REVEALED WHY GLITTER STICKS TO EVERYTHING

HOW IT WORKS

SCIENCE OF STRESS

HOW THIS PRIMAL RESPONSE AFFECTS YOUR BODY AND MIND

SCIENCE ENVIRON… …NOLOGY RA… …ORT HISTORY SPACE

+ WAR ROBOTS

How military machines will save lives on the battlefield

ANIMAL EYES

What do pupil shapes reveal about animal behaviour?

HISTORY OF TIME

From sundials to super accurate atomic clocks

DAY IN THE LIFE OF A TEST PILOT

Find out what it takes to make sure helicopters are fit to fly

INSIDE EARTH'S AMAZING CAVES

LIMESTONE CHAMBERS, MARBLE TUNNELS, ICE CAVERNS AND MORE

MICRO BEADS

How these tiny spheres cause big problems

RACE TO MARS

HOW THE 21ST CENTURY SPACE RACE WILL GET US TO THE RED PLANET

DISCOVER WHY ALL WORLD MAPS ARE WRONG

+ LEARN ABOUT

- ROAD ROLLERS
- THE BLITZ
- COMMON PLANETS
- TREE SAP
- JAMES DYSON
- GLOWSTICKS
- SLEEP IN SPACE
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ISSUE 96

WELCOME

The magazine that feeds minds!

"NASA's goal is to get humans there by the 2030s. The dream of going to Mars is very much alive..."

Race to Mars, page 12

Meet the team...

Charlie
Production Editor
We have all seen what happened in *Terminator*, so should we be worried about the development of war robots? Find out in this month's tech feature on page 62.

Dave
Editor-in-Chief
As we're always trying to hit deadline and working against the clock, I was really interested to read about the history of time-measuring devices over on page 76.

Jack
Senior Staff Writer
Turn to page 80 to discover how the British people stood firm against the terror of the Blitz that bombarded the nation for nine months during WWII.

James
Research Editor
Did you know that you can watch a high-definition live stream of Earth from the International Space Station? Follow the link on page 22 and witness our planet's incredible beauty from orbit.

Duncan
Senior Art Editor
Get your butts to Mars! Will we really see the human race set foot on the Red Planet and successfully colonise another world? Find out on page 12.

Laurie
Assistant Designer
We delve deep underground in this month's issue to discover the hidden world of caves. Take a look for yourself at these amazing natural wonders on page 24.

FOLLOW US... How It Works magazine @HowItWorksmag

On 20 July 1969, the world watched in awe as Neil Armstrong made that giant leap for humankind. That historic moment was the pinnacle of the Space Race, with competition between the US and the USSR fuelling the technological advancements and ambition required to send humans to the Moon.

Arguably, this shining example of human endeavour has not been repeated since. Our technology has advanced to the point where we can send rovers and probes out into the unknown of space and explore on our behalf, but that is all about to change.

A new space race is underway, with government agencies and private companies alike working towards the shared goal of getting humans to Mars.

Perhaps one day in the near future, we will get the chance to watch somebody take one small step on to the surface of the Red Planet, as humanity makes that next great leap forwards.

Jackie **Jackie Snowden**
Deputy Editor

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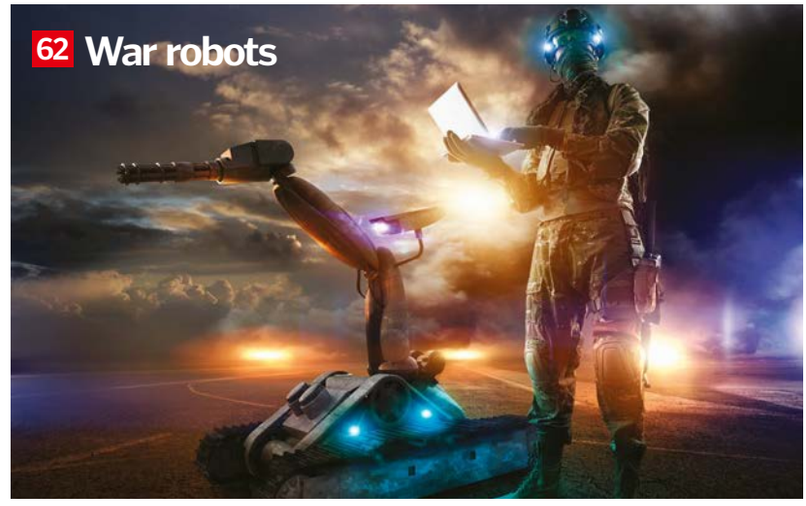


62 War robots

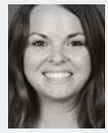
Meet the experts...

Ella Carter
Ever wondered why our eyes have circular pupils, but other animals sport slits, crescents, or even wavy w-shapes? Ella has the answers! She also investigates how waste is used to generate energy.

Laura Mears
In our science feature, Laura explains the biology of stress, what it is and how it affects our bodies as much as our brains. She also explains how plants use sunlight to produce food in this month's 60 Second Science.

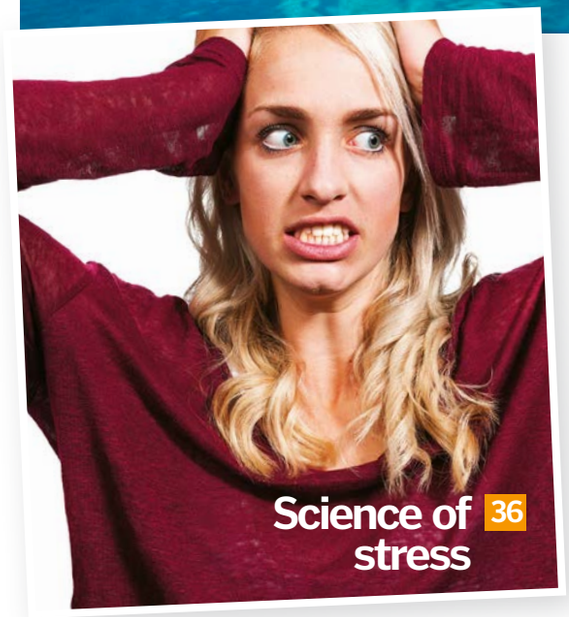
Jo Stass
Jo dusts off her spelunking gear and goes on a tour of some of the world's biggest, deepest and most impressive cave systems. She also explains why all world maps are wrong on page 32.

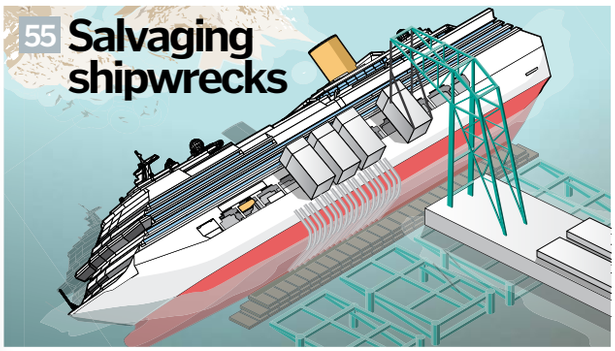
Jonny O'Callaghan
This month, Jonny investigates how different agencies and private companies are hoping to get us to Mars in the next few decades. Will we have Martian colonies by the 2030s? Time will tell!

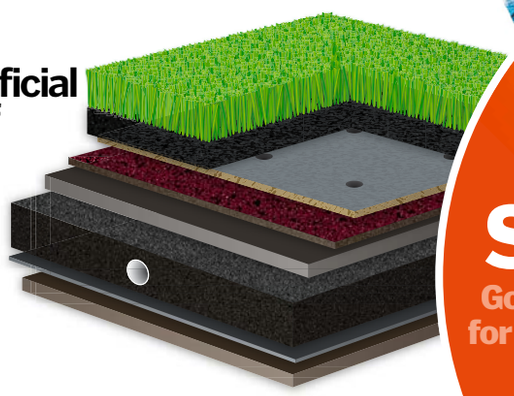


Sarah Bankes
Editor of *Photoshop Creative*, Sarah is a regular contributor to our Brain dump section. In this issue, she also investigates the science of wind chill and explains why glitter sticks to everything.

REGULARS







Tim Peake set to return to the ISS

The British astronaut will once again be heading into low-Earth orbit for another out-of-this-world mission

The British and European Space Agency (ESA) astronaut Tim Peake will be boarding the International Space Station (ISS) for a second time. In a surprise announcement made at the Science Museum, London, Peake declared that he would be returning to the ISS, probably at some point between 2019 and 2024, but it is yet to be confirmed what his new mission will be.

The Chichester-born astronaut lived on the ISS for six months, working up to 14 hours a day on the Principia mission. Peake became the seventh British-born person to go into space and the first to complete a spacewalk. In addition to carrying out over 250 science experiments during his time in space, Peake also ran the London marathon on a treadmill and tested a new augmented reality system by playing virtual Space Invaders.

Peake is said to be ecstatic at the prospect of returning to the ISS. He said that the view of Earth from space is what he's missed most and also voiced his enthusiasm for one day setting foot on the Moon. Peake made the announcement while talking at a new display of the Soyuz TMA-19M, the spacecraft that brought him safely back to Earth in June 2016 with his colleagues, Russian cosmonaut Yuri Malenchenko and American astronaut Tim Kopra.

Tim Peake landed back on Earth in Kazakhstan

"Peake is the first British-born person to have completed a spacewalk"

Some of the flight units that Peake used onboard the ISS were designed by school children in a competition run by Raspberry Pi

Peake's projects

The stress of space
Many astronauts return to Earth sick after a mission to the International Space Station. One experiment, which took samples of Peake's hair, was undertaken to see how stress affects the immune system.

Breathing tests
In microgravity, dust never settles, so astronauts are more likely to inhale particles that irritate their lungs. Nitric oxide exhalation was measured to monitor the condition of the lungs. The findings could help further studies into asthma.

Monitoring the body clock
The astronauts' bodies were examined to see the effects of a changing body clock in space. Any findings might help shed light on the effects felt by shift workers on Earth.

Germ study
Peake produced a stool sample for an investigation into the affects of space on 'good' gut bacteria. The experiment was useful for determining how to keep astronauts healthy for long durations in space.

Playing with fire
One of the experiments explored combustion in microgravity. Naked flames were ignited on the ISS in what was one of the most potentially dangerous tests conducted.

DIRECTED ENERGY LASERS COULD REVOLUTIONISE FUTURE BATTLEFIELDS

BAE Systems' concept will help military commanders observe enemy positions over huge distances

Surveillance is one of the most important aspects of warfare. Gaining information on an enemy is a vital advantage in a military campaign. A new concept unveiled by BAE Systems, known as the Laser Developed Atmospheric Lens (LDAL), exploits the Earth's atmosphere to produce advanced surveillance and defence solutions.

LDAL works due to the atmosphere's reflectiveness and the phenomena of mirages. A layer of the atmosphere called the ionosphere is naturally reflective to certain wavelengths. For example, radio broadcasts can be sent over vast distances because radio waves can be 'bounced off' the ionosphere.

Mirages are created when differences in air temperature bend (refract) light to give the illusion of objects that are not there. This is typically seen in deserts when the hot air near the sand refracts light from the sky, creating an image of the sky coming from the sand, appearing like a distant pool of water.

Using these principles, LDAL aims to temporarily change part of the ionosphere into a lens that can be used to magnify electromagnetic signals like visible light and radio transmissions to a receiver. The lens is created by highly powered pulsed lasers emitted from an aircraft, which ionise or heat a section of the atmosphere to change its optical properties, magnifying or redirecting distant signals.

As well as observing enemy movements and plans from much further away than ever before, the technology is also planned to produce a type of deflector shield to protect the aircraft from enemy laser countermeasures. LDAL is predicted to be integrated within the next 50 years and could prove to be a major turning point in warfare around the world.

The technology will use high power lasers to create temporary lenses in Earth's atmosphere

NEWS BY NUMBERS

$19.7 billion

Amount spent for Valentine's Day in the US in 2016

506 million metric tons

The estimated combined mass of all living humans

15 minutes

The time it takes NASA's GOES-16 weather satellite to provide full-disk images of the Earth

540 million years old

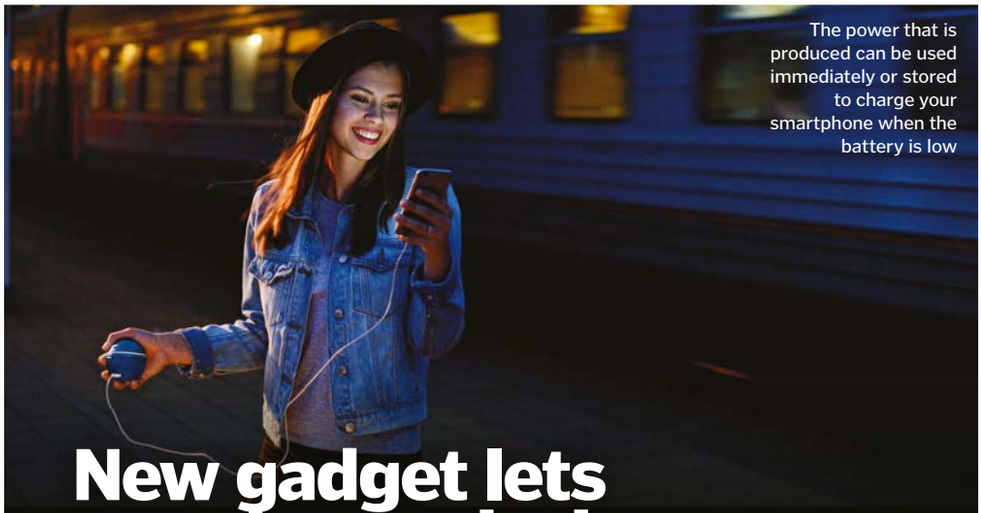
The age of *Saccorhytus coronarius*, believed to be our oldest known ancestor

Over half of primate species face extinction

Many of our primate cousins could soon be wiped out

A comprehensive study has warned that 300 species of primate are in danger of extinction. Deforestation is happening at an unsustainable rate due to the demand for timber and tree oils. Many primates are also being killed by poachers, hunted for their meat, or illegally traded. Between 1990 and 2010, it is estimated that 1.5 million square kilometres (equivalent to over two times the size of France) of primate habitat were lost. Two thirds of primates now live in only four countries (Brazil, Madagascar, Indonesia and DR Congo) and ideas are being put forward to save them.

Gorillas, chimpanzees, lemurs and lorises are all in danger of extinction and are already in decline



The power that is produced can be used immediately or stored to charge your smartphone when the battery is low

New gadget lets you charge devices with your body

The power to charge your gadgets is in your hands with HandEnergy

Thanks to a new gadget, soon you'll be able to charge your smartphone on the go by using some energy of your own. The HandEnergy is a hand-held device with a built-in gyroscope that utilises hand movement to generate electricity. As your hand rotates, the built-in rotor turns, increasing its speed up to 5,000rpm. Taking between 40 minutes and an hour to fully charge, the device generates clean, renewable energy that is ideal for commuters and travellers who are away from power sockets for long periods. Due for release in March 2017, it might make flat batteries a thing of the past.

The Go for Gold campaign is now advising people to only lightly brown their potatoes and toast

Can burnt toast lead to cancer?

New research shows that overcooked food could be a health risk

A recent study has warned against burning or overcooking carbohydrate-rich foods. Foodstuffs like potatoes, crisps and toast can contain acrylamide when overcooked as amino acids combine with sugar during heating. It's recommended that 195 micrograms of this chemical compound is the most a person should have as part of a daily intake. Fortunately a slice of burnt toast contains about 4.8 micrograms, so the cancer risk is believed to be minimal. The research itself is based on animal rather than human studies, but as scientists continue to investigate the effects of acrylamide consumption, it can't hurt to reduce your intake.

GLOBAL EYE

10 COOL THINGS WE LEARNED THIS MONTH

Wolf-sized otters roamed prehistoric China

The remains of an extinct otter recently discovered in southwest China indicate that these creatures were bigger and heavier than giant river otters, the largest species alive today. Fossil fragments were digitally reconstructed and analysed using CT scans, and results indicate that these creatures were two metres long and weighed up to 50 kilograms. They lived in warm, humid wetlands and likely feasted on molluscs and clams, using their strong jaws to crush shells.

Sound waves could stop tsunamis in their tracks

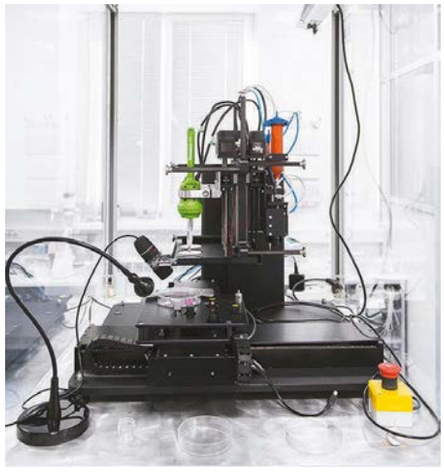
Before they hit the shore, tsunamis could be dispersed by powerful sound waves. Naturally occurring acoustic-gravity waves (AGWs) are created during geological events like earthquakes. In theory, AGWs could be fired at waves to lessen their height, momentum and power. Creating an AGW transmitter will be difficult though, and using such a defensive measure could be dangerous.

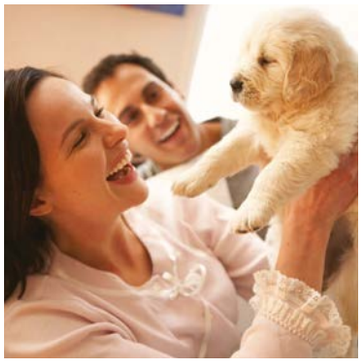
Artificial intelligence can predict heart failure

New technology can help recognise when an organ is about to fail. Using MRI scans and blood test results, the software accurately predicted if heart failure would occur within one year around 80 per cent of the time. Beats were measured using advanced image processing and then linked to past patient data. The software is being used specifically for pulmonary hypertension, which is currently considered incurable.

3D bioprinters can produce human skin

A new 3D printing procedure can replicate all the layers of the skin's natural structure. This new process will accurately recreate the skin's elasticity and strength and could be used for skin grafts to treat burns as well as testing new cosmetics and medicines. It's only in the prototype stage, but if successful, 3D bioprinters could create more organs in the future.





Why dogs respond to 'puppy talk'

In a recent study, dogs and puppies were played recordings of phrases like 'who's a good boy?', first in a high pitched tone and then in a normal voice. Puppies responded more positively to the higher pitched recordings, but it made no difference to the adult dogs. Scientists believe that slow and high-pitched speech is the natural human way of talking to nonspeakers like pets and is done to encourage interaction and engagement.

Eating spicy food could help you to live longer

A new report has found that spicy chilli peppers could have a beneficial impact on health. Chillies contain capsaicin, which may help prevent obesity while also regulating blood flow in arteries. It is also believed to possess antimicrobial properties, which can alter the microbes found in the gut.

A nearby exoplanet may have an Earth-like atmosphere

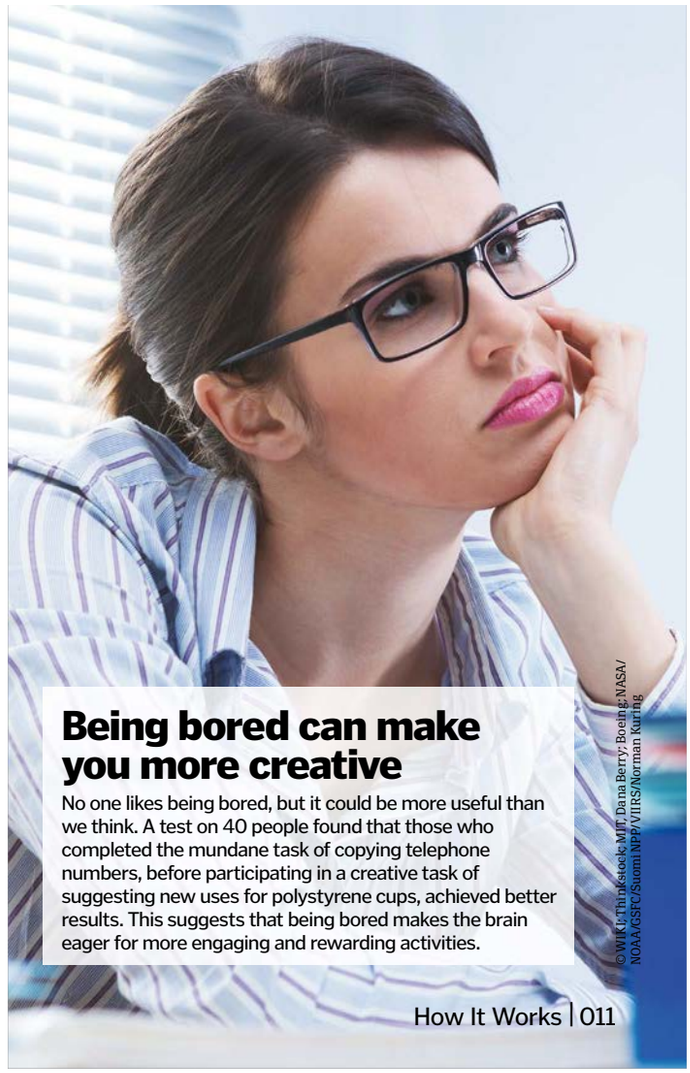
Although different in size, GJ 1132 b could be one of the most Earth-like exoplanets found so far. 39 light years away, the planet is almost 50 per cent larger in diameter than Earth, but could host a thick atmosphere that astronomers believe could contain water and methane. The discovery is another step towards understanding the possibly life-harbouring atmospheres of exoplanets.

Earth's last major warm phase was as hot as today

New research has found that 125,000 years ago, the temperature of Earth's ocean surfaces was similar to today. The difference was that sea levels were up to nine metres higher than they are currently. Scientists are using the findings to help predict future climate change.

Boeing have designed new spacesuits

Astronauts on board Boeing's CST-100 Starliner spacecraft will be donning new threads. The modern spacesuit will be lighter and more flexible than the Space Shuttle-era suits, and will have better temperature and pressure management systems. The gloves will be touchscreen-sensitive and both the helmet and the visor will be built into the suit rather than being separate as before.



Being bored can make you more creative

No one likes being bored, but it could be more useful than we think. A test on 40 people found that those who completed the mundane task of copying telephone numbers, before participating in a creative task of suggesting new uses for polystyrene cups, achieved better results. This suggests that being bored makes the brain eager for more engaging and rewarding activities.

RACE TO MARS

HOW THE 21ST CENTURY SPACE RACE WILL GET US TO THE RED PLANET

Humanity has long dreamt of sending humans to Mars, but it's often felt like something perennially beyond our reach. However, it might very well become a reality in the near future, thanks to the work of a select few visionaries.

When the Apollo missions to the Moon ended in 1972, many felt that Mars was the next step. But instead the decision was made to develop the Space Shuttle and, later, the International Space Station (ISS), and remain in the Earth's orbit. Manned missions to Mars were shelved.

But in the last decade or so, Mars has been put back on the agenda. Helped by recent discoveries that suggest it was once habitable, there's a renewed clamour to get people there and, among other reasons, find out if we are alone in our Solar System, let alone the universe.

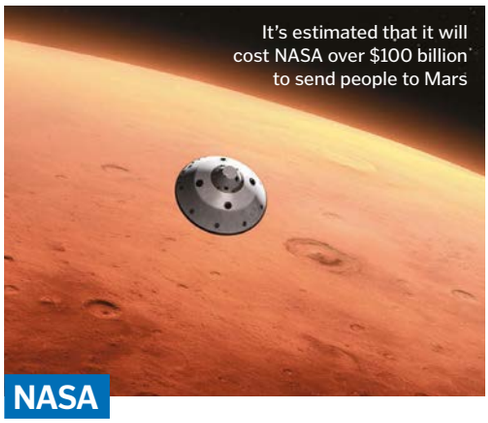
However, progress has been slow. NASA has tried and failed to start a Mars programme before called Constellation, but this was scrapped in 2009 in favour of a new plan. Now, NASA's goal is to get humans there by the 2030s. And the last few years has seen a number of private companies springing up with the same ambitions too.

Mars One, a somewhat overly ambitious Dutch and Swiss company, hopes to turn the event into a reality TV show, although they have made little progress. On the other hand, you have SpaceX CEO Elon Musk, who in September 2016 revealed a bold – and some might say crazy – plan to send 1 million people to Mars over the next 100 years.

The dream of going to Mars is very much alive. As you'll see through this feature, it might not be long before we start wondering what's next.

The competitors

The contenders hoping to win the race to Mars



NASA

The world's most successful space agency has long had its eye on manned missions to Mars, going back to the days of the Apollo missions. But progress has been slow, with the plan now to send humans there in the 2030s. Much will rely on continued support for the development of a new spacecraft and rocket being built by NASA.

SPACEX

The company run by Elon Musk has a rather ambitious goal of beginning manned flights to Mars by 2024 or 2026. The company wants to build a mammoth rocket that can take 100 people to Mars on each trip, with the ultimate aim of having 1 million people on Mars just a century after the first launch.

MARS ONE

This Dutch-led company gained notoriety when it proposed sending people on one-way trips to Mars in the 2030s funded by a reality TV show. The early hype has died though, and the company looks unlikely to succeed, but it's another example of the growing plans to put people on the Red Planet.

The key steps to Mars

The journey to the Red Planet

December 2014
NASA
Unmanned Orion
On 5 December 2014, NASA launched its Orion vehicle for the first time, on a Delta IV Heavy rocket. The unmanned flight lasted about four hours.

September 2016
SPACEX
Musk's masterplan
SpaceX CEO Elon Musk reveals his plan to send 1 million people to Mars within 100 years using the ITS.

Autumn 2018
NASA
Space Launch System
NASA will launch its huge new rocket, the Space Launch System, for the first time. This will be an unmanned mission.

2021
NASA
Orion crew
This is the earliest expected date for NASA to launch a crew on its Orion vehicle for the first time, an integral part of a future Mars mission.

"The dream of going to Mars is very much alive"

2024
SPACEX
First SpaceX mission
In 2024, SpaceX is hoping to launch its first manned mission to Mars on the ITS, after a number of unmanned test flights before.

2026
NASA
ARM
NASA plans to launch its Asteroid Redirect Mission (ARM), where a crew on the Orion vehicle will rendezvous with an asteroid that has moved into lunar orbit.

2026
SPACEX
Next SpaceX mission
If their first launch is successful, SpaceX plans to launch a human crew to Mars in every available launch window – every 26 months.

2030+
NASA
Phobos
At some point in the 2030s, NASA is aiming to put humans in orbit around Mars, possibly landing on its moon Phobos, but not necessarily on the Red Planet itself.

2031
MARS ONE
One-way
This is the proposed launch date for Mars One's first crewed mission to Mars, but it looks unlikely they'll achieve this goal at the moment.

2039
NASA
Humans on Mars
By the end of the 2030s, NASA hopes to finally put people on the surface of Mars. It's a lot later than SpaceX's plan, but it might be a more realistic time scale.

Why Mars?

Our galactic neighbour has always fascinated us

It's a question almost as old as the ambition of going there in the first place: what's the point in going to Mars? Well, there are a few reasons.

First and foremost, it satisfies our human desire to explore. Around the world, humans have always pushed beyond their boundaries. Now, the next logical step is space, and with the Moon already being graced by us, Mars is the obvious (and easiest) next step.

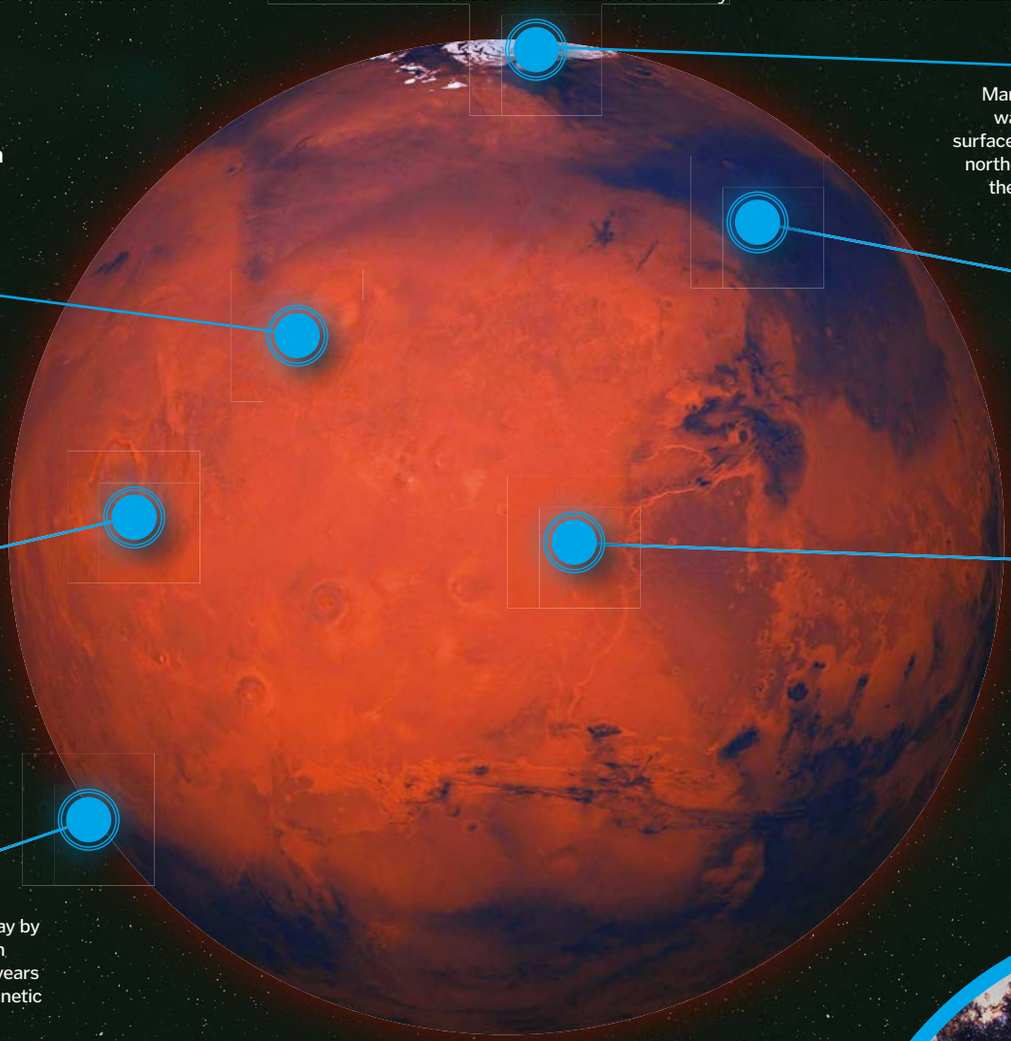
Mars also holds tremendous scientific value. Excitingly, it is now believed that the Red Planet may once have had conditions that could support life, and it may still do today. We have sent many rovers and orbiters to Mars, but none can replicate the skills and versatility of a human. It's often said that humans on the ground could replicate everything the rovers have done in a decade in a matter of days. And if Mars does host life, isn't finding out we're not alone one of the greatest reasons of all to go?

The technologies required to send people to Mars will be immense. It will almost certainly be a global undertaking, with many potential spinoffs into the fields of medicine, psychology, engineering and many more. Perhaps most importantly of all, though, going to Mars could ensure our survival.

One day, Earth will face a doomsday scenario such as an asteroid impact, or failing that, the eventual death of our Sun. Perhaps the only way to secure the future of the human race will be to permanently colonise another world. Mars could become that new home.

The Red Planet

What makes the fourth planet of our Solar System so intriguing?



Polar ice
Mars has vast amounts of frozen water and carbon dioxide on its surface, particularly at its poles. The northern cap spans 1,100km, while the southern cap spans 400km.

Ocean
Recent research suggests that the Northern Hemisphere of Mars may once have held more water than the Arctic Ocean. Evidence of ancient shorelines still exists on Mars.

Surface water
In September 2015, NASA revealed that liquid water may have been found to have flown on the surface of Mars, in the form of tiny trickles called Recurring Slope Lineae (RSL), but this has not been confirmed.

Subsurface water
Between the equator and its poles, Mars is thought to have a large amount of ice under its surface, perhaps holding more water in total than Lake Superior in North America.

Habitable
Today, the surface of Mars is mostly dry. But throughout its history, it may have gone through multiple periods of wetness, with a thicker atmosphere more conducive to life.

Atmosphere
The atmosphere of Mars has today mostly been blown away by the Sun. But it may have been much thicker about 4 billion years ago, before Mars lost its magnetic field for unknown reasons.

Mars One stirred up a debate about the idea of one-way missions to Mars

One-way missions

In 2012, Mars One caused controversy when they announced plans for one-way trips to Mars. A debate about the ethics of such journeys soon began.

Mars One's reasoning is as follows. Rather than spending a lot of money developing technology to take people there and back, they could save money by keeping people on the Red Planet. They would be largely self-sufficient, but regular resupply missions would ensure they don't meet a premature end.

Of course, there are a few problems with this, not least potentially sending people to their deaths. The cost of these resupply missions, and maintaining the colony, is likely to far outweigh the savings in not coming home.

SpaceX, for its part, is now considering something similar. But rather than sending a handful of people like Mars One, it wants to have a fully functioning colony of 1 million people on Mars' surface by 2124.

The next space race

How the effort to go to Mars compares with putting humans on the Moon


Competition between the US and the Soviet Union helped get humans to the Moon

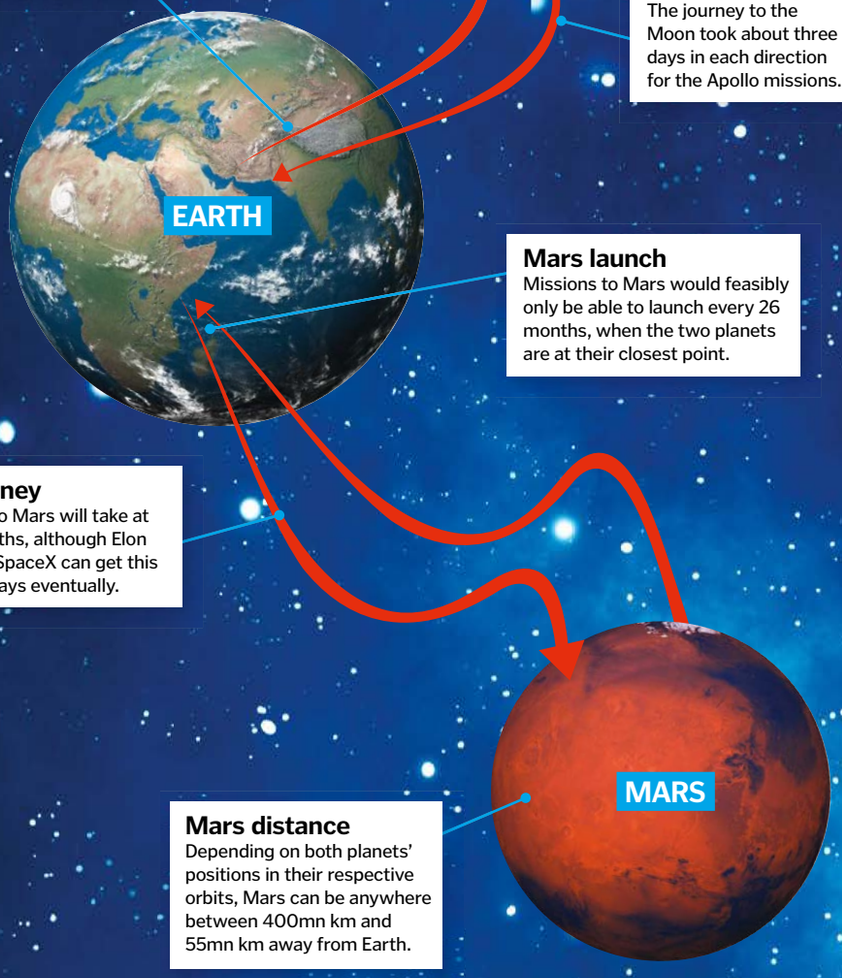
President John F Kennedy's speech at Rice University in 1962 lives long in the memory. "We choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard," he famously said. By 1969, that goal had been achieved.

We haven't quite yet had the same momentum with our Mars efforts, but we are making progress. The Apollo programme was supported by the Mercury and Gemini missions, which were tentative steps designed to see how humans coped with prolonged spaceflight. In the modern era, the best analogue is the ISS. We've been using the ISS to test out long-term spaceflight of a similar length needed for a trip to Mars for more than a decade and a half. It's also been a great testing ground for a self-sustaining crew in space.

Prior to humans landing on the Moon, we needed to test various technologies. This included sending humans on a test orbit around the Moon, and practising various rendezvous techniques in Earth's orbit. For the Mars missions, NASA is planning something similar. It's hoping to use its Asteroid Redirect Mission (ARM) to practice using its Orion vehicle in deep space, before a potential mission to Mars' orbit in the early 2030s – perhaps with a crew landing on the Martian moon Phobos.

Moon vs Mars

How getting to Mars differs from going to the Moon



Moon distance
The Moon is an average of 385,000km from Earth, a stone's throw compared to Mars.

Moon launch
Missions to the Moon can take place at any time, as the distance between it and Earth doesn't change much.

Moon journey
The journey to the Moon took about three days in each direction for the Apollo missions.

Mars launch
Missions to Mars would feasibly only be able to launch every 26 months, when the two planets are at their closest point.

Mars journey
The journey to Mars will take at least six months, although Elon Musk thinks SpaceX can get this down to 30 days eventually.

Mars distance
Depending on both planets' positions in their respective orbits, Mars can be anywhere between 400mn km and 55mn km away from Earth.

"Cooperation is going to be key"

Team effort

It's unlikely one company or nation will send humans to Mars alone. Cooperation is going to be key, and we're already seeing the first signs.

NASA has been busy enlisting private companies to help with the construction of its Mars architecture. American aerospace giant Lockheed Martin is building the command module for the Orion spacecraft, while Boeing is helping NASA build the huge Space Launch System rocket.

Other nations are likely to play a part too. Looking to the ISS, there are 15 countries working together, comprising the US, Russia, Canada, Japan, and the eleven member states of the European Space Agency. It's likely that a similar cooperative effort might be undertaken for missions to Mars, perhaps including Japan, China and SpaceX too.

With a cost in the tens of billions of dollars it will be difficult for one nation to go it alone – although Elon Musk's SpaceX think they might be able to do just that.


The ISS is a shining example of international cooperation

Blast-off!

The rockets that will take humans to Mars

To get to Mars, you're going to need a big rocket. So it's a good thing that NASA and SpaceX are working on just that.

On the NASA side of things, we've got the Space Launch System (SLS). The rocket has come in for a considerable amount of criticism, especially as NASA doesn't really have a proper idea of what they want it to do yet, not to mention its eye-watering $18 billion (£14 billion) cost. The plan at the time of writing is to develop two versions of the rocket, the larger of which (called Block 2) will be the most powerful rocket ever built – more powerful even than the Saturn V rocket that took humans to the Moon.

A first launch of the smaller version, called Block 1a, is expected to take place towards the end of 2018. This will send an unmanned Orion capsule on a flight around the Moon. A few years later, a crew will be sent on a mission to lunar orbit (Orion can seat a maximum of six). Beyond this though, there are no firm plans. The idea is that in the 2030s one or multiple SLS rockets will be used for a return trip to Mars. Some have suggested the powerful rocket could also be used for quicker unmanned missions to other destinations in the Solar System.

As for SpaceX, they have two large rockets in development. The first is the Falcon Heavy, which will mostly be used by paying customers to take satellites and unmanned spacecraft into the Earth's orbit and beyond. Their much bigger rocket, revealed in September 2016, is the Interplanetary Transport System (ITS), also known as the Mars Vehicle.

The ITS is absolutely mammoth, dwarfing even the larger version of the SLS rocket. In early concepts, the rocket will launch with a large vehicle on top that could take 100 to 200 people to Mars on each trip. The rocket itself will land back on Earth, ready to be used again, while the vehicle would travel on towards Mars on its own.

SLS vs ITS

Comparing these two massive launch vehicles

NASA'S SLS

Height
NASA's SLS Block 2 will have a height of just over 111m, making it less than a metre taller than the Saturn V.

Weight
The entire SLS rocket will weigh 3mn kg at the time of lift off.

Thrust
SLS will have a lift-off thrust of 4.2mn kg.

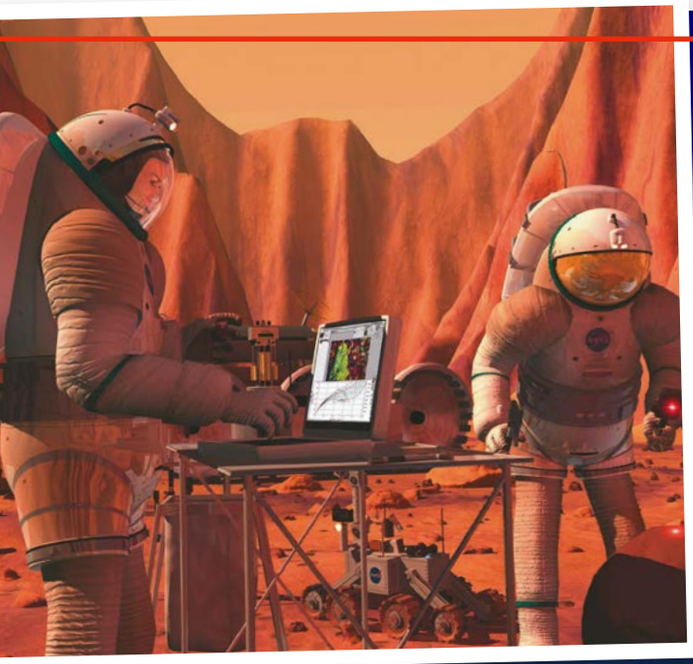
SPACEX'S ITS

Height
The ITS will be the biggest rocket ever, built at 122m tall.

Payload
The ITS will be able to take up to 550,000kg into orbit.

Weight
The weight of the ITS has not been confirmed, but we do know the booster is designed to land back on the ground, unlike the SLS.

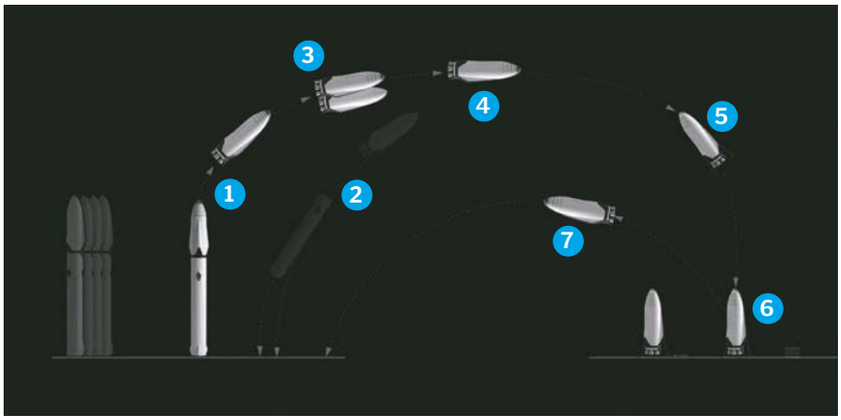
"To get to Mars, you're going to need a big rocket. So it's a good thing that NASA and SpaceX are working on it..."



