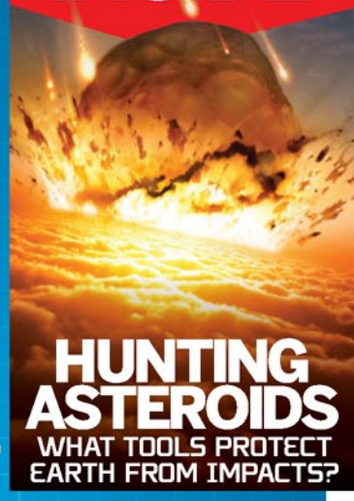
THE MAGAZINE THAT FEEDS MINDS

HOW IT WORKS

INSIDE



HUNTING ASTEROIDS
WHAT TOOLS PROTECT EARTH FROM IMPACTS?

ENVIRONMENT TECHNOLOGY TRANSPORT HISTORY SPACE

Robots become ever-more human

HOT OFF THE DRAWING BOARD!
THE TECH SET TO SHAPE THE YEAR AHEAD

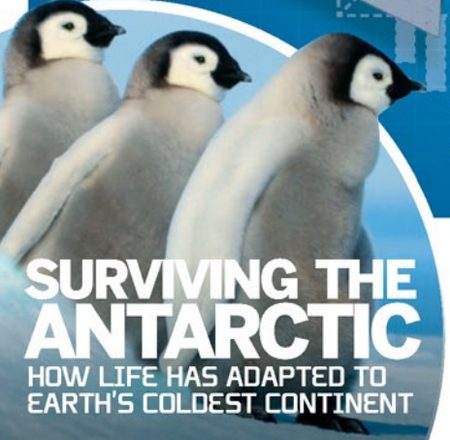
BRIGHT INNOVATIONS 2014

The wearable tech revolution

A new era of space exploration launches

Self-driving cars take to the roads

The next generation of touchscreens arrives



SURVIVING THE ANTARCTIC
HOW LIFE HAS ADAPTED TO EARTH'S COLDEST CONTINENT

+LEARN ABOUT

- URANIUM
- EQUINOXES
- DEMOLITION
- BLOWHOLES
- MANATEES
- CANAL LOCKS
- ROLLING ROADS
- GLOBE THEATRE
- TIDAL POWER
- SEEING SOUND
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5 TOP FACTS: Airfix Club

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HOW IT WORKS

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CLUB SPECIAL A82014 Operation Torch 'The Sparks of Liberation' 1:72nd

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ISSUE 55

WELCOME

The magazine t… s minds!

Page 30
Discover what tricks meerkats have picked up to cope with the perils of the African plains

The new year has always been a time to look ahead, so this issue How It Works is shining a spotlight on 2014. What amazing breakthroughs await us in the fields of science, astronomy and technology in the coming 12 months? From wearable gadgets like Google Glass and the engineering smartening up our cars, to the next-gen Orion craft about to embark on a new era of deep-space exploration, we highlight the most exciting innovations set to shake up the establishment. Also find out what experts from some of the world's most prestigious institutions, like MIT and the Science Museum, are most looking forward to. Elsewhere in the mag we wrap ourselves up for a visit to the frozen continent of Antarctica to reveal why it's such a hotspot for scientific research and home to a surprising array of wildlife.

Enjoy the issue.

Adam Millward
Deputy Editor

Meet the team…

Marcus
Senior Designer
Our innovations of 2014 feature has got me excited for advancements in car tech as well as our continued journey into deep space.

Erlingur
Sub Editor
I thought my watch was fairly precise, until I read about optical lattice clocks. Now, *they're* accurate. I'm not sure I'd wear one, though.

Jackie
Research Editor
I enjoyed the space rocks feature. It's amazing how scientists manage to keep track of the asteroids and comets in Earth's neighbourhood.

Helen
Senior Art Editor
I find it amazing how Antarctica is the harshest environment on Earth yet still provides a home to some of the most fascinating critters.

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 wearable gadgets to next-gen spacecraft and medical breakthroughs, find out what science and technology are set to shape the year ahead

Meet the experts...

Luis Villazon
Demolition
This month, Luis dons a hard hat in order to venture into the explosive world of building demolition, getting a professional to guide us through the full process.

Rob Jones
Bright innovations
2014 promises to be a bumper year for science, tech and astronomy, and Rob is here to guide us through the highlights, as well as getting some hot tips from the experts.

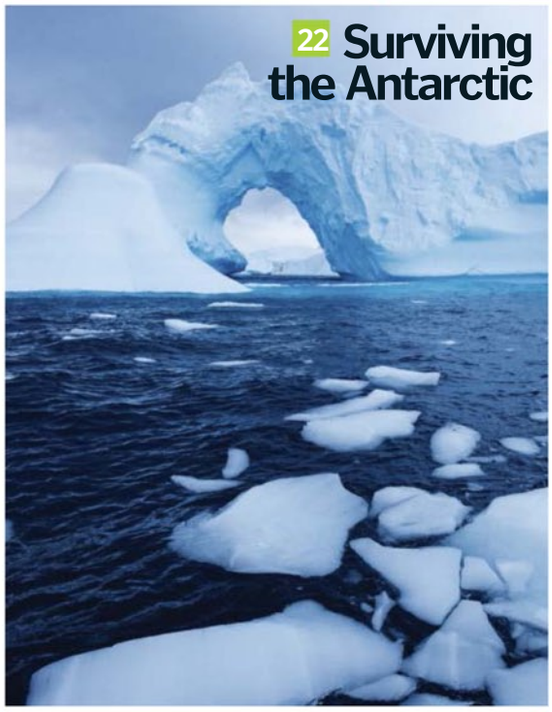
Giles Sparrow
Asteroid hunters
Astronomy buff Giles explains the origins of space rocks, what tools we use to spot them and why asteroids are seen as a valuable resource.

Alex Cheung
Amazing science machines
Having worked at the Science Museum and CERN, Alex was the perfect candidate to write about the smartest science tech.

Dave Roos
World's fastest vehicles
Dave must be a bit out of breath this month, as he's been chasing some of the quickest vehicles to reveal what powers them.

How do optical lattice clocks measure time so accurately? Find out on pg 47

42 Amazing science machines



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Some think Mount Etna's halo-shaped puffs could be a prelude to a major eruption

Mount Etna lets off some steam

Unusual smoke rings could signal mega-eruption of European volcano

Europe's most active volcano, Mount Etna in Sicily, has been pictured puffing out 'smoke rings' – some up to 100 metres (328 feet) across. In fact, this unusual phenomenon is not smoke but vortices made of steam and other gases, though quite how they form is still debated. The volcanologist who snapped the shots, Tom Pfeiffer, believes it could be the result of intense activity in the last few months altering the shape of the vent so it's more circular. It is not the first time these haloes of steam have been observed coming from Etna, but some believe they could be a prelude to a more violent eruption in the near future.

© Tom Pfeiffer/volcanodiscovery.com

Falcon 9 reaches new heights

SpaceX sends a satellite farther than ever before, continuing its meteoric success

The private space transport company SpaceX has achieved yet another milestone by inserting its first cargo into geostationary transfer orbit (GTO), which travels some 80,000 kilometres (50,000 miles) from Earth. Launching from Cape Canaveral on 3 December, the goal was to set the 3.2-ton (7,055-pound) SES-8 satellite on course to its high-altitude orbit, where it will support the growing telecommunications demand in Asia. The mission was carried out by a Falcon 9 rocket that had recently been enhanced with more powerful engines and other upgrades. Everything went without a hitch – even the tricky reignition second stage, which had previously proven a stumbling block. SpaceX founder Elon Musk commented: "The successful insertion of the SES-8 satellite confirms the upgraded Falcon 9 launch vehicle delivers to the industry's highest performance standards. As always, SpaceX remains committed to delivering the safest, most reliable launch vehicles on the market today."

This SpaceX mission was the first commercial launch from Cape Canaveral in four years

‘Floating city’ seeks investment

After being stalled by the global economic recession, the largest ocean vessel ever proposed – the Freedom Ship – is stepping up efforts to secure funding. At 25 storeys high and over 1,370 metres (4,500 feet) long, the ship would be like no other ever built in terms of scale, featuring a mini airport on its top deck and a fleet of smaller watercraft to ferry passengers to and from land. The designers envision the vessel being an ever-moving marine community (circling the globe every two or so years) – rather than a cruise liner – with businesses, shops and services like schools and hospitals all on board. However, such an engineering feat doesn’t come cheap, with the initial investment target set at £6.1 billion ($10 billion).

Phobias could be in the genes

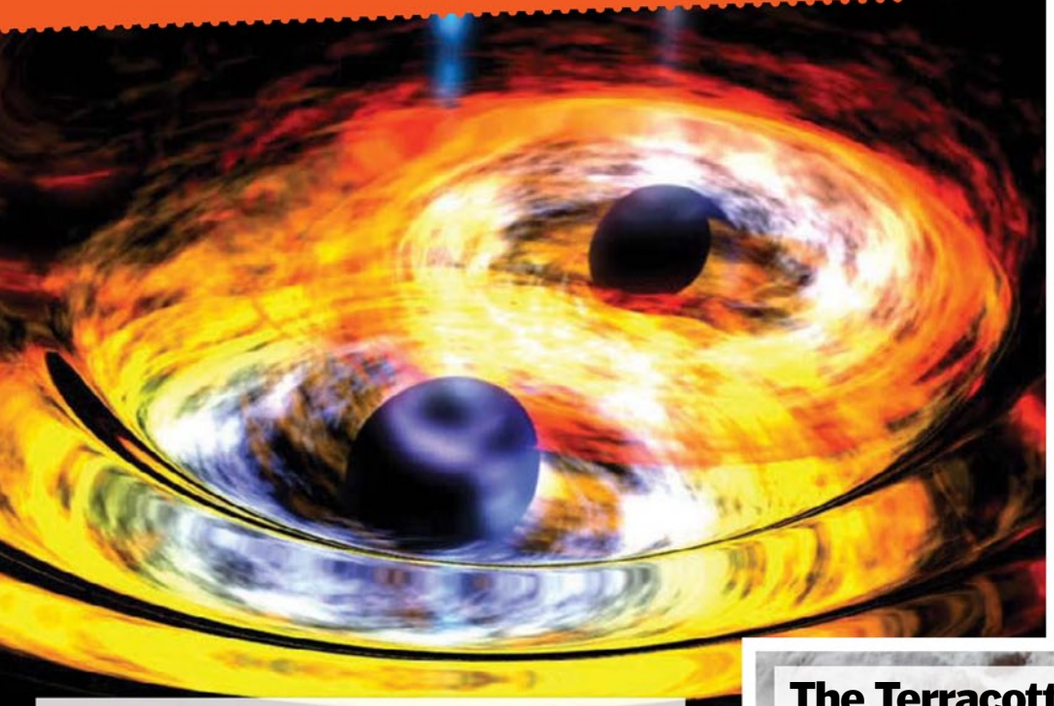
Whether it’s spiders, big crowds or more unusual phobias, we may be born with irrational fears hardwired into our genes, according to a new study. Until now, many have suggested phobias are born out of suppressed childhood experiences or something we learn as we grow up, but new research from Emory University in Atlanta, Georgia, suggests we may, in fact, get our greatest fears from our relatives. Detailed in the *Nature Neuroscience* journal, a study conditioned mice to be scared of a cherry-based scent and remarkably they found the fear of the smell persisted over two generations, across a range of scenarios, implying phobias can be written in our DNA.

New mag for the wild at heart!

Out now, the latest issue of **World of Animals** is packed with some of the biggest icons from the animal kingdom. Issue 2’s cover feature studies the plight of the orangutan, looking at everything from its human-like traits to its dwindling habitat, as well as the ongoing conservation efforts to bring them back from the brink. There’s also a tour of the home of one of the natural world’s most skilled architects – the beaver, explaining how they go about constructing their amazing lodges. **World of Animals** is available from all good newsagents, and digital copies can be picked up on iTunes. For more wildlife news and images, visit **animal answers.co.uk**.

GLOBAL EYE

10 COOL THINGS WE LEARNED THIS MONTH



Two black holes can become a giant one

NASA's Wide-field Infrared Survey Explorer (WISE) telescope appears to have spotted a pair of supermassive black holes locked together in a deadly game of cosmic chicken in a galaxy 3.8 billion light years away. Other terrestrial telescopes have also been trained on the candidate 'black hole binary' and initial data seems to support WISE's findings, with clumped material in the accretion disc and a distorted jet implying that one black hole is being contorted by another in close proximity. It's thought that they will continue to spiral ever closer until eventually merging to form a supersized-massive black hole.

Future mobile phones could be like Lego

A leading phone manufacturer has joined forces with 3D printing company 3D Systems to make the everyday mobile as customisable as Lego. The aim is to 'do for hardware what Android has done for software', making it possible to buy an endoskeleton handset and then tailor bespoke modules – eg screen, battery, keyboard etc – to best meet our needs. Project Ara has been in the works by Motorola for some time, but this new collaboration will take the concept closer to reality.

The Terracotta Army was armed to kill

With their clay hands, they might have struggled operating them, but the famous Chinese Terracotta Army boasted some seriously cutting-edge weapons. In fact, having reconstructed arrows based on those from 2,200 years ago and using an original crossbow, historians have shown it could have taken down an enemy in one shot, indicating technology well ahead of the time. The Terracotta Army comprises over 8,000 unique statues including archers, cavalrymen, entertainers, administrators and more who were built to care for Emperor Qin Shi Huang in the afterlife.

London Underground will heat homes

Heralding the start of a number of initiatives to 'green up' London, the waste heat generated in the city's Tube grid is about to be put to good use, warming more than 500 homes above the metro system. The heat will be fed through a network of pipes to a combined heat and power energy centre in Islington, already redistributing the heat that arises from making electricity. If this pioneering project – the first of its kind in Europe – proves successful, similar schemes could be rolled out across London in the coming years.

Photon cameras can shoot in the dark

Electronics engineers from MIT have developed a special camera which can gauge depth and capture images in very low light. It works on similar principles to existing lidar technology, which fires a laser at barely visible or underground objects and then uses the deflected photons as markers to calculate distance and construct an image. What's so innovative about this new camera is its speed and accuracy. This is because the system includes a clever algorithm that uses statistics to squeeze more information out of every single detected photon, as well as filtering out false readings.

Climbing mountains just got a whole lot easier

A group of US winter sports enthusiasts have invented a faster and more exhilarating way to get up a slope known as 'wind mountaineering'. This involves a parachute-like sail – 18 square metres (194 square feet) across – and a special harness with cord controls for steering. Called the UpSki, at the time of writing it was looking to secure $11,200 of funding on Kickstarter to upscale production.

Crocodilians use lures to hunt

When your species has been around for well over 200 million years, you're bound to have picked up a few tricks to survive. New research has emerged showing two crocodilian species – American alligators and mugger crocodiles – position sticks and twigs on their snouts in order to lure birds in for the kill. What's even more impressive is that the prehistoric predators seem to use this technique most frequently in the spring, when birds are building their nests. It is the first ever demonstration of reptiles using tools and one of very few animals known to use objects as hunting lures, indicating crocodilians are even more cunning than we previously thought.

Mushrooms can make their own weather

They might not be the world's most extravagant organisms, often growing on a rotting log hidden in the shadows of a woodland, but new research has shown that fungi have a special superpower: they can alter the climate. Using a combination of high-speed cameras and mathematical models, new evidence has revealed how oyster and shiitake mushrooms emit water vapour prior to releasing their spores. The vapour cools the air immediately around them, generating tiny wind currents that are used to carry the spores away, dramatically increasing the chances of success for the tiny reproductive cells. Researchers believe that all fungi could use this clever mechanism, which goes against the previous assumption that their spores' fate was wholly down to local winds.

Male and female brains are wired differently

It's been theorised for many years that male and female brains work in different ways and research by the University of Pennsylvania suggests there's some truth to this. 949 volunteers (aged 8-22) took part in the study and underwent diffusion tensor imaging (DTI) to create maps, or 'connectomes', of the fibre pathways that make up the mind. The main difference in the average brain was where neural connections were most prolific: in women, this was across the right and left hemispheres, while male brains were more connected in single hemispheres, firing front to back. The researchers believe these variations could explain why gender seems to have such a big impact on our cognitive and social abilities, though others argue studies like this are too simplistic.

Blue light offers a boost like coffee

If you're looking for a pick-me-up, you might want to hang fire on ordering that double espresso, because a new study has found that blue light can have the same boost without the negative effects of caffeine. In fact, the Mid Sweden University researchers noted that in some cases blue light was more effective for heightening brain function. This adds to a growing body of research that indicates blue light has a range of applications in the medical world, including pain therapy and firing up regions of the brain in blind people.

HOW IT WORKS PRESENTS

BRIGHT INNOVATIONS 2014

The wearable tech revolution

A new era of space exploration launches

Self-driving cars take to the roads

The next generation of touchscreens arrives

It's set to be a bumper year for innovation, with a host of scientific and technological breakthroughs charging over the horizon

Despite the legacy of a global financial crisis still taking its toll, innovation in science and technology continues unabated. This insatiable hunger to advance human civilisation is helping make all our lives easier day to day, more informed and generally more exciting, promising a brighter, more amazing tomorrow.

From projects further expanding our understanding of the cosmos, through to others developing radically advanced forms of transport, new-and-improved medical tech and a series of awesome gadgets rewriting how we interact with one another as well as the world around us, our spirit of invention is stronger than ever.

In this feature, we select a mix from all these fields to keep your eye on, as well as asking experts from respected institutions which innovations they're most looking forward to in the coming 12 months and beyond.

How we scored

We picked our top 2014 innovations based on three core criteria: how novel the technology/techniques are; how useful they are for everyday life; and their scope to develop further in the future.

Originality
Usefulness
Future potential

Smartglasses: a new outlook

Technology like Google Glass promises to change our perception of the world in many new ways

Arguably the most exciting innovation in personal tech in 2014 is going to be the wildly anticipated Google Glass. A headset that specialises in supplementing a user's vision with additional information and options, it has been in a testing programme since April 2013 and is finally set to go on sale to the public in the next year. While Google Glass is essentially just a wearable Android-powered computer system built into a pair of sleek frames, it's one of several products ushering in a new age of augmented reality, with our standard view of the world about to evolve (see 'Augmented reality' boxout for more information). As well as allowing users to access information about their surroundings, Google Glass also acts as a video recorder, camera, mobile phone and computer all in one, with a variety of commands – by voice or touchpad – allowing you to take photos, make calls, browse the internet or even record your daily experiences completely hands-free. Right now, Google Glass and similar smartglass systems like GlassUp are very much in the early adoption stage, but with more and more going on sale in 2014 this is the start of a revolution.

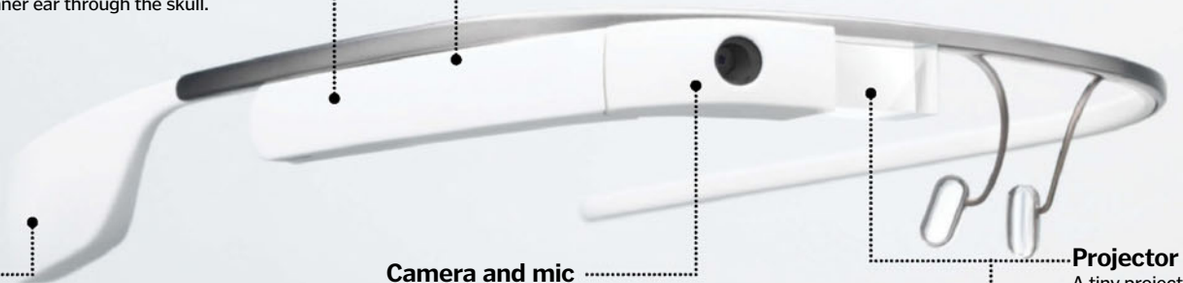
Augmented reality

Once considered a gimmick, going forward augmented reality tech looks set to become an integral part of our everyday lives, with a variety of gadgets and electronics offering to bring us enhanced levels of information. For example, by wearing a pair of smartglasses – such as Google Glass – getting lost will become a thing of the past, with live GPS map overlays brought before your eyes in an instant. Equally, while shopping, augmented reality information systems would enable a user to create a virtual shopping list or draw up recipes and information about products while you browse. Even when playing sports, such as a round of golf, augmented reality information will be able to enhance the experience, with real-time hole distances, course data and wind speed/direction all being relayed prior to taking a shot. The potential applications are quite simply endless.

Google intends to revolutionise the field of augmented reality with Glass

Anatomy of Google Glass

Check out the key components of this advanced head-mounted display



Bone transducer
Rather than forcing the user to constantly wear a pair of earphones, Google Glass is installed with a bone conduction transducer, which sends audio directly to the inner ear through the skull.

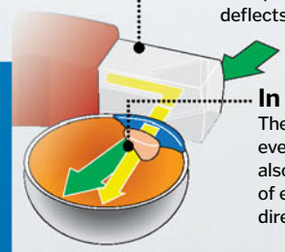
Computing system
The Google Glass headset operates off an OMAP 4430 system-on-a-chip dual-core CPU, which is partnered with 1GB of RAM and a 16GB solid-state hard drive. Glass runs a modified Android operating system.

Augmented view
The result of the prism and projector is a view that combines normal vision with a translucent overlay image, supplying instant information like directions.

Battery
The power for Google Glass comes courtesy of a lithium polymer battery array at the rear of the headset. This is rated at 2.1Wh and can keep the device running for up to 12 hours.

Camera and mic
A front-mounted camera can record video at 720p and take photos with a 5MP sensor. An adjacent microphone enables the wearer to issue voice commands.

Projector
A tiny projector sends images into a semi-transparent prism which deflects them into the eye.



In the eye
The glasses let you see everything ahead, but also superimpose a pane of extra information directly onto the retina.

"I am really excited by wearable computing. From a museum perspective, emerging products like Google Glass offer the potential to transform the museum experience, removing the clutter of in-museum screens while giving visitors access to targeted, personal interpretive content about our objects. Such technology will completely break down the barriers between our objects and the stories we tell"

Dave Patten, head of New Media, Science Museum, London

Next-gen screens are here

A host of innovative display tech is rolling out, offering new ways to interact and great scope for hardware designers

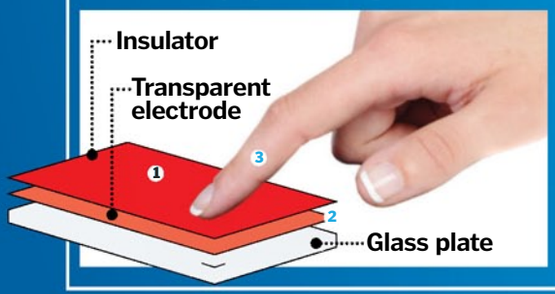
In 2014 touchscreens will no longer be merely small, rectangular panels embedded into two-tiers of mobile electronic devices, but instead flexible, transparent and widely integrated screens found everywhere, from walls to tables and even food menus.

Indeed, in 2013 Taiwan's Polytron Technologies already managed to produce a completely transparent smartphone, equipped with a fully functioning microSD card slot, battery, speakers and even a microphone. Moving into 2014, that level of technology is set to explode with many manufacturers now producing their own see-through panels. Some companies are producing screens that are curved and others that can bend.

Another touchscreen tech set to step up over the next year is haptic feedback. A current pioneering company in this emerging field is Senseg, which has created its Tixel feedback system. This system allows a sophisticated sensation of touch to be created via the use of Coulomb's force, the principle of attraction between electrical charges. Tixel works by passing an ultra-low electrical current into an insulated electrode where a proprietary charge driver then creates a small attractive force to the nearby finger. By modulating the level of attractive force, the Tixel can generate a variety of sensations. This has many exciting potential applications, such as in creative arts programs, videogames or even just general interaction with the computer; it would be a lot easier to judge browsing speed and distance if your finger received constant feedback while scrolling through a screen, for example.

How haptic touch works

Inside the display that changes how it feels



❶ Insulation layer
The finger feedback is delivered by an insulated electrode layer, which is placed on top of the touchscreen's glass panel.

❷ Electrical feedback
When the user touches the screen, a variety of sensations are generated using electrovibration, modifying the friction of the touch surface layer.

❸ Textures and resistance
The finger interprets the varying electrovibrations as specific textures. If the user is moving their finger across the screen, then depending on context, a level of natural resistance can also be generated.

A crowdsourced future

Today, one of the biggest boons to scientific and technological innovation is the emergence of crowdsourcing, a process in which pioneering new work is funded by the general public upfront rather than by private institutions or governments. This puts the power to create amazing new technologies and expand the limits of our knowledge firmly in the hands of the people, with vested interests and – in many cases – financial support no longer barriers to advancement. History has shown that much innovation has been stymied due to the inability to acquire financial backing for projects in the early stages, but by democratising the process of innovation, people can now learn first-hand what could be possible with their support. Further, with crowdsourcing platforms, anybody with a pioneering concept can quickly acquire an audience with the general public and share their cutting-edge work through open platforms such as Kickstarter (**www.kickstarter.com**). Simply put, crowdsourcing is the ultimate catalyst for innovation and is showing no signs of stopping in the near future.

Learning more from nature

The blossoming field of biomimicry offers great potential for all sectors

Biomimicry is a growing movement whereby the anatomy and behaviour of nature are studied, understood and then emulated to improve our own systems. Those 'systems' can be incredibly varied, ranging from organisational structures – such as how a call centre is tiered and operated – right through to how new materials are fabricated and energy is harnessed (such as studying a leaf's structure to create a more efficient solar cell for absorbing sunlight).

While this concept may sound obvious, and it has indeed been dipped into every now and then historically (if sometimes unwittingly), as a movement it is only now really taking off. Indeed, 2014 is set to see the Biomimicry World Summit hit San Diego in California, exploring everything from biomimicry business models, through to research and development initiatives and product design case studies.

Biomimicry has already produced new natural, eco-friendly buildings, unique technology (like adhesives based on gecko feet) and scientific techniques such as biomorphic mineralisation (a process that produces materials with structures that resemble bio-structures), so by sharing our pooled knowledge, there really is no knowing how far biomimicry can go in the future.

New era of space travel

NASA's Orion spacecraft will let us venture farther than ever before

With government-funded space exploration facing ever-tighter budgets, versatility and cost-effectiveness is key to any mission. That's why NASA's latest reusable spacecraft for manned space exploration – the Orion MPCV (Multi-Purpose Crew Vehicle) – specialises in being incredibly adaptable.

Designed as NASA's primary vehicle moving forward for taking astronauts beyond low Earth orbit (LEO), Orion is suited to conducting regular in-space operations such as rendezvous, docking and spacewalks, all the while also being capable of acting as a payload bearer; indeed, Orion can act as a backup spacecraft for deliveries to the ISS. Even more exciting looking ahead, it is also being developed for manned missions to the Moon, to local asteroids and even potentially as far as Mars. Test flights for Orion begin over the next year, a process that will see it launched 4,830 kilometres (3,000 miles) into space and pushed to speeds in excess of 32,190 kilometres (20,000 miles) per hour.

Self-driving cars rev up

A host of automotive innovations will transform how we drive our cars – or not drive them, as the case may be...

From autonomous cars navigating complex city streets to the proliferation of intelligent computing systems turning the car from a simple A-to-B into a mobile communications hub, 2014 is going to be a big year for the humble car.

Leading this charge is the Mercedes Benz S-Class, as its Intelligent Drive system is laying down a roadmap for others to follow. A holistic electronic support system for the vehicle's driver, Intelligent Drive includes an active parking assistant, a collision prevention system, automatic pedestrian detection and pre-assist braking system as well as a 360-degree camera with night vision.

Volvo is also taking car autonomy to another level this year, with backing from the Swedish government. The Drive Me project taking place in Gothenburg, Sweden, gets underway in 2014 with tech development and customer research. Eventually the aim is to get 100 self-driving cars taking to 50 kilometres (31 miles) of city roads to fully explore the potential of cars that can drive themselves, such as how they are received by other drivers.

Stian Westlake, executive director of Policy & Research, Nesta

"The UK, Sweden and Japan are setting up big public driverless car trials. Self-driving cars are safer than the human-driven sort (no human error) and faster (less stop-start driving). What's more, they can conveniently park themselves and pick you up. So their rise will affect not just the car industry but how we commute, how we shop and how we plan our towns"

Wearable tech is perfect fit

The days of losing your valuable devices could be numbered...

Watches, clothing and many other accessories we wear day to day are getting new roles. Smartwatches offer many of a phone's functions but keep you up to date when your hands are busy. While devices like the Sesame Ring (made by MIT students) mean we can pay for things like public transport without any cash or cards.

Mosquitoes beat their own disease

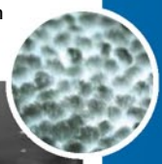
Can genetically modified bugs wipe out dengue fever for good?

Dengue fever can lead to hallucinations and even death. It is one of the world's most growing diseases, with incidents dramatically increasing since the Sixties. But a new remedy sees scientists using the power of genetic engineering to turn the fever's main ally – the mosquito – into its worst enemy, by modifying male mosquitoes to carry an antibiotic which prevents their offspring from surviving to adulthood. They are released into the wild and the mosquito population falls, reducing the amount of potential carriers. After successful trials, this year the technique could be taken up on a wider scale.

LED carpets light the way

LED-woven carpets could change the way we navigate public buildings

Carpets might not sound like the most obvious springboard for innovative technology, but Philips and Desso are proving otherwise. Their new product combines their expertise – electronics and carpeting, respectively – to create a new breed of flooring able to transmit information – like directions to safety exits – or more aesthetically just to transform a room's ambience for different scenarios. This light-transmissive carpet will be launching in the coming year so it could be guiding you to your hotel room or around airports and cinemas sooner than you think.



Baldness cure is in sight

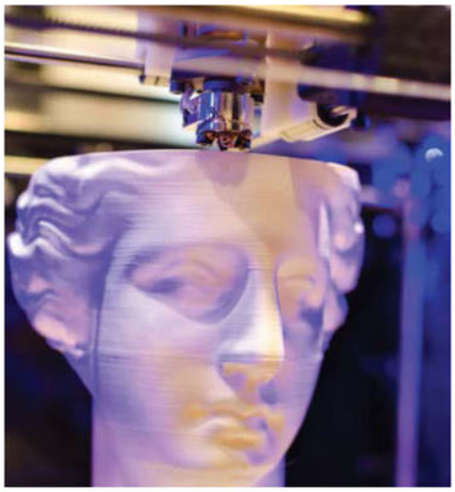
Can scientists use our own biology to reverse the effects of hair loss?

Wouldn't it be cool if, as we grew older, we kept the flowing locks of our youth? Well, thanks to scientists at the University of Pennsylvania, that dream could soon become reality, as they have discovered an enzyme that prevents hair follicles from maturing. The team found this by closely analysing the scalps of balding men where they found levels of the enzyme three times higher in balding areas than in areas with hair. Provided that the enzyme tests prove successful, clinical trials should begin later this year.

3D printing goes mainstream

3D printing power to the masses

From NASA printing food for astronauts to eat in space, through to large construction companies building flat-pack houses en masse and on to medical institutions printing organs for critically ill patients, 3D printing is already radically transforming every field that it touches. The fact that 3D printers and tools have entered high-street shops says much to the technology's growth and uptake. 2014 promises to be the year when 3D printing finally goes from the lab to the home with the scope to create replacement parts for household appliances or just cool models. The only question is, what will you print first?



Memory devices set to go large

Memristor drives are about to revolutionise the way we store data

The memristor is a growing type of RAM technology that boasts DRAM-like high speeds and greater than NAND storage density – both qualities that are going to become incredibly useful as DRAM and NAND memory tech scaling hits a limit in a few years' time. As such, work is currently underway to produce memristor drives and, starting in 2014, major IT companies such as HP are earmarking huge 100-terabyte drives by 2018 – and by 2020 even petabyte drives. What makes memristors unique is that when a current passing through one is stopped, it retains the resistance it had and, when the charge resumes, that resistance level doesn't change.

Apple builds the mobile future

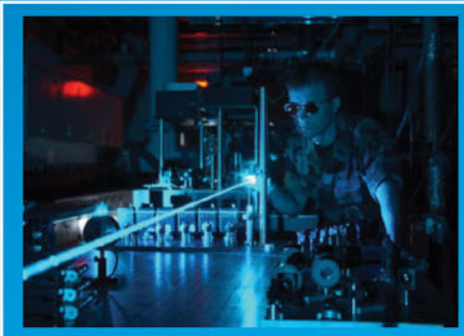
Apple promises to unleash a slew of innovative products over the next year

No matter where you stand with Apple, you can't argue with its pedigree in releasing innovative products, as it consistently pushes the boundaries of what is thought possible. And 2014 will be no different, with Apple set to unveil the iPhone 6, the 6th-generation iPad and even the long-awaited iWatch. The fact that Apple has just been granted a patent for a light-field camera – where the focus can be reallocated *after* the shot is taken – indicates the technology could soon be making its way to a handheld device near you, revolutionising the mobile camera market. Seriously, if a light-field camera is fitted to the iPhone 6, a disturbance in the force will be felt.

Extinction for extinction?

Can improving genome tech make 2014 the year of de-extinction?

Jurassic Park is one of Hollywood's most famous movies, taking viewers on an adventure romp among resurrected dinosaurs. While it sounds far-fetched, just this year the Australian Lazarus Project has done just what John Hammond does in the film, bringing an extinct species back from the dead. Admittedly, that species was the gastric-brooding frog and not a triceratops, but the feat remains equally amazing. That frog species had been extinct since 1983, but the Lazarus Project was able to collect DNA from a frozen frog's tissue and used a process known as somatic cell nuclear transfer to bring it back. The Lazarus Project's team hope they can use this as a stepping stone to reanimate other extinct species in 2014 and beyond.



Laser cannon enters service

Sci-fi-style solid-state laser weapon to be fitted to more battleships

Following the successful introduction of the Laser Weapon System (LaWS) by Raytheon Missile Systems to the US Navy's USS Ponce warship, capable of firing high-powered beams of light into aircraft, vessels and structures at long range, laser weaponry in general is set to see widespread uptake throughout the coming year. Indeed, with the LaWS specialising in what is referred to as 'graduated lethality' – essentially the ability to tailor its power according to circumstances, its flexibility and low cost of operation (each shot reportedly costs under $1) it is turning heads and could soon be partnered with more conventional missile systems.

Architects turn to the sea

A floating terminal for the world's largest cruise ships could inspire a new wave of marine architecture

The minds over at Dutch Docklands have designed a floating cruise terminal, a 300,000-square-metre (3.3-million-square-foot) sea base that promises to offer the planet's largest cruise ships a safe port many miles from land. The biggest issue in terms of cruise tourism is the damaging effects that the ships have on the environment, so the concept of moving their berths to the middle of the ocean seems like a smart idea, as well as freeing up space on land. In charge of the Floating Cruise Terminal build is Waterstudio, a Dutch architectural company which specialises in sustainable, aquatic construction projects.

Building on the ocean opens up vast opportunities for future architecture

"Applications of 3D printing are rapidly going from proof of concept to real-world impact. It will be fascinating to see how this affects the manufacturing industry as intricate part manufacture becomes cheap and automatable and transport costs become the key factor. But the USA's struggle to restrict sharing of 3D gun files shows what a challenge it will be to regulate this technology"

Dr Seán Ó hÉigeartaigh, Programme on the Impacts of Future Technology, Oxford Martin

Exploring Mars in new ways

Current missions to the Red Planet are set to uncover some of its biggest mysteries, while a new type of surface vehicle has legs

Not discounting the valuable ongoing work of the Mars Curiosity rover, which will continue to operate throughout 2014, another mission to the Red Planet is set to grab a lot of the news headlines over the next year: the Mars Atmosphere and Volatile EvolutioN (MAVEN) probe. Part of NASA's wider Mars Scout programme, MAVEN launched in November 2013 and, when it arrives at Mars in September 2014, it is set to do something never achieved before: to determine exactly how the loss of volatile gases from its atmosphere has impacted the planet.

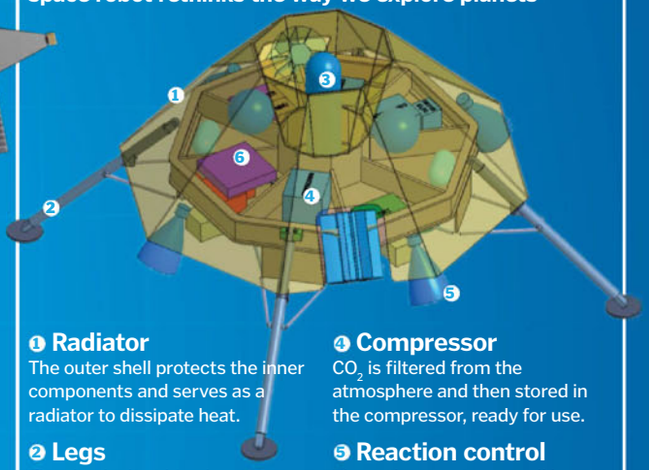
Why is this so important? Well, Mars's lack of a proper atmosphere is believed to be a key reason as to why there is no liquid water on the planet. As such, by gathering data on the state of the upper atmosphere, ionosphere and its interactions with solar winds, as well as what the current rates of escape are for its gases and ions, scientists will be able to infer how its climate changed and will continue to evolve in the future. This information can then be used as a benchmark when studying other planets – particularly in terms of habitability.

If this wasn't enough MAVEN will be joined by India's Mars Orbiter Mission (MOM), which will also study the Martian atmosphere. While down here on Earth research is ongoing into a novel way to get around Mars's surface – by hopping rather than 'roving'. This will let us simply leap over features like hills and boulder fields and open up previously off-bounds areas.

