not meet the classical defining criteria for life. It is essentially a vehicle for the transfer of genetic information – DNA or RNA packaged into a protective coat – and cannot metabolise, grow or reproduce on its own. However, when viruses hijack the biological machinery of a cell, they direct it to replicate the viral genome in order to produce viral proteins and to organise the components into new virions. Viruses evolve in response to environmental pressure, so could be considered to be extremely simplified parasites, raising the debate as to whether they do actually deserve to be classified as a form of life.



1 million spherical cocci bacteria could fit on this square

replication. This requires a complex arsenal of internal cellular machinery, including nucleic acids to store genetic information, equipment to translate that genetic message into proteins and sufficient solvent to allow metabolic reactions to take place.

One of the smallest known free-living organisms is an archaea known as ARMAN, which measures a minuscule 200 nanometres long. It has an extremely sparse genome, containing the bare minimum required to survive without resorting to parasitism.

Many of the world's smallest free-living organisms are aquatic. Living suspended in water provides a ready supply of dissolved gases and nutrients. Some float freely, while others have developed strategies to anchor themselves in one place, adhering to the surface of rocks or the mucous membrane of an animal's gut, ensuring they won't stray too far from their environmental niche.

Many other micro-organisms rely on parasitism for survival. Exploiting a host allows parasitic life to lose the genes responsible for some biological functions, saving energy and space and allowing them to reproduce more rapidly in response to any defence mechanisms that may evolve in their host.

In order to study these lifeforms, scientists use a wide range of techniques. The 'larger'organisms (ie measuring between 0.2 micrometres and one millimetre) can be imaged under an optical microscope, and fluorescent stains are often used to label different biological components. To study the structure of smaller organisms, or to study larger organisms in more detail, electron microscopes are called upon – the most powerful of which can resolve a single atom (see the 'Inside an SEM' box for more).

Imaging is accompanied by a vast array of biochemical techniques to analyse cellular processes from metabolism to signalling pathways. Gene sequencing and genetic manipulation are often used to study the function of different genes. Not only does this provide valuable information about the biology of micro-organisms, but manipulation of their genetic information has enormous potential for medical treatment – to learn more about this see our interview with Dr Alice Denton.

"Nanobes are tiny structures brought to scientific attention by their presence in a Martian meteorite"

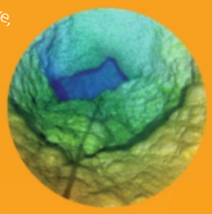
NANOMETRES

Porcine circovirus
Type: Virus
Size: 17nm
Info: This simple virus in pigs achieves its tiny size by hijacking the cellular machinery of its host. It carries genetic information for just three proteins: two to replicate its genetic material and one to make up the capsule that surrounds each virus particle. The rest of the work is done by the host's own proteins.

Nanobes
Type: N/A
Size: 20-30nm
Info: Nanobes are tiny, filament-like structures, brought to scientific attention by their presence in a Martian meteorite. It is hypothesised that these structures represent the smallest form of life, but the evidence is not conclusive and whether the biological molecules required to sustain life could fit inside a nanobe is currently unknown.

Mycoplasma genitalium
Type: Bacteria
Size: 200-300nm
Info: This bacterium represents cellular life at its simplest. It has one of the smallest genomes of any cell, containing just 582,970 base pairs (the human genome has over 3 billion), divided into 521 genes. There are smaller bacteria, but they lack the genes required to support themselves and must live as parasites in association with other species.

Nanoarchaeum equitans
Type: Archaea
Size: 400nm
Info: Nanoarchaeum equitans has the smallest genome of any living organism (a definition that excludes viruses). It cannot make many of the biological molecules that it requires to survive, so lives as a parasite. As a heat-loving extremophile, it can be found in and around hydrothermal vents and hot springs.



Bacteria under attack

Disease-causing bacteria have problems of their own: bacteria-infecting viruses...

Attachment
Bacteriophages attach to molecules on the surface of their target before injecting their genetic material into the cell.

Replication
The virus hijacks the molecular machinery of the bacterium, using it to make copies of viral DNA and produce viral proteins.

Assembly
DNA is packaged into a protein capsule at the head of the virus and the tail proteins assemble at the base.

Release
Some bacteriophages use enzymes to burst the host membrane. Others force the bacterium to release new viruses.

All shapes and sizes

Under the microscope, the dazzling array of bacterial types becomes clear

Diplococci
Spherical bacteria often form aggregations and diplococci like Neisseria will stick together in pairs.

Staphylococci
Other spherical bacteria cluster in bunches resembling berries. Most are harmless, but this group contains the superbug MRSA.

Streptococcus
Cocci can create long strings by dividing along only one axis, producing daughter cells in line with the chain.

Pseudomonas
These rod-shaped bacteria have one or more flagella, which they use like a propeller for forward motion.

Mycobacterium tuberculosis
The destructive causative agent of tuberculosis is rod-shaped and can come together to form chains.

Spirillum
There are only two known species of spiral-shaped bacteria. Spirillum have a twisted, elongated structure.

Salmonella enterica
This rod-shaped bacterium is covered in protrusions called fimbriae, allowing it to stick to surfaces, like the inside of an animal's intestine.

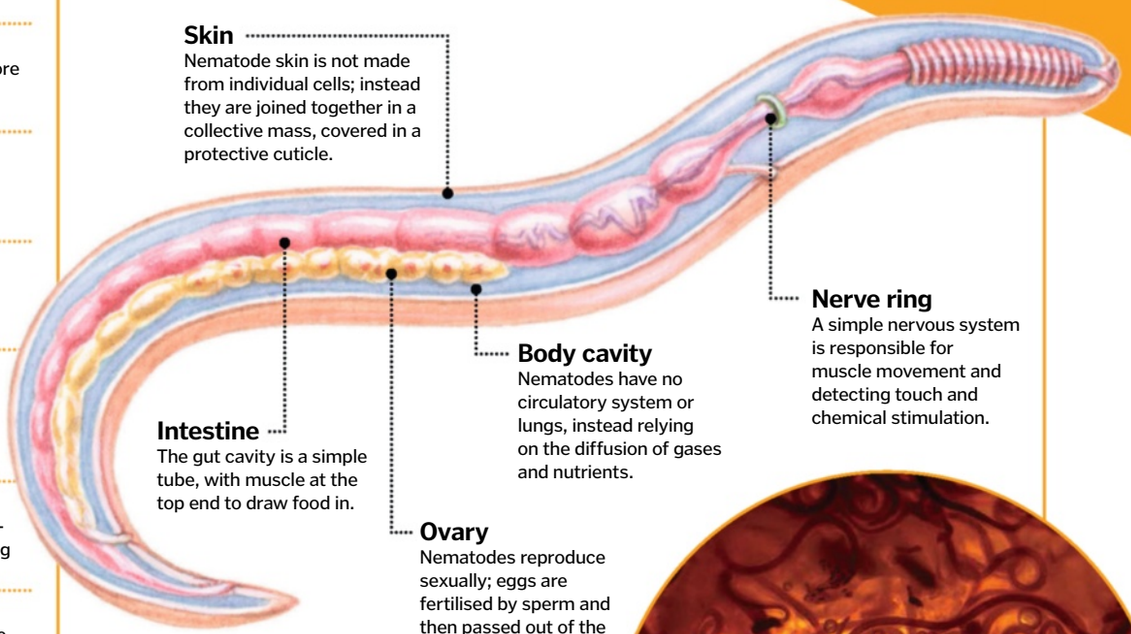
Treponema pallidum
These elongated bacteria use a corkscrew-like motion to move through fluids, twisting into a helical shape.

Vibrio
Bacteria in this genus are a variation on the rod shape, with a curved, tapered end, somewhat resembling a comma.

Clostridium tetani
The bacterium responsible for the disease tetanus is shaped like a tennis racquet.

Anatomy of a nematode

Take a look inside one of the simplest multicellular organisms on Earth



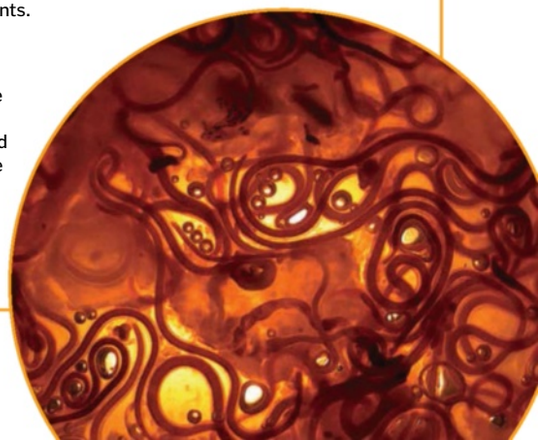
Skin
Nematode skin is not made from individual cells; instead they are joined together in a collective mass, covered in a protective cuticle.

Nerve ring
A simple nervous system is responsible for muscle movement and detecting touch and chemical stimulation.

Body cavity
Nematodes have no circulatory system or lungs, instead relying on the diffusion of gases and nutrients.

Intestine
The gut cavity is a simple tube, with muscle at the top end to draw food in.

Ovary
Nematodes reproduce sexually; eggs are fertilised by sperm and then passed out of the uterus to hatch.



What extreme environment are xerophiles found in?

A Zero g **B** Extreme drought **C** Xeros, Cyprus

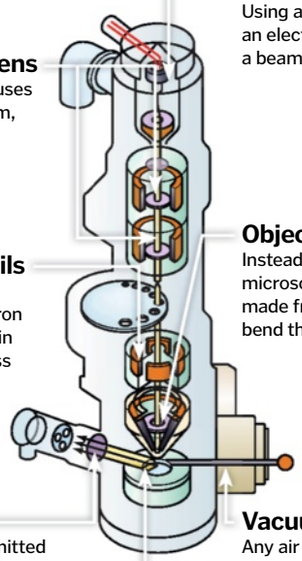
Answer:
Xerophiles are 'dry-loving' organisms and can survive in areas where water availability is extremely low. Perhaps the most incredible example is the tardigrade, which can go without food or water for over ten years!

DID YOU KNOW? *Bacteria behave differently in space, forming thicker versions of 3D biofilms that they make on Earth*

A low temperature scanning electron microscope is used to view anatomical structures needed to identify nematodes

Inside an SEM

Scanning electron microscopes can magnify samples to 300,000 times their size, but what tech powers them?



Electron gun
Using a tungsten filament, an electron gun generates a beam of electrons.

Condenser lens
A condenser focuses the electron beam, producing a spot just a couple of nanometres in diameter.

Objective lens
Instead of glass, electron microscope lenses are made from magnets that bend the electron beam.

Scanning coils
Scanning coils deflect the electron beam, moving it in a rectangle across the surface of the sample.

Detector
Scattered and emitted electrons and EM radiation are measured and used to construct an image of the sample.

Vacuum chamber
Any air would disrupt the electron beam, so samples are tested in a vacuum.

Sample
Samples are fixed to preserve their structure, dried and then coated with gold before being imaged.

Ostreococcus

Type: Plant
Size: 800nm
Info: These algae are the smallest free-living eukaryotes on the planet. Unlike bacteria and archaea, some of the machinery found inside eukaryotic cells is enclosed in membrane-bound structures called organelles. Additionally, their DNA is not free in the cytoplasm, like it is in bacteria, but instead enclosed in a nucleus, like human DNA. These cells are so small that they contain just one mitochondrion to generate energy and one chloroplast for photosynthesis, compared to tens or even hundreds in other plant cells.

MICROMETRES

Nematode

Type: Roundworm
Size: 80 micrometres
Info: Nematodes, or roundworms, are some of the smallest multicellular organisms; for context, Caenorhabditis elegans has less than 1,000 cells and just 300 neurons. This laboratory nematode was the first multicellular organism to have its genome sequenced and its simple body plan is used as a model to study development.

Stygotantulus stocki

Type: Crustacean
Size: 94 micrometres
Info: At less than 0.1mm (0.004in) long, these tiny creatures are the smallest known arthropods. They have evolved as parasites, relying on larger crustaceans like copepods to survive. The copepods themselves measure just 1-2mm (0.04-0.08in) in length, but are able to get by on their own.

3 Number of bumblebee bats that would fit on a human finger

Top 5 uses of microbes today

1 Dairy goods
Milk contains the sugar lactose, which can be broken down by bacteria to form lactic acid. It's this lactic acid that gives yoghurt, cheese and other popular fermented dairy products their signature sour taste.

2 Antibiotics
Certain moulds, eg Penicillium, produce natural antibiotics that can incapacitate bacteria. By altering the structure of these chemicals, we have created powerful and effective drugs to fight infection.

3 Sewage busters
Micro-organisms are used at several stages in the treatment of sewage. They are effective in removing nitrogen, phosphorus and other biological contamination from the waste, cleaning it.

4 Making protein
Bacteria readily take up and absorb DNA, which allows scientists to use them as miniature factories of sorts, utilising that function to produce proteins using genes from other species.

5 Vitamins
Us humans, just like plants and animals, cannot produce the essential vitamin B12 on our own. Instead we rely on various archaea and bacteria to do the work for us.

"Being small and evolving quickly has enabled micro-organisms to adapt to life in the most inhospitable of places"

Eriophyid mites

Type: Arachnid

Size: 125 micrometres

Info: These parasitic arachnids have just two functional pairs of legs, look like worms and travel from plant to plant on the wind. Infestation causes the plants to form nutrient-rich growths known as galls (below), which the mites use as a food source and protection from predators.

Dicopomorpha echmepterygis

Type: Insect (wasp)

Size: 140 micrometres

Info: The males of this wasp species are the smallest insects known. They are blind, have no wings and like many other tiny organisms, they lead a parasitic lifestyle, this time inside the eggs of other bugs. The females are much larger and are able to fly.

Nanosellini

Type: Insect (beetle)

Size: 300 micrometres

Info: The 27 species of Nanosellini beetle each measure less than a millimetre in length, with some just 0.3mm (0.01in) long. They are the smallest of the beetles and feed on fungal spores, generally living on top of, or inside, the fungus itself.

Mellisuga helenae

Type: Bird

Size: 50mm

Info: The bee hummingbird is about the same size as a large insect and is the smallest living bird, laying eggs barely larger than a pea. Like its namesake, it is a pollinator, feeding on nectar and in the process becoming covered in pollen, which it then transports to a different flower.

MILLIMETRES

Parvulastra parvivipara

Type: Starfish

Size: 5mm

Info: This yellow-orange starfish is found in rock pools and on granite rocks in southern Australia and measures less than a centimetre (0.4 inches) across. This invertebrate gives birth to live young, incubating its fertilised eggs inside its body until they hatch. When the juvenile starfish are mature, they are released into the water. Unable to migrate to new pools on their own, they must remain in their parental pool, waiting for waves to wash them out.

Echinocyamus scober

Type: Sea urchin

Size: 6mm

Info: Sea urchins have a spiny outer shell, live in oceans worldwide and can be found on the seafloor down to 5,000 metres (16,400 feet). The smallest species is just six millimetres (0.2 inches) across – about the size of a Tic-Tac.

Wolffia

Type: Plant

Size: 300-600 micrometres

Info: Commonly known as duckweed, this genus contains the smallest flowering plant on Earth – water-meal. These floating aquatic plants have no roots and cluster together to form mats on the surface of the water. A single flower forms in a pit on the surface of the oval plant cell, and consists of a single stigma (female) and a single stamen (male). When fertilised, each plant is capable of producing just one seed. They usually reproduce asexually, producing a 'daughter frond', which goes on to become a new organism.

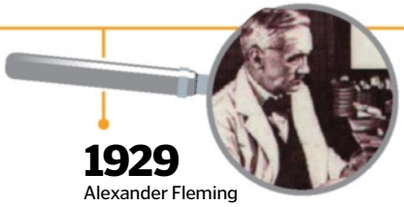
Shrinking science

We take you through the major breakthroughs in discovering the tiniest lifeforms on Earth

1890
Robert Koch publishes four criteria showing bacteria as causative agents of disease.

1893
Ticks are found to carry a parasite causing disease in both animals and humans – the first example of a zoonotic infection.

1911
Francis Peyton Rous discovers cancer can be caused by viral infection. He later receives a Nobel prize.



1929
Alexander Fleming publishes his work on penicillin, demonstrating its ability to kill gram-positive bacteria.

DID YOU KNOW? *The mitochondria that power our cells contain DNA similar to the genetic material found in bacteria*

Surviving extremes

Extremophiles are a group of organisms specialised for survival in Earth's most challenging environments. These resilient organisms can be seen in all three domains of life, but the majority are archaea and bacteria.

Acidophiles and alkaliphiles live in extremes of pH, piezophiles at extreme pressures and thermophiles at temperatures exceeding the boiling point of water. Being small and simple, reproducing rapidly and evolving quickly has enabled micro-organisms to adapt to life in the most inhospitable of places, from the Atacama Desert to hundreds of metres below the Antarctic ice.

Complex multicellular animals can also survive in harsh conditions. The tardigrade, or water bear, can dehydrate its cells, preventing the formation of destructive ice crystals. It can withstand extreme temperature, intense pressure, high doses of radiation and even survive ten days in the vacuum of space!

The tiny Brookesia micra chameleon can be found on Madagascar – if you look very closely!

Brookesia micra

Type: Chameleon

Size: 15-19mm

Info: This tiny lizard from Madagascar is one of the world's smallest reptiles. Their size is the result of 'island dwarfism'. Animals isolated on an island must compete for limited resources; smaller organisms take up less space and require less food, enabling them to survive when the island becomes overpopulated and resources become scarce. Brookesia micra have only been found in a single square kilometre on the island.