Humans will be able to collect data much faster than rovers and probes have

How the ITS works

The launch system behind SpaceX's plan to send 1 million people to Mars



1 Launch
Between 100 and 200 people will be launched on the ITS.

2 Reusable
After launching, the booster will return to the ground.

3 Orbit
The crew vehicle will dock with a fuel tanker in orbit.

4 Journey to Mars
SpaceX propose that the journey to Mars could eventually be as short as 30 days.

5 Mars landing
The entire vehicle will land passengers on Mars. It will generate 1,700°C as it enters the atmosphere.

6 Propellant
A propellant plant will turn Martian water and CO_2 into fuel.

7 Return
The vehicle will return to Earth, ready for another trip.

Payload
SLS Block 2 will be able to take 130,000kg into orbit.

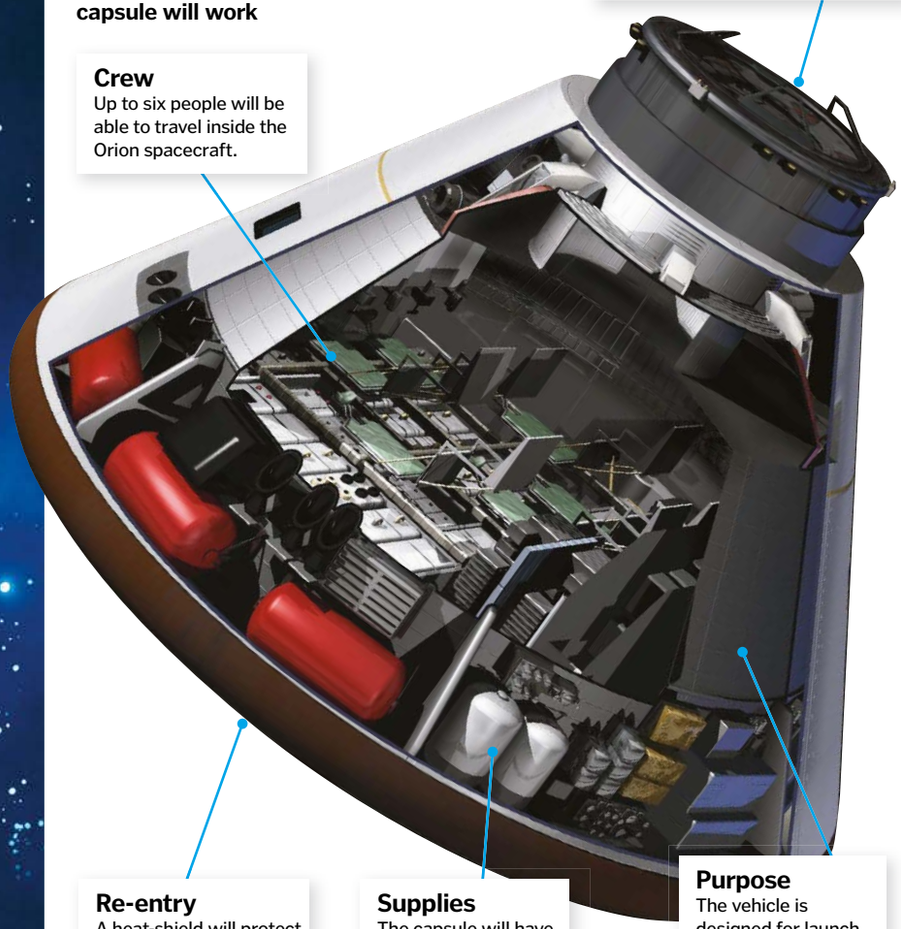
Thrust
With a lift-off thrust of 13mn kg, the ITS will be far more powerful than any other rocket built before.

Inside Orion

How NASA's Mars crew capsule will work

Docking
A docking adapter will allow Orion to dock to other vehicles, such as the SLS or a deep space habitat.

Crew
Up to six people will be able to travel inside the Orion spacecraft.



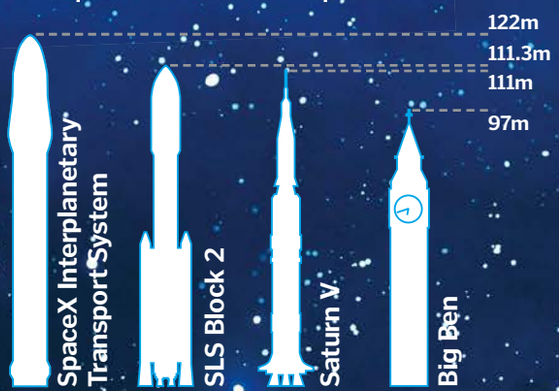
Re-entry
A heat-shield will protect the spacecraft during Earth re-entry.

Supplies
The capsule will have basic life-support and cargo capabilities.

Purpose
The vehicle is designed for launch, long travel durations and re-entry.

Size comparison

How SpaceX's rocket stacks up to NASA's



The Mars Base Camp

Lockheed Martin's plan to put humans into Mars orbit

Sending people to Mars will probably not be a single-mission endeavour. We will likely need other missions to prepare, such as test missions to Mars orbit, or even supply missions to the surface of the planet. An agency like NASA wouldn't be too keen on sending people to Mars and having them fend for themselves – it would be wise to have some sort of infrastructure in place beforehand.

With this in mind, Lockheed Martin unveiled its plan for a Mars Base Camp in 2016. The idea basically revolves around building an ISS-lite in Mars' orbit. This orbiting laboratory could be visited by Orion spacecraft, and used by astronauts to study Mars and control rovers on its surface. The latter is known as telerobotics, and has been proposed as a way to speed up Mars exploration. There is a lag of tens of minutes when controlling a rover on Mars from Earth, but that would be reduced to just seconds from Mars' orbit.

Lockheed Martin's proposal would involve beginning construction of the Base Camp first in cis-lunar space (near the Moon). The company say that NASA could use this as a place to dock its Orion spacecraft and, in 2023, astronauts could practice controlling rovers on the surface of the Moon. Then, in 2027, the entire station would be relocated to Mars. By 2028, it would be ready for humans to visit, and it could be used as a staging outpost for trips to the surface in the 2030s.

Whether NASA will adopt the plan remains to be seen. But it's an enticing one as it lays out a steady roadmap for Mars exploration. Unlike SpaceX's plan, it also seems quite realistic. The technologies are not beyond our reach, and it builds on things we've done before.

Explore
One of two Orion vehicles could be used to explore the Martian moons Phobos and Deimos.

Fuel tanks
Liquid oxygen and hydrogen fuel will be stored in these tanks.

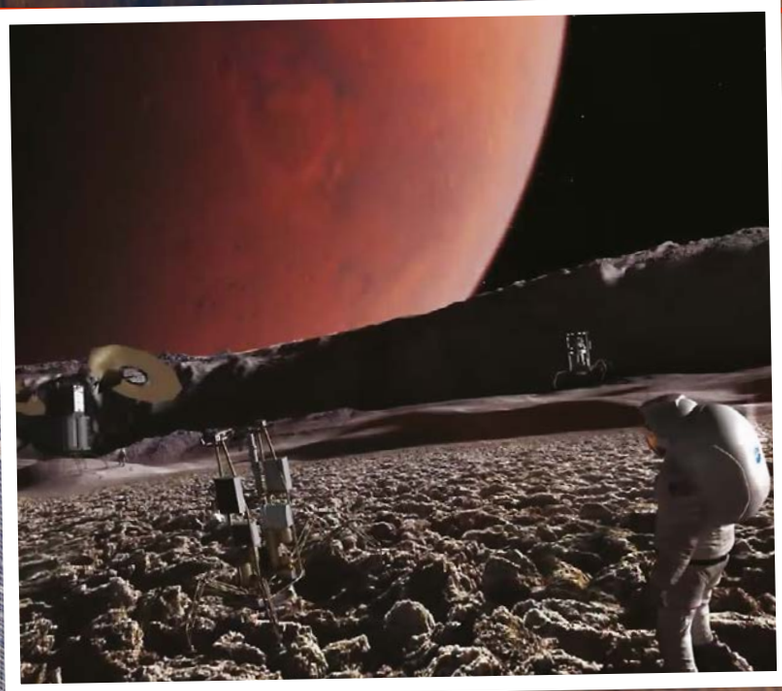
Habitat
The station would have space for astronauts to live and work in.

Laboratory
Here astronauts could conduct experiments and control rovers on Mars.

Mars Base Camp
Building a space station in orbit around Mars

"Sending people to Mars will probably not be a single mission"

It will cost around $16 billion to prepare Orion for its first manned mission, scheduled for the 2020's



Other potential exploration strategies involve setting up Martian moon bases on Phobos or Deimos

Radiators
Like the ISS, the station would have radiators to expel heat into space.

Orion
The Mars Base Camp would have two docking ports for two Orion vehicles.

Solar arrays
The spacecraft's power would come from large solar arrays.

Propulsion
A cryogenic propulsion stage would move the spacecraft from lunar orbit to Mars.

Hibernation

One of the problems with getting to Mars is working out what to do with the astronauts on the way. With a journey time of up to several months, the astronauts will need to keep fit, ready and alert. One possible way to do this is to have a rotating section to simulate Earth's gravity. But another way is to put the crew into hibernation, an idea that NASA has funded research for.

A small crew could be unconscious for two weeks at a time on a rotational basis, with one person always staying awake for a brief time. Every two or three days, that astronaut would go into hibernation, and another would wake up. While asleep, the astronauts would be kept at temperatures as low as 32 degrees Celsius – down from our more regular 37 degrees Celsius – to slow their metabolisms.

US company SpaceWorks Enterprises Inc are investigating the feasibility of induced hibernation for space travel

A home on Mars?

One major criticism of the Apollo missions was that there were no plans to keep people on the Moon permanently. The longest mission on the surface, Apollo 17, was about 12 days, and we have not been back to the Moon since.

Many are keen for Mars exploration to not simply be a series of 'boots on the ground' missions, but rather a plan to keep a base or colony on the surface. It's unclear which route NASA is favouring at the moment, so time will likely tell what they are aiming for.

As for SpaceX, we know that they want to have a massive colony on the surface in the next 100 years or so. They envisage sending 100 people or more at a time and reusing their rocket for multiple trips, eventually leading to a colony of 1 million people on Mars. Elon Musk has also touted the idea of terraforming Mars and making it liveable for humans, but that's a story for another day.

© Lockheed Martin; SpaceX

SpaceX wants to have a colony of 1 million people on Mars in around 100 years

Air-launch systems

How and why rockets are launched from aircraft

You're probably familiar with 'normal' rockets, which launch vertically from the ground. But you might be less familiar with air-launch systems, where a rocket is launched from the underbelly of a plane.

This type of launch is not particularly new. There have been dozens over the past few decades, with one of the most successful systems being the Pegasus rocket, developed by American company Orbital ATK.

The Pegasus system involves attaching a rocket, measuring either 15 metres for the regular rocket or 16.9 metres for the XL version, underneath a huge Lockheed L-1011 TriStar aircraft known as Stargazer. At a height of 12,400 metres the rocket is released, and it ignites its engine to make the rest of the journey to space on its own.

One of the benefits of using this system is that it is somewhat cheaper than launching rockets using conventional ground-launch systems – at least for smaller payloads. For this reason, NASA recently used a Pegasus XL to launch its CYGNSS spacecraft, a suite of eight satellites that will study tropical storms. They are part of NASA's Earth Venture programme, which focuses on low-cost, science-driven missions to study Earth, and Pegasus offers a cheaper way to access space than a standard rocket.

However, the actual benefits of an air-launch system are debated. Some say that the speed and altitude gained from the aircraft is not that significant, as the rocket still has to do much of the legwork. But, at the very least, it's very impressive to see one launch.

Pegasus provides a lower-cost route to space

How Pegasus works

How this rocket makes its way into space

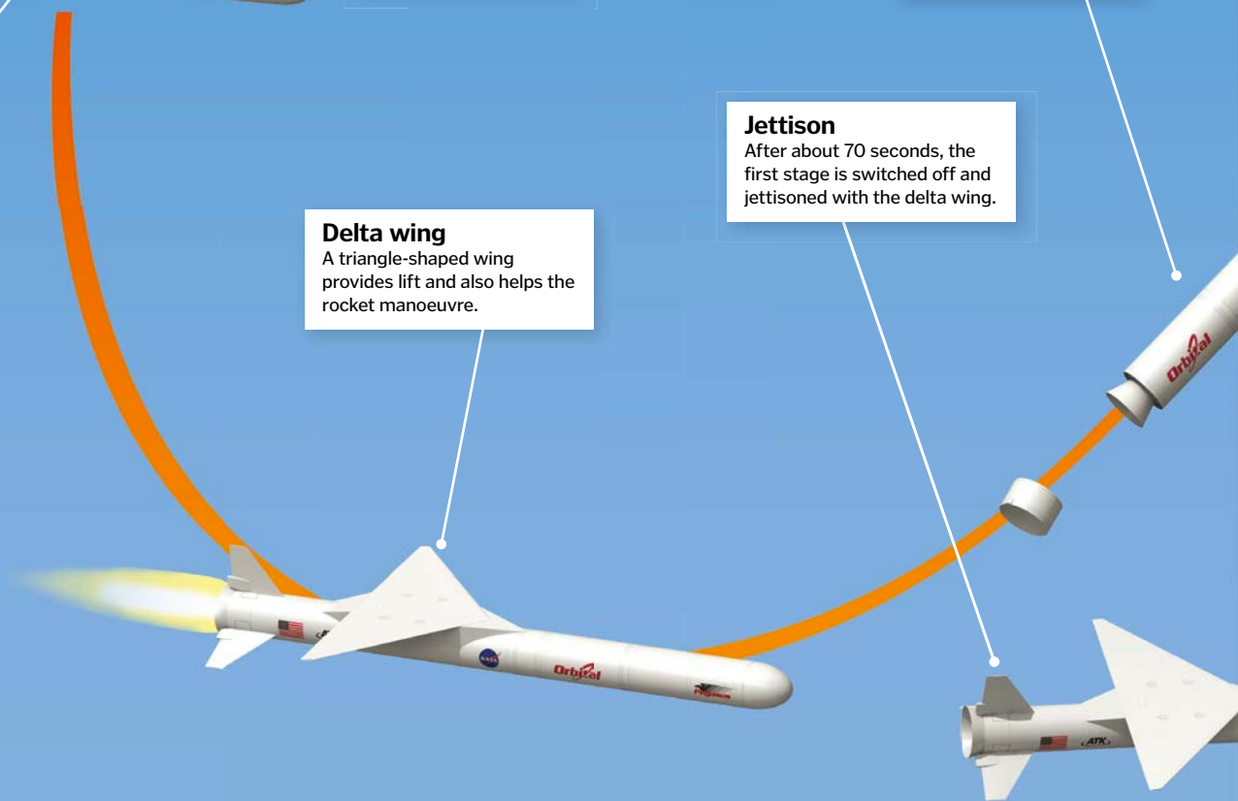
Release
At a height of around 12.4 kilometres, the rocket is released from the carrier aircraft.

Stage 2
Now at a height of 71 kilometres, Stage 2 of the rocket fires its engine.

Jettison
After about 70 seconds, the first stage is switched off and jettisoned with the delta wing.

Delta wing
A triangle-shaped wing provides lift and also helps the rocket manoeuvre.

Stage 1
After five seconds of freefall, the rocket's first stage ignites its engine.

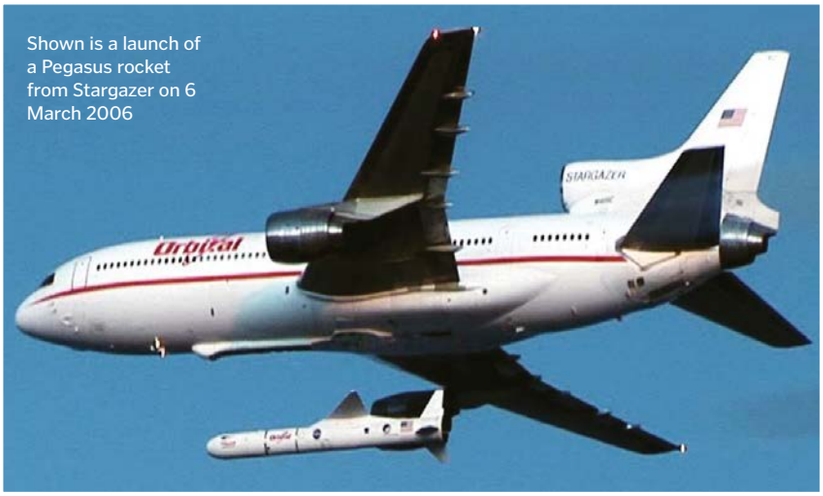


"The actual benefits of an air launch system are debated"

Stargazer

Stargazer is a modified Lockheed L-1011 TriStar aircraft used by Orbital ATK to launch its Pegasus rockets into orbit. It has a top speed of 1,053 kilometres per hour using three engines: two on the wings and one on top of the aircraft. Both its length and wingspan measure 50 metres.

Orbital ATK began using Stargazer on 27 June 1994, with more than 35 launches being completed since then. Previously, Orbital had used the NASA-operated Boeing NB-52B Balls 8 to launch its Pegasus vehicle. Most flights take place from Vandenberg Air Force Base in California, but some have also lifted off from elsewhere in the US, the Marshall Islands and even Spain.



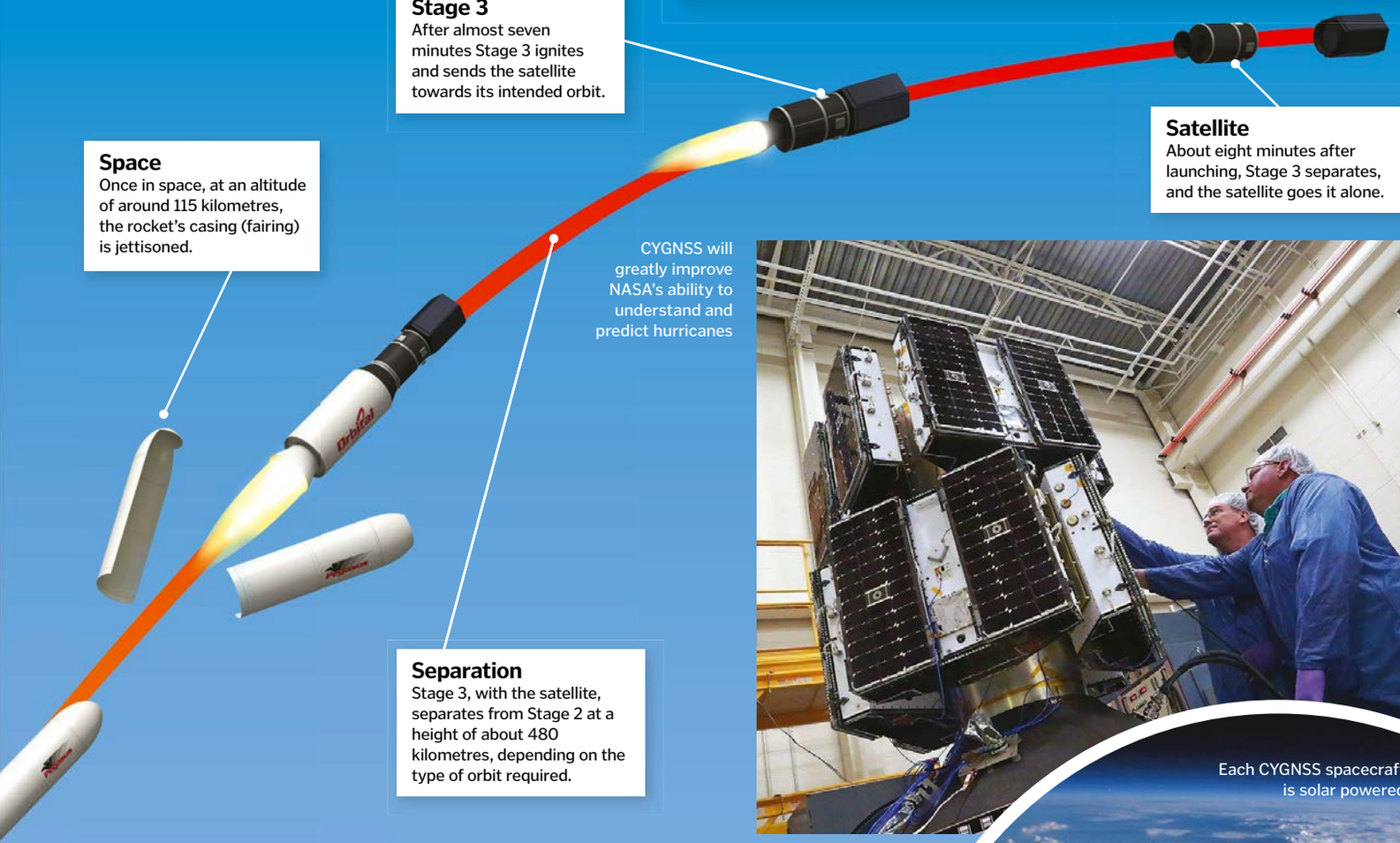
Shown is a launch of a Pegasus rocket from Stargazer on 6 March 2006

Stage 3
After almost seven minutes Stage 3 ignites and sends the satellite towards its intended orbit.

Satellite
About eight minutes after launching, Stage 3 separates, and the satellite goes it alone.

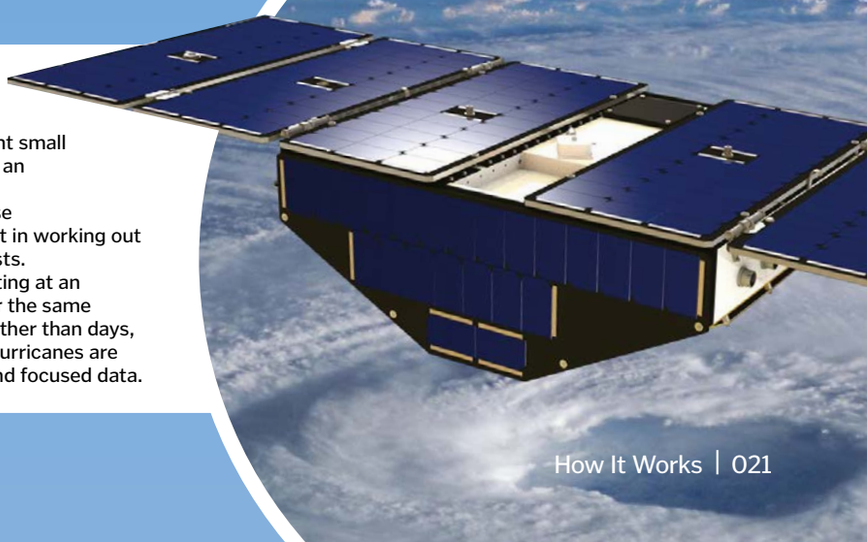
Space
Once in space, at an altitude of around 115 kilometres, the rocket's casing (fairing) is jettisoned.

Separation
Stage 3, with the satellite, separates from Stage 2 at a height of about 480 kilometres, depending on the type of orbit required.



CYGNSS will greatly improve NASA's ability to understand and predict hurricanes

Each CYGNSS spacecraft is solar powered



CYGNSS

NASA's Cyclone Global Navigation Satellite System (CYGNSS) consists of eight small microsatellites, each one just 51x64x28 centimetres, that will give scientists an unprecedented look at tropical storms and hurricanes.

The spacecraft will look for GPS signals reflected in the oceans, using these measurements to monitor hurricane wind speeds. This data will be important in working out how intense a storm is, significantly improving tracking and intensity forecasts.

Each spacecraft is deployed in a slightly separate location over Earth, orbiting at an altitude of approximately 500 kilometres. Successive satellites will pass over the same region every 12 minutes, letting us see the evolution of storms over hours, rather than days, from a single satellite. They will look exclusively at the tropics, where most hurricanes are found, rather than the whole world, letting them gather much more useful and focused data.

Viewing Earth in HD

The cameras on the ISS that provide a live feed of our planet

Chances are, if you've ever watched a live stream of Earth from space, you've probably been watching it via NASA's High Definition Earth Viewing (HDEV) cameras.

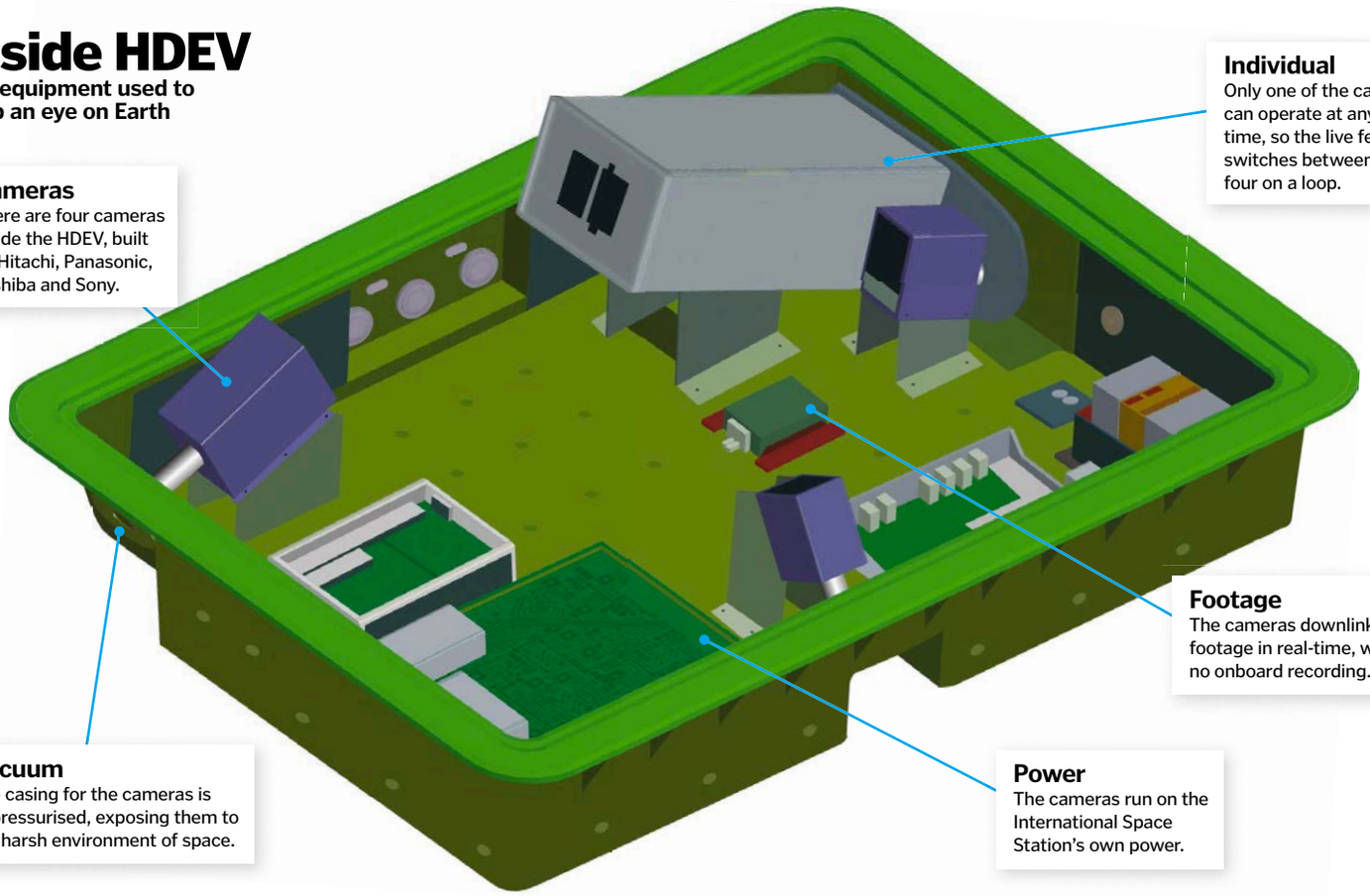
Launched to the International Space Station (ISS) on a SpaceX Dragon capsule in 2014, the four cameras provide an almost continuous stream of footage of Earth. They are mounted externally together outside the station's Columbus laboratory module, with teams of students involved in the experiment.

But while the pictures might be pretty, the goal of the experiment is not public outreach. Instead, HDEV is designed to monitor how HD video cameras cope with the harsh environment of space. One camera continuously looks forward, one looks downward, and the other two point backwards, giving different views.

Head to **eol.jsc.nasa.gov/ESRS/HDEV** to watch the live stream in all its glory

Inside HDEV

The equipment used to keep an eye on Earth



Cameras
There are four cameras inside the HDEV, built by Hitachi, Panasonic, Toshiba and Sony.

Individual
Only one of the cameras can operate at any one time, so the live feed switches between all four on a loop.

Footage
The cameras downlink their footage in real-time, with no onboard recording.

Power
The cameras run on the International Space Station's own power.

Vacuum
The casing for the cameras is unpressurised, exposing them to the harsh environment of space.

Italian ESA astronaut Samantha Cristoforetti in her sleeping bag in her crew quarters in 2014

How astronauts sleep

The tricks to getting 40 winks on the ISS

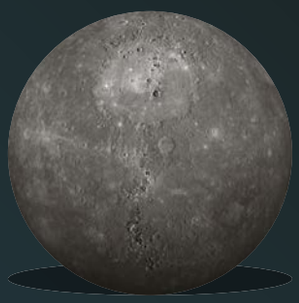
How do you sleep if you're weightless? Well, for one thing, you don't need a horizontal bed. On the ISS, each crew member has a phone-booth sized sleeping compartment, with little room to move around. A sleeping bag is attached to the wall, which the astronauts zip in to so they don't float around.

In front of them is a 'desk' of sorts for a computer, held down with Velcro, although many choose not to mix work and rest. Some astronauts use pillows, or blocks of foam, and others also use earplugs and a sleep mask to block out noise and light, just like on Earth. The lights are turned on at 6am to signal to the astronauts when it's time to get up.

Astronauts get 8.5 hours of allocated sleep time for every day on the ISS. They operate on Greenwich Mean Time (GMT), because the ISS completes an orbit of Earth every 90 minutes; GMT was a happy medium between time zones in the US and Russia, the two major partners on the ISS.

Planet types

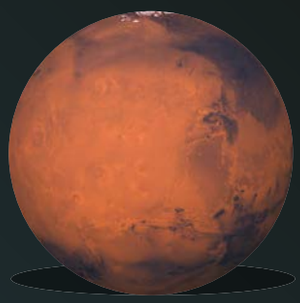
How we categorise the different worlds found in our galaxy



MINITERRAN

Radius compared to Earth: 0.03 to 0.4 R_E
Mass compared to Earth: 0.00001 to 0.1 M_E

Miniterrans are the smallest spherical rocky worlds, according to the Planetary Habitability Laboratory (PHL). Due to their size, which is similar to that of Mercury, they are very hard to find – only five have been found outside the Solar System to date. Those we have found are close to their star, and thus very hot and have no atmosphere.



SUBTERRAN

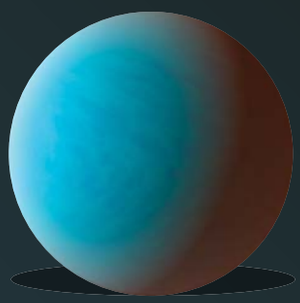
Radius compared to Earth: 0.4 to 0.8 R_E
Mass compared to Earth: 0.1 to 0.5 M_E

These rocky worlds are similar in size to Mars and again, like miniterrans, they are incredibly difficult to locate outside of our Solar System. Most of the 69 identified so far orbit close to their star, and are hot and hellish worlds, prone to regular bombardment from asteroids. Mars is the only subterran world in our Solar System.

TERRAN

Radius compared to Earth: 0.8 to 1.5 R_E
Mass compared to Earth: 0.5 to 5 M_E

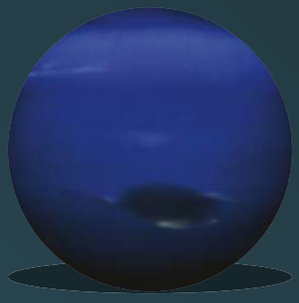
Terrans are similar in size to Earth and Venus, and are often billed as the most likely worlds to be habitable. Of the 664 found outside the Solar System to date, about 15 are thought to be in their star's habitable zone, also known as the Goldilocks zone – the region where liquid water, and maybe life, could exist.



SUPERTERRAN

Radius compared to Earth: 1.5 to 2.5 R_E
Mass compared to Earth: 5 to 10 M_E

Superterrans, also known as super-Earths, are rocky worlds considerably larger than Earth. About 29 are known to orbit in their star's habitable zone, although due to their enormous size, it is sometimes difficult to discern if a superterran is rocky like Earth, or a gas planet similar to Neptune.



NEPTUNIAN

Radius compared to Earth: 2.5 to 6 R_E
Mass compared to Earth: 10 to 50 M_E

As their name suggests, neptunians are similar in mass to the planet Neptune. They are likely to be gas giants too, and due to their size, we can more easily find them in the 'cold zone' at the edge of their planetary system, where water turns into ice. Our own Solar System's edge, known as the Kuiper belt, is home to the dwarf planet Pluto.

JOVIAN

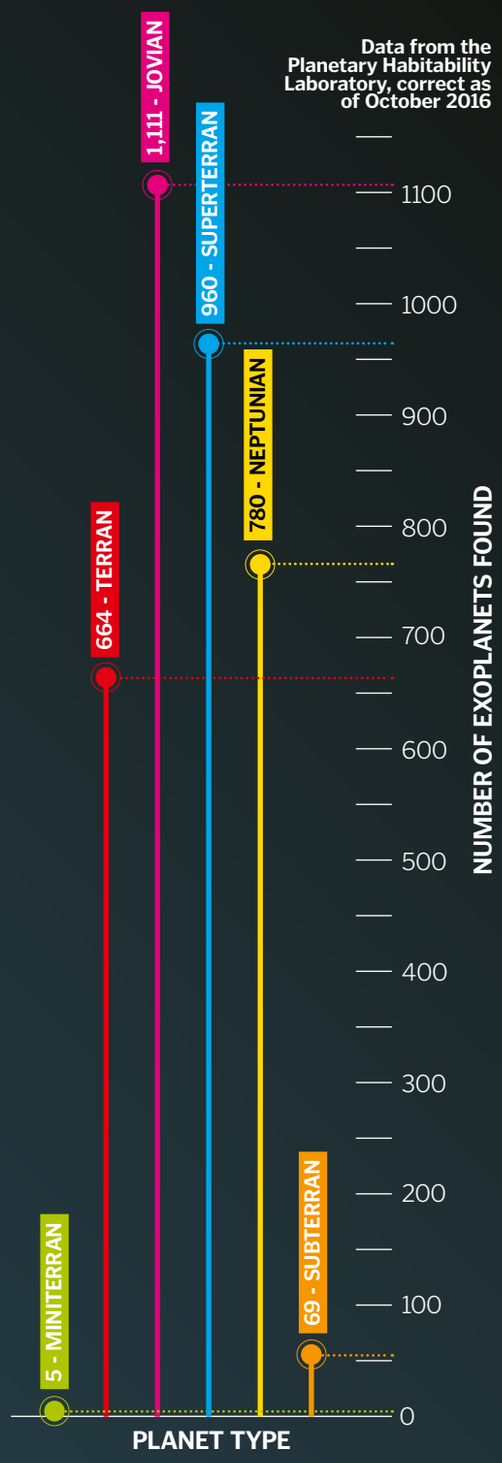
Radius compared to Earth: > 6 R_E
Mass compared to Earth: > 50 M_E

Jovians are worlds that are similar in size to Jupiter – or even bigger – and are primarily composed of hydrogen and helium gas. Being so large they are relatively easy to find. But scientists were surprised to find many orbiting close to their host star – known as hot Jupiters – which has forced a rethink in how planetary systems evolve.

The most common planet

So far, the most common types of planet we've found tend to be the larger ones: subterran and upwards. But the reason for this is not necessarily that they're the most abundant, but rather due to limits in our observational techniques.

Most exoplanets are found using the transit method: observing the dip they produce in their star's light as they pass in front. But to confirm a planet, we need to observe these orbits. This is most easily done for large planets in close orbits, such as hot Jupiters. Recent studies, however, suggest mini-Neptunes – worlds between Earth and Neptune in size – may actually be the most abundant.



AMAZING CAVES

DELVE DEEP UNDERGROUND AND EXPLORE SOME OF EARTH'S HIDDEN NATURAL WONDERS

Hang Son Doong Cave

Quang Binh Province, Vietnam

The world's largest cave was only discovered in 1990 and first explored in 2009, but has been forming over the past 3 million years. It has been carved from limestone by the Rao Thuong River flowing beneath the Annamite Mountains and it is now so large that a 747 aircraft could fit within its biggest cavern. Inside are 80-metre-high stalagmites, cave pearls the size of baseballs, and even clouds formed as a result of the cave's own localised weather system. Massive sinkholes have also opened up sections to the outside world, allowing jungle to take root inside.

Cave types

The many varieties of caves that can be found around the world

Solution

Groundwater containing natural acid seeps through the earth to dissolve the soluble rocks – such as limestone, chalk and dolomite – beneath.

Lava

As lava flows downhill, its surface cools and solidifies, but hot lava will continue to flow underneath, leaving a hollow cave behind.

Sea

Also known as littoral caves, these are formed when waves slowly erode zones of weakness in sea cliffs, carving out caves.

Glacier

Water running through or underneath a glacier gradually melts the ice around it. Eventually a cave is formed as a result.

Sistema Sac Actun Caves Mexico

The network of watery caves beneath Mexico's Yucatan Peninsula contains the longest underground river in the world, measuring 312 kilometres. It is also the second longest cave system, behind Mammoth Cave in the US, but its true size was only discovered in 2007 when a group of divers found a passageway linking the Sac Actun and Nohoch Nah Chich cave systems together.

Sistema Sac Actun is constantly flooded with a mixture of fresh and salt water

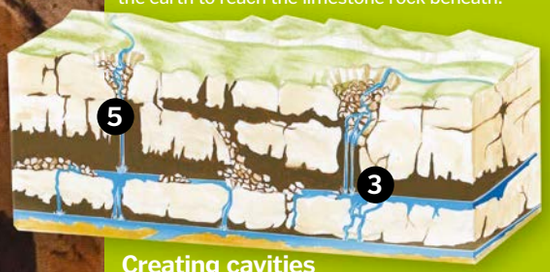
"Hang Son Doong Cave is now so large a 747 aircraft could fly through its biggest cavern"

How do caves form?

Discover the processes that create solution caves over thousands of years

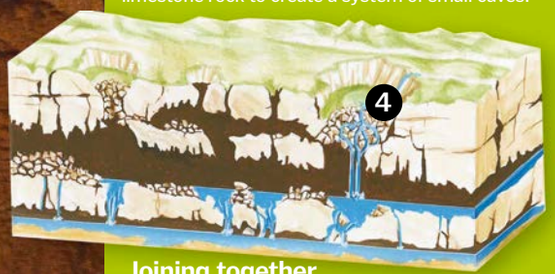
Going underground

Groundwater seeps through cracks or fractures in the earth to reach the limestone rock beneath.



Creating cavities

The slightly acidic water slowly dissolves the limestone rock to create a system of small caves.



Joining together

As more water enters, the caves get bigger and eventually join together, becoming one large cavern.

1. Hard rock
The upper layers of rock are harder and so dissolve more slowly than the soft limestone.

2. Acidic water
Groundwater mixes with carbon dioxide in the air and soil to create weak carbonic acid.

3. Underwater caves
Caves situated below the water table are always flooded with water.

4. Collapsing cracks
Cracks in the upper layers of rock gradually become bigger, collapsing into sink holes.

5. Rock chemistry
Minerals in the rock can also make the groundwater more acidic as it passes through.

Fracture

Layers of more soluble minerals located between layers of less soluble rock are dissolved by acidic groundwater, leaving fractures.

Talus

The openings that form between large boulders that have fallen into a heap at the base of cliffs are known as talus caves.

Eolian

Common in deserts, these caves are formed by winds blowing fine sand against a rock face, eroding the surface.

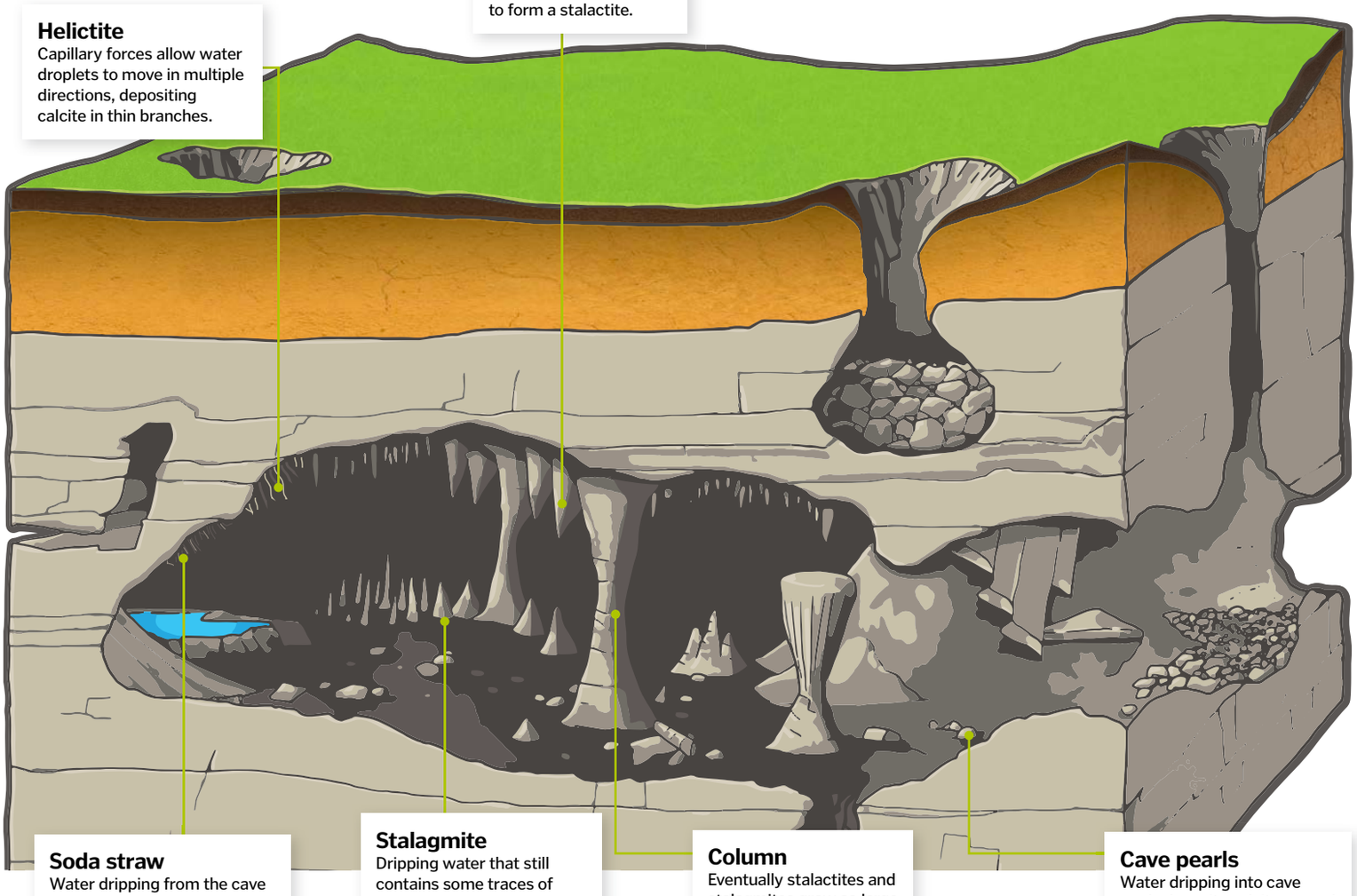
Anchialine

Typically found along coastlines, these flooded caves contain a mixture of both fresh water and salt water.