MAVEN will be the next part of NASA's in-depth research into the Red Planet

Inside the Mars hopper

Developed by Astrium and Leicester University, this space robot rethinks the way we explore planets



1 Radiator
The outer shell protects the inner components and serves as a radiator to dissipate heat.

2 Legs
The shock-absorbing legs use electromagnetic tech not fazed by temperature or vacuum.

3 RTG
It uses a radioactive isotope to rapidly heat CO_2, which is expelled to provide its jumping power.

4 Compressor
CO_2 is filtered from the atmosphere and then stored in the compressor, ready for use.

5 Reaction control
These thrusters use small bursts of cool CO_2 to make fine adjustments during descents.

6 Hazard avoidance
On-board equipment helps detect potential hazards and reacts to alter direction, speed etc.

Solar-powered flight takes off

Powered by the Sun, the Solar Impulse is set to soar into the record books

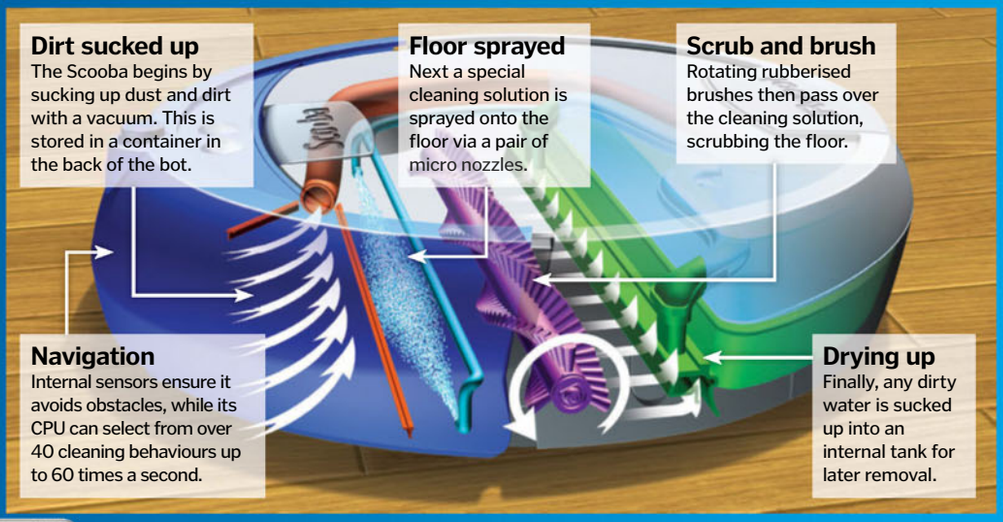
So far solar power, despite seeing widespread adoption in the passive energy industry, has not been transferred successfully to more active and demanding roles, like vehicles. The Solar Impulse, however, is looking to buck this trend, with the solar-only aircraft looking to build on its previous achievement of flying non-stop across the United States, by flying all the way around the world. According to Alexandra Gindroz, who works for the Solar Impulse project, its success will be based on more than just the miles it covers: [The Solar Impulse] will also motivate everyone to implement the necessary measures to reduce our dependence on fossil fuels." The innovation doesn't stop at the solar-powered motor, either, including a "structure made of carbon-fibre sheets which are three times lighter than paper", and "a man-machine interface to inform the pilot of the aircraft's bank angle through a vibration device". The future is looking bright for solar power, indeed.

Helper bots clean up

With domestic robot uptake on the rise, 2014 promises to deliver more helpers to take the stress out of the chores

For those who hate housework, did you know there are robots available to vacuum your floor, clean your windows and mow your lawn? Well, if you didn't now then by the end of 2014 you will, with the number of robotic assistants ever growing. iRobot has been creating military and industrial robots since the Nineties, is currently leading the charge, with the Roomba, Scooba, Looj and Braava units helping with their owners' chores, from cleaning kitchens to swimming pools. And what's more, they are doing it much more efficiently than us.

The Scooba, for example, is a robot floor cleaner that can not only automatically navigate around a room thanks to its embedded sensors but also cleans with a four-stage wash (see annotation below). With that kind of elbow grease robots beat humans hands down! Many of these robots, like the Samsung NaviBot CornerClean vacuum cleaner, also have the ability to take themselves back to their charging dock when power is low and can recognise virtual barriers to stop them passing into unwanted areas.



Domestic robots are moving beyond the house, cleaning our pools, mowing the lawn and more

Professor Hiroshi Ishii, associate director, MIT Media Lab

"2014 will be the year of the leap beyond intangible pixels locked behind the flat touchscreen. inFORM is the instance of such a quantum leap invented by the Tangible Media Group of MIT Media Lab. inFORM is the dynamic 3D shape-shifting display to make online digital information tangible and transformable"

Phones and tablets merge

Is it a phone? Is it a tablet? No, the time of the hybrid phablet is here

The phablet, a new hybrid mobile device gaining ever-more popularity worldwide, promises to go truly mainstream in 2014. Providing the communication features of the smartphone in addition to the big-screen features of a tablet, the phablet combines the best of both worlds, offering users a one-device solution for their daily gadget needs. Devices like the Samsung Galaxy Note 3 are leading the charge in this phablet revolution, however with rumours circulating that smartphone giant Apple is to release its own phablet shortly, we expect to see a wide range of makes and models hitting the consumer market. Watch this space.

Take a holiday in space

Space tourism finally gets off the ground in the coming year

After years of high-level research, construction and testing, Richard Branson finally gets to make history in 2014 with the first flight of his phenomenally exciting Virgin Galactic project, the first commercial space tourism company. In terms of innovation the SpaceShipTwo is right up there, with the project seeing the world's first spaceport, the first viable commercial spaceship for passenger transport and the safest commercial launch vehicle all built. The news that Virgin Galactic has just signed a deal with US broadcaster NBCUniversal to provide an exclusive televised three-hour launch special has done nothing to quell anticipation.

Space rocks prospected

2014 will see the asteroid mining industry step things up a gear

Earth has a finite quantity of minerals and the rarest of those fetch serious money as a result. But with near-Earth asteroids loaded with rare minerals such as platinum and cobalt in vast quantities, by tapping into them with space-based mining operations, the mineral market could be turned on its head. Planetary Resources Inc, an asteroid mining company set up in 2010, clearly realises this and from 2014 is to begin the process of identifying potential targets with space telescopes. Next the company will run a series of missions in which they will fly by and 'prospect' select asteroids before finally running the more challenging recovery process.

RoboThespian: not quite the life of the party yet, but it's getting there

Robots get more interactive

Discover why cyborgs have never been more sociable

While we are still quite a way from automated, walking and talking robot companions, in terms of interactive robot information points, we are much closer to widespread adoption than you think, with companies like Engineered Arts producing multilingual, expressive bots that interact in increasingly sophisticated ways.

Currently, RoboThespian is the most advanced of these machines, with the humanoid robot – in its third generation – capable of fluidly delivering messages, gestures and complicated routines to the public. It also excels as a learning tool, with children capable of taking control of its movements, speech and expressions via an interactive touchscreen interface. Obviously, even RoboThespian has its limits for now, but with development progressing at its current rate, it's not hard to imagine machines like this soon coming to our aid in the public spaces of tomorrow.

Virtual currency evolves eShopping

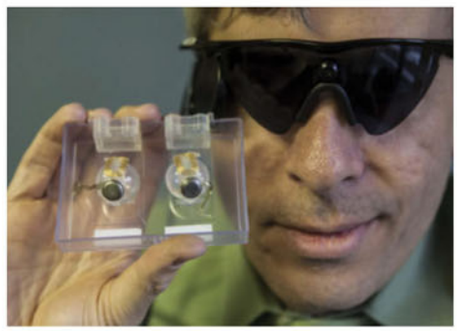
The Bitcoin currency is ready to revolutionise online trade

Right now paying for products on the internet is done in one of the many real-world currencies, with physical money crossing over into virtual funds, being traded for goods or services, before being transformed back into physical cash. That system is now being challenged by a virtual one – Bitcoin – which is only going to get bigger in 2014. Bitcoin is a virtual currency system that uses peer-to-peer technology to operate its payment network, with no bank or governmental authority managing transactions. The result of this is that Bitcoin is open source and features a public design that arguably offers greater flexibility than established systems, though security concerns have already been raised.

New prostheses help regain sight

How special chips could transform the lives of the visually impaired

One of the most exciting developments in prosthetic science in recent years has been the epiretinal prosthesis – in-eye implants that are placed on top of the retina that, when partnered with a camera mounted on glasses, help the visually impaired regain sight. This year is set to see systems such as the Argus II Retinal Prosthesis System by Second Sight become more widely available, as the technology becomes more accessible. But other prosthetics companies, like Monash Vision Group, are looking to hone the technology even further in 2014; they are aiming to skip out the retinal stage altogether – helping to conserve sight in those with already limited vision – developing a direct link between the camera and a chip implanted in the brain's visual cortex.



Lightning-quick internet

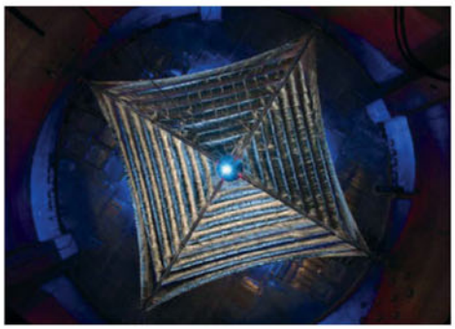
Forget radio waves – visible light is the future of wireless internet

Wi-Fi transmits data using radio wave frequencies, typically at 2.4 or 5.2-gigahertz bands. Unfortunately, this spectrum is limited and incredibly busy, restricting data density transmission and even causing interference between signals. That is why scientists have recently been exploring an alternative system to Wi-Fi. Referred to as Li-Fi, this new method of wireless data transfer uses the spectrum of visible light rather than that of radio waves, which not only is far larger (by 10,000 times to be precise) but also can deliver transmission speeds 250 times faster. Li-Fi works by switching tiny, micro-LED light bulbs on and off incredibly quickly to stream several lines of data in parallel, which are then decoded by specialist hardware.

Space propulsion turns to the Sun

How reinvented forms of locomotion will help us explore the cosmos

Some of the best innovations are tweaks on former technology, with core concepts being revisited and tweaked. A great example is NASA's Solar Sail propulsion system, an ultra-thin sail that can be attached to spacecraft and used, just like the ocean-going vessels of old, to cover great distances. There is no wind in space, but the Solar Sail ditches that in favour of pressure waves generated by sunlight. The 'Sunjammer' programme is set to make great strides in 2014, with an anticipated launch date in 2015.



Security devices to use our biology

A new breed of bio-security gadget keeps its finger firmly on the pulse

Biometrics is nothing new, with high-level institutions using bio-security devices – such as fingerprint scanners – for decades. However, following Apple's incorporation of Touch ID (using your fingerprint as the passcode) into the iPhone 5s, biometrics is becoming more everyday. One such gadget is the Nymi wristband, which uses a person's unique cardiac rhythm to authenticate their identity to unlock everything from cars to smartphones. Considering that we use mobile devices to share confidential information more than ever before, personal bio-security is a bright new market that's bound to grow and grow.

DIY health checks made easy

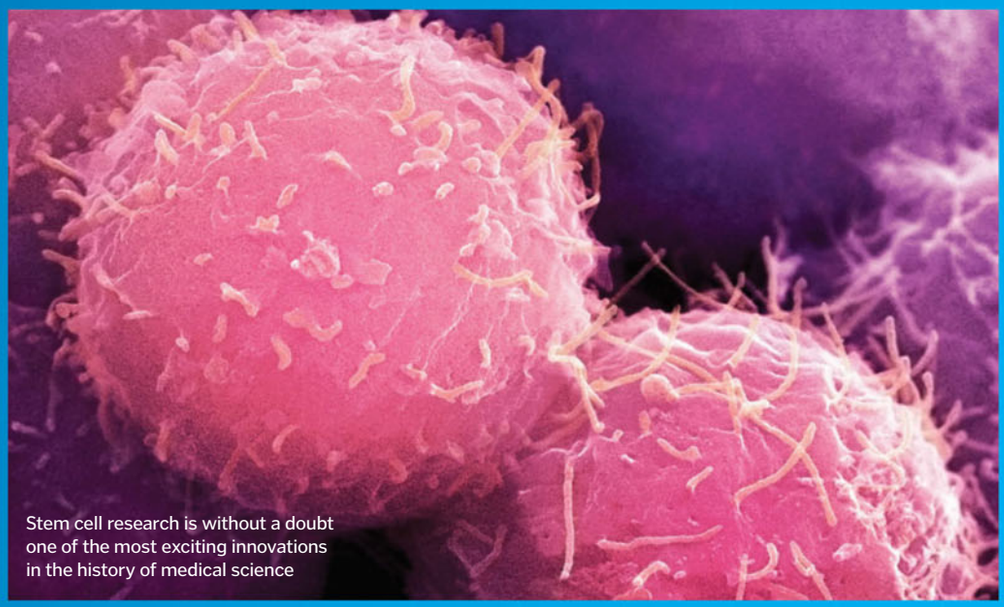
Sending your smartphone to med school in 2014

Checking our body's vital statistics, without the hassle of booking doctor appointments or sitting in waiting rooms, is about to get a lot easier, thanks to the introduction of devices such as the Scanadu Scout. This small mobile scanner enables us to perform a basic physical examination by placing it to our forehead, with the information gathered then easily read off a connected smartphone. Indeed, with a series of similar products due to hit the market in 2014, a movement toward more constant and accessible personal health checks seems inevitable, with everything from immediate symptoms to long-term health trends readable so you feel much more informed about your body. This tech can also help us understand what makes us ill and keep tabs on our recovery post-illness.

Stem cell potential explored

Taking great strides into the promising field of stem cell therapy, this year is a milestone for medical treatment

Stem cell therapy could radically change the way we treat diseases. By using the natural regenerative capabilities of these cells, scientists hope to find methods of repairing damaged or diseased cells and tissues, effectively leading to treatments for diseases like cancer, diabetes and neurological conditions like Alzheimer's. So far, research has been limited to animal and laboratory trials, but human trials are finally set to take place over the coming year, bringing the tantalising prospect of a disease-free future that little bit closer. For example, researchers at King's College London are due to begin clinical trials involving the ability of cardiac stem cells to prevent and treat heart failure.



Stem cell research is without a doubt one of the most exciting innovations in the history of medical science

"Wearable technology will become a mainstream reality in 2014, as Google Glass and Apple's much-awaited smartwatch join the ranks of wearable smart and quantified-self devices. The success or failure of wearable technologies will depend on one thing: user experience. The focus from device manufacturers will be on the 'integrated self' and generating the desire to wear technology"

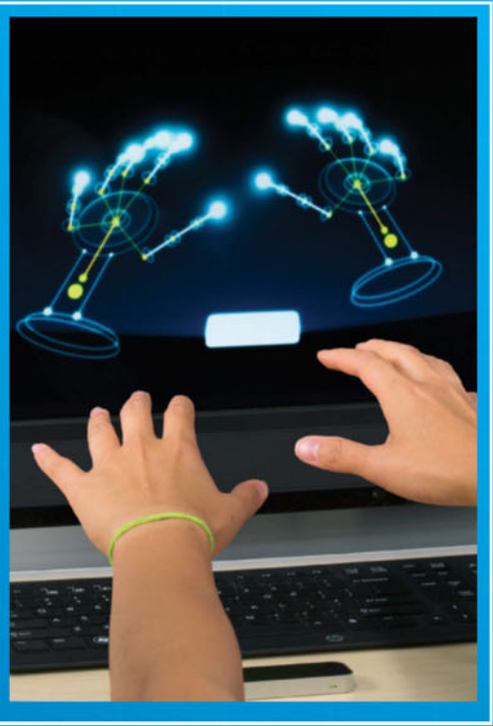
Steve Haigh, senior software engineer, Cambridge Consultants

Touch-free control

Those who have had enough of mice and controllers, raise your hand...

The Leap Motion controller, with a tiny, tapered rectangular box, plugs into your computer and recognises all manner of pointing, waving, grabbing and swiping manoeuvres. With Leap Motion, users can now browse webpages or flip through photos with a simple flick, draw in creative apps directly with the fingertip or even navigate 3D maps by hand, pointing, rotating and zooming with ease.

Of course, right now systems like Leap Motion and the Myo gesture control armband – a futuristic device that measures movements based on muscle activity – are very much complementary to existing tech such as mice and keyboards. But as more and more of these products are released, it's really not that hard to envision a world where gesture control is the only way to interact with electronic devices and perhaps even beyond, such as buildings and vehicles.



China's biggest skyscraper opens

When completed in 2014, the Shanghai Tower will be the world's second-tallest building

Building innovation continues at pace in 2014 with the Shanghai Tower becoming not just China's tallest building but also one of its most advanced and environmentally friendly. Sustainability is at the heart of its design, with the tower built with a windload-reducing glass façade that reduces the amount of steel needed for its build by 25 per cent, a vertical-axis wind turbine array that generates up to 350,000 kilowatt-hours of its electricity needs per year, and a heating and cooling system that uses geothermal energy sources. Combined, these features grant the Shanghai Tower an incredibly low carbon footprint, arguably making it a worthy blueprint for all future skyscraper construction.

Efficient construction
The building is divided into nine zones marked by belt trusses, both speeding up and lowering the cost of construction.

Aerodynamic shape
The Shanghai Tower's tapered, asymmetrical form and rounded corners have been designed to mitigate typhoon-level winds.

Record breaker
When completed the Shanghai Tower will be China's tallest building, topping out at 632m (2,073ft). It will only be beaten by the Burj Khalifa in Dubai.

Foundations
1,079 concrete and steel bore piles secure the skyscraper 6m (18ft) beneath the ground.

Green engineering
By maximising natural light and incorporating wind turbines and green spaces, the skyscraper is expected to save some 34,000 tons of carbon per year.

The future of innovation...

Let there be no mistake, we are living in exciting times in terms of science and technology with world-changing breakthroughs not only consigned to 2014 but emerging all the time.

So what should we expect going forward over the next ten years? While specifics are obviously beyond our reach, trends can be predicted with a decent degree of accuracy. Biotechnology, for example, is a burgeoning field right now that's likely to mature tremendously over the next decade, bringing life-changing advances to prostheses and bionics. Likewise, how we interact with the world will also continue to evolve, with new devices such as smartglasses and touchless interfaces offering an ever-more detailed and seamless augmented reality experience. And, of course, there's also the non-stop march of the invisible field of nanotech, which will continue to revolutionise technology and devices at the smallest of scales.

Regardless of the field though, it's safe to say that scientific and technological innovation will remain unchecked throughout this decade and beyond and, in these uncertain times, that is something we can all be thankful for.

SURVIVING THE ANTARCTIC

Why the coldest continent on the planet is a surprising hotspot for both scientific research and wildlife...

Antarctica is Earth's coldest, driest and windiest continent, but many resilient life forms have adapted to survive the harsh environment. Among them is Earth's tallest penguin, the largest mammal and the Antarctic icefish – the only bony animal with transparent blood.

The coldest temperature ever officially recorded was on a high snow plateau in Antarctica, at an altitude of around 3.5 kilometres (two miles) – over twice the height of Britain's biggest peak, Ben Nevis. Around 99 per cent of the land surface is covered with ice and air temperatures can be so extremely cold that atmospheric water vapour freezes to form ice crystals. These crystals catch the sunlight as they fall, and sparkle like diamonds, hence why they've gained the nickname 'diamond dust'.

High altitude renders Antarctica considerably colder than its northern polar counterpart, the Arctic. Air temperature falls by approximately 6.5 degrees Celsius (11.7 degrees Fahrenheit) with each kilometre (0.6-mile) rise in elevation. Antarctica is also Earth's fifth-largest continent, and the vast interior receives little heat from the ocean, which is warmer than the ice.

If the climate wasn't extreme enough, Antarctica experiences 24-hour darkness for a couple of months in midwinter. The continent straddles the South Pole and in late June – southern winter – the pole is tilted away from the Sun. Even in summer, most incoming sunlight is absorbed by Earth's atmosphere before it can warm the ground.

Still, unlikely as it may seem, animals and plants survive in Antarctica's ice-free regions. In the windswept McMurdo Dry Valleys, the continent's biggest ice-free area, fungi and algae manage to thrive inside the insulated blanket of sandstone and granite rocks.

The continental coast and Antarctic Peninsula are host to only two flowering plant species. The biggest creatures include mites and primitive insects called springtails. Just one to two millimetres (0.04-0.08 inches) long, they have natural antifreeze in their blood, and they feed on a variety of moss, lichens and other tiny plant life available to them.

5 TOP FACTS
JUST DESERTS

Antarctic
1 Antarctica is Earth's largest desert with a land area of 14mn km² (5.4mn mi²). The tiny amount of annual snowfall here is equivalent to rainfall in the Sahara Desert.

Sahara
2 Earth's biggest hot desert, Sahara covers around 9mn km² (3.5mn mi²) in northern Africa. Around 20 per cent is sand dunes, which can be taller than the Eiffel Tower.

Arabian
3 Summer temperatures in the Arabian Desert can reach 54˚C (129˚F). It covers 2.3mn km² (900,000mi²) of the Arabian Peninsula, mainly in Saudi Arabia.

Gobi
4 The rocky Gobi Desert covers 1.3mn km² (500,000mi²) of Mongolia and China. Temperatures range between 45˚C (113˚F) and -40˚C (-40˚F) in a year.

Kalahari
5 The Kalahari basin has Earth's biggest diamond mines. This southern African desert covers over 900,000km² (350,000mi²) and almost 70 per cent of Botswana.

The biggest iceberg on record was the size of Jamaica. It calved off the Ross Ice Shelf in 2000

The smallest icebergs are called growlers. Slightly bigger bergs are 'bergy bits' and the biggest are 'very large bergs'.

The resilient emperor penguin has made its home in Antarctica

In contrast, the Southern Ocean encircling Antarctica is among Earth's most biologically rich oceans. The melting of sea ice in the spring draws nutrient-rich waters from the depths, feeding phytoplankton. Incredibly, a litre (0.3 gallons) of water can contain more than a million of these tiny life forms.

The phytoplankton are eaten by krill, the powerhouse of Antarctica's ecosystem. These shrimp-like creatures can grow to six centimetres (2.4 inches) long and form swarms big enough to see from space. They are the food source for most Antarctic predators, including the blue whale – Earth's biggest animal. During the feeding season, a blue whale can consume 40 million krill on a daily basis! ▶

Antarctica's climate explained

Antarctica is Earth's largest desert, but is covered by kilometres of frozen water. Snowfall accumulates because it can't melt in the cold, but yearly snowfall equals less than 50 millimetres (two inches) of rain. Few clouds form in the dry air. All deserts receive less than 250 millimetres (ten inches) of annual rain.

It's also Earth's windiest continent. The ice reflects away 80 per cent of incoming sunlight, cooling the overlying air, which sinks. This heavy air gusts downhill at speeds exceeding 200 kilometres (124 miles) per hour. Summer temperatures rarely rise above freezing, even at the coast.

The continental interior is colder (around -20˚C/-4˚F in summer) because it's mountainous and farther from the ocean. Winter temperatures there plummet so low, they could freeze diesel.

Air temperatures have remained stable over Antarctica since the Fifties, except for the Antarctic Peninsula. This peninsula juts into the ocean and is among Earth's fastest-warming places.

Scientists in Antarctica have to cope with some extreme conditions

Tour of the frozen continent

1 Mount Vinson
Just over 1,000 climbers have scaled Mount Vinson in the Ellsworth Mountains, Antarctica's highest summit – fewer than have climbed Everest. The massif is 4,892m (16,050ft) above sea level. Despite 24-hour sunlight, the average summer temperature is -30°C (-22°F).

2 Halley VI
This British research station has hydraulic legs to 'climb' from the 1.2m (4ft) of snow that builds up annually. The station can be towed inland on giant skis fitted to the legs so it won't float off on an iceberg as the Halley ice shelf moves into the sea.

3 Lake Vostok
The icy, dark waters of Antarctica's biggest sub-glacial lake could be teeming with life, despite being buried 4km (2.5mi) beneath the ice for millions of years. In July 2013, scientists revealed that ice collected near the lake waters contained genetic material from 3,507 critters, including bacteria.

4 East Antarctic Ice Sheet

5 Transantarctic Mountains

6 South Pole

7 West Antarctic Ice Sheet

8 Ross Ice Shelf
The world's biggest ice shelf was the starting point for many expeditions, including Roald Amundsen's 1911 discovery of the South Pole. It extends 950km (600mi) deep into the continental interior. It covers over 472,000km² (182,000mi²) – an area bigger than Japan.

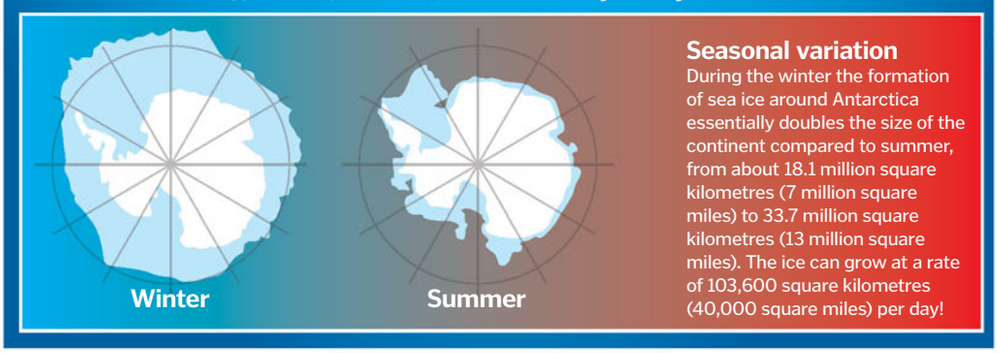
9 Larsen Ice Shelf

10 Weddell Sea

11 Pine Island Glacier

12 Antarctic Peninsula

13 McMurdo Dry Valleys



Seasonal variation
During the winter the formation of sea ice around Antarctica essentially doubles the size of the continent compared to summer, from about 18.1 million square kilometres (7 million square miles) to 33.7 million square kilometres (13 million square miles). The ice can grow at a rate of 103,600 square kilometres (40,000 square miles) per day!

"Fossilised pollen even shows that rainforests grew on the continent around 52 million years ago"

Most of the world's seals also live in Antarctic waters. These carnivorous mammals live, hunt and can even sleep underwater. Elephant seals also hold the record for having the biggest relative size difference between males and females of any mammal.

The most common birds in this frozen land are penguins, though of Antarctica's 17 species, only five breed on the continent itself. Emperor penguins – the world's tallest, largest penguin – live exclusively in the Antarctic. Males go without food for nine weeks during winter while incubating their eggs, and the females make a long, perilous journey to seek food for when the chicks hatch.

Islands in the Southern Ocean, surrounding Antarctica are wetter, milder and have more varied vegetation than the mainland. Bird Island, South Georgia, for example, has an average summer temperature of four degrees Celsius (39 degrees Fahrenheit). Its dominant coastal vegetation is tussock grass, which can grow to two metres (6.6 feet) tall.

Even Antarctic icebergs can be home to life. Young icefish hide from predators in holes in the ice. Snow petrels also nest on the bergs, which are generally safer than the mainland.

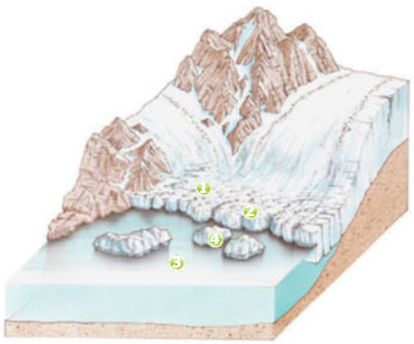
Antarctica was not always an icy desert. Dinosaurs and other megafauna lived in Antarctica when it was warmer. For instance, fossils of a car-sized armadillo, which lived around 45 million years ago, were discovered near the Antarctic Peninsula. Fossilised pollen evidence even shows that rainforests grew on the continent around 52 million years ago, but eastern Antarctica began to freeze over some 34 million years ago, when Earth's climate cooled dramatically.

How icebergs form

In November 2013, the ice shelf attached to Antarctica's Pine Island Glacier shed an iceberg the size of Singapore. Gigantic ice shelves fringe 30 per cent of the Antarctic coast, and thousands of huge blocks of ice break off each year.

Icebergs can be streaked green by algae growing beneath them or bluish if they're made of compacted ice, which scatters lots of blue light.

They float because ice is less dense than the surrounding seawater. As water freezes, the molecules spread out into ice crystals. The crystals fill more space than seawater, but have identical mass, making them lighter.



1 Glacier
Snow builds up in Antarctica's continental interior until it slides downhill under its own weight, forming an ice stream.

2 Ice shelf
When the glacier reaches the coast, it won't stop there, but extends into the sea to form a floating platform called an ice shelf.

3 Ocean
The ocean's tidal motion raises and lowers the ice shelf, causing cracks. Warm seawater melts and weakens the shelf bottom from below.

4 Iceberg calving
Chunks of ice break off the shelf and crash into the ocean, creating huge waves. Icebergs are born.

Life in the freezer

Discover how a wide range of wildlife has adapted to the bitter Antarctic terrain

Southern elephant seal
Males are up to ten times heavier than females. Elephant seals must live off their fat stores while onshore to breed.

Antarctic fur seal
They have fine fur close to their skin and a waterproof layer on top – like a jumper underneath a wetsuit.

Leopard seal
These predators survive by devouring almost anything. Special teeth help them eat prey ranging from krill to other seals.

Fish
Half of Antarctica's 200 fish species have blood containing natural antifreeze. They can survive water temperatures as low as -2°C (28°F).

Antarctic krill
In harsh winters, krill use up their body energy and shrink. Sometimes they turn to cannibalism and eat each other!

KEY DATES
ANTARCTIC EXPLORATION

1772
James Cook sets sail for the Antarctic Circle, realising rock-strewn icebergs came from an undiscovered continent.

1911
Norwegian Roald Amundsen becomes the first to reach the South Pole, beating the British explorer Robert Scott.

1914
Ernest Shackleton attempts to cross Antarctica, but is stranded for almost two years after winter ice crushes his ship.

1929
US explorer Richard Byrd is the first to fly over the South Pole. He goes on to lead five expeditions to map Antarctic territory.

1996
Borge Ousland makes the first unassisted solo crossing of Antarctica towing a 180kg (400lb) sled with skis and a sail.

DID YOU KNOW? *Blue whales are the largest ever-known animal. As heavy as 24 elephants, they mainly eat paperclip-sized krill*

Wandering albatross
They keep warm and dry thanks to their thick, oily plumage, which is water-resistant and acts like an insulating blanket.

Killer whale
These warm-blooded predators have a layer of fatty blubber 8-10cm (3-4in) thick to prevent heat loss.

Emperor penguin
Emperors incubate eggs on their feet during Antarctica's harsh winter, keeping warm with dense feathers, thick fat and by huddling together.

Antarctica's biggest solely land-based animal is a wingless midge called Belgica antarctica that is just 1.3cm (0.5in) long.

Vostok Station measured the coldest temperature ever officially recorded, a chilling -89.2°C (-128.6°F). A typical freezer is set at -18°C (-0.4°F).

Science in Antarctica

In summer, around 4,000 scientists and support staff live in Antarctica's various research stations.

Biologists seek microbes in Antarctica's sub-glacial lakes, which may help us explore the possibilities of alien life elsewhere, like Jupiter's icy moon Europa.

Astrophysicists benefit from cloud-free skies to study faint light from the Big Bang that created our universe, while the IceCube Neutrino Observatory beneath the South Pole uses the pure ice to detect almost-massless particles released by exploding stars (read more on IceCube in 'Amazing science machines' on page 42).

Psychologists can even gain insights for future deep-space missions from life in Antarctica's cramped, isolated research stations.

"Everything, even solid land – believe it or not – experiences the tidal pull from our cosmic neighbours"

The life of manatees

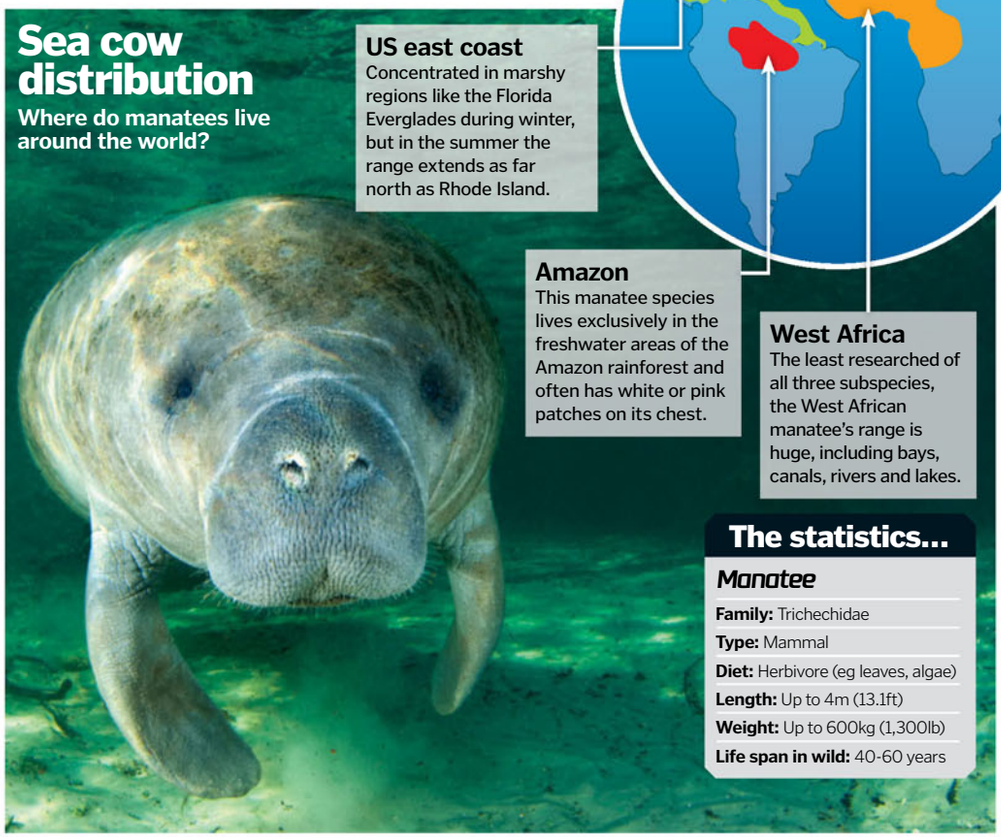
Why do we call these unusual aquatic mammals 'cows of the ocean'?

Also called sea cows, manatees might not immediately resemble your average land-based bovine, but they do share a number of their characteristics. They are bulky, generally peaceful creatures and spend a large proportion of their time grazing on plants; in fact, they're the only marine mammal with an exclusively vegetarian diet.

Surprisingly graceful in the water, they use their powerful flippers and tails to navigate tropical coastal regions and river networks. Their average speed is just eight kilometres (five miles) per hour, but they are able to reach 24 kilometres (15 miles) per hour for short spurts.

Although they never venture onto land (like whales and dolphins they're even born in the water) they're actually more closely related to elephants than other water-based animals. They also need a ready supply of air; the longest they can go submerged is about 15 minutes.

Due to their slow movement and typical habitat coinciding with highly populated areas, manatees were extensively hunted in previous centuries. They remain vulnerable to extinction to this day because their tendency to swim near the surface means they often fall victim to motorboat propellers and fishing nets.



Sea cow distribution

Where do manatees live around the world?

US east coast
Concentrated in marshy regions like the Florida Everglades during winter, but in the summer the range extends as far north as Rhode Island.

Amazon
This manatee species lives exclusively in the freshwater areas of the Amazon rainforest and often has white or pink patches on its chest.

West Africa
The least researched of all three subspecies, the West African manatee's range is huge, including bays, canals, rivers and lakes.

The statistics...

Manatee

Family: Trichechidae
Type: Mammal
Diet: Herbivore (eg leaves, algae)
Length: Up to 4m (13.1ft)
Weight: Up to 600kg (1,300lb)
Life span in wild: 40-60 years

The Great Lakes look, well, great, but only experience small tides

Seiches can often be mistaken for tides

Can lakes have tides?

Are other bodies of water as affected by gravity as the sea?

Anyone who has ever spent the day at a beach will know that the sea is not static. Indeed, over 24 hours a shoreline can change dramatically as the gravitational interaction between Earth, the Moon and the Sun dictates the ocean tides.

But are other large bodies of water on Earth subject to tides as well? Well, technically the answer is yes, because everything, even solid land – believe it or not – experiences the tidal pull from our cosmic neighbours. However, it all comes down to proportions. Because lakes are so much smaller in volume and also self-contained – unlike the oceans which are interconnected – the level of water displacement is far smaller. For instance, according to NOAA, the most powerful spring tides in the Great Lakes in North America (which combined contain over 20 per cent of all the world's fresh water) amount to a mere five centimetres (two inches) at most. Therefore, in smaller bodies of water, the lake tides are simply too minuscule for us to notice.

Something often mistaken for tidal movement is a seiche, or standing wave, which can reach several metres in height. These waves are caused by strong winds or extreme changes in pressure and rebound back and forth in an enclosed or semi-enclosed body of water, much like the sloshing motion you often see in your bathtub. Depending on the scale of the lake or bay, the high and low points of the seiche can be up to seven hours apart, hence why many mistake this phenomenon for tides.

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"At high tide, the sea floods a cavern and, over centuries, eats away at the roof, creating more faults"

How blowholes form

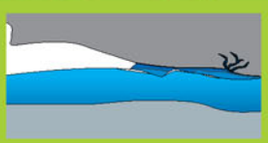
Discover the origins of these marine geysers that blast out of the ground

On the surface there aren't many things more solid than rock, but over thousands of years it can change dramatically. Nowhere is this more evident than the world's coastlines where the rock is constantly under barrage. The hydraulic action of the waves slamming into the cliffs causes fractures, which over time grow into cracks, which themselves develop into caves that stretch ever deeper inland.

But water doesn't only attack in one direction. At high tide, the sea floods a cavern and, over centuries, eats away at the roof, creating more faults. The movement of the waves forces air into these fissures, putting the rock under increasing stress.

Similarly, the land above is also undergoing its own gradual erosion through processes such as weathering and chemical dissolution. Eventually a fracture in the cave roof will reach its breaking point. No longer able to cope with the combined assault of the sea and the pressure of trapped air pushing from below, part of the surface crumbles. Facing no resistance, at high tide or when the sea is rough, jets of seawater, air and spray erupt out of the new-formed hole as high as 30 metres (98 feet), often with a loud hissing noise.

Blowhole locations around the globe



1. Cave forms
The constant movement of the ocean eats away at the bottom of cliffs over time to create sea caves.

2. Roof erodes
As well as eroding rock horizontally the seawater can also creep upwards, forming a series of cracks.

3. Breakthrough
Trapped air expands fissures and eventually the rock is so weak it crumbles, leaving a hole.

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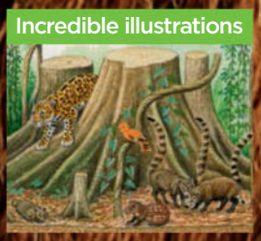

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"As soon as any threat is detected, the lookout will give a shrill warning bark"

Meerkat survival tactics

Meet the sociable critters that play to their strengths by living in tight-knit groups

Meerkats might not be the biggest animals on the African plains, nor appear to boast any particularly formidable weapons, like the rhino's horn, or impressive skills, like the cheetah's speed. Nevertheless, through a combination of hardy biology, smart tricks and a unique community spirit, these mammals have adapted perfectly to their harsh environment.

They escape the most extreme temperatures of southern Africa – as well as the vast majority of predators who'd like to make a meal of them – by living in underground burrows. Some of these subterranean networks can play host to up to 50 or so individuals, though an average colony is about half this size, with two or three families living together communally.

A type of mongoose, they are equipped with sharp, curved claws – each about two centimetres (0.8 inches) long – used for digging and self-defence, as well as acute vision, which comes in very handy for spotting danger.

In fact, when they do venture out of their burrows en masse to search for food, there will always be at least one meerkat that stands sentry – often on a rock or in a bush – primarily looking to the skies for their number-one enemy: birds of prey. As soon as any threat is detected, the lookout will give a shrill warning bark and the others will immediately make a dash for a nearby bolthole or other cover. It's thought that meerkats have dozens of different calls to signify a range of threats.