Photocorynus spiniceps

Type: Fish

Size: 6.2-7.3mm

Info: Male anglerfish of the Photocorynus spiniceps species are the smallest known adult fish. Their primary function is to pass on their genetic information and they spend most of their lives attached to the larger female, which use bioluminescence to lure in their prey and have to keep their male passengers alive.

Paedophryne amauensis

Type: Frog

Size: 7-8mm

Info: The world's smallest known vertebrate is Paedophryne amauensis, native to Papua New Guinea. These fingernail-sized frogs hide on the forest floor, feeding on small insects. Their eggs do not hatch into tadpoles, and instead, fully formed 'hoppers' emerge, increasing in size until they reach adulthood. The frogs make insect-like noises and can jump distances 30 times their body length – an impressive 20 centimetres (7.9 inches).

Thorius arboreus

Type: Salamander

Size: 17mm

Info: Thorius arboreus is currently the smallest known salamander and lives in Mexico. There are several species of miniature salamander and more are still being discovered all the time, so – like with all tiny organisms – it is possible that an even smaller species exists but has yet to be found.

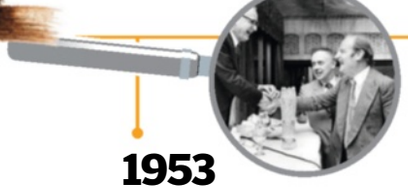
Craseonycteris thonglongyai

Type: Bat

Size: 30-40mm

Info: Kitti's hog-nosed bat, also known as the bumblebee bat, is a contender for the title of world's smallest mammal, measuring just 30 millimetres (1.2 inches) long and weighing less than two grams (0.07 ounces). It is found only in Thailand and Burma, living in limestone caves. The Etruscan shrew weighs even less, at just 1.8 grams (0.06 ounces), but its tail makes it slightly longer.

1 bee hummingbird could fit on a 50-pence coin



1949
Lab techniques to grow poliovirus inside human cells allow viruses to be studied outside the body.

1953
James Watson and Francis Crick publish the double helix structure of DNA, paving the way for genetic analysis of micro-organisms.

1979
Smallpox is eradicated following the last natural case of infection in Somalia.

1983
HIV is identified as the causative agent responsible for acquired immunodeficiency syndrome (AIDS) in humans.

17

Echinocyamus scaber urchins can fit on a stamp

Studying the micro world

Dr Alice Denton, from the University of Cambridge, answers some big questions about tiny life

What kinds of equipment do you use to grow and study micro-organisms?
Alice Denton: Bacteria are relatively straightforward to grow in the lab: just feeding them some nutrients and incubating them at the right temperature is really all you need to do. This gets a little trickier when you are trying to grow bacteria that are found in extreme conditions, such as salt lakes, soil or underwater volcanic vents, as we don't yet know how to imitate their growth conditions [artificially].

Because viruses cannot replicate themselves, they are a bit more difficult to work with. Viruses must infect a host and use that host's own machinery to replicate. To grow your own virus, you need to find the right kind of host.

How do you use viruses to study diseases like cancer?
AD: Viral vectors, such as retroviruses and adenoviruses, are a handy tool that allow efficient delivery of genetic information into cells. They are also being investigated for therapeutic use, eg harnessing the host's immune system to eliminate the cancer, either by improving the immune cells' ability to recognise and kill the cancer cells, or making the cancer cells more susceptible to immune attack. Our lab uses viral vectors in many different ways, from introducing known cancer mutations into cells to model cancer progression to simply marking different cell types with colours so we can follow their interactions with the tumour.

How do you minimise the risk when working with dangerous microbes?
AD: All potential pathogens are classified by how dangerous they are, such as the likelihood of escape and the potential havoc they could wreak. Different classes of pathogens must be used in the specified levels of containment. This goes from simply using a biological safety cabinet, which filters the air coming out to prevent escape, up to those that must be housed in limited-access facilities with double-filtered air supply that ensures nothing leaves the room.

"The secret to freeze-drying is turning ice directly into water vapour – called sublimation"

How freeze-drying works

Why does this simple process stop food and pharmaceutical goods from perishing?

The micro-organisms that degrade food, medicines or biological samples all need water to survive. By eliminating almost all water, freeze-drying (formally known as lyophilisation) increases the shelf life of these products dramatically. What's more, unlike traditional dehydration methods, freeze-drying preserves the structure of foods, meaning it has less of an effect on the taste and texture once the item has been rehydrated.

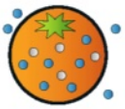
The secret to freeze-drying is turning ice directly into water vapour – without going through the liquid phase – a process called sublimation. First the material to be preserved is frozen. The freeze-drier then drops the air pressure, lowering the boiling point of water. A slight increase in temperature then provides the ice molecules with enough energy to break free from their bonds to form a vapour. This process removes almost all the water from the material to be preserved, without affecting its structure.

From astronaut food to flower petals, freeze-drying uses sublimation to get rid of water and preserve materials for longer

Freeze-drying step-by-step

We take you through the key stages of preserving food

1. Freezing
The food is rapidly frozen at very low temperatures to avoid the formation of large ice crystals that could damage its structure.



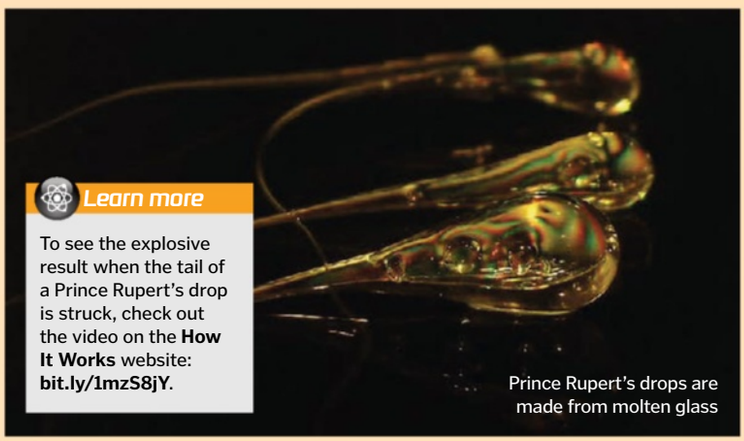
2. Sublimation
Decreasing the pressure and then increasing the temperature allows the water to sublimate, passing directly from a solid state to a vapour.

3. Dried product
Containing one to five per cent of its original moisture content and sealed in moisture and oxygen-proof packaging, it can be kept for years.

4. Rehydration
Certain freeze-dried foods (including fruits such as apples) can be eaten as is. Others are restored to their original form by adding water.

What are Prince Rupert's drops?

Find out why these glass globules are simultaneously tough as nails yet prone to shatter



Learn more

To see the explosive result when the tail of a Prince Rupert's drop is struck, check out the video on the **How It Works** website: **bit.ly/1mzS8jY**.

Prince Rupert's drops are made from molten glass

Hit the head of a tadpole-shaped Prince Rupert's drop (aka Dutch tear) and it seems pretty tough. But tap its tail lightly and the whole thing shatters in a cloud of glass fragments. Prince Rupert's drops are made by pouring molten glass into cold water. The outside of the glass cools and solidifies very quickly, forming a hard casing. The centre shrinks as it gradually cools, but the solid outer shell cannot mould itself to this new shape. This results in a great deal of internal stress as the centre of the drop pulls the outside inwards. This tension makes the tail vulnerable to even the tiniest of cracks, which can spread along the drop's full length in under a millisecond as the built-up stress is released. Curiously, the same structure makes the head of the drop super-strong (ie it can survive a hammer blow) since the internal stress keeps it tightly compressed.

5 TOP FACTS
VESTIGIAL NATURE

Grounded beetles
1 Certain species of beetle cannot fly at all, despite still being born with wings. In fact, these wings are often fused together, which makes them rather useless.

Leggy snakes
2 Some snakes, such as pythons, have residual pelvis bones formed into spurs, suggesting snakes may once have had legs, or evolved from species that had legs.

Non-flying birds
3 Penguins, ostriches and kiwis are examples of winged birds that can't fly. These birds may have lost the ability because their habitats were once free of larger predatory birds.

Blind salamanders
4 These small newt-like amphibians live out their entire lives in dark caves and now are completely blind. However, they still possess non-functioning eyes.

Whale pelvic bones
5 If you go to a natural history museum and look at a whale skeleton, you'll see residual, non-functioning pelvic bones. This suggests whales may once have been land-dwellers.

DID YOU KNOW? *Your appendix is about 10cm (4in) long but a koala's can grow over 2m (6.6ft) long to digest eucalyptus leaves*

Useless body parts

Why have humans and other animals stopped using certain organs and functions which were once crucial for survival?

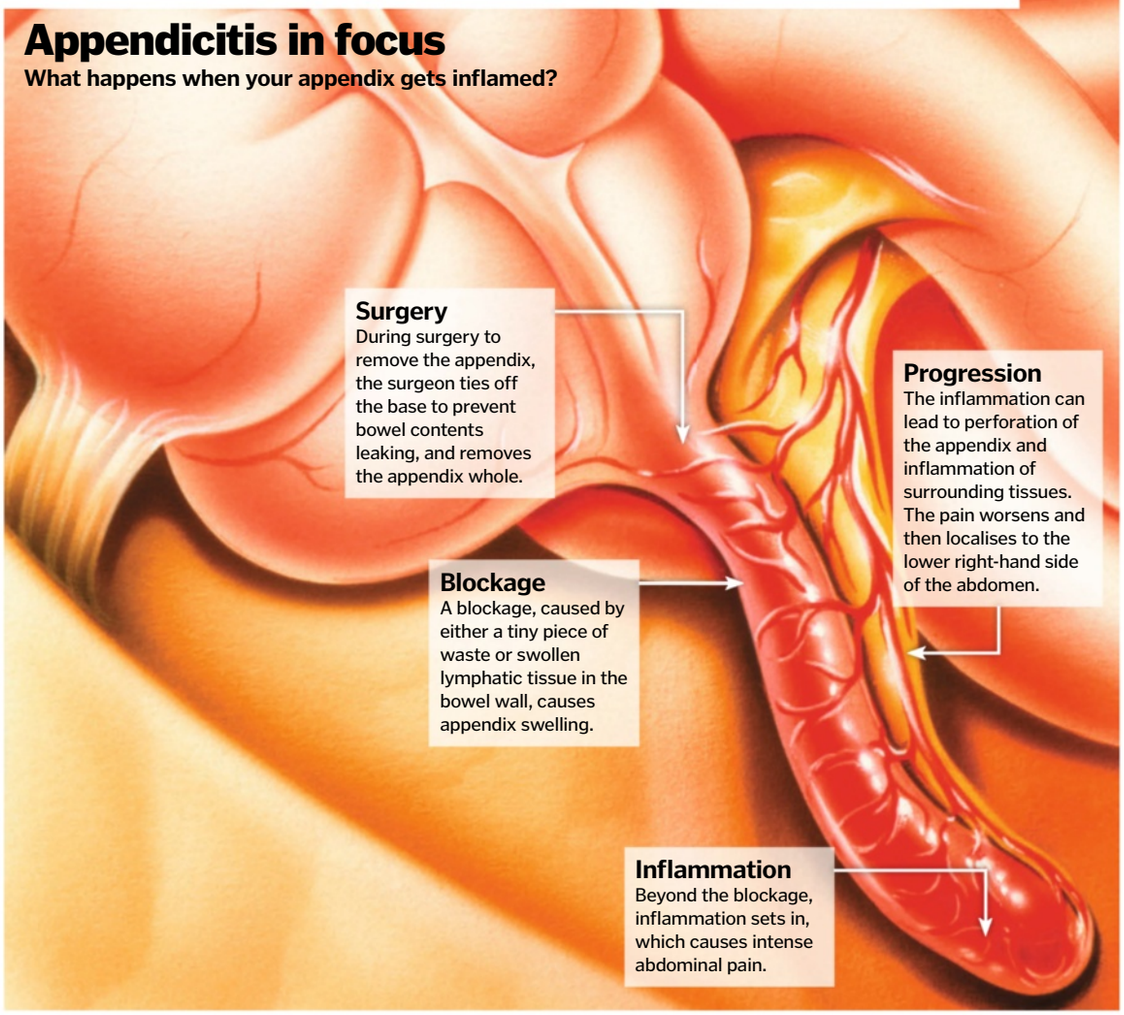
Charles Darwin is one of history's most famous naturalists. Living in the 19th century, he became celebrated for his theories on evolution. In his seminal work *On The Origin Of Species* he described how similar animals were likely to be related by common ancestors, rather than be completely unrelated. As subsequent generations are born, traits and features that did not bring a survival benefit to that species were eliminated. That, in a nutshell, is the theory of evolution.

As a consequence, some organs and traits left in the body lose their function and are no longer used. This applies to modern human beings as much as other creatures; some of our physical attributes and behavioural responses are functional in other animals, but they do not seem to be of any benefit to us. These evolutionary remnants that no longer serve any purpose are called vestigial organs, though this can apply as much to behaviour and other body structures as it does to actual organs.

Evolution has also adapted some existing features to help us in new ways, in a process known as exaptation. For example, birds' wings not only help them to fly but keep them warm too. These changes in function may take thousands of years to develop, and in some cases the original role is eventually eliminated from subsequent generations altogether.

Appendicitis in focus

What happens when your appendix gets inflamed?



Evolution's leftovers

1 Appendix
The best known of the vestigial organs, the appendix is used in animals to help digest cellulose found in grass, but in humans it serves no clear function now.

2 Tailbone
The hard bone at the bottom of your spine, the coccyx, is a remnant of our evolutionary ancestors' tail. It has no function in humans, but you could break it if you fall over.

3 Goosebumps
Animals use body hair for insulation from the cold, by trapping a warm layer of air around the body. Each hair can stand on end when its own tiny muscle contracts, but as human beings have lost most of their body hair, a jumper is more effective.

4 Plica semilunaris
The fleshy red fold found in the corner of your eye used to be a transparent inner eyelid, which is still present in both reptiles and birds.

5 Wisdom teeth
These teeth emerge during our late teens in each corner of the gums. Our ancestors used them to help chew dense plant matter, but they have no function today. In fact, they can cause a lot of pain so are often removed.

"At intervals along the lymphatic vessels are between around 600 and 700 lymph nodes"

Immune system's highway

Learn what role our lymphatic system plays in keeping nasty bugs at bay

The red blood cells that carry oxygen around our bodies travel through blood vessels suspended in fluid known as plasma. It moves through vessels at such pressure that plasma can leak into the tissues. The lymphatic system helps remove it from the tissues and return it to the circulation.

The lymphatic system is similar to the circulatory system, in that it is composed of a series of vessels, found mostly in the skin and around internal organs. But the tubes do not make a circuit and there is no pump. The fluid, known as lymph, relies on the contraction of nearby muscles to return to the circulation at the subclavien veins near the collarbones.

The lymphatic system is also a transport route for the immune system. At intervals along the lymphatic vessels are between around 600 and 700 lymph nodes. Larger organs like the spleen and thymus are also connected to the network.

These organs manage immune surveillance; if an antigen-presenting cell (APC) of the immune system encounters a pathogen, it will return to the nearest lymph node with intel about the intruder. The specialist attack cells of the immune system, lymphocytes, circulate through the lymphatic system, scanning for matching patterns and, if one is found, they use the lymph node as a base to adapt until an army of enemy-specific clones is created.

Swollen lymph glands are often a sure sign of infection or disease

When the lymphatic system goes wrong

One of the most common problems associated with the lymphatic system is blockage. If any of the vessels becomes occluded, fluid cannot be properly drained from the tissues and from that point it begins to accumulate. This condition, medically known as lymphoedema, results in a buildup of fluid in the limbs, causing swelling.

Certain species of parasitic worm rely on the human lymphatic system for part of their life cycle, and the presence of a worm infection can be one cause of lymphoedema. This is further complicated by the immune system, which responds to the worms, and any bacteria they might be infected with, leading to thickening of the skin and a condition known as elephantiasis.

Illness also affects the lymph nodes, which become swollen during infection as immune cells divide. Sometimes, cancerous transformation occurs in one of the immune cells, leading to lymphoma and eventually forming a tumour in the node.

5 TOP FACTS
LYMPHATIC TRIVIA

Tissue fluid
1 The average adult has ten litres (2.6 gallons) of fluid in their tissues. It provides a solvent for nutrients, waste products and other chemicals, allowing them to be exchanged among cells.

Educating T-cells
2 The thymus teaches T-lymphocytes the difference between 'self' and 'non-self'. This organ helps to prevent cells of the immune system from attacking healthy tissue.

Moving without a pump
3 Lymphatic vessels run close to muscles, and as they contract, vessels are squeezed. A series of valves ensure this increase in pressure pushes the lymph up towards the heart.

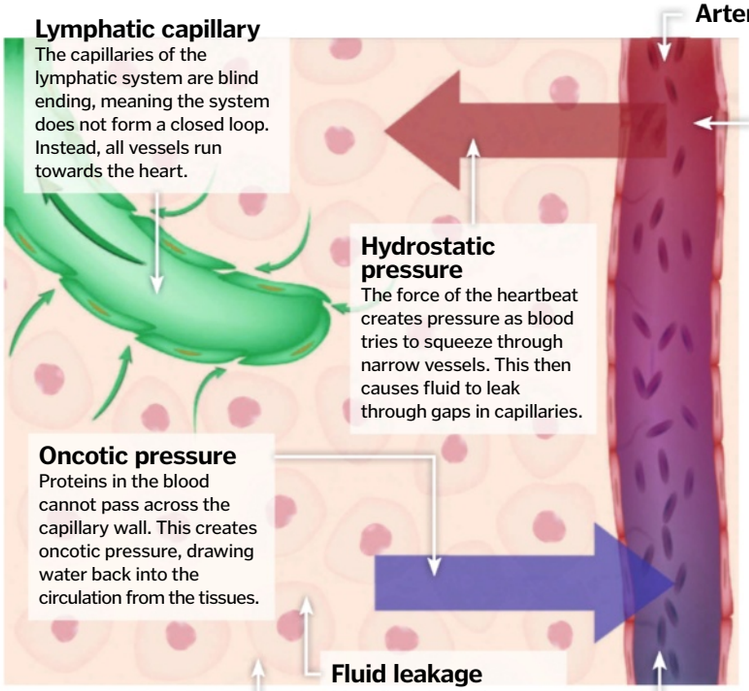
Fatty fluid
4 Lymph returning from the digestive system is known as chyle. It contains high concentrations of fatty triglycerides, which turn it a milky white colour.