Cave formations

Explore some of the incredible features that can be found inside caves

"Sarawak Chamber is the largest cavern by surface area in the world"



Helictite
Capillary forces allow water droplets to move in multiple directions, depositing calcite in thin branches.

Stalactite
Water dripping from the ceiling of the cave leaves behind the mineral calcite, which builds up to form a stalactite.

Soda straw
Water dripping from the cave ceiling sometimes deposits rings of calcite, which build up to create hollow stalactites.

Stalagmite
Dripping water that still contains some traces of calcite, aragonite or gypsum falls to the cave floor and creates stalagmites.

Column
Eventually stalactites and stalagmites grow so large that they join together to form calcite columns.

Cave pearls
Water dripping into cave pools deposits calcite around grains of sand, forming rounded lumps of calcite.

Mammoth Cave

Kentucky, United States

With over 650 kilometres of surveyed caves and passageways, Mammoth Cave is the longest cave system on Earth. It is thought to have begun forming around 10 million years ago, when acidic rainwater started seeping through cracks in the area's shale and sandstone cap and into the limestone beneath. Over time the water dissolved the limestone rock, creating an enormous network of caves still being discovered today. Nearly every type of known cave formation has been found here, as well as over 130 species of flora and fauna.

There are more than 200 caves within Mammoth Cave National Park

Marble Caves

Patagonia, Chile

On a peninsula of solid marble in the glacial General Carrera Lake is a series of swirling blue caves. Formed over the past 6,000 years by waves crashing against the rock, dissolving and then washing away the calcium carbonate, their colour is a result of the lake's azure waters reflecting off the grey marble, meaning its intensity and hue changes depending on the water level and time of year. The lake is also home to Marble Cathedral and Marble Chapel, two small marble islands.

Vatnajökull Glacier Caves

Vatnajökull, Iceland

Inside the Vatnajökull Glacier, the largest glacier in Europe, winds a series of spectacular ice caves. Some, such as the Kverkfjöll Caves, are formed when geothermal heat from hot springs beneath the glacier melts the ice, sculpting long, mesmerising open spaces that tunnel deep through the frozen water.

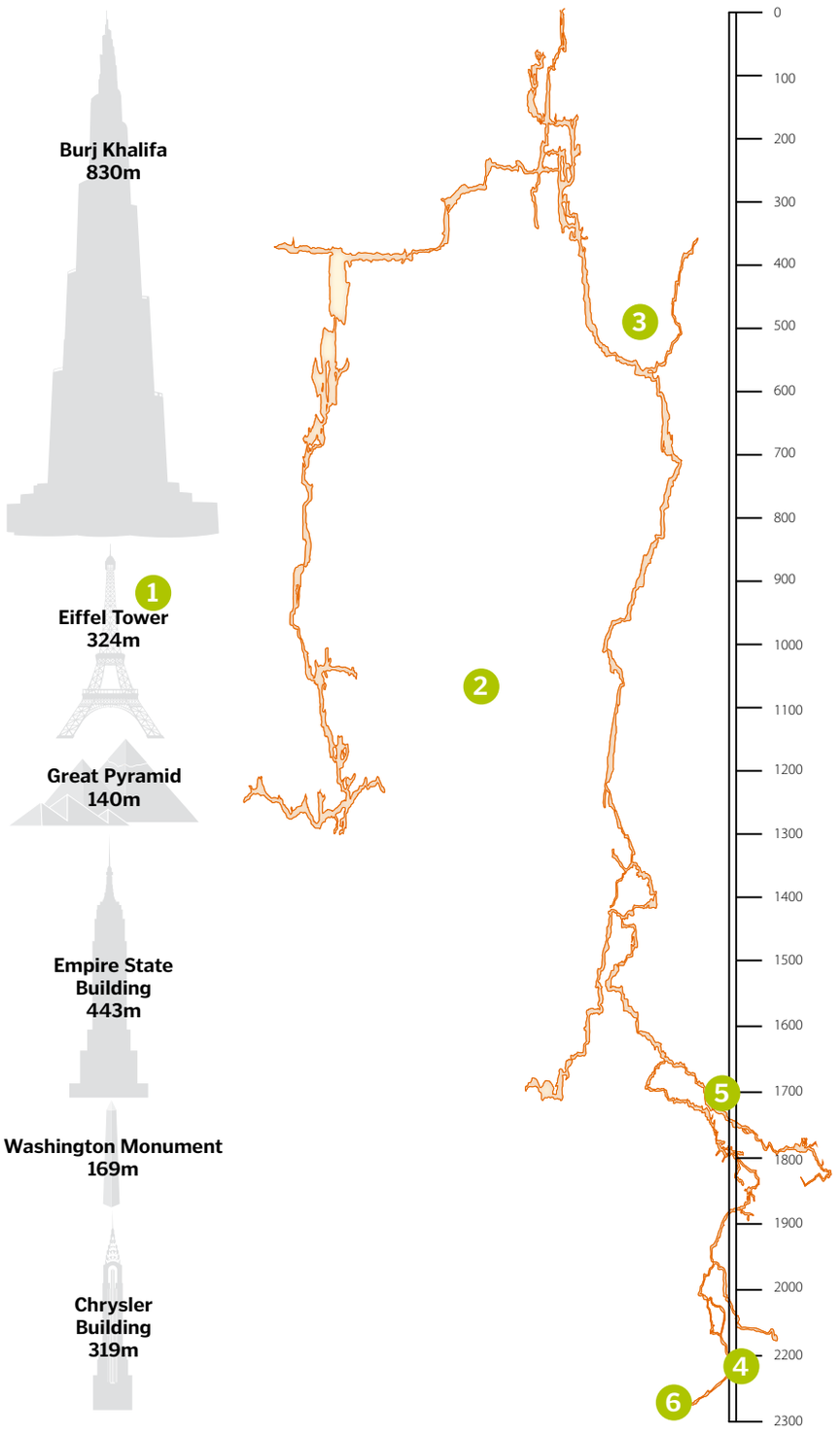
Gua Nasib Bagus Cave

Sarawak, Malaysia

The enormous Sarawak Chamber in Borneo's Gua Nasib Bagus Cave is the largest cave chamber by surface area in the world, able to fit 40 Boeing 747 jets inside. Its Gunung Mulu National Park home is also host to the largest cave passage on Earth, Deer Cave, which could house up to five St Paul's Cathedrals.

Krubera Cave

Formed of a chain of limestone pits connected by narrow passageways, the Krubera Cave in Abkhazia, Georgia is the only known cave on Earth deeper than 2,000 metres



1. Landmark size

The cave is the same height as six and a half Eiffel Towers stacked on top of each other.

2. Rock corridors

The entire cave is 13,432 metres long, as the multiple tunnels branch off in different directions.

3. Explorer camps

It's impossible to reach the bottom in one go, so explorers set up camps to rest along the way.

4. Underwater pass

The cave contains depressions where water collects known as sumps, so divers must swim through cold pools.

5. Mark the spot

Cave divers will often use special probes in order to assess the depth that they have reached.

6. Deepest point

Ukrainian diver Gennady Samokhin has travelled the deepest into the cave, reaching 2,197 metres down in 2012.

Gebihe Cave system

Guizhou Province, China

Lying beneath the peaks of southern China are some of the world's largest caves, but new laser scanning technology has only recently revealed just how impressive they really are

Controversy
There is some debate as to whether the Miao Room is one cavern, or two domed chambers connected by an 852-metre passage.

Record breaker
The Miao Room is the world's largest cavern by volume, measuring a gigantic 10.8 million cubic metres.

A big space
A Boeing 747 could comfortably fit inside the Miao Room, providing you could get it through the narrow entrance.

Entrance
The cave can be accessed by boat via a lake that has been created by a dam.

Growing bigger
Cave collapses have increased the size of the cavern over time, leaving behind rocky debris as evidence.

Hidden secrets
Laser scanning has revealed a previously unknown passage and other openings leading from the main cave.

The Miao Room

Before the 2013 laser scanning expedition to the Miao Room, the Sarawak Chamber in Malaysia was considered to be the world's largest cave chamber. It had been scanned with the help of the same British-led team in 2011, and found to be approximately 9.6 million cubic metres in volume. However, when the results of the Miao Room scan were analysed, the Chinese chamber was found to be ten per cent larger, breaking the Sarawak record. There is still some debate as to which is officially the biggest though, as the Malaysian chamber still has the greater surface area even if it is now the second largest by volume.

Scanning the caves

The enormous Miao Room was first discovered in 1989, but no one could see its true size. Even modern LED torches are not bright enough to illuminate the entire cave at once, so in 2013 a British-led expedition enlisted the help of a laser scanner to penetrate the pitch-black darkness. The scanner – a metal cylinder that sits on top of a tripod – emits laser pulses as it spins 360 degrees, then records how long it takes for the light to be reflected back. It can take 122,000 measurements per second, recording everything within a 610-metre radius. The data captured is then sent to a laptop and used to produce a 3D model of the cave, revealing its interior features in unprecedented detail.

True size
The surface area of the Miao Room covers 118,000 square metres, which is the second largest in the world.

Cave features
The cave is littered with house-sized boulders and sheets of calcite deposits flowing down the walls known as flowstones.

Deep below
The caves are located at up to 100 metres underground in places, and have been carved out of limestone over millions of years.

In the shadows
Some areas uncovered by the laser scanner have yet to be fully explored in the cave's pitch-black darkness.

Central stream
During rainy periods, a stream flows through the chamber, carving a deeper canyon and washing away fallen debris.

"There is still some debate as to which chamber is officially the largest"

Animal pupils

Ever wondered why sheep have oblong pupils and foxes have cat-like slits? It's all to do with lifestyle

Cats are ambush predators that hunt close to the ground in many light conditions, so their pupils have evolved to match

The pupil is the opening in the eye's iris that lets in light. It appears black because the light is absorbed by the eye tissue. The dilation and contraction of the iris is a reflex action to adjust the amount of light entering the eye. If you were able to stare into the eyes of various animals (careful with the predators) you'd notice that there's no one-size-fits-all option.

In a recent study, scientists have looked at the different pupils of animals and concluded that the different shapes perform different jobs to benefit the ecological niche of the animal. For example, the pupils of prey animals offer a wide field of view that helps them scan for predators as well as decide where to flee.

Conversely, the pupils of predators dilate much more, to better equip them for hunting in all light conditions and to allow them to gauge the distance of prey without moving their heads and giving up their position before it's time to pounce.

One especially interesting trait is how the oblong, horizontal pupils of animals such as sheep, goats and horses are able to rotate to stay parallel to the ground, even when the animal moves its head – a process called cyclovergence. This incredibly clever evolutionary adaptation helps the pupils to work best for the animal, and proves invaluable should the animal need to run.

Read on to find out about the other types of pupil shape, and how they link to the animal's lifestyle.

Round pupils

Animals like dogs, wolves and big cats have round pupils. They actively chase down prey, mostly in daylight. Round pupils mean that the field of view isn't spectacularly wide, but as top predators their vision isn't required to help them flee from attack.

Vertical slit pupils

The animals that sport these pupils are small ambush predators that hunt close to the ground: cats, foxes and even crocodiles. The slits allow a greater expansion of the pupil to let in much more light – an adaptation to predators hunting in a variety of light conditions.

Horizontal pupils

Horizontal, oblong-shaped pupils are a feature of prey animals – sheep, goats and horses. These curious-looking pupils provide a wide field of view, allowing the animals to scan for potential predators. The pupils also keep the ground in sharp focus to aid escape.

Horizontal slit pupils

These pupils are also a feature of prey-like animals, seen in some frogs, toads, snakes and octopuses. This pupil type allows the animal to spot the vertical motion of predators and therefore take evasive action. They also extend wide to let plenty of light in for day and night foraging.

Crescent pupils

This pupil type is shown in stingrays, flatfish and some catfish. Crescent pupils enhance vision by decreasing the effects of distortion in the water, providing a wide field of view to look out for any predators lurking nearby or spot potential prey. They also boost contrast.

W-shape pupils

Shown in cuttlefish, these pupils are a modified horizontal-split pupil. In darkness the pupils are almost circular but form a W-shape in bright light. This allows light to enter the pupil from many different directions and boosts image contrast and distance vision.

Vertical beaded pupils

Geckos (as well as some fish) have pupils that decrease to very thin vertical slits with multiple pinholes in bright light. These multiple 'beads' work together to help the lizard perceive distance as well as allow hunting in various environments.

Invertebrates' compound eyes do not feature pupils, but some have dark spots called pseudopupils

Map projections

Discover why all world maps are a little bit wrong

Viewing the Earth as a globe is the best way to see its true measurements

Turning a three-dimensional globe into an entirely accurate two-dimensional map is impossible, as the spherical image is always going to become distorted in some way when you flatten it out. Therefore, in an effort to create a more portable representation of the world, mapmakers have had to sacrifice the accuracy of shape, distance, direction or land area depending on the map's use.

One of the most recognisable world maps is the Mercator projection, developed in 1569 and currently used in US schools and by Google Maps. It was originally created to aid marine navigation, and so features parallel lines of latitude and longitude to accurately represent direction and the shape of countries.

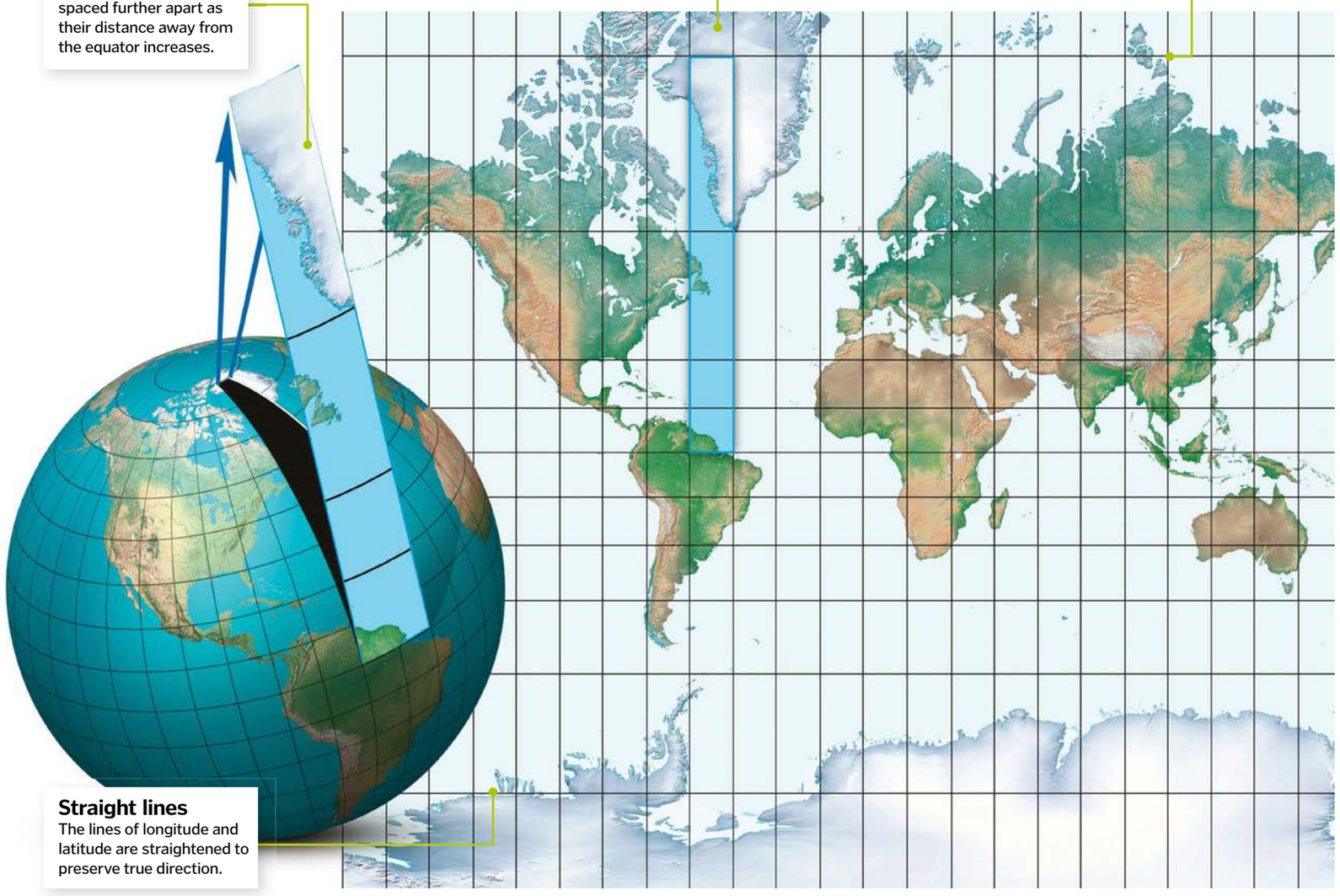
However, as a result the size of the countries are distorted, particularly near the polar regions, causing some political controversy about its representation of the world. Some people believe that by making Europe and North America look much bigger than they are, the Mercator map also makes them appear more powerful, perpetuating ethnic bias against the Southern Hemisphere.

A popular alternative to the Mercator map is the Gall-Peters projection, introduced in the 1970s. It managed to accurately represent direction, aiding navigation, and also show the true size of countries, but their shapes are distorted, making them appear stretched.

However, with the development of GPS, world maps are no longer widely used for navigation, so direction accuracy is not as important. As a result, one of the more popular maps today is the Winkel Tripel projection, developed in 1921 and recently adopted by the National Geographic Society. By spreading the distortion equally across shape, distance, direction and land area, this projection minimises distortion overall, creating one of the most accurate two-dimensional representations of the globe.

Flattening the Earth

How a 3D globe is turned into a 2D Mercator map

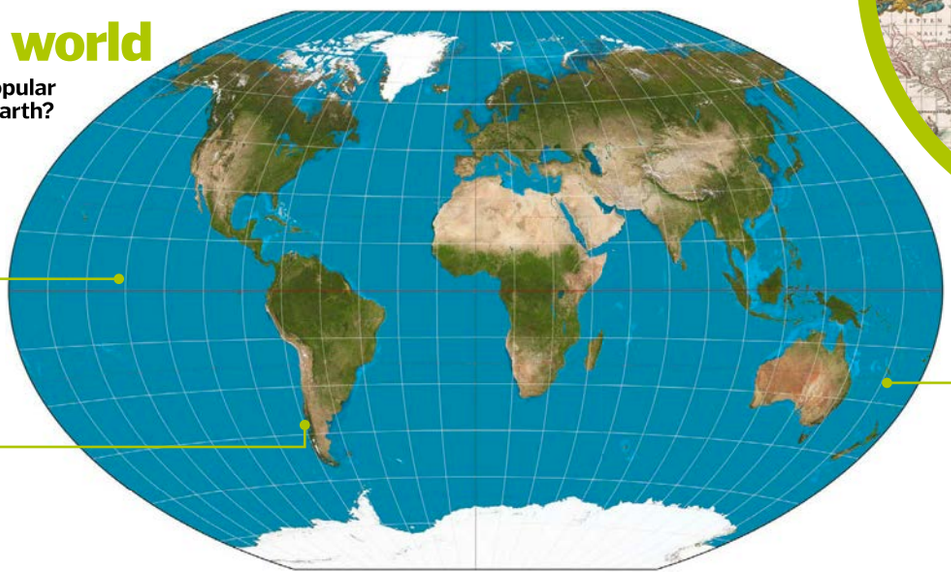


Maps of the world

How do three of the most popular map projections represent Earth?

Cartography has improved over the centuries, but no flat world maps are completely accurate

Winkel Tripel

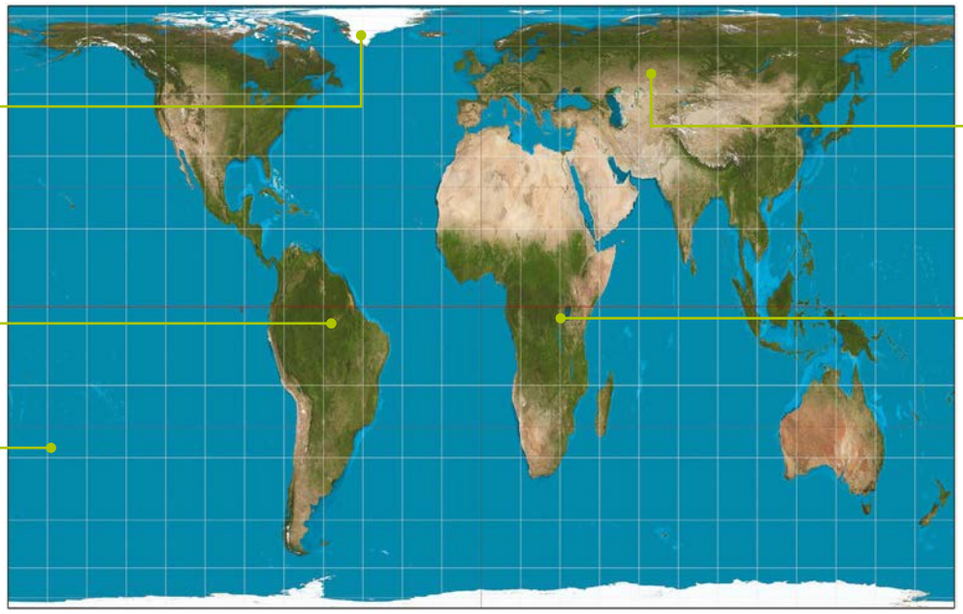


Not rectangular
The outer lines of latitude and longitude are slightly curved and non-parallel.

Minimal distortion
There is minimal distortion of shape, distance, direction and land area across the map.

Whole world map
Distortion becomes more evident when zoomed in, so the map is typically used as a whole.

Gall-Peters



Wider regions
Areas near the poles are stretched horizontally, making the countries appear wider.

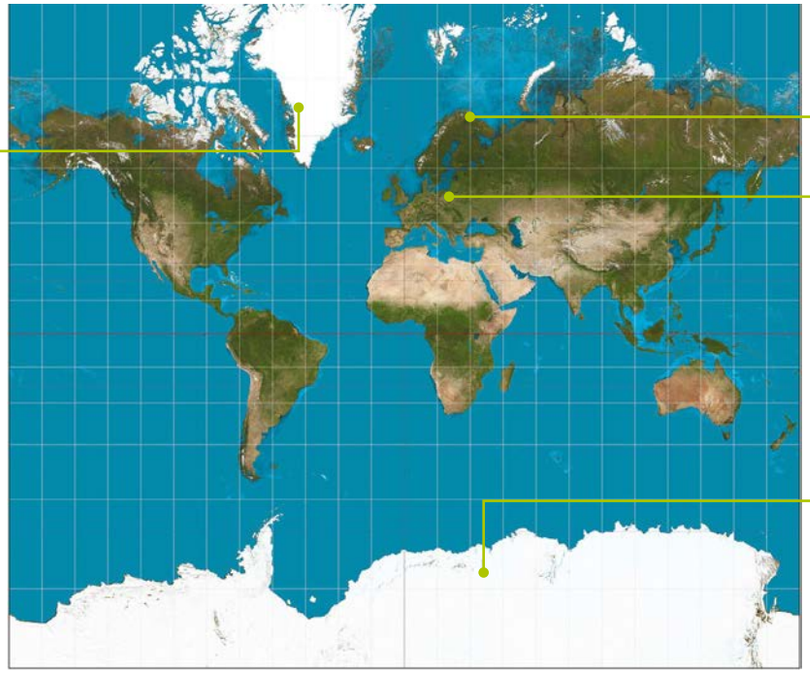
Distorted shapes
Although the country sizes are more accurate, their shapes are still distorted on this version of the world map.

Mapped out
Arno Peters' map was found to be almost identical to a map created by cartographer James Gall in 1855.

Correct areas
The size of the countries is very accurate while also preserving true direction.

Longer regions
Areas near the equator are stretched vertically, making the countries appear longer.

Mercator



Greater Greenland
Greenland appears to be the same size as Africa, but in reality it could fit inside the continent 14 times.

Norse so fast
This map implies that the Scandinavian countries are bigger than India, but India is actually over twice as large.

Enlarged Europe
Europe appears to be a similar size to South America, but is in fact just over half it's size.

Alternative Antarctica
Antarctica appears to be the biggest continent but it is actually the third smallest.

"Mapmakers have had to sacrifice the accuracy of their maps"

The wind chill factor

Discover why it feels so much colder on windy days, even if the air temperature hasn't actually decreased

The wind chill factor is the temperature that a person feels due to the wind. This is different to the air temperature, and many weather forecasts distinguish between the two by stating what the actual temperature is, as well as the 'feels like' temperature.

A breeze can make it feel colder than it actually is, because when air circulates and blows across our skin, heat is lost from our bodies by evaporative cooling. The faster the wind speed, the greater this effect. The wind chill factor expresses the rate at which heat is lost from our exposed skin.

Wrapping up warm and covering bare skin will help prevent heat loss

How the wind chill factor works

The process by which a breeze draws heat away from the body

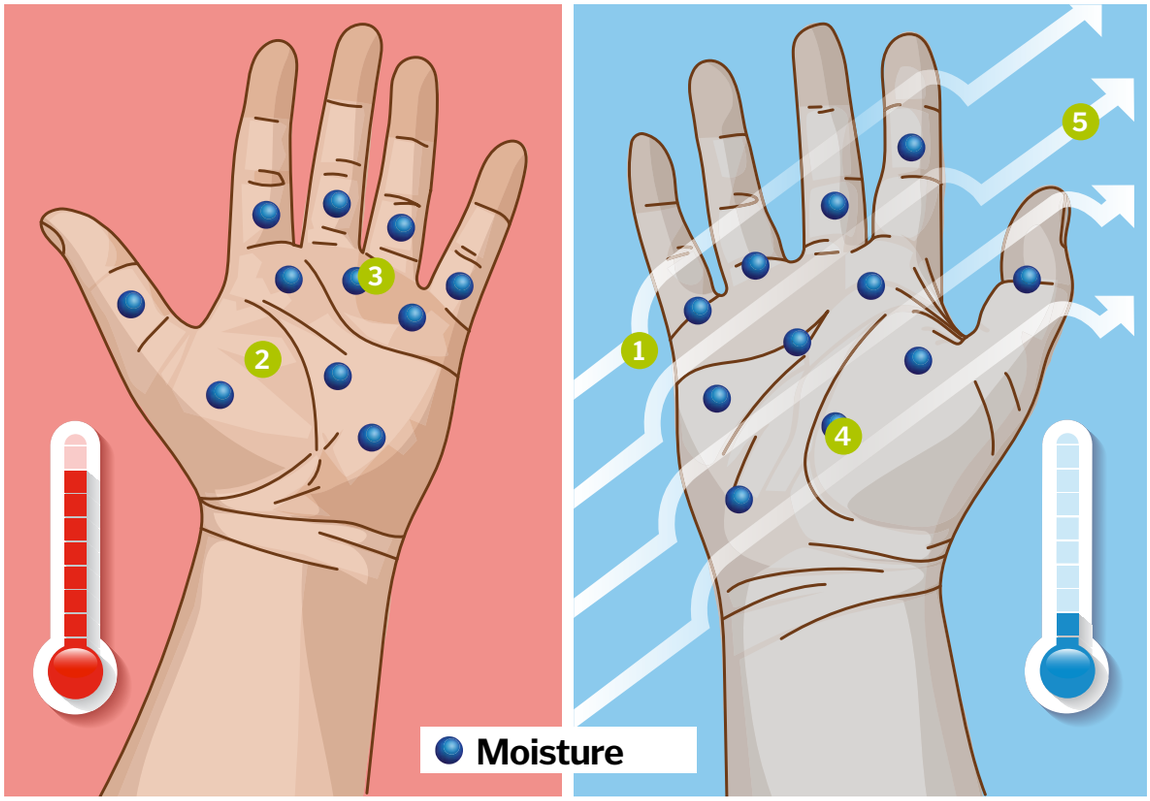
1. Strong winds
If the wind is very strong then the body will become colder much faster.

2. Dilation
In a warm environment, our blood vessels dilate, allowing more heat to be lost to the air.

3. Moisture loss
In warm weather, the evaporation of sweat helps keep us cool, but breezes in cold weather can also increase the rate at which moisture evaporates.

4. Constriction
In a cold environment, our blood vessels constrict, limiting heat loss to the air.

5. The cooling process
As the wind brings cold air in contact with the skin, moisture evaporates and body heat is lost.



Tree sap

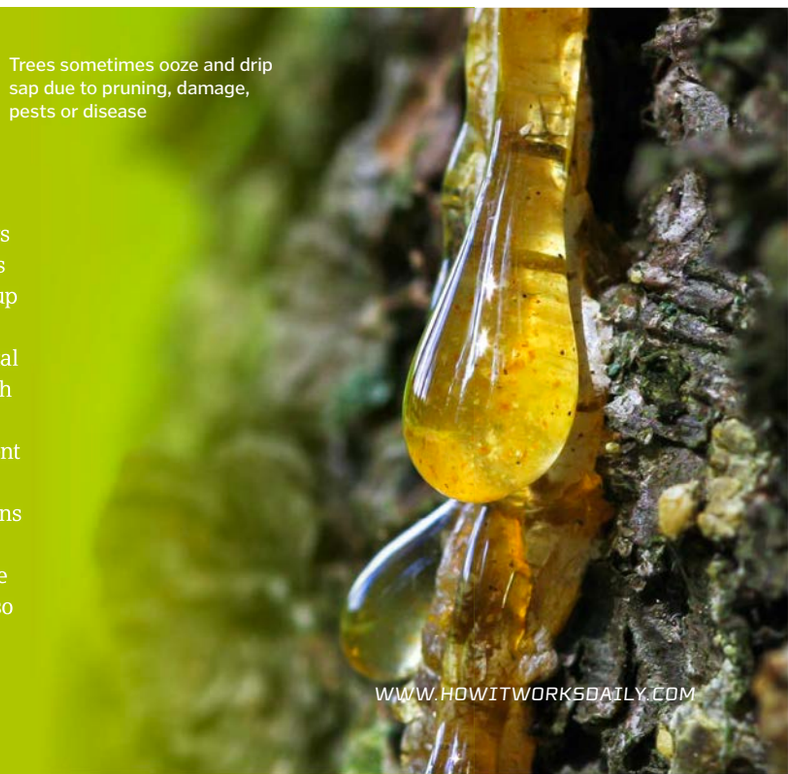
Unearth what tree sap consists of and exactly what its role is

Tree sap is a fluid consisting of water, hormones and minerals, which is transported via the xylem or phloem cells of a tree, depending on what kind of sap it is.

Phloem sap contains sugars and travels through phloem cells from sugar-rich areas of the tree – such as the leaves – to distribute the sugars, hormones and minerals to sugar-poor areas, like the trunk and roots.

The other type of tree sap is known as xylem sap, which travels through xylem cells. Also consisting of dissolved hormones and minerals – but not sugars – this type of tree sap includes nutrients from the environment too, and travels up from the tree's roots to the leaves. By transporting such goodness, sap is a vital part of a tree's life, essential for its health and development.

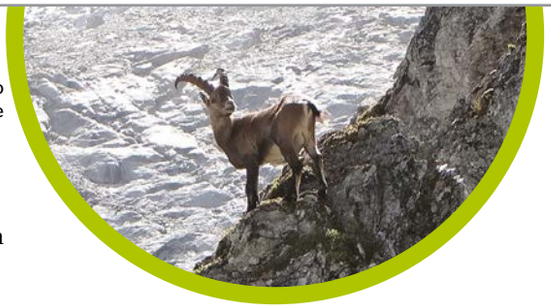
Different species of trees have different sap profiles. For example, sap from the manchineel tree contains so many toxins that it can cause burns, blistering and inflammation by just touching it. On the other hand, sap from the maple tree is so safe it's even edible.



Trees sometimes ooze and drip sap due to pruning, damage, pests or disease

Ibex

Meet the daredevil rock climbers that live life on the edge



Ibex can balance on ledges no wider than a tightrope

Balancing on a tiny ledge just big enough for all four hooves, it may look like the ibex is destined for a long and fatal fall. However, these mountain goats are equipped to navigate seemingly impossible slopes, and very rarely slip or lose their footing.

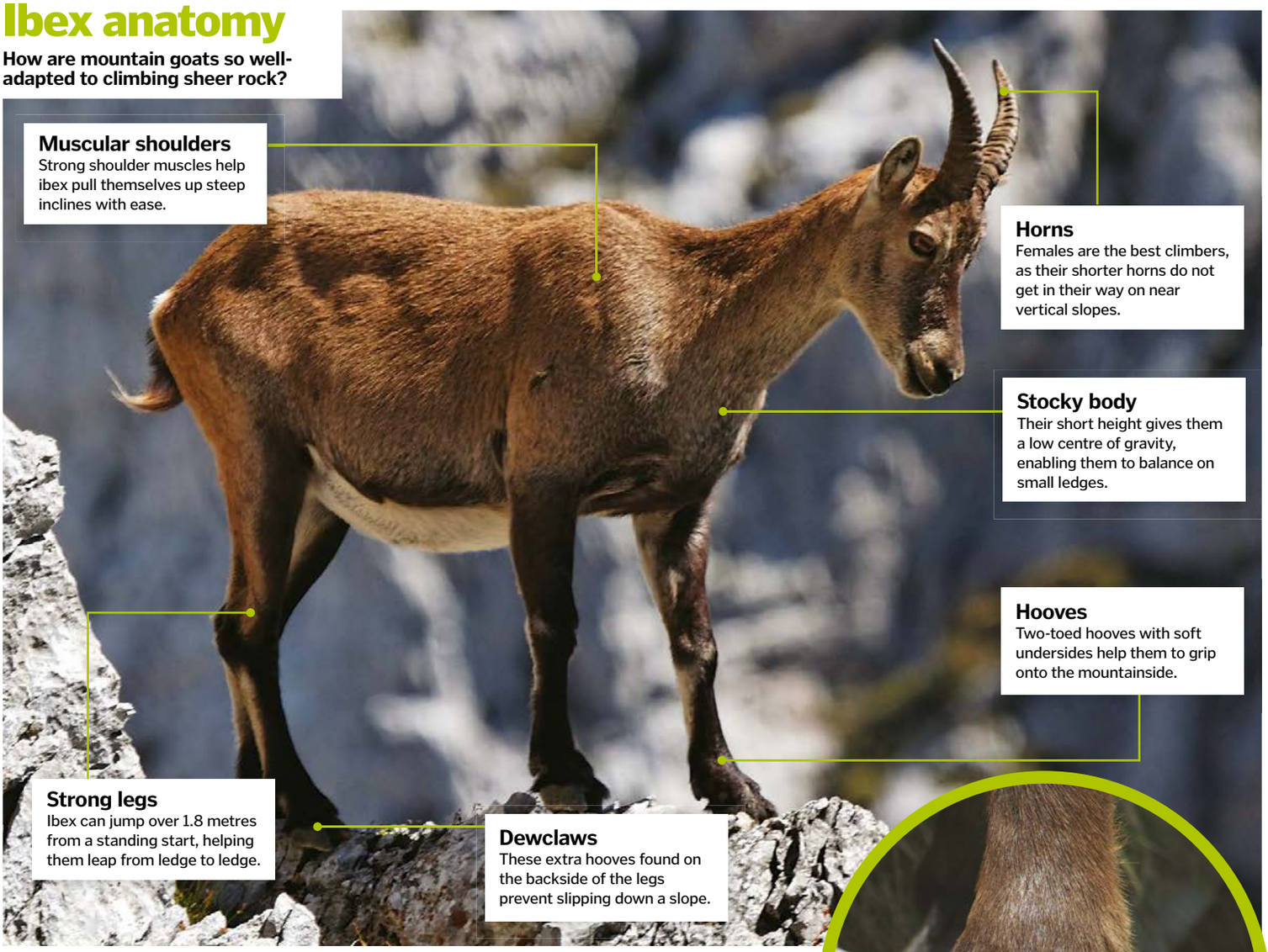
Living in the mountainous regions of Europe, northern Asia and northern Africa, they can effortlessly leap up crumbling rock faces, gripping on to tiny footholds with their specially adapted hooves, and then run back down with just as much ease. This special skill is particularly useful for escaping predators, as very few creatures can follow their daring lead, but there are other benefits to living the high life too.

Alpine ibex in northern Italy have been spotted scaling the near-vertical Cingno Dam to lick the rocks at the very top. The rocks contain salt, which provide the goats with essential minerals such as calcium that are lacking from their vegetarian diet. However, to get to them they have to endure a perilous ascent, climbing more than 30 metres with only tiny cracks and ledges to cling onto.

This impressive climbing ability is mainly practiced by females and their young, as the larger body mass and cumbersome horns of the males make balancing on narrow ledges difficult.

Ibex anatomy

How are mountain goats so well-adapted to climbing sheer rock?



Muscular shoulders
Strong shoulder muscles help ibex pull themselves up steep inclines with ease.

Horns
Females are the best climbers, as their shorter horns do not get in their way on near vertical slopes.

Stocky body
Their short height gives them a low centre of gravity, enabling them to balance on small ledges.

Hooves
Two-toed hooves with soft undersides help them to grip onto the mountainside.

Strong legs
Ibex can jump over 1.8 metres from a standing start, helping them leap from ledge to ledge.

Dewclaws
These extra hooves found on the backside of the legs prevent slipping down a slope.

Hooves made for climbing

Ibex hooves are well-adapted for climbing steep slopes, with two pincer-like toes on each foot. The top of each toe is made from hard keratin, the same material our fingernails are made from, making them incredibly strong, while the underside is soft and rubbery - this textured surface creates friction to provide extra grip. The hooves also spread when under load, distributing weight evenly.

The two toes of each hoof can move independently from each other, helping to compensate for uneven terrain and allowing the ibex to cling on to any protrusions in the rock.

Science of STRESS

WHAT HAPPENS TO YOUR BODY WHEN IT'S PUT UNDER PRESSURE?

The man who first defined stress, Hans Selye, once told reporters: "everyone knows what stress is, but nobody really knows." From a mental health perspective, stress describes the feeling of excessive emotional pressure. It can manifest itself as anxiety, trouble sleeping, altered eating patterns, destructive behaviour, headaches or muscle pain. This is the stress that we are all familiar with. But, from a broader biological perspective, stress is the body's response to any kind of disruption, whether it's psychological trauma, extreme temperature, lack of food, or confrontation with a predator.

There's no proper medical definition of stress, but when it comes to biology, it describes any threat to the body's normal balance. In order to cope with that threat, whether it's real or imagined, the body takes steps to protect itself. The bloodstream floods with chemical signals that heighten awareness, increase heart rate, quicken breathing, dull pain, and even induce euphoria. At the same time, non-essential functions like digestion and growth slow right down. When the stress response is activated surviving becomes the key concern; the future becomes less important.

The brain kick-starts the stress response. The amygdala, which deals with emotion and fear,

sends a message to the hypothalamus, setting off a chain of electrical and chemical messages that prepare the body to respond. The first step is to put the nervous system into 'fight or flight' mode. It does this by signalling to the adrenal glands to increase production of adrenaline.

This chemical messenger surges into the bloodstream, triggering a wave of energy release by raiding the body's stores of fats and glycogen. Blood sugar rises and fatty acids are released to fuel the body in its time of need. These molecules are then shuttled to the muscles and brain by the bloodstream. Blood vessels in non-essential areas constrict, heart rate increases and breathing becomes faster, diverting extra resources to the places that need them most. Senses become heightened and the brain is put on alert. This response happens instantly, sometimes even before the conscious brain has processed it.

Depending on the situation – and the individual – the exact pattern of these chemical surges differs. If escape or confrontation is not an option, another response, known as 'aversive vigilance' might replace 'fight or flight'. Under these circumstances, movement stops, and blood is diverted away from the skin and extremities to the organs in the core.

Rather than revving the body up for physical activity, this response helps to minimise bleeding in case of injury. Though most stresses we experience now don't carry a risk of physical harm, this would have been useful in our evolutionary past. Which response is chosen varies on circumstances, but individuals are more likely to favour one or the other, and it's thought that these patterns are set early in life.

At the same time, a slower but more persistent stress response is also activated. The hypothalamus pumps out a molecule called corticotropin-releasing factor (CRF). This is the

The stress response

The body has a well-tuned system for dealing with the first signs of stress

1. Hypothalamus
This part of the brain is responsible for maintaining balance in the body, and it kicks off the stress response.

2. Pituitary
This pea-sized organ produces many hormones, including the stress messenger adrenocorticotropic hormone.

3. Adrenals
These glands are found on top of the kidneys, and produce steroids in response to stress.

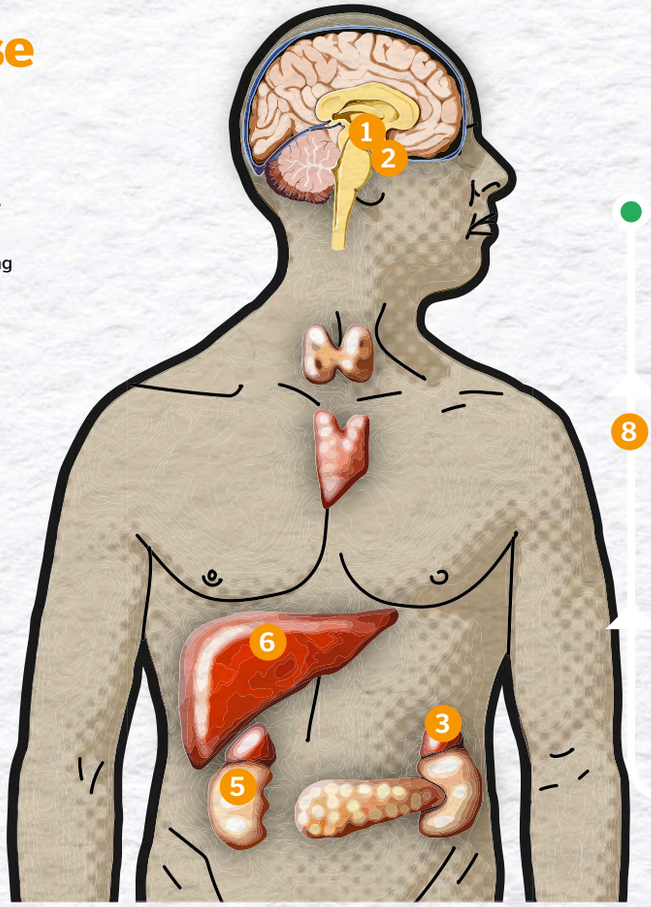
4. Corticotropin releasing factor
This chemical messenger carries the stress signal from the hypothalamus to the pituitary.

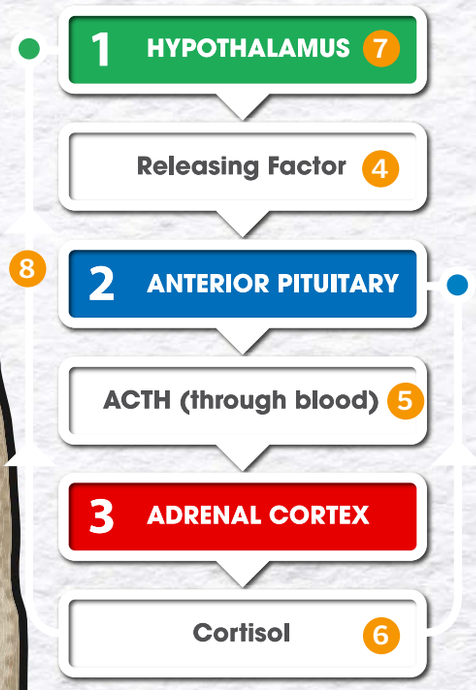
5. Adrenocorticotropic hormone
This hormone travels through the bloodstream, carrying the chemical message to the kidneys.