As well as hunting together over a territorial range that can cover as much as ten square kilometres (four square miles), meerkats also share childcare duties. Typically, only the colony's alpha pair will mate, but all the others pitch in to babysit, grooming and feeding the pups, as well as demonstrating valuable life skills, like where to find food, play-fighting and which parts of a scorpion to eat.

Biology of a meerkat

They may be small, but their bodies are tough

Eyes
Binocular vision helps them detect predators like eagles from as far as 1km (0.6mi) away, while the black eye patches reduce glare. Nicitating membranes act like goggles to keep sand out while digging.

Ears
The ears are small and round and can be closed when the meerkat is digging or caught in a sandstorm.

Fur
Varies in colour from light tan to dark brown depending on the terrain, with unique stripe patterns on the back. Fur is thinner on the belly and meerkats will often sunbathe in the morning to warm up.

Tail
Almost doubling the meerkat's length, the long tail is a useful aid for balancing when standing on their hind legs.

Claws
2cm (0.8in)-long claws (four on each paw) are used to dig their burrows as well as to forage for insects and roots in the arid ground.

Are they immune to venom?

Meerkats are renowned for picking fights with creatures that even the most powerful hunters give a wide berth, like snakes and scorpions, but are they really impervious to venom? Well, to some degree this may be true, because mongooses have often demonstrated a much higher tolerance to venom than most animals due to a slightly mutated neurotransmitter, which prevents the toxins from causing muscle paralysis. However, this doesn't mean meerkats are immune – they *can* die if they get stung or bitten several times or by particularly toxic species. But to sway the odds in their favour, they've developed some clever hunting tactics, including 'mobbing', where they encircle an enemy and attack it from all angles. Or in a scorpion's case, they move with lightning-quick reflexes to bite off the stinger before it can do any harm, then rub the toxic outer layer of the exoskeleton on the ground before eating it.

One meerkat will always stand guard while the others are occupied

AMAZING VIDEO! SCAN THE QR CODE FOR A QUICK LINK

See how life in a real meerkat mob works!

www.howitworksdaily.com

DID YOU KNOW? *Meerkats obtain most of the water they need from the insects and vegetation they eat*

Meerkats live in colonies of up to 50 individuals and they rely on each other for food, defence and rearing their pups

The statistics...

Meerkat

Type: Mammal

Binomial: Suricata suricatta

Diet: Omnivore, eg insects, fruit, lizards, roots, birds

Body length: 30cm (12in)

Weight: 750g (26oz)

Average life span in the wild: 10 years

WORLD'S FASTEST VEHICLES

Blink and you'll miss these speed machines, but what high-octane engineering is under the hood?

In 1906, on the packed sands of Ormond Beach in Florida, USA, mankind's obsession with speed shifted into an entirely new gear. Powered by kerosene-burning steam engines, the world's first racecars broke the 160-kilometre (100-mile)-per-hour mark, igniting a race for the record books – one that roars on today. In 2014, the Bloodhound SSC hopes to speed past the 1,600-kilometre (1,000-mile)-per-hour barrier, smashing the current land-speed record by nearly 400 kilometres (250 miles) per hour and reaching a velocity that could outrun a Magnum 357 bullet. The quest to build the world's fastest vehicles on land, air and sea is equal parts physics, robust materials and, to a certain extent, abject lunacy. Hundreds have lost their lives piloting home-made rocket boats and blasting experimental aircraft to the edge of space. But as long as there's a new milestone to reach – speed of sound, Mach 20, perhaps even the speed of light – our brightest scientific minds and wildest daredevils will be willing to take on the challenge.

F1 engine Custom-built by Cosworth, this 559kW (750hp) engine will pump 800 litres of high-test peroxide oxidiser to the hybrid rocket.

5 TOP FACTS
QUICK TRIVIA

Fastest tin can
1 Apollo 10 astronauts hold the record for fastest re-entry when their lunar capsule reached speeds of over 11km (6.9mi) per second on its fiery return to Earth.

High-speed paddleboat
2 In 1991, a team of MIT students set the world record for fastest human-powered boat with a propeller-driven hydrofoil moving at 34.2km/h (21.3mph) – 18.5 knots.

G-force
3 In the Fifties, Air Force physician John Stapp built a customised rocket sled to test the effects and limits of g-forces on the human body. He reached 46.2 g.

Ferrari on rails
4 The Formula Rossa at Ferrari World in Dubai is the world's fastest rollercoaster, blasting off to a staggering 240km/h (150mph) in five seconds and experiencing 4.8 g.

Speed of the Sun
5 The Australian student-built Sunswift IV is the world's fastest solar-powered vehicle (with no battery). It reached 88.7km/h (55.1mph) in 2011 – and that was a cloudy day!

DID YOU KNOW? *NASA's unmanned X-43 plane reached Mach 9.8 in 2004 with a scramjet engine breathing supersonic air as an oxidiser*

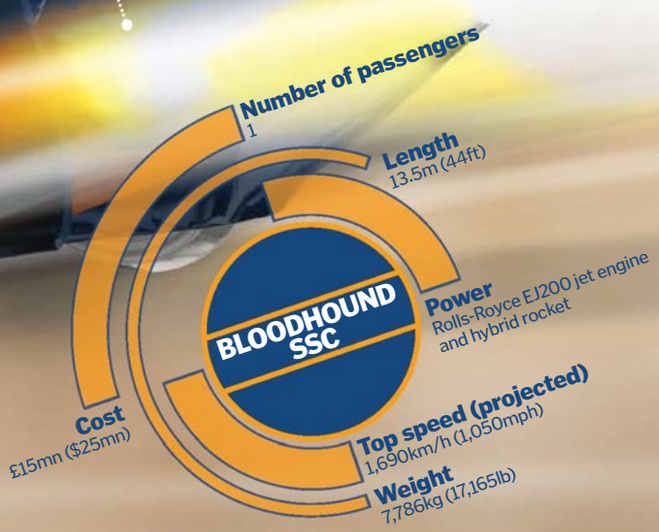
Jet-powered cars

A sonic boom echoed off the stone cliffs of the Black Rock Desert in Nevada, USA, as the British-made Thrust SSC became the first land vehicle to break the sound barrier back in 1997. To qualify for a land-speed record of 1,149 kilometres (763 miles) per hour, the car needed to have four wheels and be under complete control of the driver. It also needed to withstand air pressure upwards of ten tons per square metre. To improve stability, the rocket-shaped car was equipped with twin Rolls-Royce Spey jet engines, one on each side. Each engine produced 89 kilonewtons (20,000 pounds-force) of thrust, roughly equal to 145 Formula One cars. The next-generation Bloodhound SSC – pictured here – aims to exceed 1,600 kilometres per hour (1,000 miles per hour) in 2014 with a Eurofighter Typhoon jet engine and a hybrid rocket strapped to its sleek carbon-fibre and titanium cage frame. The Bloodhound will rocket from zero to 1,690 kilometres (1,050 miles) per hour in just 40 seconds on 900-millimetre (2.9-foot) aluminium alloy wheels.

Jet engine
Designed for the Eurofighter Typhoon plane, the Rolls-Royce EJ200 will accelerate the Bloodhound to 563km/h (350mph).

Hybrid rocket
The largest in the UK, the rocket burns solid fuel with a liquid oxidiser to produce a peak thrust of 122kN (27,500lbf).

Aluminium alloy wheels
Forged from an aerospace alloy of aluminium and zinc, the solid discs must cope with forces in excess of 50,000 g at the rims.



"Air is much denser at ground level than at high altitude, meaning cars have to be ultra-aerodynamic"

The bumps in the road

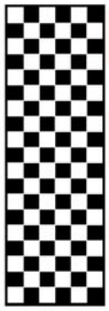
Drag is one of the greatest engineering challenges to designing a supersonic land vehicle capable of breaking speed records. Even low-flying fighter jets have only reached 1,600 kilometres (994 miles) per hour and that's without the friction of wheels on the ground. Air is much denser at ground level than at high altitude, meaning cars have to be ultra-aerodynamic (hence the rocket shape) and produce insane amounts of thrust. The Aussie Invader 5R, one of the land-speed contenders, solved this problem by sitting its driver atop what is essentially a 16-metre (52-foot) rocket engine capable of producing 276 kilonewtons (62,000 pounds) of thrust. Wheels are another huge challenge, as they need to rotate at unimaginable speeds while sticking firmly to the ground. The solution is tireless wheels machined from either titanium or aluminium, which boast a very high strength-to-weight ratio. The Aussie Invader's aluminium wheels are built for 10,000 rotations per minute. When the Thrust SSC broke the sound barrier, the shockwave 'fluidised' the sandy soil beneath the vehicle, making it difficult to steer. Next-gen rocket cars are using computer modelling to muffle those vibrations.

Some have contested the Venom GT is faster than the Veyron Super Sport overall but this is yet to be confirmed

Speed vs acceleration

In January 2013, a Hennessey Venom GT ripped down an airport runway in Texas to break the world acceleration record: 0-300km/h (186mph) in 13.63s. Acceleration is not the same as speed. Acceleration is a product of the V8 engine's torque (force) divided by the Venom GT's mass (ie a = f/m). The Venom accelerates so quickly because its lightweight 1,244kg (2,743lb) frame is cranked by 160kg/m (1,155lb/ft) of torque. The heavier Bugatti Super Sport loses to the Venom GT in a sprint, but can hold the road at higher maximum speeds.

Other speed demons... on land



Fastest wind-powered car

Ecotricity Greenbird, 203km/h (126mph)

Fastest motorcycle

Ack Attack, 606km/h (377mph)

Fastest piston engine car

Speed Demon, 743.5km/h (462mph)

WORLD'S FASTEST PRODUCTION CAR

The first thing you notice about the Bugatti Veyron Super Sport isn't its Lamborghini good looks, but its Tyrannosaurus roar. The Bugatti's 16-cylinder engine delivers over 1,200 horsepower, ripping from 0-100 kilometres (60 miles) per hour in a staggering 2.5 seconds. The only thing preventing the Bugatti from pushing over 431 kilometres (268 miles) per hour is the rubber tyres, which would tear apart from the force. And at £26,000 ($42,000) for four tyres, it's better to be safe than sorry! To deliver that much power, the eight-litre engine gulps down fuel; at full pelt, the Bugatti would drain its entire tank in about 12 minutes.

VEYRON SUPER SPORT

Weight
1,888kg (4,162lb)

Transmission
7-speed

Price
£1.5mn ($2.5mn)

Top speed (restricted)
415km/h (258mph)

Acceleration
0-97km/h (60mph) in 2.5 seconds

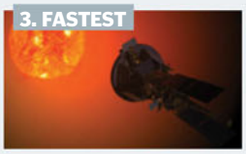
Engine
16 cylinders, 895kW (1,200hp)

1. FAST

New Horizons
When the deep-space explorer separated from its Atlas V launch vehicle in 2006, it was travelling at more than 16km (9.9mi) per second.

2. FASTER

Helios I and II
Launched in the Seventies, these twin probes reached speeds of more than 70km (43.5mi) per second when whirling past the Sun.



3. FASTEST

Solar Probe Plus
Set for 2018, this NASA probe will get so close to the Sun that its gravity will propel it to 200km (124mi) per second!

DID YOU KNOW? *To simulate a missile flight, US Air Force researchers built a rocket sled that reached 10,325km/h (6,416mph)*

WORLD'S FASTEST MANNED AIRCRAFT

The fastest-ever manned aeroplane made its record-setting flight 47 years ago. In the early days of the Space Race, the X-15 was designed to test the limits of aeronautical engineering at the edge of space. Built like a short-winged fighter jet, the X-15 packed a rocket under its hood. To fly, it would hitch a ride on a massive B-52 up to 13,700 metres (45,000 feet). Dropped from the bomber, the X-15 lit its liquid propellant rocket capable of 500,000 horsepower. The X-15 only carried enough fuel for 83 seconds of powered flight – but it was enough to rocket its pilots into the record books.

Top speed
7,274km/h (4,520 mph)

Top altitude
107,960m (354,200ft)

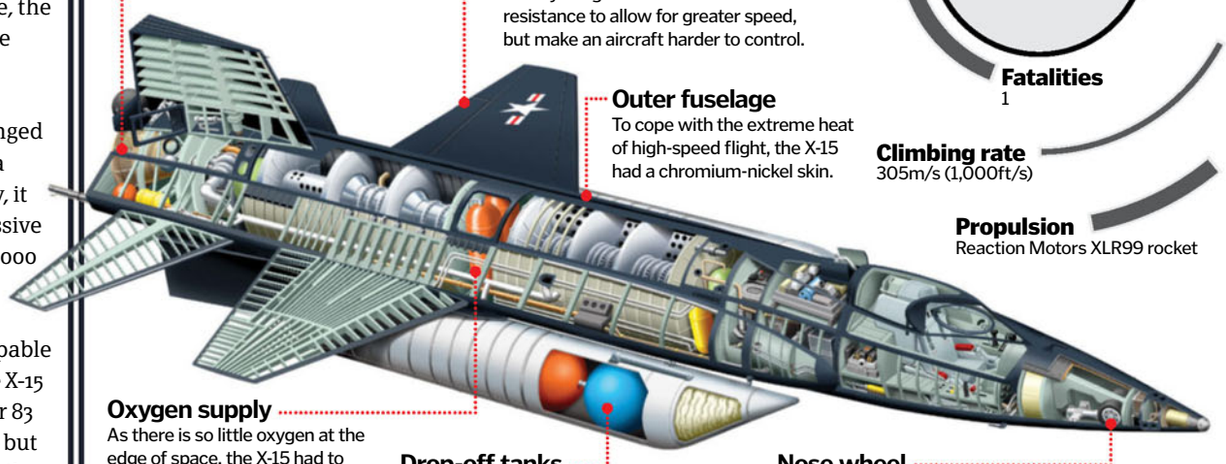
NORTH AMERICAN X-15

Mission flights
199

Fatalities
1

Climbing rate
305m/s (1,000ft/s)

Propulsion
Reaction Motors XLR99 rocket



Rocket engine
The XLR99 engine was throttled, which meant thrust could be adjusted from half to full.

Short wings
Stubby wings create less air resistance to allow for greater speed, but make an aircraft harder to control.

Outer fuselage
To cope with the extreme heat of high-speed flight, the X-15 had a chromium-nickel skin.

Oxygen supply
As there is so little oxygen at the edge of space, the X-15 had to take its own for burning fuel.

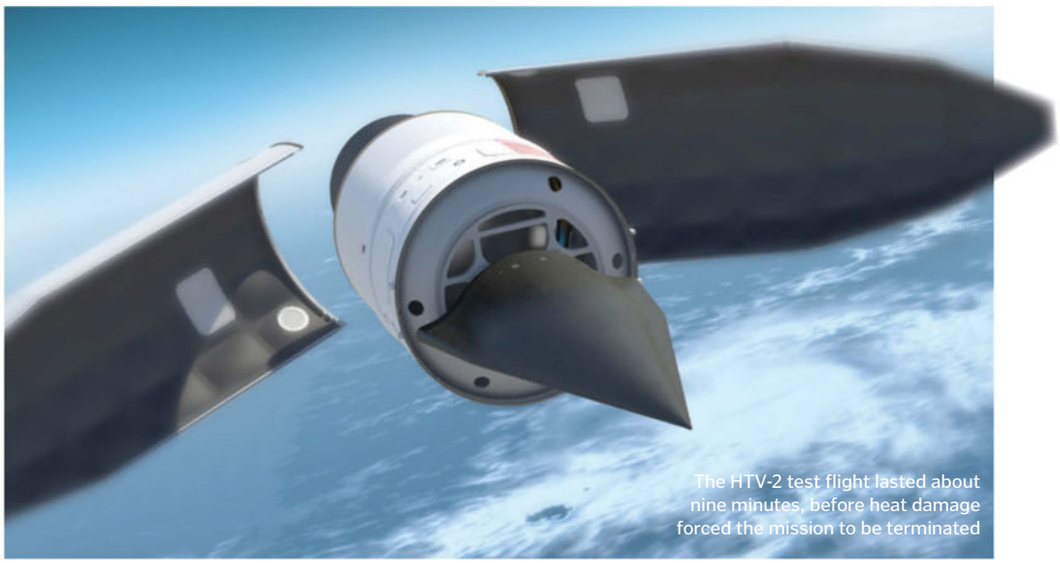
Drop-off tanks
When the second iteration of the X-15 was damaged on landing, the fuel tanks were redesigned to fall away.

Nose wheel
The front wheel could not be steered so the X-15 had to land on a lake bed rather than a runway.

Aerodynamic challenges

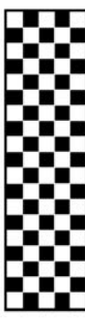
The engineering challenges for high-speed aircraft are surprisingly similar to building the world's fastest cars. Drag is still public enemy number one. As an aircraft approaches the speed of sound, the gas flowing around the plane grows more viscous, 'sticking' to the surface and altering the aerodynamic shape of the craft. Any friction with that high-velocity stream of gases will cause bone-rattling turbulence, incredible heat and shockwaves. To achieve the best aerodynamic profile, supersonic planes have swept-back wings that stay safely inside the cone of a supersonic shockwave. The F-14 fighter jet can pull its wings in tight for maximum speed and stretch them out for greater control at lower speeds. Supersonic craft are also made from lightweight materials like aluminium to further reduce drag.

Of course, you'll never reach supersonic speeds without serious engine power. X-1, the first plane to break the sound barrier in 1947, was propelled by a rocket, but modern turbojet engines like the Concorde's four Rolls-Royce turbofans, are also capable of supersonic flight. Hypersonic flight – ie greater than Mach 5 – has its own unique set of challenges because gas molecules begin to break apart and create multiple overlapping shockwaves. Experimental hypersonic designs such as the Falcon HTV look more like wingless sci-fi vehicles than traditional planes.



The HTV-2 test flight lasted about nine minutes, before heat damage forced the mission to be terminated

Other speed demons... in the air



Fastest space plane
Virgin Galactic's SpaceShipTwo, 1,752km/h (1,089mph)

Fastest jet aircraft
Blackbird SR-71, 3,185km/h+ (1,979mph+)

Fastest unmanned plane
Falcon HTV-2, 20,921km/h (13,000mph)

"If you watch a speedboat race, most of the boat lifts out of the water"

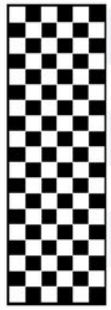
Slicing through the water

Just like air and land, the greatest obstacle to record-breaking speeds on the water is drag. Water is about 1,000 times denser than air, so the best way to increase speed on water, ironically, is to make as little contact as possible with the water itself. If you watch a speedboat race, most of the boat lifts out of the water at top speeds – an aerodynamic engineering feat called 'foiling'. The twin hulls of America's Cup catamarans lift entirely out of the water, riding only on razor-thin hydrofoil blades. The catamaran design increases overall stability without the necessity of a single hull sitting deep in the water.

Spirit of Australia

Since childhood, Australian speedboater Ken Warby dreamed of breaking the world speed record. His hero, British daredevil Donald Campbell, died trying. In the Seventies, without a sponsor, Warby built the Spirit of Australia in his Sydney backyard, buying three clunky jet engines in a RAAF surplus auction. Warby used years of speedboat experience to draft the three-point hydroplane design, in which only three parts of the underside of the boat touch the water at high speeds, greatly reducing drag. With help from a university wind tunnel and the RAAF, Warby reached a death-defying 511.1km/h (317.6mph) in 1978 – a record that still stands to this day.

Other speed demons... in water



Fastest warship

US Navy Independence, 83km/h (52mph)

Fastest hovercraft

Universal UH19P: Jenny II, 137.4km/h (85.4mph)

Fastest hydrofoil

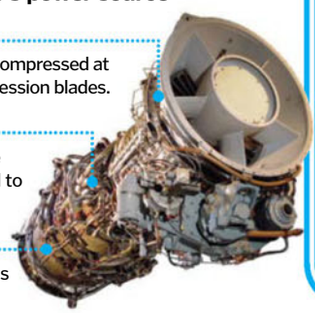
US Navy Fresh-1, 155.6km/h (96.7mph)

WORLD'S FASTEST PASSENGER FERRY

It's one thing to see a tiny speedboat race across the ocean surface, but it's downright mind-blowing to watch a 99-metre (295-foot) ferry hit speeds of more than 50 knots (93 kilometres/58 miles per hour) while carrying up to 1,000 passengers and 150 cars. The Francisco is Australian shipmaker Incat's latest breakthrough; a twin-hulled catamaran powered by two massive turbine engines running on liquefied natural gas (LNG). The turbines force water through two enormous waterjets that propel and steer the craft, which cuts through the waves like a warm knife through butter. The Francisco will ferry passengers in style and speed from Buenos Aires in Argentina, to Montevideo in Uruguay.

LM2500 marine gas turbine

A closer look at the Francisco's power source



Compressor
Rotating fan blades draw in air that's compressed at an 18:1 ratio through a series of compression blades.

Combustor
Liquid natural gas is injected into the compressed air chamber and ignited to release tremendous energy.

Turbine
The flow of hot exhaust spins a series of turbines connected to a waterjet.

On the clock: London to New York

How long would it take the world's quickest vehicles to hop across the Atlantic at max speed – pretending there's a bridge?

Scorpion FV101 tank
76.8 hours

VeloX3 bicycle
41.7 hours

Bugatti Veyron Super Sport
12.7 hours

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Take an animated tour inside the Bloodhound

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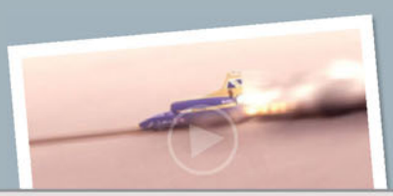


DID YOU KNOW? *According to Einstein's theories no spacecraft will ever reach the speed of light as it would need infinite mass*

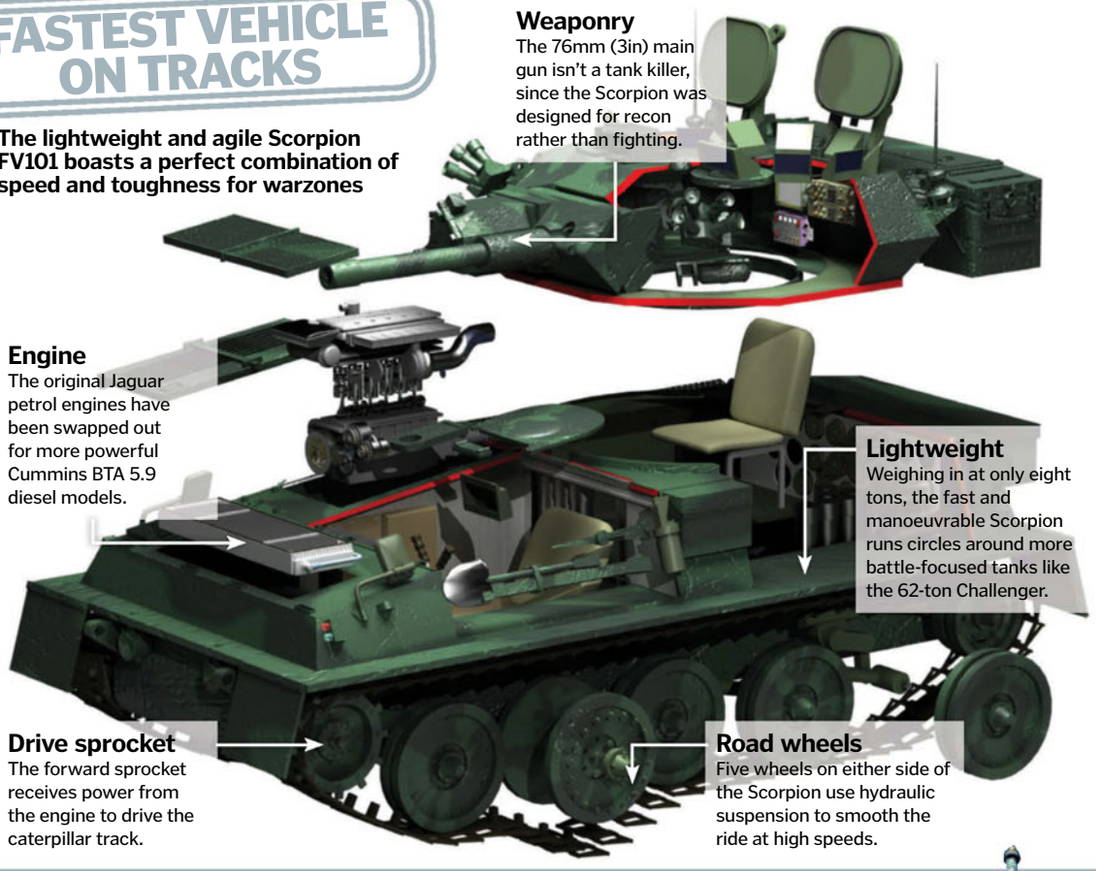
Speed on the rails

The future of high-speed trains is without a doubt magnetic. The principle of magnetic levitation (maglev) allows trains to reduce drag by floating on a one to ten-centimetre (0.4 to four-inch) cushion of air created by opposing electromagnetic fields in the track and car. The Shanghai Maglev Train in China became the first commercial maglev in 2003 and still holds the operational speed record for a commercial train: 431km/h (268mph). However, Japan is developing its own maglev line between Tokyo and Nagoya, with trials hitting the 500km/h (310mph) mark. Tech entrepreneur Elon Musk (founder of SpaceX) plans to take maglev to the next level. His Hyperloop design propels train cars through a sealed, low-pressure tube on cushions of air at speeds approaching 1,300km/h (800mph). Today, conventional high-speed lines in Spain, France, Italy, South Korea and elsewhere reach speeds exceeding 300km/h (186mph), using a combination of streamlined aerodynamics, lightweight plastics and electric-powered locomotives.

The new L0 maglev train being tested in Japan has already clocked 500km/h (311mph)

FASTEST VEHICLE ON TRACKS

The lightweight and agile Scorpion FV101 boasts a perfect combination of speed and toughness for warzones



Weaponry
The 76mm (3in) main gun isn't a tank killer, since the Scorpion was designed for recon rather than fighting.

Engine
The original Jaguar petrol engines have been swapped out for more powerful Cummins BTA 5.9 diesel models.

Lightweight
Weighing in at only eight tons, the fast and manoeuvrable Scorpion runs circles around more battle-focused tanks like the 62-ton Challenger.

Drive sprocket
The forward sprocket receives power from the engine to drive the caterpillar track.

Road wheels
Five wheels on either side of the Scorpion use hydraulic suspension to smooth the ride at high speeds.

Spirit of Australia
10.9 hours

Thrust SSC rocket car
4.5 hours

X-15 rocket plane
46 minutes

Fast and curious...

1 Milk float
By swapping the milk delivery truck's electric motor with a V8 engine, British Touring Car Championship driver Tom Onslow-Cole reached 124.8km/h (77.5mph) in the not-so-aerodynamic buggy as part of the eBay Motors Mechanics Challenge.

2 Lawnmower
Honda UK's 'Mean Mower' goes from 0-97km/h (60mph) in four seconds and claims to reach top speeds (on the track, not the lawn) of 209km/h (130mph). Makes quick work of cutting the grass, but the 1,000cc motorcycle engine might bother the neighbours!

3 Police fleet
Only in Dubai... In 2013, the city of unrepentant excess made some additions to its public safety patrol: a £275,000 ($450,000) Lamborghini Aventador and a Ferrari FF. Criminals have no chance of making a getaway!

4 Bicycle
The VeloX3, built by a team of Dutch university students, looks like an elongated egg. The recumbent bicycle is covered in a hyper-aerodynamic shell that enabled it to reach record speeds of 133.8km/h (83.1mph) in 2013.

5 Skateboard
Mischo Erban is king of the daredevil maniacs who practise the competitive sport of downhill skateboarding. Erban set a new world record in 2012, reaching 130km/h (80.7mph) on a mountain road in Québec, Canada.

"The laid-back body position means the rider is more comfortable as body weight is more spread out"

Recumbent bike engineering

Discover the reclining bicycles that offer a laid-back alternative to traditional pushbikes

Recumbent bicycles have been in production for decades, with a history stretching back to the 19th century along with its more familiar bicycle brethren. Recumbent bikes place the rider in a more horizontal position with more framing and a larger seat, with the alloy frame extended between the larger wheelbase to position the rider directly between the wheels and lower to the ground. They work by the rider pedalling either the front or rear wheel. Steering is controlled using extended handlebars directly above the seat from the front fork, or indirectly via cables and rods for under-seat systems.

A recumbent bicycle boasts several advantages over a traditional bicycle. First, the laid-back body position means that the rider is more comfortable, as body weight is more spread out and not merely cantered on the bones in the buttocks. Second, a recumbent bicycle can have better aerodynamics, as the reclined, legs-forward position ensures a smaller frontal profile, reducing drag.

It has disadvantages though including manoeuvrability, as a recumbent bike can have a large turning radius as a result of its wheelbase, and poor visibility on busy roads.

What role do outriggers play?

How these simple devices have stopped boats from capsizing for centuries

Outriggers are a type of buoyancy aid used to increase a boat's stability and speed. The float (known as an 'ama') is joined to the vessel via fixed rigid spars typically made of wood or aluminium; these are called 'iako'. It is usually of equal length to the boat it is supporting, running parallel to the hull by a distance of some two metres (6.6 feet). They are kept thin in order to reduce drag.

An outrigger effectively stops a vulnerable hull from capsizing by spreading the weight of the boat over a larger surface area. This extra buoyancy is useful in rough seas and when the boat is attempting to make sharp turns. These flotation devices can be fixed to both sides of a small boat for extra stability, though sometimes only one is used, typically on the port (left) side.

History of outriggers

Outrigger boats have been around in some form or another for thousands of years. Traditionally popular in South-east Asia, outrigger canoes were used as an ocean-going vessel from Polynesia and New Zealand to Madagascar. They were ideal for migrating between the many islands around the Pacific and Indian Oceans. These wooden boats were bound together by rope and bamboo. Outriggers are still popular today, most commonly used for fishing and transport between towns and villages, though petrol engines have mostly replaced paddles.

DID YOU KNOW? *Most rolling roads cater for upwards of 1,200bhp – far above the current typical power of the modern supercar*

What are rolling roads?

See how mechanics put a car through its paces without a road or track in sight

A rolling road – also known as a dynamometer or dyno – is a machine used to measure a car's top power without the vehicle having to move from the spot or cover any physical ground. By allowing the wheels to be spun by the power of the car's engine over a set of fixed rollers, a computer can measure power and torque while re-creating the temperature, pressure and humidity of a public road or track – all crucial variables in how well an engine performs.

This is achieved by having a large fan feed air to the front of a vehicle, for example, replicating the air an engine gets from a car while racing down a highway. This helps to give accurate, real-time performance figures.

In basic terms, a dyno works by having a computer measure a car's acceleration, calculating the rate at which the rollers are spun by the engine under load. This data is established through roller speed and torque transducers, which send the information to tailored software on a nearby computer, which plots the information on a performance graph.

Dynamometers are not only a good way of testing a car's maximum power, but are also effective for tuning purposes. For example, a dyno will be used before and after any modifications to the vehicle's weight, body shape and materials, etc, are carried out to determine if they improve or undermine the car's overall performance.

Dynamometers for people

Dynamometer devices can also be used by humans to help evaluate strength, such as hand or pinch grip – particularly after injuries. Commonly used as part of a physician's arsenal of diagnostic tools, one such example of this is the handgrip dynamometer, which works by having the patient hold two parallel metal bars repelled by strong steel springs. The patient must then squeeze the bars as close together as they can, compressing the springs, and an analogue gauge then calculates the compression rate.

Dyno in focus

What major components work together to put a vehicle's power to the test?

1 Rig
The car being tested is driven up the ramp and is then secured to the dynamometer rig in order to keep it sturdy while the wheels are rapidly spinning.

2 Rollers
The wheels are positioned over a series of rollers on either side, so when the rollers rotate the wheels spin too, mimicking a car as it drives along the road.

3 Speed transducers
These sensors process the variations in rotation from the rollers and convert them to an electric signal, which can then be interpreted by computer software.

4 Computer
The computer calculates the speed of the rollers' revolutions, plotting a graph of the vehicle's typical power across the entire rev range.

"The chevron points upstream, allowing the natural water pressure to hold the gates shut"

Locks are the mechanism that enable boats to pass through uneven terrain

Canal lock mechanics

Discover the engineering that enables boats to travel up and down hills

Locks enable canal boats to travel across uneven terrain, replacing flowing inclines with static chambers that move up and down vertically.

The most common type of lock is known as a 'pound lock', and has a chamber with a gate at either end. The lock is essentially comprised of three sets of components: a watertight chamber, two sets of watertight gates and lock gear to raise or lower the water level.

A boat travelling downstream enters the lock at the top. The water level in the chamber is maintained by the lower gate, consisting of a pair of half-gates, closed in a chevron shape. The chevron points upstream, allowing the natural water pressure to hold the gates shut. Once the boat has entered the lock, the upper gate is closed behind it, using a long balance beam for leverage.

The water level in the lock is raised and lowered using a paddle system; paddles covering holes in the gates let water enter through the top gate to fill the lock, or to exit through the bottom gate to empty it.

The paddles are then raised using the winding gear, which is turned by hand using a lock key that acts as a crank arm to turn the sprocket. The sprocket engages a toothed bar, which moves a rod attached to the paddle, moving it upwards. Once the paddle is fully lifted, it is caught by a pawl bar, which holds it in place so the other paddles can be lifted.

Once the water has drained from the lock, the pressure behind the lower doors is relieved and they can be opened, allowing the boat to continue moving downstream. The pawls holding the paddles open are disengaged and the paddles are wound back to their original position, once again covering the holes. The whole process generally takes 10-20 minutes.

Travelling in the opposite direction, the process is simply reversed, and water is allowed to enter the lock using paddles fitted to the top gate. Filling the chamber is typically quicker, taking five to ten minutes.

THE STATS
PANAMA CANAL

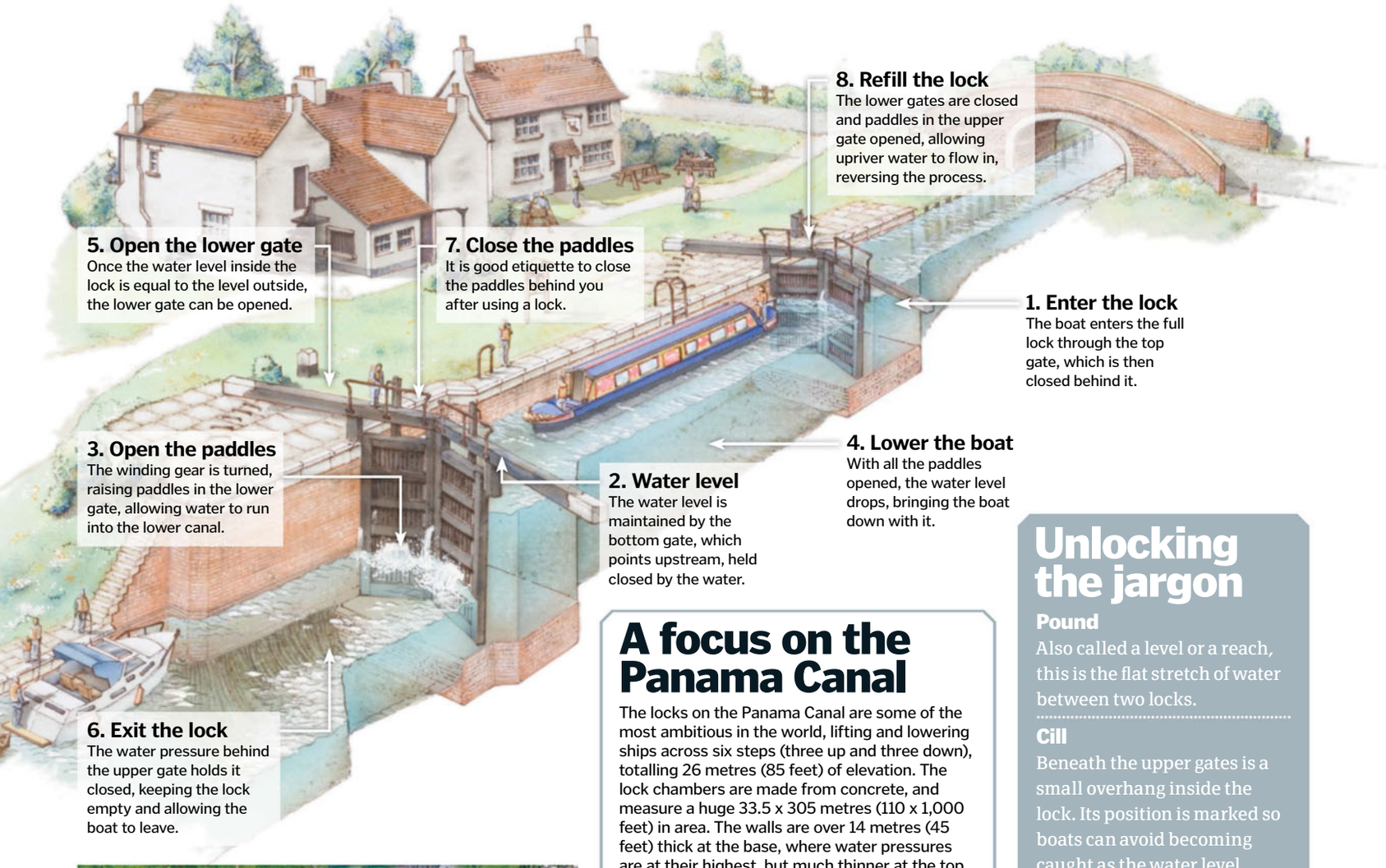
TOTAL LENGTH 77.1km | NUMBER OF LOCKS 6 | TONS SHIPPED EACH YEAR 300mn

SHIPS PER YEAR 14,000 | HEAVIEST GATE 662 tons | ELEVATION 26m

DID YOU KNOW? *The pound lock – a chamber with a gate at either end – was invented in China in the late-tenth century*

How to use a lock

Follow this step-by-step guide to passing through a lock



8. Refill the lock
The lower gates are closed and paddles in the upper gate opened, allowing upriver water to flow in, reversing the process.

5. Open the lower gate
Once the water level inside the lock is equal to the level outside, the lower gate can be opened.

7. Close the paddles
It is good etiquette to close the paddles behind you after using a lock.

1. Enter the lock
The boat enters the full lock through the top gate, which is then closed behind it.

3. Open the paddles
The winding gear is turned, raising paddles in the lower gate, allowing water to run into the lower canal.

4. Lower the boat
With all the paddles opened, the water level drops, bringing the boat down with it.

2. Water level
The water level is maintained by the bottom gate, which points upstream, held closed by the water.

6. Exit the lock
The water pressure behind the upper gate holds it closed, keeping the lock empty and allowing the boat to leave.