Mega lymph node
5 The spleen is essentially a massive lymph node and is absolutely rammed with immune cells. It also plays an important role in the recycling of old red blood cells.

DID YOU KNOW? *As lymph travels through the lymph nodes it picks up immune cells, which then return to the blood*

Capillary fluid exchange in action

Zoom in to see how lymph is transferred between the circulatory and lymphatic systems



Lymphatic capillary
The capillaries of the lymphatic system are blind ending, meaning the system does not form a closed loop. Instead, all vessels run towards the heart.

Arteriolar end

Blood capillary

Hydrostatic pressure
The force of the heartbeat creates pressure as blood tries to squeeze through narrow vessels. This then causes fluid to leak through gaps in capillaries.

Blood flow

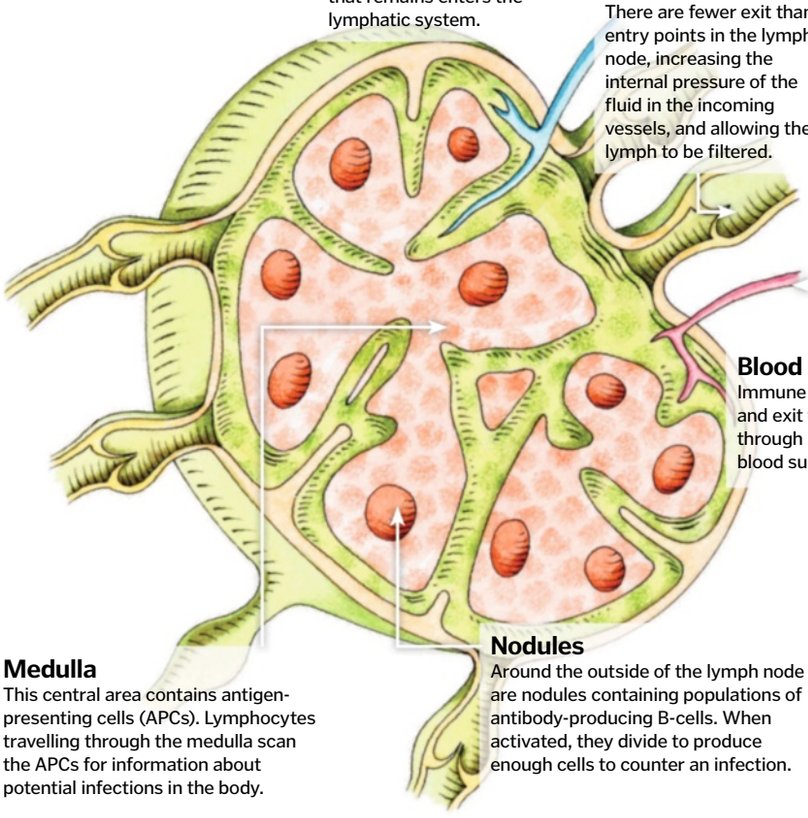
Oncotic pressure
Proteins in the blood cannot pass across the capillary wall. This creates oncotic pressure, drawing water back into the circulation from the tissues.

Interstitial space

Fluid leakage
Most fluid that leaks out of the circulation is recaptured by the effects of oncotic pressure. Any that remains enters the lymphatic system.

Venular end

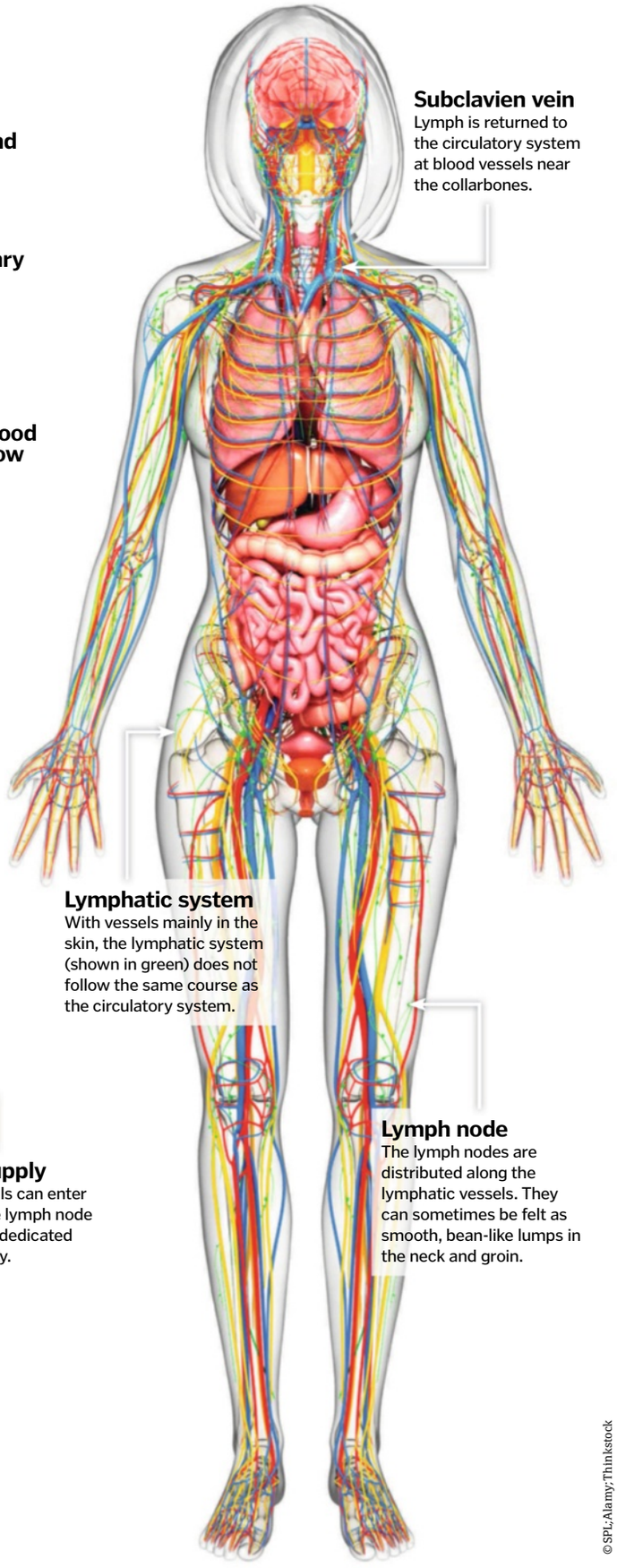
Efferent vessel
There are fewer exit than entry points in the lymph node, increasing the internal pressure of the fluid in the incoming vessels, and allowing the lymph to be filtered.



Blood supply
Immune cells can enter and exit the lymph node through its dedicated blood supply.

Medulla
This central area contains antigen-presenting cells (APCs). Lymphocytes travelling through the medulla scan the APCs for information about potential infections in the body.

Nodules
Around the outside of the lymph node are nodules containing populations of antibody-producing B-cells. When activated, they divide to produce enough cells to counter an infection.



Subclavien vein
Lymph is returned to the circulatory system at blood vessels near the collarbones.

Lymphatic system
With vessels mainly in the skin, the lymphatic system (shown in green) does not follow the same course as the circulatory system.

Lymph node
The lymph nodes are distributed along the lymphatic vessels. They can sometimes be felt as smooth, bean-like lumps in the neck and groin.

AGE OF THE DINOSAURS

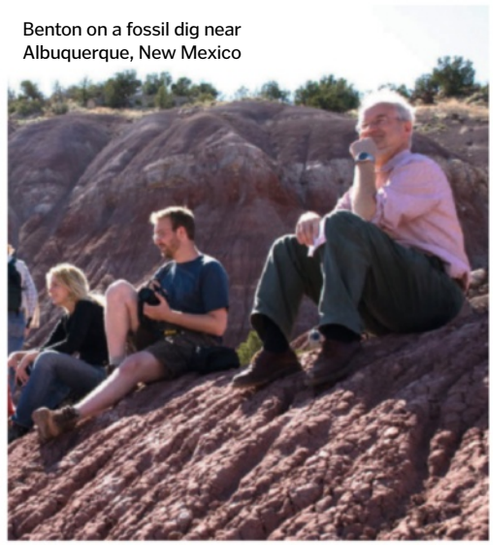
From birth to extinction, get to know these prehistoric beasts inside and out with our comprehensive A-Z guide

Dinosaurs have long sparked our imagination. From the Ancient Greeks' perception of their remains as evidence of a time when giants ruled Earth, right through to modern man's pursuit of their resurrection – be that in films like *Jurassic Park* or in laboratories via advanced DNA cloning techniques – dinosaurs remain a tantalisingly alien part of our world's history.

They may no longer roam the land like they did millions of years ago, but thanks to their genetic legacy and preserved remains they still remain a very real presence today.

From the fossils lying trapped in the ground through to the descendants flying above our heads, dinosaurs have unique tales to tell.

In this special History feature we take a closer look at this ancient world through an A-Z encyclopedia of all things dinosaur. You'll learn not just about the creatures themselves but the tools and techniques used to study them, and what Earth was like during their reign. This guide truly has it all, so strap yourself in and prepare for one wild, prehistoric ride...



Benton on a fossil dig near Albuquerque, New Mexico

Professor Mike Benton, palaeontologist

Mike Benton is the Professor of Vertebrate Palaeontology at the University of Bristol, UK, and is a world-renowned dinosaur specialist. His areas of expertise include the diversification of life through time, the origin of dinosaurs and the end-Permian mass-extinction event. He can often be found working on digs in Russia and China. He offers some words of wisdom throughout our dino guide, but for a more in-depth interview, head to www.howitworksdaily.com.

252.2mn years ago (Ma)
Triassic starts – The Triassic period begins, marking the beginning of the Mesozoic era. The first dinosaurs emerge at this point.

252.2 Ma
Induan is hot – The first stage of the Early Triassic, known as the Induan, is characterised by a hot and largely deserted world.

250 Ma
Archosauriformes appear – Archosauriformes, a clade of diapsid reptiles, evolve and take over all semi-aquatic environments.

247.2 Ma
Mid Triassic – The Mid Triassic period begins, consisting of the Anisian and Ladinian ages. Ferns and mosses dominate the flora.

Amber & dino DNA

Amber is fossilised tree resin that, due to a chemical change after burial in the ground, turns into a solid. Despite its stable state today, when the majority of the Earth's amber formed, it was far more fluid, which means many little organisms unwittingly became stuck within it – including plant matter and insects. Today these appear frozen within the amber and have been perfectly preserved. While one or two studies in the Nineties claimed to extract DNA from these organic inclusions (as portrayed in *Jurassic Park*), more recent research suggests this isn't possible. Scientists at the University of Manchester using advanced DNA sequencing in 2013 were not even able to find traces of DNA in copal (a precursor to amber) only 10,000 years old, so they're very doubtful that dino DNA could have survived from millions of years ago.

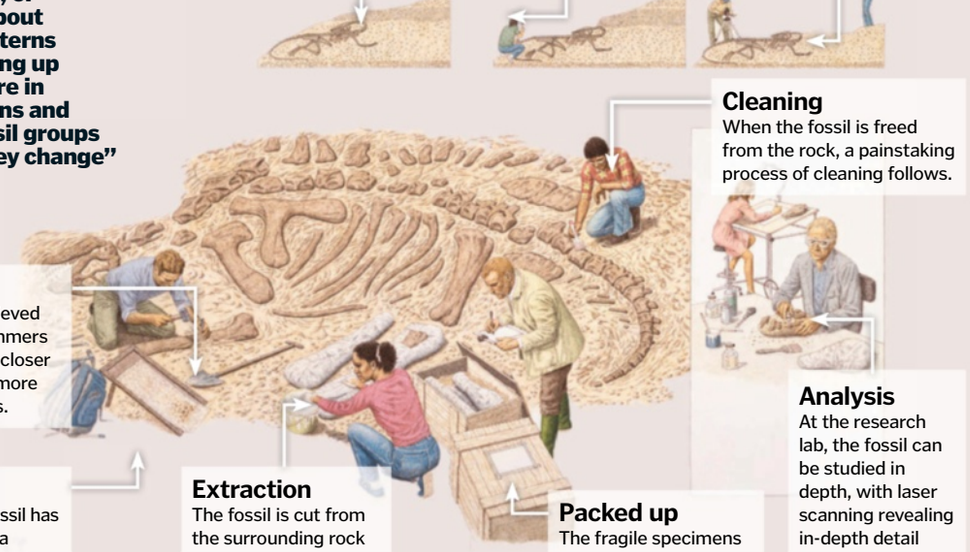
Communication in focus

Dinosaurs, much like the many species of animal alive today, communicated in very different ways. From complex dance-like movements to more obvious calls and scent markings, each dino marked their territory, warned of potential predators and relayed information regarding food in its own unique way. One of the most interesting examples comes in the form of the hadrosaurid (above), a duck-billed dinosaur family sporting a distinctive bone crest on their heads. These crests were used as a resonating chamber for projecting their calls. Considering the hadrosaur's modest size and its wide range of predators, the ability to amplify its calls was no doubt a valuable defensive mechanism.

Bone secrets

Dinosaur bones are one of a palaeontologist's greatest sources of information, supplying data about their age, anatomy, distribution and much more. The bones of dinosaurs can only be found if they went through the process of fossilisation, where the tissue of the creature dissolves and gets replaced with minerals under pressure beneath the ground. Finding and extracting these fossilised bones is a major challenge for palaeontologists, with a carefully planned out dig site essential.

"Certain kinds of excavation and study out in the field can be for palaeoecology, trying to reconstruct food webs and modes of locomotion, or they can be about looking at patterns over time, going up metre by metre in rock formations and analysing fossil groups to see how they change"



Discovery
Most fossils are discovered at first only in part, with just a small fragment visible above the surface.

Shooting in situ
Photography plays a crucial part of any excavation. The specimen is continuously snapped from its discovery right through to removal.

Clearance
Once the fossilised bone has been photographed, the rock around it is carefully cleared to allow better access to the fossils.

Cleaning
When the fossil is freed from the rock, a painstaking process of cleaning follows.

Tools
Clearance is achieved with chisels, hammers and spades. The closer to the fossil the more delicate the tools.

Boundary
As soon as the fossil has been confirmed, a boundary is staked, protecting the area so palaeontologists can work unhindered.

Extraction
The fossil is cut from the surrounding rock and removed piece by piece, with each one meticulously labelled.

Packed up
The fragile specimens need to be transported with great care, with fossils placed in padded containers.

Analysis
At the research lab, the fossil can be studied in depth, with laser scanning revealing in-depth detail about the dinosaur.

230 Ma

Lagosuchus – The small archosaur Lagosuchus emerges. This creature can run quickly on its hind legs for short periods like later dinosaurs.

225 Ma

Sharovipteryx glides – An early gliding reptile called Sharovipteryx mirabilis evolves, capable of flying between tree habitats.

216 Ma

Coelophysis arrives – The theropod dinosaur Coelophysis flourishes on land. It is a slenderly built carnivore that walks on two legs.

201.3 Ma

Triassic ends – The Triassic-Jurassic extinction event wipes out nearly 30 per cent of marine life.

Diplodocus: a dino titan

Of all the dinosaurs that lived on Earth few can truly lay claim to be a terrestrial giant – but the Diplodocus can. Built like a suspension bridge, the Diplodocus measured over 25 metres (82 feet) long – that's longer than five African elephants! It weighed over 12 tons, roughly 170 times more than the average human. It had an incredibly long neck and counterweight tail, the former used to elevate its head into the foliage of trees for food, while the latter was its primary form of defence. With a typical Diplodocus estimated to have lived between 50 and 80 years, it also had one of the longest life spans of any dinosaur from the Jurassic period.

Feathered fiends

Since palaeontologists began uncovering dinosaur remains in the 19th century, our depictions of them in the flesh have been largely coloured by a few initial artist impressions, with figures such as Charles Knight often drawing species in inaccurate postures and with factually incorrect sizes, colours and features. Based on current evidence, the lack of feathers on most species is one of the most obvious flaws in these early depictions, with half of all non-avian theropods now thought to have been partly feathered. The main cause for these misassumptions has been the lack of evidence, with feathers and soft tissues rarely preserved like fossilised bone.

"Colour in dinosaur feathers was a topic I think people thought that we would never know the answers to. But we were able to rely on a fair number of fossil feathers that were exceptionally well preserved and deep within their internal structure we could see colour-bearing organelles. So by using some smart observations and techniques we have proved it to be possible"

Extinction

Dinosaurs perished some 65 million years ago in what is known as the K-Pg (formerly K-T) extinction event. This cataclysmic event at the Cretaceous-Palaeogene boundary led to 75 per cent of all species on Earth dying off. From the smallest ocean plankton to the largest land beasts, the K-Pg extinction event resulted in devastation at every level of the world's ecosystems, with all non-avian dinosaurs eradicated. The current theory for the catalyst of this global wipeout is an asteroid impact in South America, but the real cause for such widespread carnage was not the impact itself but its knock-on effects. These include plants not being able to photosynthesise due to dust blocking out the Sun plus a series of epic tsunamis and fire storms.