6. Cortisol
These natural steroids trigger changes across the body, helping it to deal with stress.

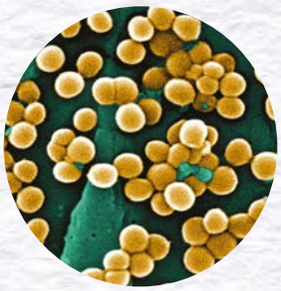
7. Activation
Several areas of the brain feed into the hypothalamus, triggering the stress response.

8. Suppression
High levels of glucocorticoids in the blood feed back to the brain, switching off the stress response.





Stress isn't just human



Bacteria
These microbes cope with changes to their environment by altering the way they use their genes. Molecules called sigma factors change which genes are switched on, and which are turned off.

Plants
Water stress can be a real problem for plants, so they respond by conserving moisture. This includes producing rapid chemical signals that close the pores in their leaves.

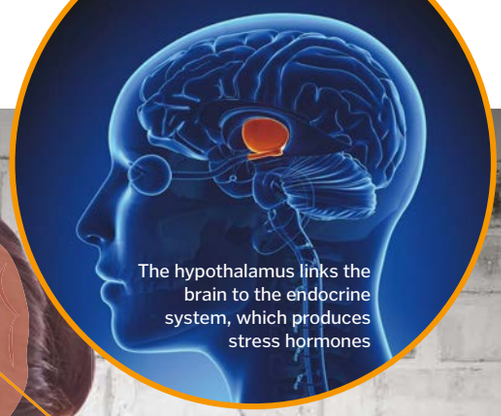
Fish
Fish have a similar stress response to other vertebrates, with a cycle of chemical signals that starts in the brain, preparing the body to release energy and shut down unnecessary activity.

Birds
Like us, birds make corticosteroids in response to stress. The amount goes up in birds that breed in higher places, which helps them to cope with the risks associated with nesting at high altitudes.

Mice
These rodents are often used as a model for human biology, but recent research showed that they are stressed by male scientists. The effect seems to be related to their smell, and it may skew the results of tests.

The effects of stress

Too much stress can have a negative effect on different parts of the body



The hypothalamus links the brain to the endocrine system, which produces stress hormones

1

Nerves
Stress during brain development can affect the structure of the growing brain.

2

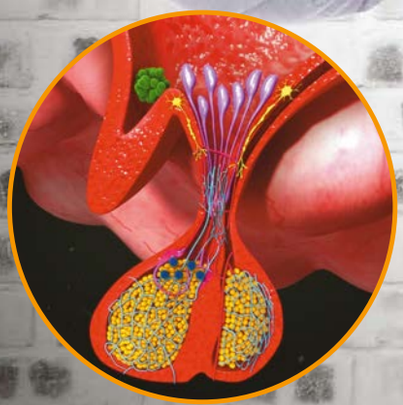
Muscles
Tense muscles in the head, shoulders and neck can lead to headaches.

3

Breathing
An increased breathing rate can result in panic attacks and hyperventilation.

4

Heart rate
Raised heart rate and blood pressure can cause gradual damage to the cardiovascular system.



The pituitary gland is packed with hormone-producing endocrine cells

5

Hormones
Stress hormones like cortisol affect cells all over the body, including dampening the immune response.

6

Digestion
Changes in blood flow to the digestive system and different eating patterns can affect bowel function.

7

Reproduction
Fertility and libido can be affected by chronic stress in both men and women.

"It turns out that if we believe that stress is bad, it is more likely to do us harm"

trigger for the biological response that puts the body into survival mode. From the hypothalamus, CRF hops a short distance through the bloodstream to the pituitary gland, where it triggers the release of a second, longer-range chemical message. Known as adrenocorticotropic hormone (ACTH), this molecule travels around the body in the bloodstream, reaching the kidneys, where it triggers the next step in the stress response process.

On top of each kidney is a hormone factory known as an adrenal gland, and within each is a compartment known as the adrenal cortex. The cells here produce glucocorticoids, the body's natural steroids. And it's these steroids that help the rest of the body to deal with stress. Cortisol interferes with insulin, helping to keep blood sugar levels up. It helps to balance the body's pH; it dampens the immune response; and it even affects the formation of memories.

Short-term stress is quickly corrected by the body, and, to prevent the cycle continuing forever, the cortisol also acts as an off switch. It feeds back to the brain, letting it know that the stress response has been fully activated, and helps to switch off the production of CRF and ACTH. But sometimes, stress can develop into a long-term, chronic problem.

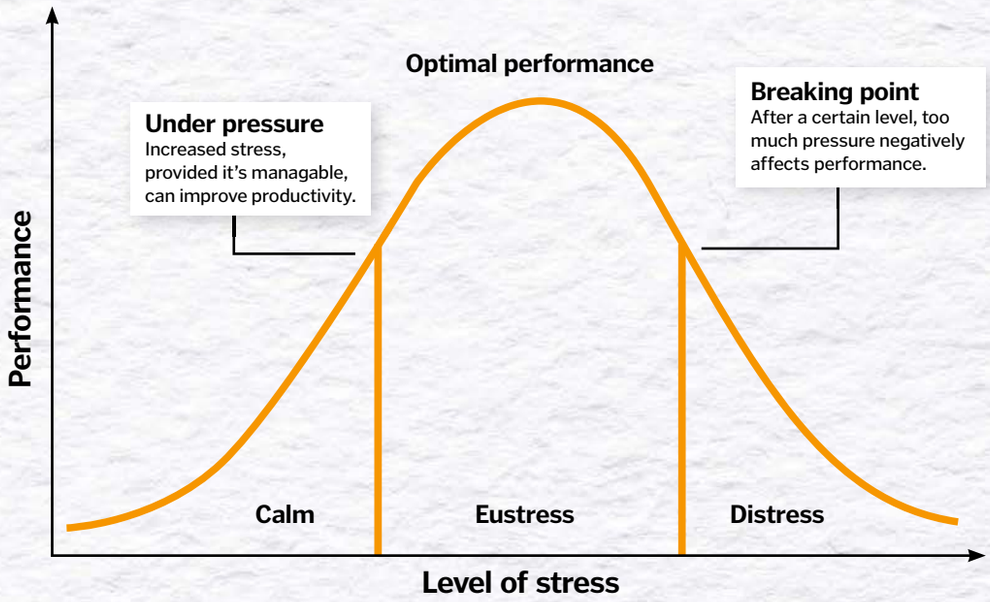
Humans are unique among animals (as far as we know) in that we think abstractly about the world and ourselves. Our enormous brains are a gift, but they can also lead to long-term stress as we worry over problems that just wouldn't occur to other animals, like work and money.

While the stress response has been honed by evolution to boost the chances of survival during short periods of increased environmental pressure, in the long term it can cause damage. Ultimately, it can lead to illness if left unchecked.

Exposure to stress during childhood, be it war, neglect or even divorce, can make people more likely to experience mental health problems as

Eustress vs distress

How can stress levels affect our ability to work?



Good stress?

In 1936, endocrinologist Hans Selye wrote a letter to the scientific journal, *Nature*, describing the "general alarm reaction of the organism". He was one of the first people to identify and investigate biological stress. He continued his investigations, and after nearly 40 years of research, Selye came to the conclusion that stress wasn't all bad.

People had known for a long time that there's a link between 'stress' and productivity. In 1908, two researchers, Yerkes and Dodson, showed that there's a sweet-spot, where there's just enough pressure to encourage productivity, but not so much that it becomes too much for the person to handle.

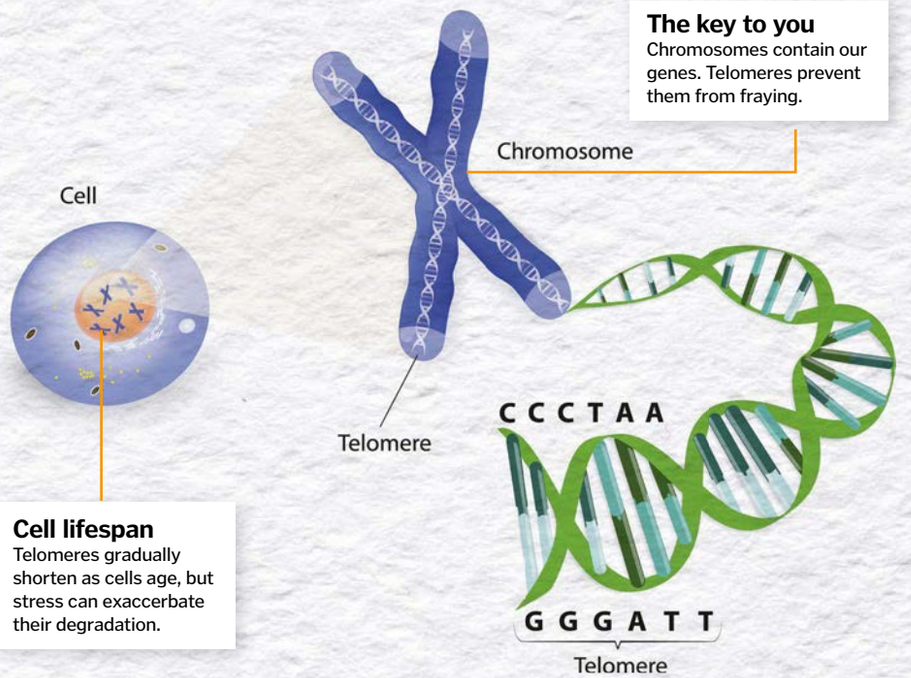
Selye was interested in the idea that the feeling of stress isn't so much about what happens to the body, but about how each individual reacts to the changes. In the 1970s, he introduced two new words, 'eustress' and 'distress', to describe what he saw. Eustress was beneficial stress, and distress was bad.

Stress-related damage

Long-term, or chronic, stress can be bad for our health, but it's challenging to pin down exactly why. Is it to do with poor lifestyle choices made under pressure, or is there something happening inside the body as a result of a prolonged stress response?

In 2004, a research team from the US published a paper in the journal *PNAS* that investigated what happens to our cells under stress. They looked at the genetic code, homing in on the protective caps that cover the ends of each chromosome. Known as telomeres, these structures shorten as cells get older. An enzyme called telomerase can replenish telomeres, but stress diminishes the supply of this regenerative enzyme.

The team studied a group of 58 women, and they found that the longer the women had been stressed, and the more stressed they felt, the more likely they were to have shortened telomeres – a sign that their bodies were feeling the strain. Exactly why this happens is not currently known.



The key to you
Chromosomes contain our genes. Telomeres prevent them from fraying.

Cell lifespan
Telomeres gradually shorten as cells age, but stress can exaccerbate their degradation.

Serious trauma or stress at an early age can cause telomeres to be shortened for life

adults. During this period, the brain is still developing, and chronic stress can cause structural changes that affect the way that it functions. As adults, chronic stress puts strain on the heart and blood vessels, contributing to cardiovascular disease, heart attacks and strokes, and it can also damage the immune system.

During an acute stress response, immune cells are mobilised in case they need to fend off infection, but the stress steroid cortisol affects their function in the long term. In fact, drugs based on cortisol are used to dampen down the immune system in patients in need of immunosuppression.

Long-term stress can be a real problem. Not only does the response itself put pressure on the body, but coping mechanisms, including drinking and smoking, can all damage our insides. However, it's not just about the physical effects. 'Stress' is a loaded word, and recent research has been looking at how our perceptions of stress affect its impact on the body. It turns out that if we believe stress is bad, it is more likely to do us harm.

Studies in the US have shown that people who are stressed have an increased risk of dying. But – and this is critical – only if they believed that stress itself could cause them harm. In fact, people who were stressed but didn't believe it was bad for them had a lower risk of dying than those who were barely stressed at all.

The negative connotations of the word 'stress' bothered Hans Selye, who had first pointed out the stress response in the 1930s. Part of the trouble is that stress isn't just used to describe the body's response to challenging situations. In physics, strain is the change in shape or size of an object as a result of an external force, and stress is the internal force associated with it. The use of the same word links the two in people's minds.

Astonishingly, changing the way you think about stress seems to be able to change the effect it has on you. Seeing sweaty palms, increased heart rate and rapid breathing as signs that your body is trying to help you alters your internal response. Heart rate still increases, but blood vessels can stay relaxed, which is much better for the cardiovascular system. What's more, there's another component to the stress response that is often overlooked: oxytocin.

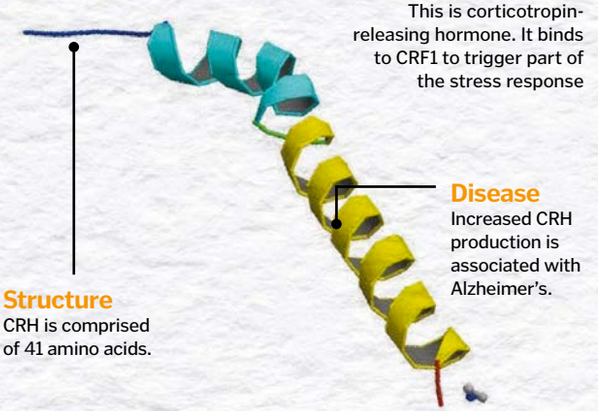
Popularly known as the 'cuddle hormone', oxytocin helps mothers to bond to their babies, and it's released by the brain when we are hugged. It is also produced during stress, helping us to seek social support. Oxytocin also helps by dilating blood vessels, lowering blood pressure and even helping to repair the heart.

While stress can feel unpleasant, it is there to help us deal with life's challenges. Believing in your body, and seeking support when things become too much, can help keep it under control.

Blocking stress molecules

The hypothalamus is the part of the brain responsible for kicking off the stress response, and it does this by producing corticotropin-releasing factor (CRF). This hormone travels to the nearby pituitary gland, where it tells the cells to begin pumping out adrenocorticotropic hormone (ACTH), which in turn tells the kidneys to make the stress steroid cortisol. One of the critical molecules in this pathway is known as CRF1: corticotropin-releasing factor receptor 1. It is the molecule that detects the CRF, and in 2013, scientists managed to work out its shape.

CRF1 sits on the surface of cells in the pituitary, and other structures in the body, and waits for CRF to arrive. When it does, the hormone sticks to the receptor and triggers molecular pathways that contribute to the stress response. Understanding its shape could help drug developers to design treatments that interfere with this interaction, stopping the hormone from slotting into its hole in the receptor, dampening the stress.

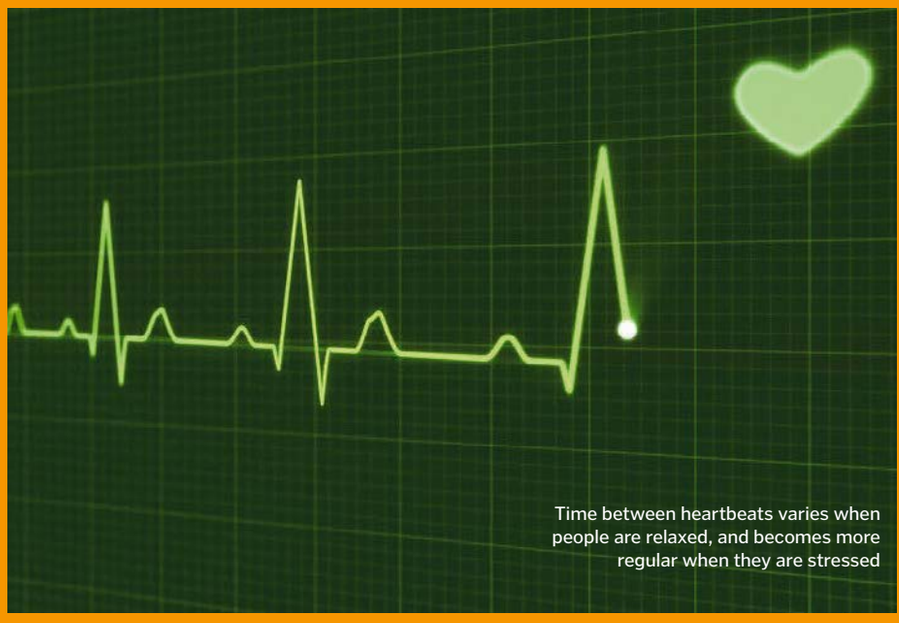


Monitoring stress

The tech that can tell if you're having a tough time

There are several electronic gadgets that claim to be able to track your stress levels by tapping into your heart rate, breathing, skin conductance and blood oxygen. The idea is to help you to identify, and avoid, your stress triggers.

However, although some of the science behind the measurements they take is sound, it's not always easy to decipher what they mean. For example, the time between heartbeats varies less when you are stressed, but also when you are excited. A device that picks up on these changes won't be able to tell you which mood you are in unless it knows what else is happening around you.



Time between heartbeats varies when people are relaxed, and becomes more regular when they are stressed

Dealing with distress

There are several coping strategies that can help to combat stress

Believe in your body

Some studies have shown that stress is more harmful if you believe it is harmful. Trusting that your body is preparing you to cope helps to minimise damage.

Exercise

The fight or flight response prepares your body for activity, so use up that nervous energy by exercising. Exercise also releases natural endorphins that boost your mood.

Talk

People are social creatures, and the phrase 'a problem shared is a problem halved' didn't come out of thin air. Seeking support can help to reduce stress.

Take care of yourself

Some people seek comfort in damaging activities during times of stress, but nicotine, alcohol, food and other addictive substances don't help the underlying problem.

Help others

Going out of your way to help other people when you are already stressed might seem counterintuitive, but it can help to give you purpose and perspective.

Make a plan

Sometimes there are things you can't change, but identifying the areas that you can and making a realistic plan to tackle them can help to guide you through stressful times.

Try mindfulness

Stopping and focusing on the present moment through meditation or mindfulness can help to change the way that you think and feel.

Keep a stress diary

Noting down the things that trigger feelings of stress can help you to prepare for them in the future.

Boomerang science

The secret to the strange flight path of a boomerang is in its wings

A stick will tumble through the air in a relatively straight line before crashing to the ground, but a boomerang curves in a wide arc and comes right back to your hand. The key is in its shape.

Boomerangs have two wings, each with an aerofoil design: one side is flat, and the other side curved. This shape changes the flow of air across the aerofoil, creating a difference in pressure above and below it, which generates lift. But this is only part of the story.

The placement of the wings is the secret to getting the boomerang to return. The sharp, leading edge of each wing face the same way, turning the curved stick into a kind of propeller.

Boomerangs are thrown upright, and as they leave the hand they start to spin. As they travel through the air, the top wing spins forwards, moving in the same direction as the throw, while the bottom wing turns backwards, moving against it. The combination of the spin and throw mean that the top wing moves faster than the bottom, and as this happens, the boomerang starts to tilt. The effect is called precession.

The boomerang has angular momentum and spin, and it will try to keep spinning in the same direction unless a force is applied. But the fast-moving top wing pushes it out of line. The boomerang leans to the side, turning full circle before coming back to where it was thrown.

Do all boomerangs come back?

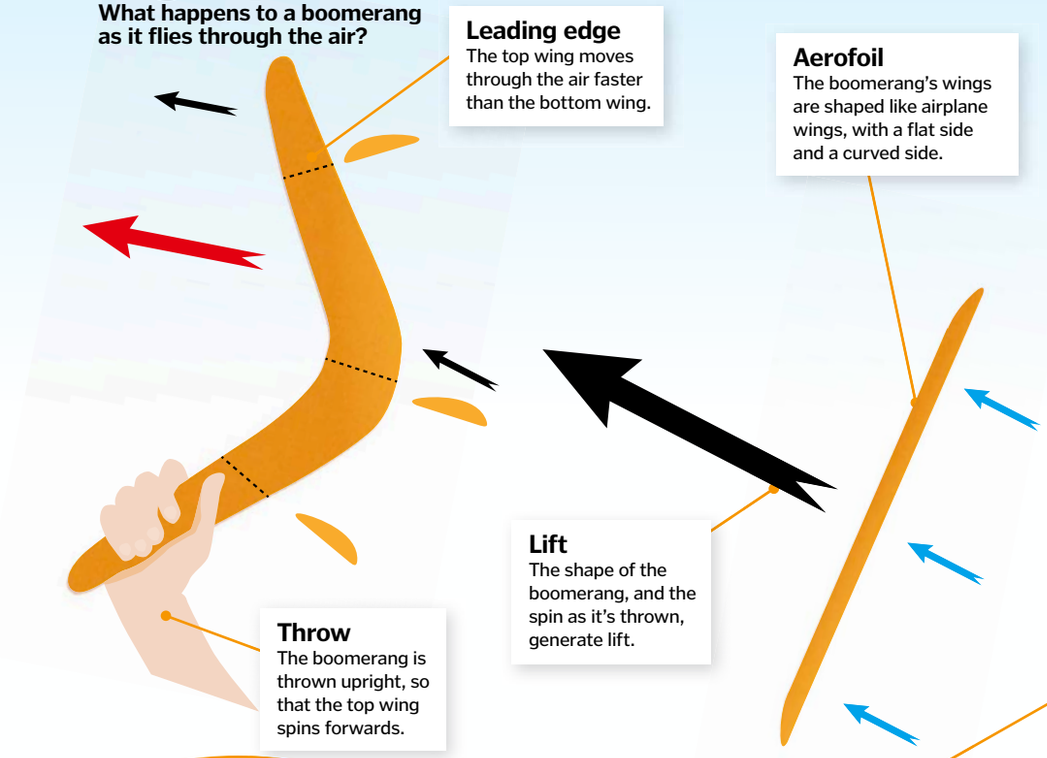
Boomerangs are famous for coming back to their owners, but though this feature is interesting, it's not very practical. Returning boomerangs are toys, but the original boomerangs were hunting weapons, and flying through the air in a wide arc would make them difficult to aim.

Hunting boomerangs aren't designed to come back. They are precision throwing weapons, constructed to be bigger and heavier and to stop when they strike their target. Rather than having two equally curved arms, one side is often longer than the other, helping them to cut through the air quickly and accurately.

Depictions of boomerangs being used to hunt appear on some of the world's oldest rock art

Flight path

What happens to a boomerang as it flies through the air?



Leading edge
The top wing moves through the air faster than the bottom wing.

Aerofoil
The boomerang's wings are shaped like airplane wings, with a flat side and a curved side.

Angular velocity
The boomerang spins around its centre point as it cuts through the air.

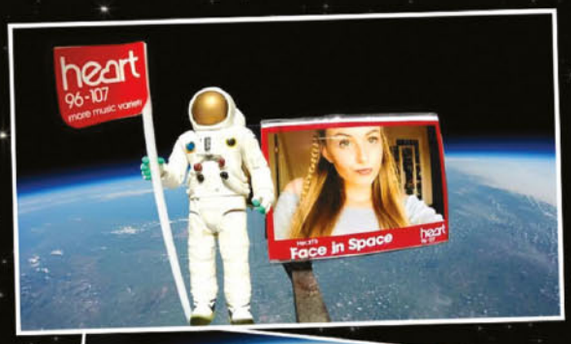
Lift
The shape of the boomerang, and the spin as it's thrown, generate lift.

Throw
The boomerang is thrown upright, so that the top wing spins forwards.

Return
The boomerang moves in an arc as it spins through the air.

Precession torque
The difference in air flow over the top wing compared to the bottom causes the boomerang to twist.

Boomerangs spin through the air like the propellers of a helicopter



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Sunlight and skin

Our star kicks out some serious radiation, but what does it do to our skin?

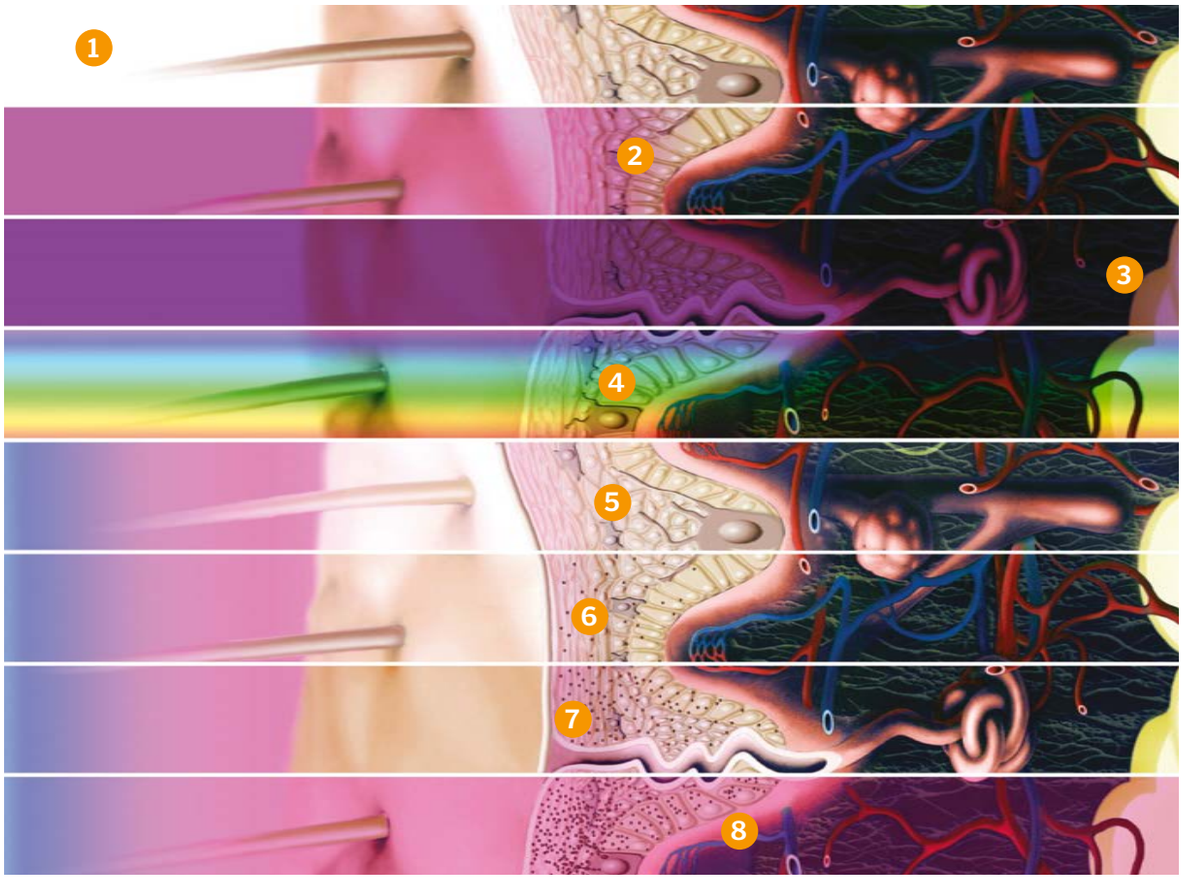
We've all heard of the damage that sunlight can do to skin, but different parts of the spectrum interact with our cells in different ways.

Visible light (the light we can actually see) is responsible for revealing the colour, texture and tone of our skin as it is absorbed and reflected by the molecules inside, and it can also trigger the formation of the brown pigment, melanin. Longer wavelengths of infrared light transmit heat, making skin feel warm, while shorter wavelengths of ultraviolet light are responsible for sunburn, ageing, wrinkles and even skin cancer.

Sunscreen stops UV radiation before it can penetrate the skin

Skin deep

How deep under the surface can the different wavelengths of light penetrate?



1. UVC
The shortest UV wavelengths are filtered out by the atmosphere before they even reach the skin.

2. UVB
Medium wavelengths of ultraviolet light don't get far, but they can still cause burns and skin cancer.

3. UVA
The longest UV wavelengths sink deep into the skin, contributing to ageing and wrinkles.

4. Visible light
The light we can see travels deep into the skin, revealing blood vessels under the surface.

5. No pigment
People with the condition albinism have very little or no protective pigment, allowing light to penetrate their skin easily.

6. Some pigment
Pigment, known as melanin, helps to protect the skin from damage by absorbing UV light.

7. More pigment
The more pigment the skin has, the better protected it is against damage caused by the Sun.

8. Infrared
Infrared light travels deep below the surface, warming the skin.

What are microbeads?

Why these tiny spheres are facing a blanket ban to save the environment

The quest for smooth, airbrushed skin has driven cosmetics companies the world over to create dozens of exfoliating scrubs and washes, but one controversial ingredient is now facing a ban in the UK in 2017: microbeads.

Microbeads are miniature fragments of exfoliating plastic included in shower gels, facial cleansers and toothpastes. They are usually made from polyethylene, polypropylene or polystyrene, and because they're plastic they don't break down over time.

Wastewater is cleaned before it enters rivers and oceans, but these tiny beads slip through the filters and wash out into the wild. Tens of thousands are rinsed down the plug hole each time one of these scrubs is used, and in the UK alone 680 tons of the plastic pellets are believed to be washed away every year.

The little pellets can pick up toxins, and the concern is that they are being swallowed up by marine animals, including fish, crabs and oysters. Their digestive systems can't break them down, and over time they are contaminating the food chain.

Companies are now being urged to switch to natural alternatives, such as salt, sugar and crushed nut husks in a bid to prevent any further damage to marine life.

These tiny shards of plastic can be harmful to marine life

60 SECOND SCIENCE

Photosynthesis

OUR QUICK-FIRE GUIDE TO HOW PLANTS CAPTURE ENERGY FROM THE SUN

BACKGROUND

Sunlight streams onto the Earth's surface every day, supplying an estimated 175 watts of power for every square metre of our planet. Most of this light is reflected, absorbed or scattered, but some of it is captured by green plants, phytoplankton and cyanobacteria. These organisms then use it to create the building blocks of life, powering almost every living thing.

Using the Sun's energy, these organisms transform carbon dioxide and water into a sugar called glucose, which is then used for respiration. Oxygen is a by-product of this process, which is known as photosynthesis.

IN BRIEF

Cells capable of transforming carbon dioxide and water into sugar and oxygen are known as photosynthetic. They contain pigments that absorb light; when the Sun shines, electrons inside the pigments become excited and break away from their atoms. The cells then shunt these through an 'electron transport chain', storing their energy in molecules called ATP and NADPH. This energy is then used to build sugar molecules. In order to keep the system running, the electrons are replaced by splitting water molecules, creating oxygen in the process.

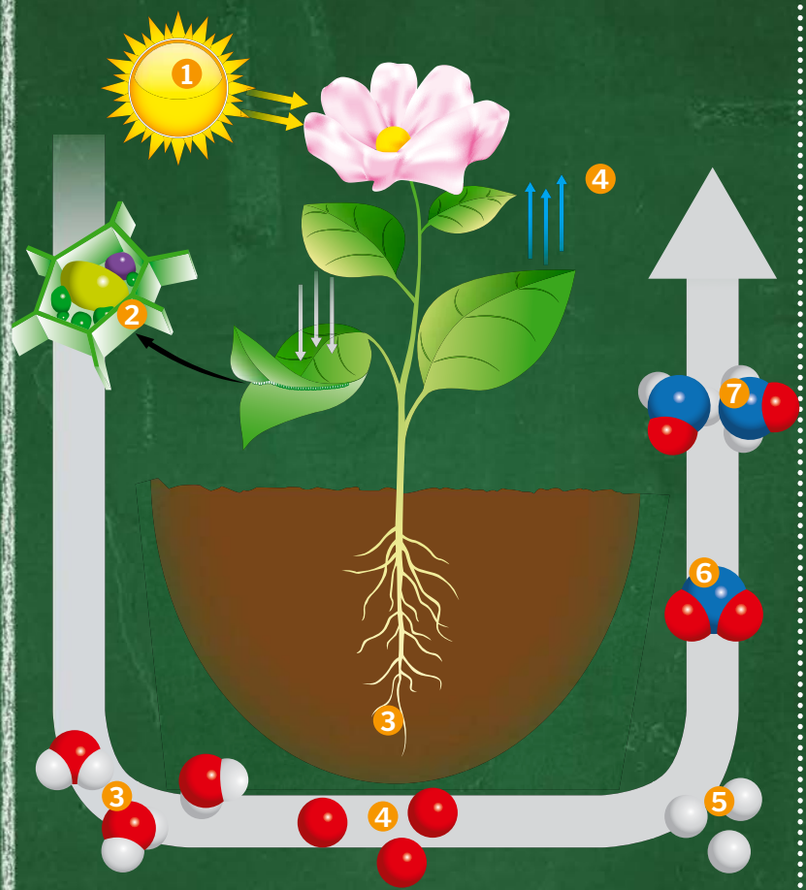
The most well-known pigment is chlorophyll A, which absorbs red and blue light and reflects green, giving plants their familiar hue.

SUMMARY

Plants capture energy from the Sun using the pigment chlorophyll. They use this energy to build sugar molecules, and generate oxygen in the process. Without photosynthesis most life on Earth would not survive.

Photosynthesis in action

This simple process keeps life on Earth supplied with energy



1 Sunlight
Light from the Sun strikes the plant's leaves, hitting the cells inside.

2 Chlorophyll
Certain cells contain chlorophyll, and as the sunlight strikes, electrons become excited.

3 Water
The plant takes in water and splits the molecules into oxygen, electrons and hydrogen ions.

4 Oxygen
The oxygen can either be used by the plant, or released into the air.

5 Hydrogen
The hydrogen atoms are saved to be used in building sugar molecules in the next stage.

6 Carbon dioxide
The plants take in carbon dioxide and, using the energy they have trapped from the sunlight, they combine it with hydrogen.

7 Sugar
The result is brand-new sugar molecules, which can be used for energy or as the building blocks for making starch.

LIMITING FACTORS

THE SPEED OF PHOTOSYNTHESIS IS AFFECTED BY THREE KEY FACTORS: THE AMOUNT OF LIGHT, THE AMOUNT OF CARBON DIOXIDE AND THE TEMPERATURE.

IF THERE'S TOO LITTLE OF EITHER OF THE KEY INGREDIENTS – LIGHT AND CARBON DIOXIDE – PHOTOSYNTHESIS SLOWS DOWN. IF THE SUN IS TOO BRIGHT AND TOO MUCH LIGHT REACHES THE LEAVES, THE PIGMENTS CAN BECOME DAMAGED.

CAPTURING LIGHT FROM THE SUN DOESN'T RELY ON TEMPERATURE, BUT USING THE STORED ENERGY TO BUILD SUGAR MOLECULES DOES. THIS PART OF THE PROCESS IS DONE BY MOLECULAR MACHINES CALLED ENZYMES. IF IT IS TOO COLD, THE ENZYMES CAN'T MOVE FAST ENOUGH TO PERFORM THE REACTIONS, AND IF IT IS TOO HOT, THEY CAN BECOME BENT OUT OF SHAPE.

PLANTS ALSO NEED MAGNESIUM. IT IS USED TO MAKE CHLOROPHYLL, AND WITHOUT IT THE LEAVES TURN YELLOW AND PHOTOSYNTHESIS SLOWS.

Carbohydrates explained

These biological building blocks are an essential food group that we need to eat to survive

Carbohydrates are sugars, starches and fibres, and the word 'carbohydrate' gives a bit of a clue about their structure. The 'carbo' part stands for carbon (C), while the 'hydrate' bit refers to water, in the form of hydroxyl groups (OH-). They have the simple formula $C_x(H_2O)_y$.

Carbohydrates are divided into four major categories based on their size. The simplest are monosaccharides, or 'simple sugars'. These single blocks are made up of a small number of carbon atoms, attached to hydrogen and oxygen atoms, and include glucose, fructose and galactose. Then there are the disaccharides, or 'double sugars', like sucrose and lactose. These are made from two simple sugars bonded end-to-end.

Finally, there are the oligosaccharides and the polysaccharides, meaning few and many sugars respectively. Oligosaccharides are chains of between three and six simple sugars, and polysaccharides are even longer, with chains of simple sugars that can be linked together in their thousands.

P Fibre
Some long carbohydrates cannot be broken down by our digestive systems. Collectively, these are known as fibre. They pass all the way through the digestive system, helping to keep things moving.

P Cellulose
This type of carbohydrate is another long chain of glucose made by plants, but it can't be digested.

M Galactose
This simple sugar is mostly found bound to glucose to form lactose, but it can also be found on its own in nuts and peas.

D Lactose
Lactose is 'milk sugar', and is made from glucose and galactose bonded together.

D Sucrose
This is the familiar sweet-tasting table sugar. It's made from a combination of fructose and glucose.

"Our bodies evolved to run on sugar"

M **Glucose**
Glucose isn't often found on its own in foods, but is a key building block of bigger carbohydrates.

D **Maltose**
This two-part sugar is made from two molecules of glucose. It is sometimes known as 'malt sugar' and it can be found in grains.

P **Starch**
Potatoes, wheat and corn contain lots of these complex carbohydrates. They are long chains of glucose made only by plants.

Raffinose
This is an oligosaccharide, with three simple sugars attached in a chain. It's found in beans, cabbage, sprouts and other veg.

M **Fructose**
Also known as 'fruit sugar', this simple sugar is found naturally in fruits and honey.

Where to find them

Carbohydrates come in many shapes and sizes in different foods

M **Monosaccharides**
These are the 'simple sugars'. They form structures with at least three carbon atoms arranged in slightly different ways, which affects how the body processes them.

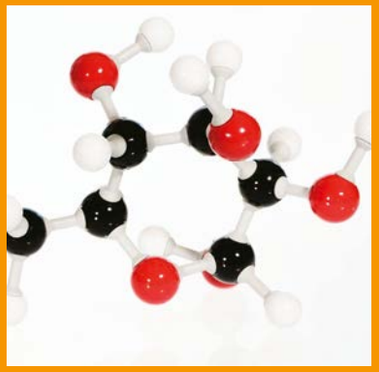
D **Disaccharides**
These are the 'double sugars', made from two simple sugars joined end-to-end. They come in different varieties depending on the types of simple sugar that they contain. The body splits them into simple sugars before use.

P **Polysaccharides**
These are the 'many sugars', made from long chains of simple sugars, either joined end-to-end in chains, or joined side-to-side to form large, branching structures. These are sometimes known as 'complex' carbohydrates.

How do we use carbohydrates?

Our bodies evolved to run on sugar. Every cell is packed with molecular machinery that takes the simple sugar (glucose) and breaks it down to release usable energy.

The other carbohydrates need some processing before the body can access their fuel. The long chains of polysaccharides are snipped apart by enzymes called carbohydrases, and the simple sugars that come away are then converted into glucose. To ensure that the body never runs out of fuel, some of the excess is stuck back together and stored in long, branching chains called glycogen, which can be cut up and used on demand.



Glucose is a very important source of energy for living organisms

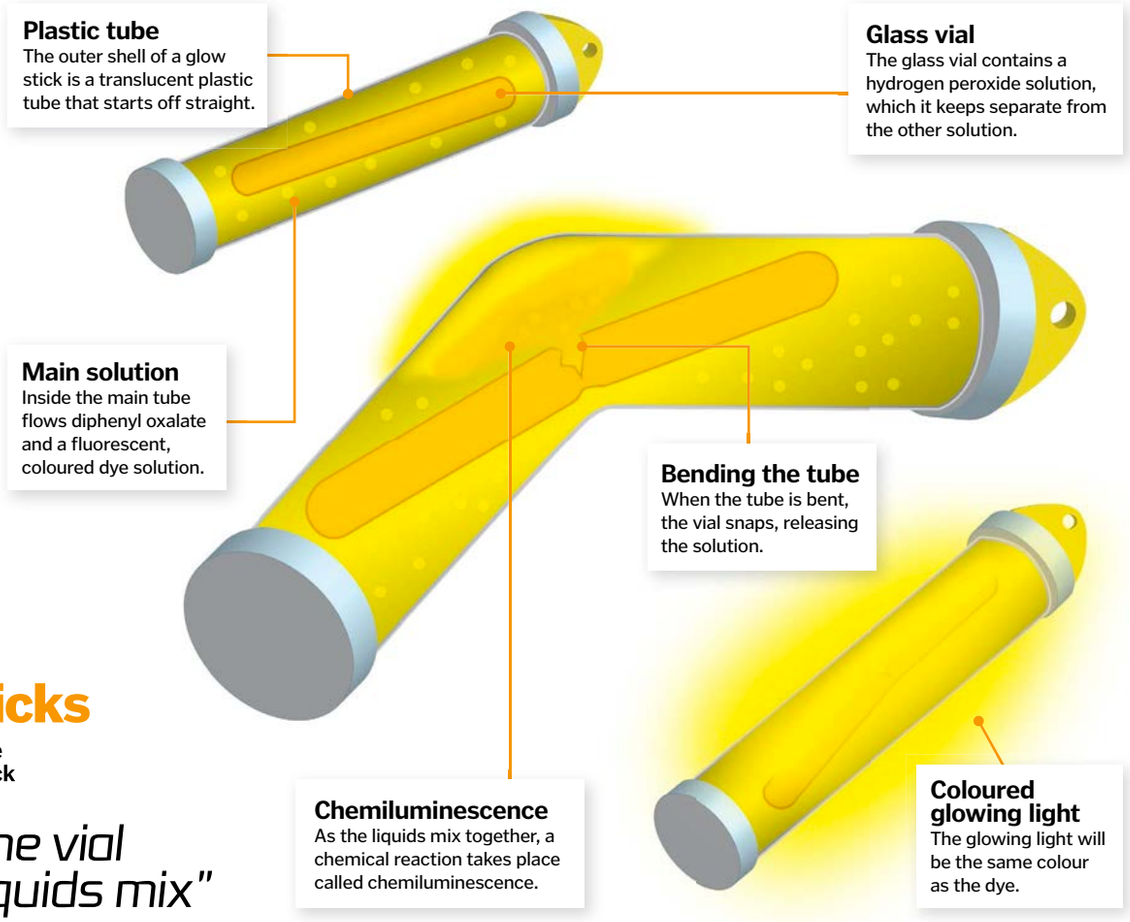
The colour of a glow stick depends on the colour of the dye that's inserted

How glow sticks work

They're used by partygoers, campers, divers and other outdoor adventurers, but what makes a glow stick glow?

A glow stick is a translucent plastic tube that contains two liquids: hydrogen peroxide and diphenyl oxalate. The latter is also mixed with a fluorescent dye. The diphenyl oxalate and dye solution flow freely in the glow stick, whereas the hydrogen peroxide solution is contained in a fine, glass vial within the tube. When the stick bends, the vial breaks and the liquids mix together.

A chemical reaction then occurs, known as chemiluminescence, which results in a glowing light. This happens as the electrons in the dye rise to a higher energy level, become excited, and then release coloured light as they fall back down.



The science behind glow sticks

See how chemistry plays a vital role in putting the glow in your glow stick

"When it bends, the vial breaks and the liquids mix"

Why glitter is so sticky

Discover what glitter is made from and why it sticks to almost everything

Although craft glitter used to be made from different types of metals, these days cosmetic and craft glitter are both made of plastic composed of polymer molecules. The materials are produced on thin sheets, and the shine comes from a coating of reflective metal, like aluminium foil. Colour is applied before the sheets are treated and then cut into tiny pieces using a special machine.

The material glitter is made from, along with its small size, both contribute to its stickiness. Since plastic easily picks up electrons, it's likely that static electricity occurs when glitter comes into contact with dry surfaces.