There are 47 locks along the 202km (126mi)-long Rideau Canal in Canada

A focus on the Panama Canal

The locks on the Panama Canal are some of the most ambitious in the world, lifting and lowering ships across six steps (three up and three down), totalling 26 metres (85 feet) of elevation. The lock chambers are made from concrete, and measure a huge 33.5 x 305 metres (110 x 1,000 feet) in area. The walls are over 14 metres (45 feet) thick at the base, where water pressures are at their highest, but much thinner at the top, measuring 2.4 metres (eight feet). The chambers have a capacity of 101 million litres (26.7 million gallons) and a series of culverts are used to move water in and out. When the lock needs to be raised, water is brought in from the lake, and when it needs to be emptied, water is drained into the sea. Given the high quantities of water, the gates were engineered to be extremely strong, using the same chevron shape to hold the gates closed under the pressure of the water.

Unlocking the jargon

Pound
Also called a level or a reach, this is the flat stretch of water between two locks.

Cill
Beneath the upper gates is a small overhang inside the lock. Its position is marked so boats can avoid becoming caught as the water level continues to drop.

Paddle
A sliding panel, made from wood or plastic, used to regulate the flow of water in and out of a lock.

Windlass
Also called a lock handle or lock key, this is a crank used to turn the winding gear and open the paddles.

Snubbing post
To slow a horse-drawn boat down as it came into the lock, rope was wound around posts to generate friction.

Amazing science machines

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

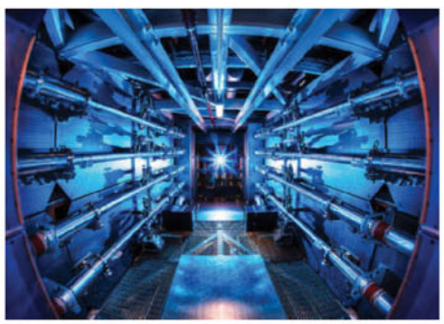
DID YOU KNOW? *The James Webb Space Telescope is sensitive enough to spot a penny about 40km (25mi) away!*

The world's biggest laser

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

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

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

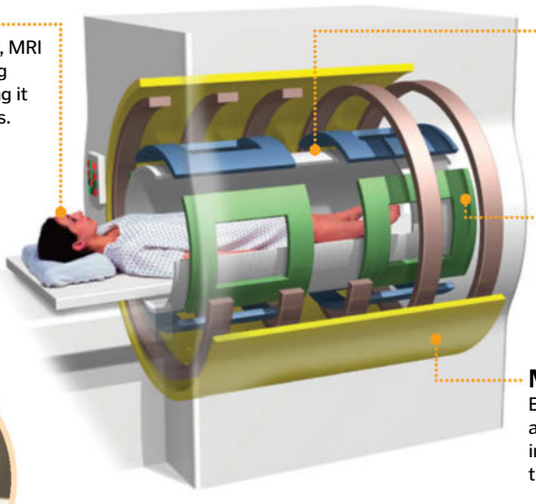


Hubble's successor

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

A number-crunching computing colossus

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



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

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

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

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

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

Revealing our bodies' secrets

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

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

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

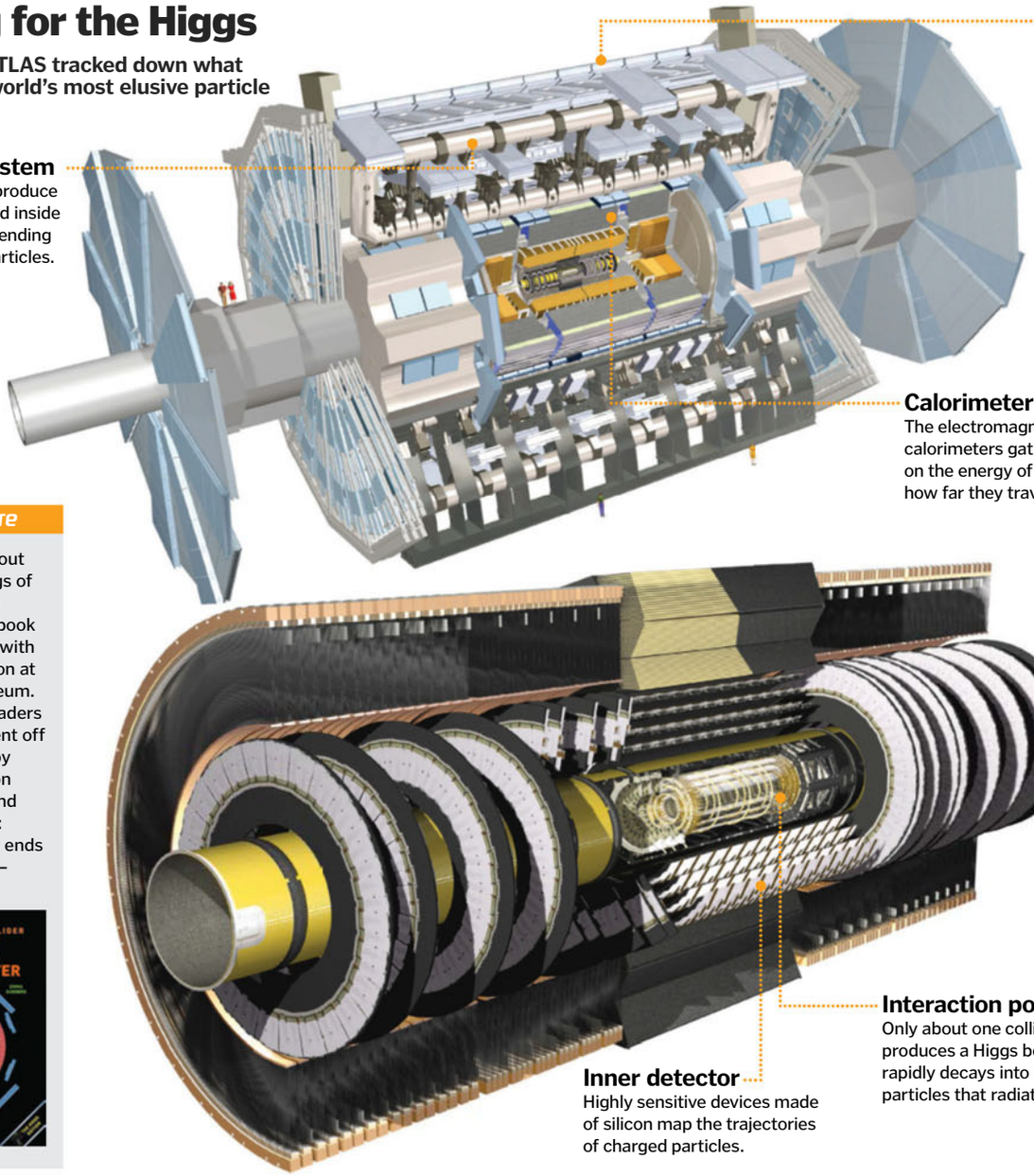
Rebooting the LHC

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

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

Hunting for the Higgs

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



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

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

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

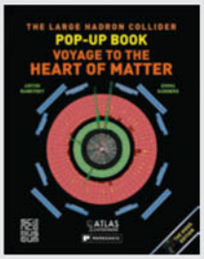
Beam pipe
The LHC accelerates protons, which speed around in opposite directions before colliding inside particle detectors.

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

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

Learn more

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



5 TOP FACTS
ROOM FOR ERROR

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

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

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

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

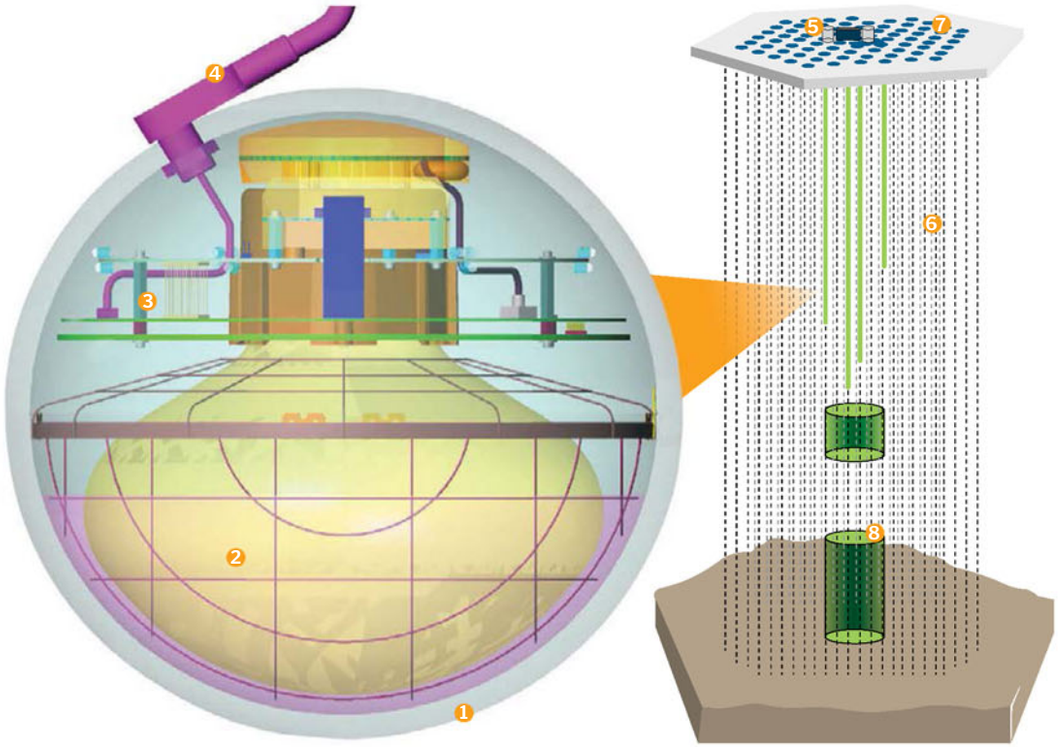
5 Challenger disaster
One of the most tragic scientific failures took place in 1986, when space shuttle Challenger broke apart minutes after launch, killing its seven crew members.

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

IceCube: a new era of astronomy

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

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



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

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

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

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

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

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

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

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

Quantum computer makes waves

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

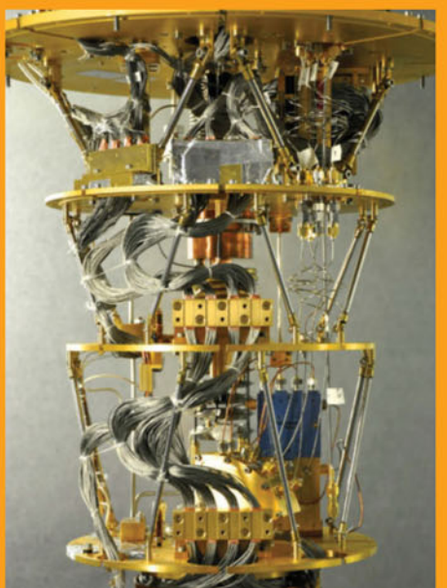
What kind of problems is NASA investigating with the D-wave computer?
NASA has a bunch of difficult optimisation or search problems. Say you want to plan a certain navigation route for the Mars rover; there are many ways of charting that route, but you want to minimise the resources you use. This is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

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

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

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

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



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KEY DATES
HISTORY OF TIME

1500 BCE
Ancient Egyptians divided night-time into 12 parts and daytime into 10, with two hours for dawn and dusk.

1283
The first weight-driven clock was created in England; it sounded a bell to indicate time, hence the Celtic name 'clocca'.

1300s
The hours of the day were standardised, divided into two 12-hour periods and measured beginning at midnight.

1656
The pendulum clock, developed by Christiaan Huygens, was the first to show seconds on its face.

1949
The first atomic clock was built in the USA, allowing extremely accurate timekeeping.

DID YOU KNOW? *Quantum clocks use aluminium and magnesium ions and are even more precise than optical lattice clocks*

Redefining the second

How do laser-powered optical lattice clocks measure time so precisely?

A grandfather clock uses a pendulum to keep time – a swinging weight that oscillates back and forth at fixed intervals. However, if the pendulum swings once every second, a tiny error quickly spirals into a major timekeeping problem. The solution is to break the second down even further and to use a 'pendulum' that swings much faster.

Atomic clocks, developed in the Fifties, are based on this principle. Instead of a swinging pendulum, these devices use the oscillations of caesium atoms as they jump between energy states when exposed to microwave radiation. In a single second, a caesium atom oscillates an incredible 9,192,631,770 times.

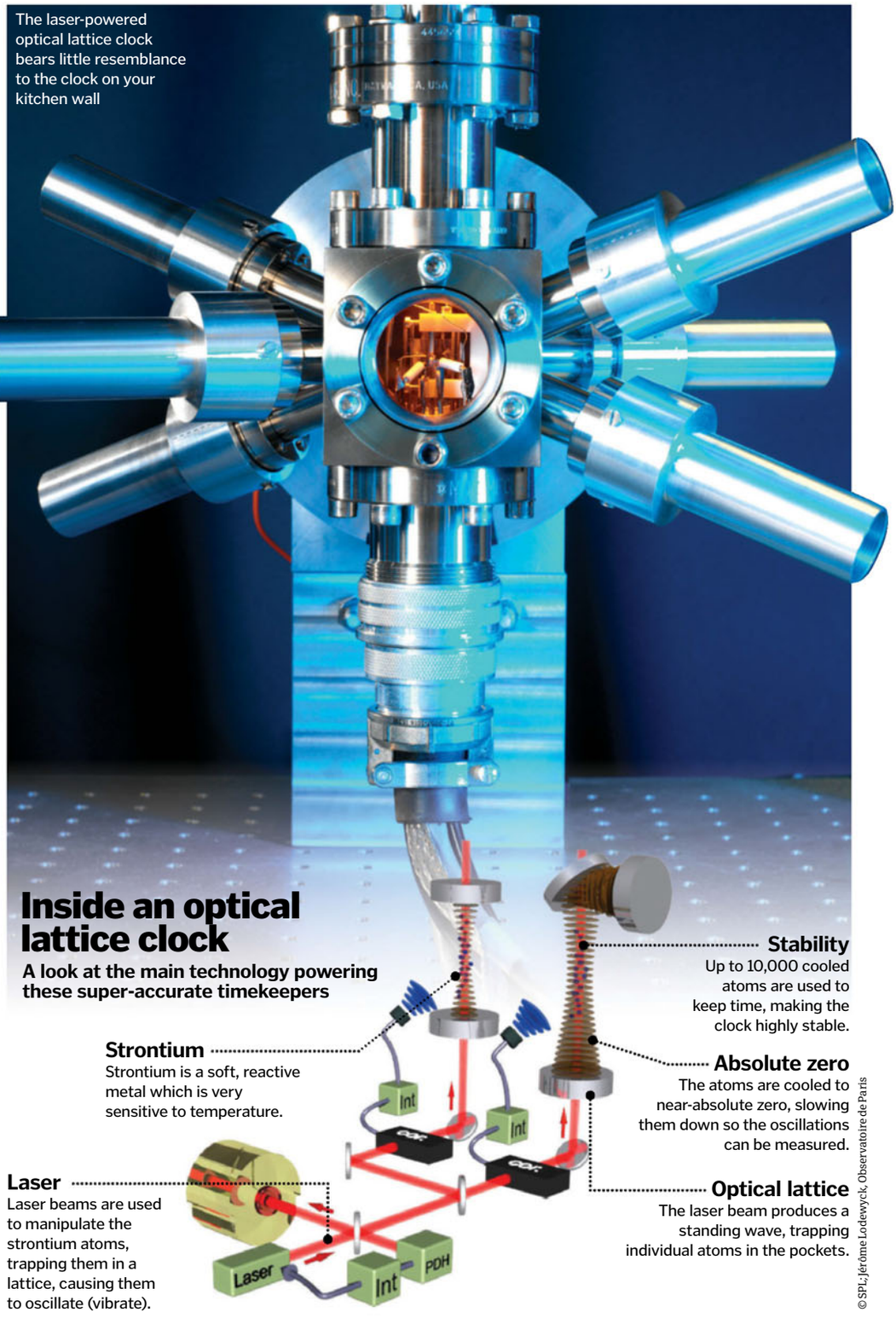
Optical lattice clocks take this idea one step further still. Instead of exciting atoms with microwaves, laser beams are used. These oscillate much more rapidly, splitting the second into even more fragments, and thus enabling more precise measurement.

Strontium atoms are cooled by lasers until they move no faster than a few centimetres every second. The laser beam creates a pattern similar in shape to an egg box, which traps the individual atoms in a regular lattice, allowing their atomic 'tick' to be measured.

Second nature

From 1000 CE and right up until the Sixties, a second was defined, much as you might expect, as 1/86,400 of the average solar day – ie 60 seconds in every minute, 60 minutes in every hour, 24 hours in every day. However, given that the Earth wobbles on its axis and our orbit around the Sun is not consistent, a more accurate means of measuring time was required.

The atomic clock enabled us to measure time much more precisely, defining one second as the time it takes a caesium atom to cycle between two energy states exactly 9,192,631,770 times.



"The sheet has set frequencies at which it will naturally resonate as the sound waves travel through it"

Seeing sound

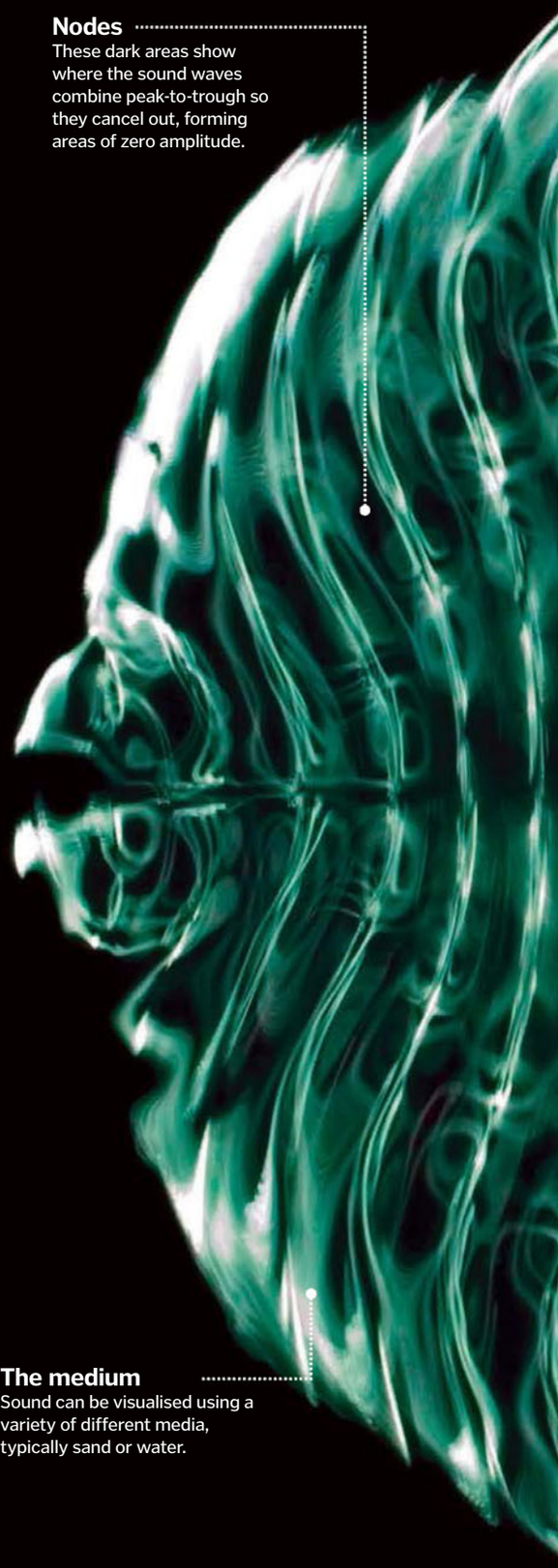
Discover the science of cymatics, which enables us to observe the behaviour of sound waves

The incredible geometric patterns on this page may look artificial, but they are, in fact, the visualisation of how sound waves interact as they travel across a surface. The study of these figures is called cymatics, which derives from the Greek word 'kima' (wave) and was first coined by Swiss scientist Hans Jenny in 1967, but the phenomena had been observed for hundreds of years by the likes of Da Vinci and Galileo.

The patterns are best observed using thin sheets of either metal or glass, known as a Chladni plate after its inventor (see the 'Ernst Chladni' boxout), connected to a signal generator which can oscillate at a variety of audio frequencies. The sheet has set frequencies at which it will naturally resonate as the generated sound waves travel through it. This creates a patchwork of areas where the waves either combine destructively (ie peak meets trough) to cancel each other out, or constructively (ie peak meets peak) forming a larger wave. These sections are called nodes and antinodes, respectively.

The effect of these vibrations is invisible until a medium – usually a liquid, or fine particles of a solid material such as sand or salt – is added to the plate. When the generator is set to one of the plate's natural frequencies, the water or sand will shift away from the busy antinodes and towards the quieter node regions. The resulting figures vary depending on the rate of oscillation as well as the shape and size of the Chladni plate, but all demonstrate unbelievable symmetry.

This method for visualising sound, as well as being a remarkable form of natural art, can be used across many fields of scientific research. One example is oceanography, where the cymatic patterns of dolphin sonar are being used to better understand how the marine mammals communicate.



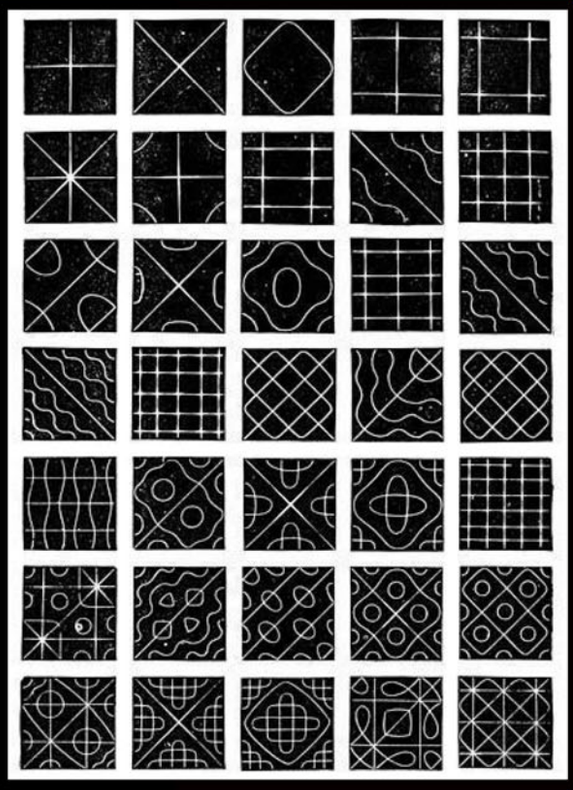
Nodes
These dark areas show where the sound waves combine peak-to-trough so they cancel out, forming areas of zero amplitude.

The medium
Sound can be visualised using a variety of different media, typically sand or water.

Ernst Chladni

German-born physicist and musician Ernst Florens Friedrich Chladni investigated cymatics around the turn of the 19th century. By running a violin bow along the edge of a metal plate covered in fine sand, he was able to make the plate vibrate at its resonant frequency, producing intricate patterns in the grains. Chladni experimented with a variety of plate shapes and sizes, making extensive sketches of the different sand patterns (right), which were published in his book *Die Akustik* (*The Acoustic*) in 1802. From his studies, he was able to derive a formula known as Chladni's Law, which predicts the patterns that will form on circular plates.

Ernst Chladni was a research pioneer in the field of cymatics



AMAZING VIDEO! SCAN THE QR CODE FOR A QUICK LINK

Check out a Chladni plate experiment in action

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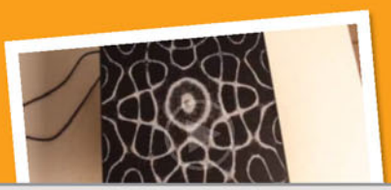
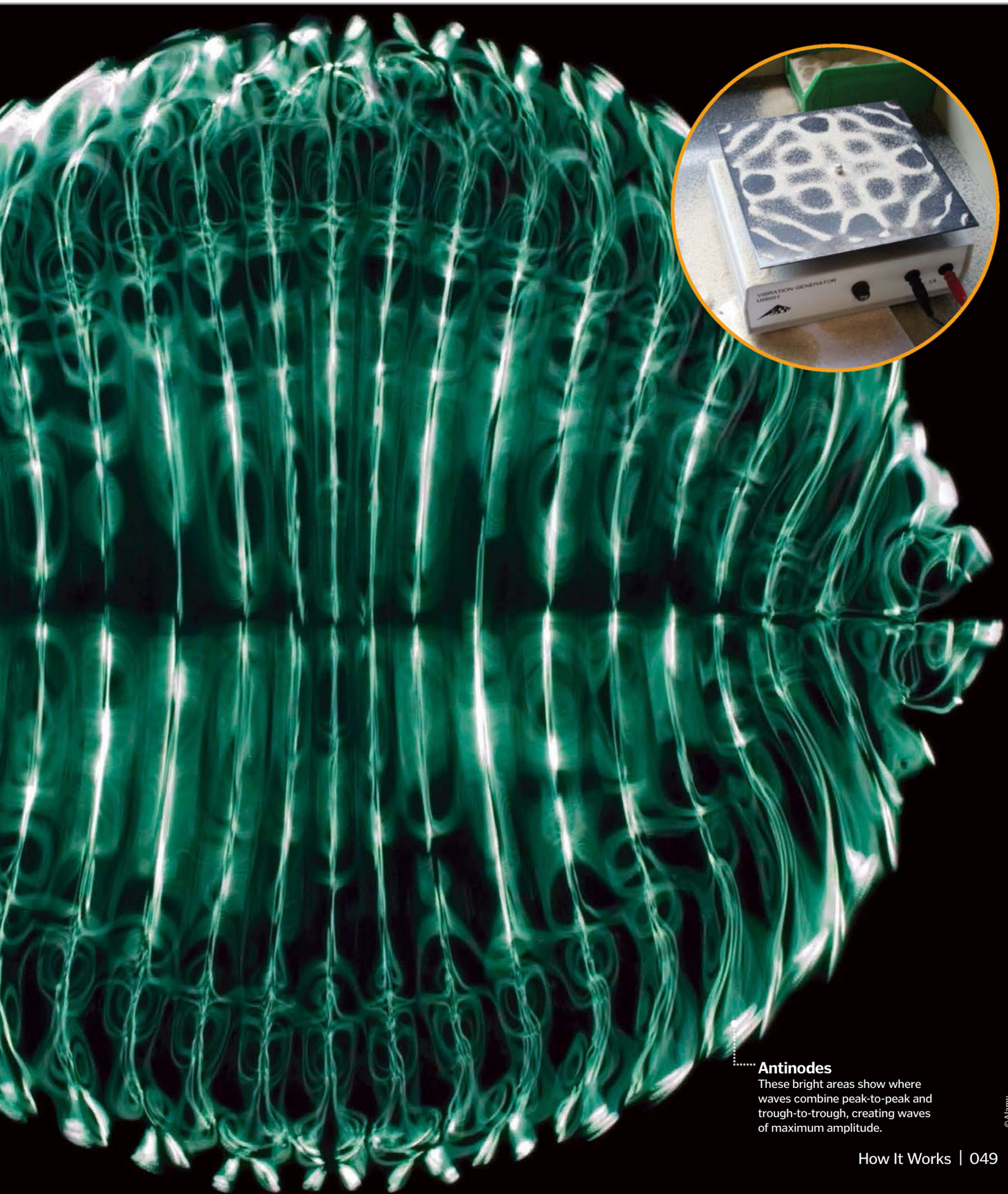


DID YOU KNOW? *Napoleon was so impressed by Chladni's cymatics research he funded a French translation of* Die Akustik



Antinodes
These bright areas show where waves combine peak-to-peak and trough-to-trough, creating waves of maximum amplitude.

5 TOP FACTS
PEPPERY FACTS

Protecting postmen
1 Pepper spray was invented in the Sixties as an animal repellant, and has been used since the Eighties by the US Postal Service to protect staff if they're attacked by a dog.

Mace vs pepper spray
2 Mace is not the same as pepper spray – it is actually a derivative of tear gas, which contains the toxic substance phenacyl chloride (CN).

Killing pain
3 Capsaicin creams and patches can be used to relieve chronic pain. Repeated stimulation of nerves with capsaicin causes them to become overloaded, preventing them from firing.

How hot?
4 The Scoville scale measures the relative heat of chillies. Pepper spray is between 500,000 and 5,000,000 (over three times hotter than a Carolina Reaper chilli).

Pepper eggs
5 Spices have been used as a weapon for centuries in Japan. The ninja made 'black eggs' containing ground spices, sand or glass to throw into their opponents' eyes.

DID YOU KNOW? *It takes two molecules of hydrogen gas (H_2) and one of oxygen gas (O_2) to make two molecules of water*

Why can't we make water?

Water has such a simple chemical structure, so why can't we replicate it in the lab?

We all know water comprises just two chemical elements – oxygen and hydrogen – both of which exist as gases in Earth's atmosphere. Making water should therefore be as simple as smashing the two together with enough force to overcome the energy barrier keeping them apart – right?

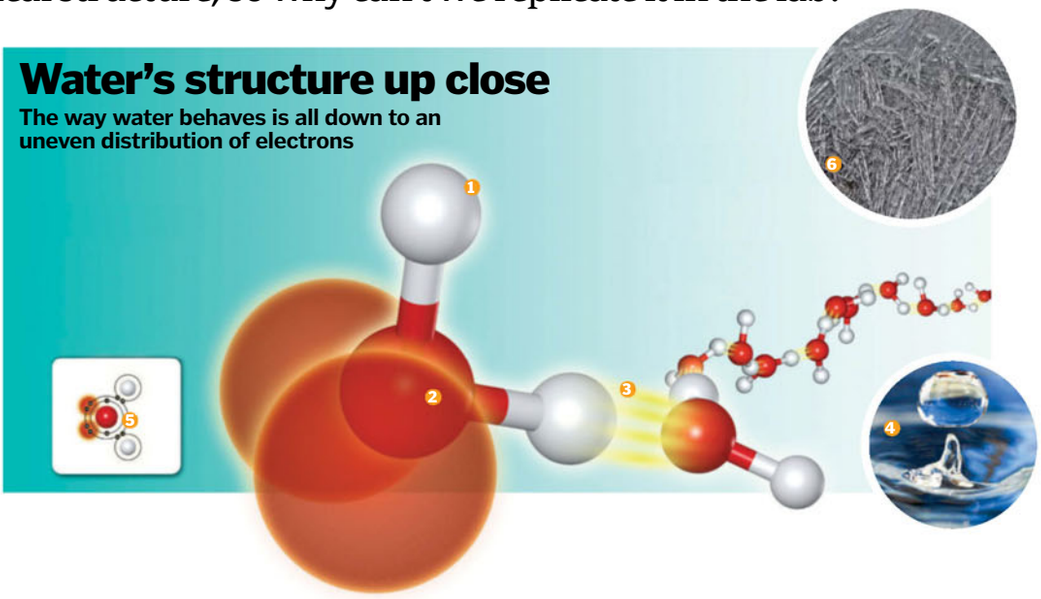
However, this reaction produces a huge amount of energy, as demonstrated in the 1937 Hindenburg disaster, when a hydrogen-containing airship caught fire and exploded. Although this reaction does create water, constructing a facility able to contain the explosion would be both technically challenging and extremely expensive.

An alternative to 'making' new water is to extract the H_2O that is already in the air. Using sheets of cooled metal, the air temperature can be rapidly dropped, allowing the water vapour to condense. The Whisson Windmill is one such invention designed to do just this; as its chilled blades rotate, they condense up to 12,000 litres (2,600 gallons) of water every 24 hours, and at very little environmental cost.

A more portable solution, designed for disaster zones, uses a generator to draw air through a cooled chamber, collecting 545 litres (120 gallons) of condensed vapour per day.

Water's structure up close

The way water behaves is all down to an uneven distribution of electrons



1 Hydrogen
The smallest element in water – hydrogen – has just one electron, which is easily drawn away by the electron-hungry oxygen atom.

2 Oxygen
Oxygen is an electronegative atom. This means it has a tendency to attract electrons.

3 Weak bond
The slight positive charge of the hydrogen atom and the slight negative charge of the oxygen produce a weak bond between adjacent water molecules.

4 Liquid
The network of hydrogen bonds between water molecules holds them closer together than similarly sized molecules, giving it a liquid state at room temperature.

5 Polarity
Oxygen attracts the electrons of both hydrogen atoms, gaining a slight negative charge as a result and leaving the hydrogen slightly positive.

6 Ice
When water freezes, it forms a hexagonal crystal structure, supported by regular hydrogen bonds.

The science of pepper spray

Discover the eye-watering chemistry behind this weaponised plant extract

The active ingredient in pepper spray – capsaicin – comes from the chilli plant. Produced to protect the plant's seeds from being crushed by the teeth of grazing animals, this molecule binds to TRPV1 receptors on the endings of pain nerves, causing them to fire and inducing a feeling similar to burning.

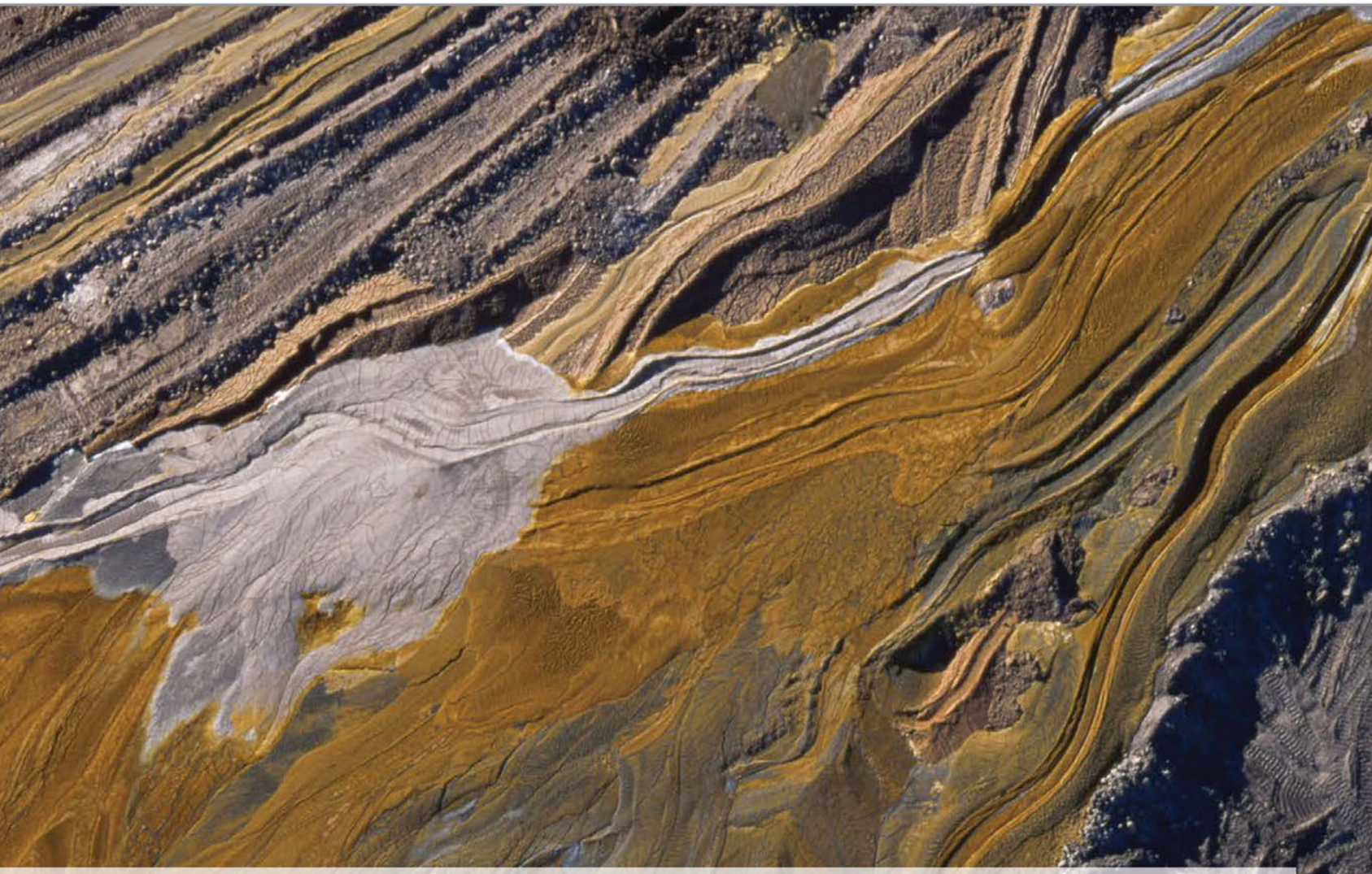
Pepper spray is a concentrated capsaicin solution that is designed to irritate the eyes, nose and mouth. It is used as a means of self-defence, in police crowd control, by the military and even as a deterrent against aggressive animals like bears in the wild.

Capsaicin does not dissolve in water, so it cannot be easily washed away, but relief from the pain can be achieved using gentle shampoo, which acts as an emulsifier, drawing the chemical into solution and away from the eyes and skin. Capsaicin will dissolve in fat, and milk or oil-based products can also help to soothe the burning sensation.

Turning chillies into a weapon

Capsaicin is a chemical deterrent contained in the fruits of the Capsicum genus, including peppers and chillies, to protect their seeds. It is not water soluble, so in order to extract it from the fruit it is dissolved in ethanol. The capsaicin-infused alcohol is removed and the fluid evaporated off, leaving a resin. To get the resin to mix with water for use as a spray, it is emulsified using propylene glycol, which helps suspend the fat-soluble particles in the watery solution. The concentration of capsaicin is then measured and adjusted before being pressurised in aerosol cans, ready for use.

"All uranium isotopes are unstable, but only one is capable of establishing a nuclear chain reaction"



Understanding uranium

Discover the chemistry of this naturally radioactive metal and how it is mined

Uranium is a metal of the actinide series: a group of large, radioactive elements, represented as an additional row on the periodic table. It is the heaviest of the naturally occurring elements and has 92 protons and 92 electrons. Like every element heavier than lead – which has 82 protons and 82 electrons – uranium is unstable and will gradually break down, emitting particles of ionising radiation.

Like all other elements, the number of neutrons in a uranium atom varies, and several isotopes of slightly different molecular weights exist in nature. All uranium isotopes are unstable, but only one is capable of establishing a nuclear chain reaction. The uranium isotope uranium-235 is a fissionable material; when it is struck by a neutron, the nucleus splits, releasing energy and more neutrons, sparking a chain reaction. It is this particular property that makes uranium an ideal fuel source for nuclear power plants, submarines and weapons, among other things.

However, the radioactive decay of uranium poses a significant danger to people and the environment. Not only is uranium radioactive, but it is also toxic and the products of its decay produce ionising radiation. Therefore, nuclear waste is handled with great care, first being stabilised and then encased in shielded vaults with reinforced, super-thick walls, either above or below ground.

Uranium has been at the heart of nuclear power for decades, but new materials and techniques are now emerging

AMAZING VIDEO!

SCAN THE QR CODE FOR A QUICK LINK

A closer look at natural uranium in the lab...

www.howitworksdaily.com

DID YOU KNOW? *All elements heavier than iron were created in the intense heat and pressure of an exploding supernova*

Mining uranium

Uranium is a commonly found element in the Earth's crust and ore deposits are distributed across the globe, with the highest concentrations in Australia, Kazakhstan and Canada.