Genetic legacy

Today the study of dinosaurs is entering an exciting new age, where we can achieve an unprecedented level of accuracy through cutting-edge analysis. After a T-rex's soft tissue was discovered within a bone sample, we can now study things like proteins, blood vessels and other micro-anatomy to help us determine how individuals lived and died, as well as how dinos evolved.

Hunting strategies

Whether dinos hunted and scavenged alone like the T-rex or in large packs like the Deinonychus – the model for the Velociraptor in *Jurassic Park* – carnivorous dinosaurs were no doubt the apex predators on Earth. However, debate rages as to how co-ordinated dinosaur pack hunters were. Since first described in 1969 by palaeontologist John Ostrom, the Deinonychus has been imprinted in the public consciousness as a highly intelligent, synchronised team hunter. However, many modern dino experts disagree with this assumption, believing that while Deinonychus did move and chase prey in groups, they did so with little co-ordination, with each individual simply acting out of self-interest rather than working together like, say, lions.

201.3 Ma

Mid Mesozoic – The middle period of the Mesozoic era begins, with the Jurassic following the Triassic mass-extinction event.

199.6 Ma

Plesiosaurus – The large marine sauropterygian reptile Plesiosaurus evolves and goes on to become an apex predator of the oceans.

196.5 Ma

Sinemurian age – The Early Jurassic sees the Ichthyosaurus genus diversify and mammalian life such as Hadrocodium appear.

183 Ma

Toarcian turnover – The Pliensbachian stage of the Early Jurassic ends with anoxic ocean waters leading to wide-scale marine extinctions.

Ichthyosaurus

Although technically not a true 'dinosaur', Ichthyosaurus, or 'fish lizard', filled the same niche in Earth's oceans and was one of the most dominant marine species of the Mesozoic era (252-65.5 Ma) Resembling today's dolphins, Ichthyosaurus measured in at roughly two metres (6.6 feet) in length and was capable of cruising through the water at around 40 kilometres (25 miles) per hour, enabling it to catch fish and squid with ease. The fact that Ichthyosaurus had a very large pair of eyes protected by a pair of bony, structural-supporting rings has led some palaeontologists to believe the species frequently hunted at great depths where pressure was very high.

1 Eyes
Large eyes were protected by rings of bone to keep them intact at great depths.

2 Teeth
The jaws were lined with rows of sharp, conical teeth, primed for shredding soft prey such as squid.

3 Fins
Stunted limb-like fins were used for stability and manoeuvring rather than propulsion.

4 Prey
Fish, squid and marine reptiles were the main food of Ichthyosaurus, but the sharp teeth could crush shellfish as well.

5 Body
Its body was streamlined, with a curved spine and no neck. By undulating its body it could alter its speed and direction.

6 Tail
A top speed of 40km/h (25mph) came courtesy of the bilobed, shark-like tail.

Jurassic lark Five factual bloopers from the famous Hollywood films

Timing problems
Jurassic Park portrayed many famous dinosaur species, including T-rex and Triceratops, but most of the animals shown actually lived in the Cretaceous period, not the Jurassic.

Out of proportion
One thing the film's producers definitely need punishing for is the depiction of the park's Velociraptors. Portrayed as being as tall as a man, in reality they barely stood 0.5m (1.6ft) off the ground.

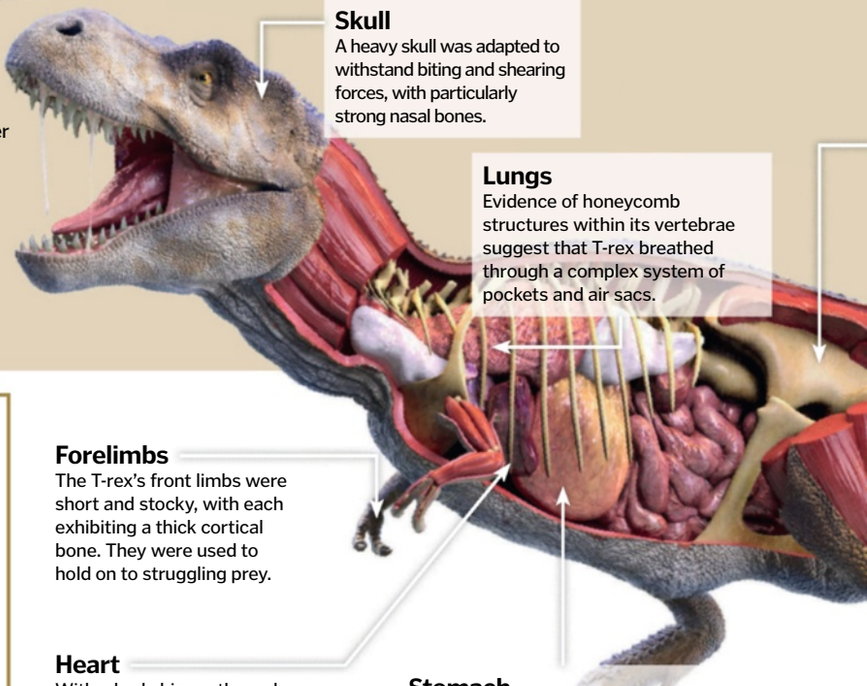
Feather-brained
Another massive omission in *Jurassic Park* was the lack of any feathers. Most dinosaur species, especially sauropods, had some plumage on their bodies.

No grudge match
In the third film, the Spinosaurus is shown going toe-to-toe with its supposed arch-nemesis, the T-rex. In reality they never met as they lived on different continents of prehistoric Earth.

Spit on a grave
Another creative addition was Dilophosaurus's ability to spit out poison. However there is no evidence to suggest it could do this; neither did it have a frilled neck.

King of the dinosaurs

While not the biggest or smartest, the Tyrannosaurus rex was no doubt the closest to a king the dinosaurs ever had. A colossal bipedal carnivore, the T-rex measured in at over four metres (13 feet) tall and over 12 metres (39 feet) long, weighing over seven tons. It was no slow-poke either, with computer models estimating that the dino was capable of hitting a top speed of around 29 kilometres (18 miles) per hour chasing prey. When it caught up it could quickly dispatch them with a single bite that had a force of three tons – the equivalent weight of a fully grown African elephant. Yikes!



Skull
A heavy skull was adapted to withstand biting and shearing forces, with particularly strong nasal bones.

Lungs
Evidence of honeycomb structures within its vertebrae suggest that T-rex breathed through a complex system of pockets and air sacs.

Forelimbs
The T-rex's front limbs were short and stocky, with each exhibiting a thick cortical bone. They were used to hold on to struggling prey.

Heart
With a body bigger than a bus, the T-rex needed a huge pump to transport blood at adequate pressure. Current estimates suggest its heart was over 100 times bigger than a human's.

Stomach
The T-rex had a hardy stomach due to its high-meat diet and the fact that it scavenged frequently from long-dead carcasses. Analysed T-rex dung has revealed many fragments of bone.

Lufeng: a fossil treasure trove

One of the most prolific dinosaur hotspots in the world is Lufeng in Yunnan Province, China. Since 1938, 33 species, each with its own complete fossil, have been found there. Some of the finds have been record-breaking, with many of the vertebrate fossils uncovered the oldest on record – eg, the Lufengosaurus fossil (pictured right) dates from 190 million years ago. Lufengosaurus was a genus of prosauropod that lived during the Early Jurassic period. Tourists can see many excavated dinosaur finds at the nearby Lufeng Dinosaur Museum.

176 Ma
Mid Jurassic – The second epoch of the Jurassic period begins, with marine life flourishing and pliosaurs growing to the size of killer whales.

175 Ma
Pangaea rifts – The first phase of the supercontinent Pangaea's breakup into several continents begins, with the Tethys Sea forming.

154 Ma
Diplodocus – The famous Diplodocus evolves due to the dominance of sauropods in the dino kingdom. It measures 25m (82ft) long.

145 Ma
Jurassic ends – The Tithonian epoch of the Late Jurassic ends, with the Cretaceous period following.

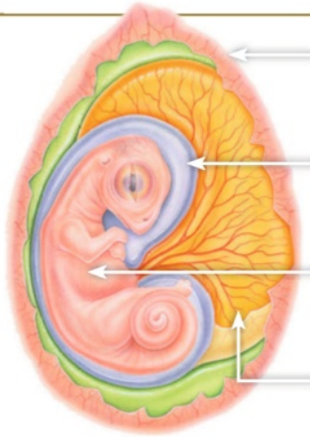
Mesozoic world

Beginning 252.2 million years ago and coming to a close about 65 million years ago, encompassing a colossal stretch of time that includes the Triassic, Jurassic and Cretaceous periods, the Mesozoic era truly defined the age of dinosaurs. All the famous species you can think of lived within it.

The Mesozoic was generally warm with a significantly smaller temperature differential between the equatorial and polar regions – ideal conditions for the emergence and proliferation of flora and fauna. Not only was the Mesozoic famous for its domination by dinosaurs, but also for being the time period where the ancestors of today's major plant and animal groups emerged.

Nesting & dinosaur eggs

Dinos organised their nests, laying their eggs in patterns suggesting complex social behaviours. Palaeontologists have identified two main types of egg-laying strategies – clutches and linear patterns – further divided by the shape of the nest and distribution of eggs. For example, the ornithopod Maiasaura nests generally consisted of bowl-shaped excavations roughly two metres (6.6 feet) wide and 0.8 metres (2.6 feet) deep, the opening covered by loose vegetation. Each nest was spaced roughly seven metres (22 feet) apart and was used by their offspring until they were over a metre (3.3 feet) long.

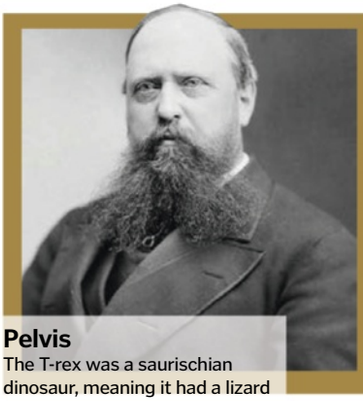


Outer shell
Dinosaur eggs were elongated and had hard, brittle shells. Some of the largest found to date were 0.6m (2ft) long.

Amniotic membrane
Encompassing the dinosaur was a thin membrane, helping keep the embryo hydrated during development.

Embryo
At the centre lay the dinosaur embryo that, depending on the species, could take weeks or months to hatch.

Yolk sac
This contained proteins and fat which served as food for the baby dino.

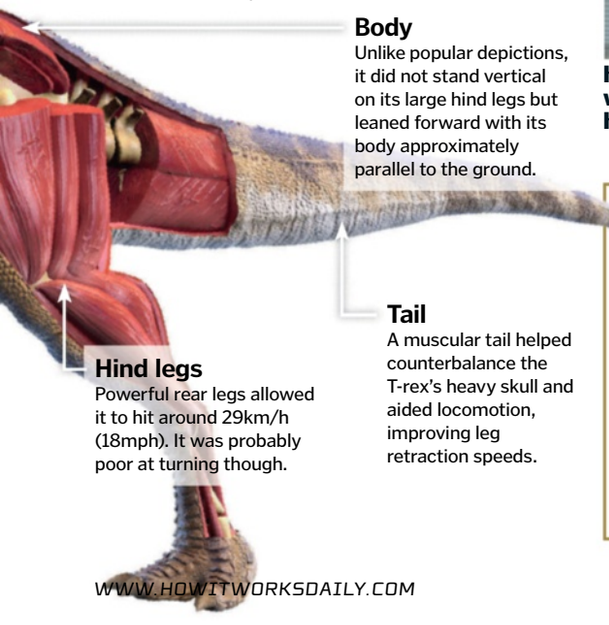


Palaeontology: key players

Most of our current knowledge of the dinosaur kingdom comes courtesy of palaeontologists, who dedicate their lives to uncovering the secrets of their prehistoric kingdom. From the earliest dinosaur hunters such as Othniel Marsh (pictured left), who discovered and named the Allosaurus, Stegosaurus and Triceratops, to 20th-century scientists who revolutionised our understanding of the dinosaurs' legacy, such as John Ostrom who gained fame for his suggestion that birds were modern-day descendants, palaeontologists have helped provide tantalising glimpses of the prehistoric world.

One of the more contemporary palaeontologists who has helped introduce dinosaurs to the general public is Dr Philip J Currie. He is also a museum curator who helped found the prestigious Royal Tyrrell Museum of Palaeontology in Alberta, Canada.

"Weighing something like five tons yet walking bipedally makes the T-rex incredibly interesting, as it pushes the absolute limits of what is possible. I mean, you look at an elephant and think, 'Wow, that's amazing', however, an elephant has to walk on four legs and weighs roughly the same amount, so understanding how T-rex functioned is a fascinating area of research"



Pelvis
The T-rex was a saurischian dinosaur, meaning it had a lizard hip arrangement. Its pubis bone pointed forward and down rather than backward and down like ornithischian species.

Body
Unlike popular depictions, it did not stand vertical on its large hind legs but leaned forward with its body approximately parallel to the ground.

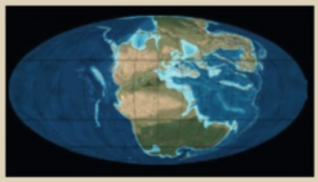
Tail
A muscular tail helped counterbalance the T-rex's heavy skull and aided locomotion, improving leg retraction speeds.

Hind legs
Powerful rear legs allowed it to hit around 29km/h (18mph). It was probably poor at turning though.

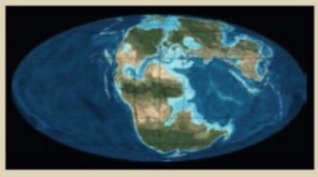
Queensland

If you were to visit Queensland's more remote regions, you may very well find yourself standing face to face with one of many 100-million-year-old beasts. That's because Queensland's outback was once part of the Great Inland Sea, a huge swampy inland ocean that existed in the age of the dinosaurs. As such, hundreds of fossils have been excavated from this region and there is even an established 'Australian Dinosaur Trail' that tourists can follow.

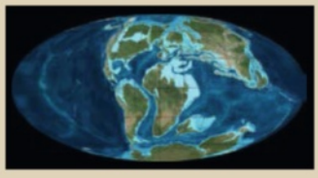
Oceans & continents



1 Triassic
At the beginning of the Mesozoic era in the Early Triassic period, all the land on Earth was joined together into the supercontinent of Pangaea, itself surrounded by the superocean Panthalassa.



2 Jurassic
As the Mesozoic progressed and the Triassic made way for the Jurassic period, plate tectonics split Pangaea into two mega-continents: Gondwana and Laurasia, separated by the Tethys Sea.



3 Cretaceous
As the Mesozoic came to a close, Gondwana and Laurasia had split into many of the continents we know today, including North and South America and Antarctica.

4 Palaeogene
In the Palaeogene period – the era immediately following the K-Pg extinction event – those continents continued to move to their current positions.

145 Ma

Cretaceous starts – The last period of the Mesozoic era, the Cretaceous, begins with all types of dinosaurs dominating on land, sea and air.

135 Ma

Geosaurus gone – After some 14 million years of swimming the Earth's seas, the crocodyliform Geosaurus goes extinct.

135 Ma

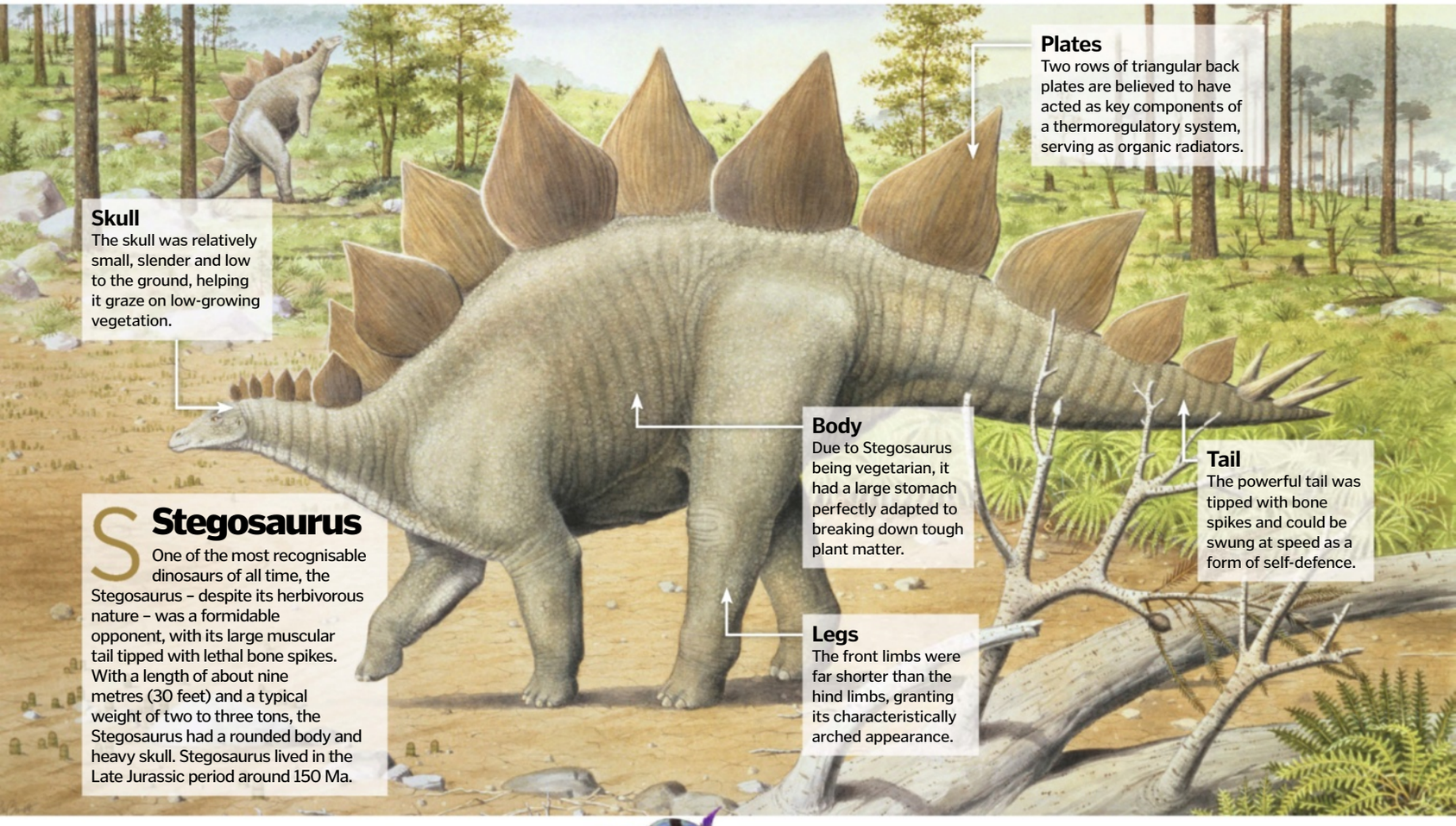
Gallornis spreads – Gallornis, a genus of prehistoric birds, is very successful throughout the humid conditions of the Early Cretaceous.