Experts state that the viscosity of air might also play a part in glitter's stickiness. Since a glitter particle is flat, when it rests on a smooth object it pushes out the air from beneath it, and the air on top of the glitter particle pushes it down. Unless air is somehow let under it to enable it to rise, the glitter will remain relatively stationary.

Another theory is that glitter gets its stickiness from van der Waals forces, the weak electronic interactions that occur between electrically neutral molecules.

It's believed that machinist Henry Ruschmann invented glitter in 1934

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Hovercraft

Inside the vehicles that are equally at home on land or sea

In the mid 1950s, British engineer Sir Christopher Cockerell set to work with a cat food can, a coffee can, an industrial air blower and a pair of kitchen scales. His idea was to prove a concept for a vehicle that would float on a cushion of air and, in so doing, reduce its friction with the surface of the sea while also allowing it to travel across land. Propellers would be used to achieve forward motion, but getting it to hover was more of a challenge.

The idea wasn't a new one but, until then, nobody had come up with a practical design. Cockerell's plan was to abandon attempts to direct the air into the entirety of the underside of the vehicle, the approach others had taken. Instead, the air would be pumped into a ring around the perimeter of the vehicle while allowing some of it to escape into the area immediately below the vehicle. This, he argued, would very much reduce the size of the engines required to maintain the air cushion.

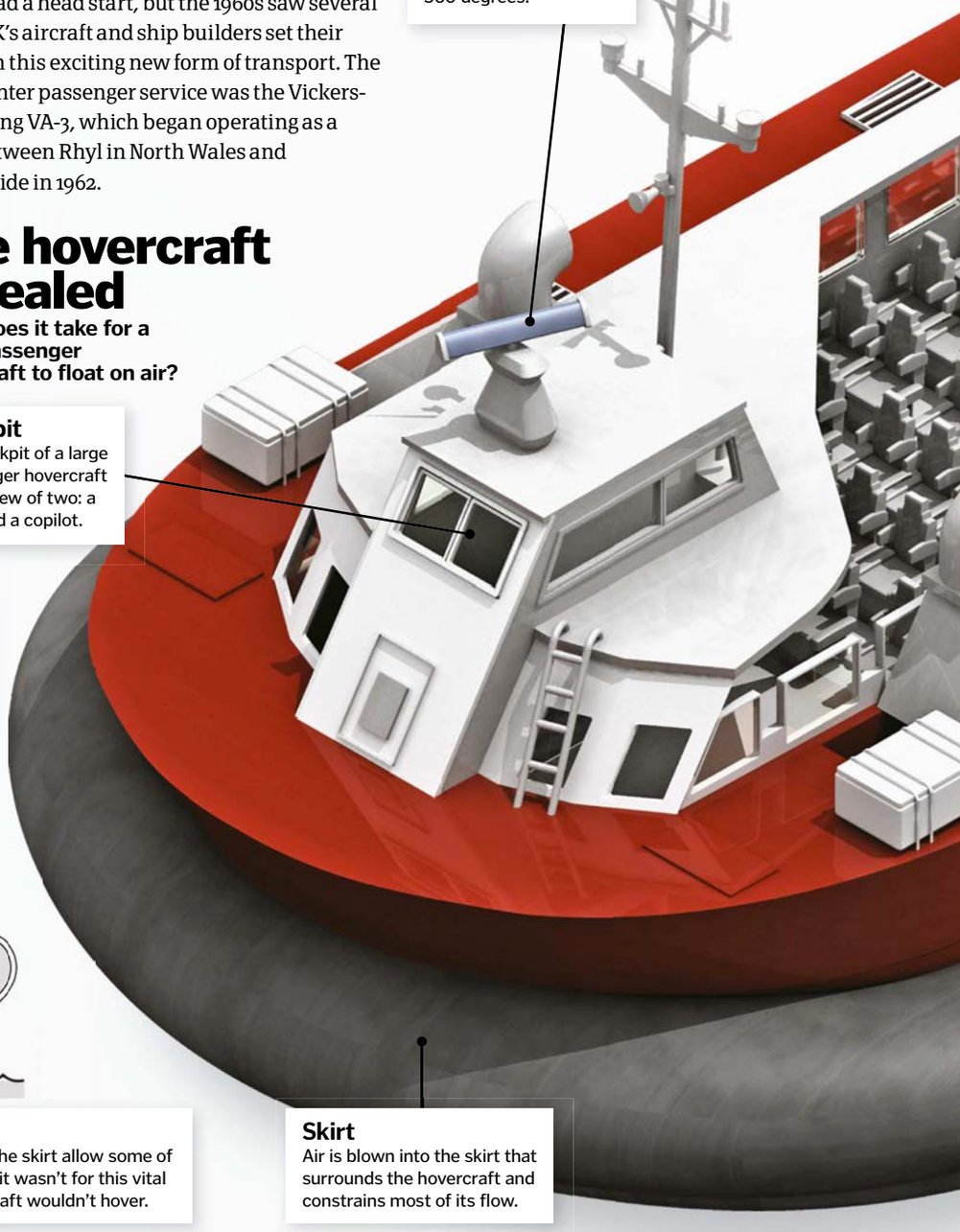
With Cockerell's small-scale experiments proving his theory, he was soon granted a patent for a vehicle he described as "neither an airplane, nor a boat, nor a wheeled land craft". He also referred to his novel approach, which has now evolved to make use of the familiar 'skirt', as "a very expensive motorcar tyre with a permanent puncture". Just four years later, the world's first hovercraft, the SR.N1, crossed the English Channel – a totally new form of transport had been born.

Although initially a military secret, by the end of the 1950s the hovercraft was declassified with the aim of kick-starting a British hovercraft industry. Saunders-Roe, the developer of the SR.N1, had a head start, but the 1960s saw several of the UK's aircraft and ship builders set their sights on this exciting new form of transport. The first to enter passenger service was the Vickers-Armstrong VA-3, which began operating as a ferry between Rhyl in North Wales and Merseyside in 1962.

Bavaria's Steinberg Fire Brigade are seen here using a hovercraft for rescue operations

The hovercraft revealed

What does it take for a large passenger hovercraft to float on air?

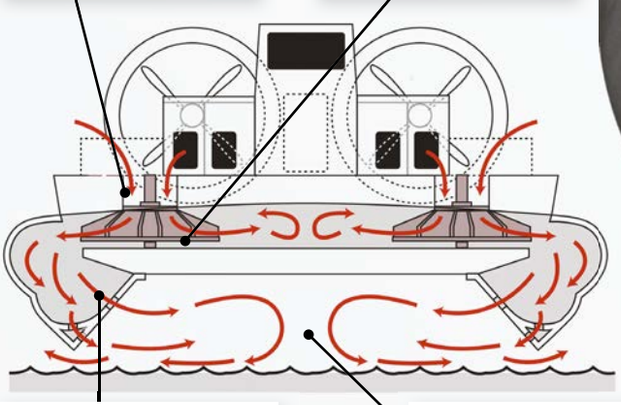


Radar antenna
Like any large vessel at sea, radar is an essential safety feature. The rotating antenna allows the crew to detect nearby objects through 360 degrees.

Cockpit
The cockpit of a large passenger hovercraft has a crew of two: a pilot and a copilot.

Air intakes
The lift fans take their air from the air intakes, which are protected with a mesh.

Lift fans
Lift fans create the essential downward force that enables hovering.



Skirt
The idea to deploy a skirt means that heavy, expensive engines can be avoided.

Escaping air
Small apertures in the skirt allow some of the air to escape. If it wasn't for this vital feature, the hovercraft wouldn't hover.

Skirt
Air is blown into the skirt that surrounds the hovercraft and constrains most of its flow.

"A resurgence of passenger hovercraft is easily possible"

Thrust fans
With just the lift fans, a hovercraft would float but it wouldn't move forward. Forward thrust is, therefore, provided by the thrust fans.

Rudders
Steering a hovercraft is achieved by using rudders that direct the air coming out of the back of the thrust fans.

Passenger cabin
Large passenger hovercraft accommodate passengers in aircraft type seats. The largest carried 400 people.

Thrust fan engines
While small hovercraft use the same engine for lift and thrust, larger models use different engines, probably more than one for each function.

Lift fans
By elevating the hovercraft the lift fans allow it to travel at speed over the water.

Lift fan engines
Power for the lift fans comes from diesel engines. More modern hovercraft use electrical motors.

The Griffon 2000TDX Mk II – shown with the skirt inflated (left) and deflated – in service with the Lithuanian Coast Guard

At home on any surface

Wheeled vehicles need a hard surface to gain traction and avoid sinking; boats require a minimum depth of water. Thanks to the cushion of air on which they ride, hovercrafts require neither. They're at home on land or sea and anywhere in between, including ice, mud and even in swamps.

Because the vehicle barely comes into contact with the surface of the sea or ground, effects such as waves on the sea and low-friction surfaces like ice don't affect the hovercraft. We might imagine that irregular surfaces would cause problems due to a poor seal between the vehicle and the ground but, because of the flexible skirt, adequate air pressure is maintained, even when travelling across rough ground or stormy seas.

Ice fields pose no risk to the hovercraft since it floats on a cushion of air

Carrying just 24 passengers, this was small fry compared to what was soon to come. In 1968, the SR.N4 pioneered a cross-Channel service, carrying up to 400 passengers and 55 cars. Commercial services started in other countries too but, by and large, passenger-carrying hovercraft were a British phenomenon with several routes plying the island's coastal waters. However, this wasn't to last. Due to a combination of competition from the Channel Tunnel, increasing fuel costs and noise concerns, the year 2000 marked the end for hovercraft on the Channel.

Today only one regular hovercraft passenger service remains in Europe. Linking Southsea, near Portsmouth, with Ryde on the Isle of Wight, a service run by Hovertravel crosses the Solent in approximately ten minutes, which is twice as fast as a catamaran and four-times quicker than a passenger ferry.

Hovercraft might now be marginalised as passenger vessels but they remain important for the military and coastguard services worldwide. For the military, the most obvious advantage is their ability to transition seamlessly from sea to land, thereby obviating the need for a dock or a pier. Users include the United States Navy, the Japan Maritime Self-Defense Force, the Russian Navy and the People's Liberation Army Navy of China plus, of course, the British Marines.

To coastguards they are indispensable because they can be used in shallow water and mudflats to carry out searches in areas where neither boats nor 4x4s can be used. They have also found favour as recreational vehicles and even for racing.

"It's a very expensive motorcar tyre with a permanent puncture"

The hovercraft might be limited mostly to niche applications today but, according to some experts, the passenger hovercraft could be about to enjoy a new lease of life. Using hybrid technology, the newly introduced 12000TD hovercraft from Southampton-based company Griffon Hoverwork – that now serves the Isle of Wight – has addressed some of the concerns that hampered the Channel service. It might just be a pointer to the future.

It is up to 30 per cent more efficient than previous passenger hovercraft and is also much quieter. According to Warwick Jacobs, hovercraft expert and former trustee and curator of the Hovercraft Museum in Gosport, plans are afoot to develop a fully electric hovercraft. Such vehicles would be quieter and more efficient than past models, which could see hovercraft brought back into regular service once again.

A US Navy hovercraft providing humanitarian support in Indonesia following the catastrophic 2004 tsunami

Future hovercraft

A concept by Yuhan Zhang, a designer from China, shows how the hovercraft could represent the future of personal transport. Her short-listed entry to a competition sponsored by Volkswagen is a vehicle dubbed the Volkswagen Aqua.

Designed to cope with the huge variety of terrain that can be found in China, the Aqua could be used on lakes, rivers, coastal waters, roads, wetlands, snow and ice.

Powered by a hydrogen fuel cell, the Aqua would be a clean, zero-emission vehicle. The craft's appearance is cleverly styled to look similar to today's road vehicles and, intriguingly, when the Aqua is parked, its two downward- pointing fans retract into the body so they look like rear wheels.

Could the Volkswagen Aqua represent multi-terrain vehicles of the future?

Military hovercraft

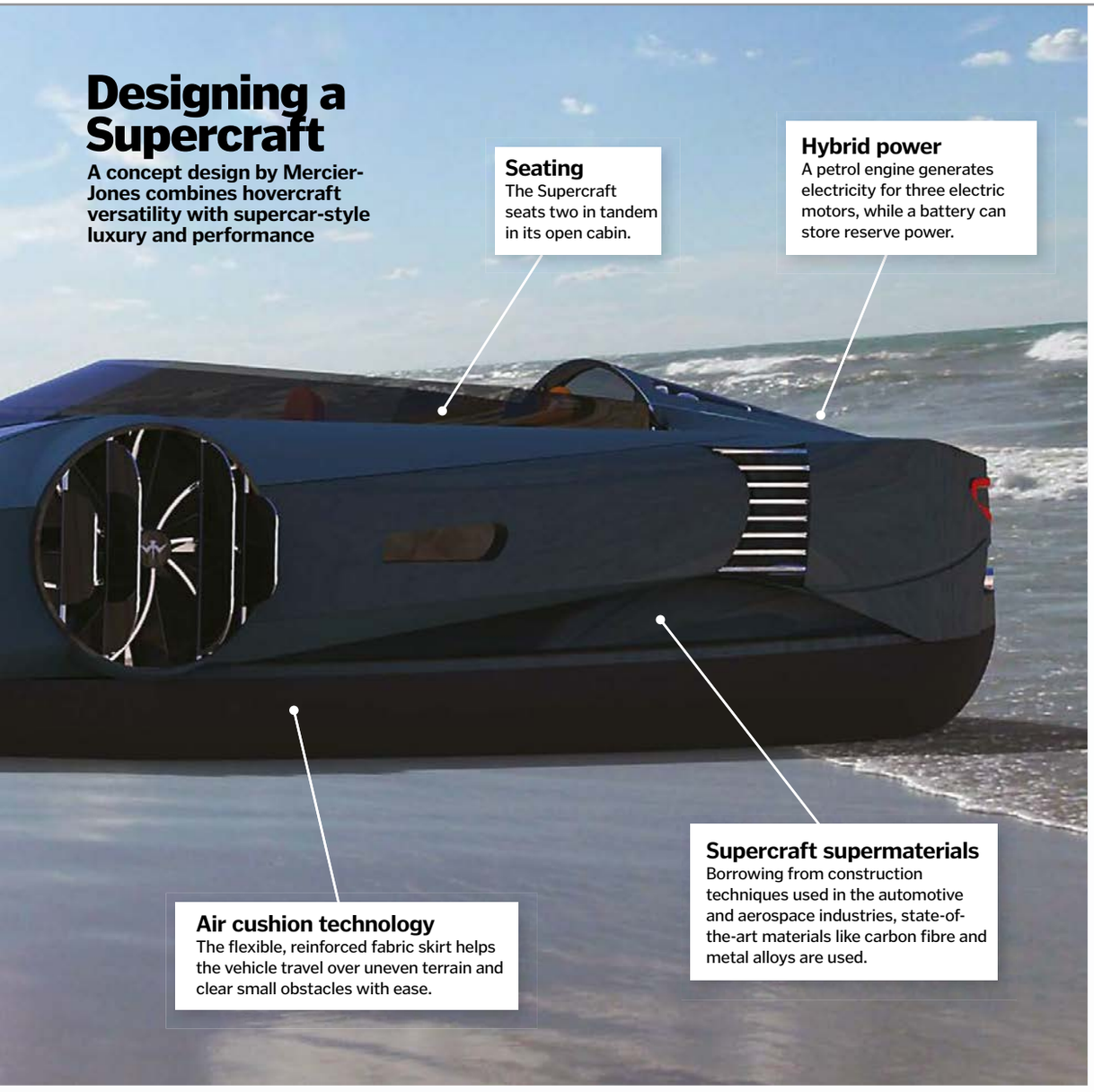
Today the military are the prime users of hovercraft. Typically they are used for sealifting amphibious assault units – often comprising troops and tanks – from ships to the shore in the absence of docking facilities.

The Zubr-class Landing Craft Air Cushion (LCAC) is intended for just this sort of application and is currently the world's largest hovercraft. Operated by the Russian and Greek navies, and with multiple units on order by the Chinese military, it can either carry three main battle tanks, ten armoured vehicles, 375 fully equipped soldiers or up to 500 people.

This US Navy hovercraft has been deployed in the Persian Gulf

Designing a Supercraft

A concept design by Mercier-Jones combines hovercraft versatility with supercar-style luxury and performance



Seating
The Supercraft seats two in tandem in its open cabin.

Hybrid power
A petrol engine generates electricity for three electric motors, while a battery can store reserve power.

Supercraft supermaterials
Borrowing from construction techniques used in the automotive and aerospace industries, state-of-the-art materials like carbon fibre and metal alloys are used.

Air cushion technology
The flexible, reinforced fabric skirt helps the vehicle travel over uneven terrain and clear small obstacles with ease.

Racing hovercraft can boast a power-to-weight ratio greater than that of the fastest road cars

A turn of speed

Few vehicles haven't been raced, and the hovercraft is no exception. Races are held worldwide, with courses combining solid ground and water. Like motor racing, hovercraft racing is divided into formulae, with F1 representing the pinnacle of achievement. An F1 hovercraft engine can deliver in excess of 171.5 kilowatts but weighs as little as 200 kilograms thanks to its Kevlar and carbon fibre hull. This equates to some serious performance – 0-100 kilometres per hour in just four seconds and a top speed of nearly 130 kilometres per hour, if you have the nerve.

Other hovering technology

Hovercraft aren't alone in their use of an air cushion

Hovertrain
Like ordinary trains, hovertrains ran on tracks or, more accurately, they hovered above them. They never really caught on.

Flymo lawnmower
The Flymo is the most familiar face of air cushion technology. These hover lawnmowers are lightweight and manoeuvrable.

Hover Cover
The Hover Cover, now installed at Lord's cricket ground, makes it quick and easy to protect the pitch when rain stops play.

Air hockey
It looks like a pool table, but an air hockey table blows air through tiny holes so the pucks float above its surface.

The origami kayak

Find out about this foldable kayak and how it works

Taking inspiration from Greenland kayaks and the Japanese art of paper folding, Oru Kayak's innovative design introduces the first folding kayak.

Aptly nicknamed the origami kayak, it is made from a single sheet of corrugated plastic, which not only makes it incredibly lightweight, but also means it requires no tools to assemble - it can be assembled in just 20 minutes. The five-millimetre, double-layered, custom extruded polypropylene gives the kayak structure and sturdiness while maintaining durability. Being so compact also makes it very easy to store and carry.

Buckling up
Various straps, buckles and latches fasten all the components together.

Adjustable seats
The seat and backrest slot into the cockpit, and are adjustable, just like the footrest.

Dual functions
The orange floorboard was formerly the lid of the box.

Folding up the kayak
When assembling and disassembling, coloured stickers guide you on where to make folds.

Storing and carrying
With no separate case, the kayak folds up to create its own box!

Navigating the origami kayak

Working out the various components and building your kayak

How Tesla Superchargers work

Discover the technology behind the electric car maker's fast charging facilities

Tesla's electric cars run on direct current (DC) electricity delivered from an internal battery. Standard Tesla charging stations feed alternating current (AC) electricity from the grid to the battery through a rectifier in the car that converts AC to DC. This rectifier is necessarily small, which limits how fast the current flows to the battery.

Supercharger stations overcome this problem with multiple built-in rectifiers. Once the current has been converted, the charge is transferred directly to the car's battery. To prevent overcharging, a computer in the car slows the charging rate as the battery nears capacity.

Early Supercharger stations were rated at 90 kilowatts and could charge compatible batteries to 80 per cent in around 40 minutes. Tesla has since introduced 120-kilowatt units. Home chargers only have a charging capacity of up to 20 kilowatts. In just one hour that can charge the battery enough for approximately 80 kilometres of travel. A 30-minute charge at a Supercharge station can store enough power in the battery for over 200 kilometres of travel.

Salvaging a shipwreck

How the largest marine salvage in history raised an ill-fated Italian cruise ship

In 2012 the Costa Concordia ran aground with over 4,000 passengers and crew on board. 32 people sadly lost their lives. For nearly two years it sat dormant in the Tyrrhenian Sea, a constant reminder of the tragedy for the population of the nearby island of Giglio off the coast of Tuscany, Italy.

The cruise ship had capsized after it had collided with rocks as its captain tried to perform a sail-by 'salute'. Resting on a shallow seabed, most of the stricken ship was still visible above the water. The raising had to be meticulously planned.

There were concerns that if the operation went wrong the ship could tumble down and be submerged completely. To further complicate matters, the wreck was surrounded by a marine national park with a coral reef, which plays host to a range of wildlife, including several endangered and rare species. This meant the raising was undertaken as a closed operation to ensure no debris could escape and contaminate the ocean further.

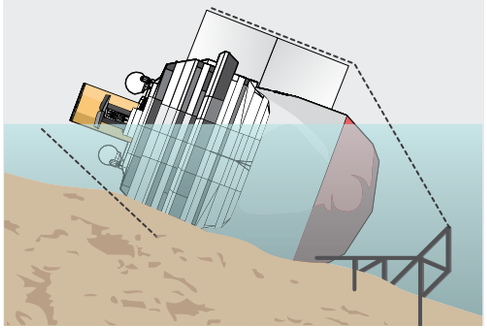
When the salvation operation was complete, the ship was towed over 350 kilometres to a dry dock in Genoa, where the deck was stripped piece by piece and then completely dismantled and scrapped. Back at the wreck site, sea grasses were replanted as efforts were made to restore the seabed and reverse the damage done. A part of the rock that tore the Costa Concordia's hull open is to be used as a memorial.

The salvage operation cost an estimated £700 million ($862.5 million) and took 18 months to complete

The ship was righted in September 2013 following an extremely delicate procedure known as parbuckling

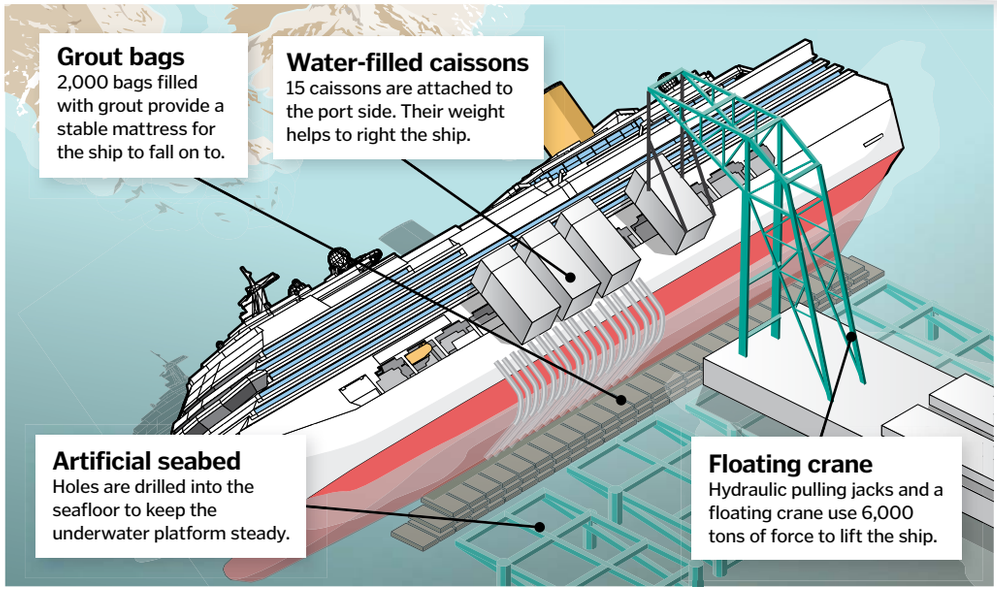
Raising the Costa Concordia

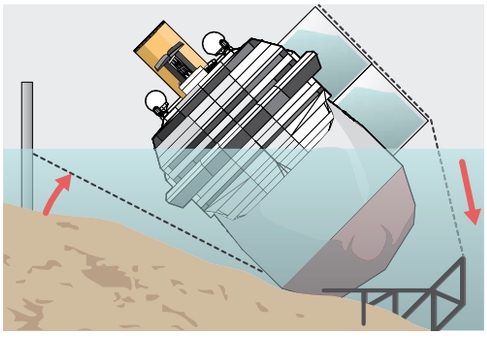
The ingenious methods that were used to recover the wreck



1 Anchored in place

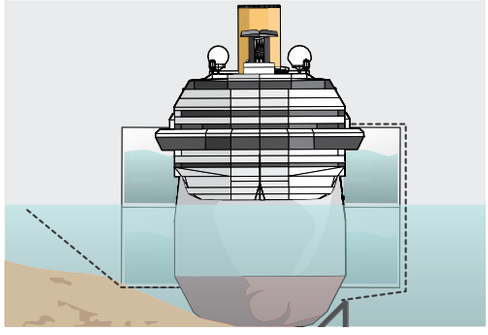
Anchor chains are fixed to the port side, taken underneath the ship and attached to retaining towers to hold it steady. An underwater steel platform adds support.





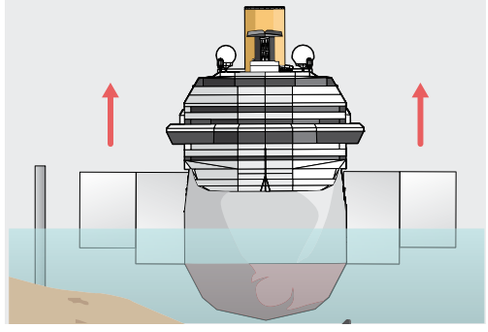
2 Rolling the ship

The ship is rolled to a 25-degree angle using pulling cables attached to the platforms. The weight of the water-filled caissons helps lift the ship off the slope.



3 Maintaining stability

Caissons are welded to the starboard side. This helps keep the wreck – which is now resting on the constructed platform – stable.



4 Final raising

The water is pumped out and replaced with air. This increases the ship's buoyancy, helping to raise it off the platform. The vessel is now ready to be towed away.

A test pilot

How new helicopters are certified in order to be deemed fit to fly

Before a helicopter can take to the skies, it is required by law to undergo a series of assessments. Dick Ormshaw is a UK chief test helicopter pilot for Airbus and his job is to review different types of helicopter both on the ground and in the air. Ormshaw is certified to fly 15 different types of helicopter, and carries out test flights on both military and civilian choppers. Depending on the job, the role will focus on testing particular components. It is through a thorough testing campaign that helicopters are deemed capable of flying in different climates and environments across a wide variety of missions.

MORNING BRIEFING
8.30am

We begin the day with a briefing. Weather conditions are very important to how the day will pan out. For example, if there has been a cold front recently the air may be too unstable to test in. We also check air traffic restrictions and whether we need to cordon off an area if we need to work on manoeuvres or formations.

PRELIMINARY ASSESSMENT
9am

The briefing over, we assess the state of the helicopter and the kit within it. The crew (myself and the flight test engineer) then have a full flight brief, where we decide what speed we're going to depart the airport and with what actions or manoeuvres we're going to perform.

THE TESTING BEGINS
10am

The helicopter examination is incremental, so we start off with the simplest procedures before moving on to more severe ones. After a risk assessment to refresh our memory on where potential issues may lie, the on-ground testing gets underway. What we test first varies depending on the

Dick Ormshaw has a history of naval test flying and previously tested how helicopters landed on ships

Customer training is a big part of flight testing. Pilots need to know if any modifications have affected handling

"Up to three times as much testing is done on the ground as in the air"

Some helicopters have such good autopilot systems that the tests become very straightforward

An Airbus test pilot requires a flight test rating from one of the world's top four test pilot schools

airframes we get sent, as these might need specific parts to be tested, such as the engine or the rotor.

UP IN THE AIR
11am

On this occasion we are testing a thermal camera mounting to check for vibrations, which have to be monitored extremely carefully as they can cause damage. Upon landing it's found that the HD camera isn't harmonic to the helicopter's vibration. If this isn't fixed it can break equipment and is potentially dangerous, as harmonics cause vibrations which can shatter or unscrew parts of the chopper.

RECAPPING GROUND TESTS
12pm

After the issue has been resolved, we go through the initial ground results to try and find any clues as to why the camera vibrated. Up to three times as much testing is done on the ground as in the air. You sometimes discover something unexpected, which is precisely why flight tests are needed.

LONG DISTANCE TESTS
2pm

In the afternoon, we will start putting the helicopter through its paces. We fly over the countryside, away from built up areas, and it needs to be a specific route just in case the fuel transfer falters. 75 per cent of the flying I do is over Oxfordshire and Warwickshire, and the furthest I've been on a test is Scotland and back.

MEASURING PROGRESS
5pm

At the end of the day we have a debrief. Everything we do is noted down for proof if further analysis is needed. During the test everything I say in the cockpit is recorded, while a pitot static bird towed behind the helicopter takes independent recordings of the flight, which are compared to the on-board instrumentation to ensure all data is accurate.

NIGHT SHIFT
8pm

Helicopters also have to be tested in the dark to check lighting equipment and night vision goggles. We can use a small hangar known as a dark room, but we also head out into the night. Only some helicopters require this type of testing, such as police helicopters or air ambulances, which are often required to be operational 24/7.

AJAX armoured fighting vehicles

Discover the sophisticated vehicles that will serve as the Army's eyes and ears in battle

Imagine being a soldier in a war zone and your transport sustains damage to its armour from enemy fire. You'd probably have more confidence in your chances of survival if you knew the damaged component could be replaced there and then. That's one of the principles behind the design of AJAX, the British Army's latest armoured reconnaissance vehicle. Due to enter service in 2017, AJAX has some of the most advanced battlefield surveillance technology available.

Versatility and flexibility are key elements of its design. In addition to the base model, there are five variants that have been engineered for different objectives. Since each is based on AJAX, all share that vehicle's modular armour system and what is called scalable Electronic Architecture. Put another way, important hardware and software can easily be replaced or upgraded if they are damaged or superseded by better components.

It's not just the protective shielding and computer systems that are state-of-the-art though. AJAX has a 40-millimetre cannon that can fire five types of projectile. These can be side-loaded to leave more room in the cab for a crew of up to four and a supply of spare parts and ammunition.

AJAX has been designed to play a central role in the British Army's contribution to Intelligence, Surveillance, Target Acquisition and Reconnaissance (ISTAR). This integrated international approach is intended to help commanders make better combat decisions.

General Dynamics will supply 589 AJAX vehicles at a cost of £3.5 billion ($4.4 billion)

AJAX anatomy

Find out what makes the AJAX one of the British Army's most advanced armoured vehicles

Connected conflict
Network-enabled digital communication equipment allows information to be shared rapidly and reliably.

Wide-angle vision
The Primary Sight provides a wide panoramic view of the surrounding area.

On-site repair
If a piece of modular armour is damaged in battle, it can potentially be replaced without returning to base.

Attacks from below
Measures to protect the crew from mine explosions under the AJAX include suspending their seats from the roof.

AJAX variants

Five adaptations of AJAX that will have their own special assignments

ARES

Designed to transport a crew of two for surveillance close to enemy targets, the ARES has a Remote Weapon System.

ATLAS

Built to rescue casualties, the ATLAS is fitted with a recovery package that includes two winches and an anchor.

ARGUS

The focus of this two-person vehicle is engineering-relevant data such as the topography of the surrounding landscape.

ATHENA

The ATHENA's onboard mapping and surveillance equipment will be used to synchronise decision-making.

APOLLO

The APOLLO variant comes equipped with a crane and towing equipment for recovering damaged vehicles.

Unconventional ammunition
The rounds fired by the cannon are comparatively small and can travel up to 1,500 metres per second.

Firepower
The 40mm telescoped cannon can fire training, airburst high explosive, aerial airburst, armour piercing and point detonating rounds.

Diesel engine
The 805-horsepower diesel engine gives the AJAX a top speed of over 70km/h.

Load bearing
Classed as a 'medium-weight' vehicle, AJAX can operate under a total weight of up to 42 tons.

"Versatility and flexibility are key elements of the AJAX design"

Road rollers

Learn about the vehicles that ensure new roads don't give us a bumpy ride

Road rollers, or roller-compactors, are used for construction projects that produce flat surfaces such as highways, runways and car parks. In principle, the weight of the roller, in combination with the rotation of one or more cylindrical drums, compresses materials on or under the ground to provide a firm foundation.

As the name suggests, smooth-wheeled rollers, such as vintage steam rollers, have steel, iron or concrete drums with smooth surfaces. Generally, these rollers have a drum at the front but some designs complement or substitute this with drums at the back.

Vibratory rollers are a variation on this design that achieve greater compaction by inducing vibration or oscillation in the drum. Weights attached eccentrically to the drum's central shaft unbalance its rotation. The vibrations produced are transmitted to the ground, causing particles in the substrate to settle into a dense configuration.

Sheepsfoot and padfoot rollers differ from smooth-wheeled rollers by having protrusions sticking out from the drum. These types of rollers are often used to compact heavy or silty clays and soils. The protrusions compress the soil as they are thrust into it by the drum. Coarse-grained soils are usually compacted using grid rollers, which have drums made of steel bars that form a grid of square holes.

Pneumatic rollers typically have four to six small rubber-tyred wheels at the front and back. Some pneumatic rollers can weigh over 25 tons.

Road rollers are often mistakenly called steam rollers, but technically this refers to the roller vehicles that were powered by steam engines during the 19th century (see the boxout below).

How roller-compactors work

Discover the mechanics that give road rollers the power to compress

Moving parts
Modern rollers are controlled by hydraulic systems that aren't easily damaged by the surface being compacted.

Driver cab
Some models feature an enclosed cab to improve safety and shield the driver from any fumes given off by hot paving material.

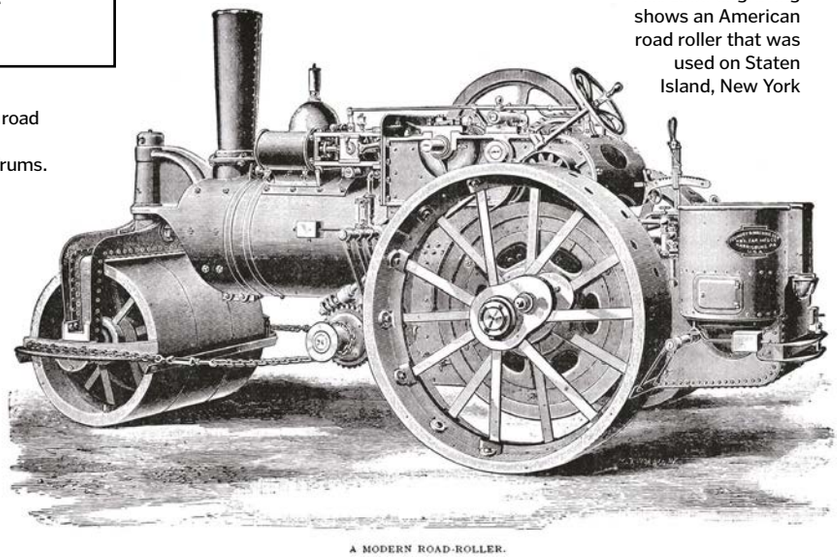
Hi-tech features
Some rollers have sensing equipment that monitors coverage and adjusts compactive effort to achieve even compaction across the surface.

Rear tyre
Tandem rollers have front and rear drums for further compaction, but others are fitted with rubber tyres.

Curve handling
Articulating swivels allow the drum to be turned, increasing the roller's manoeuvrability.

Added weight
Ballast, such as water or sand, can be added to drums to increase their weight and compaction efficiency.

Surface contact
To increase compaction achieved by static drums, road rollers can by fitted with oscillating and vibratory drums.



A MODERN ROAD-ROLLER.

This 1893 engraving shows an American road roller that was used on Staten Island, New York

Rolling through time

Although it isn't clear who invented the steam roller, early models of steam-driven devices that could be used as road rollers were demonstrated in the mid-1800s in France and Britain. Some of these were made by traction engine manufacturers who modified their existing designs to include a cylinder in place of the front or rear wheels. Horse-drawn devices that were capable of limited compaction preceded these vehicles. However, they lacked the weight and power to be viable as demands for road construction increased. Although the term 'steam roller' is still widely used, steam was largely superseded by liquid fuels in the 20th century and most road rollers now run on diesel.

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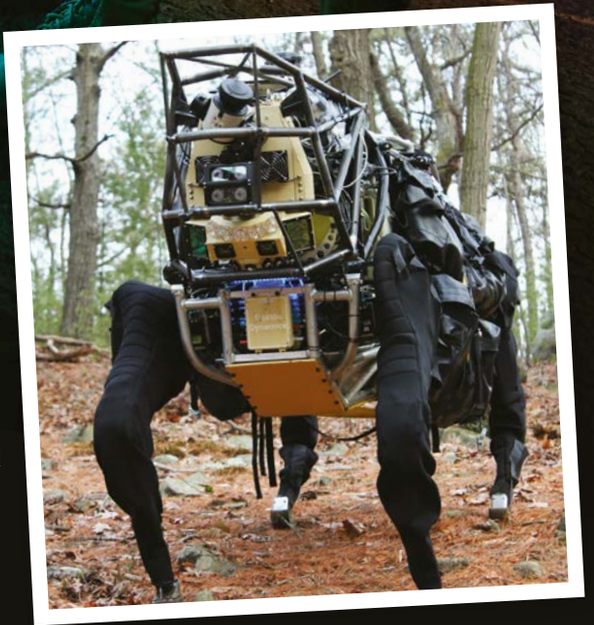
WAR ROBOTS

Advanced technology that's changing the face of warfare

Military hardware has undergone major changes in the last couple of decades as media coverage of recent conflicts has revealed. Put simply, advances in weaponry have made it possible, at least in part, to take a much more hands-off approach to waging war. For example, the Tomahawk cruise missile, that was famously used in the 1991 Gulf War, is capable of navigating itself to a target area up to 1,600 kilometres away, at which point it uses cameras and image analysis software to pin-point the exact target. More recently, the Predator and Reaper UAVs (Unmanned Aerial Vehicles) have come to public attention. Known colloquially as drones, these unmanned aircraft are controlled by a pilot, who could be located on the other side of the planet, and can be used for both reconnaissance and attack missions.

Intelligent cruise missiles and remotely controlled aircraft could be thought of as military robots but they are just the tip of the iceberg. Here we put war robots under the spotlight but, because that's such a broad area, we're concentrating mainly on battlefield robots. While not as much in the public eye as drones, these futuristic-sounding machines have already been put to work in Syria and Iraq, while future developments are exercising minds at some of the most prestigious defence companies and military research establishments in the world.

Despite their high-tech image, war robots aren't as new as we might have thought. As long ago as 1898, electrical engineer, radio pioneer and inventor Nikola Tesla demonstrated a radio-controlled boat for military applications. Tesla failed to gain the support of the US Navy – indeed there are suggestions that he was considered a crackpot – perhaps not surprising in an era when most people had never heard of radio. Closer to the



DARPA's Legged Squad Support System was designed to act as a robotic pack mule

current day, and closer to the modern concept of a battlefield robot, the Soviet Union developed a remote-controlled tank called the Teletank in the 1930s, while Germany produced a counterpart called Goliath that was deployed during the Second World War. In hindsight, the fact that neither proved a major success is hardly surprising as the necessary pieces of the jigsaw had not yet been developed. Today, however, the combination of reliable world-wide communications, satellite-based navigation and ample computing power is fuelling a new era of military robotics which might change the face of warfare.

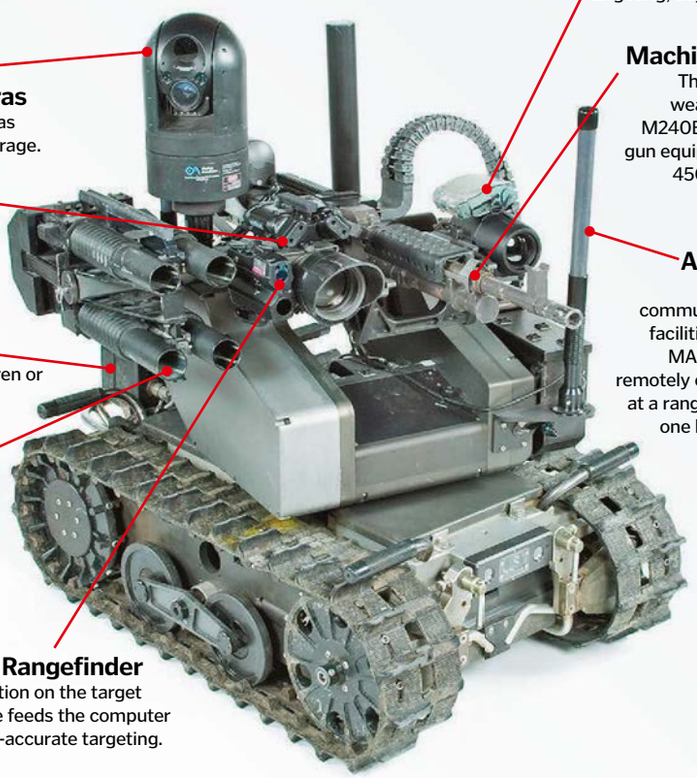
Military robots can be divided into three categories – tele-robotic, semi-autonomous and fully-autonomous. Tele-robotic devices are radio-controlled – they are driven by human operators, albeit at a distance, who have control over every aspect of their operation. Fully autonomous robots, on the other hand, require no human intervention whatsoever. Once they are programmed to carry out their task they will perform their assigned duty using inbuilt artificial intelligence. Semi-autonomous robots fall somewhere in between these two extremes and could encompass a whole range of possible scenarios. In a military context, for example, we could envisage a remotely controlled drone which has an auto-pilot that could be enabled by its remote pilot for routine flying operations, just as a pilot would use the auto-pilot onboard a passenger airliner. Alternatively, a robot fitted with a lethal weapon could act autonomously right up to the point of having targeted the enemy but would require human intervention before it is able to fire.

Military drones such as the Reaper are now being joined by robots on the battlefield

Today's military robots are under human control; future autonomous robots are more controversial

MAARS battlefield robot

QinetiQ's Modular Advanced Armed Robotic System aims to assist in reconnaissance, surveillance and target acquisition missions



Situational Awareness Cameras
Pan, tilt and zoom cameras provide 360-degree coverage.

Warning Laser
A green laser provides a non-lethal warning device, dazzling a potential threat.

Two-way Hailer
The hailer can sound a siren or enable two-way verbal conversation.

Grenade Launcher
Quad 40mm grenade launcher with independent controls permits round selection.

Laser Rangefinder
Information on the target distance feeds the computer for ultra-accurate targeting.

Gunnery Cameras
Daylight and thermal imaging cameras are used for weapons targeting, day or night.

Machine Gun
The primary weapon is an M240B machine gun equipped with 450 7.62mm rounds.

Antenna
Radio communications facilities permit MAARS to be remotely controlled at a range of up to one kilometre.

Part of the rationale for using robots in warfare is exactly the same as the justification for using them in other spheres of activity, namely improving productivity. In the motor manufacturing industry, for example, robots have long been used because they are considered more cost-effective than using manual workers for mundane tasks. Exactly the same applies to military robots. However, when it comes to armed combat, another – and highly important – consideration comes into play. If a robot comes under attack, the potential cost is one of repair or replacement. If a human soldier was to carry out the same task, the risk is much more serious, namely injury or death. This, in turn leads to another benefit. According to some analysts, if the risk to human life is eliminated, this opens up the possibility of engaging in much more daring missions than might otherwise be considered.