There are three main methods for retrieving uranium. It can be extracted using open-pit mining or underground mine shafts. In pit mines, the ore is exposed by drilling and blasting before being cut directly from the ground, while underground shafts are cut for ore buried deeper down.

The third alternative is in-situ leaching, a form of chemical mining. It uses an acid or alkali to dissolve uranium in the ore into a solution, before pumping the fluid to the surface for processing.

Due to its radioactive properties, mining uranium is a dangerous pursuit. As uranium decays it produces radium, which in turn decays to form carcinogenic radon gas. Inhaled radon gas increases the risk of lung cancer. As a result, advanced ventilation systems are installed in uranium mines and workers wear protective gear.

When uranium goes nuclear

Uranium-235 is unique among the element's isotopes as it can sustain a nuclear chain reaction, as shown here

1 Neutron
Subatomic particles with no electrical charge are introduced to a reactor containing uranium-235.

2 Collision
When a neutron smashes into a uranium nucleus it gains energy and becomes unstable.

3 Fission
The uranium nucleus breaks into two parts, forming two smaller elements and releasing spare neutrons.

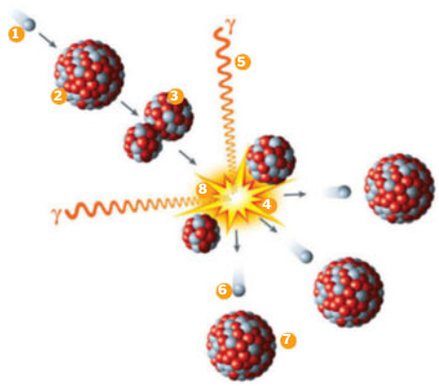
4 Smaller elements
The fission of uranium also produces smaller elements, such as krypton and barium.

5 Gamma radiation
Fission reactions release extremely high-frequency ionising gamma radiation which must be contained.

6 Propagation
A split uranium atom releases two or three neutrons, which go on to collide with more uranium nuclei.

7 Nuclear chain reaction
Uranium atoms' ability to produce neutrons when they split sets up a chain reaction.

8 Energy
Each fission event releases some 200 million electron volts of energy.



Raising the radioactivity

Natural uranium only contains about 0.7 per cent of the most useful isotope, uranium-235, which is insufficient to sustain a nuclear chain reaction. Through a process known as enrichment however, this proportion can be increased up to around 90 per cent.

In order to enrich the uranium, the uranium-235 atoms must be separated from the uranium-238 isotope that makes up over 99 per cent of the natural metal. This is usually done using a gaseous compound of uranium – uranium hexafluoride. The enrichment processes take advantage of the slight difference (less than two per cent) in mass between the two isotopes to gradually increase the amount of uranium-235. The depleted waste material is less radioactive than natural uranium, but is still hazardous and is kept in secure storage for safety.

Atomic vapour laser isotope separation (AVLIS) in action

HUNTING ASTEROIDS

Renegade rocks can wreak havoc on Earth, but an astronomical taskforce is painstakingly tracking the skies to keep us safe...

5 TOP FACTS
DEEP IMPACTS

1 Small but heavy
With an estimated mass of 10,000 tons, the Chelyabinsk meteor was roughly the equivalent weight of the Eiffel Tower – or around 2,000 African elephants!

2 Distant echoes
Low-frequency infrasound waves resulting from the Chelyabinsk explosion were detected by nuclear weapons monitoring stations as far away as Antarctica.

3 Forest floored
The 1908 Tunguska explosion is thought to have knocked down around 80 million trees in Siberia. The blast was big enough to sweep people off their feet 64km (40mi) away!

4 Danger frequency
Objects a few metres across strike Earth several times a year, those between 10-20m (33-66ft) once every few decades and those up to 100m (328ft) twice a millennium.

5 NEO classification
NEOs in Earth-crossing orbits are classed as Apollos if they spend most of their time farther from the Sun than Earth and Atens if they spend most of their time closer.

DID YOU KNOW? *In November 2013, CSS astronomers announced the discovery of two big NEOs, both up to 20km (12mi) across*

On 15 February 2013, the peace of a central Russian winter morning was shattered by the sudden appearance of a blazing light above the city of Chelyabinsk. This spectacle streaked across the sky in a matter of seconds, shining brighter than the Sun before disappearing with a huge explosion in Earth's upper atmosphere. As shockwaves from the blast reached the ground, they smashed windows and shook buildings across six cities, leaving at least 1,500 people injured.

The so-called 'Chelyabinsk Event' was tiny by the standard of interplanetary impacts, yet it still unleashed the energy of 30 Hiroshima bombs and was recorded as a 2.7-magnitude earthquake. Classified as a 'superbolide' (an extremely large meteoroid, or shooting star), it was created by a small lump of space rock only 17-20 metres (56-66 feet) in diameter. It approached Earth at about 60 times the speed of sound, heating up as it collided with air particles in the thin upper atmosphere and finally breaking apart at an altitude of roughly 23 kilometres (14 miles) in an event called an airburst. It was a timely reminder of the threat rocks from space can pose to our world.

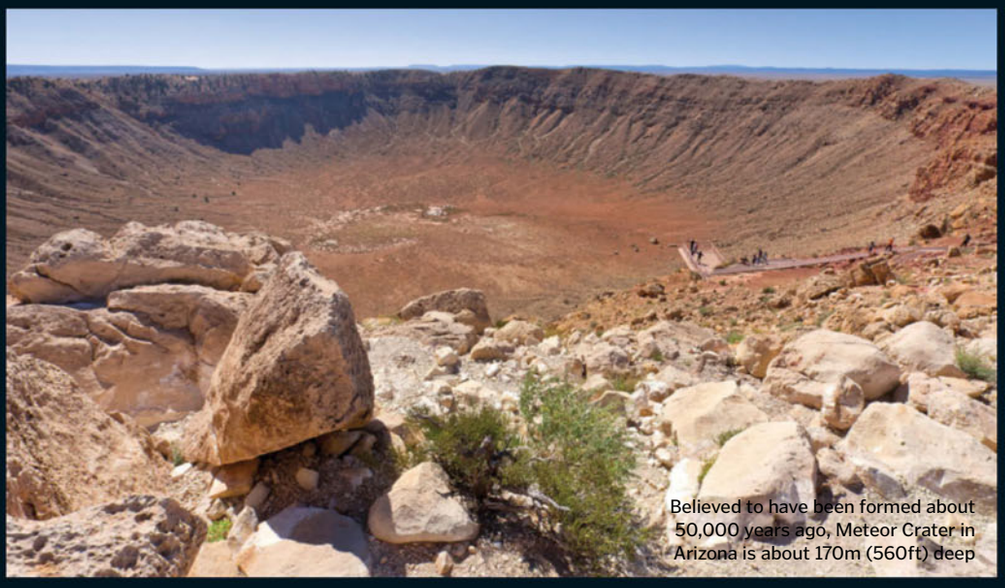
Major impacts from space are an infrequent but inevitable part of life on our planet. A century ago a similar but much larger airburst flattened more than 2,100 square kilometres (800 square miles) of forest around Tunguska, Siberia. 50,000 years ago, a 40-metre (150-foot) space rock carved the famous 1.2-kilometre (0.7-mile) Meteor Crater out of the Arizona Desert, and around 65 million years ago, a ten-kilometre (6.2-mile) impact in what is now Mexico's Yucatán Peninsula formed a crater 180 kilometres (112 miles) across and triggered a global environmental disaster that wiped out the dinosaurs and many other species.

Even if such large impacts are extremely rare, their potential consequences are so huge that we would be foolish to ignore them. The first step to defusing a threat is to know that it's coming, and fortunately, a number of teams around the world are doing their best to watch for space hazards. Just a few hours after the Chelyabinsk explosion, astronomers monitored a predicted close encounter in another part of the sky, as a 50-metre (164-foot) asteroid, designated 2012 DA14, came within 28,000 kilometres (17,400 miles) of Earth.

2012 DA14, like the Chelyabinsk meteor, was a near-Earth object (NEO) – a small asteroid whose orbit crosses or comes close to that of Earth. Because NEOs spend most of their time in nearby space they are the current focus for most major asteroid-tracking projects. These include Spain's La Sagra Sky Survey (which discovered 2012 DA14), the Pan-STARRS project in Hawaii and, most successful of all, the NASA-funded Catalina Sky Survey (CSS).

Based in the Catalina Mountains north of Tucson, Arizona, the CSS is part of the University of Arizona's Lunar and Planetary Laboratory. "We're working toward the goal of finding 90 per cent of NEOs with diameters of 140 metres [460 feet] or more," explains principal investigator Eric Christensen: "We use two wide-field telescopes, each fitted with a research-grade digital camera with a 16-megapixel CCD sensor."

Asteroid hunting at Catalina is a delicate business. The CCD images capture the faint sunlight reflected off their dark surfaces among a host of other stars, and specially ▶



Believed to have been formed about 50,000 years ago, Meteor Crater in Arizona is about 170m (560ft) deep

Incoming dangers

The small wandering bodies that have the potential to threaten Earth generally fall into two distinct categories: comets and asteroids.

Asteroids are dominated by rock, and range from solid objects to clouds of rubble loosely held together by gravity. Most inhabit the main Asteroid Belt between Mars and Jupiter.

Comets, meanwhile, consist of ice mixed with rock, and mostly originate in the outer Solar System. When disrupted, they can fall into elliptical orbits that see them pass through the inner Solar System at high speed, and an incoming 'long-period' comet on a collision course, though an extremely unlikely event, has the potential to inflict the greatest damage.

Encounters with the enormous gravity of Jupiter and other giant planets can shorten the orbits of comets and even push them into orbits around the Asteroid Belt or even as NEOs. The impact threat from comets is estimated at about one per cent of the threat from asteroids.

"For the moment, it's largely a case of watching the skies and building up our understanding of the dangers"

written software then compares several images of the same area of the sky in order to identify which objects are changing from one frame to the next. A human researcher then reviews these 'candidate' objects in order to rule out further 'false positives', in addition to known NEOs, satellites and other interlopers.

Eric Christensen takes up the story: "The original survey instrument is a 0.7-metre [2.3-foot] Schmidt telescope with a field-of-view (FOV) of 8.2 square degrees. This allows us to cover most of the night sky visible from our latitude a few times per month. Our second telescope is larger (with a 1.5-metre [4.9-foot] mirror), but has a smaller FOV of 1.2 square degrees. With this telescope we tend to survey close to the ecliptic (the plane of the Solar System), where most of the asteroids tend to reside. Until July 2013 we also operated a survey telescope from Siding Spring, Australia, which was the only professional survey conducted from the southern hemisphere. We've been the most productive NEO survey since 2005."

The range of objects that CSS or any other asteroid survey can detect depends on a variety of factors, including their size, surface brightness, distance from Earth and location in the sky. "The smallest NEO we've discovered is a few metres in diameter," Christensen continues. "The largest is a few kilometres across. Our discoveries typically fall somewhere in the range of 20-100 metres [98-328 feet] in diameter. It's an oft-repeated misconception that objects like Chelyabinsk are too small for current ground-based surveys like CSS to find. In fact, we find small objects like this on a regular basis, though the total number we have discovered represents a tiny fraction of the total population of small objects. For larger objects, a much greater proportion are known – for instance, at one kilometre [0.6 miles] and larger, approximately 95 per cent of the population have been catalogued."

So why didn't we spot the Chelyabinsk object? Part of the problem was its small size, but the meteor also approached on a trajectory that kept it hidden from view of any Earth-based telescopes and observatories, lost in the glare of the Sun.

Sometimes, though, it *is* possible to spot an incoming threat at short notice, even if there's little we can do about it. "In 2008 we discovered an object designated 2008 TC3,

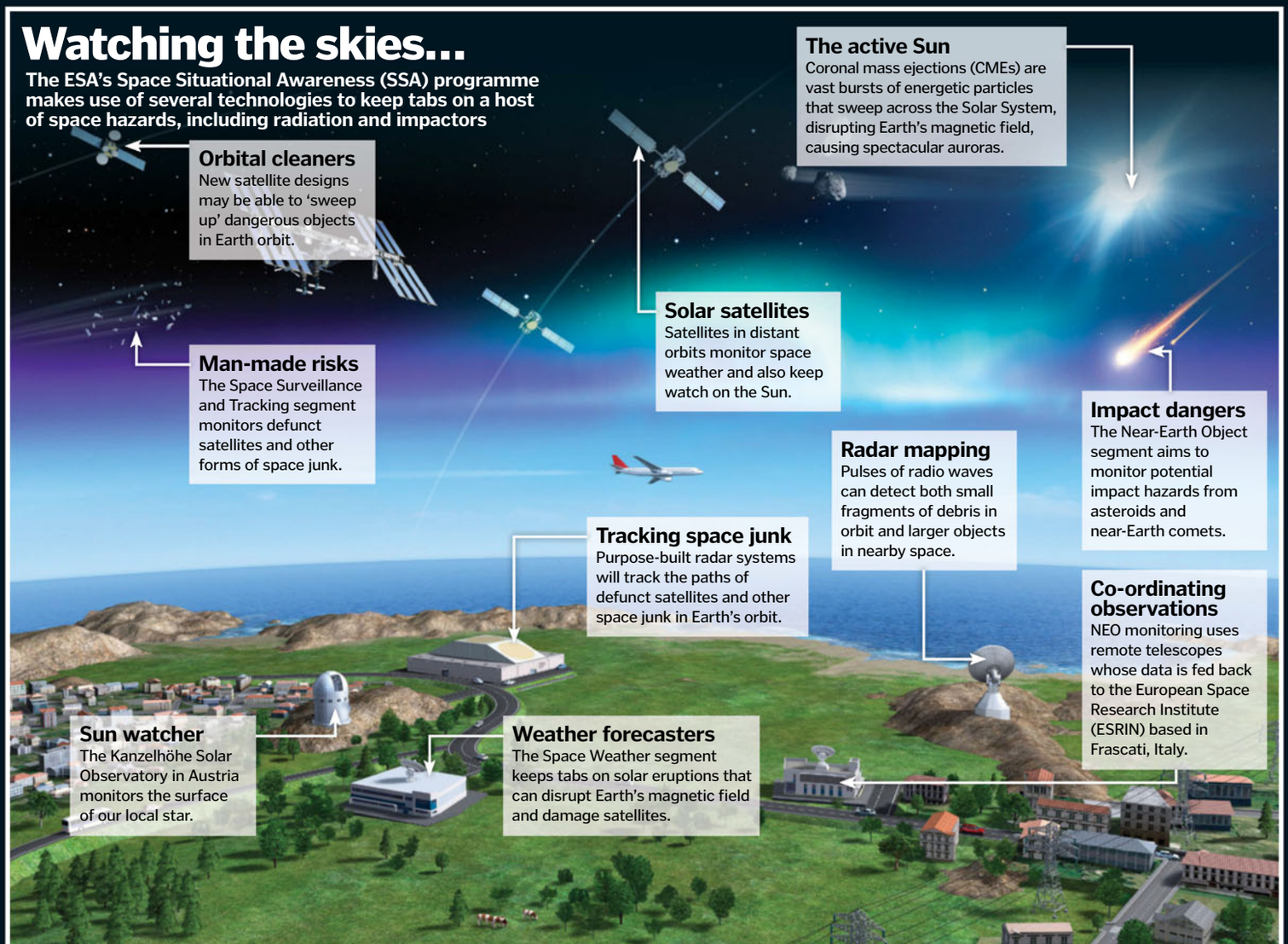
Measuring the risk

Astronomers use two impact hazard scales to describe the risks associated with NEOs. The simpler Torino Scale runs from 0 to 10. Objects rated 0 are either highly unlikely to strike Earth, or too small to survive the passage into the atmosphere, while an object meriting a 10 would be a certain impact large enough to cause global catastrophe. Low numbers are assigned to newly discovered objects requiring further observation, while numbers above 5 are assigned to objects that may threaten Earth with various degrees of devastation.

The Palermo Technical Scale, on the other hand, combines the likelihood of collision with scale of potential devastation in a more mathematical way, incorporating a background risk level for objects of the same size, set as 0. Objects with positive values are potential threats, while those with values above -2 merit more in-depth observation.

Watching the skies...

The ESA's Space Situational Awareness (SSA) programme makes use of several technologies to keep tabs on a host of space hazards, including radiation and impactors



What was so special about NEO 2006 RH120?

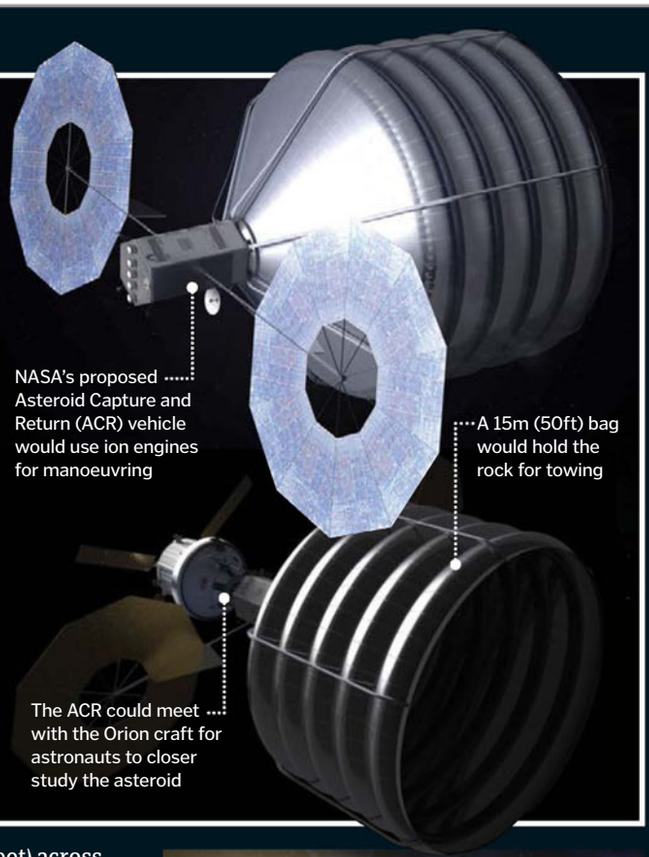
A It was CSS's 10,000th NEO **B** It was 100% tin **C** It was orbiting Earth

Answer:
In 2006, the Catalina Sky Survey discovered a small object in loose orbit around Earth. At first, 2006 RH120 was thought to be space junk, but later it was confirmed as a natural asteroid briefly trapped in Earth orbit. It has since escaped.

DID YOU KNOW? *Apophis will have several close encounters with Earth; it had a Torino level of 4 before being downgraded to a*

How to catch an asteroid

There's a big leap from detecting asteroid threats to being able to do something about them, but first we need to understand them. NASA is planning a manned mission to an asteroid by 2025, which involves launching a spacecraft to a small (read: 500-ton) asteroid, snagging it in a 'capture bag', and then hauling it back to an orbit around the Moon using a lightweight but highly efficient ion engine. Once in orbit, the asteroid could be explored by both robot probes and astronauts. Commercial organisations, meanwhile, have similar plans to not just capture asteroids, but to mine them. These rocks are potentially rich sources of metals such as iron and nickel. Understanding how to manoeuvre asteroids between different orbits, whether dragging or pushing them, with ion engines or conventional rockets, would be a major leap in our ability to protect Earth.



which was about four metres (13 feet) across. What was unusual about this object was that 20 hours after discovery, it impacted the Earth over northern Sudan," recalls Christensen: "It was reported within an hour of discovery and follow-up from other observatories refined its orbit to the point where the time and place of impact were known to one second and one kilometre [0.6 miles]. This was the first and so far only time an asteroid impact had been correctly predicted, but asteroids of this size impact Earth several times per year.

"Chelyabinsk and the Sudan meteor were very small objects, but on the larger scale we now know about 875 NEOs of a kilometre and larger – that's the threshold where an impact would likely have global consequences – and CSS has discovered 150 of those. Fortunately, such impacts are much rarer, and none of these objects have a possibility of impacting Earth within the next century. But for these bigger objects, the idea is to find them decades in advance, providing enough time to fully characterise them and plan to mitigate any likely impact."

Happily, though, our discovery of the significant threat from space has coincided with the development of technology that could help us avert disaster. In the future we may use satellites to monitor the area around for incoming objects, or even send robot or manned missions to divert the path of their orbits (see the 'How to catch an asteroid' box above for a full explanation).


NASA's WISE telescope has been given a new lease of life as an asteroid hunter

For the moment, though, it's largely a case of watching the skies and building up our understanding of the dangers. And Eric Christensen is rightly proud of CSS's contribution: "In total, CSS has discovered around 45 per cent of all known NEOs. We've incidentally discovered more than 270 comets, including a few near-Earth comets and main-belt comets in the Asteroid Belt. We have also found over 100,000 main-belt asteroids."

While we cannot yet avoid future impacts, with projects like CSS watching the skies we do at least have an ever-greater chance of advance warning, and the technology that could stop space rocks in their tracks is already well under development.

Space rocks in numbers

10,000+
Number of objects currently classified as NEOs

454 Number of objects currently on NASA's Sentry risk register

5,480km
Closest recorded NEO approach not to end in an impact (2011 CQ1)

70 Estimated number of 1km (0.6mi)-plus NEOs awaiting discovery

32km Diameter of 1036 Ganymed, the largest known NEO

1,000 Estimated total number of NEOs with diameter 1km (0.6mi) or larger

18.6km/s
Speed of the Chelyabinsk meteor's entry into Earth's atmosphere

10,000 tons
Approximate mass of the Chelyabinsk object

Every 2,000-3,000yrs
Estimated frequency of Tunguska-scale impacts

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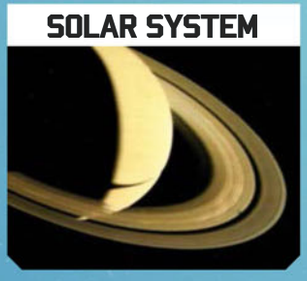

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What can be disrupted during equinoxes?

A Satellites **B** Weather **C** Birds

Answer:
Solar interference known as a 'Sun outage' affects geostationary communication satellites during the equinox. This is due to the overwhelming radiation they encounter as they pass directly through the line of sight between the Sun and Earth.

DID YOU KNOW? *Many cultures and religions celebrate or observe holidays around the equinoxes*

Equinoxes explained

They come around twice a year, but what exactly are equinoxes and why do they happen?

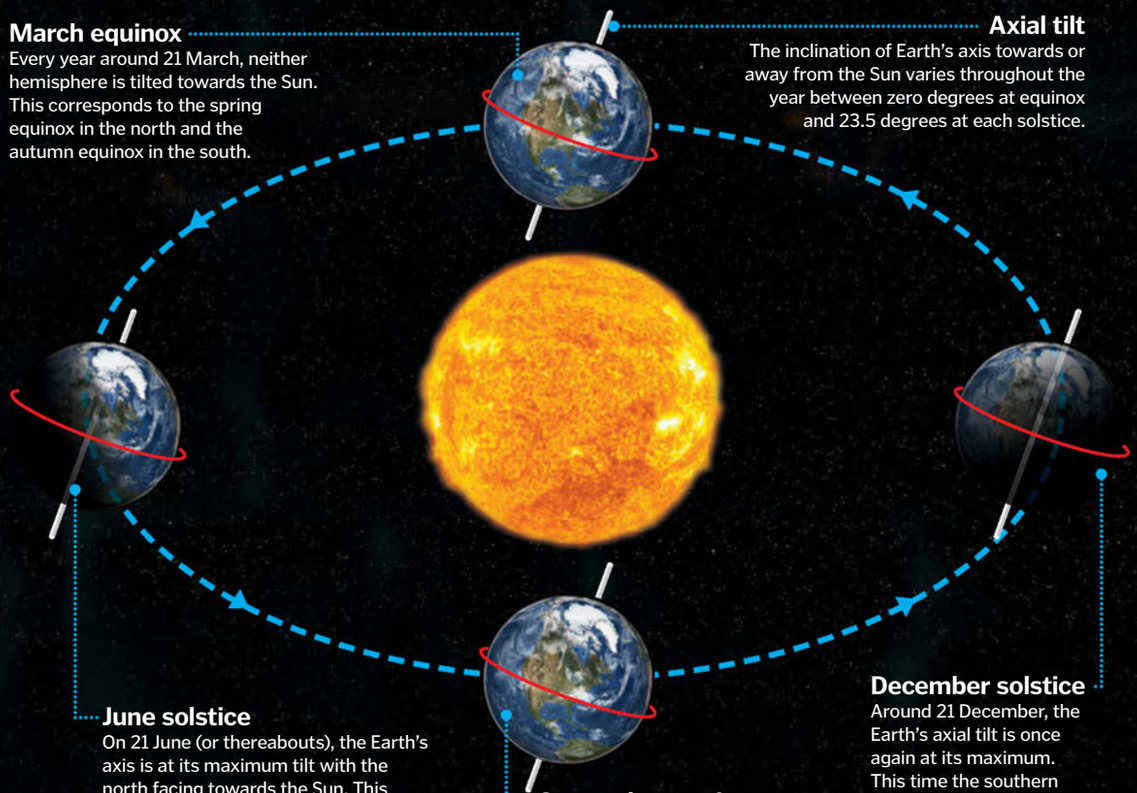
Throughout the year, Earth's axis tilts slightly towards or away from the Sun, so that one hemisphere will have a longer day than the other, depending on which is more inclined towards our star. But every March and September, Earth reaches a point in its orbit where neither hemisphere is tilted towards the Sun, as it passes directly over the equator. As a result, day and night are virtually the same length – 12 hours – no matter where you are on Earth.

Despite the term equinox, which is Latin for 'equal night', day and night are not *exactly* the same globally. Variations in atmospheric temperature and pressure affect the extent of refraction of sunlight, which causes the Sun to be visible for longer than 12 hours.

Technically, daytime is also longer as sunrise is the moment the upper edge of the Sun, rather than its geometric centre, becomes visible over the horizon. This is also the case for sunset, which is defined as the moment the Sun's topmost edge disappears below the horizon.

Daylight over the year

How does the Earth's tilt affect the length of day and night?



March equinox
Every year around 21 March, neither hemisphere is tilted towards the Sun. This corresponds to the spring equinox in the north and the autumn equinox in the south.

Axial tilt
The inclination of Earth's axis towards or away from the Sun varies throughout the year between zero degrees at equinox and 23.5 degrees at each solstice.

June solstice
On 21 June (or thereabouts), the Earth's axis is at its maximum tilt with the north facing towards the Sun. This creates the year's longest day in the northern hemisphere and its longest night in the southern.

September equinox
Occurring around 22 September each year, the Sun shines directly on the equator, meaning that a 12-hour day is observed across the globe.

December solstice
Around 21 December, the Earth's axial tilt is once again at its maximum. This time the southern hemisphere faces towards the Sun, resulting in the north's longest night and the south's longest day.

Ageing the universe

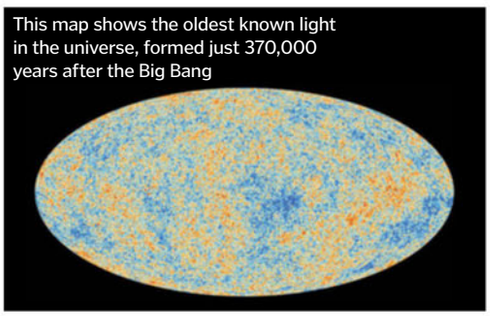
What techniques do we use to pin an age on the cosmos?

The age of the universe is calculated by measuring its rate of expansion and working backwards to the Big Bang. It was first estimated by American astronomer Edwin Hubble, whose initial calculation we have improved upon today.

In 1929, Hubble realised the universe is expanding when he noticed the farther a galaxy was from Earth, the faster it was moving away. From this he came up with a value for the rate of expansion of the universe, known as the Hubble Constant, which he estimated at 500 kilometres (310 miles) per second per megaparsec (3.26 million light years). Although his value was somewhat higher than what we now know it to be, it allowed him for the first time to put an age on the universe: the time that had elapsed since the Big Bang.

However, our calculations are dependent on the rate of acceleration of the universe's expansion. If it's getting faster the universe might be older than we think, and vice versa.

Our current estimate for the age of the universe is 13.82 billion years. Scientists have managed to refine, revise and improve this value using a more recent model called the Lambda-CDM (Cold Dark Matter) model, which builds upon Hubble's calculations to take into account other factors that could influence the age of the universe, including cosmological inflation and dark energy.



This map shows the oldest known light in the universe, formed just 370,000 years after the Big Bang

"Lagrangian points are fascinating, and it just so happens they are incredibly useful for space exploration"

Gravity-neutral space

Learn how Lagrange points are able to perform a cosmic balancing act

Any two bodies that are gravitationally bound, such as Earth and the Sun, have five regions of gravitational stability. In these regions, the forces of gravity from the two bodies balance out, and anything located at these regions, known as Lagrangian points (or simply Lagrange points) will remain stationary.

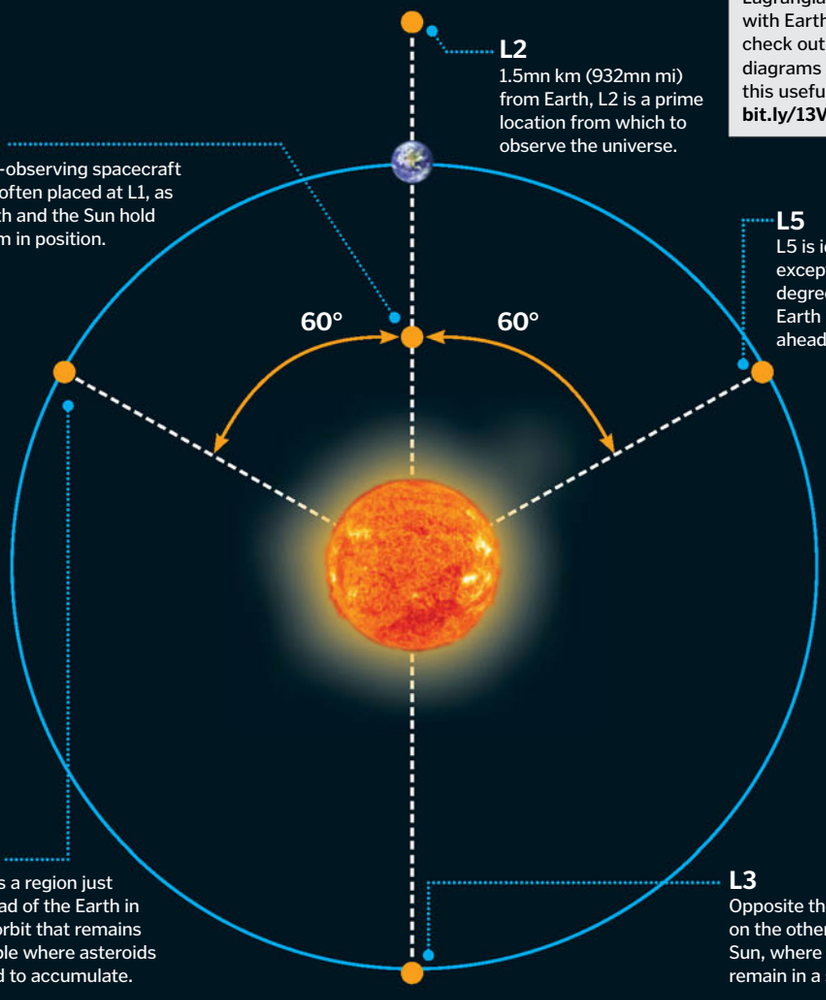
Lagrangian points are fascinating, and it just so happens they are incredibly useful for space exploration. To understand how they occur, let's examine the Earth-Sun system. Earth, as we know, is in a stable orbit around the Sun. Our planet and the star are pulling on one another. As you travel away from Earth, the gravity of the planet pulls you back. At the same time, however, the gravity of the Sun pulls you inward into the Solar System. Travel far enough from Earth in the direction of the Sun, and you will be pulled into the Sun. Conversely, if you travel only a short distance from Earth with a speed that is not great enough to escape the planet's gravity, you will be pulled backwards.

However, there are points around the Earth-Sun system, or indeed any such system, such as Venus and the Sun, for example, where the gravity of each body essentially 'balances out'. In the diagram you are able to see the areas where these points occur.

The interesting thing about Lagrangian points is that an object placed on them will remain stationary, if it is not already moving, unless acted upon by something else. This makes Lagrangian points crucial stopovers for many spacecraft (see boxout below).

Earth-Sun Lagrange points

Around Earth and the Sun are five regions of gravitational stability



Learn more

To see where the Lagrangian orbits fit in with Earth and the Sun, check out the animated diagrams available at this useful ESA website: **bit.ly/13V88oH**.

Making use of Lagrange points

Over the past few decades many spacecraft have made use of Lagrangian points in the Earth-Sun system, specifically L1 and L2, for a number of reasons.

L1 is an area of stability between Earth and the Sun. It is a prime location for Sun-observing telescopes, as they can get full views of the entire Sun over the course of a year without interference from Earth. In addition, the don't need to exhaust much fuel to remain in position.

L2, on the opposite side of Earth, is a good location for space observatories as they can get views of the universe without any obstruction from Earth. It has also been touted as a possible location for a future space station that could be used as a 'pitstop' for manned spacecraft venturing further into the Solar System.

Meanwhile, Lagrangian points L4 and L5 are known to play host to numerous asteroids and could be a viable destination for future asteroid-hunting spacecraft.

The International Sun-Earth Explorer 3 (ISEE3) was the first spacecraft to orbit a Lagrange point (L1) in 1983

Snooze at the Zoo!

A great experience from...

Discover the Fun!
PARADISE WILDLIFE PARK

Imagine falling asleep to the distant howling of wolves and waking up to the lions' roar. Well now you can, and you don't have to travel to Africa either! Paradise Wildlife Park in Hertfordshire has just launched their new overnight visitor experience, 'Snooze at the Zoo'.

The park is giving guests the opportunity to spend the night in one of three themed luxury apartments, Tiger, Leopard or the largest of the three, the Zebra suite. Each room has been designed to the highest standard to ensure all guests get a good night's sleep before an action packed day at the park. But rest assured you certainly won't need an alarm clock as the lions will be on hand to help. Continental breakfast is served in the secluded Tiger Treetops Cafe. Exclusively yours for the morning, it overlooks the tiger enclosure. Devour freshly made croissants and coffee while the tigers enjoy their breakfast with you!

You're then free to spend the rest of the day enjoying the activities Paradise has to offer. These include three adventure playgrounds, mini golf and the Paradise Lagoon paddling pool. The highlight of your stay is a VIP guided tour by one of the well trained keepers. You'll learn all about the conservation work that happens at the park, and can get hands on with some of the smaller creatures too. But the fun doesn't stop when the gates close. After hours you will have exclusive use of the Paradise Lagoon and Woodland Walk surrounded by foxes, deer and owls. To finish the day the park has teamed up with a selection of local restaurants to give you exclusive discounts for your evening meal.

Come and Snooze at the Zoo, in Paradise in 2014!

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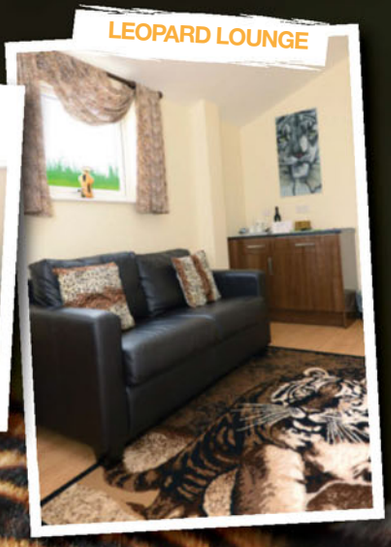

Paradise Wildlife Park is signposted from junction 25 of the M25. The Park is easily accessible by train to Broxbourne mainline station. Paradise operates a mini bus service for £1 per person to and from the station.

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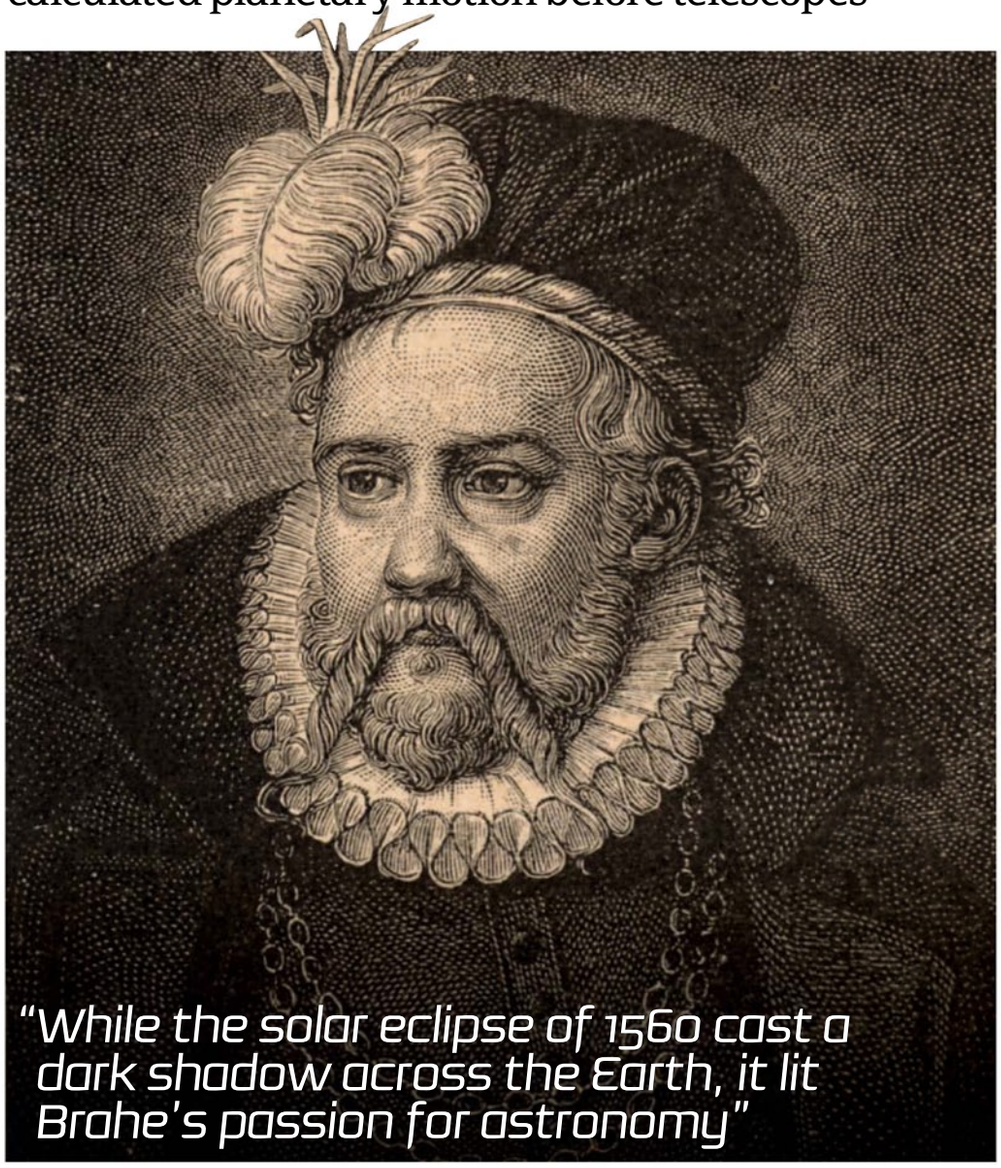
Tycho Brahe

Meet the man who coined the term 'nova' and calculated planetary motion before telescopes

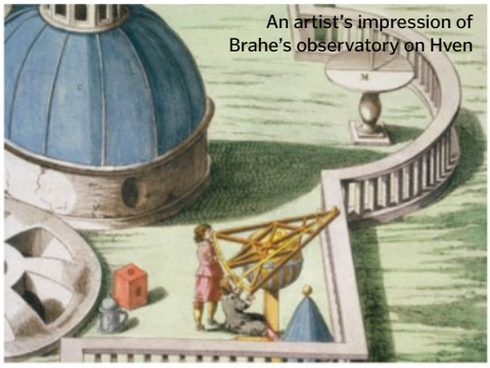


"While the solar eclipse of 1560 cast a dark shadow across the Earth, it lit Brahe's passion for astronomy"

Few other naked-eye astronomers have plotted the movement of planets quite as accurately as Danish nobleman Tycho Brahe. His observations of a new star in 1572 and the Great Comet of 1577 helped to shake off the Aristotelian belief that the planets and stars were unchanging and locked in 'immutable' celestial spheres.