125 Ma

Leptocleidus passes – After 15 million years of marine dominance, the plesiosaur Leptocleidus dies out once and for all.

Relatives in the modern world

Massive scientific effort has been put into identifying which creatures today can trace their roots back to these prehistoric beasts. One of the best examples of this was the hunt for the nearest living relative of the once-mighty T-rex, undertaken by a research team at the North Carolina State University in 2007. To go about this the researchers sequenced proteins from a 68-million-year-old T-rex tissue sample and, much to their surprise, discovered that the king of the dinosaurs' molecules showed remarkable similarity to the common chicken and that its collagen makeup was almost identical. So, at least for the time being, the humble chicken is the rightful ruler of the Earth...



Plates
Two rows of triangular back plates are believed to have acted as key components of a thermoregulatory system, serving as organic radiators.

Skull
The skull was relatively small, slender and low to the ground, helping it graze on low-growing vegetation.

Body
Due to Stegosaurus being vegetarian, it had a large stomach perfectly adapted to breaking down tough plant matter.

Tail
The powerful tail was tipped with bone spikes and could be swung at speed as a form of self-defence.

Legs
The front limbs were far shorter than the hind limbs, granting its characteristically arched appearance.

Stegosaurus

One of the most recognisable dinosaurs of all time, the Stegosaurus – despite its herbivorous nature – was a formidable opponent, with its large muscular tail tipped with lethal bone spikes. With a length of about nine metres (30 feet) and a typical weight of two to three tons, the Stegosaurus had a rounded body and heavy skull. Stegosaurus lived in the Late Jurassic period around 150 Ma.

Tall tails

You'll struggle to find a dinosaur without a tail. This is because the majority of dinosaurs used their tails for two important roles: the first being balance and the second being self-defence. Large animals like the T-rex and Diplodocus, thanks to their skulls or necks, were very top-heavy. They needed long and heavy tails to counterbalance this, especially when running. Other smaller creatures such as Ankylosaurus (left) used its tail when under attack, evolving a large bony club at the end which could painfully bludgeon assailants.

Unenlagia: half bird, half dinosaur

One of the most telling links between dinosaurs and birds is the Unenlagia, a genus of theropod dinosaur from the Late Cretaceous that in almost all aspects, aside from flight, resembles a modern bird. It was discovered in 1997 and to date two species have been confirmed – U comahuensis and U paynemili – both of which share an almost identical pelvic structure to the early bird species Archaeopteryx.

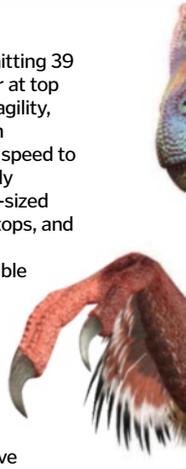
Velociraptors debunked

Due to their appearance in the *Jurassic Park* films, the Velociraptor is easily one of the most recognisable of all species. Importantly though, this image of the Velociraptor is way off the mark in terms of reality.

In contrast to the movie monster, research evidence suggests that the Velociraptor was actually a feathered dinosaur under 0.6 metres (two feet) in length, with colourful plumage used in mating rituals and visual displays. The species also had hollow bones, much like birds, and built large nests to protect their offspring.

The Velociraptor did impress in ground speed – one thing *Jurassic Park* got right – with it capable of hitting 39 kilometres (24 miles) per hour at top speed and boasting amazing agility, being able to change direction incredibly quickly. It used this speed to chase down prey, which largely consisted of small to medium-sized herbivores such as Protoceratops, and then kill them with its nine-centimetre (3.5-inch) retractable claws and sharp teeth.

As mentioned in 'Hunting strategies' new research suggests that, while sociable compared with other carnivorous species, Velociraptors were not apex pack hunters, with co-operative kills possible but infrequent.



99.6 Ma

Albian ends – The Albian age closes and gives way to the Cenomanian, made famous for its dramatic, anoxic end event.

68 Ma

Late to the party – The giant herbivorous Triceratops becomes one of the last non-avian dinosaur genera to appear before the K-Pg extinction event.

67 Ma

King is born – Tyrannosaurus rex takes over as the apex terrestrial predator on Earth. It retains this title until all dinosaurs are wiped out.

65.5 Ma

Dino death – A massive space rock smashes into Earth, sparking a chain of events that very few creatures survive, resulting in the K-Pg extinction event.

Winged wonders

While not technically dinosaurs, pterosaurs were very much the winged wonders of the dinosaur era. Flying reptiles that evolved throughout the Late Triassic and dominated the skies until the Late Cretaceous, pterosaurs were the earliest vertebrates currently known to have evolved powered flight. Pterosaurs are not related to modern-day birds or bats, with the many species evolving earlier and separately.

The genus Pterodactylus was one of the most notable, with the species Pterodactylus antiquus one of the most impressive, with a toothed beak, large eyes and clawed wings. In terms of wingspan P antiquus could extend its wings up to a metre (3.3 feet) and had a long, narrow skull packed with dozens of sharp, pointed teeth. It used these to snap up fish and smaller reptiles.

"Microraptor was a small, four-winged dinosaur... very close to the origin of birds. Its remains show it had wings on its arms and legs. It couldn't fly properly, but used its wings to glide. This shows the origin of flight in birds and their ancestors was much more complex than expected"

1 Beak
Up to 90 teeth in the long beak intermeshed when the jaw was closed, and were perfect for grabbing fast prey.

2 Wings
A wingspan of around 1m (3.3ft) was typical for Pterodactylus, with the wings structured in a way that indicates it would have flown like an albatross.

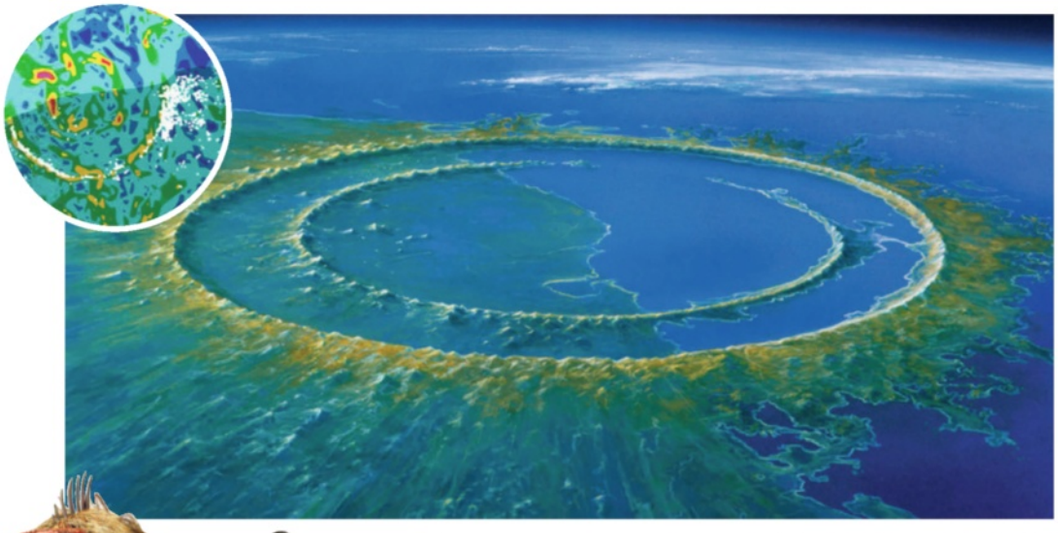
3 Body
Not as large as depicted in fiction, Pterodactylus was very lightly built with hollow bones and a long neck.

4 Limbs
Pterosaurs evolved a unique pteroid bone on the wrists of their forearms, used to support the forward wing membrane located between the wrist and shoulder.

5 Tail
Unlike some other pterosaurs, Pterodactylus had a relatively short, stubby tail.

X-raying prehistoric remains

X-ray scanners have become incredibly useful and important tools in the world of palaeontology as they can reveal many fossils and features that otherwise would remain hidden. For example, in November 2013, researchers in Germany used an X-ray machine to unveil the detailed structure of a fossil trapped within a plaster cast, all without ever having to break it open and risking damage to the specimen. What's more, the researchers then made use of a 3D printer to re-create the X-ray scans in solid form, allowing palaeontologists to pick up and handle a cast of the fossil as fine and detailed as the real thing. Modern technology is set to further our understanding of dinosaurs by no bounds.



Yucatán impact

The colossal Chicxulub crater in the Yucatán Peninsula, Mexico, since its discovery in the Seventies, has heavily hinted as to how 75 per cent of all life on Earth was eradicated around 65.5 million years ago. The crater indicates that a space rock – probably an asteroid – at least ten kilometres (six miles) across impacted Earth. As a result of the extensive damage caused directly by the collision and consequently by tsunamis, dust storms and volcanism, it caused a total collapse in the world's ecosystems, with all non-avian dinosaurs at the top of the death list. Despite being challenged repeatedly, the impact's link to the K-Pg mass extinction has recently been reaffirmed with even more detail, with a research team linking the two events in time to within 11,000 years. That said, the researchers also highlighted that various precursory phenomena, such as dramatic climate swings, also contributed to the end of the dinosaurs post-impact.

Zalmoxes sized up

Zalmoxes, a genus of herbivorous dinosaur from the Late Cretaceous period, is believed by some to be one of the earliest examples of insular dwarfism – a condition whereby a species undergoes a continuous reduction in size to better suit its environment, shrinking over several generations. Fossils from at least two species of Zalmoxes have been found in central Europe and one of its closest ancestors is thought to be the much larger Iguanodon.

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Translated, what does the Latin 'velocipede' mean?

A Pedal foot B Fast foot C Rail bike

Answer:
Velocipede means 'fast foot' and the term is often used to describe a variety of man-powered vehicles invented in the 19th century, from the pedal-less 'running machine' (or Laufmaschine) to early pedal bicycles such as the penny farthing.

DID YOU KNOW? *Ear trumpets known as Pinard horns are used by midwives to listen to a baby's heartbeat in the womb*

Tricycles for railroads

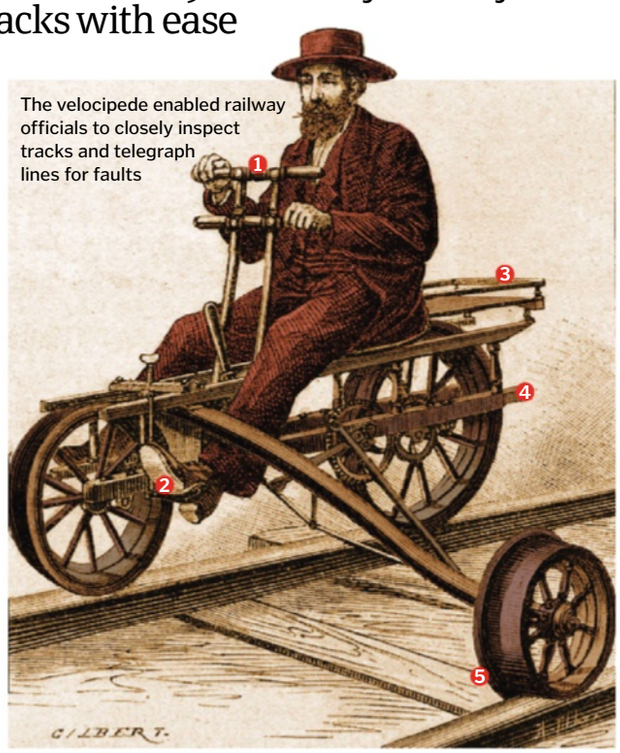
How man-powered velocipedes enabled 19th-century railway workers to travel along train tracks with ease

Patented in 1879 by American farmer George S Sheffield, velocipede handcars allowed maintenance workers to quickly traverse railways in search of areas that needed repair.

The vehicle was similar to a bicycle, with the rider sitting between two wheels on one side of the track. However, in order to allow the velocipede to travel along the thin beam of a railway line, it was balanced by a third wheel, which extended on a long arm to the other side of the tracks. Each wheel had a lip on the inside, preventing the vehicle from derailing.

Velocipedes had pedals, but the majority of the power to drive the wheels was generated using a walking beam – the handlebars were rowed back and forth around a central pivot point in a piston-like motion, turning the crankshaft and then the wheels.

The entire vehicle only weighed some 65 kilograms (140 pounds), so could easily be lifted off the tracks to allow a train to pass.



The velocipede enabled railway officials to closely inspect tracks and telegraph lines for faults

Velocipede engineering

Lightweight construction allowed for speedy travel along the tracks

1 Walking beam
Rowing the lever rotated the crankshaft, which caused the wheels to turn.

2 Pedals
A secondary source of power could also be gained by pedalling like a normal bicycle.

3 Passenger seat
Velocipedes were used for rail inspection and repair; one person would drive, allowing a passenger to inspect the track.

4 Wooden frame
The frame and wheels were constructed from hardwood, while the tyres, axles, crankshaft and pedals were made of iron.

5 Flanges
An internal lip on each wheel prevented the velocipede derailing when in motion.

Hearing aid evolution

Find out why modern electronic hearing aids were made possible by Alexander Graham Bell and his telephone

Up until the late-19th century, hearing aids were little more than just passive tubes that relied entirely upon capturing sound waves and funnelling them as much as possible towards the ear.

It wasn't until the invention of the telephone, which contained technology capable of converting sound energy into an electrical signal, that advances in hearing aid devices were made possible. This could then be amplified and sent to a speaker positioned near, or inside, the user's ear.

The key piece of tech was the carbon transmitter, invented independently by Thomas Edison, Emile Berliner and David Hughes, but Edison was awarded the first patent. The transmitter contained carbon granules, which reduce their electrical resistance when compressed by the pressure generated by sound waves. Miller Reese Hutchison used this device in 1898 to create the Akouphone, the first electric hearing aid.

Carbon transmitter hearing aids were very bulky, but the invention of smaller amplifiers – first the vacuum tube and later on the transistor – allowed for increasingly portable devices. Transistors were not only smaller, but they also consumed less power, meaning battery size could be reduced, making hearing aids ever-more practical for users.

The development of computers – particularly microprocessors – allowed hearing aids to be digitised. This enabled the incoming sound to be processed before being sent to the speaker, allowing the signal to be separated, with individual frequencies modulated to boost weak sounds and adjustments made according to incoming pitch and volume.

Hearing aids have developed from basic trumpets to digital devices tiny enough to fit inside the ear

Direct to the brain

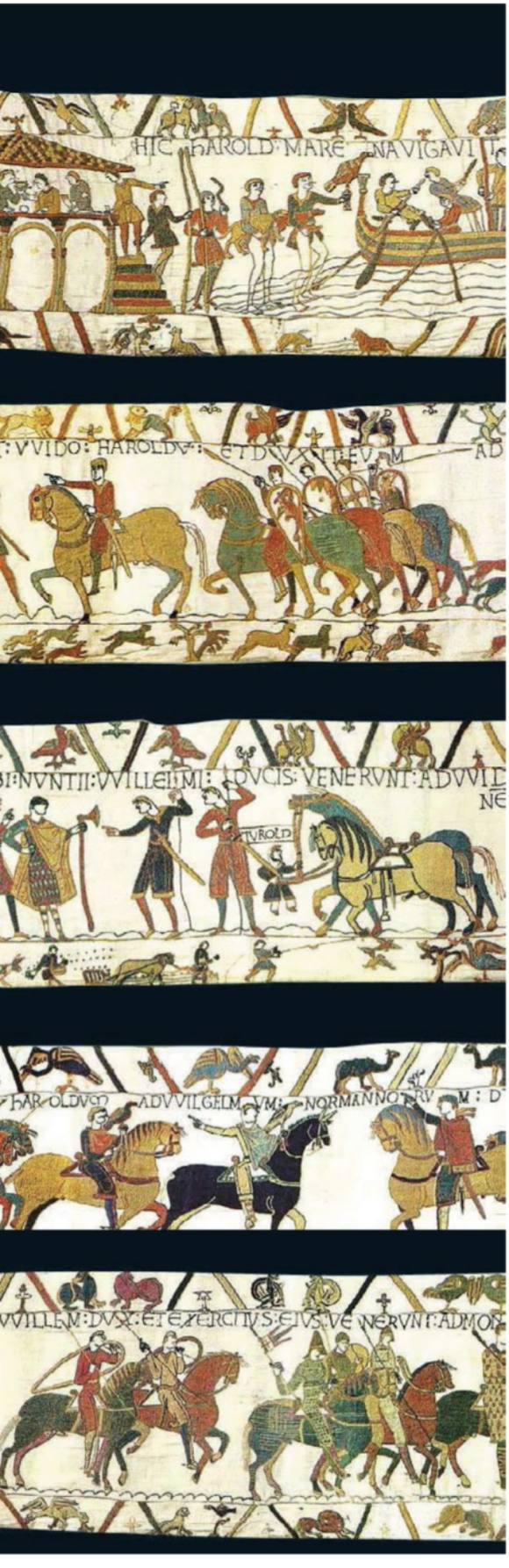
Today's hearing aid technology is more advanced than ever. A cochlear implant is commonly used to deliver electrical signals through the cochlea to the auditory nerve. But if the nerve itself is damaged, auditory brainstem implants may be used instead. The cochlear nucleus is the area of the brain responsible for processing signals from the auditory nerve and can be stimulated artificially with electrodes. A processor is worn on the outside of the ear and transmits a signal to a receiver, implanted just beneath the skin. The receiver is connected to a silicon-coated implant array, which terminates on the brainstem, directly stimulating the nerves so sound can be perceived.