As we turn our attention to the applications of war robots, it seems fair to say that, in time, they'll probably be capable of carrying out most

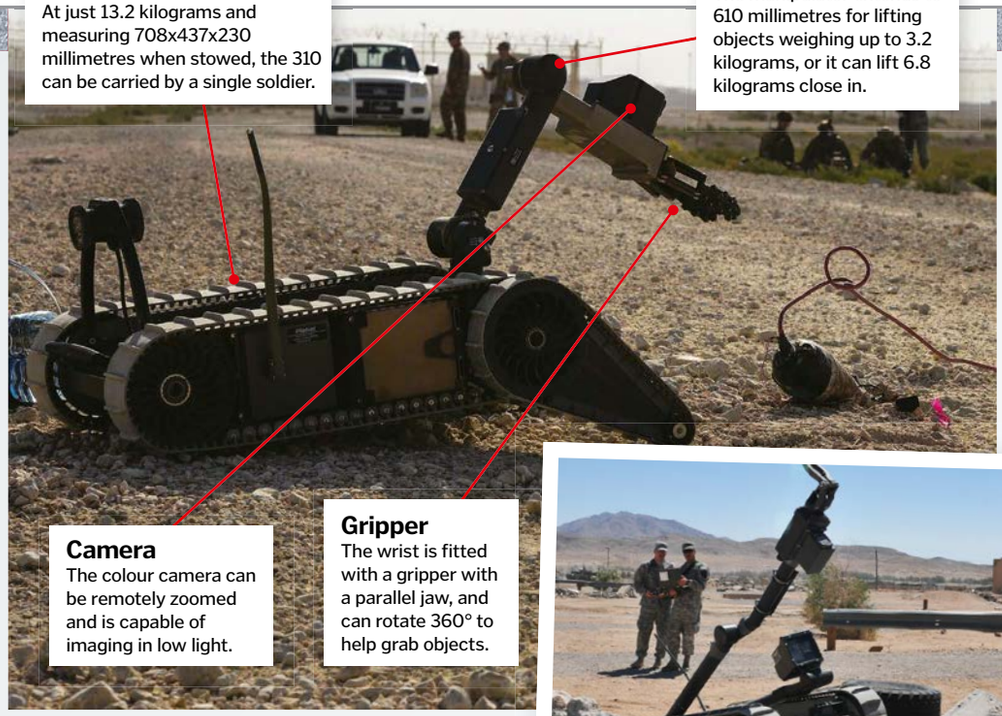
actions that are currently performed by soldiers and military vehicles, although some applications are more obvious beneficiaries of automation than others. For while few people expect to see robots on parade, providing transportation and taking a load off the infantry are both obvious applications of robotic technology. Robots are also ideal tools for disarming bombs, and for finding and disabling the landmines that pose such a risk to civilians in previously war-torn regions.

Reconnaissance is currently one of today's primary uses of military robots, with surveillance relying on a wide range of cameras and environmental sensors. We can also envisage robots being used in engineering tasks such as carrying out excavations, and there's been talk of military 'medbots' that would be capable of retrieving injured soldiers from the battlefield and even performing surgery inside armoured vehicles. However, the most controversial way in which robots might be put to on the battlefield is in yielding weapons.

> "'Medbots' would be capable of retrieving injured soldiers from the battlefield"

There's no single answer to what military robots look like and what method of locomotion they employ. Of those battlefield robots currently available commercially, tracked vehicles are the most common. Carrying a range of cameras, sensors and perhaps non-lethal and lethal weapons, these look like small tanks and are generally manually-operated, perhaps with a small degree of autonomy. More futuristic are legged robots and several are under development. Inspired by four-legged animals, Boston Dynamics' experimental Big Dog was designed as a robotic pack mule while the Cheetah, from the same company, can travel at 45 kilometres per hour, making it the world's fastest legged robot. Flying robots are also being developed for battlefield applications. Unlike the military drones such as the Predator that fly at altitudes measured in thousands of metres, these robots work much closer to the ground, allowing them to fly through windows to conduct surveillance inside buildings. These might be a similar size to the familiar quadcopters but there's also interest in micro-drones, perhaps as small as insects. The US Army Research Laboratory, for example, has developed a pair of robotic insect wings just three centimetres long, made of lead zirconium titanate, which bend and flap when a voltage is applied. The same team has also developed a millipede-type crawling robot with similar applications in mind.

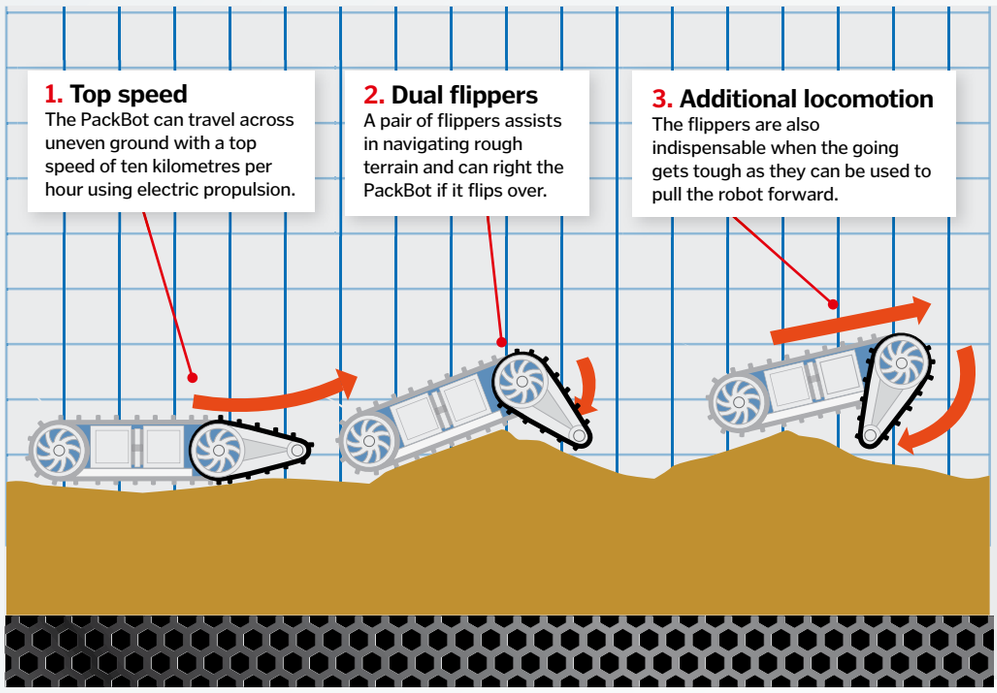
An exciting concept that is being researched for these types of micro-robots is collaboration. Otherwise known as swarming technology, the rationale is that robots can work together in such a way that their combined power is greater than the sum of its parts. Ant colonies provide an example of this philosophy working in nature. Robot swarms may even consist of a mix of different types of robots working together to perform a complex task.



Military robots are already in service in Afghanistan, Iraq and Syria

PackBot

iROBOT's 310 SUGV is intended for gathering situational awareness in dangerous conditions



Military robots might seem like science fiction but they're migrating from fiction to fact

BEAR – the Battlefield Extraction-Assist Robot

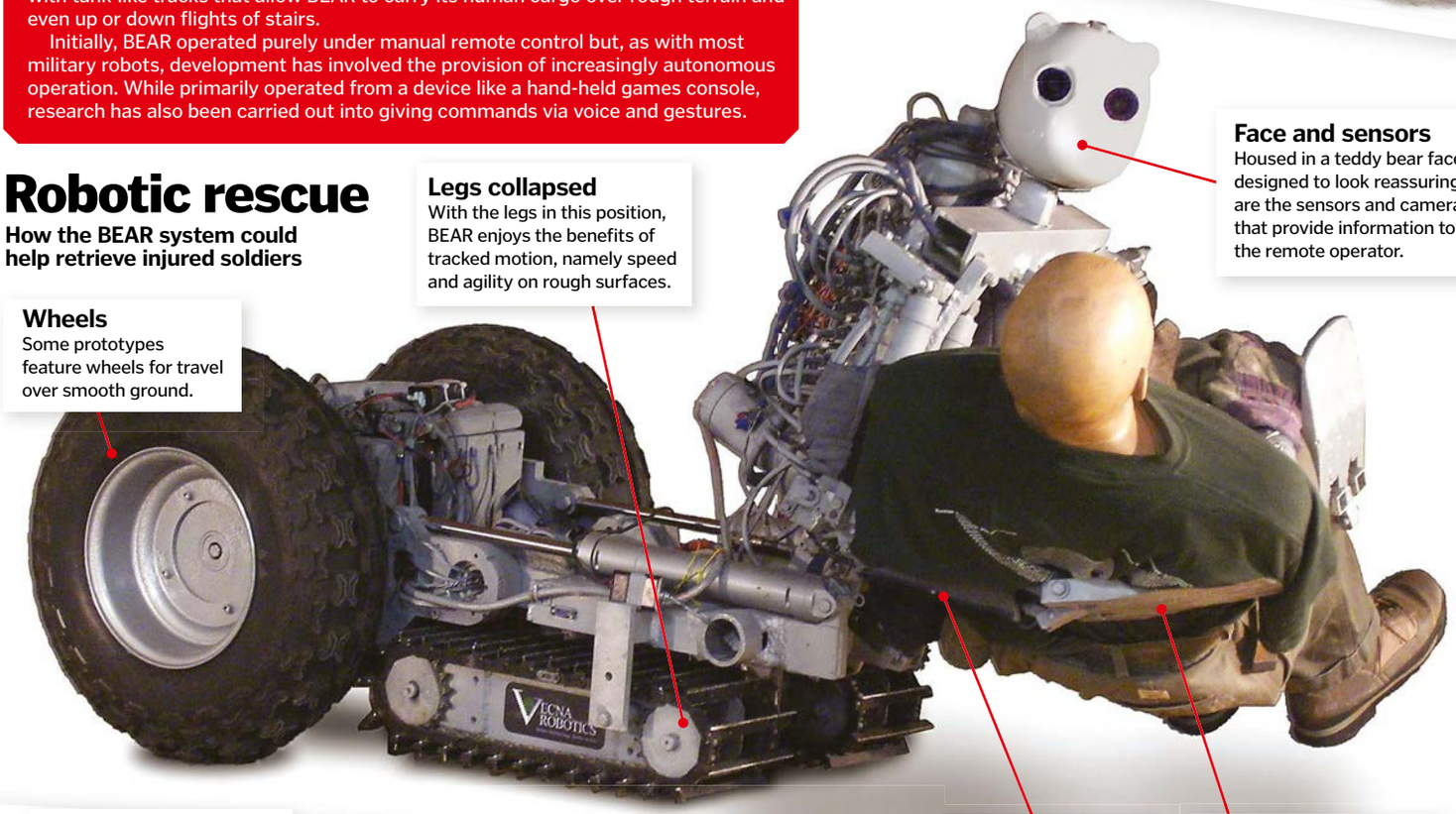
Designed with the aim of rescuing wounded soldiers without risking further lives, BEAR boasts mobility over various surfaces plus the ability to lift and carry a casualty to safety at up to 16 kilometres per hour. Being able to extract injured soldiers from a dangerous environment means that the robot must be capable of going anywhere that people can, something that most robots aren't yet able to do. This has been achieved by using legs with a difference. Its two legs are augmented with tank-like tracks that allow BEAR to carry its human cargo over rough terrain and even up or down flights of stairs.

Initially, BEAR operated purely under manual remote control but, as with most military robots, development has involved the provision of increasingly autonomous operation. While primarily operated from a device like a hand-held games console, research has also been carried out into giving commands via voice and gestures.

BEAR has been tested by the US Army at Fort Benning, Georgia

Robotic rescue

How the BEAR system could help retrieve injured soldiers



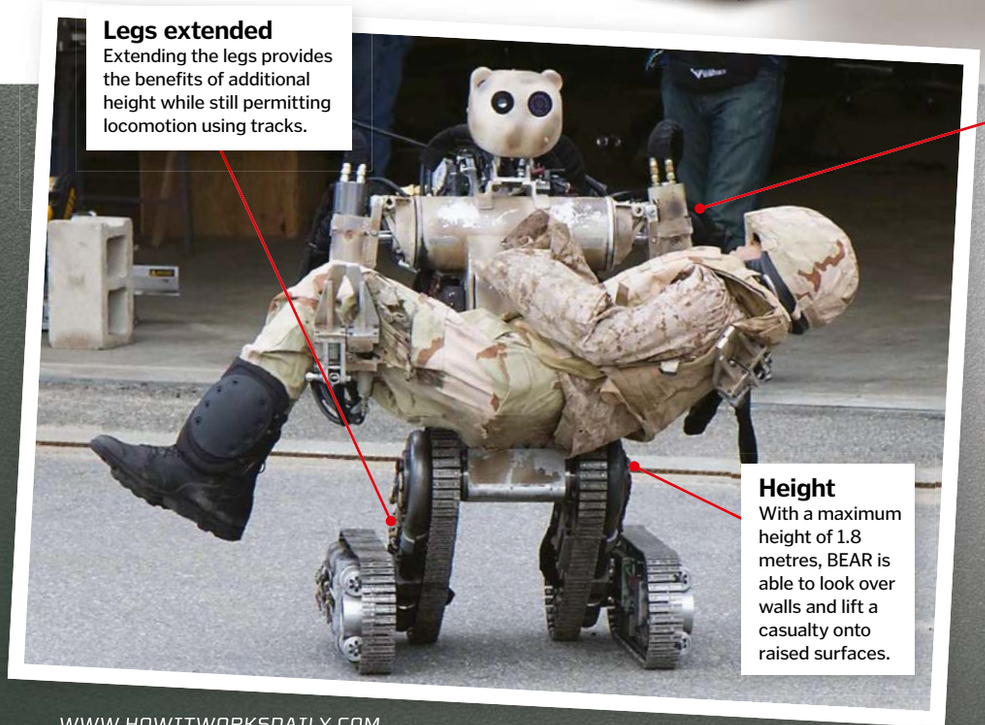
Face and sensors
Housed in a teddy bear face, designed to look reassuring, are the sensors and cameras that provide information to the remote operator.

Legs collapsed
With the legs in this position, BEAR enjoys the benefits of tracked motion, namely speed and agility on rough surfaces.

Wheels
Some prototypes feature wheels for travel over smooth ground.

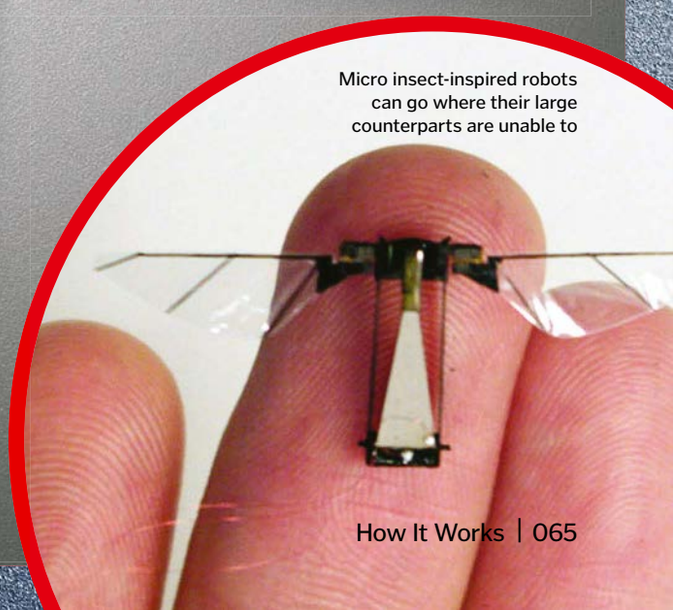
Arms
Key to lifting and carrying a casualty, the arms can bear a load of 227 kilograms.

Hands
Occasionally BEAR will need to handle objects in its environment so its hands and are capable of precise manipulation.



Legs extended
Extending the legs provides the benefits of additional height while still permitting locomotion using tracks.

Height
With a maximum height of 1.8 metres, BEAR is able to look over walls and lift a casualty onto raised surfaces.



Micro insect-inspired robots can go where their large counterparts are unable to

So much for the technology, but we can't leave this subject without touching on the ethical issues raised by war robots. One of the concerns expressed is that it's morally questionable for an army to engage in warfare without endangering their own soldiers. This, in turn, it is argued, makes it much more likely for an aggressor to take military action. While these concerns are understandable, much the same has applied throughout history as military hardware has advanced. Where robot technology is a game-changer, though, is when autonomy comes into play, raising all sorts of questions.

For a start, writing error-free code remains a challenge to say the least. So, if an autonomous robot gets it wrong and attacks friendly forces or even civilians, who is ultimately responsible? Suffice it to say that there are more questions than answers but the subject has been discussed in the United Nations, and the US Department of Defense currently has a ban on the use of autonomous weapons.

Less controversially and more positively, the GPS satellite navigation system gives a glimpse of the possible civilian spin-offs of research into war robots. Designed for military use, GPS now powers in-car sat navs and smartphone navigational apps, and this is by no means unique. Throughout history, military developments have, sooner or later, reaped benefits to mankind. It remains to be seen whether the same will be true of military robots.

Squad X Core Technologies

While robots might, one day, replace human soldiers, in the meantime they could work alongside fighters, providing them with the information to operate as effectively and safely as possible. This is the rationale of a DARPA programme, designed to improve situational awareness on the battlefield. Called Squad X Technologies, it is envisaged that the initiative will involve a variety of ground-based and aerial robots, gathering information on the location of both friendly forces and threats and making it available to troops. According to DARPA, one of the key challenges is providing the necessary awareness without imposing the physical and cognitive burdens associated with large, bulky and complicated displays.

DARPA's Squad X Technologies programme aims to facilitate man and machine working in harmony

The future battlefield

Robot technology could change the battlefield beyond all recognition

Body-worn sensors
In addition to robots and drones, information will be gathered from body-worn sensors.

Communications
Drones and swarming robots will play an important role in acting as communications relays.

Unburdened soldiers
By offloading surveillance to robots, future soldiers will be freed of the requirement to carry heavy loads.

Ground surveillance
Ground-based robots will carry out surveillance and target recognition from a low level perspective.

"Flying robots are also being developed for battlefield applications"

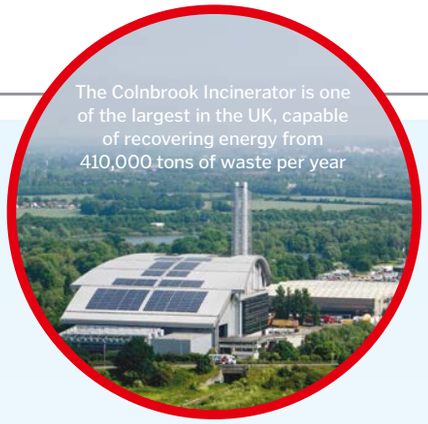
Swarming robots

In an impressive illustration of swarming technology, the US Department of Defense recently demonstrated a swarm of no less than 103 flying micro-drones. Inspired by biological colonies, control was distributed throughout the swarm as individual robots communicated with each other. It's claimed that there are several benefits of robot swarms when compared to single robots.

For a start, while individual robots are expensive, robots capable of swarm behaviour are cheap. What's more, because there is no single point of failure, individual robots are expendable and a few losses won't massively degrade the overall capability of the swarm. Supporters of the technology also claim that a simple set of individual rules can result in complicated swarm behaviour. According to the UK Ministry of Defence, potential applications include tracking individuals, tracking vehicles, area mapping, area surveillance and providing communications relays.

Waste-to-energy plants

They say one man's trash is another man's treasure – that's exactly the case when it comes to waste energy


The Colnbrook Incinerator is one of the largest in the UK, capable of recovering energy from 410,000 tons of waste per year

In 2014, the UK generated 209 million tons of rubbish. Of that, 44.9 per cent was recovered (including recycling and energy recovery) and 23.1 per cent was sent to landfill. We are constantly searching for a more efficient and beneficial way to dispose of our waste.

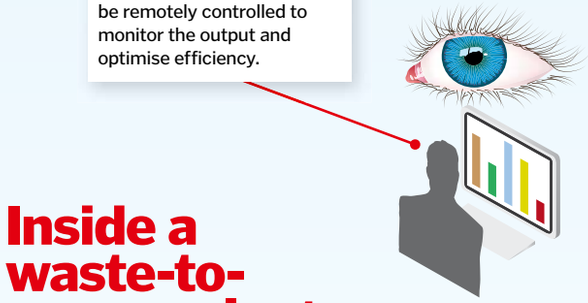
As well as diligently recycling our rubbish, waste-to-energy plants provide one alternative to landfill: the waste is disposed of and used to provide energy to produce fuel and electricity. There are a few different ways that this can be done using thermal energy and biological processes. Thermal processes involve methods like gasification, thermal depolymerisation and pyrolysis; all rather complex procedures that essentially use the application of high temperatures to break down the waste and release energy. The non-thermal waste-to-energy processes use microorganisms to decompose organic matter and release biogas. These processes often take much longer but are considered much more eco-friendly.

The advantages of waste-to-energy technology are that less waste gets sent to landfill. This means less methane – a damaging greenhouse gas – is produced from decomposing rubbish and less leachate (which pollutes groundwater) leaks from the site. Another advantage is that more energy can be created without burning fossil fuels and releasing greenhouse gases. However, despite the advantages, there are also some serious environmental concerns.

The burning of so much mixed waste can release harmful chemicals, such as dioxins and furans (carcinogens released by burning plastics such as PVC) as well as heavy metals, acidic gases, sulphur and nitrogen oxides and particulate matter. Although there are many pollution control processes in effect, not enough is yet known about the extent of the chemicals released and their impact on the environment and human health.

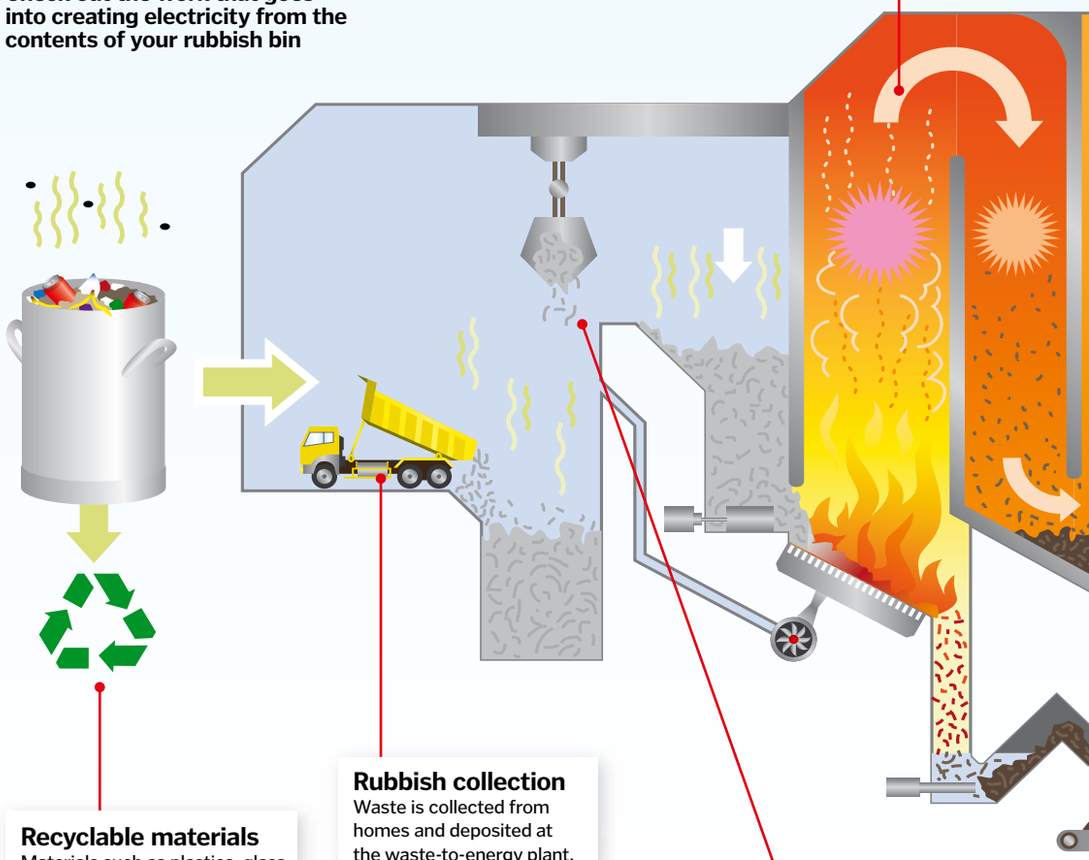
Inside a waste-to-energy plant

Check out the work that goes into creating electricity from the contents of your rubbish bin



Control the process
Every part of the process can be remotely controlled to monitor the output and optimise efficiency.

Combustion
Rubbish in the combustion chamber burns at 1,100°C. The waste is constantly moved around and supplied with oxygen to ensure an efficient burning process.



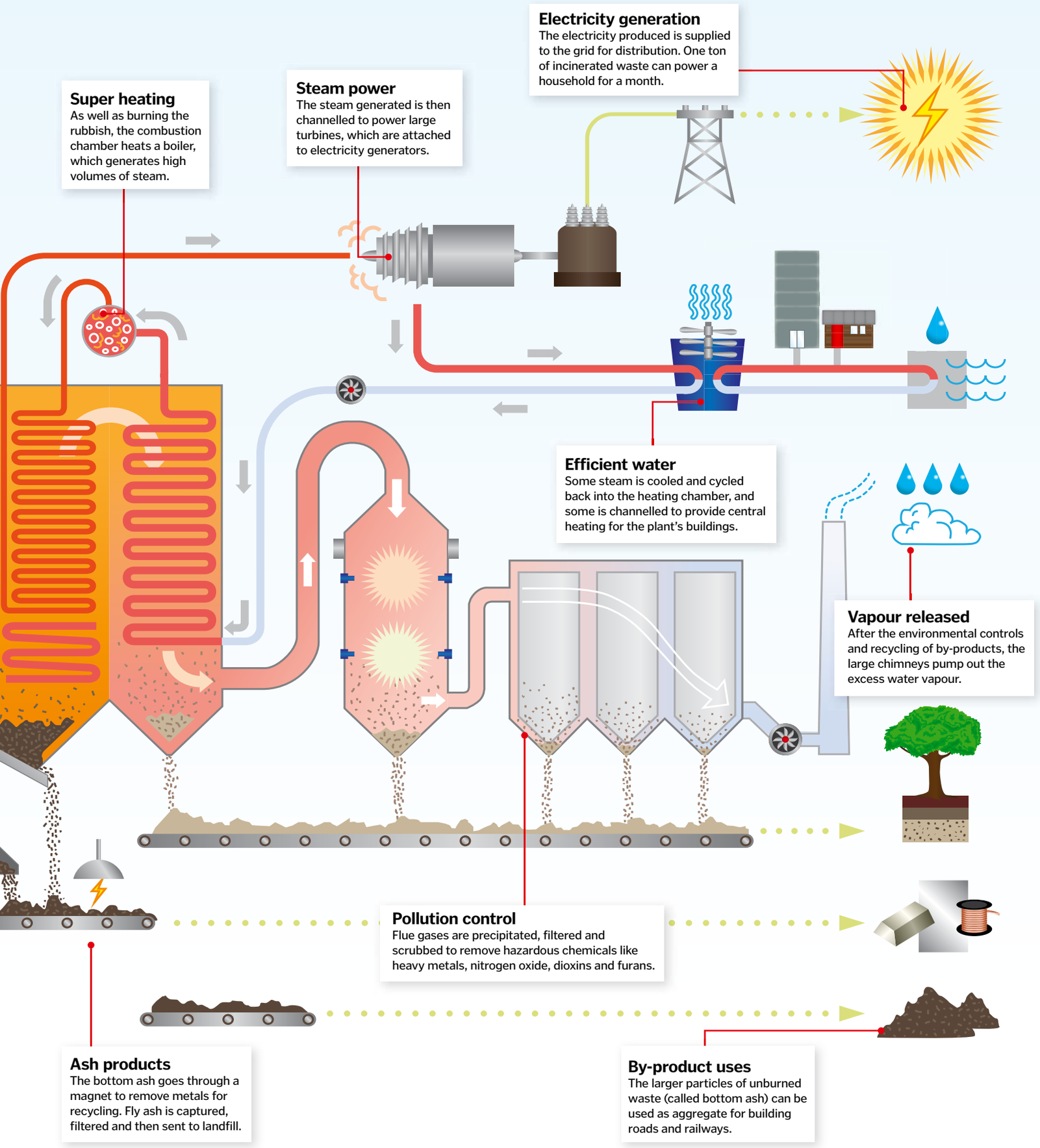
Recyclable materials
Materials such as plastics, glass and paper should be separated from other waste and processed at recycling plants.

Rubbish collection
Waste is collected from homes and deposited at the waste-to-energy plant.

Waste materials
The rubbish is mixed thoroughly before being transported and added into the incinerator.


Landfill sites are lined and sealed to hold rubbish and then buried when the site is full

"Less waste gets sent to landfill and less methane is produced from decomposing rubbish"



Electricity generation
The electricity produced is supplied to the grid for distribution. One ton of incinerated waste can power a household for a month.

Steam power
The steam generated is then channelled to power large turbines, which are attached to electricity generators.

Super heating
As well as burning the rubbish, the combustion chamber heats a boiler, which generates high volumes of steam.

Efficient water
Some steam is cooled and cycled back into the heating chamber, and some is channelled to provide central heating for the plant's buildings.

Vapour released
After the environmental controls and recycling of by-products, the large chimneys pump out the excess water vapour.

Pollution control
Flue gases are precipitated, filtered and scrubbed to remove hazardous chemicals like heavy metals, nitrogen oxide, dioxins and furans.

Ash products
The bottom ash goes through a magnet to remove metals for recycling. Fly ash is captured, filtered and then sent to landfill.

By-product uses
The larger particles of unburned waste (called bottom ash) can be used as aggregate for building roads and railways.

Widely used on sports pitches, artificial turf can also be used in gardens

Artificial turf

From sports stadiums to parks, synthetic surfaces are an effective alternative to grass

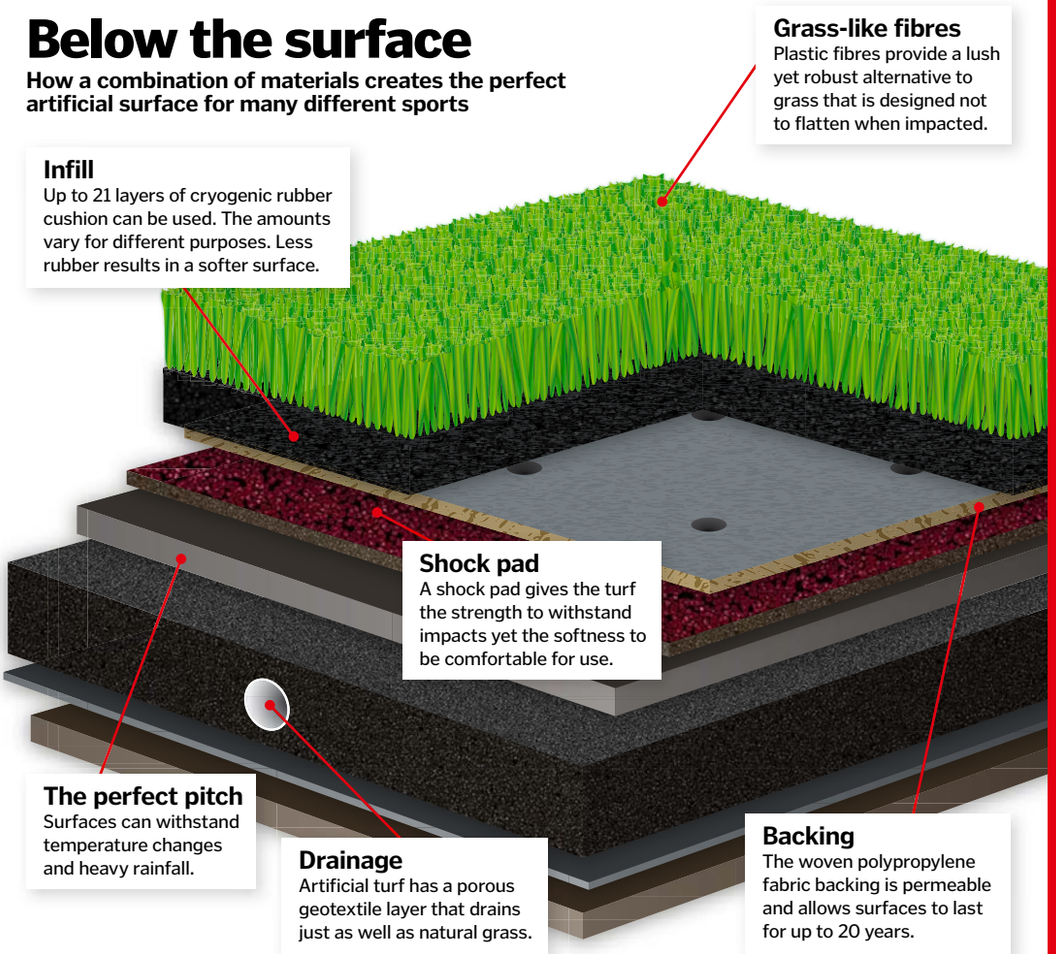
Artificial turf is a practical and realistic substitute for grass used across the world for sports and recreation.

First invented in the 1960s, it can be laid in places where it is difficult to grow natural grass, such as in covered stadiums or inner-city locations, where sunlight is limited. Modern artificial turf is comprised of synthetic 'grass' fibres, typically made of nylon or polypropylene, which are supported by a layer of sand or small rubber pellets at its base.

Artificial turf also has the benefit of being more durable, so it can cope with repeated use and intensive wear during sporting events, and is comparably low maintenance without the need for watering or mowing.

Below the surface

How a combination of materials creates the perfect artificial surface for many different sports



Grass-like fibres
Plastic fibres provide a lush yet robust alternative to grass that is designed not to flatten when impacted.

Infill
Up to 21 layers of cryogenic rubber cushion can be used. The amounts vary for different purposes. Less rubber results in a softer surface.

Shock pad
A shock pad gives the turf the strength to withstand impacts yet the softness to be comfortable for use.

The perfect pitch
Surfaces can withstand temperature changes and heavy rainfall.

Drainage
Artificial turf has a porous geotextile layer that drains just as well as natural grass.

Backing
The woven polypropylene fabric backing is permeable and allows surfaces to last for up to 20 years.

Auto-tune tech

Discover what this controversial tech does and the physics behind it

Auto-tune technology is used to correct pitch, and consequently make a singer's voice sound better. While it's great for correcting an 'off note' here or there, the extent of its use is controversial, particularly when employed in so-called talent shows.

The science behind the tech is all down to signal processing. Sound is vibrating air molecules connecting with the eardrum at varying frequencies and amplitudes. Auto-tune technology is concerned with frequencies, because the pitch of a sound you hear depends on the frequency of the sound wave produced: the higher the pitch, the higher the frequency of the sound wave.

Auto-tune technology works by manipulating the frequency to retune a slightly high or low note to the nearest semitone. However, digital technology is essential in achieving a natural sound. Without it, changing the frequency would also change the speed or duration of the sound wave and result in fast, chipmunk-like or slow, deep sounds. The digital nature of auto-tune technology means that sound engineers can change the frequency without changing the speed.

Advances in digital technology have made it possible to alter the pitch of sounds

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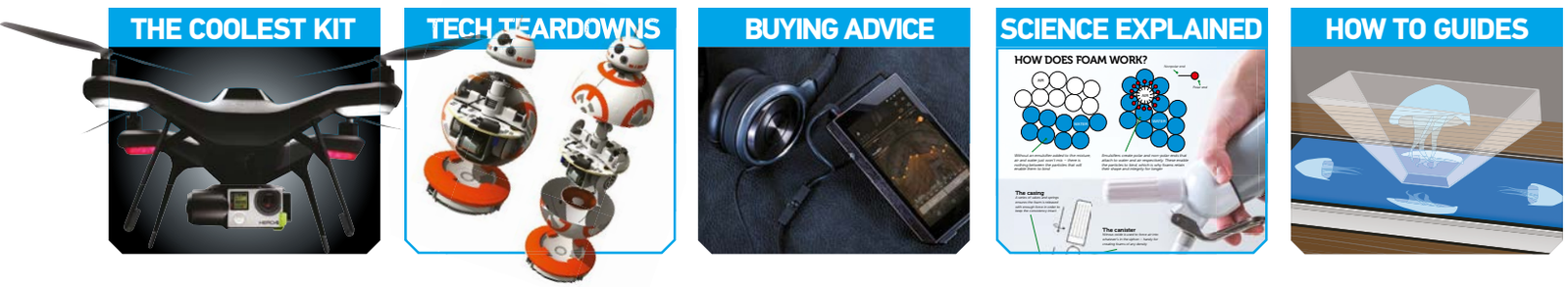

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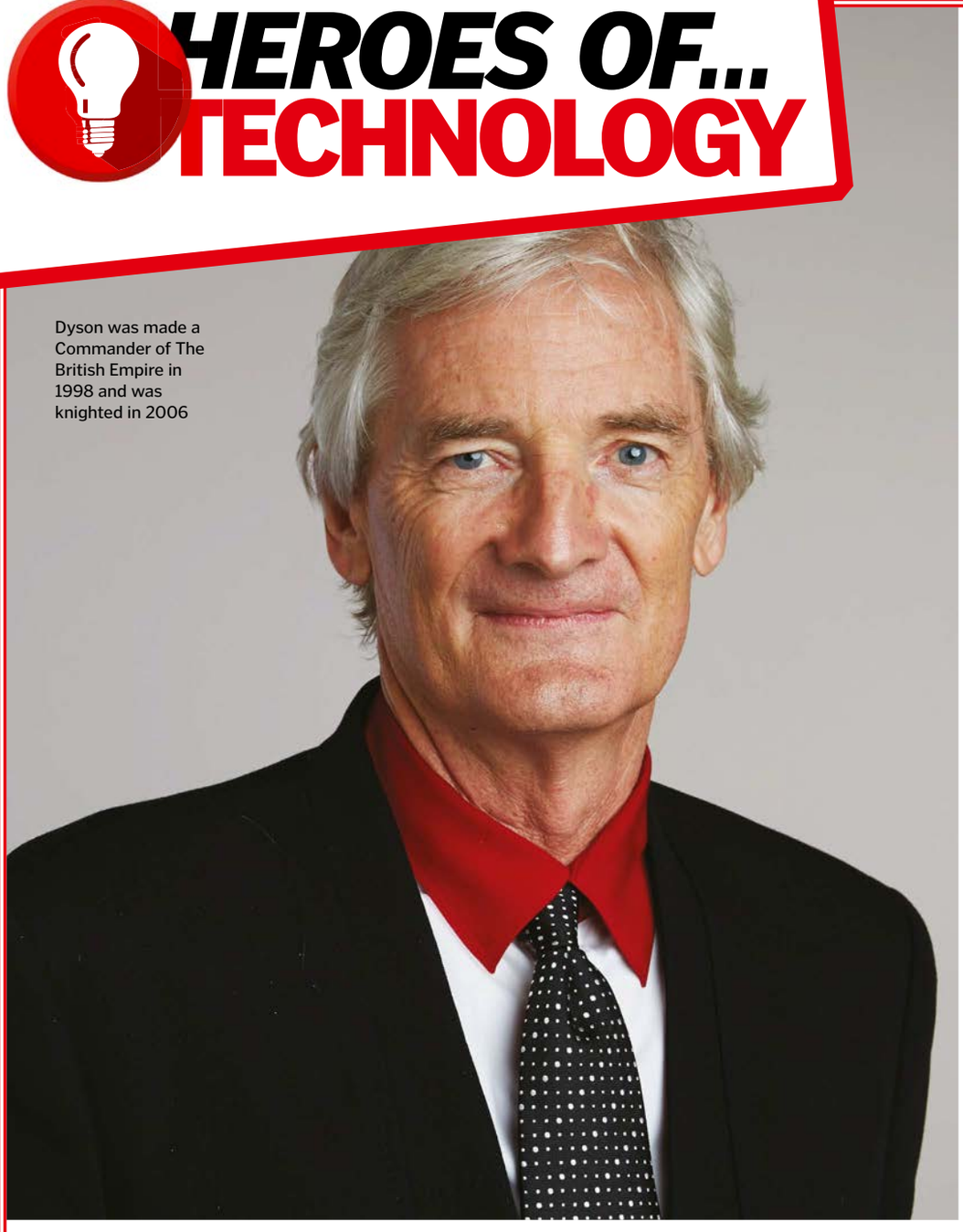


Dyson was made a Commander of The British Empire in 1998 and was knighted in 2006

Sir James Dyson

The famous British inventor with an illustrious list of novel creations

James Dyson clearly didn't believe in the phrase "if it ain't broke, don't fix it". Vacuum cleaners had been popular in the home for years but the innovative inventor believed he could improve them. Dyson first got his idea in the 1970s after he became irritated with dust clogging his vacuum cleaner.

Growing frustrated with his own bagged vacuum cleaner's diminishing performance, his eureka moment came when he considered applying the same principal he'd used to design a cyclone tower in his factory. The machine used centrifugal force to separate paint particles from air, inspiring Dyson to employ this concept in his new vacuum cleaner design. He believed cyclonic separation could be incorporated into a much smaller, bag-less device.

After five years of trial and error his first model was ready. The system received unenthusiastic feedback at first from vacuum cleaner companies who scoffed at the new idea. In fact, only one company took a chance on the new cleaner and decided to buy it in 1983. Branded as the G-Force and sold in Japan, it was only made in bright pink and retailed at the equivalent of £2,000 ($2,514). It was a huge success. Its popularity meant it received a US patent in 1986 and won a design prize in 1991. Due to the large cleaning companies having no interest in what he had to offer, Dyson set up his own company, with a base in Wiltshire. Promoted by the slogan 'say goodbye to the bag', just two years later it had become the top-selling vacuum cleaner in the UK, and Dyson was a household name.

The Dyson vacuum continued to grow in popularity. It was put on sale in the US in 2002 and within three years it had become a market leader. Not content with just one best-selling invention, Dyson went on to release more products to critical acclaim. The Airblade was released in 2006 and is now frequently installed in public bathrooms as a superfast hand dryer.

Three years later his next invention, the Air Multiplier Bladeless Fan, was the first development in fan technology for over a century. A ring-shaped device, the novel design generated a constant and amplified stream of air despite the lack of blades or a grille.

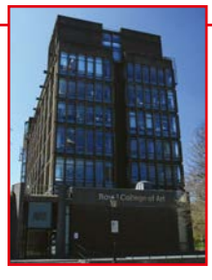
A LIFE'S WORK

A closer look at the life of one of the world's most innovative inventors

1947
James Dyson is born on 2 May in Cromer, Norfolk to Alec and Mary Bolton Dyson.

1965
Dyson moves to London and enrols to study at the Byam Shaw School of Art.

1966
A year later, Dyson attends the Royal College of Art to study furniture and interior design.



1974
Dyson founds his own company and creates the Ballbarrow to help improve manoeuvrability.

1978
Dismayed at clogged air filters, Dyson decides to try and install cyclonic separation.

1983
The G-Force is introduced in Japan, quickly becoming a huge success for Dyson.

The big idea

How cyclonic separation was downsized into a vacuum cleaner

The technology is a system of clever yet simple physics. Dirt and dust is sucked up by quickly rotating brushes and swirled around by a powerful fan. It is then separated at high speed by centrifugal force around a central cone. The heavy dust is brought to the side and gravity does the rest as it settles at the bottom of the cylinder. The dust is then ready to be released and disposed of. Meanwhile the air that has been separated from the dirt is purified by two filters that remove the smaller dirt particles. The clean air is then released back into the room.