Brahe's schooling began at an early age. Indeed, at just two years old, he was taken from the family home by his uncle to start his education. At age 12, he began studying law at the University of Copenhagen, as was the norm for sons of nobility. However, while the solar eclipse of 1560 cast a dark shadow across the Earth, it lit Brahe's passion for astronomy, and he emerged himself in the works of the great astronomers of the time.

For some time Brahe studied abroad, but upon his return another uncle – Steen Bille – funded the construction of an observatory and chemical laboratory at Herrevad Abbey. It was here in 1572 that he first noticed the appearance of a very bright star. At the time, the popular theory was that the planets and stars were carried on material spheres (spherical shells) that fitted tightly around each other. Brahe's observations proved that his sighting was indeed a new star and not a local phenomenon, and therefore this arrangement was impossible. A year later he published his first book – *De Nova Et Nullius Aevi Memoria Prius Visa Stella*



An artist's impression of Brahe's observatory on Hven

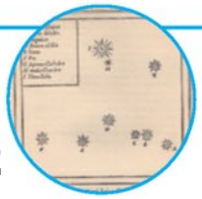
A life's work

A quick guide to Tycho Brahe's illustrious career as an astronomer

1546
Tycho Brahe is born at Knutstorp Castle in the then-Danish Scania, to nobleman Otte Brahe and his wife Beate Bille.

1559
Brahe begins his studies in law at the University of Copenhagen.

1560
The prediction of a solar eclipse on 21 August 1560 impresses Brahe enormously, and inspires him to study astronomy.



1572
Brahe first observes a new star, now known as SN 1572, from the Herrevad Abbey observatory.

1573
Brahe publishes his book, *De Nova Stella*, coining the term 'nova' for a new star.

Kepler collaborated with Brahe and continued his work after he died

Brahe was born a nobleman, but became fascinated by astronomy at an early age

In their footsteps...

Johannes Kepler

During his time in Prague, Brahe was assisted by Johannes Kepler, a former maths teacher from Germany. The pair had come head-to-head after Kepler publicly criticised the Tychonic system. In 1601, Brahe invited him to Prague and was so impressed by his ideas that he made him his successor. Kepler then used Brahe's data to develop his three laws of planetary motion.

Isaac Newton

Brahe and Kepler's work provided a foundation for Sir Isaac Newton's laws of gravity, presented in 1687, explaining how the planets could stay in orbit without being fixed to solid spheres. Gravity also meant that the planets must orbit around the Sun. He also modified Kepler's third law, stating that all the planets and the Sun orbit around a common centre of mass.

The Tychonic system

The Tychonic system is a model of the Solar System developed by Brahe. Unlike Copernicus's heliocentric model (with the Sun at the centre), he believed that Earth was too 'hulking' and 'lazy' to be continuously in motion. Religion also played a part in Brahe's rejection of heliocentrism, and cited the Bible in his work. Instead, he suggested a 'geo-heliocentric' model in which the Earth is at the centre of the universe, with the Sun and Moon orbiting the Earth and the other planets orbiting the Sun.

(*On The New And Never Previously Seen Star*) – and it was from this that the term 'nova' came into common use to describe a new star.

After another tour abroad, King Frederick II, desperate to keep Brahe in Denmark, offered him the island of Hven and funding to set up another observatory. In 1576 Uraniborg was built, and later an underground observatory called Stjerneborg. As well as being observatories, they also functioned as workshops where Brahe designed and built new instruments. With these he was able to make incredibly accurate observations and the precision of his celestial positions was said to be more accurate than any before.

When King Frederick died in 1588, Brahe's popularity declined. In 1599, after falling out with the new king, Christian IV, Brahe moved to Prague (then part of Bohemia). Sponsored by the Bohemian king Rudolph II, he built a new observatory at Benátky nad Jizerou. Here he was responsible for compiling the Rudolphine Tables – astronomical tables that would allow calculations of the planetary positions for any time in the past or future. Here Brahe also met Johannes Kepler, who came to be his assistant until Brahe's death in 1601. He entrusted the continuation of his extensive research to Kepler, who published the finished astronomical tables 26 years later.

Top 5 facts: Tycho Brahe

1 Naked eye
Brahe was the last of the major naked-eye astronomers, as it wasn't until seven years after his death that the first telescopes came into use.

2 Hard nosed
At the age of 19, Brahe lost the bridge of his nose in a sword fight with a fellow student. For the rest of his life he wore a metal prosthesis.

3 Tycho the tyrant?
It is rumoured that Brahe led an oppressive regime on the island of Hven, and that he was deeply despised by the people living there.

4 Murder mystery
It was suggested that Brahe had been poisoned, but after being exhumed from his grave in 2010, results indicated that he probably died from a burst bladder or similar.

5 Lunar legacy
Brahe lives on among the stars – literally. The crater Tycho on the Moon is named after him, as is the crater Tycho Brahe found on Mars.

1576
King Frederick II of Denmark offers Brahe the island of Hven, where he builds the Uraniborg observatory.

1577
Brahe's observations of the Great Comet (above) prove that objects can move through the celestial spheres.

1599
After a disagreement with the new Danish king Christian IV (right), Brahe moves to Prague, becoming Bohemia's official imperial astronomer.

1601
Brahe suddenly contracts a kidney or bladder ailment and dies 11 days later, aged 54.

BUILDING DEMOLITION

What goes up must come down – but how exactly do we recycle giant buildings?

An excited hush falls across the deserted tower block. Neighbouring residents look on as the police helicopter overhead double-checks that the exclusion zone is clear. The countdown reaches zero and the button is pushed. An explosive shockwave ripples through 1,500 separate charges, shattering the supporting concrete columns. With surprising grace, the huge 24-storey tower block folds downwards into a billowing skirt of dust.

The mere seconds it takes for the building to come crashing down might be the only part that makes the local evening news, but the real work can extend for months before and after the big bang. Mark Coleman is the managing director of Coleman & Company – one of the UK's leading demolition firms. In an exclusive interview, he talks us through the key stages in the high-rise demolition process.

The first four or five months are spent planning, he explains: "The Health and Safety Executive, the local council… the people who are being evacuated, the firearms and explosives division of the police: you've got to convince these people that you are competent. You have a structural engineer to ensure that up to the point of pressing the button, the building will stand up; an explosives engineer to make sure that at the point of pressing the button, the building will fall down, and that it will fall down at the right place, not spread too far and not damage anything."

Work begins by stripping the building completely. Specialist contractors remove toxic materials, such as asbestos. Furniture, fitted cabinets, electrical wiring, plumbing, flooring and even the windows and plasterboard panels are all taken out as well. In fact, Coleman & Company aims to recycle as much as 98 per cent of a building during the demolition process, and it's much easier to do that *before* it is reduced to rubble. "We don't even throw settees in the skip any more," says Coleman. "We take the fabric off and that gets shredded, we strip the wood, that gets recycled and any metal in there goes into the scrap metal skip."

Once the building has been reduced to a concrete shell, the next six to eight weeks are

5 TOP FACTS
EXPLOSIVE TYPES

Dynamite
1 Invented by Alfred Nobel, dynamite consists of unstable nitroglycerine mixed with fine clay to make it safer. It needs careful handling, and isn't used for demolition anymore.

PETN
2 Pentaerythritol tetranitrate is chemically similar to nitroglycerine and is one of the ingredients of Semtex. In demolition, PETN is used as the detonating cord core.

TNT
3 Trinitrotoluene is a stable high explosive used in demolition. It needs another more sensitive explosive to set it off, and can be melted and poured into moulds without detonating it.

RDX
4 Also known as hexogen, RDX is even more powerful than TNT. It is used as a cutting charge in demolition to sever stronger structural steel beams.

Tovex
5 This water-gel explosive which includes ammonium nitrate has replaced dynamite in many cases – mainly because it's less toxic and is generally safer to use and transport.

DID YOU KNOW? *Police helicopters use thermal-imaging cameras on demolition days to look for anyone still in the building*

High-stakes demolition

When it was built in 1908, the headquarters of the Singer sewing machine company in Manhattan, New York, was the tallest building in the world. When it was demolished in 1968, it was the tallest building ever to be torn down. If you don't count the terrorist destruction of the World Trade Center in 2001, it still is. Since Lower Manhattan is so crowded, explosive demolition was out of the question in this case. Instead, the 47-storey building was demolished the same way it was built – with a crane on the top and crews of workers who dismantled it floor by floor.

Types of demolition

We weigh up the pros and cons of three deconstruction methods (1 = low/5 = high)

Machines	
Noise	5
Risk level	4
Disruption	5
Total time	3
Expense	3

Explosives	
Noise	3
Risk level	5
Disruption	3
Total time	4
Expense	4

Hydraulic jacks	
Noise	1
Risk level	2
Disruption	2
Total time	2
Expense	5

Jets of water are often blasted at buildings during demolition to reduce dust levels

spent 'pre-weakening' of the structure. "This does two things," Coleman continues. "One, it allows you to get access [for the explosive charges], but two, it also allows you to use fewer explosives to collapse it. Typically, you remove 1.5-metre (4.9-foot) rectangular arches out of a wall and then try to demolish the next two to three metres of concrete by the use of explosives. BS5607, which is the British Standards code for the Safe Use of Explosives, says you need to minimise the amount you use, so you're not blasting the hell out of it and sending concrete flying all over the place."

The type of explosive used depends very much on the building. A tower block is a relatively weak structure, held up by simple reinforced concrete pillars. These can be destroyed using detonating cord. This resembles coaxial TV aerial cable, but the core is filled with PETN (pentaerythritol tetranitrate) high explosive. This 'det cord' is used as a high-speed fuse for large jobs; it burns at about 7.2 kilometres (4.5 miles) per second, but for tower blocks it has enough explosive power to get the job done by itself. "When you start moving into bigger, more industrial structures – eg power stations and heavy concrete or steelwork – it's a different ball game altogether," explains Coleman. "You are now into shaped, cutting charges. You use these to induce failure in the already pre-weakened section – to blast out the remaining piece that's holding the whole thing together."

While the drilling and pre-weakening is going on, arrangements have to be made for the nearby residents. "Typically on an inner city site, you can be evacuating a few hundred properties and catering for a few thousand ▶

Demolition machines

1 Wrecking ball

A steel ball weighing up to 5,400 kilograms (12,000 pounds) is swung from a long chain. At one time the most common demolition machine, the wrecking ball is used much less now because it has a shorter reach than modern excavators.

2 High-reach excavator
A variant of the JCBs used to dig ditches, the high-reach excavator has a much longer boom arm and a wide base to provide a stable platform. The tallest excavators can reach 67 metres (220 feet) – about 23 storeys – and weigh 200 tons.

3 Concrete pulveriser
The concrete pulveriser is a huge hydraulic hammer. They can weigh as much as six tons, and are used to break up thick foundation slabs and chisel away at stubborn concrete pillars.

4 Shears

This attachment chews up walls and beams using powerful jaws. Large ones can open up to 1.2 metres (four feet) wide and weigh over four tons. Their bite force is 145 tons – about 40 times as much as a Tyrannosaurus rex!

5 Brokk robot
Where access is restricted or the maximum loading of a supporting floor is limited, specialist robotic demolition machines offer much higher power-to-weight ratios than manned excavators. The Brokk 50 can pass through ordinary doorways and climb stairs.

"Demolition day is nearly always on a Sunday to minimise the disruption to traffic and businesses"

people on the day, so it's a bit like a military operation," says Coleman. "You have to survey and contact each of the properties for any issues such as security and pets. We have to create a safe, sterile environment, which is generally [equivalent to] three times the height of the structure. So, say, if you have a building that is 50-70 metres [164-230 foot] high, you are talking about an exclusion zone in the region of 150-200 metres [492-656 feet].

"Generally, we try to negotiate our way through it without money changing hands. So if you're close to the structure, we'll put you up for the weekend at a hotel. If you're not too close we might look at other proposals, such as locking you into the building and putting a policeman outside. It's all about finding [the safest] process. If you're standing within a few metres of the building you're going to get squashed, but if you're 50 metres [164 feet] away you've got no problem."

A week or two before the day of the demolition, the detonating cord is fed into the holes and grouted firmly in place. This improves the detonation efficiency as the expanding gas from the explosives has nowhere to go and the force is concentrated into the concrete wall.

But it also prevents the explosives from being stolen by opportunist thieves or terrorists. There is no risk of accidental explosion without the detonators, but to be safe the ground floor of the demolition site is still guarded around the clock by specialist security teams.

Demolition day itself is nearly always on a Sunday to minimise the disruption to local traffic and businesses. Around 5am, workers begin surrounding the perimeter of the demolition exclusion zone with security fencing. "Around the fence zone we have sentries, and they all have to have a line of sight between each other so they can maintain visual security of the zone in the event of the radios not working," Coleman explains. "Each sentry will have a police officer with them, so if there is a breach the police will deal with it."

The spider's web of detonation cord laced through the building is brought together into bunches at strategic points, and at about 7am, the explosives engineer begins attaching the detonators to each bunch. Even at this point, key connections are left open in order to ensure absolute safety: "They wait there ready until the team can say, guaranteed, everyone is out. Then we'll start a ten-minute countdown, with a series of final connections carried out in the last few minutes. There's a series of horns that sound to keep everybody alert. There's an electric atmosphere in the air and a deathly silence falls.

"When we're doing the countdown, we'll count from 20 down to ten, and that will be audible over the radios, then you'll hear a shot go, which we use to frighten any birds out of the building. And then everyone will think 'What's happening?' But we've actually started the real ten-second countdown; the purpose of the radio silence is that in those crucial seconds, if someone needs to [stop the blast], all they need to do is say, 'Abort!'."

Incredibly, it takes between just three and five seconds for a 45,000-ton tower block to crumble down into a pile of rubble. Once the dust has settled, the explosives engineer inspects the debris to be certain that all the explosives detonated. Next excavators and street-sweeping machines and workers with brushes and brooms move in to clean up the surrounding area, and the neighbouring

How to implode a tower block

A step-by-step guide to blowing up several thousand tons of concrete and steel with maximum safety and efficiency

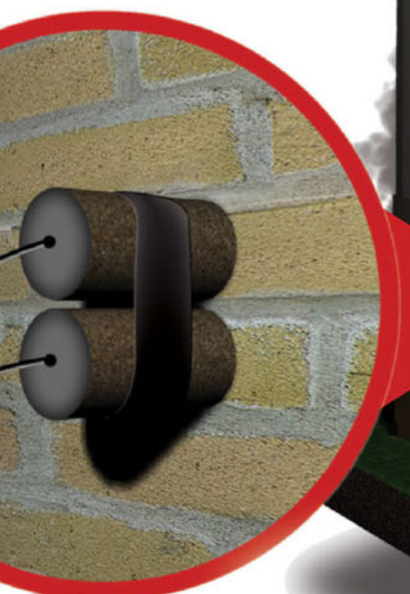
DID YOU KNOW? *The largest building demolished with explosives was the Sears Merchandise Center in Philadelphia*

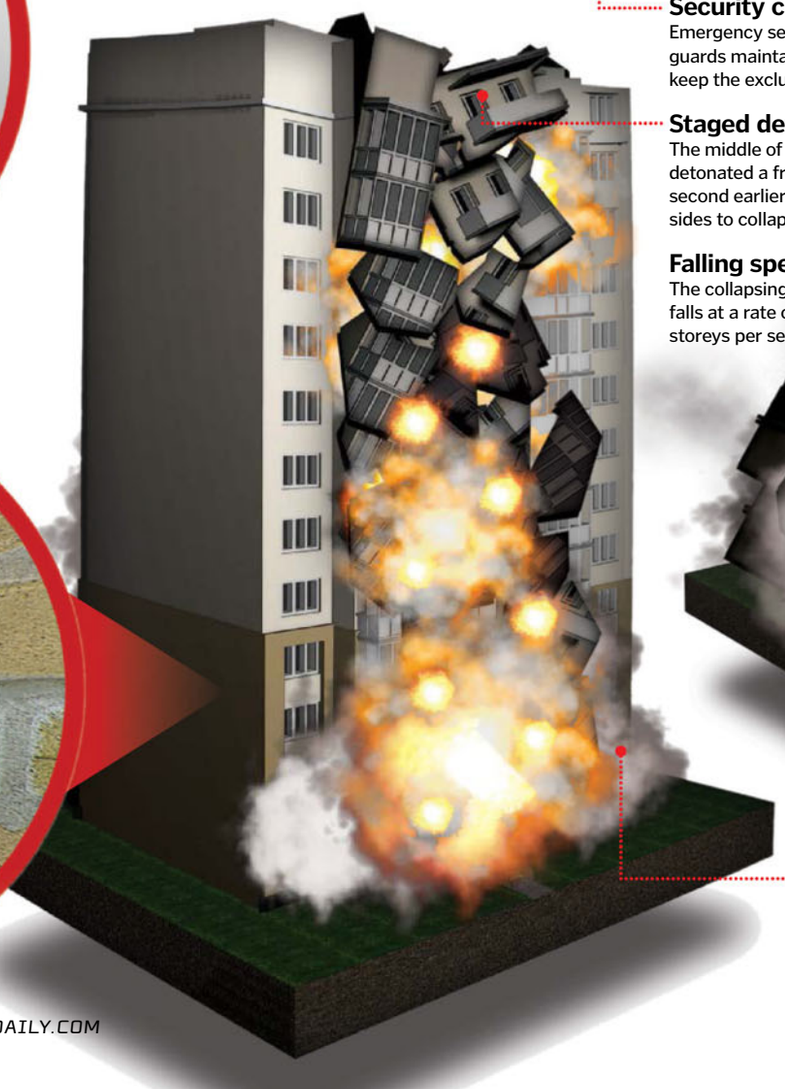
residents are allowed back into their homes. "Then we lift the fencing and go off to the pub for a couple of pints," says Coleman. "After that we come back for typically about 12 weeks to munch up all the material and remove it from the site. Once it's all been taken away and we have exposed the slabs of the foundation, they are then broken out, processed and removed, and the void is backfilled and ready for the house builders to take over the site."

A forensic operation

When a building catches fire or partially collapses, it can be so badly weakened that demolishing it is the only way to make it safe. If there are fatalities, the bodies must be carefully extricated. But if arson or negligence is suspected, demolition contractors must try to preserve any evidence for accident investigators. The building has to be peeled away one layer at a time without disturbing the layers below. Sometimes a building actually has to be strengthened before it is torn down to ensure it doesn't collapse in an uncontrolled way.

An exclusion zone with sentries is set up around the demolition site to ensure no one enters





Security cordon
Emergency services and security guards maintain a perimeter to keep the exclusion zone safe.

Clearing up
Wrecking machines and bulldozers break up any pieces still standing and then remove the rubble and foundations.

Staged detonation
The middle of the building is detonated a fraction of a second earlier, causing the sides to collapse inwards.

Secondary charges
Explosives on the upper floors are triggered when the building is already falling to break up the rubble into smaller pieces.

Falling speed
The collapsing building falls at a rate of five storeys per second.

Flying debris
Large debris is contained using a metal-reinforced netting. Dust can be minimised by using large water hoses.

Steel girders
Buildings with heavy steel beams require much more powerful explosives, such as RDX.

"The machine must be able to withstand the extreme forces required to flatten a steel chassis"

How are cars crushed?

Learn how our old, unwanted vehicles are recycled step by step

Over 1 million cars are scrapped in the UK alone every year, but this is not the end of their life. Cars contain a wide variety of valuable metals that can be recycled and reused. Powerful car crushers compact the scrap steel, making it much easier to transport for the recycling process.

Modern car crushers tend to employ hydraulics to compact the scrap metal – using a powerful motor and large hydraulic cylinders. Pressurised fluid generates huge crushing forces behind the plates. The body of the machine must be able to withstand the extreme forces required to flatten a steel chassis, so they are constructed from even tougher materials – most often hardened steel.

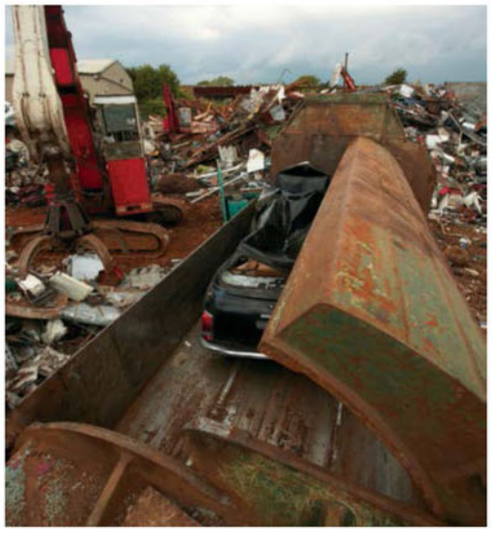
As steel is magnetic, cars can be loaded onto the crusher using a crane and a large magnet. However, other heavy machinery such as forklift trucks and cranes with lifting claws (see below) are also called upon for the task.

Once the cars have been compacted, they are shipped to a shredder with the resulting metal scraps sorted according to type before being melted down for reuse. Crushers typically contain a reservoir to collect motor oil that leaks from the vehicles during crushing, and even this can be reused.

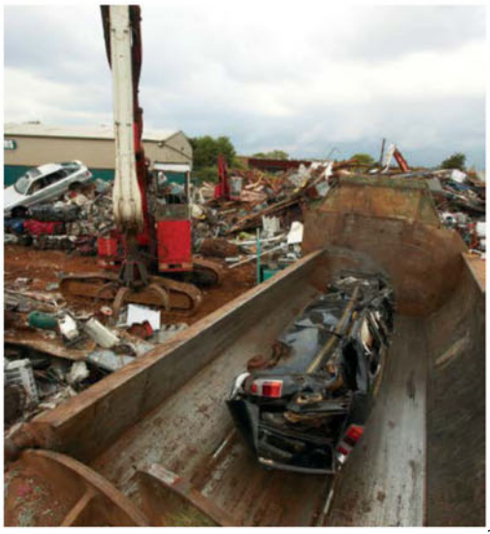
How hydraulics work

Hydraulics work on a simple principle: transferring force from one place to another using an incompressible fluid – often oil. A pump supplies oil at high pressure, which is fed to hydraulic cylinders and pistons. The fluid is not compressed, allowing most of the force to be transferred to the crushing plates. By altering the piston and cylinder size, the force generated by the pump can be massively multiplied, allowing relatively small amounts of fluid to do huge amounts of work – like scrunching up a car as easily as a packet of crisps!

1. Preparation
The car is examined to determine its condition with any reusable parts removed. The fluids are drained from the vehicle and any hazardous materials taken out, eg the battery. The stripped car is then lifted into the crusher.



2. Under pressure
Modern car crushers can be operated at the press of a button. A hydraulic crushing plate is forced onto the top of the car, producing pressures of several thousand pounds per square inch. The process takes just minutes.



3. Ready for recycling
Once the car has been compacted, it's sent to a shredder to be turned into manageable chunks, which can then be sorted and melted down. Motor oil is collected from beneath the crusher and is often recycled too.

KEY DATES
SCANNING THE PAST

1897 – The first X-ray of a mummy takes place just two years after X-rays are discovered by Wilhelm Roentgen (right).

1977 – Derek Harwood-Nash is credited with being the first person to perform a CT scan on a mummy.

2007 – A new pulse sequence with an MRI scanner is first used to scan dry ancient tissues.

2010 – 3D models of artefacts are now routinely created to preserve objects from loss, damage or theft.

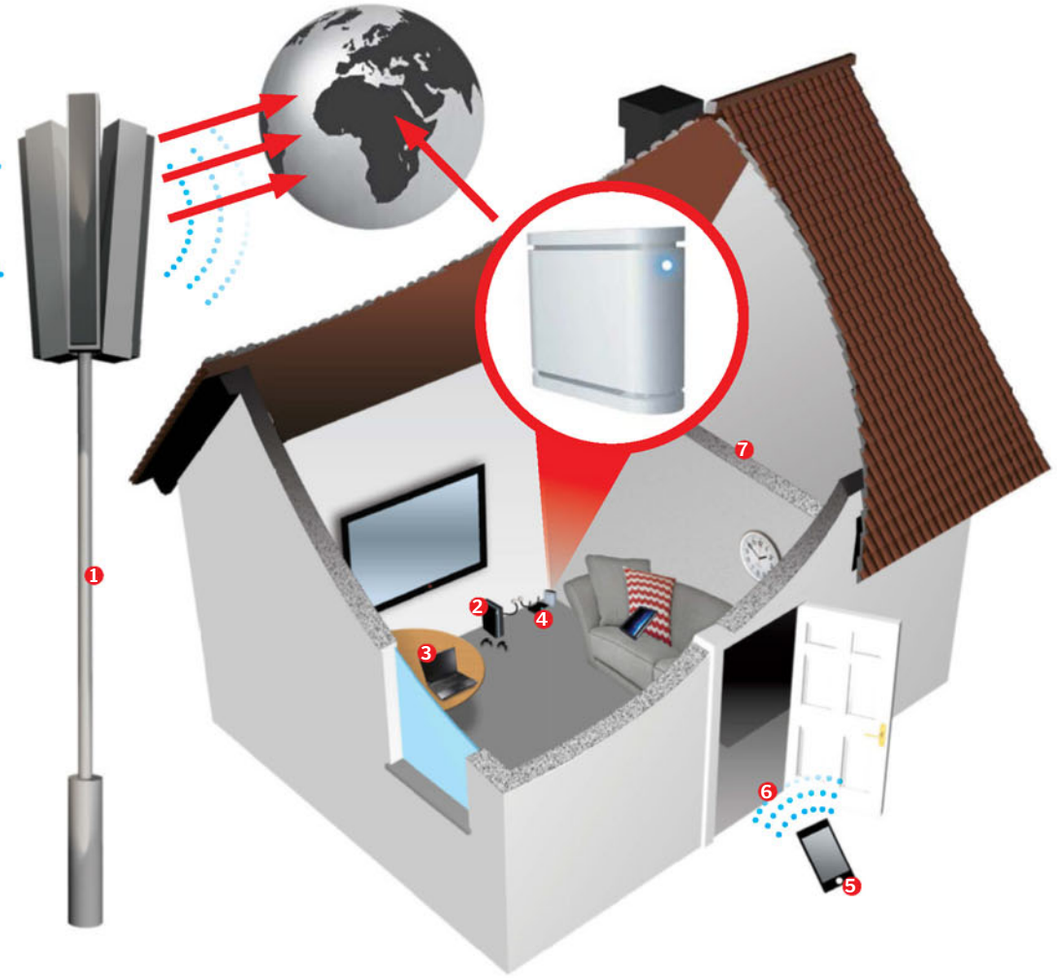
2012 – Laser-sensing technology known as LiDAR is used to search for the fabled remains of La Ciudad Blanca in Honduras.

DID YOU KNOW? *Femtocells were developed by a group of Motorola engineers, who created the first mini UMTS base station*

Home nodes explained

Find out why femtocells are perfect if you live in a signal black spot

Femtocells can be the solution to poor cellular reception by turning your broadband landline into a 'home node' – a mini mobile phone base station. Once set up, your mobile phone and other gadgets are automatically recognised and any voice calls use VoIP (Voice over Internet Protocol) data packets to connect a call. Unlike Wi-Fi, femtocells don't drain your devices' battery life either.



1 Cell tower
Rather than relying on overcrowded cell towers in the area, the femtocell interacts with the internet directly.

2 No interference
An operator-licensed spectrum is used which means there should be no interference from other technology around the home, like video consoles.

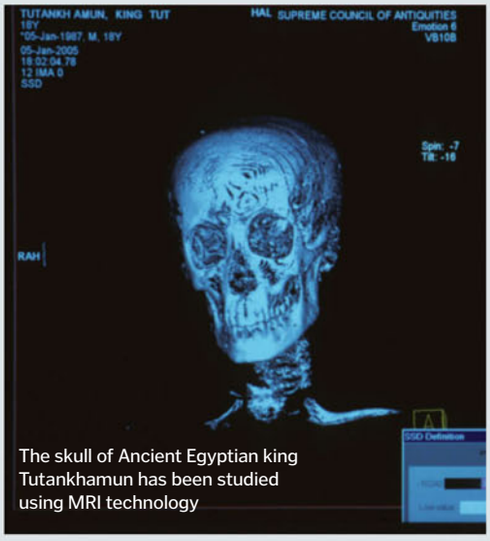
3 Home network
The femtocell automatically syncs your device with the wider home network for easy media sharing.

4 Modem
The femtocell is plugged into a spare Ethernet socket on a modem. Input your phone number via a webpage and you can start using all the usual mobile phone services.

5 Improved calls
As the femtocell is taking over voice calls, many users experience improved levels of call clarity.

6 Instant recognition
You can connect many devices to the femtocell, which are automatically recognised when they come into range.

7 Boosted signal
The femtocell increases the speed and reliability of data transmission, extending the range to about 30m (98ft), improving signal in homes with thick walls/basements.



The skull of Ancient Egyptian king Tutankhamun has been studied using MRI technology

How to scan a mummy

Why modern scanning methods are being used by archaeologists to reveal previously concealed secrets…

As some of the world's most ancient treasures are incredibly fragile, using non-invasive scanning techniques such as X-ray CT (computed tomography) and MRI (magnetic resonance imaging) allows artefacts to be examined in greater detail without the risk of damage.

Existing MRI systems use strong magnets to excite hydrogen molecules in water present in the body. But a new MRI system doesn't need a mummy, for instance, to be rehydrated before scanning. Other delicate artefacts such as papyrus documents that would disintegrate if water were to be applied are excellent candidates for this new technique.

The new MRI scanning techniques have come from research in how a quantum computer could be built. This research resulted in what is called the 'quadratic echo' that narrows the MR spectrum of solids. This technique has been used to scan bone and other solids to produce some of the first images of their kind.

"Electricity can only be generated for around ten hours per day – at high tide and low tide"

Harnessing tidal power

How do these marine power plants turn the sea's motion into electricity?

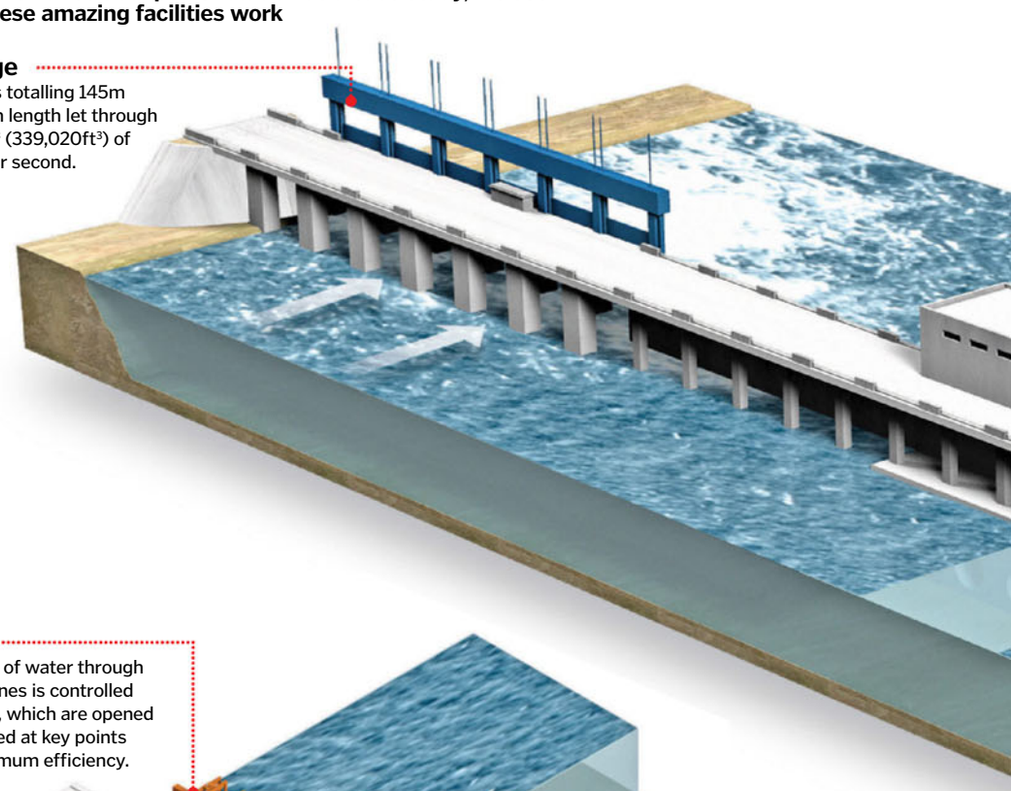
Tidal power plants use the rise and fall of tides to produce electricity. One way to harness tidal power is to build a barrage – a dam with gates that regulate water flow – across an estuary. When the gates are open, water flows through turbines, generating electricity. Water flows through at high tide, filling up the river or estuary behind it. The gates are then closed until low tide, creating a lower water level on the sea-facing side.

Next, the gates are opened, allowing the water to flow back out towards the sea. One downside is that electricity can only be generated for around ten hours per day – at high tide and low tide. However, tides are very predictable, making tidal power considerably more reliable than, say, solar or wind energy.

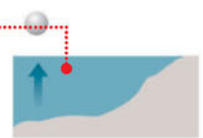
One of the negatives is that building tidal power plants often requires emptying parts of an estuary, which can have devastating consequences for local marine life.

Turning tides into electricity

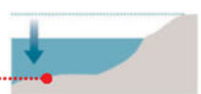
Using the Rance tidal power station as a case study, we see how these amazing facilities work



Barrage
Six gates totalling 145m (476ft) in length let through 9,600m³ (339,020ft³) of water per second.



High tide
The gravitational force between the Moon and Earth (as well as the Sun) pulls on the oceans, generating tides. High tide usually occurs when the Moon is directly overhead or underfoot.



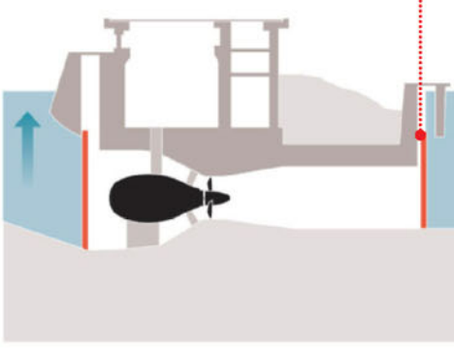
Low tide
The Moon is no longer directly above or below, leaving behind an area of low-level ocean.

Gates
The flow of water through the turbines is controlled by gates, which are opened and closed at key points for maximum efficiency.

Turbines
Water flows through a tunnel, turning huge propellers on the turbines. This rotational energy generates electricity.

Foundations
A solid concrete base supports the power station on the estuary floor, stopping it from sinking into the soft seabed.

Filling the estuary
The gates open to let the water fill up the estuary during high tide. The gates close when the water level is at its highest point.



RECORD BREAKERS
SIHWA LAKE

254MW

BIGGEST TIDAL POWER STATION

Sihwa Lake Tidal Power Station, located in South Korea, was finished in 2011 and can pump out 254 megawatts of electricity – enough to power 50,000 homes.

DID YOU KNOW? *Tidal power is the only technology to work from gravitational energy in the Earth/Moon orbital system*

The AK1000 is one of the most powerful single axis tidal turbines on Earth

Location
The power station sits in the La Rance estuary, where water flows into the English Channel.

Turbines
Water flows through 24 turbines, transferring kinetic energy from the water into electricity.

Electrical substation
Voltage is stepped up from low to high to make it suitable for the national grid.

High-voltage grid
The electricity is distributed from here, powering towns and cities in northern France.

Changing water levels
Low tide creates a difference in water level between the two sides of the barrage.

Generation
The open gates allow water from the estuary to flow back through the tunnel, turning the turbines to generate electricity.

Rance: the first tidal power station

The Rance Tidal Power Station, situated on the Rance River estuary in France, was built in 1966. The site was chosen for its extreme tide levels – an average of eight metres (26 feet) difference between high and low tide. Two temporary dams were made to allow drainage of the construction site, protecting it from the sea. It is still the second largest in the world today, the biggest being the Sihwa power station in South Korea.

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Biggest ever land mammal

Find out how this prehistoric mega-mammal – eight times the size of a modern-day rhinoceros – used to live

Imagine a beast taller than a giraffe and heavier than two elephants. Paraceratherium was the dinosaur of its day. It filled the same ecological niche as the huge sauropod dinosaurs, like Diplodocus, that lived 120 million years earlier, roaming through lightly forested plains and eating the leaves of trees, which it stripped off the branches with its front teeth. Unlike the dinosaurs, Paraceratherium didn't have a long tail to counterbalance the weight of its neck and head. Instead, it had much more powerful neck muscles, anchored to tall extensions at the top of its spine. This brought its centre of gravity much farther forward, onto the front legs, resulting in a much stockier shape overall.

Paraceratherium lived during the Oligocene epoch, around 30 million years ago. The climate cooled suddenly during this period; Antarctica developed its ice cap for the first time and the Alps began to push upwards to form mountains. As the climate changed, the dense tropical forests were replaced with more open landscapes containing a mixture of trees and grass. These made it harder for medium-sized animals to hide from predators, so natural selection favoured ever-larger individuals able to fend off attacks. Along with competition between males for breeding rights, this drove the evolution of heavier grazing animals. The culmination of this was the Paraceratherium, which weighed a whopping 20 tons.