"It shines a light on more everyday medieval life, including agricultural practices and fashion trends"

THE STATS
BAYEUX FIGURES

PEOPLE 626 | HORSES 190 | DOGS 35 | TREES 37 | LATIN INSCRIPTIONS 57 | SHIPS 37

DID YOU KNOW? *Halley's Comet, an ill omen, is in the upper border of the tapestry above the scene of Harold's coronation*



Making of the Bayeux Tapestry

We unravel the origins of this famous artwork to find out what it can tell us about the Battle of Hastings

Despite its name, the Bayeux Tapestry is technically an embroidery – the distinction being that the 58 scenes are hand-stitched onto a 'ground fabric', rather than woven as part of the base linen on a loom. Stretching 70 metres (230 feet) long and 50 centimetres (20 inches) wide, it is one of the finest surviving examples of embroidery from the Middle Ages, dating back over 900 years.

Depicting the events leading up to and during the Battle of Hastings, as well as mythological figures and hunting scenes in the borders, it's an extremely valuable historical artefact. Having said that, its accuracy has to be taken with a pinch of salt to some extent as it only shows the Norman perspective. Beyond providing details of one of the most significant conflicts in European history, it also shines a light on more everyday medieval life, including agricultural practices and fashion trends.

Debate has raged for centuries as to where the hanging was made, with many adamant it was produced by William I's wife, Matilda, and her ladies-in-waiting in France. However, the main school of thought nowadays is that it was commissioned by William's half-brother, Bishop Odo, shortly after the Norman victory to hang on special occasions in Bayeux Cathedral.

The nine distinct sections were most likely stitched by a team of professional seamsters in south-east England (where Bishop Odo ruled) before later being assembled into one under an artist's direction. Due to certain stylistic inconsistencies, it's still not certain if the embroidery was made in a single workshop or across several different ones.

The needlework is extremely fine, which supports the English origins theory, as Anglo-Saxon textiles (called Opus Anglicanum) were revered for their quality throughout Europe at this time. Additionally, many of the Latin captions (known as tituli) are written with Anglo-Saxon spelling variations.

Two major types of embroidery have been employed in the artwork: stem stitch for text and outlines, and couching, or laid work, to serve as the 'filler'. The designs are all created with woollen yarn spun from fleeces stained with vegetable dyes, such as woad (blue), madder (red) and rocket (green/yellow). Perhaps what's most incredible though, considering its quality, is that the embroiderers responsible for the Bayeux Tapestry would have been working with fairly basic tools and conditions, yet the result of their skill and labour has truly stood the test of time.

The man behind the embroidery

Bishop Odo is thought to be the driving force behind the tapestry, as written records link it to his cathedral in Normandy, also constructed in the 1070s. He also appears at least twice in the work – first feasting before the battle and again in combat, with a caption implying his role was to 'rally the troops' rather than fight. However these depictions are not believed to be realistic, suggesting Odo had a hand in their design.

Odo acquired a tyrannical reputation after being installed as the Earl of Kent in 1067, and his rule sparked several local revolts. Still, he played a crucial role in William I's government in the difficult transitional period – even serving as regent when the king travelled abroad. His hunger for power would eventually prove his downfall, though, when a dispute with William over plans to depose the Pope led to his imprisonment and his lands being seized.

BRAIN DUMP

Because enquiring minds need to know...

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howitworks@imagine-publishing.co.uk

MEET THE EXPERTS

Who's answering your questions this month?

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*.

Alexandra Cheung

Having earned degrees from the University of Nottingham as well as Imperial College, Alex has worked at many a prestigious institution around the world including CERN, London's Science Museum and the Institute of Physics.

Rik Sargent

Rik is a science communicator who has a background in physics and public engagement, having worked at the Institute of Physics. Pastimes include experimenting with sound, baking cakes as well as the complex science of brewing coffee.

Dave Roos

A freelance writer based in the United States, Dave has written about every conceivable topic, from the history of baseball to the expansion of the universe. He has an insatiable appetite for everything related to science and technology.

A bungee cord stretches under its own weight as it hangs

What are the physics involved with bungee jumping?

Dana Adamus

■ We are taught that everything falls towards Earth with the same acceleration of g = 9.8 metres (32.2 feet) per square second – ignoring air resistance. However, a bungee jumper often accelerates much faster than this. Of course, this depends on variables like the tension in the cord, as well as the weight of the cord and jumper. This phenomenon can be visualised by dropping a Slinky and a ball at the same time. Hold the Slinky, letting it hang but not touching the floor. The ball should be level with the top of the Slinky. Release both of them at the same time and watch as the top of the Slinky descends faster than the ball. The top of the Slinky not only accelerates due to gravity, but has a tension force from being stretched, also pulling down on it. A bungee cord stretches under its own weight as it hangs. So when someone jumps, they are pulled down not just by the force of gravity but by the tension in the cord as well. **RS**

How do plants underwater differ from plants on land?

Maria Guanell

Freshwater aquatic plants have to deal with a much darker environment, with lower levels of available CO_2. The scarce light is already mostly mopped up by the soup of single-celled algae floating in the water. So aquatic plants either have extremely thin, feathery leaves to maximise their surface area, or they try their best to get their leaves out the water. Water lilies have large, flat leaves that float; reeds poke their leaves all the way up into the air. The main adaptation they have for this life is called *aerenchyma*. This is a spongy, air-filled tissue in the stems that stores and transports oxygen around the plant. The oxygen isn't absorbed from the surrounding water (there isn't enough of it); instead it's produced by the plant itself as a by-product of photosynthesis. You can see surplus oxygen forming on pondweed as tiny bubbles. **LV**

COOL FACTS

The rarest eye colour is red

The rarest eye colour is red, associated with albinism. This genetic condition inhibits the production of melanin, the pigment that determines eye colour. People with albinism sometimes have translucent or very pale-blue irises, making red blood vessels behind the retina visible and giving the appearance of red or purple eyes.

Where is the best place in the world for stargazing?

J Pieterson

You must find a balance between dark skies and accessibility. Mountaintop observatories like those on Mauna Kea, Hawaii, offer unparalleled views of the sky, but most will never visit. For amateur stargazers, the best locations are the Dark-Sky Parks and Reserves defined by the International Dark-Sky Association. The largest of these are the Death Valley National Park, California, USA and the Aoraki/Mount Cook park on New Zealand's South Island, but there are now three in the United Kingdom as well: Northumberland National Park, Brecon Beacons National Park and Galloway Forest Park. **GS**

National parks make great locations for astronomers

Why do we sometimes get mouth ulcers?

S Hardwick

Ulcers are small lesions usually triggered by physical damage to the inside of the mouth, for example biting your cheek accidentally, eating sharp food or brushing your teeth. They are very rarely contagious and usually heal within ten days. Recurrent ulcers have a variety of causes, the most common being stress and hormonal changes. In other cases, recurrent ulcers may be symptomatic of conditions including B12 or iron deficiencies, gastrointestinal diseases or immunosuppressant diseases such as HIV. Ulcers are sometimes triggered by sensitivity to certain foods including strawberries, almonds, tomatoes, cheese, chocolate and coffee. **AC**

Why do some insects have such short lives?

Ray Hooper

Although adult mayflies only live for less than a day, the insect has already spent a year or two as a larva living in a stream or pond, building up its energy reserves. The larval form represents the majority of most insects' lifespan; mayflies are just an extreme example. Adult mayflies don't eat and have a digestive system filled with air. They exist only to reproduce – like the seeds from a dandelion. By all emerging together, mayflies reduce the risk of predation and increase their chances of finding a mate before they run out of energy. **LV**

Is it possible to cheat by counting cards?

Nathan Watkins

An experienced card counter can increase their odds of winning at blackjack without 'cheating'. Card counting is a mathematical system for tracking the odds of which card will be flipped next. Blackjack tables typically play with six or more different decks shuffled together. A card counter keeps a running tally of how many tens and aces have been flipped versus low cards (two through to nine). If a string of low cards are flipped, that increases the odds – although slightly – that the next card will be a ten. The card counter uses that information to bet big on 'ten rich' hands. While card counting isn't illegal, casinos reserve the right to kick you out is they suspect you of doing it. **DR**

What would happen if we had two moons? Find out on page 82

BRAIN DUMP

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The jet stream blows from west to east, explaining the difference in journey duration

Why do some flights take less time in one direction than the other?

Geraldine Stone

Flying east to west commonly takes longer than flying west to east, because a high-altitude wind called the jet stream blows from the west, slowing the aircraft down. The jet stream always blows in the same direction because of Earth's rotation. Warm air from the equator rises and moves north or south towards colder regions. Areas nearer the poles rotate slower than the equator. Air from the equator has the same 'fast' rotation speed around the planet as the equator, and as this air moves to regions where the ground beneath it rotates slower, it turns into a wind moving from west to east. **RS**

Would anything be different on Earth if we had two moons?

Dylan Fitzpatrick

In order to remain stable in its orbit, a second moon of Earth would have to sit at one of the Lagrangian points – sweet spots where the gravitational forces of Earth and Moon partially neutralise each other. The second moon's gravitational tug on Earth would increase its tides, either complicating their pattern if it pulled from a different direction, or adding to its pull to that of the current Moon if the two were lined up. This could cause much higher tides and widespread flooding, or far *less* tidal variation, with disastrous consequences for sealife. **GS**

Are UK red squirrels starting to recover?

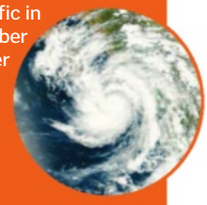
Dani

Red squirrel numbers are increasing, particularly in Anglesey and the north-east of England. The red squirrel had been declining since the grey squirrel was introduced from North America 140 years ago. Grey squirrels thrive better in British woodland as they can eat acorns, which reds cannot. They also carry the squirrel pox virus, which only affects red squirrels. A determined effort to selectively kill grey squirrels in certain areas has allowed the red squirrel population to recover slightly. There are still only about 140,000 red squirrels in the UK, compared with over 2.5 million greys. **LV**

COOL FACTS

Hurricane John is the longest storm ever recorded on Earth

Hurricane John lasted 31 days as it moved from the east Pacific basin to the north-west Pacific in August and September 1994. It covered over 11,300 kilometres (7,000 miles) and was a Category 5 hurricane, but its effect on land was minimal.



The highest ever trip in a hot-air balloon reached 21,000m

In 2005, Indian textile tycoon Vijaypat Singhania ascended to 21,027 metres (68,986 feet) in a sealed aluminium capsule lifted by a 49-metre (160-foot) hot-air balloon. The world-record ascent took three hours to reach the lower stratosphere where the air temperature is -93°C (-135°F).

Astronauts' starting salary is around $65K

Astronaut wages vary, and not all of the details are publicly available. However, NASA's civilian astronauts are employed as civil servants on a US Federal Government pay scale, with starting salaries around $64,700 (£39,360), rising to about $141,700 (£86,210) for the most experienced. European astronaut salaries are roughly comparable, while Russian cosmonauts are paid more while in space, but less when training on the ground.

When was Valentine's Day first celebrated?

Sam Collier

Valentine's Day began as a pagan Roman fertility rite around the third century BCE and was transformed by the Catholic Church and the gift-card industry into a day to celebrate love and friendship. Lupercalia, or 'Wolf Festival', was a Roman bacchanal celebrated on 15 February. A goat and dog were sacrificed and young women were lashed with strips of bloody animal skin to impart fertility. According to legend, single men and women put their names in an urn and were paired up for the duration of the festival. St Valentine was a third-century priest who performed secret wedding ceremonies in Rome and was martyred on 14 February. Pope Gelasius created St Valentine's Day in the fifth century, possibly to whitewash the existence of Lupercalia. Still, 'romance' was in the air and the first Valentine's poems and letters appeared in the Middle Ages. Today, Valentine's Day cards and gifts have grown into an £11 billion ($18 billion) industry. **DR**

Valentine's Day cards and gifts are an £11bn ($18bn) industry today – not that we're being cynical...

How do lava lamps work?

Raif Sadik

Lava lamps exploit the relative densities of two liquids, fine-tuned so that one is very slightly denser than the other. One common pairing is water and a combination of paraffin wax, oil and perchloroethylene (PCE). At room temperature, the wax mixture is denser than the water, and rests at the bottom of the vessel. Flick the switch and a tungsten bulb underneath the vessel heats the wax, which expands and becomes less dense than the water, rising up. As it cools, its density increases and it sinks back down to the base, ready to repeat the cycle. **AC**

Do some people have addictive personalities?

Sarah

Psychologists have identified a number of personality traits that make certain people more vulnerable to addiction. Described as an addictive personality, this psychological makeup predisposes its owner to a range of compulsive behaviours. One key trait is impulsivity, the tendency to act without thinking of consequences. Others include sensation-seeking, a poor ability to manage stress and a sense of social alienation. Everyone exhibits some of these behaviours, but addictive personalities experience them more intensely. These characteristics have some genetic basis: genes causing abnormal dopamine levels in the brain, for instance, may contribute to risk-taking behaviour. But environmental factors, such as upbringing and early-life experiences, are likely to be just as influential. Although 10-15 per cent of people have addictive personalities, not all become addicts. Addiction often begins when a trigger – for example, a traumatic experience – leads someone to gravitate towards addictive behaviours. **AC**

How is denim made?

Jade Lawson

Denim is a tightly woven fabric of two different colours of cotton yarn, indigo (blue) and white. In textile manufacturing, denim is known as twill weave. In this type of weave, the indigo yarn runs top to bottom and the white runs side to side. The weaving equipment is programmed to weave the white under the indigo with an alternating pattern that creates the trademark diagonal blue lines on the denim surface and white lines on the back. When the indigo yarn gets worn down or faded, the white yarn shows through. **DR**

Do goldfish really forget everything in seconds? Find out on page 84

BRAIN DUMP

Who first invented the zip wire?

Kenny Wellman

Natives in the Himalayas have used ropes and cables since quite early in their cultures as a quicker and easier form of transport for navigating the extreme terrain, but it's not known for certain who first invented the zip wire, or zip line. Initially it was something borne out of absolute necessity to transport food or people, rather than the fun sport we're more familiar with today. More recently zip lining has been the preserve of biologists as a way of accessing remote areas of rainforests, without impacting too much on the environment, until it became a popular thrill-seeking activity – that's not to say that biologists don't enjoy zip lining too! **RS**

Zip lines were originally used to cross gorges and other difficult terrain

What is litmus paper?

Adam Chambers

Litmus paper is absorbent paper treated with litmus, a mixture of dyes which change colour with pH. One of many acid-base indicators, litmus reacts to concentrations of hydrogen ions (in other words, the pH), turning increasingly red under acidic conditions (below pH 7) or blue in basic conditions (above pH 7). The indicator molecule can exist in two different-coloured states: one associated with hydrogen, and the other not. In an acidic solution, excess hydrogen ions lead the red, hydrogen-associated form to dominate. Conversely, in a basic (alkaline) solution the equilibrium is shifted and the blue, the hydrogen disassociated form dominates. **AC**

Do goldfish really have terrible memories?

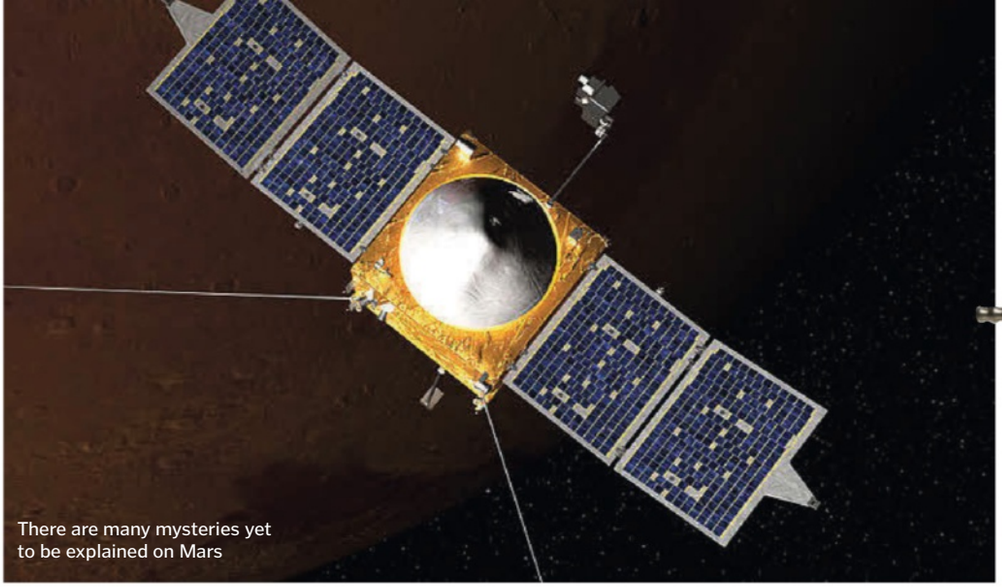
Callum J

The 'fact' that fish only have a three-second memory is actually a myth. We tell ourselves fish have short memories to justify placing them in small, otherwise empty tanks. But researchers around the world have found that goldfish and other fish varieties can be trained to swim through mazes, respond to light and sound cues, and return to a food source at the same time each day. Instead of three seconds, goldfish memories can last at least three months. **DR**

COOL FACTS

The blue whale is the strongest mammal in the world

Strength is proportional to the cross-sectional area of your muscle. So the strongest animal is also the largest: the blue whale. A blue whale's tail applies approximately 50,000 Newtons of force when accelerating – about half as much as the jet engine from an F-22 Raptor fighter plane.