One of the mechanism's greatest advantages is that it doesn't lose suction as it picks up more dirt

Most recently, Dyson has applied his patented Air Multiplier technology to completely redesign the hairdryer. The Supersonic was released in 2016, following four years of product development and over 600 prototypes.

A number of other companies now sell vacuum cleaners that use cyclonic technology, and Dyson itself does business in over 65 countries. James Dyson may not have been the first person to think of using a cyclone to remove dust, but he was the first to realise that it could work in the humble vacuum cleaner. His idea revolutionised the industry.

Bladeless fans are another Dyson invention that improved on conventional mechanisms

"Within three years on sale in the US, the Dyson vacuum had become a market leader"

The ContraRotator washing machine didn't replicate the incredible success of the Dyson vacuum cleaner

Dyson's vacuum cleaner has been improved by the Ballbarrow, which makes it even more manoeuvrable

Five things to know about... SIR JAMES DYSON

1 He also invented a watercraft
While studying at the London Royal College of Art in 1970, Dyson invented the Sea Truck. A high-speed watercraft with a flat hull, it was built to land without the need for a jetty.

2 A new type of wheelbarrow
Another early invention was the Ballbarrow, a wheelbarrow with a ball instead of a wheel. He would later use a similar idea in a Dyson vacuum cleaner.

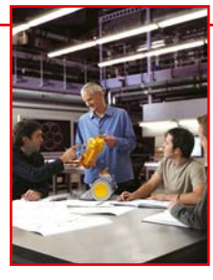
3 If at first you don't succeed
Dyson's vacuum cleaner design didn't come easy. He created an astonishing 5,127 prototypes before he settled on a model that he was confident would work.

4 His washing machine wasn't a success
Buoyed by his success with vacuum cleaners, Dyson also tried to shake up the washing machine market. However, his ContraRotator was a commercial flop.

5 Running helped his career
James Dyson was a keen runner in his youth and credits this early experience of competition with giving him the determination to succeed as an inventor.

1993
The Dyson Dual Cyclone becomes the best-selling vacuum cleaner in the UK and the company opens its first plant.

2002
The James Dyson Foundation is set up to support the teaching of design and engineering with grants.



2015
The first ever filterless vacuum cleaner is created by Dyson. It uses flexible rubber nozzles that are able to separate dust particles.

2016
The Dyson Supersonic is released. Its motor spins six-times faster than any other hairdryer, generating air speeds of up to 170 kilometres per hour.

How digital pens work

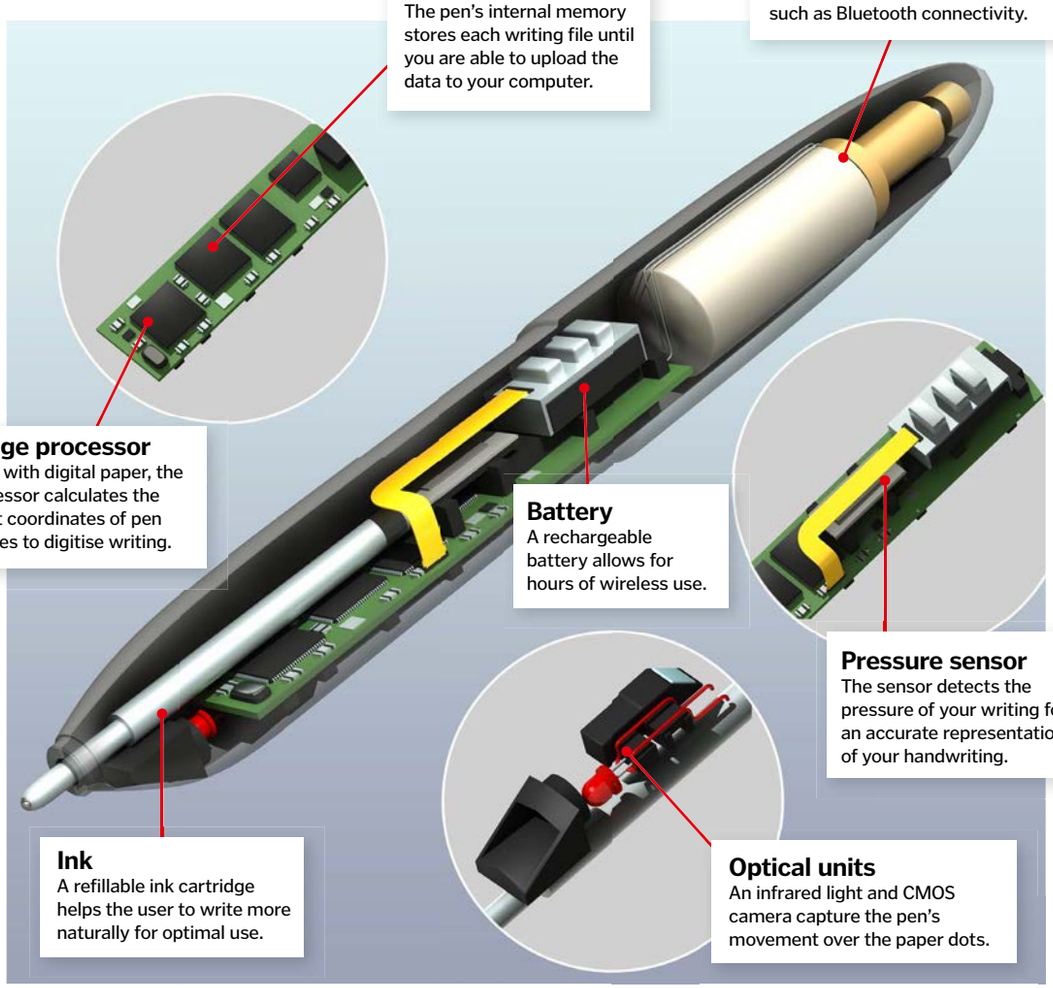
Say hello to the future of note taking, with pens that are able to talk to your computer

Revolutionising the way we take notes forever, digital pens use the same kind of technology that optical computer mice have used for decades to understand what we write on paper and translate it to a digital platform. An LED and light receiver track the way the pen moves (helped with compatible digital paper in some models), which can then be uploaded to a computer where a digital version of your handwritten notes will be waiting for you. Some models can simply turn your handwriting into a digital file, while others can translate your notes into handy text documents.

Inside a smartpen

The handwriting hardware that helps you say goodbye to typing up your scribbles

"A receiver tracks the pen as it moves"



FM vs DAB radio

Digital and analogue enter the ring for the battle of the airways

Digital Audio Broadcasting uses a digital signal broadcast across thousands of different carrier frequencies, which ensures that, unlike the analogue Frequency Modulation (FM) radio, it doesn't suffer from interference.

This provides a much clearer signal than FM, and because the digital signals use the broadcasting spectrums more efficiently than FM radio, there is also a much larger selection of stations. In addition, data can be transmitted alongside the audio signal, which allows the names of songs to be displayed on the screen as well as images (depending on the radio model itself).

The drawbacks of DAB are that if the signal is lost, the audio will stutter and even cut out completely. This can be very frustrating for the listener, whereas the sound of an FM radio will simply sound fuzzy when the signal strength weakens.

Much like the digital TV switchover that was completed in the UK in 2012, there are plans to fully switch to DAB radio in the near future. But it's thought that this will not take place before 2020, as DAB listening numbers were only at 36.3 per cent in 2015. More transmitters need to be installed before a switchover date can be confirmed, but it appears that the future of radio belongs to DAB.

DAB radio offers listeners more choice, but FM is still a popular medium

How Alexa works

Inside Amazon's incredible digital assistant, set to revolutionise homes forever

Named after the ancient library of Alexandria, Amazon's virtual personal assistant, Alexa, is intended to rival even the most competent of human aides. Enabled devices, such as the Echo unit, include a series of speakers and sensors that work together, centrally controlled by Alexa.

Alexa is the wake word for the Echo smart speaker. This is furnished with seven microphones and uses beamforming technology to hear you from wherever you are in the room. Users simply need to say 'Alexa' followed by their request and the Echo or Echo Dot unit closest will then respond.

Once you've said your request, Alexa uses a programme called Alexa Voice Services (AVS) to send the recording via the internet to Amazon. Alexa has a predetermined set of 'skills', which Amazon is constantly updating and adding to. When the recording is sent to Amazon's cloud service, the skill is identified and then actioned. The data is sent back to your Echo and you'll hear Alexa's voice confirm it or give you the information before completing the task. Alongside this, the companion Alexa app for tablets and smartphones will show you a relevant graphical representation, such as a weather report or task list.

1. Say 'Alexa'
This is all it takes to wake up the Echo unit and get Alexa to start listening.

2. Recording
Echo's seven far-reaching microphones record your voice from anywhere in the room.

3. Alexa Voice Service
Using the internet, the recording is sent to Amazon's cloud, which analyses the request.

4. Skills in action
The specific 'skill' that you've requested is actioned, and the relevant data is sent back to your Echo.

5. Alexa speaks
Alexa then tells you that the request is completed, and you will then hear the music or information over the speakers.

6. Alexa App
The app will also flash up on your phone or tablet to show you any visual data that you've asked for.

The Alexa effect

The process behind Alexa's amazing ability to get things done

The Alexa family can revolutionise the way you listen to music and run your entire home

Meet the Alexa family

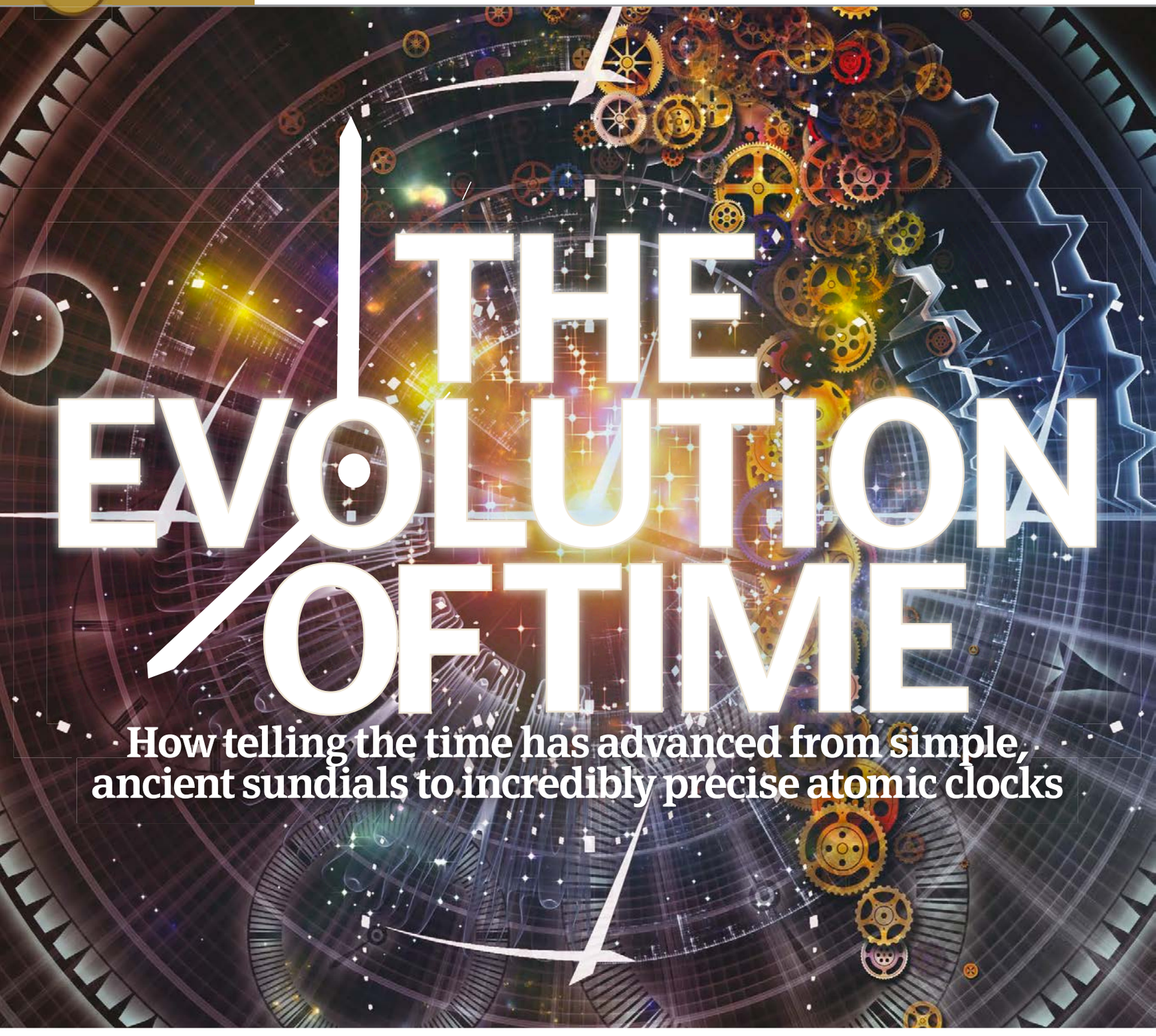
The cutting-edge tech that is changing home entertainment

Tap
An Alexa-enabled portable Bluetooth speaker, Tap streams your music from your phone or tablet and links with Alexa when connected to Wi-Fi.

Echo
An interactive speaker and smart home hub, Echo connects with Alexa to play music, news and provide information.

Fire TV
Amazon's Fire TV stick plugs into a TV to stream all kinds of digital media. An accompanying voice remote has a button that you can press to speak to Alexa.

Echo Dot
A versatile speaker, like Echo, but newer and designed to hook up Alexa for use with your existing sound system.



THE EVOLUTION OF TIME

How telling the time has advanced from simple, ancient sundials to incredibly precise atomic clocks

Just before midnight on 31 December 2016, the world gained an extra second to compensate for the fact that Earth's rotation is ever so gradually slowing down. Modern atomic clocks are *too* accurate compared to Earth's inconsistent spinning speed, and they tick away at the same rate for millions of years. To ensure our standard time continues to match our atomic clocks – which provide a stable timescale – 26 so-called 'leap seconds' have been added since 1972.

Today, the human race can tell the time with ease and exceptional accuracy, but it wasn't always that simple. At first the only way was to locate the Sun in the sky, and sundials were the first timepieces to appear in ancient civilisations like Egypt, China and Greece. Naturally with the changing of the seasons altering daylight hours this system was flawed and various methods were invented to try and tell the time more accurately.

As well as devices, there also needed to be a set numerical system to measure time. The numbers used to calculate time were first theorised by the ancient Sumerians, who devised the sexagesimal system. It's theorised that this was based on counting on their hands, using the thumb of one hand to count the three joints in each of the four fingers to reach 12. Using the five digits on their other hand to tally the counts of 12, this system allowed people to count to 60 using both hands. As 60 is also divisible by many smaller numbers it was the perfect number to centre on. Another figure that was used and considered important by ancient civilisations was 12, as it was the number of lunar cycles every year. This number is an important one in timekeeping, finding its way into day and night, which are divided up into two 12-hour periods, and the 12 months.

Thus, the standardised idea of time was born and unanimously incorporated (the French attempt to create a ten-hour day with 100-minute-long hours in the late 18th century aside). But this was only the beginning.

Shadow clocks

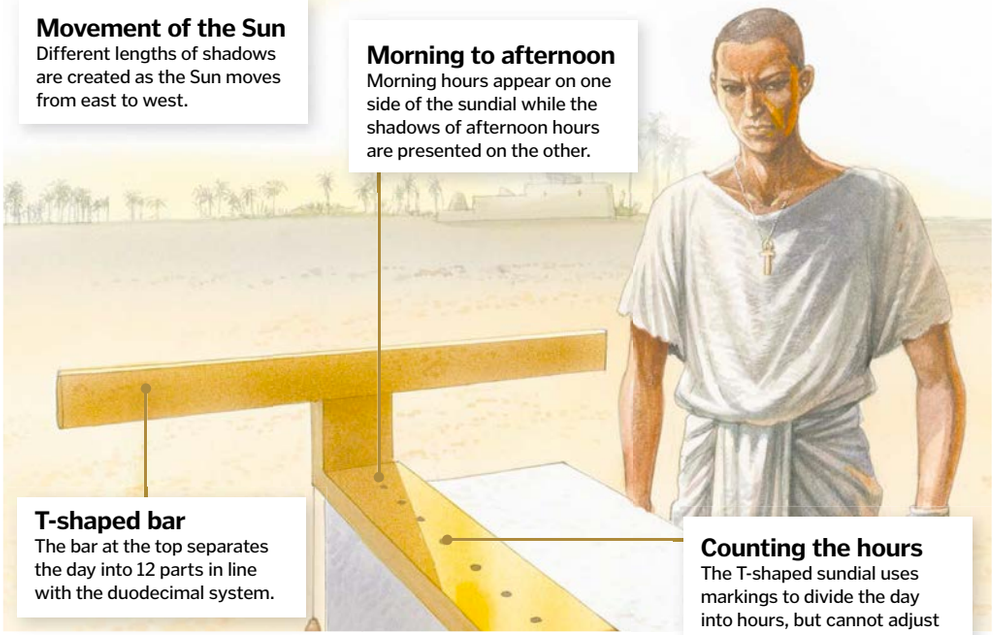
The simple yet effective mechanisms that used the Sun to help to tell the time

The first timepieces were sticks that measured the length of a shadow to give a rough indication of the time. These sundials became more elaborate and were later developed to point to the nearest pole to be more accurate. They helped divide the day into hours, but were not sophisticated enough to take the weather into account – they were useless at night or on overcast days!

The Egyptians improved on sundials with the invention of the merkhet around 600 BCE, which could be used at night. Lined up with the pole star, the time was measured by known stars crossing the line.

T-shaped sundial

The advanced sundial created by the ancient Egyptians to judge the passing of time more accurately



Movement of the Sun
Different lengths of shadows are created as the Sun moves from east to west.

Morning to afternoon
Morning hours appear on one side of the sundial while the shadows of afternoon hours are presented on the other.

T-shaped bar
The bar at the top separates the day into 12 parts in line with the duodecimal system.

Counting the hours
The T-shaped sundial uses markings to divide the day into hours, but cannot adjust for seasonal changes.

History of calendars

Months and years were first devised after ancient civilisations gazed up at the stars

The Moon has a near 30-day cycle from new to full and to new again. This helped conceive the idea of a month and was the first method that humans used to measure time without using the Sun.

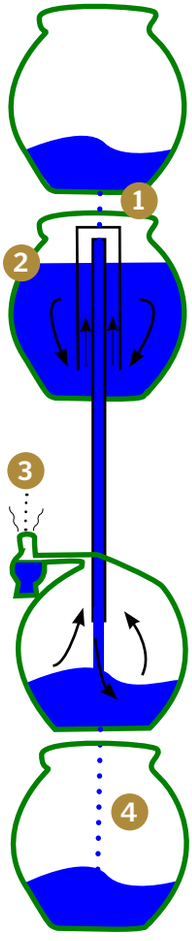
Other early markers of time were the beginnings of a rainy season or the appearance of the star Sirius, which in ancient Egypt coincided with the annual flooding of the Nile. The next progression was the Julian calendar. Invented by the Romans, it was based on the orbit of the Earth around the Sun. This helped to establish the idea of a year, and so began the Christian calendar.

This was not followed in all societies though, and both the Islamic and Jewish calendars are still based on the movement of the Moon, while the ancient Mayan calendar had 18 months of 20 days and one month of five days. The Julian Calendar was later replaced in the UK when the 1750 Calendar Act introduced the more accurate Gregorian calendar.

"The French tried to create a ten-hour day with 100-minute -long hours in the late 18th century..."

Plato's alarm clock

The first ever alarm clock was reportedly invented by the famous Greek philosopher



1. Beginning the process
The mechanism starts with a set amount of water being added to the top jar, which trickles down through the system.

2. Reaching a set level
Once the water reaches a certain level it is siphoned off into the third jar.

3. Sounding the alarm
The quick influx of water pushes air into the third container that – through a narrow opening – sounds a whistle as a wake up call.

4. Excess water
The bottom jar collects any surplus water, which can be re-used for the next wake up call.

Water clocks

The first ever water clock was found in an ancient Egyptian pharaoh's tomb and is believed to originate from 1,500 BCE. The clocks were either cylindrical or bowl-shaped clay containers that worked by measuring water levels. Two designs existed: an inflow model which measured how much water had filtered out, and an outflow model that calculated how much water remained.

Measurements of hours were marked on the containers. If it took one hour for the water level to drop by a centimetre, then if it dropped by two centimetres, two hours had passed, and so on. The downside was that they couldn't work in cold conditions, as the water would freeze, and they needed supervision, as a constant flow of water was required.

The ancient Greek Tower of the Winds used both a sundial and a water clock called a clepsydra to track the time

Mechanical clocks

How clockwork became widespread and helped change society

The first mechanical clocks only had one hand but they were much more reliable than previous models. The escapement system they used was possibly invented in China in 1275.

The basic process used springs or weights to work a toothed wheel. However, it could go up to five minutes out of sync per day, and was replaced by the pendulum clock.

Pendulum clocks were first developed by Christiaan Huygens, who was inspired by Galileo's discovery that a pendulum swings at a particular rate depending on its length, making each complete swing in roughly the same period of time.

One of the greatest achievements of mechanical clocks was giving the concept of time to almost all sections of society, not just a select few. Clock faces had appeared in the towers of churches and cathedrals all over Europe by the 14th century, and people could now set proper meal times, bed times and working hours.

1. Ticktock
The escapement system alternates with the swing of the pendulum. The horizontal verge and vertical verge work like a seesaw.

2. Counting seconds
A notched wheel turns the gear, which in turn moves the hands at a constant rate. Each ticktock sound represents one second.

3. Weight
A weight powers the mechanism. As it drops, it pulls the second hand around the clock face. These must regularly be raised manually in order to keep the clock running.

4. Pendulum
The pendulum manages the rate of the mechanical clock, based on its regular swinging motion.

5. Energy conversion
The pendulum converts potential energy into kinetic and back again as it swings back and forth. This ensures that a constant motion is maintained.

6. Complementing mechanism
The escapement helps the pendulum work too. The mechanism helps maintain the pendulum swing so it's not slowed down by friction or air resistance.

"Mechanical clocks brought the concept of time to almost all sections of society"

Pocket watches and wristwatches

The first clocks that could be carried around and used on the go

As clockwork became more compact, spring mechanisms became small enough for portable clocks or watches.

The first true pocket watch was invented by Peter Henlein in 1509, who devised a way to create a clock without the need for a pendulum or falling weights. The spring-loaded design was known as the Nuremberg Egg. It was very heavy but quickly became popular.

The next major advancement came when Christiaan Huygens tweaked the design so it now included a minute hand. More wheels within the watch were also added, meaning it had to be wound less frequently.

These improved pocket watches fast became essential as conductors used them to help the trains run on time and army generals used them to synchronise orders and missions.

Wristwatches were invented in 1868 by Swiss company Patek Philippe. They were initially only popular with noblewomen, as men preferred to carry pocket watches, but this all changed in World War I.

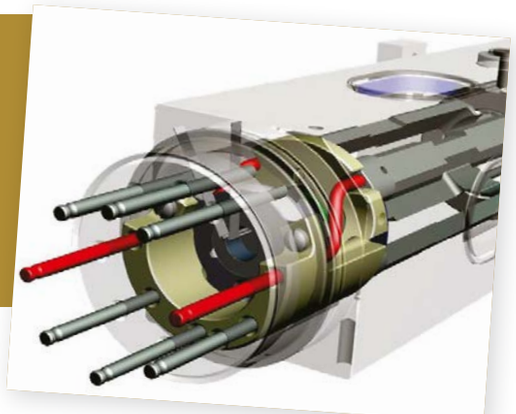
Soldiers now wore wristwatches to help time artillery barrages and infantry rushes. The masculine image of the troops wearing watches soon caught on at home.

Atomic clocks

After the success of quartz clocks, it seemed like there wasn't much more improvement to be made. Then came the atomic clock. First created in 1955, three major types have been made since: caesium, hydrogen and rubidium.

The modern definition of a second is based on the caesium atomic clock. Electrons around a nucleus orbit at set energy levels, but when they absorb or release energy they can 'jump' up or down to the next energy level respectively. Lasers are used to make a caesium atom's electrons move between specific energy levels, so the radiation they emit will always be the same frequency, which can then be measured.

The results are incredibly precise: the best types are predicted to lose one second in over 50 million years. Atomic clocks form the basis for GPS tech, space mission navigation and the synchronisation of the internet.



Quartz clocks

How tiny crystals helped make watches and clocks more accurate

Perhaps the biggest jump in timekeeping technology came in the second half of the 20th century with the advent of quartz clocks.

Quartz crystals have piezoelectric properties, meaning they can generate an electric current when pressurised and will also vibrate when an electric current is passed through it. These properties were exploited to create quartz clocks and watches.

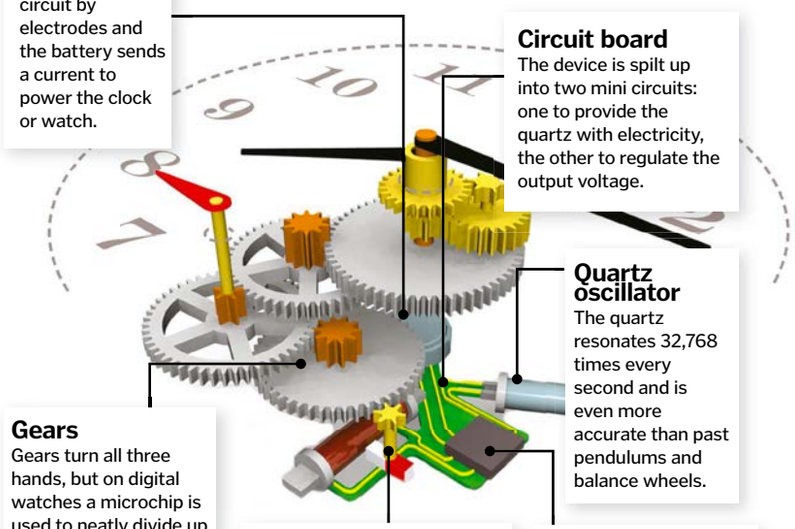
First built in 1927 by Warren Marrison and J W Horton of Bell Telephone Laboratories in New Jersey, US, the quartz clock was operated by a battery feeding a crystal with electricity, which then moved a standard clock face or powered a digital LED display. These new clocks didn't need winding and didn't rely on gravity in order for them to work properly.

The signal emitted by the crystal oscillator was set at a very precise frequency, meaning quartz clocks quickly proved to be at least an order of magnitude more accurate than their mechanical predecessors.

Extremely energy efficient and very reliable, the use of quartz crystals was a turning point in the evolution of clockwork. They are now the world's most widely used clocks.

Inside a quartz device

How the vibrations of a crystal help power the majority of modern clocks and watches



Battery
The crystal is wired to the circuit by electrodes and the battery sends a current to power the clock or watch.

Circuit board
The device is spilt up into two mini circuits: one to provide the quartz with electricity, the other to regulate the output voltage.

Quartz oscillator
The quartz resonates 32,768 times every second and is even more accurate than past pendulums and balance wheels.

Gears
Gears turn all three hands, but on digital watches a microchip is used to neatly divide up the oscillations into precise hours, minutes and seconds.

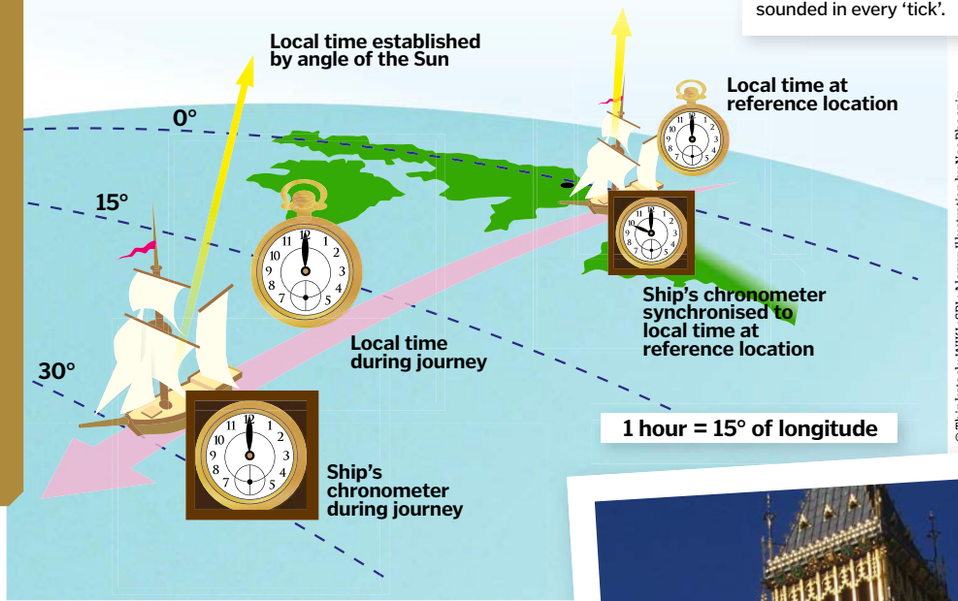
Regulating the clock
The motor uses electric pulses created by the microprocessor to drive the gears that work the hands.

Microprocessor
Each circuit has a processor that reduces the quartz oscillation to one vibration every second, which is sounded in every 'tick'.

Telling the time at sea

In 1714, the British Government established the Longitude Act, offering a £20,000 reward to any inventor who succeeded in inventing a clock that worked at sea. Knowing the positions of their ships was very important for maritime nations, and the time of day was an important factor in calculating longitude. Accurate timekeeping was difficult at sea as temperature changes, humidity and interference from a ship's motion stopped pendulum clocks working effectively.

John Harrison's H4 device led the way and was the first marine chronometer with a spring and a balance mechanism inside that could withstand the problems that affected pendulum clocks. Local time was found using the position of the Sun, which was then compared against the time on the chronometer that had been set at a selected reference point, such as the start of the ship's journey. With this system mariners could find out the time difference and therefore accurately gauge where they were in the world.



Fathers of time

Meet the people who devised the timekeeping devices we now take for granted

Peter Henlein
1480-1542
Henlein designed the first watch. His portable brass devices become so popular he was asked to design a clock face for a German castle.

Christiaan Huygens
1629-1695
The Dutch scientist patented the first pendulum clock in 1656, based on the theory of pendulum motion that was first discovered by Galileo.

Eli Terry
1772-1852
Terry set up a clock making business in his home state of Connecticut, US. His firm helped mass-produce wooden shelf clocks for US citizens.

Louis Essen
1908-1997
Essen was a talented physicist who helped create some of the world's first atomic clocks and develop the idea of a standard second.

The Blitz

The devastating eight-month long bombing campaign that pushed Britain to breaking point in World War II

Following RAF bombing runs on Berlin, Adolf Hitler declared that in retaliation against the British he would "erase their cities from the Earth." The Führer believed that a devastating bombing campaign concentrated on cities would break the morale of the British people.

The Blitz began on 7 September 1940 as over 250 Luftwaffe aircraft dropped over 300 tons of bombs overnight on the capital. London would be bombed for the next 57 nights.

The British anti-aircraft guns didn't have the firepower to respond effectively and the attacks continued as cities like Coventry, Liverpool, Birmingham and Glasgow were also targeted. Approximately 150,000 people sought refuge in the London Underground every night while others took cover in corrugated iron Anderson shelters or simply hid under the stairs during the raids.

The Luftwaffe's Knickebein system used radio beams to accurately bomb targets. This later evolved into a four-beam system that had a clockwork timer for when to release the payload and cause maximum damage. The devastation continued until the spring of 1941, when on 10 May the biggest raid of the entire Blitz killed 1,436 civilians in one night.

Despite this, it became clear that the British could not be broken, even in the face of such heavy losses. As Hitler turned his attention east to an invasion of the Soviet Union, the bombing subsided. It was only in 1944, in the form of V1 and V2 rockets, that the attacks would return.

The Blitz in numbers

September 1940 -May 1941

INJURED	DEAD	HOMELESS
51,000	43,000	2.25M+

503 TONS

EXPLOSIVES DROPPED ON CITY OF COVENTRY

"150,000 people sought refuge in the London Underground every night"

79 underground stations were used as bomb shelters, but only 40 per cent of Londoners used them

Music boxes

How these immaculately designed mechanical instruments create distinctive melodies

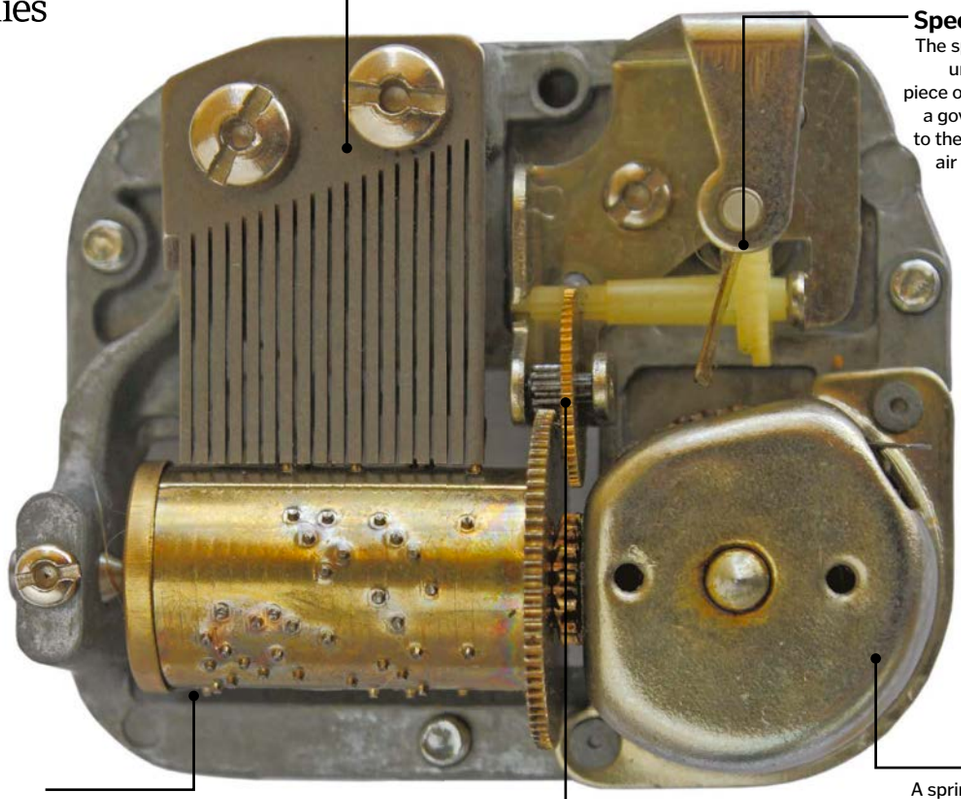
Many music boxes were adorned with beautiful designs that moved in time with the music

During the 19th century, a popular method of listening to contemporary tunes was with a music box. First designed in Switzerland, the sounds are created by a cylindrical drum covered in tiny, specifically placed pins, and a metal comb. The comb's prongs are different lengths to produce a range of notes, so as the drum rotates, its pins brush against the prongs to produce a predetermined melody.

The mechanism is powered by a spring unfolding in the same way a mechanical clock works. More complex versions with two drums were later invented to play harmonies, and the drum itself was later replaced with a disc. Music boxes were fixed into jewellery boxes, toys and furniture, but their popularity waned in the early 20th century with the invention of phonographs and radio.

Music box mechanics

The inner workings of this novel invention



Comb
Longer teeth create a lower note while shorter teeth result in a higher note. The teeth are weighted at the end to enhance the resonant frequency.

Speed regulation
The speed of the spring unfurling is set by a piece of apparatus called a governor. Connected to the gear train, it uses air resistance to limit the rotation.

Drum
Small projections, or pins, are arranged in a sequence to pluck the teeth of the comb as the drum rotates. Each drum is made to play a specific tune.

Gear train
A series of intersecting gears transfer the motion from the unwinding spring to the drum.

Spring
A spring is placed inside the mechanism and wound using a key. It then unwinds to power the music box.

Phineas Gage

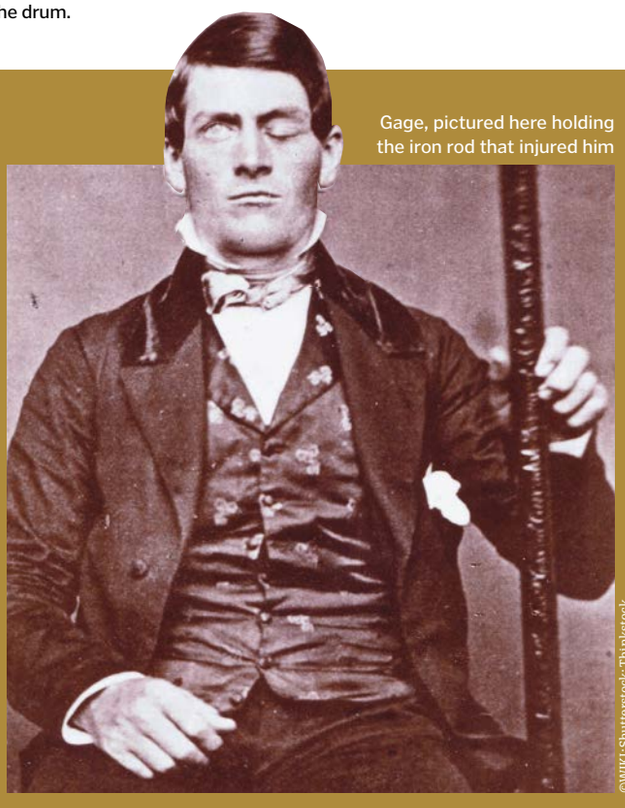
The shocking story of a freak injury that helped progress the study of neuroscience

Phineas Gage was having just another day at work in 1848 when his life changed forever. The railway worker from Vermont, US was setting explosives when the iron rod he used to tamp down charges scraped a rock. The resulting sparks set off the gunpowder prematurely and the metre-long pole launched upwards, puncturing Gage's skull. It punctured his cheek, shot through his skull, and landed over 30 metres away.

Gage was instantly blinded in his left eye, his optic nerve completely severed, but remarkably he still managed to ride into town after the incident. He went to inform his local doctor, who performed surgery that closed the wound.

Gage lived for 12 more years, but underwent a drastic personality change. The professional and polite man became reckless and rude. This was the first physical evidence that the brain is closely associated with behaviour and cognition.

Recent X-rays and 3D computer modelling of the accident has confirmed that the rod impaled Gage's frontal lobe, an area of the brain associated with reasoning, decision-making and social cognition. His case remains a pivotal moment in the study of neuroscience and psychology and understanding the brain.



Gage, pictured here holding the iron rod that injured him

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BRAIN DUMP

Because enquiring minds need to know...

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MEET THE EXPERTS

Who's answering your questions this month?

Laura Mears

Laura studied biomedical science at King's College London and has a master's from Cambridge. She escaped the lab to pursue a career in science communication and also develops educational video games.

Alexandra Cheung

Having earned degrees from the University of Nottingham and Imperial College London, Alex has worked at many prestigious institutions, including CERN, London's Science Museum and the Institute of Physics.

Tom Lean

Tom is a historian of science at the British Library where he works on oral history projects. He recently published his first book, *Electronic Dreams: How 1980s Britain Learned To Love The Home Computer.*

Sarah Bankes

Sarah is the editor of *Photoshop Creative*, has a degree in English and has been a writer and editor for more than a decade. Fascinated by the world in which we live, she enjoys writing about anything from science and technology to history and nature.

Joanna Stass

Having been a writer and editor for a number of years, **How It Works** alumnus Jo has picked up plenty of fascinating facts. She is particularly interested in natural world wonders, innovations in technology and adorable animals.

The very first roller skating demonstration ended in disaster

Who invented roller skates?

Joe McKinley

The first recorded use of roller skates was in the 1760s, when Belgian-born John Joseph Merlin decided to demonstrate his new invention at a fancy masquerade party in London. After donning his inline skates with small metal wheels, he proceeded to glide around the room while playing the violin. However, having had very little practice, he soon struggled to control his speed and direction and ended up crashing into a large mirror, suffering some serious injuries in the process. Perhaps it's no surprise that Merlin decided not to patent his creation. The first two-by-two skates were invented by American James L Plimpton in 1863, and proved much easier to steer. **JS**

Who invented the crash test dummy?

Jeremy May

Potentially millions of lives have been saved on the world's roads thanks to physicist Samuel Alderson, the inventor of the crash test dummy. In 1949 he received a contract to design a human-like dummy for testing aircraft ejection seats, leading to the creation of 'Sierra Sam'. His invention soon attracted the attention of the automotive industry, as at the time the number of traffic fatalities was starting to rise and the use of cadavers as test dummies was producing unreliable results. Alderson later produced VIP, a dummy designed specifically for testing cars. It had the same weight distribution as the average male, and featured a steel rib cage, articulated joints and a flexible neck. **JS**

Crash test dummies replaced cadavers for testing the effects of vehicle collisions

The first film shown at the Regent Street Cinema was made by the Lumiere brothers

Where was the first cinema?

Lars Whittaker

Although some sources claim that l'Eden Theatre in France holds the title, no one knows for sure where the first cinema in the world was. However, the UK's first cinema was the Regent Street Cinema, which first opened as a lecture hall on Regent Street, London in 1848. It showed the UK's first screening of moving footage in 1896. The world's first cinema exclusively devoted to showing motion pictures was the Nickelodeon, which opened in 1905 in Pittsburgh, in the US. **SB**

Piano pedals can control the resonance and softness of notes

What do the pedals on a piano do?

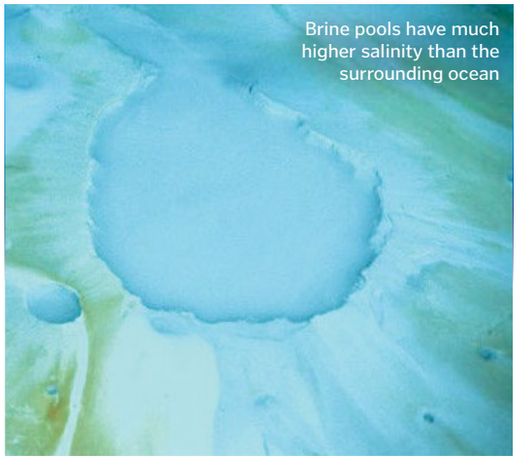
Gemma Reed

When you press a piano key, a hammer inside hits the corresponding strings, just as a device called a damper is lifted. This enables the strings to vibrate, producing a sound before the key is released and the damper returns to its position, stopping the vibration. Pressing the piano's right-hand pedal keeps the damper off the strings, even after the key's released, allowing the vibration to continue and the note to resonate. The middle pedal, called the sostenuto pedal, has a similar purpose, but only lifts the damper off the strings you've hit, enabling the effect to be controlled. Finally, the left-hand una corda pedal is used for a softer sound. Most treble keys of a piano are attached to three strings, but this pedal will cause the hammer to only hit two instead of all three at once. **JS**

What is the 'hot tub of despair'?

Eugene Peters

The 'hot tub of despair' is an underwater brine lake on the ocean basin, a kilometre below the surface of the Gulf of Mexico. The brine lake formed via a process known as salt tectonics, which is the dissolution of large salt deposits. As such, water in the lake is extremely salty, and much denser than the surrounding water. Due to high salinity raising the density of the brine, it also has a distinct surface and shoreline. It is named the 'hot tub of despair' because the salty water and dissolved methane are toxic, killing anything that enters it. **SB**



Brine pools have much higher salinity than the surrounding ocean

© Thinkstock/WIKI

BRAIN DUMP

The number of bees is decreasing, but a lot can be done to reverse this

Are bees really dying out?