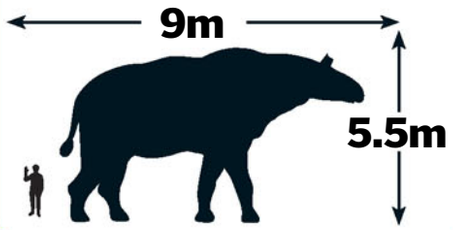
The largest predators at the time were a kind of marsupial hyena, no more than two metres (6.6 feet) long. An adult Paraceratherium was far too large to be troubled by these animals. Instead, they may have been eventually driven extinct by the rise of early elephant species. These would have knocked down the trees Paraceratherium relied on for food. As the grasslands expanded, Paraceratherium was replaced by smaller grazing mammals.

The problems with bone identification

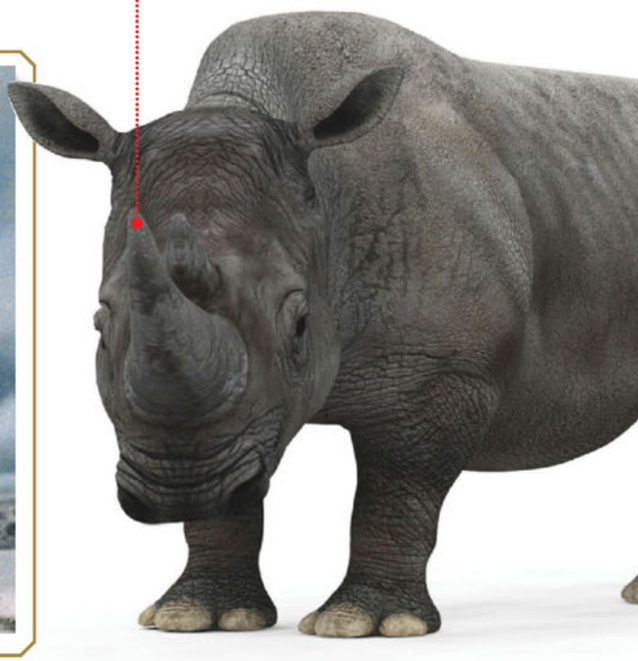
The first Paraceratherium fossil bones were found in 1911 by the palaeontologist Clive Forster Cooper. Two years later, he found more bones he took to be from a related genus and named the animal Baluchitherium because the fossils were found in Baluchistan, in what is now Pakistan. In 1915, Aleksei Borissiak found a third set of bones and named the animal Indricotherium, after the Indrik, a monster from Russian folklore.
None of these fossil finds were anything like a full skeleton, and it can be very hard to decide whether you have found a completely new animal or just a larger example of an existing one based on a single neck vertebra. The scientific consensus is now that all three sets of fossils belong to the same genus, which is called Paraceratherium, because this was the first one to be described scientifically. To date, five species of Paraceratherium have been identified.

Size matters

How would the Paraceratherium have measured up against a person?

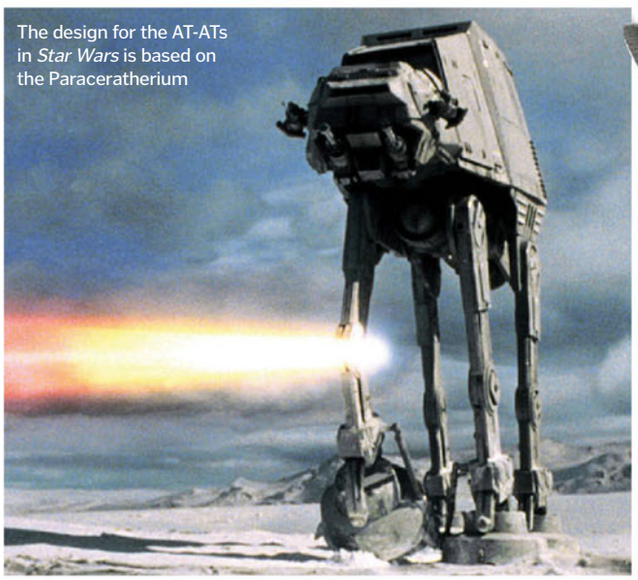


Horn
All modern rhinos have horns for defence, but Paraceratherium was too big to need one.



In a galaxy far, far away...

When Phil Tippett was designing the special effects for *Star Wars Episode V: The Empire Strikes Back*, he needed a reference model for the giant mechanical AT-AT walkers that assault the rebel base on Hoth. Initially, his team studied elephants to animate the leg movements, but the final design is much taller and more menacing. That's because they are based on the Paraceratherium. The AT-ATs portrayed in the film are three times as tall as the prehistoric mammal, but the lumbering gait and joint articulation is probably very close to the way the real Paraceratherium would have moved around.


The design for the AT-ATs in *Star Wars* is based on the Paraceratherium

5 TOP FACTS
MEGAFAUNA

Toxodon
1 This 1.5-ton hoofed animal looked like a hornless rhinoceros, but had much larger front legs than hind legs. Herds of them roamed South America 20,000 years ago.

Diprotodon
2 The 'hippopotamus wombat' was the largest marsupial ever. 3m (9.8ft) long and weighing 2.8 tons, its fossils may have inspired Aboriginal legends of the 'bunyip'.

Megatherium
3 This ground sloth weighed about four tons. It only went extinct 10,000 years ago and, at the time, only the Columbian and woolly mammoths were larger.

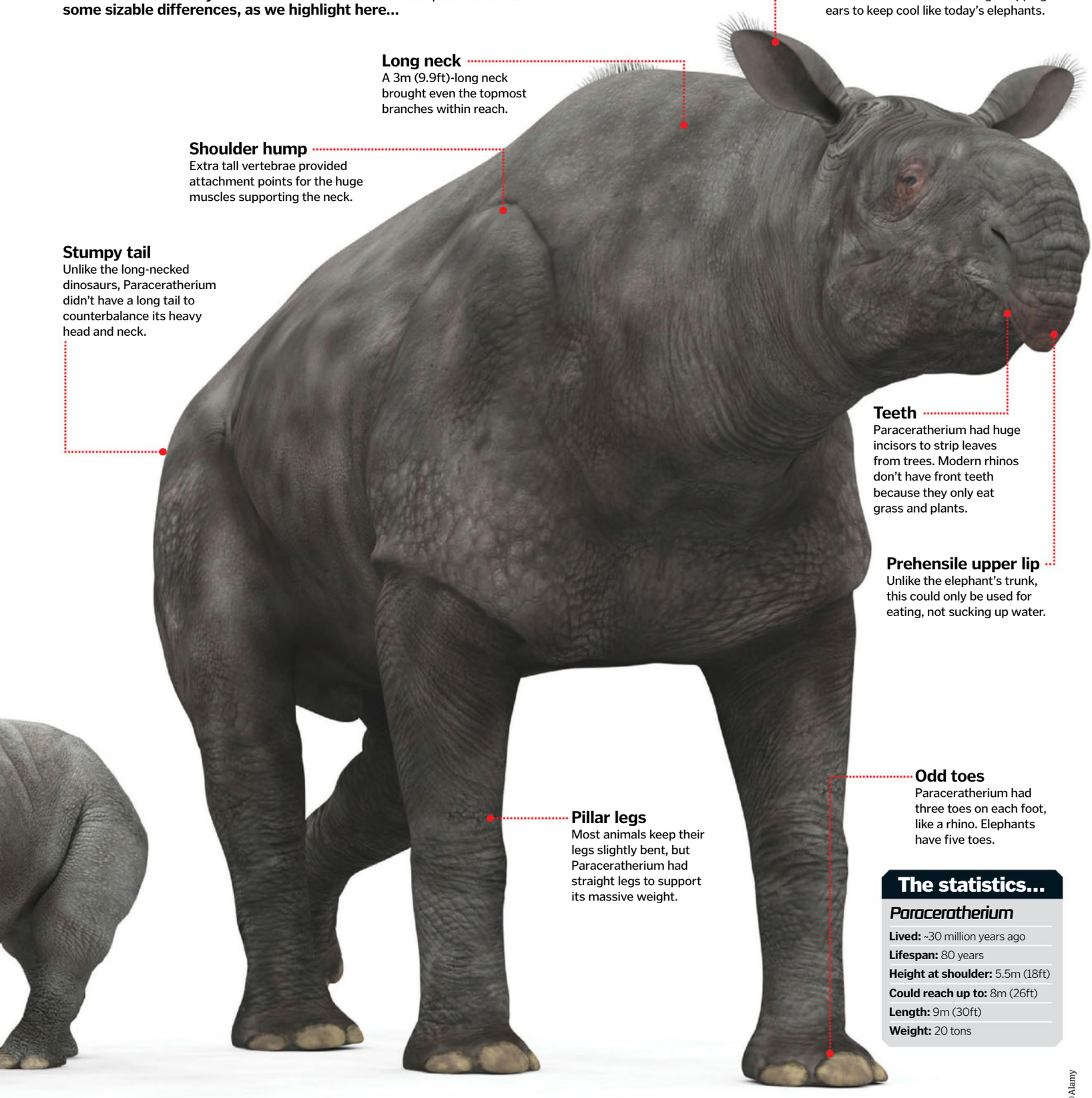
Deinotherium
4 Although they aren't closely related, Deinotherium looked like an overgrown elephant, but with larger front legs and tusks pointing down. It lived about 7 million years ago.

Woolly mammoth
5 At 3.4m (11.2ft) tall and weighing six tons, these ice age relatives of the elephant had tusks up to 4.2m (13.8ft) long that could weigh over 90kg (200lb).

DID YOU KNOW? *Paraceratherium was bigger than Diplodocus; although the dino was longer, Paraceratherium was bulkier*

Anatomy of a mega-mammal

Paraceratherium may be related to the modern rhino, but there are some sizable differences, as we highlight here...



Mystery ears
Soft ears don't fossilise, but it's possible that Paraceratherium had large flapping ears to keep cool like today's elephants.

Long neck
A 3m (9.9ft)-long neck brought even the topmost branches within reach.

Shoulder hump
Extra tall vertebrae provided attachment points for the huge muscles supporting the neck.

Stumpy tail
Unlike the long-necked dinosaurs, Paraceratherium didn't have a long tail to counterbalance its heavy head and neck.

Teeth
Paraceratherium had huge incisors to strip leaves from trees. Modern rhinos don't have front teeth because they only eat grass and plants.

Prehensile upper lip
Unlike the elephant's trunk, this could only be used for eating, not sucking up water.

Odd toes
Paraceratherium had three toes on each foot, like a rhino. Elephants have five toes.

Pillar legs
Most animals keep their legs slightly bent, but Paraceratherium had straight legs to support its massive weight.

The statistics...

Paraceratherium

Lived: ~30 million years ago
Lifespan: 80 years
Height at shoulder: 5.5m (18ft)
Could reach up to: 8m (26ft)
Length: 9m (30ft)
Weight: 20 tons

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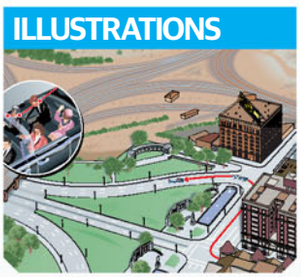

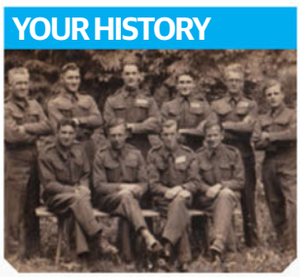

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5 TOP FACTS
NAZCA THEORIES

1 Astronomical calendar
German mathematician Maria Reiche was convinced that the Nazca lines represented an astronomical calendar, used to document important astronomical events.

2 Water rituals
Peru's Nazca region is extremely dry, so some archaeologists believe that the lines were created as part of a ritual to bargain with the gods for rain.

3 Ancient astronaut
One of the figures vaguely resembles an astronaut, and given that the images are best viewed from above, some people have suggested that the Nazca were able to fly!

4 Alien airport
Due to the abrupt start and finish points on some of the Nazca lines, the idea was put forward that the area was a landing strip for ancient extraterrestrials!

5 Sports park
Many of the figures have a defined entry and exit point and can be walked in one line, like an elaborate set of running tracks in an enormous outdoor sports stadium.

DID YOU KNOW? *The upper layer of Nazca gravel is dark in colour due to the presence of ferrous oxide*

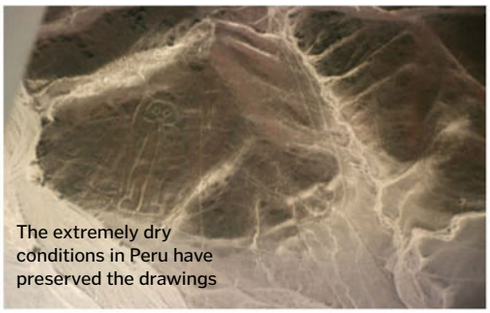
What are the Nazca lines?

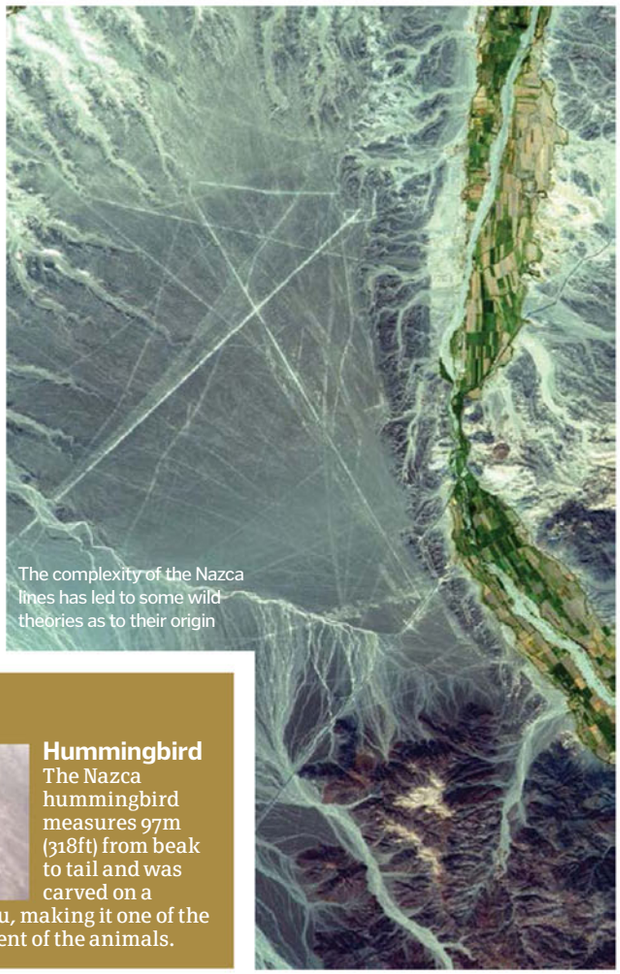
Ancient drawings cover the Peruvian plains, but where did they come from?

The Peruvian coastal plain in South America is home to a wonder of archaeology. The ground is scarred by images, or geoglyphs, known as the Nazca lines, thought to have been constructed by the people of Nazca between 500 BCE and 500 CE.

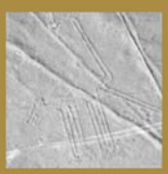
The ancient artworks – most easily viewed from the air – were created by methodically removing dark-coloured gravel from the surface to reveal lighter material below. The plains' unique climate has preserved the lines for thousands of years. Each year, the region receives just 20 minutes of rainfall on average, and the ground is mostly stone and gravel, which prevents the striking images from eroding in the wind.


These intricate patterns were created by using very simple tools and methods


The extremely dry conditions in Peru have preserved the drawings


The complexity of the Nazca lines has led to some wild theories as to their origin

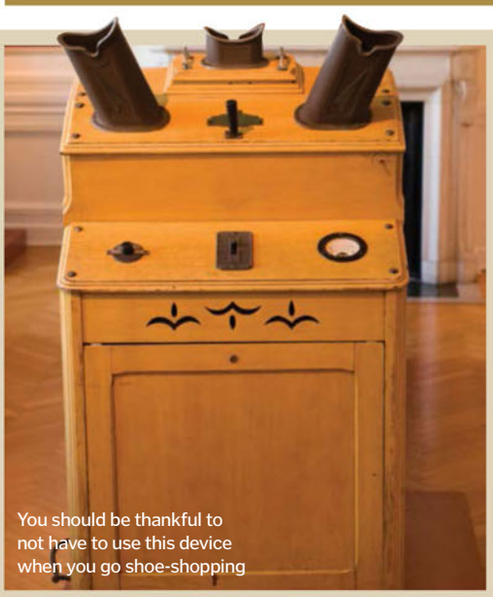
Going on a Nazca safari...



Dog
This 51m (167ft) canine is thought to be an image of an ancestor of the hairless Peruvian dog. This was kept by the Nazca people as a pet and used as a watchdog.

Spider
An impressive 45m (150ft) in length, this Nazca arachnid was one of the very first figures to be studied in the region by scientists back in the Thirties.

Hummingbird
The Nazca hummingbird measures 97m (318ft) from beak to tail and was carved on a raised plateau, making it one of the most prominent of the animals.


You should be thankful to not have to use this device when you go shoe-shopping

X-ray shoe fitting

A visit to the shoe shop once involved a blast of radiation!

The pedoscope was a modified medical device consisting of a metal box, covered by wood and with a series of viewing portals. Marketed to shoe shops in the early-20th century, it claimed to enable sales assistants and customers to take a detailed look at the fit of a pair of shoes.

The customer would place their feet inside the box, between an X-ray source and a fluorescent screen. The feet were exposed to X-rays for about 20 seconds, and absorption by the foot bones and the shoe materials cast a shadow on the screen, forming a moving image.

In reality, the pedoscope was of very little use in selecting a good pair of shoes. The calcium in bone absorbs most of the X-rays, but the soft tissues do not and therefore don't show up very well on the screen. Without seeing the fleshy parts of the foot, fit was effectively being judged using bone structure alone.

Not only were the machines less effective than advertised, but they actually had the potential to cause serious harm. X-rays produce ionising radiation, and the devices were often leaky, repeatedly exposing customers and staff to low-level doses of radiation.

"The Globe proved a great success, with its 3,000 capacity frequently tested to the limit"

The Globe Theatre's story

The most famous and historic theatre in Britain – if not the world – the Globe was the original home to William Shakespeare's greatest plays

The Globe Theatre was an Elizabethan-era playhouse part-owned by the great playwright William Shakespeare. Built from the remains of an existing theatre in Shoreditch, London, made by English actor and theatre owner Richard Burbage and his brother Cuthbert, the Globe was constructed over just a few months in 1599. The playhouse became the home of the Lord Chamberlain's Men, a troupe of which Shakespeare and the Burbages were members. The group went on to perform many of the Bard's most famous plays there. Reportedly, the first performance was *Julius Caesar,* with subsequent plays such as *Richard II, Romeo And Juliet* and *A Winter's Tale* also shown there.

The Globe proved a great success, with its 3,000 capacity frequently tested to the limit, both in the cheap standing-only pit area as well as in the more prestigious tiered seating located around the inner walls. Unfortunately, however, on 29 June 1613 during a performance of *Henry VIII,* a theatrical cannon misfired and ignited the wooden beam and thatch roof, leading to the entire building burning down. Luckily, the success of the Globe's owners and its performances resulted in the theatre being rebuilt again in 1614, with the new playhouse continuing to host many acting troupes well after Shakespeare's death in 1616. In fact, it was not until 1642 that the theatre was closed down – a casualty of the English Civil War.

The Shakespeare's Globe standing today (inset) is an accurate reconstruction of the original Globe Theatre

The Globe over time

Check out some of the main events in the theatre's history now

1599: Grand opening
The Globe Theatre is opened on Bankside, London.

1601: *Richard II* runs
Shakespeare's acting troupe, the Lord Chamberlain's Men, are commissioned to stage *Richard II.*

1608: Blackfriars bought
The Globe's co-owner, Richard Burbage, acquires the lease for the Blackfriars Theatre, which is then used for winter performances.

1614: Globe rebuilt
Following a disastrous fire that burned down the Globe, it is rebuilt a year later on the original foundations.

1997: Resurrection
An accurate reconstruction of the Globe is built near to the site of the original building. It stages Shakespeare's works and is a popular tourist attraction to this day.

1644: Globe destroyed
The theatre is razed to the ground again – this time by order of the Puritans. Landowner Sir Matthew Brend builds tenement houses on the site in its place.

1642: Plays suppressed
In the English Civil War, Parliament issues an ordinance that forbids all stage plays. The Globe is shut down.

1616: Mortal coil
William Shakespeare dies aged 52 in Stratford-upon-Avon, where he is buried in the Holy Trinity Church.

A modern-day Globe

Theatre fans today can visit the Globe, but it's not the Globe of Shakespeare's day but instead a modern reconstruction. It was nevertheless made to be historically accurate, consulting the plans, construction methods and materials of the 1599 original, albeit with modern safety standards in mind. Shakespeare's Globe is built from 100 per cent English oak, with components linked with mortise and tenon joints – both features shared by the original – and also has the only thatched roof permitted in all London since the Great Fire of 1666. The attention to historical detail even extends to the pit area, which remains standing only, albeit with a concrete surface rather than the earthen/straw mix of the 16th/17th century. A second Shakespearean play venue, the Blackfriars Theatre, is also being reconstructed and is due to open by 2014.

5 TOP FACTS
GLOBE TRIVIA

Motto
1 The Globe's motto was 'Totus mundus agit histrionem', derived from Roman courtier Petronius' statement that 'all the world plays the actor' – hence its name, the Globe.

Shareholders
2 The Globe was owned by actors who were also shareholders in the Lord Chamberlain's Men. Shakespeare owned a single share, equal to 12.5 per cent.

Breeches on fire!
3 According to reports of the Globe fire in 1613, no one was seriously injured, the only incident involving a man's breeches being set alight and then put out with ale.

Puritan shutdown
4 Like all other theatres at the time, the Globe was closed down by Puritans in 1642 before being torn down two years later to make way for cheap residential housing.

Car park
5 Today, while an incredibly accurate reconstruction of the Globe exists – named Shakespeare's Globe – the remains of the original are located under a car park.

DID YOU KNOW? *The modern reconstruction of the Globe is located 230m (750ft) from the original site*

Trip around the Globe

This famous theatre is unique – but how was it structured?

Roof
In 1599, the Globe had a thatched roof, but it was replaced with tiles after catching fire in 1613. The performance space was open air.

Balcony
The Globe's balcony was used for performing as well as a place to position the company's musicians. The balcony was flanked by large wooden columns that supported an overhanging roof.

Stage platform
The stage platform extended the stage into the centre of the theatre's pit. At 13.1m (43ft) wide and 8.2m (27ft) deep, the stage was raised approximately 1.5m (4.9ft) off the floor. It had a trapdoor at the centre for quick entrances and exits.

Tiring house
The stage's back wall had three doors on the ground floor and a couple on the first floor as well as a balcony. These doors led to the theatre's backstage area, known as the 'tiring house', where props and costumes were stored and actors prepared to perform.

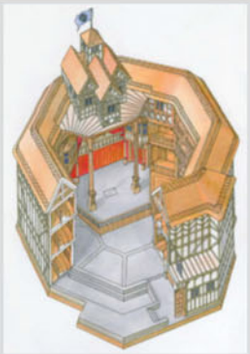
Pit
Surrounding the platform lay the pit, a standing-only area where the poorer visitors could watch. Food and drink were sold here and any rubbish was dropped onto the mud and straw on the ground.

Storeys
The Globe had a three-storey seating arrangement used by the middle and upper classes. Basically the higher the seat, the more expensive it was.

Foundations
Despite appearing circular in design, with a diameter of just over 30m (98ft), the Globe's foundations were actually a 20-sided polygon (icosagon). At the centre of the theatre lay the rectangular stage platform.

Entrance (not shown)
There was one main entrance to the theatre, which was directly opposite the stage and led into the pit. Two sets of stairs near the entrance led into the upper seating tiers.

The statistics...



Globe Theatre

Opened: 1599
Capacity: 3,000
Stage width: 13.1m (43ft)
Stage depth: 8.2m (27ft)
Theatre diameter: 30m (100ft)
Closed: 1642

BRAIN DUMP

Because enquiring minds need to know...

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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*.

Michael Simpson

Michael has a doctorate in moss as well as teaching awards from the University of Alberta. When he's not working as a botanist or environmental consultant, he writes about his expertise for magazines and online.

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.

Dogs have better social smarts, but cats are more attentive

Which are smarter: cats or dogs?

Jenny R

■ There's really not much in it. The ratio of brain to body size is slightly higher for dogs than cats, which may be because dogs are a social species and have evolved some extra brain to handle more complex communication and interaction. But cats have almost twice as many neurons in their cerebral cortex, the area involved in memory, attention and perception. Cats are harder to train, and won't fetch things or guard their owner. But does that mean dogs are smarter, or cats are? **LV**

What is the most radioactive thing we encounter day to day?

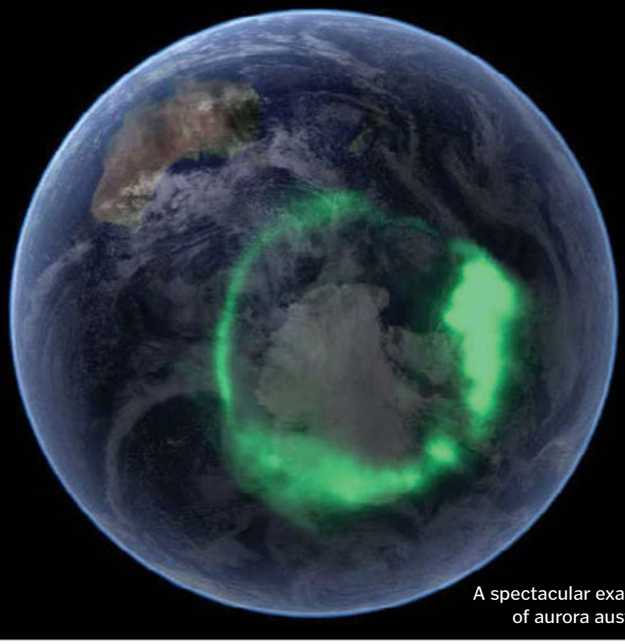
Joseph Bywater

Radon is a radioactive, colourless and odourless gas that is found all around us in very small amounts and is responsible for most of our daily dose of radiation. Radon gas is one of the decay products of radium, which in turn is a decay product of uranium – the most common naturally occurring radioactive substance on Earth. Small amounts of uranium are found in the soil, with an average 2.6 square kilometres (one square mile) of surface soil containing about one gram (0.03 ounces) of radium. Radon gas seeps into the atmosphere from the ground, where its primary way of entering the body is by inhalation. This doesn't pose a serious health risk, though, as levels are generally low. However, some places have higher concentrations of uranium, leading to dangerous buildups of radon gas, particularly inside homes where the gas can't easily escape. Radon gas is the second-biggest contributing factor toward lung cancer after smoking, as it continues to decay inside the lungs, damaging living tissue. **RS**

Are polar auroras stronger at the North Pole?

Valerie Peters

They're not actually stronger at the North Pole, but they are seen more frequently because the aurora borealis, or northern lights, tend to happen over more populated areas than their southern equivalent, the aurora australis. The poles aren't the best place to see auroras anyway – they tend to form in broad 'auroral ovals', around 10-20 degrees from the pole, relating to the region where magnetic field lines leading to or from the pole pass through the upper atmosphere – the auroras themselves appear as energy-rich particles from space are drawn down along these field lines and collide with particles high in the air to emit beautiful glows. **GS**



A spectacular example of aurora australis

5-SECOND FACTS

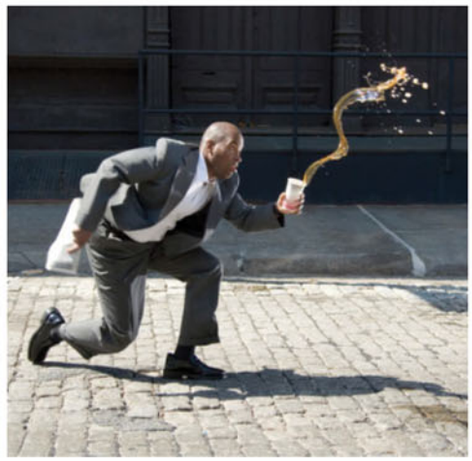
Diamonds come in many colours

Coloured diamonds – blue, green, pink and yellow – are formed when impurities are trapped in the diamond's crystal structure. A 'pure' diamond is 100 per cent carbon and perfectly clear. If traces of boron are trapped during diamond formation, you get blue diamonds. Green is the result of exposure to radioactive rock. Brightly coloured diamonds are extremely rare and as a result carry an even heftier price tag.

How do lottery machines work?

Alessandro Vassalo

There are two major types of lottery machine – 'gravity pick' and 'air mix'. A gravity pick machine has a chamber with rotating paddles inside, spinning in opposite directions. Numbered balls are dropped into the chamber and mixed until a sliding door opens, allowing the desired number of balls to pass through, one at a time. Air mix machines, on the other hand, have a fan in the bottom that blows the balls around. A valve to a tube opens, and the balls that are blown into the tube are the winning numbers. The balls are evenly weighted and are usually locked away in vaults when not in use, in order to prevent tampering. **RS**



Is clumsiness a biological trait?

Kathy Green

Mild clumsiness – such as tripping over shoelaces, bumping your elbow, dropping your keys, etc – is not likely to be a biological or hereditary trait, but doctors do believe that severe clumsiness has genetic causes. Studies have shown that severe childhood clumsiness is often caused by a developmental disorder. Such children take far longer to reach developmental milestones like walking, running, dressing themselves, etc. Occupational therapy works wonders in many cases. Severe clumsiness in adults can also be cause for concern. Symptoms like involuntary movements and an unsteady gait can be early signs of Huntington's disease, a hereditary degenerative brain disorder, though don't panic – often clumsiness is simply a case of poor co-ordination. **DR**

Who invented the first vending machine?

Laura Cornett

Hero of Alexandria, a Greek engineer and mathematician who lived in the first century CE – introduced the first vending machine. For a small fee, you could purchase your very own holy water. A coin was placed into a slot where it fell onto a pan attached to a lever. The lever controlled a valve allowing the holy water to flow. The weight of the coin caused the pan to tilt until the coin would slide off, and a counterweight restored the pan to its original position, cutting off the flow of water. **RS**

Can we harness energy from lightning? Find out on page 82

BRAIN DUMP

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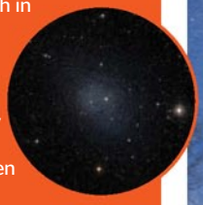
5-SECOND FACTS

The smallest galaxy has about 1,000 stars

The smallest galaxy so far discovered is Segue 2, a cluster of just 1,000 stars roughly 115,000 light years from Earth in the constellation of Aries. This 'tiny' galaxy only holds itself together thanks to the gravity of about 550,000 Suns' worth of unseen 'dark matter.'



Curved gas tanks are much stronger than square ones

Gas tanks contain substances under high pressure, which means they need to be as strong as possible to reduce the risk of an explosion. Circular designs tend to be stronger than other shapes because force is spread around the continuously curved surface and encounters no corners, which are weak points.

The oldest fish in the world are over 300 million years old

The hagfish and lampreys are primitive kinds of jawless fish that haven't changed much in the last 300 million years. There were some very early marine vertebrates as far back as 530 million years ago but they looked more like prawns than modern fish and none of those species are around today.

What are the origins of snowboards?

Aisha

The modern snowboard was invented in mid-Sixties America, but the roots of boarding go back centuries. Turkish villagers in the remote Kackar mountains have been riding sideways on wooden boards for at least 150 years and possibly as long as 400 years. Like other early snowboard pioneers, they tie a short length of rope to the nose of the board for better control. Americans Gunnar and Harvey Burgeson and Vern Wicklund patented a similar 'Sno-Surf' board in 1939, but it never took off. In the Sixties, 'snurfing' boards built by Tom Sims and Sherman Poppen gained widespread popularity, eventually evolving into the modern snowboard we're familiar with today. **DR**

Snowboarding became an Olympic sport in 1998

How do some tyres run even after a puncture?

Dave Mellow

Not surprisingly, this usually depends on the size of the puncture; the smaller the hole, the more time it will take for air to escape. A bicycle tyre with a slow leak can often be ridden without any problems, although more frequent pumping of the tyre will be needed. In this case the hole can be so small, it is almost impossible to locate, and a new inner tube is usually the best course of action. Cars today are often fitted with run-flat tyres – reinforced tyres that in the event of a puncture can be ridden at reduced speeds for a limited distance. **RS**

Is there any way to capture and use energy from lightning?

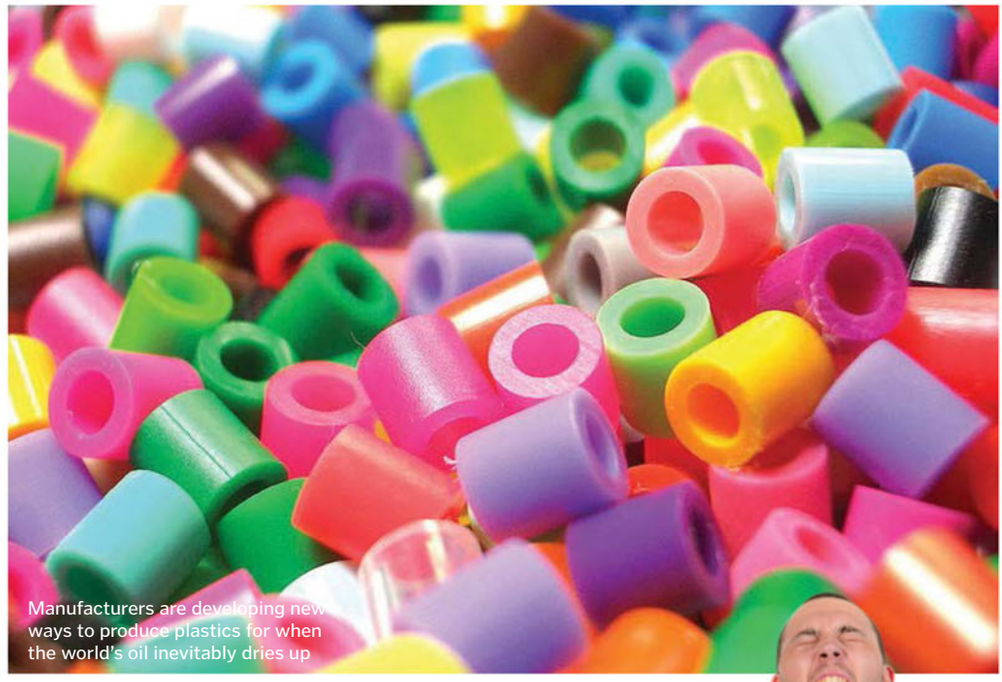
Jake

Deriving energy from lightning is problematic not least because you can't guarantee when and where strikes will occur. Furthermore, lightning bolts are literally gone in a flash so their energy would have to be captured instantly. Currently, no device can do that and developing one is not an appealing investment opportunity, given that bolts that reach the ground have lost a lot of their energy on the way down. One researcher claimed to have powered a light bulb with lightning when it zapped a giant capacitor connected to grounding wires, but that result has never been reproduced. **MS**

How will we produce plastic when oil runs out?

Oliver Elvidge

As the global oil supply dwindles over the coming decades, plastics manufacturers will turn to natural gas, biomass and recycling as the feedstock of the future. Today, just about every plastic product – from Tupperware bowls to polyethylene carpet – is derived from petroleum, a non-renewable fossil fuel that will eventually dry up. The plastics industry has already shifted to natural gas, a more abundant fossil fuel, for most polyethylene production. Biomass holds real promise as a renewable source of plastics. Crops like corn, sugarcane, beets and potatoes contain dextrose, which can be fermented to produce lactic acid. Lactic acid can then be converted into lactide, a molecule that easily forms long chains similar to petroleum-based polymers. The resulting polylactic acid is now the world's most popular bioplastic, used widely in food packaging. Experts also predict that we will eventually resort to mining old landfills in the search for recyclable plastics. **DR**



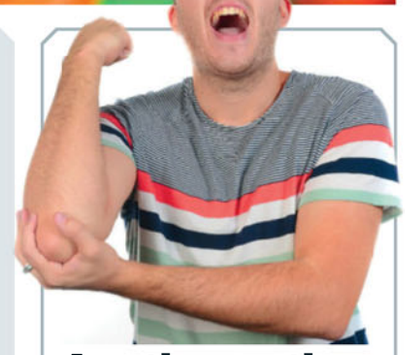
Manufacturers are developing new ways to produce plastics for when the world's oil inevitably dries up

Can animals count?

Shaun French

When we add up the apples in a basket, we step through the sequence of numbers until we run out of apples. This requires the language ability to remember the words for each number and their order. Animals probably can't do this. But there is another sort of counting where you intuitively judge the number of objects without starting from one. This is called *subitising* and most humans can do it for four or five objects and sometimes more. Many animals have this skill too, even quite primitive ones. Red-backed salamanders can tell the difference between one, two and three. Mosquitofish can manage up to four. Ring-tailed lemurs can also put groups of different numbers of objects in order of size. They can tell which group is larger, but only when one group is at least twice as big as the other. **LV**

Many animals can count but not in the same way that humans do



Are there other 'funny bones' in the body?

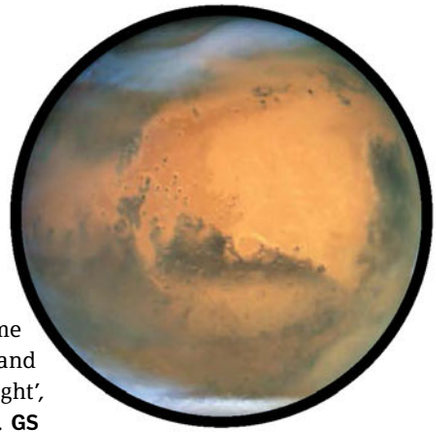
Katie Tatton-Smith

The term 'funny bone' is misleading because it refers to the painful sensation you experience when you trap your ulnar nerve between the skin and the bones of the elbow joint. This happens in the so-called cubital tunnel, which directs the nerve over the elbow but has little padding to protect against external impacts. The ulnar nerve takes its name from the ulna bone, which is one of two bones that runs from the wrist to the elbow; the other is the radial bone, or radius. No other joint in the human skeleton combines these conditions and duplicates the this erroneously named reaction so we only have one 'funny bone'. **MS**

Do any planets other than Earth experience seasons?