There are many mysteries yet to be explained on Mars

Why are we still sending probes to Mars?

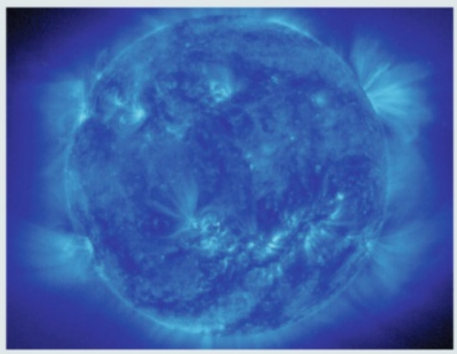
Joao Rodriguez

Mars is perhaps the most interesting, and certainly the most Earth-like, world in the Solar System, and there's a huge amount still to find out about it. So far we've put fewer than a dozen space probes successfully into orbit around Mars, each carrying specialised instruments to teach us about new aspects of the surface, while the Curiosity rover was only the seventh safe landing on the Red Planet (and the fourth rover). Despite its more-or-less uniform colour, Mars is a hugely diverse world, with a variety of different environments and landscape features – we really have only scratched the surface, but as we do so, we're discovering evidence for an increasingly Earth-like past, raising major questions we still can't fully answer. How much water flowed on the surface? Did Mars ever have seas? What happened to its atmosphere and oceans? Did simple life ever manage to get a foothold and might it still cling on somewhere? These are mysteries that new craft like MAVEN and MOM are hoping to solve. **GS**

What are lithographs?

Adam Croxley

It's a printing technique where the picture is drawn onto a block of limestone with an oily paint or wax crayon. The stone is then dunked in a mixture of weak nitric acid, which reacts with the stone to create calcium nitrate on all the blank parts of the image. The thin layer of wax attracts oil-based printing ink, whereas the wet calcium nitrate repels it. You create prints by pressing paper against the stone plate. Lithography is still used by the printing industry but modern systems use flexible aluminium or plastic plates coated with a light-sensitive emulsion. **LV**



Do dead stars still shine in the sky?

Brydon Allan

Astronomers talk of a star 'shining' only when it is generating energy within itself by nuclear fusion, but stars continue to shine in the normal sense, pumping out huge amounts of light and other radiation, long after their fuel is exhausted and fusion has come to an end. White dwarf stars have superhot surfaces with temperatures of 100,000 degrees Celsius or more, and blaze with a searing mix of white light, ultraviolet light and X-rays – they're only faint because they're so tiny. They continue to glow for many millions of years as they gradually cool and fade. **GS**

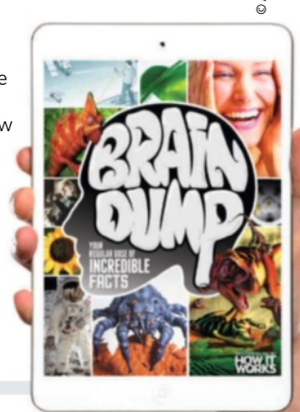
How do ionisation chambers work?

Charley Abbot

Ionisation chambers are gas-filled radiation detectors that use electric charges to determine radiation levels. Ionising radiation – eg X-rays, gamma rays and beta particles – knocks electrons off atoms as they pass through materials. When atoms lose electrons, they become positively charged ions. Ionisation chambers consists of a gas with two conductors on either side. Radiation creates ions in the gas. A voltage is applied, causing positive charges to move to the negative conductor, and vice versa. The leftover charge on the conductors is measured and used to calculate how much ionisation took place, which means you can work out how much radiation is present. **RS**

Knowledge on the go!

The latest edition of **How It Works**' digital-only sister magazine **Brain Dump** is now on the virtual shelves, packed with fascinating bite-sized facts from the fields of science, space, transport and more. In issue 9 you'll find the answers to some of life's trickiest questions, including what makes the wind blow, why don't Ancient Egyptian mummies rot and even an overview of chaos theory. **Brain Dump** is the perfect companion for those always on the move who want to learn something new every day. For the answers to those questions and more, download the new issue from iTunes or Google Play. You can ask your own questions at **www.facebook.com/BraindumpMag** or Twitter – @BrainDumpMag.



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REVIEWS

All the latest gear and gadgets

This Bosch chopper is compact but has the power to pulverise most foods

Want beans with your toast? The Toast N'Bean is a one-stop solution – but it's not the most convenient tool for making big breakfasts

Cool kitchenware

A selection of gadgets to turn kitchen carnage into culinary bliss

Checklist
- ✔ Fryer
- ✔ Induction hob
- ✔ Can opener
- ✔ Toaster
- ✔ Food processor
- ✔ Smart grill

Today's kitchen appliances aren't just about saving time, they're about making cooking accessible to more people and in healthy, tasty ways too. With their mini motors, electric heating elements and programmed microchips, our range of kitchenware here is a long way from the basic stoves and pots of centuries past. While the hardware may be evolving, many of the traditional culinary practices still hold true, so even the Jamie Olivers reading this can rest assured that quality doesn't have to be sacrificed for convenience.

1 Healthy fryer
Tefal ActiFry 2in1
£279.99/$TBA
www.homeandcook.co.uk
We're told that owning kitchen appliances like a toastie maker and a deep-fat fryer is a sure-fire way to put on weight. Luckily, the ActiFry 2in1 bucks this trend. It's a twin-tier fryer able to cook up to 1.5kg (3.3lb) of potatoes, meat, veg or any two items you need cooking. Amazingly the ActiFry only needs a single tablespoon of oil to do the job, resulting in healthier food, less greasy odours and less cleaning up. It's a win-win-win situation.
Verdict: ●●●●●

2 Portable hob
Smart Touch Induction Hob
£99.99/$N/A
www.lakeland.co.uk
An induction hob uses an alternating electric current to produce a magnetic field that creates a harmless electric current in your cooking receptacle. Cooking by induction is not only quicker and more energy efficient but because the hob only cooks via resistive heating, it's very difficult to burn yourself. Lakeland's portable version with touchscreen controls is ideal for caravans or small kitchens and a bargain price too.
Verdict: ●●●●○

3 Next-gen toaster
Tefal Toast N'Bean
£39.99/$TBA
www.homeandcook.co.uk
Reminiscent of Rube Goldberg-inspired novelty breakfast makers, the Toast N'Bean is a perfectly fine toaster that can also poach or boil eggs, heat your beans or cook your bacon and sausages. As long as you only want eggs on toast, or beans on toast… or bacon and poached eggs for that matter, as not all combinations are possible at once. We struggle to see the practical use of this even if you do get a perfectly decent toaster out of it.
Verdict: ●●○○○

4 Easy can access
Culinaire One-Touch Can Opener
£21.99/$N/A
www.lakeland.co.uk
Can openers have come a long way since the pointy shards of metal once used to pry open tins. For those who don't want to use any elbow grease to access their food, a solution like the Culinaire One-Touch is a no-brainer. It takes two AA batteries and sits on top of the can, tightening to the lid via magnets once activated by a button. It's practical, if a little too enthusiastic: it can take a few presses to stop it once it's started!
Verdict: ●●●○○

5 Food processor
Bosch MMR08R1 Midi chopper
£29.99/$N/A
www.bosch-home.co.uk
Living up to its title in the kitchen, the onions for our soup were annihilated in seconds – as was the garlic and even chunky pieces of butternut squash. Simply by holding down on the motor unit, food is promptly broken up into a fine mush. And the difference this single kitchen appliance made to the flavour of the soup was astonishing. Granted, it's a bit awkward to clean, but it's keenly priced and extremely good at its job.
Verdict: ●●●●○

6 Automated grill
Tefal Optigrill
£149.99/$179.95
homeandcook.co.uk / t-falusa.com
For some, cooking is simply a means to putting grub in their mouths. If that's you, then a steak grill that cooks your meat to taste is just the ticket. Tefal's Optigrill cooks chicken, fish, burgers, bacon, vegetables and a host of other barbecue-type items at the push of a button (well, more like a couple). A colour-changing dial shows the progress, so you can see when it's cooked to perfection. A real result for those who struggle with timing.
Verdict: ●●●●○

EXTRAS

Three top resources to help you become a culinary connoisseur

BOOK

Cooking For Dogs
Price: £10.99/$N/A
Get it from: www.firebox.com
If your foodie pooch is turning its nose up at the bog-standard canned or dried chow, it might be time for you to turn canine chef. In this cookbook you'll find 20 recipes and snacks for your pampered pet, from 'Beef Feast' to 'Fish Ahoy'.

APP

Epicurious
Price: Free
Get it from: iTunes
This app enables you to devise a recipe based on the dish type, occasion, dietary requirement or whatever ingredients you have in the fridge. It's surprisingly effective and comes in useful when you're too tired or busy to plan a meal.

WEBSITE

jamieoliver.com
Since we mentioned TV chef Jamie Oliver earlier, we thought we'd point you to his tasty website, packed with recipes and useful videos.

GROUP TEST

Putting products through their paces

Telescopes

How It Works puts three scopes under scrutiny to figure out which is the best for amateur stargazers

1 Celestron 60LCM Computerised

Price: £229/$373.95
Get it from: www.celestron.uk.com
Celestron is a big name in the world of astronomy and though the 60LCM appears at the lower end of its range, it packs a lot of features into a relatively small package. It's a refractor – a traditional type of optical telescope invented centuries ago that most people picture when they think about astronomy. The 60LCM uses a lens as the objective to form an image. In this case, a 60-millimetre (2.4-inch) lens aperture combined with a 700-millimetre (27.6-inch) focal length makes it great for observing the planets and the Moon, if not so good at peering deeper into the cosmos.

The scope comes in three main pieces: an extendable aluminium tripod, the telescope itself and a motorised mount controlled by a handheld computer – a big selling point of the 60LCM. It's simple to assemble even without the instructions and you can go from sealed box to celestial observer in as little as ten minutes. It even comes with two eyepieces – one 25-millimetre (one-inch), one nine-millimetre (0.4-inch) – so you don't need to spend a penny more than the asking price to start stargazing. Considering you can easily spend the best part of a thousand pounds on a quality computerised scope, Celestron's 60LCM is a pretty tight deal.
Verdict:

2 Moonraker Dark Matter 80ED

Price: £TBA/$TBA
Get it from: www.moonrakertelescopes.co.uk
If nothing else, this handmade refractor – currently scheduled to launch in June 2014 – will certainly be a standout feature in your living room. Looking something like a prop from a vintage cinema or perhaps even an extra-terrestrial weapon, the Dark Matter 80ED on first impressions might easily be a case of style over substance – but we can assure you that it most certainly isn't.

The main scope features an 80-millimetre (3.1-inch) lens of superb quality, with very little chromatic aberration (colour separation is a flaw inherent in this type of telescope). It is coupled with two smaller guide and finder scopes that allow the stargazer to seek out and home in on their target, before focusing with the powerful main telescope. The focuser movements are silky smooth and the hand-turned body is made of high-strength aluminium alloy, which allows the telescope to cool much more quickly when taken outside than a plastic-body telescope, which is desirable as it reduces image noise. It makes a great all-round telescope for picking out stars, planets and deep-sky objects. Although this high-end instrument is expected to come with a bigger price tag, it's clearly aimed toward seasoned amateur astronomers, and it certainly won't disappoint.
Verdict:

3 Celestron AstroMaster 130EQ

Price: £189/$393.95
Get it from: www.picstop.co.uk/www.opticsplanet.com
Unlike the two telescopes above, Celestron's AstroMaster 130EQ is a reflector telescope, as opposed to a refractor. It uses polished mirrors (the 'reflectors') to form the image, collecting light onto the primary mirror at the bottom of the tube and focusing it onto a secondary mirror in the centre. This makes it cheaper to manufacture with none of the chromatic aberration of the refractors but with other inherent design flaws, especially blurring objects towards the edge of the image.

The AstroMaster 130EQ makes up for this though by being a superb light gatherer making it ideal for observing galaxies, comets, nebulas and other similarly diffuse objects that can be tricky to make out without the right tools. Unlike the 60LCM, it's completely manual, so you'll have to rely on star charts and good old-fashioned astronomy skills to find your target, but objects like the Andromeda Galaxy look stunning through this scope.

The equatorial mount it rests on is more fiddly to set up than the other two models in this test, but on the whole it's fairly simple to assemble. The kit comes complete with eyepieces too, so you really have everything a beginner to intermediate stargazer needs to get started.
Verdict:

Astronomy software
The AstroMaster 130EQ comes with a piece of computer software called 'The SkyX – First Light Edition', a database of over 10,000 sky objects that will reveal when and where you can point your telescope plus what you can expect to see.

Space snapper
Although the Dark Matter 80ED can be used as a standalone telescope, it's designed with astrophotography in mind. Using an adaptor to clamp a decent camera to the main tube, you can capture some stunning shots of the night sky.

1

Handheld computer
While it's possible to use the 60LCM manually, once calibrated, the handheld computer can automatically point the telescope to any one of thousands of pre-programmed night-sky objects. Simply plug in the code and the motorised mount will do all the tricky calculations for you.

ON THE HORIZON

Three other astro gadgets we're keen to get our hands on...

NGT-18 Reflector

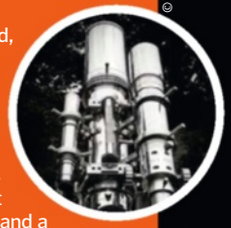
This portable 457mm (18in) Newtonian reflector telescope by JMI has been around for a while, but has seen various tweaks over the years. It's finally moved into the digital age with a built-in star database with nearly 30,000 catalogued objects and a computerised GoTo mount. It's not cheap though.

Cosmos 90GT Wi-Fi

The hot astronomy item at CES was the first ever WiFi-operated amateur scope, from Celestron. The 90GT Wi-Fi combines a 90mm (3.5in) refractor with a 120,000-strong database of objects, all of which can be remote-controlled with a free app for tablets and smartphones.

Dark Matter 102 f7 Doublet

A relative of the 80ED from Moonraker, the f7 Doublet is also handmade so each is unique. This model similarly comes with an optional finder and guide scope and, fully loaded with extras, costs up to £1,599 – but you're paying for quality here. Sadly the initial run of ten has already sold out but with such high demand a new batch is sure to be coming soon, so watch this space!



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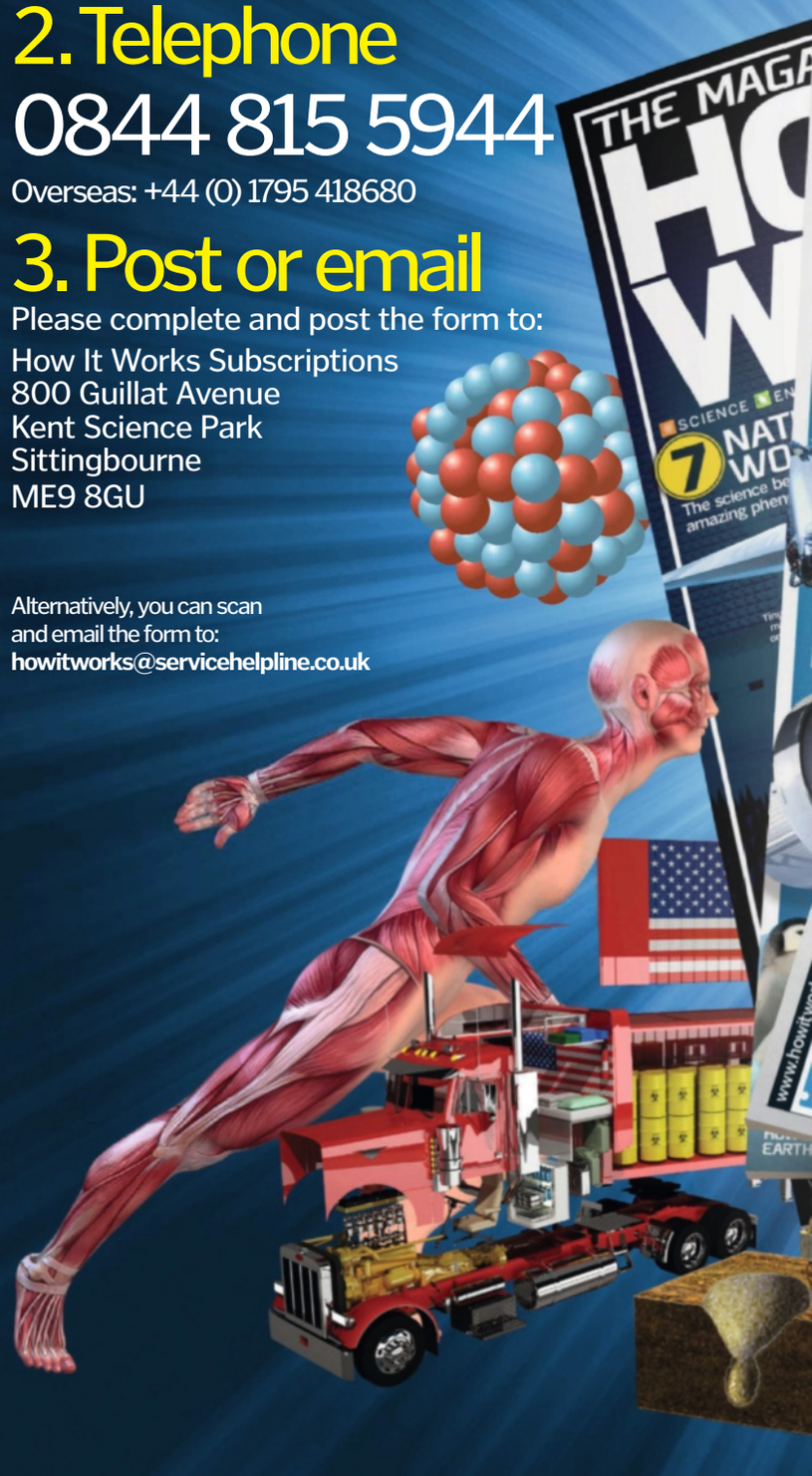

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Escape from quicksand

Before setting out on a hike, it's essential to be ready for that sinking feeling

1 Be prepared

If you expect to be hiking in terrain where quicksand is known to occur, such as swamps or tidal flats, then you should try not to go alone – or at least let someone know where you're walking. A rope is always a useful piece of kit to have on hand, while a stick can serve as a support and a way to test the ground ahead. When hiking, stick to main paths and be vigilant for any areas of damp-looking sand with ripples on the surface.

2 Remove your gear

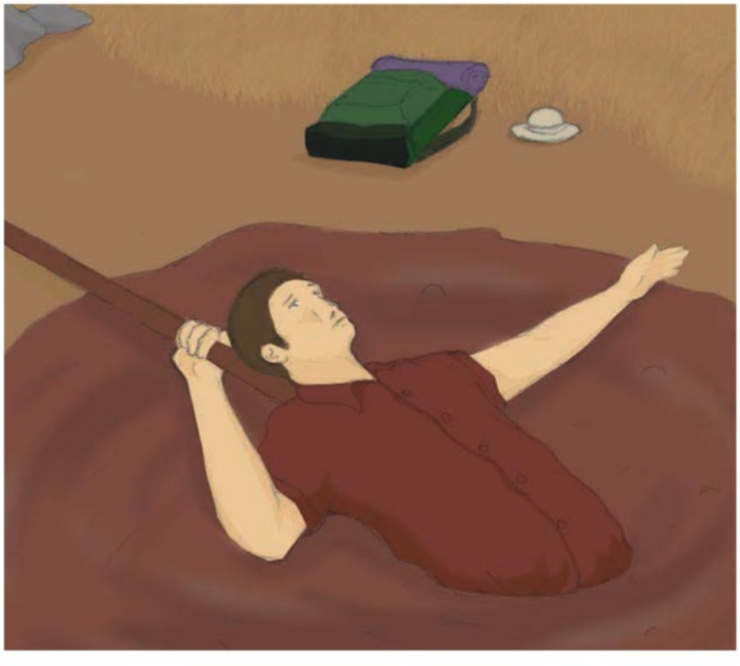
Sometimes, despite preparation, quicksand can still catch us out. The first thing to do if you get stuck is to remove any heavy items and drop anything you're carrying (but keep walking sticks close to hand – see step 5). Not only will the weight reduction buy you time, but it also makes it much easier to manoeuvre. If you can get your feet out of your shoes, now's the time to do it, as shoes increase the amount of suction working against you.

3 Don't panic

Without a doubt, it can be a very scary situation – particularly if you're alone – but it's essential that you keep all movements slow and deliberate; frantic motions will just agitate the quicksand further, which means you'll sink quicker. By relaxing your body as much as possible, you'll also breathe more deeply, which will help calm you down so you can think more clearly. It will also increase your buoyancy.

4 Think big

Create a big profile to reduce the amount of pressure being exerted by your feet. If you're at the edge of a quicksand pit, sit back on the more solid ground and lean back to pull your feet up. When you feel some give, roll sideways to get free. If you are deeply stuck in the centre, lie on your back with your arms outstretched. Work each leg to the surface bit by bit, essentially doing a backstroke to haul yourself towards solid ground.



5 Stick with it

Freeing your limbs from quicksand can be exhausting, so use your energy economically and take short breaks. Your walking stick may be of use now. Place it behind your back in the quicksand to serve as a buoyancy aid; it works even better if you can position it beneath your hips to free your legs. When your legs are out, slide along the stick slowly, using it as a guide to the edge of the quicksand.

In summary...

Being stuck in quicksand can be a terrifying ordeal but remember: you'll only sink if you panic. Just get rid of any dead weight straight away, take deep breaths and make as big a surface area as you can to evenly distribute your weight. Keep movements small and concise, working on freeing one leg at a time, and use any natural resources in the vicinity, such as branches, to aid your escape.

NEXT ISSUE
- Build your own nestbox
- Fillet a fish

Deal with frozen car doors

Don't let the cold weather stop you from getting on with your day...

1 Check the forecast

If you're in for a frosty night, it's worth cleaning your car's rubber door seals (ie gaskets) with soapy water and then drying them thoroughly as often it's the accumulated dirt and moisture that cause doors to freeze shut. For extra protection, treat the seals with silicon spray or even cooking oil as this will make it harder for ice to form. You can buy specialist lubricant just for the door lock too – a worthwhile investment.

2 A little pressure

A cold spell can catch us all unawares and you might wake up to find your car door completely frozen shut. In this scenario, your first move should be to apply some pressure to the door by leaning on it with your palms as hard as you can. This may be enough to crack the ice around the seal, or at least weaken it. If the door is still refusing to budge, use the edge of an ice scraper around the door rim to try and finish the job.

3 Heat things up

If brute force isn't working and you haven't got all morning to wait for the Sun to melt it, you might have to raise the temperature artificially. Pour warm water around the door seals to thin the ice and reintroduce the scraper – you might have to do this a few times, depending on the ice's thickness. If the lock is frozen it's best to use de-icer, or you could try a hairdryer or hold a gloved hand over the lock for a few minutes.

In summary...

When you've got places to be, there's nothing more annoying than being shut out of your car because of a big freeze. While there are ways to get through the ice, it's much less hassle to plan ahead. Lubricating the door seals and your locks in advance can make all the difference.

QUICK QUIZ

Test your well-fed mind with ten questions based on this month's content and win a model of the Eurofighter Typhoon jet!

Answer the questions below and then enter online at **www.howitworksdaily.com**

1. How many kilometres is Uranus from the Sun?
2. In what year did Henry Ford introduce the Model T car (pictured below)?
3. How many Latin inscriptions are stitched into the Bayeux Tapestry?
4. What is the average depth of the Grand Canyon (in metres)?
5. There are three types of neutrino: tau, electron and what?
6. How much will the Poseidon Undersea Resort weigh (in tons)?
7. What is the estimated top speed of the Ichthyosaurus?
8. For how long can a tardigrade survive in space?
9. Which country produced the greatest amount of coal in 2012?
10. What was the name of the longest-lasting recorded hurricane?

ISSUE 55 ANSWERS

1. 40mn **2.** 1967 **3.** 10,000 tons **4.** 23.5° **5.** 4m
6. 1,228km/h **7.** 3,000 **8.** Mexico **9.** 92 **10.** Nose

INBOX
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WIN A HOME CHEMISTRY SET!
Next issue's Letter of the Month writer will get a chemistry set by Thames & Kosmos, which offers over 125 experiments. A word of warning, this one's only suitable for those aged 10+.

Letter of the Month

What goes around...

Dear Sir,
I would like to refer you to your 'Understanding plastics' article in issue 52 (page 23), under the heading 'In the future', in which you mentioned the possibility of making bioplastics from plants, such as corn or cane sugar.

You might be interested to know that in the late-Fifties and early-Sixties, before the formation of OPEC [Organization of the Petroleum Exporting Countries] and when oil was very cheap, the possibility of producing bioplastics from starch was underway. One of the plastics derived from corn starch was polyurethane, for use in insulation.

The project was not commercial at that time, because it could not compete with the price of cheap oil. I worked on such a process and looked at the possibility of using waste paper among many raw materials, for making polyurethane, and all were suitable starting materials. I guess it's a case of 'what goes around, comes around' – there is rarely anything original, just the recycling of other people's work.

Yours sincerely,
Peter Hull

It's always fascinating when you delve into seemingly modern science and technology to find that the concepts have actually been on the drawing board, or even under development, for many years. Like you say, Peter, there are very few ideas that are brand-new – just refinements or tweaks to existing ones, but that doesn't make them any less important to our future. Who knows, now we're in the 2010s, maybe the time of bioplastics has finally arrived. Congratulations on winning the *Large Hadron Collider Pop-Up Book* – it's a whole new angle on this amazing science machine.


If we were to make more plastic from plants like sugar cane we could hugely cut down on fossil fuel use

Droning on...
Hi,
I just wanted to let you know how much I enjoyed your feature about drone aircraft [in issue 54]. They never seem to be out of the news at the moment, but so many of the articles I read are purely focused on what makes them so deadly and why they're too dangerous to be allowed in the sky. It was refreshing to hear about some of the other roles they're performing, being used by emergency services and scientific organisations, for example. You joked about it being some time before drones will be delivering our shopping, but with Amazon revealing its Prime Air unmanned delivery service currently under development, perhaps such a possibility is not so far off after all...
James Reynolds

Could we see drones delivering our books and DVDs from Amazon soon?

A bit more weird science
Hi **How It Works**,
Some of the weird science facts in issue 54 really blew my mind – especially the ones about cows moving with magnetic field lines, the universe being beige and that some animals actually have virgin births. It inspired me to do a bit more research into other unusual phenomena and I thought I'd write in to share a couple more oddities I found. Did you know that the ozone layer is meant to smell a bit like geraniums? Even more amazing though is that humans share about 50 per cent of the same DNA with a banana. Weird science rocks!

Best wishes,
Sarah Jennings

"It would be amazing if it could push the land speed record to over 1,600km/h (1,000mph)"

It's always great to hear when our articles have inspired readers to go away and look at a topic in more depth, Sarah, so thanks for letting us know. And they are some excellent wacky facts – it certainly puts bananas in a whole new light. Having said that, bananas don't quite keep up with chickens (with 60 per cent the same DNA as humans) or rats, which believe it or not share around 90 per cent of our genetic code.

Eager beaver

Dear **HIW**,
I am very impressed with the **How It Works** magazine.

It is filled with enticing and very informative articles that I think all ages – both males and females – can enjoy.

I have subscribed to **How It Works** from issue #27 but my favourite issue so far has to be issue #53 – I have enjoyed learning about why a beaver's butt smells like vanilla!

I haven't witnessed any spelling errors and the captions are always clear.

How It Works is such an enjoyable and worth-reading magazine. It is a pleasure to receive it in the mail.
Anika (11)

We had a surprising amount of positive feedback about that beaver news article, Anika! We hope you continue to enjoy reading the mag.

Where was Concorde?

Dear **How It Works**,
I loved reading about the world's fastest vehicles in issue 55, but I was a bit surprised that Concorde didn't appear in the article – I always thought that it was the fastest plane ever to fly? I'm going to be keeping a close eye on the Bloodhound SSC car. It would be an amazing breakthrough if it could push the land speed record to over [1,600 kilometres] 1,000 miles per hour.
Dean

We're glad you enjoyed reading about the high-octane speed demons of the transport world, Dean. You're quite right that Concorde does hold a number of speed records, but unfortunately we didn't have enough space to include every record-holder. Even with its later faults Concorde remains an incredible piece of engineering, so thanks for writing in!

Waking up with HIW

Hello!
I love reading **HIW** because it gets my mind going for the day. I especially like issue 54 because of the 'Smashing atoms' article. I've written to ask two questions: what's the most common species of plant and what make of car pollutes the most? I'm also a big fan of stargazing. I have seen some mountains on the Moon and soon I might get a bigger telescope. I went on holiday recently and saw Saturn's rings, M39 and a galaxy behind another. I love science – especially Isaac Newton's laws of motion. Can't wait for the next issue!
James Hadlow (10)

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...

Liam Kelly @liamkellylk23
@HowItWorksmag Have you ever answered a question about how there could be a sort of zombie apocalypse or that there is no way at all? :)

Aekmad @Aek_Mad
@HowItWorksmag – I read it and it's really interesting thank you HIW!!!

Hee Soo Shin @heyheesoo
And the loudest animal is... a shrimp :D

C.R.E.A.M @nicksummerz
@joerogan @HowItWorksmag Yetis and Bigfoot may not be primates, but instead bears

TheMedjyn™Show @bronzeskin **@HowItWorksmag** One minute I was eating next minute I'm knocked out in a bed. Why is that? Had to Google it [bit.ly/1dOKcax]

Lisa L. @lisalo17
@HowItWorksmag I got a new turntable and a couple of new vinyls. Oh and also [a HIW Annual] ;)

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Imagine Publishing Ltd
Richmond House, 33 Richmond Hill
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www.greatdigitalmags.com

Magazine team

Deputy Editor Adam Millward
adam.millward@imagine-publishing.co.uk
☎ 01202 586215
Editor in Chief Dave Harfield
Research Editor Jackie Snowden
Senior Designer Marcus Faint
Senior Art Editor Helen Harris
Sub Editor Erlingur Einarsson
Photographer James Sheppard
Head of Publishing Aaron Asadi
Head of Design Ross Andrews

Contributors
Mike Anderiesz, Aneel Bhangu, Ben Biggs, Ella Carter, Alex Cheung, Megan Davis, Alicea Francis, Shanna Freeman, Ian Moores Graphics, Robert Jones, Peter Kavanagh, Laura Mears, John Ndojelana, Jonny O'Callaghan, Terry Pastor, Peters & Zabransky, Vivienne Raper, Dave Roos, Rik Sargent, Lee Sibley, Giles Sparrow, Luis Villazon, Nigel Watson, Jonathan Wells, Suzanne Worthington

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Dreamstime; Eurofighter/Planefocus Ltd; Getty; Look and Learn; Peter Davies/MOD

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Advertising
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Advertising Director Matthew Balch
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Head of Sales Hang Deretz
☎ 01202 586442
hang.deretz@imagine-publishing.co.uk
Account Manager Liz Tucker
☎ 01202 586431
liz.tucker@imagine-publishing.co.uk

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☎ 01202 586200

Founders
Group Managing Director Damian Butt
Group Finance and Commercial Director Steven Boyd

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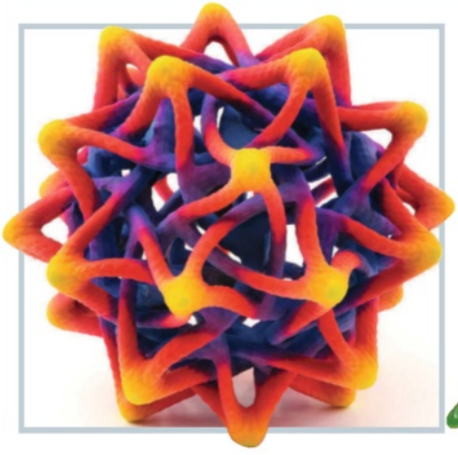

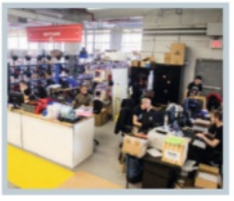

3D PRINTING

From replacement body parts and robotics to space food and clothing, are there any limits to additive printing technology?

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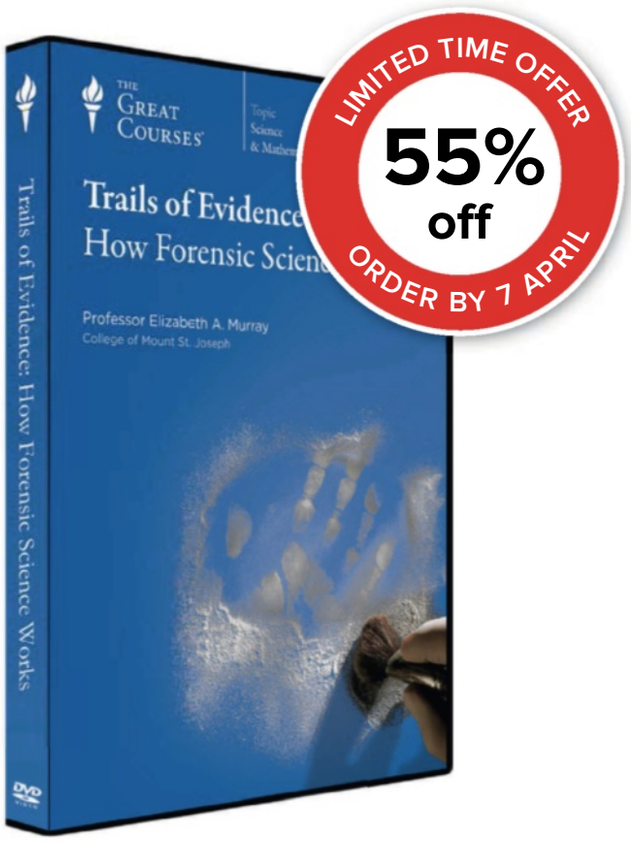

Go Inside the Forensics Lab

Ever wonder how accurate detective dramas are? The truth is, fictional portrayals of crime scene investigations often get it wrong. It's a shame, because knowing how scientists approach cases isn't just fascinating, it can actually help you be a better juror or witness, sharpen your analysis of headline-grabbing crimes, and make you a more critical thinker.

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