Jonathan Cole

Yes, plenty! For a planet to have seasons as we normally perceive them, its axis of rotation must be tipped over at an angle, so that the amount of sunlight reaching different parts of its surface changes as it orbits the Sun. In our Solar System, Mars (right), Saturn and Neptune all have axes tilted at roughly the same angle as Earth's, so they experience a similar cycle of spring, summer, autumn and winter (though over a much longer period). Uranus is tipped over at a much sharper angle so it experiences even more extreme seasons, while Jupiter, Venus and Mercury are more or less 'upright', and don't experience seasons. **GS**



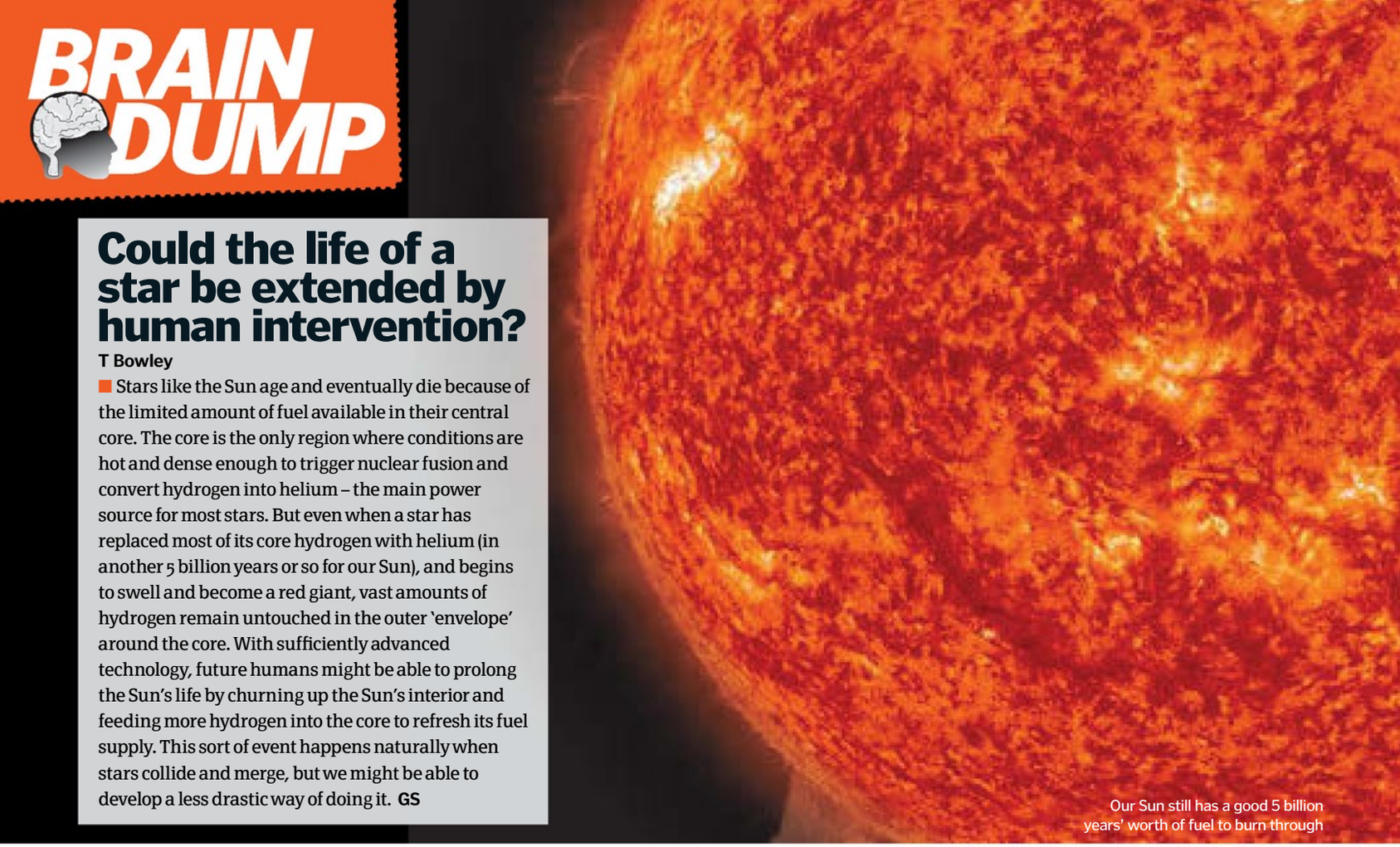
Why do geese often fly in a V-formation? Find out on page 84

BRAIN DUMP

Could the life of a star be extended by human intervention?

T Bowley

Stars like the Sun age and eventually die because of the limited amount of fuel available in their central core. The core is the only region where conditions are hot and dense enough to trigger nuclear fusion and convert hydrogen into helium – the main power source for most stars. But even when a star has replaced most of its core hydrogen with helium (in another 5 billion years or so for our Sun), and begins to swell and become a red giant, vast amounts of hydrogen remain untouched in the outer 'envelope' around the core. With sufficiently advanced technology, future humans might be able to prolong the Sun's life by churning up the Sun's interior and feeding more hydrogen into the core to refresh its fuel supply. This sort of event happens naturally when stars collide and merge, but we might be able to develop a less drastic way of doing it. **GS**



Our Sun still has a good 5 billion years' worth of fuel to burn through

5-SECOND FACTS

Leaves can be bigger than trees

The Raffia palms, native to tropical Africa, and Central and South America, have the biggest leaves in the plant kingdom. Reaching up to 25 metres (80 feet) long, the leaves can be bigger than the trees themselves, which tend to grow to about 21 metres (69 feet) tall.

Why do flocks of geese fly in a V-formation?

Victoria Randall

It's more efficient. Every time a bird flaps its wings, it generates a vortex of air at each wingtip that spirals behind the bird, widening as it gets farther away. A bird following behind can position itself at the edge of this vortex, at the point where the air is circling upwards. This updraught provides lift, which means that the bird needs less energy to stay aloft. For large birds like geese, the effect can reduce drag by up to 65 per cent. They take it in turns to fly at the front, so that each one benefits from the vortex effect. **LV**

How do tumbleweeds survive?

Lisa Shepherd

Tumbleweeds are ordinary plants with leaves and roots for most of their lifecycle. The tumbling is just a way of scattering their seeds. Dandelions and thistles produce seeds that separate from the plant and are blown by the wind. In a tumbleweed, all the seeds are carried together by the whole plant. When the seeds are mature, the plant dies back, becoming desiccated and much lighter. The stem detaches from the roots in the same way that trees drop their leaves in autumn. The top part then rolls along the ground, dropping seeds as they are shaken loose by the ride. **LV**

Fighter aircraft have to be reinforced to prevent inertial coupling

What is inertial coupling?

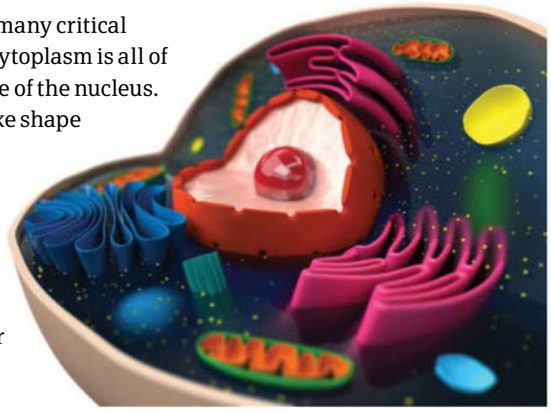
Joao Rodriguez

Inertial coupling is a dangerous effect which can undermine the performance of aircraft trying to manoeuvre at high speed. It is not an aerodynamic effect, but one caused by the simple laws of conservation of angular momentum – when an aircraft attempts to roll at high speed, centrifugal forces cause it to buck, pitch and yaw about all three axes. The effect was discovered when engineers and pilots tried to break the sound barrier in the Forties, and is made worse by long, thin aircraft designs with stubby wings and small tail planes. Enlarging these aerodynamic surfaces helped to negate inertial coupling's effects. **GS**

What does a cell's cytoplasm do?

Fred Jennings

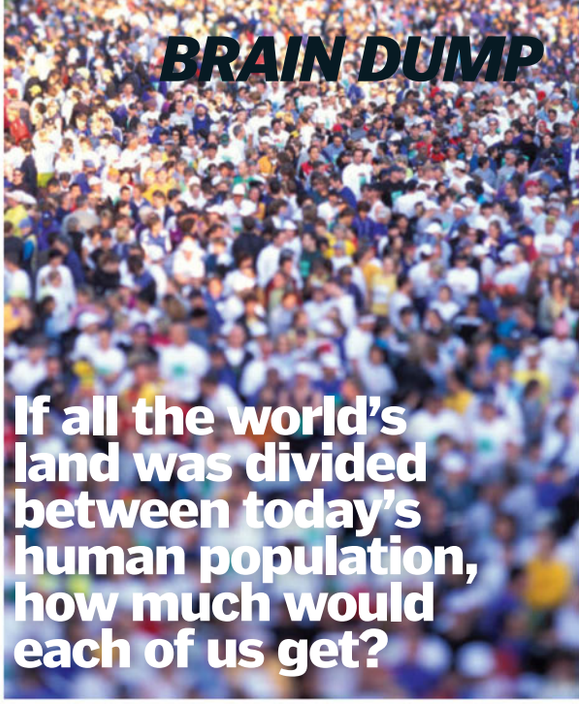
Cytoplasm is more than filler; it performs many critical biological functions in a cell. By definition, cytoplasm is all of the liquid inside a cell membrane but outside of the nucleus. Cytoplasm gives the cell its open, balloon-like shape through a scaffolding of microtubules and microfilaments, called cytoskeleton. Organelles also use microtubules as pathways to travel throughout the cell. In addition to water, cytoplasm contains enzymes that break down glucose into a substance digestible by mitochondria. Other enzymes dissolve cellular waste so it can be removed through the cell membrane. **DR**



How does light therapy help people with SAD?

H Fletcher

Seasonal affective disorder (SAD) is a form of depression associated with a lack of bright light. It can be most severe during autumn and winter when outdoor light is in reduced supply. Most indoor lights have been found to produce little or no benefit for sufferers and even increased exposure to sunlight is often ineffective. High-intensity light boxes have produced positive results, but it is not 100 per cent certain why. Researchers believe light stimulates mood-controlling chemicals in the brain, possibly in conjunction with the body's internal clock, which regulates hormone secretion and other basic functions such as sleep. **MS**



Claude Bisset

At press time the world's population was around 7.2 billion people, most of whom live on approximately 150 million square kilometres (58 million square miles) of land. In basic terms, this means everyone would have roughly 0.02 square kilometres (0.008 square miles) of land if it were divided up equally. That doesn't account for deserts, polar regions and other inhospitable areas, though. Also, according to a 2005 estimate by *National Geographic*, as much as 40 per cent of the Earth's land is currently used for agriculture. Assuming this is required for food production, each of us would have around 0.008 square kilometres (0.003 square miles). Some allowance must also be made for continuing population growth. Luckily, not everyone needs a plot right away, including the estimated 370,000 babies born each day. As each new generation gets older, though, we're all going to have to squeeze closer together with our neighbours. **MS**

More bite-sized facts!

A new issue of Imagine Publishing's digital science magazine **Brain Dump** is now available, offering a wealth of fascinating facts and quick-fire answers to your most burning questions. In the latest edition you'll find out how X-ray machines offer a window into our bodies, what exactly absolute zero is and whether all pooches are descended from wild wolves. Issue 8 of **Brain Dump** is stuffed with handy trivia that's bound to come in useful for quizzes or just impressing your friends. So for the answers to those questions and many more be sure to download the latest issue on the iTunes App Store. You can pose your own questions at **www.facebook.com/BraindumpMag** or Twitter – @BrainDumpMag.

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Winter sports gear has been designed to be a lot tougher than summer kit

The Cerium LT jacket has everything you need, offering warmth but not hampering movement

Winter sports kit

Warmth, practicality and protection are all top priorities in this roundup

Snowboarding, skiing or indeed any outdoors sport you might embark on during the winter brings with it a set of challenges unique to this season. Clothing needs to be light, yet keep the body warm, while devices need to remain functional under duress; in the case of some of the items we've chosen here, the two have been combined out of pure practicality. The last thing you want to be caught doing in sub-zero temperatures is pulling off layers or readjusting gadgets as the weather closes in.

Checklist

- ✔ Gloves
- ✔ Video camera
- ✔ Watch
- ✔ Goggles
- ✔ Jacket
- ✔ Fitness checker

1 Connected gloves

KJUS GSM Glove
£200/$N/A
www.snowandrock.com
One of the most practical items in this month's group, this GSM Glove combines a thick and well-insulated glove with protective leather palms – ideal for any snowy pursuits you have in mind – with built-in mobile handset functionality. A USB port and Bluetooth in the wrist enables you to issue voice commands via a mic in your palm. It takes all the sting away from making a call or using an app, so you can keep your hands warm without sacrificing the ability to stay in touch.
Verdict: ●●●●○

2 Action camera

GoPro Hero 3+ Silver
£279.99/$N/A
www.snowandrock.com
It's become something of a legend, even outside its traditional extreme sports audience. The invention of the GoPro, a rugged and waterproof digital video camera with a mount that allows it to be fixed to almost anything, has given everyone from skiers to skydivers a simple way of taking high-quality video when the hands are busy. It can shoot 1080p video at ten frames per second, as well as ten-megapixel photos. Its diversity across so many sports is a testament to its practicality.
Verdict: ●●●●●

3 Exercise watch

Garmin Forerunner 310XT
£280/$N/A
www.snowandrock.com
Designed with triathletes in mind, but equally useful for winter sports fans, Garmin's 310XT model of its Forerunner watch series couples a number of cool features on to a single device. It's loaded with stopwatch and workout functions that allow you to focus on your training, and couples these with a heart rate monitor and calorimeter. The main feature is its integrated Multisport GPS device, a high-sensitivity system that tracks you even when under cover from trees and rocks on the slopes.
Verdict: ●●●○○

4 Vari-goggles

Anon M2 Goggle
£190/$N/A
www.snowandrock.com
If you're caught out on the mountains on a bright day without goggles, you're going to know it. Similarly, if you're only prepared for a blindingly sunny day, packing the snow goggle equivalent of a welder's mask isn't much help. So, Anon's M2 range comes with two detachable lenses: a blue 'solex' one that allows 25 per cent light transmission for sunny days, and blue 'lagoon' for gloomy days, allowing 80 per cent transmission. These are held tightly in place by powerful magnets.
Verdict: ●●●○○

5 Breathable jacket

Arc'teryx Cerium LT Jacket
£240/$N/A
www.snowandrock.com
You wouldn't believe how insulating this jacket is by holding it: it's fairly thin and extremely light. But pop it on and it's a serious piece of winter clothing. Designed as a lightweight and cosy overcoat during finer winter weather and an undergarment for bulkier jackets when things get more severe, Arc'teryx's Cerium is made from synthetic insulation material that lets your skin breathe and keeps the wind out while keeping the warm air in. It won't take up all your suitcase either.
Verdict: ●●●○○

6 Fitness electrode

FAM Sports Check
€199/£N/A/$N/A
www.checkmylevel.com
For professional winter sports people or even serious amateurs, it can be hard to judge whether you've overdone the training. FAM Sports Check is a small, MP3 player-sized device can help by assessing muscle fatigue. It simply sends a low voltage through an electrode attached to your wrist and measures the muscle response, sending the data to an app on your phone. A slow response means your body hasn't recovered. With this you get the most out of a trip without harming yourself.
Verdict: ●●●○○

EXTRAS

Three brilliant ways to get even more help with winter sports

BOOK

Go Ski

Price: £9.99/$N/A
Get it from: www.dk.com
This amazing book offers not only step-by-step instructions of all the skiing basics, but also a 30-minute DVD guide so you can practise your technique before hitting the slopes.

APP

Garmin Connect

Price: Free
Get it from: iTunes/Google Play
Upload your activities and all your stored training data to your phone and then share with others.

WEBSITE

www.epicski.com

For avid skiers, EpicSki is an excellent online resource. You can chat with like-minded enthusiasts, read reviews of the latest gear as well as share your most amazing images and top tips with others.

Super satnavs

We test three of the best navigational tools on the market to help point you in the right direction...

1 TomTom GO 6000

Price: £299.99/$N/A
Get it from: www.maplin.co.uk

Vacuum cleaners have Hoover, public address systems have Tannoy, flying airfoil disc toys have Frisbee and in-vehicle satellite navigation systems have TomTom. The Dutch company has been manufacturing these devices for just over a decade, only to have its business threatened not by other satnav manufacturers, but by the increasingly sophisticated smartphone market and the range of apps available. There's still plenty of room for dedicated devices, though – particularly a good one.

The GO 6000 is the latest premium satnav from TomTom, an effortlessly accessible device that sacrifices a few common features (that you won't miss) for the sake of a simple, icon-driven interface. Boasting a 15-centimetre (six-inch) touchscreen that trumps the majority of satnavs on the market, it quickly becomes a reliable friend. The GO 6000 sticks to clear demarcation of the route, with the distance to the next waypoint and the next few points of interest listed as icons on the right-hand side.

Road-tested over 320 kilometres (200 miles) of motorway, as well as minor roads, the GO 6000 proved to be a very dependable in-car navigator.

Verdict: ★★★★☆

Screen projection
Looking a bit like something out of *Star Trek*, a simple bit of Bluetooth pairing, then some route plotting on your smartphone, and this satnav will project the data straight onto a small transparent panel on your windscreen.

Lifetime maps
TomTom offers lifetime map updates for 45 European countries on this product and lifetime traffic updates, which can be updated via your PC or Mac. To keep your GO 6000 alerting you to speed cameras at the appropriate times, you will need to pay an annual subscription fee though.

2 Garmin Nuvi 3598LMT-D

Price: £299.99/$N/A
Get it from: www.maplin.co.uk
Weighing in at the pricier end of the satnav market comes a product from Garmin that is somewhat smaller than the dedicated device TomTom has to offer. The Nuvi 3598LMT-D features at the top of Garmin's range, and though its 12.7-centimetre (five-inch) screen is nothing to boast about, this lightweight and slinky device is packed with features.

It too has lifetime maps access and digital travel updates, voice activation and built-in Bluetooth that allows you to use the Nuvi hands-free with full internet access – provided you've linked it to an online device such as your phone, of course. It's a function gadgeteers will love, as it opens up a world of add-ons, some a lot more useful than others.

The road test really showed where the Nuvi 3598 excelled over, say, a 3G smartphone alternative. Voice and directions are effortlessly precise and touches that might seem fairly insignificant on paper – like the split-screen street view/aerial map – really come into their own in practice.

The price might seem like a stretch, but it's no more than the GO 6000 and the Nuvi's features really make it an indispensable companion on the road.
Verdict: ★★★★☆

3 Garmin HUD

Price: £159.99/$N/A
Get it from: www.maplin.co.uk
If the Nuvi 3598LMT-D is something of a gadgeteer's satnav fantasy, then the Garmin HUD is the weapon of choice for the science fiction-loving commuter. Its unique functionality is to project digital navigation data onto your windscreen. In a generation of multiple screens and metadata being pioneered by the likes of Google Glass, it's exactly the kind of satnav product an iPhone owner might appreciate.

The Garmin HUD is designed to be paired with the Garmin StreetPilot app for iPhone or NAVIGON software, and is little more than a futuristic-looking gimmick. By projecting the data onto your transparent windscreen, you never have to take your eyes off the road. Its feature set is fairly basic compared with the others in this group: it shows speed, distance to next waypoint and direction to turn as well as other standard data, but nothing above and beyond. It's also dead simple to set up, requiring just a few clicks from your smartphone. It might not have all the fancy bells and whistles of the others in this group, but by yoking the functionality of your smartphone, the Garmin HUD comes in at nearly half the price of GO 6000 and the Nuvi 3598, so it's well worth considering.
Verdict: ★★★☆☆

Active Lane Guidance
It's our favourite feature in this group: whenever you approach a junction or an exit, Garmin's Active Lane Guidance pops up with a graphical display that uses arrows to indicate precisely the transition to the correct lane. It makes us wonder why no one else has done this before.

ON THE HORIZON

Four other cool gadgets we're keen to get our hands on...

Apple Mac Pro

The new Mac Pro, the only Apple device capable of supporting the latest generation of ultra-high resolution 4K monitors, has two dedicated AMD FirePro GPUs, an Intel Xeon E5 CPU and retails at around £2,499 ($2,999).

LG 84LM960V

We've talked about the Apple computer that will handle this beast, so here's the latest Ultra HD TV. It has a native resolution of 3,840 x 2,160px, an eye-popping 84in screen and an equally huge £14,999 ($24,500) price tag.

Meta SpaceGlasses

With a launch date slated for later this year, Meta SpaceGlasses are a potential rival for Google Glass. Combining existing technologies such as Microsoft's Kinect sensor, it allows you to manipulate virtual objects within our own three-dimensional reality.

Scanadu Scout

If you've ever wanted your own personal and portable digital physician, this is it. The Scanadu Scout can be applied to your head to measure heart rate and blood pressure, or check your saliva for viruses. You can read more on this medical gadget in our innovations feature on page 12.

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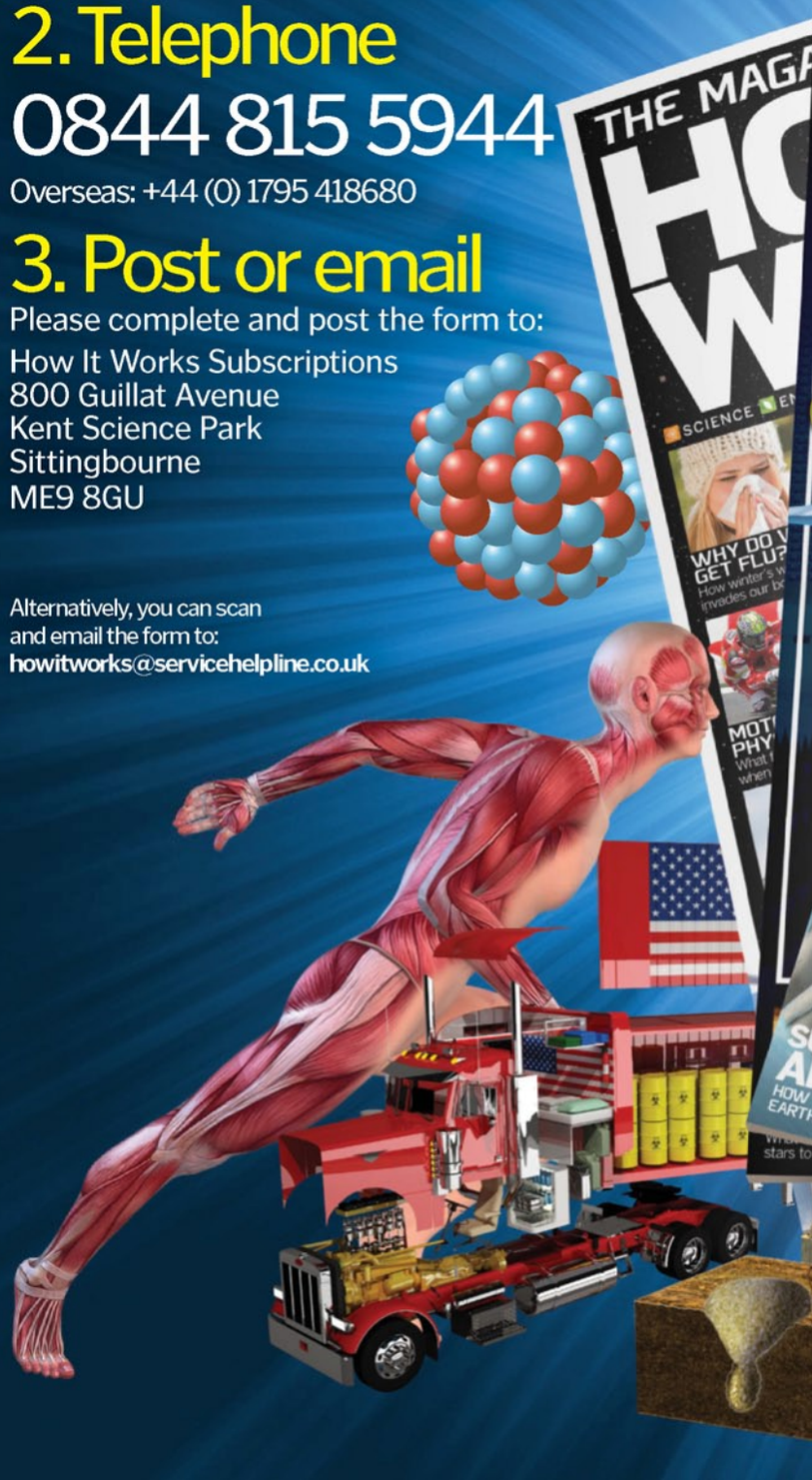

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Ride a snowboard

Taking your board to the slopes for the first time? Use this guide to get on track

1 The right gear

Snowboarding kit is not cheap. Therefore, it's a good idea to hire your equipment to begin with, until you're certain this is a hobby you'd like to pursue. Most things are available to rent at the park, from the board itself to the boots and bindings; you'll also be able to get help with repositioning the bindings for optimum balance and comfort. A shorter board (no higher than your chin when on its end) offers greater control.

2 What's your stance?

First, you need to establish whether you're regular (left foot forward) or goofy (right foot forward), as most people will only feel natural riding one way or the other. There are several methods to work out which stance is for you. You can try dropkicking a ball; the foot that stays on the ground should go at the front of the board. Alternatively, the foot you naturally use on the first step when running up a staircase should be at the rear.

3 Walk before you glide

While you're still on flat ground you should practise walking with the board attached. Strap your front foot into the binding and move forward with the other. Bear more weight on your free foot for balance and use the board edge to cut into the snow for extra grip. Once you're comfortable with this manoeuvre you can try gliding; push off with your free foot then place it on the board, just inside the back binding, similar to a skateboard.

4 Learn to stop

Being able to stop safely is a must before you take to the main slope, so you're not a liability to yourself and everyone else on the hill. Think of the board as an accelerator pedal; the more you press down, the faster you'll go. You are essentially using the entire back edge of the board to increase friction with the snow in order to come to a halt. Keep your legs bent, your back straight and look in the direction you want to go.

5 Tackle the chairlift

The chairlift can be daunting for first-time boarders, but remember, everyone was a beginner once. Use the gliding technique to approach the spot and then watch for the chair before sitting back into it. Once seated, secure the bar over your head and let the board hang at a slight angle, using the footrest to take some of the strain. When you approach the top, only lift the bar when a sign indicates and shift so you're side-on. Point the board tip up, ready to push off when the snowboard makes contact with the ramp.

6 Take a lesson

You can read books, browse tips on the internet and listen to advice from others, but sometimes the only way to learn a new skill is from an expert on location. When it comes to snowboarding, it's worth forking out a bit of money to get a handle on the core skills, whether it's your posture or falling safely. They can also offer local knowledge, such as the best runs for beginners and any hazards to look out for.

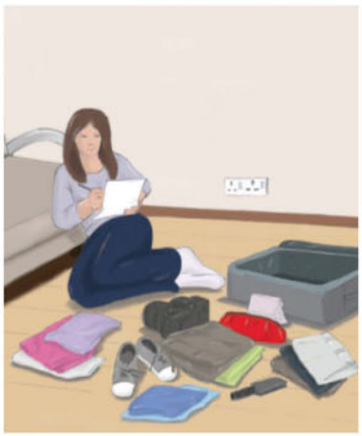
In summary...

There's a lot to take in on your first snowboarding day, but you can get off on the right foot by making sure your equipment (personal or hired) is tailored to you. Instructors don't come cheap, but they will give you a solid basic grounding. Be mindful of other skiers and boarders and master stopping before any other trick.

NEXT ISSUE
- Escape quicksand
- Open a frozen car door

Pack a suitcase

Before jetting off on a winter break, get the most out of your luggage space

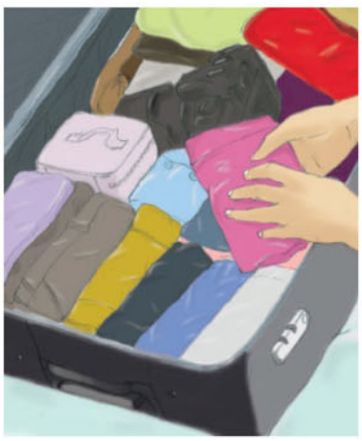


1 Plan ahead

We've all taken things we never wear or use on holiday. This can be avoided with a little more foresight. Lay your gear out on the floor before putting a single item in your case and write a list of what you'll need. Check what's available at the accommodation to save taking big items like towels or hairdryers unless necessary – and don't forget to consult the weather forecast for a general heads-up of what to expect.

2 Roll or fold?

There's some debate as to which method is the best when it comes to packing, but rolling clothes arguably wins in terms of quantity. Fold your garments in half then roll from the bottom up as tightly as possible to limit creases; this works for everything from T-shirts to trousers and even underwear. You might want to invest in plastic vacuum bags to help condense bulkier clothes like ski jackets by sucking the air out.



3 Layer by layer

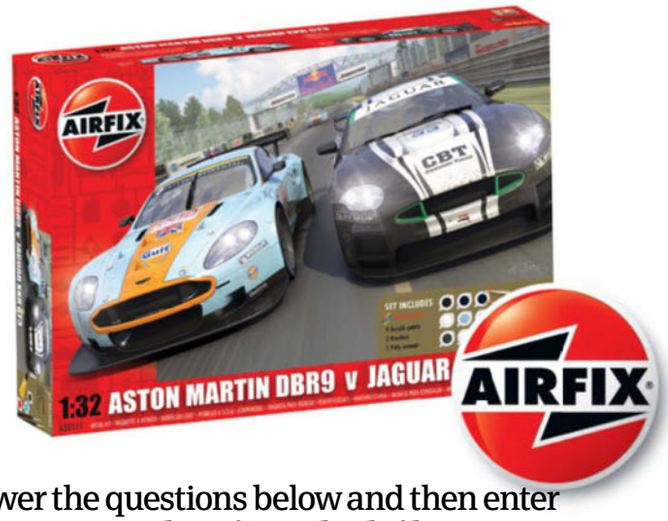
Put heavier items like shoes in the bottom, near the wheels for better stability. Don't waste the valuable space inside shoes; it's perfect for socks or delicate items like watches and perfume bottles. Next, build up your rolled clothes, placing anything fragile you can't take as hand luggage in the centre so it has some cushioning. Lay any smart clothes that you don't want to roll on the very top and fill any gaps with small items like socks.

In summary

Leave yourself enough time to prepare. Don't just throw everything in – justify each item by writing a checklist tailored to the trip. Wearing your bulkiest clothes and footwear on the plane can save a lot of case space too.

QUICK QUIZ

Test your well-fed mind with ten questions based on this month's content and you could win a model of two classic racecars!



Answer the questions below and then enter online at **www.howitworksdaily.com**

1. How many krill can a blue whale eat on a daily basis?
2. When was the term 'cymatics' first used to describe the study of sound wave patterns?
3. What is the estimated mass of the 2013 Chelyabinsk meteor (in tons)?
4. By how many degrees is Earth's axis inclined towards/away from the Sun during a solstice?
5. What length can manatees grow to (in metres)?
6. How fast did the Thrust SSC go when it broke the land speed record (in km/h)?
7. What was the capacity of the original Globe Theatre?
8. In which country is the Punta Banda Peninsular blowhole located?
9. How many protons and electrons does the element uranium have?
10. Where on his body did astronomer Tycho Brahe receive a serious injury when he was 19?

ISSUE 54 ANSWERS

1. 1kW **2.** 5kg **3.** 9,500 **4.** 22,500MW **5.** 3,571m **6.** 1395 **7.** 40,000 **8.** 30 **9.** Vomeronasal **10.** Alfredo Moser

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WIN!

We enjoy reading your letters every month, so keep us entertained by sending in your questions and views on what you like or don't like about the mag. You may even bag an awesome prize for your efforts!

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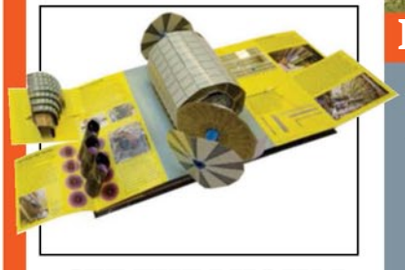

SEE THE LHC IN A WHOLE NEW LIGHT

Next issue's top letter will win a copy of *The Large Hadron Collider Pop-Up Book* for an unparalleled insight into this amazing science machine.

It's hard to imagine how anyone couldn't be impressed by ancient wonders like Machu Picchu!

Letter of the Month

Something for everyone

Dear HIW,

Some people may get very sniffy at finding articles on the likes of dry stone walling and the construction of old church buildings in their issue of HIW, but I salute you for covering the vast range of human ingenuity, past and present.

The construction, centuries ago, of huge buildings without the use of modern power tools is every bit as ingenious and fascinating as, say, the performing of medical operations by means of robots; from stone to silicone, it's an amazing tale of endeavour. Please maintain HIW's commendable mix of subject diversity.

Many thanks,

Alan Thomas

Thanks for writing in, Alan. We always do our best to include a wide range of science and technology in every issue, because we know many of our readers, like yourself, have an insatiable appetite for all kinds of knowledge – not just a select field. From cutting-edge scientific techniques to classical engineering, or hi-tech equipment used in outer space to the more familiar gadgets we use every day, no subject is too big nor too small for How It Works. We hope you enjoy playing with the remote-controlled car, which is speeding its way to you now for claiming this issue's Letter of the Month spot.

No to tommyrot!

Dear HIW,

I'd like to start by saying THANK YOU. I've been searching for a quality magazine that highlights most of the important things in life rather than a lot of tommyrot gibberish. I love the way you focus on different key elements making it actually worth reading. How It Works is also highly associated with Airfix, one of my biggest passions. So I'm going to finish this letter as I started, THANK YOU.

Yours,

Kieran Baddeley (12)

A big THANK YOU right back at you, Kieran. It's always encouraging to hear readers are enjoying the magazine. And 'tommyrot gibberish' is our new favourite phrase!

A musical interlude

Hi HIW,

In issue 52 (page 95), Dylan asked the question: 'What makes a song catchy?'. I may have a possible answer. In a book titled *How Long Is A Piece Of String?*, there is a chapter on 'What makes a hit single?' Condensing the chapter into a few points:

- A drumbeat is fairly common, beating at the same rate as the heart
- Regularity of verse, chorus, verse, chorus makes the song easy to listen to
- The right balance between music that is totally predictable and totally unpredictable needs to be struck.

Too much variety makes the song impossible to follow, but too little variety makes the tune sound too dull.

Is there a formula for writing the perfect song?

"It's so great to learn new things, so thank you for teaching me"

Interestingly, rhythms of five are less common in number one hits. Our brains recognise patterns of one, two and three at a very early age. It's not that we don't like songs with rhythms of five, but we are less automatically drawn to them.
Peter Roberts

Going viral

Hi How It Works,
I want to thank everyone at **How It Works**, your magazine is amazing. I find it so entertaining I have to read it at least five times, it's so great to learn new things, so thank you for teaching me.

I was reading 'Inside the flu' [in issue 53] and I got thinking, how many viruses are there? What is the most deadly and least deadly virus? How many are man-made, and which is the most deadly man-made virus? Also, what about bacteria: how can some be good for you and some make you sick? If you could answer these I would be so happy.

Keep up the great work, I love you guys.
John-Paul Brown

Hi John-Paul, we're actually looking to run a feature on the tiniest organisms on Earth, including bacteria, in the new year, so be sure to keep your eyes peeled – really peeled, they are microscopic, after all!

Nuclear know-how

Good morning,

As an active member of our corporate outreach team promoting STEM and the nuclear industry, it's amazing to have such an informative magazine I can recommend to children. **How It Works** is an incredible publication and provides inspiration to our next generation of scientists and engineers.

What an amazing article on next-gen nuclear power [in issue 53]. With your permission, I'd like to share this article with a number of our new starters with the company, who I feel may find this extremely useful.

Thank you again to your whole team for producing such an inspiring magazine for our budding scientists!

Best wishes,
Robert Alford, National Nuclear Laboratory

They might be small, but bacteria play a big part in all our lives

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 NOW THAT I KNOW THERE COULD BE LIGHTSABERS I WANT ONE NOW!!!!! I love issue 53!! Great job!

Sara Czerniawska @CzerniawskaSara
@HowItWorksmag just arrived! Love 'controlling the weather'!

Vicki @vickitickets
Weird science fact 3. Don't hot things ALWAYS lose heat faster **@HowItWorksmag** – I boil the kettle for quick ice cubes! #thermodynamics

Vi @dreamer4_life
Learn something new every day **@HowItWorksmag**

Angapunk @angapunk
@HowItWorksmag I love u! My brain is so happy right now!!

Sookie Lioncourt @sookielioncourt
Cool! :) How the Sphero works

Photoshop Creative @PshopCreative
Giveaway from **@HowItWorksmag** WIN prizes worth over £500 for filling in a little questionnaire. Why not!

A close-up view of salmonella which can cause stomach bugs

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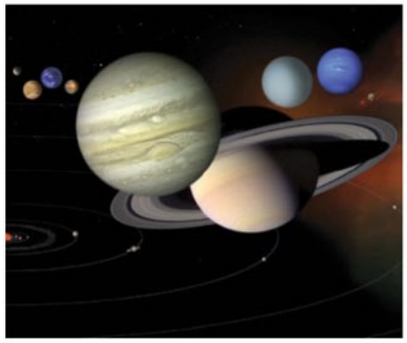

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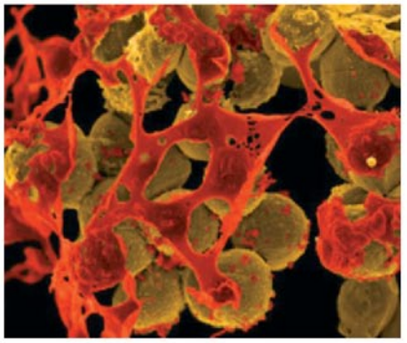

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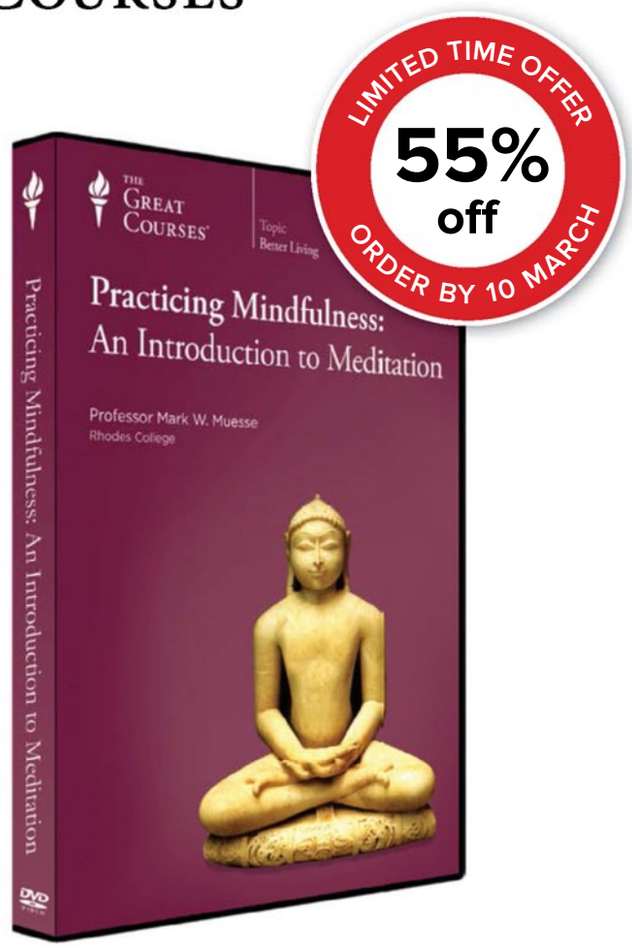

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