Daisy Westlake

According to the Bumblebee Conservation Trust, bumblebees are in decline in the UK due to changes in agricultural practices that have resulted in fewer wildflowers and therefore reduced food sources for bees. Furthermore, scientists have reported that commercial agriculture across the globe has led to an increase in insecticides and pesticides, many of which have been killing off honeybees at an alarming rate. As the main pollinator of many major fruit crops, the loss of native bees has impacted – and will continue to impact – humans and animals all over the world. Planting certain flowers and using fewer commercial sprays in our gardens can help the situation. **SB**

Delivery drones may soon be a common sight bringing packages to our homes

How will delivery drones navigate to my house?

Caroline Ball

Delivery drones will probably use a variety of technologies to automatically guide them to your home. Much like a car driver using a sat nav, the drone will be programmed to fly along a flight path calculated by a computer, using signals from global positioning system (GPS) satellites to keep track of where it is, and correct its course if wind or obstacles divert it. Sensors – perhaps using laser beams or sound waves to detect objects – will help the drone to avoid obstacles – like buildings or other drones – during its flight and monitor its altitude, until finally it lands safely at your home by auto-pilot. **TL**

FASCINATING FACTS

What was the longest traffic jam ever?

In distance, the longest traffic jam stretched 175 kilometres between Paris and Lyon in 1980. In duration, a 100-kilometre jam on the road to Beijing in 2010 lasted 12 days. **TL**

France holds the record for the world's longest distance traffic jam

How many asteroids are there in the Asteroid Belt?

It is estimated that there are between 1.1 and 1.9 million asteroids larger than one kilometre in diameter and millions of smaller asteroids in the Asteroid Belt. **SB**

Most of the Solar System's asteroids orbit the Sun between Mars and Jupiter in the Asteroid Belt

What are the Geneva Conventions?

The Geneva Conventions are international treaties and protocols, overseen by a body of Public International Law. Their agreements and rules establish the standards of international law for humanitarian treatment in conflict in order to ensure vulnerable and defenceless people are protected. **SB**

The Geneva Conventions are binding on all states that accept them

The British Empire ruled over around 500 million people on Earth at one time

What was the biggest empire in history?

Gordon Stephenson

Among the hundreds of empires that have existed on Earth, deciding what even constitutes a formal empire is a controversial subject. However, when studying maximum land area and the percentage of world land area, the British Empire was by far the biggest empire in history. At its peak in the early 20th century, the British Empire had control over more than 35 million square kilometres of land area, equating to almost a quarter of the total land area of the Earth. As a result, British influences can be seen all over the globe, even today. **SB**

How does the Asimo robot manage to walk?

Tom Cook

It's remarkably difficult to get a robot to walk like a human, but Honda's Asimo does so better than most. The computer controlling Asimo is linked to sensors allowing it to detect and react to the world around it, and also monitor its balance and acceleration. The computer also controls the servomotors that drive Asimo's movements. When the robot walks it doesn't just move its legs: the technology inside all works together to move other parts of its body, allowing it to shift its weight. **TL**

The Asimo robot can walk, run and even use stairs

How much power does a USB provide for plug-in gadgets?

Nick Walker

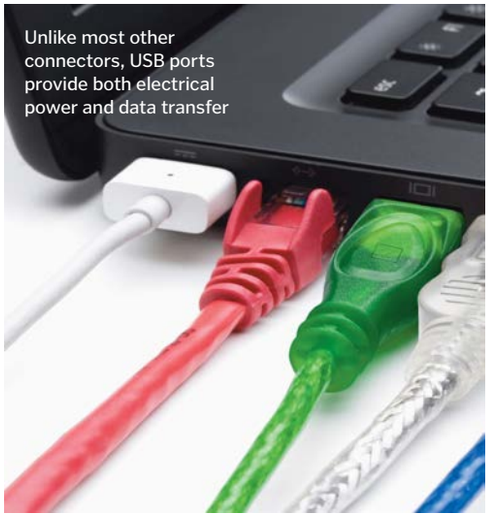
Different types of USB provide different amounts of power. USB 2.0 ports on computers provide up to 2.5 watts of electrical power, or 4.5 watts for the newer USB 3.0 ports. USB wall chargers of the sort used with mobile phones or tablets normally provide more power than computer ports – perhaps 10.5 watts – leading to faster charging times. To put this into perspective, that's an awful lot less power than the 3,000 watts that standard three-pin electrical mains plugs can provide, but most of the electronic gadgets that use USB power require far less power than kettles or washing machines, for example. **TL**

Moisturisers can make the skin appear temporarily smoother

What do anti-wrinkle creams do?

Emma Fraser

Most anti-wrinkle creams haven't been subjected to rigorous testing, so it can be tricky to determine whether they actually decrease wrinkles. Many work by reducing the appearance of lines, as opposed to physically improving the skin. The simplest way they do this is by adding moisture, plumping and smoothing the skin. However, this is true of any moisturiser, and the effect is only temporary. Some contain retinoic acid, which according to some studies can help repair damaged skin if given at a prescription-strength dose. **LM**

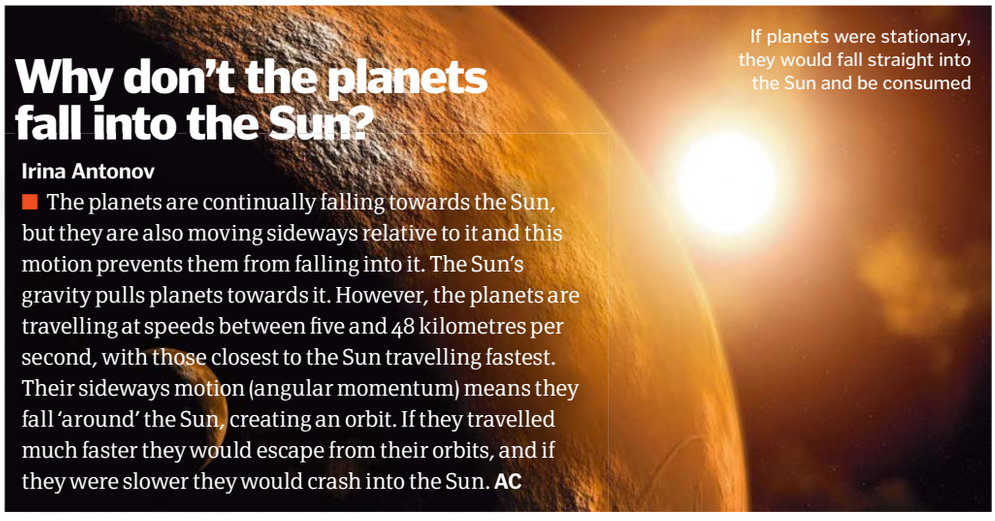


Unlike most other connectors, USB ports provide both electrical power and data transfer

Why don't the planets fall into the Sun?

Irina Antonov

The planets are continually falling towards the Sun, but they are also moving sideways relative to it and this motion prevents them from falling into it. The Sun's gravity pulls planets towards it. However, the planets are travelling at speeds between five and 48 kilometres per second, with those closest to the Sun travelling fastest. Their sideways motion (angular momentum) means they fall 'around' the Sun, creating an orbit. If they travelled much faster they would escape from their orbits, and if they were slower they would crash into the Sun. **AC**



If planets were stationary, they would fall straight into the Sun and be consumed

BRAIN DUMP

Allergies are becoming increasingly common in nations that are industrialised

Why do we have allergies?

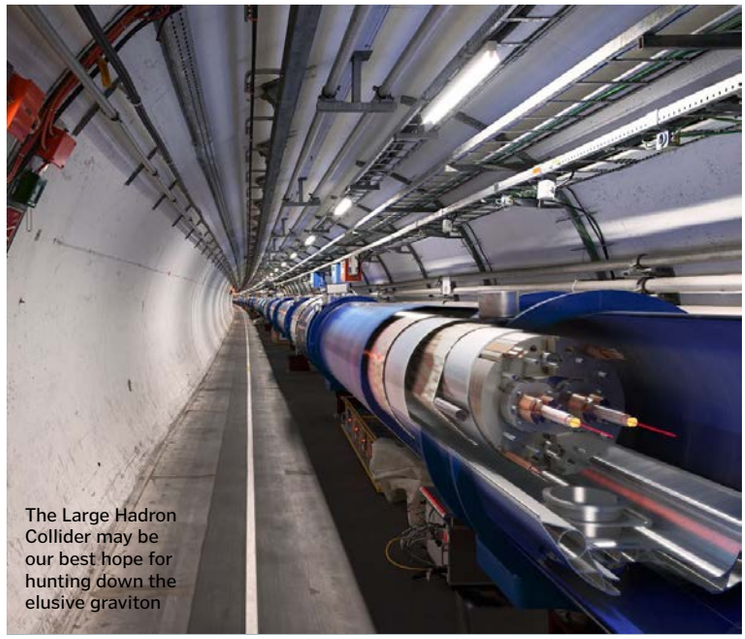
John Evans

Scientists are unsure about why we experience allergies, but a leading theory, known as the hygiene hypothesis, proposes that reduced exposure to parasites and microbes may cause our immune systems to overreact, attacking harmless targets such as dust or pollen. The immune system's function is to recognise foreign organisms that enter our bodies and eliminate them by attacking them. Over the course of human evolution, our bodies have tackled a constant onslaught from parasitic worms, and are primed to detect and respond to proteins associated with these worms. But in the sanitised environments of the developed world, so the hypothesis goes, a lack of parasites leaves our immune systems under stimulated. In some cases they may become oversensitive and react to environmental proteins similar to those associated with parasites. In trying to expel these harmless invaders, the body produces the runny nose, inflammation and other symptoms familiar to allergy sufferers. **AC**

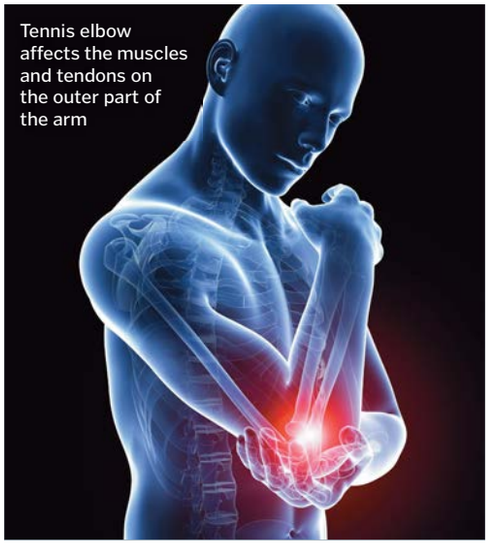
What are gravitons?

Emma Shaw

A graviton is a hypothetical particle that is believed to carry the force of gravity, in the same way that photons transmit electromagnetism. Gravitons have never been observed, but scientists predict that they would be tiny, massless particles since the range of gravity is infinite. Although gravitons' distinctive properties would make them easy to recognise in theory, their interactions with other particles are incredibly weak, making it extremely difficult to detect their presence. Some speculate that the Large Hadron Collider might be able to confirm the existence of gravitons by detecting the imbalance in momentum and energy that they would leave behind after a particle collision. **AC**



The Large Hadron Collider may be our best hope for hunting down the elusive graviton



Tennis elbow affects the muscles and tendons on the outer part of the arm

What is tennis elbow?

Catrina Lewis

It's an injury to the outer part of the elbow, affecting the muscles and tendons that connect the elbow to the wrist. Tennis isn't the only cause, other activities can also cause this strain. **LM**

Can red and blue light treat pimples?

Coloured lights are being investigated for their acne-fighting abilities

Isla Edwards

Laser treatment can be used to treat various skin conditions, but it's expensive and requires training and expertise to deliver. Red and blue lights are one option being explored. According to the American Academy of Dermatology, blue light with wavelengths between 405-420 nanometres can help to treat acne by killing bacteria. Red light from 600-950 nanometres is also being investigated in the hope it can trigger skin cells' energy factories (mitochondria), but it's unknown how effective this might be. **LM**

FASCINATING FACTS

What's a Faraday cage?

Kevin Norton

A Faraday cage is a container made from a conductive material (usually metal) that distributes electromagnetic charge around its exterior, protecting whatever is inside from external electric fields. **AC**

A plane can act as a Faraday cage, protecting passengers from lightning

The scattering of light by gas molecules was first discovered by Lord Rayleigh, who also helped to discover argon

Why is the sky blue?

Ayo Ighalo

Molecules in the atmosphere scatter blue light more than other wavelengths of light, giving the appearance that the sky is blue. The Sun's light looks white but is actually made up of all the colours in the rainbow, with each colour corresponding to a different wavelength. As this light passes through the atmosphere, it encounters molecules of oxygen and nitrogen, which deflect the light in all directions. Blue light has a shorter wavelength and is therefore scattered more strongly than longer wavelengths of light (towards the red end of the spectrum). This blue light reaches our eyes, making the sky look blue. **AC**

How can astronauts travel safely to Mars?

Michaela Nichols

Travelling to Mars and back will bombard astronauts with an estimated 662 (plus or minus 108) millisieverts (mSv) of radiation. That's not enough to cause radiation sickness, but it is more radiation than 6,000 chest X-rays, and close to the 1,000mSv limit set by the European Space Agency for an astronaut's entire career. Most of the radiation will be in the form of galactic cosmic rays, but there are two possible options to minimise their impact. The first is to build spacecraft with thicker walls to interrupt the rays, but this could make them too expensive to launch. An alternative is developing better shielding materials. NASA is investigating nanotubules coated in hydrogen, which are particularly good at blocking cosmic rays. **LM**

Humans travelling to Mars will push space technology to its limits

Can shouting really make glass shatter?

Oscar Schultz

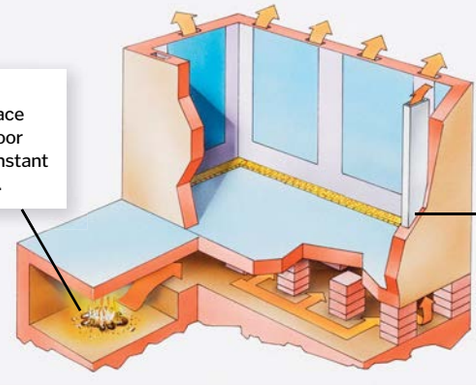
In theory, yes. Everything has a resonant frequency – the speed that it naturally vibrates if knocked. For wine glasses, this frequency is within the human vocal range, so if a singer – or shouter – creates the same note, the sound waves produced by their voice can set the glass vibrating. This doesn't mean that the glass will break though. For it to shatter, there need to be microscopic imperfections in the surface of the glass that will crumble under the strain of the vibrations. The louder the sound is, the harder the glass vibrates, and the more likely it is to buckle. **LM**

The human voice can resonate glass, stressing its structure and potentially causing it to break

How did Roman central heating work?

Gavin Cooper

A bit like modern heating systems, the Romans used a sort of underfloor central heating, called a hypocaust. The tiled floors of villas and public baths were built on pillars, creating space under the floor for air to circulate. This space was heated by hot air from a blazing furnace run by slaves. The hot air warmed the floors from underneath and the floors warmed the building. **TL**



Roman hypocaust central heating worked by heating the floor using hot air from a fire

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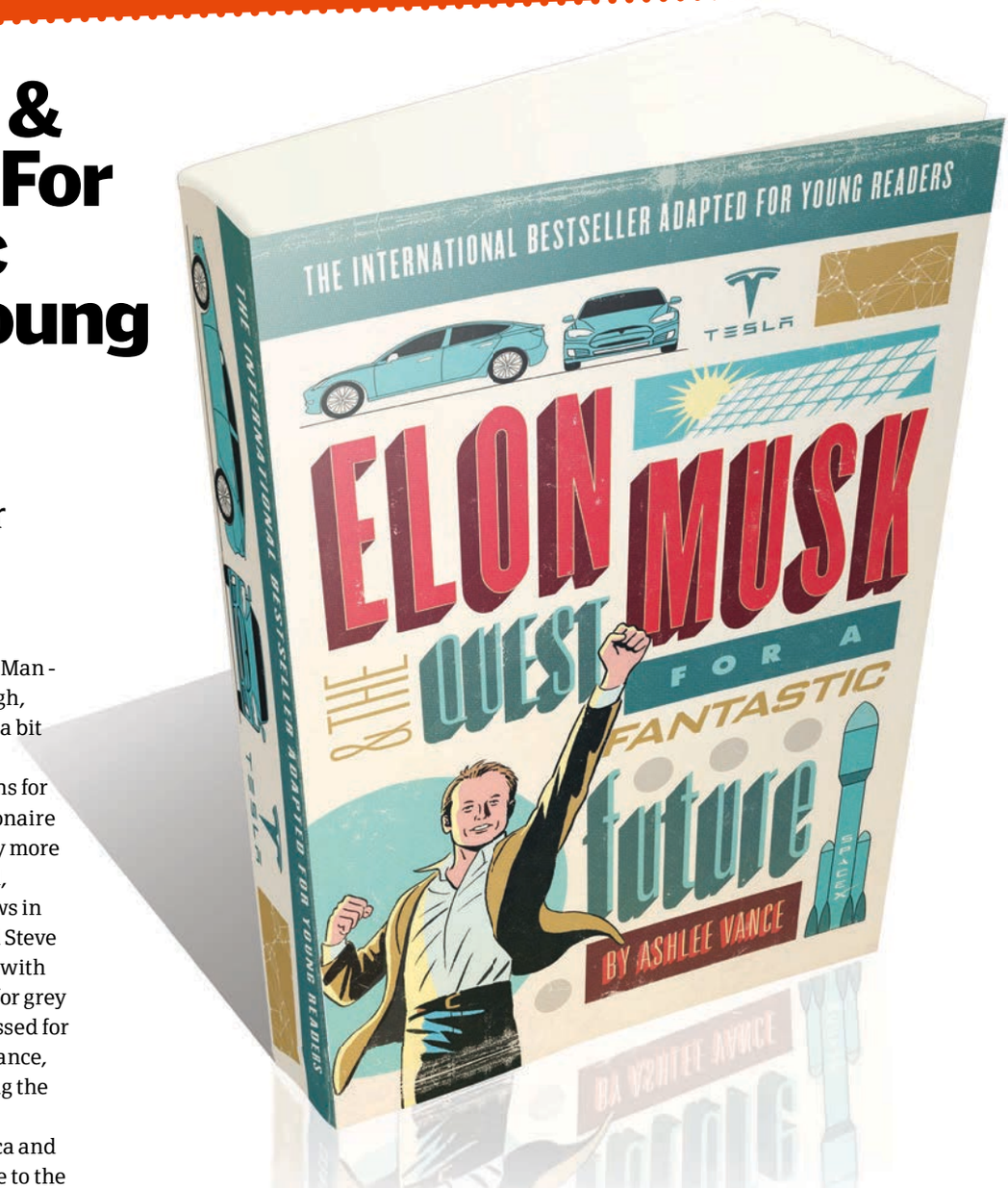
BOOK REVIEWS

The latest releases for curious minds

Elon Musk & The Quest For A Fantastic Future – Young Readers' Edition

SpaceX – the final frontier

- Author: **Ashlee Vance**
- Publisher: **Virgin Books**
- Price: **£5.69 / $6.99**
- Release date: **Out now**



It's a sad fact that Tony Stark – aka Iron Man - doesn't exist in real life. If he did though, then the chances are that he might be a bit like Elon Musk.

Aside from being one of the inspirations for Robert Downey Jr's portrayal of the billionaire playboy philanthropist, Musk has plenty more strings to his bow. The founder of PayPal, SpaceX, Tesla Motors and more, he follows in the tradition of the likes of Bill Gates and Steve Jobs in that he has become synonymous with creative endeavour and a high capacity for grey matter. Here, his story has been compressed for younger readers by biographer Ashlee Vance, who does a succinct job of deconstructing the rock-star entrepreneur.

From his youth in Pretoria, South Africa and early dalliances with coding, to his move to the US and the establishment of Zip2 and PayPal, a narrative of a man driven by vision and powered by unswerving commitment to his cause is laid out.

Even more amazingly, in retrospect it seems as if PayPal and revolutionising the way we pay for things online is just a warm-up for what is to come. Vance seems almost at pains to underline the messiah complex that sustains Musk's outlook: he wants to aid the survival of the human race by making interplanetary travel possible. SpaceX is contracted by NASA to supply the International Space Station, and wants to set up a colony on Mars. This vision drives Musk, and he is uncompromising with any who don't measure up to his standards.

This book is besotted with Musk the genius, and while there are critiques to be had, generally the less appealing aspects of his character are deemed a necessary by-product of his methodology. While it remains the case that the majority of the general public are yet to experience first-hand the fruits of Musk's greatest achievements, this book generally does a decent job of telling you why you should pay him further attention. That it does so in such an accessible manner is what makes this title all the more remarkable.

★★★★☆

YOU MAY ALSO LIKE...

Steve Jobs: The Man Who Thought Different

Author: **Karen Blumenthal**
Publisher: **Square Fish**
Price: **£8.99 / $9.99**
Release date: **Out now**

From his genius and unique outlook, to his at times colourful private life, there are plenty of parallels with Musk, as documented in this biography.

Breakthrough: How One Teen Innovator Is Changing The World

Author: **Jack Andraka, Matthew Lysiak**
Publisher: **Scribe UK**
Price: **£12.99 / $18.99**
Release date: **Out now**

This book from 20-year-old Jack Andraka – best known for his work on pancreatic cancer detection – is an essential read.

Rita Levi-Montalcini: Discoverer Of Nerve Growth Factor

Author: **Lisa Yount**
Publisher: **Chelsea House Publications**
Price: **$7.99 (approx. £6.40)**
Release date: **Out now**

A biography of the woman who discovered new paths for the study of neurobiology, this is a fascinating read.

Why It's Not All Rocket Science

A short history of nearly everything we know

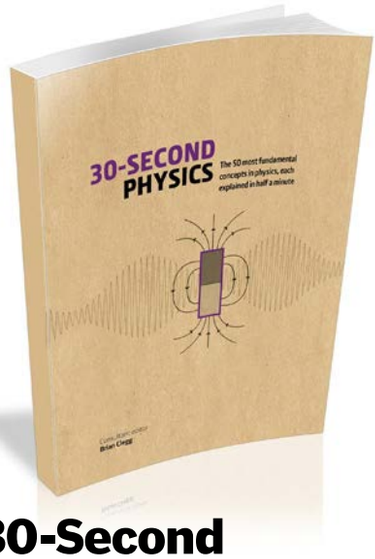
- Author: **Robert Cave**
- Publisher: **Thames & Hudson**
- Price: **£9.99 (approx. $12.50)**
- Release date: **Out now**

Some of the most momentous discoveries in history can trace their origins back to some pretty bizarre experiments or schools of thought, a timeline that Robert Cave aims to map out in his latest book.

From Archimedes' 'eureka' moment to the Mars probes, we bear witness to some of the most memorable instances of innovation and wonder in history, backed up by illustrations and photos that help to set the scene.

As well as being an intriguing and insightful read, it serves as a sobering reminder of just how far we've come. Once we were electrocuting animal corpses. Now we're heading into the cold, dark reaches of space.

★★★★★



30-Second Physics

Half-minute marvels

- Author: **Brian Clegg (editor)**
- Publisher: **Ivy Press**
- Price: **£14.99 (approx. $18.50)**
- Release date: **Out now**

The titular claim of being able to inform readers of key physics concepts in half a minute is a bold one, but is it a realistic one? If you can read quickly, then yes. But flippancy aside, a lot has been achieved in this compendium.

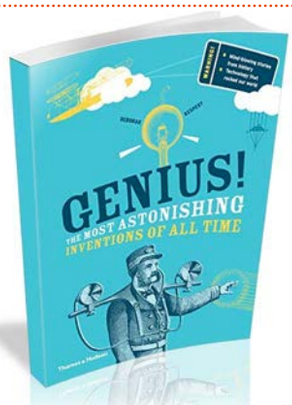
From essential terminology and theories to mini biographies of those who helped shape our collective knowledge of the subject matter, everything is presented in a clear and concise way that is suitable for both newcomers and those who are simply brushing up on their science. Definitely a worthy purchase for the family's budding Isaac Newton.

★★★★★

Genius! The Most Astonishing Inventions Of All Time

A celebration of history's greatest innovations

- Author: **Deborah Kespert**
- Publisher: **Thames & Hudson**
- Price: **£12.95 / $19.95**
- Release date: **Out now**



Starting with the wheel and finishing with a DNA test kit, there are inventions and inventors aplenty in this superb book, which is filled with bright and colourful imagery. Each invention is listed with its significance, applications and background. Some of the entries also have a 'how to make' section, so in no time readers will be constructing their own Archimedes' Screw.

Deborah Kespert has crafted a carefully selected and well researched rundown with heaps of information on offer. This lively release really captures the imagination behind each invention and makes you wonder what inventions will be in this book in 100 years time.

★★★★☆

A History Of The First World War In 100 Objects

An incredible collection of items and imagery from the Great War

- Author: **John Hughes-Wilson**
- Publisher: **Cassell**
- Price: **£20 / $39.95**
- Release date: **Out now**

World War One was a pivotal event in history and has left behind many fascinating relics. This visually stunning book captures every facet of the Great War, from Archduke Franz Ferdinand's bloodstained tunic to a football kicked on the first day of the Somme. All of the objects on show are from the Imperial War Museum's collection, and a century later, the ferocity of the 'war to end all wars' still shocks. Reading this book is the next thing to visiting the museum itself, and each item has been selected to best showcase the enduring legacy of the war. Quite simply essential for anyone interested in this period of history.

★★★★★

RMS Queen Elizabeth 2 Owners' Workshop Manual

Inside one of the most famous ocean liners in the world

- Author: **Stephen Payne**
- Publisher: **Haynes**
- Price: **£22.99 / $36.95**
- Release date: **Out now**

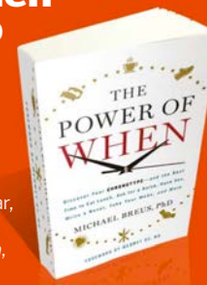
This latest release from Haynes' popular workshop manuals celebrates the career of the iconic and much loved QE2 50 years since its launch. The book covers the history, technology and culture of the ship extensively. This title offers an insight into the construction of the ship as well as photographs documenting some of the rarely seen areas on board. The visual tour shows just how lavish the ship was, with its five restaurants, a 481-seat cinema and three swimming pools. While this is another excellent manual from Haynes', the subject matter may not be of interest to everyone.

★★★★★

The Power Of When

Learn the best time to do just about everything

- Author: **Michael Breus**
- Publisher: **Vermilion**
- Price: **£12.99 / $28**
- Release date: **Out now**



Did you realise that you are a dolphin, bear, lion or wolf? Well according to Michael Breus PhD, author of *The Power Of When*, you have a spirit animal of sorts that characterises your approach to life, and in this book he aims to help you understand it. The book explores the science of chronobiology and how the way we feel and function fluctuates throughout the day. A combination of self-help handbook and slice of psychological insight, it informs you how to plan your life, explaining which times are best to eat, sleep or work, and why. You may raise your eyebrows at some of the more speculative parts, but on the whole this is a well assembled book.

★★★☆☆

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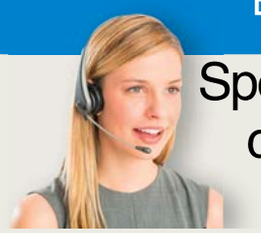

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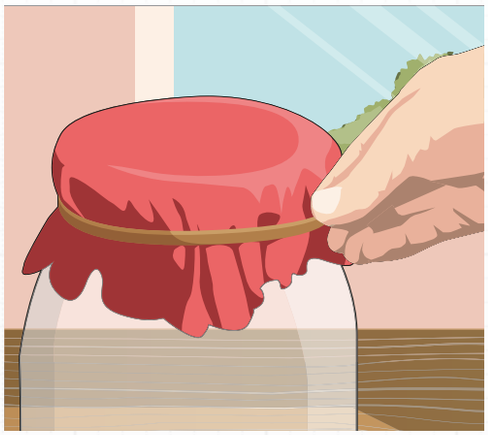
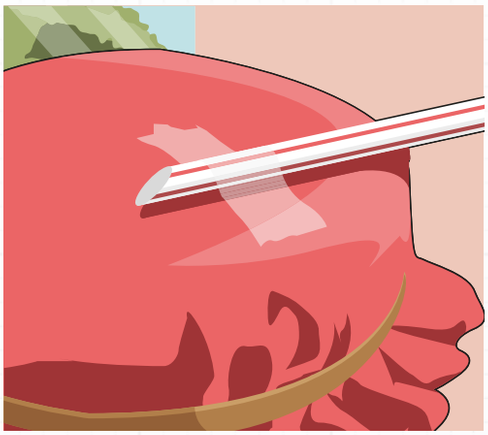
Build a barometer

Measure air pressure to create your own accurate weather forecasts

DON'T DO IT ALONE
IF YOU'RE UNDER 18, MAKE SURE YOU HAVE AN ADULT WITH YOU





1 Make a lid

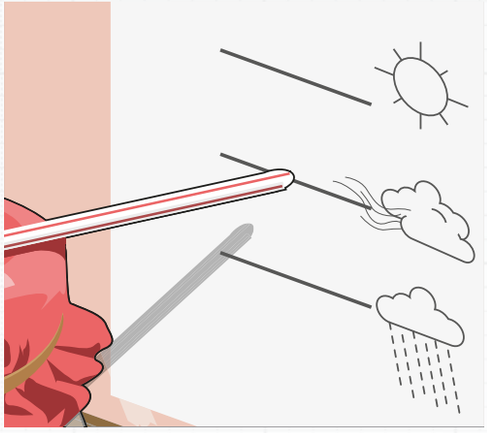
Take a deflated rubber balloon and cut off the bottom third with a pair of scissors. Discard the neck section and then stretch the top of the balloon over the top of an empty container, such as a drinking glass or jar. Make sure it is stretched flat with no dimples, then secure it in place with a rubber band so that it forms an airtight seal.

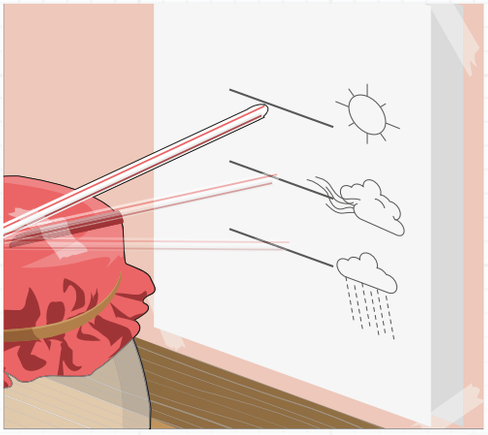
2 Attach a pointer

Get a drinking straw and using a pair of scissors, cut one end at a 45-degree angle so that it forms a point. Now secure the other end of the straw to the balloon lid of your container using a piece of sticky tape. Make sure that the end of the straw is directly in the middle of the lid before you stick it down securely.

3 Create a scale

Fold a piece of plain A4 card in half vertically. Stand it behind the straw attached to your container and mark where the straw currently points with a pencil. Add more marks above and below at 0.5-centimetre intervals, using a ruler to help you measure. A total of nine marks, with four above and four below the original, will be fine.





4 Leave it to work

Next to the top mark on your piece of card, write the word sunshine or, if you prefer, draw a picture of a Sun. Then, next to the bottom mark, write the word rain or draw a picture of some raindrops. Now place your piece of card back behind the pointed straw that is attached to your container, leaving them both in a place where you know that they will not be disturbed in any way.

5 Record the results

Check your barometer regularly throughout the day, ensuring you record which marker the straw is pointing to on each occasion. If it's pointing towards the top marker, this should mean that dry weather is on the way, but if it's pointing towards the bottom marker then it should be about to start raining. If the straw stays in the centre then the weather is unlikely to change.

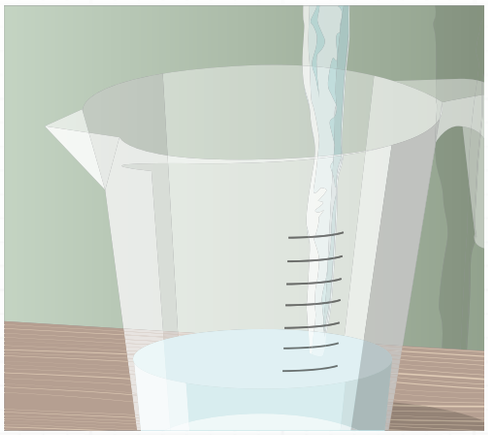
"If the straw is pointing towards the bottom marker, it's about to rain"

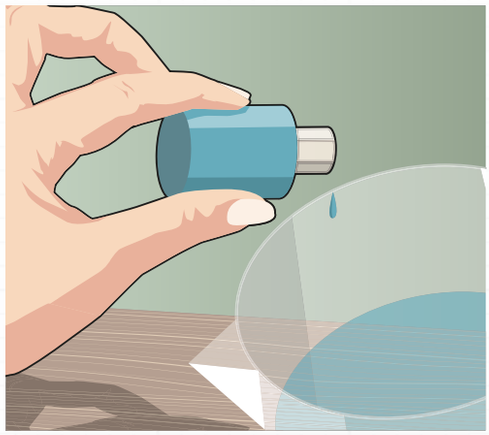
In summary...

A barometer measures air pressure to predict short-term changes in weather. Wet weather is often associated with low air pressure, which is caused by warm air expanding and rising. This causes the air molecules inside the jar to push outwards, making the balloon dome and the straw point downwards. The opposite is true for dry weather.

Make an air freshener

Keep your house smelling lovely with some homemade scent science





1 Make the gel mixture
Boil some water in a kettle or pan, then pour 150 millilitres of it into a measuring jug. You may need to get an adult to help you with this. Next, place four sheets of gelatine into a bowl of cold water. When they've gone soft, squeeze them out and place them in the jug of boiling water. Using a spoon, stir the mixture until the gelatine sheets have completely dissolved, then top up the jug with 150 millilitres of cold water.

2 Add a scent
Add ten to 15 drops of an essential oil you like to the mixture in the jug. Next, choose which colour you want your air freshener to be. If you are happy for it to be clear, then leave it as it is. However, if you want to add colour, mix in a few drops of food colouring until your happy with the shade. Stir in a tablespoon of salt, as this will stop any mould growing in your freshener, which could prevent the scent being released later.

3 Leave to set
Pour your mixture into some empty containers, such as glass jars, and leave them to set. To speed up the process, you could place them in the fridge. Once the gel mixture has hardened, your air fresheners are ready to place around the house. You could even decorate the containers with some ribbon or stickers. Over time the gel will slowly evaporate, releasing a continuous scent into the room.

"Salt will stop mould growing on your air freshener"

In summary...
The gelatine in the air freshener is a polymer, which means it's made up of long chains of molecules that weave together, trapping the essential oil particles inside. As the gel slowly evaporates, these trapped particles are freed, releasing their scent into the room.

NEXT ISSUE
MAKE FOSSILS
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What was the planet Mars named after?

a) **The Roman god of war**

b) **The British chocolate bar**

c) **US singer-songwriter Bruno Mars**

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Letter of the Month

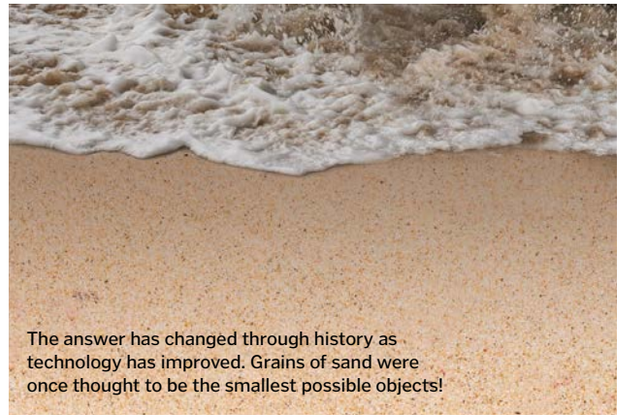
Smallest thing in the universe

Dear **HIW**,
I love your magazine. It is the only magazine I read from cover to cover and I am still interested when I've finished it. I wondered if I could contribute a question: what is the smallest thing known to man, and what is the highest magnification of the strongest microscope in the world? I would be very happy if you answered!
William Hamer

There are currently a few candidates for the smallest things in the universe, although more could be discovered as technology develops.

Atoms were once thought to be the smallest building blocks, but in the 20th century scientists split them into electrons, protons and neutrons. Further experiments managed to split these into even smaller particles called quarks, which are estimated to be less than 100 billion-billionths of a metre ($1x10^{-16}$m) across. These particles are the smallest we know of so far, but it's theorised that quarks may consist of smaller particles called preons.

As for microscopes, traditional visible-light devices can see anything as small as 200 nanometres (200 billionths of a metre). More powerful microscopes using single molecule imaging or X-rays can see down to 20 nanometres ($2x10^{-8}$m). The Scanning Transmission Electron Holography Microscope at the University of Victoria can focus to 35 picometres ($35x10^{-12}$m). That's 20 million-times smaller than what the naked eye can see!


The answer has changed through history as technology has improved. Grains of sand were once thought to be the smallest possible objects!

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The sound of your voice

Dear **HIW**,
I love your magazine and I get it every month. My question is: why do other people hear my voice differently to how I hear it? I hope you have time to answer it.
Thanks
Zac Lovat

When you hear something, sound waves travel through the air into your ear and vibrate your eardrum. The sound then enters the cochlea before being processed by the brain. This is how you hear your voice on a recording. When you hear your own voice as you speak, the sound travels by an additional path. As your vocal chords vibrate, the sound travels through bone and tissue before it makes its way to your ear.

This enhances the lower frequency vibrations, making your voice sound deeper than it actually is. When you hear your own voice on a recording, that is what you really sound like to other people!


You hear your own voice as air-conducted and bone-conducted vibrations

Black holes and light

Dear **HIW**,
I've been told that light has no mass, but if that's so, then why is light pulled towards black holes? Surely it is influenced by gravity, which means it must have mass?
Nikolai, 15

Isaac Newton believed that a gravitational force could only be produced between two objects with mass. So in his view, light shouldn't be affected by a black hole. But Einstein's work showed gravity in a strikingly different way. Einstein described gravity as a curvature of space-time: the more mass an object has, the more it warps the space around it.

This means that light moving through the gravitational influence of a black hole is actually moving through a warped region of space. The light isn't 'pulled' by the force of the black hole directly, but is actually travelling through a region of space-time that is curved towards the centre of the black hole.

Black holes are created when a massive star collapses in on itself

Making different sounds

Dear **HIW**,
Your mag goes from strength to strength. Here's a hard one! If I strike a wooden block with a mallet, why does it make a noise? Why do different materials make different noises when struck?
From a 70yrs+ subscriber with an ever-questioning mind

When the mallet strikes the wooden block, the kinetic energy from the impact is transferred to the atoms in the objects, causing them to vibrate, which in turn can create sound we can hear if the vibrations are at a frequency that is audible to us.

Different materials make different sounds because their masses and densities aren't the same, which affects how they vibrate. The wooden block only makes a short sound, whereas something like a bell will continue to ring after it has been struck. This is because the wooden block loses energy at a quicker rate than the bell.


A material's composition and the force of impact affect the noise it makes

HOW IT WORKS

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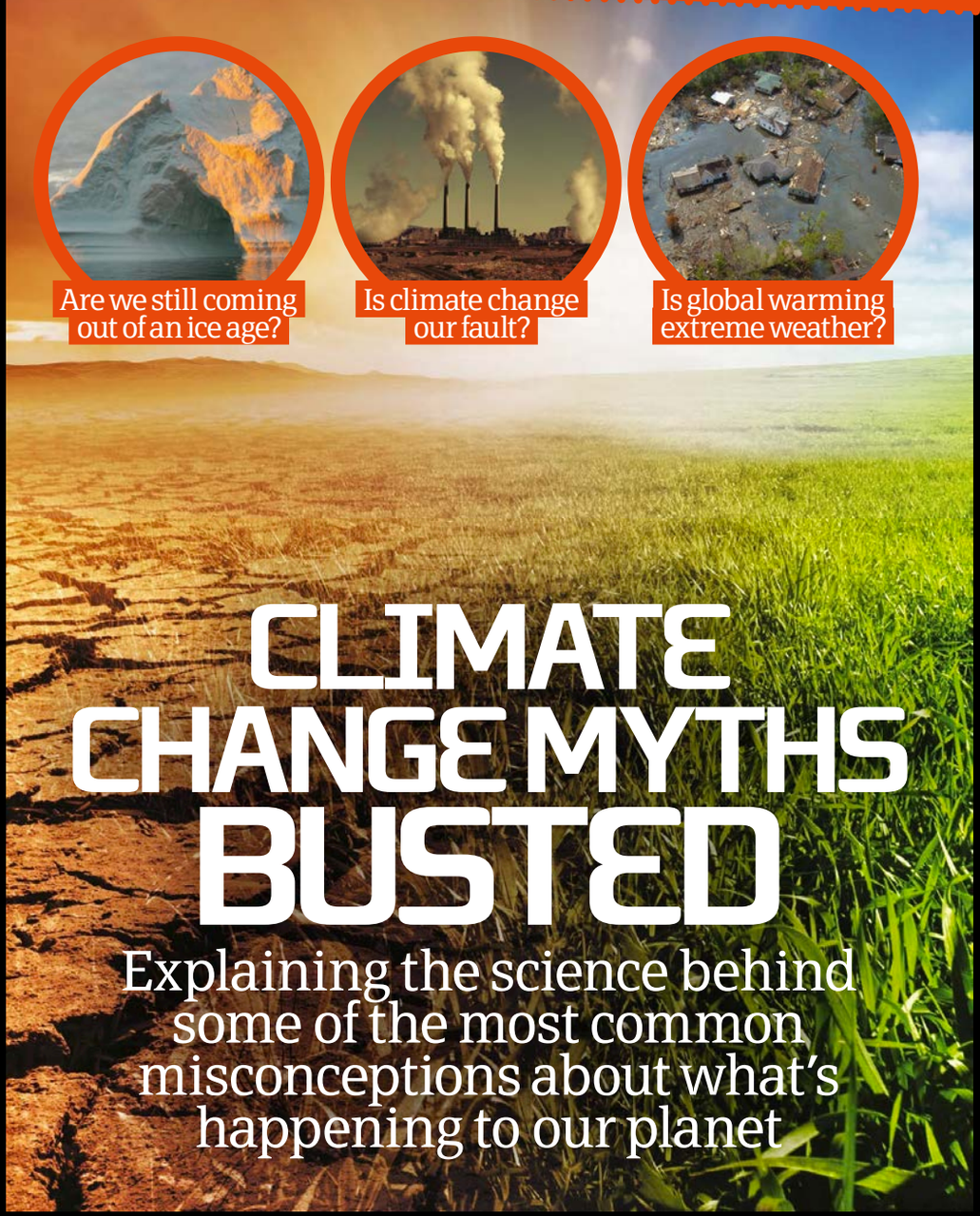

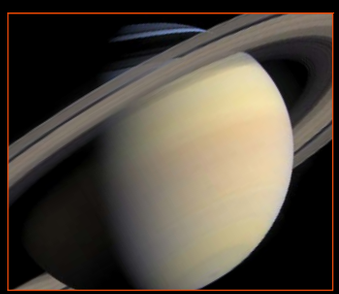

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FAST FACTS

Amazing trivia to blow your mind

HUMAN SKIN CAN BURN WITHIN 15 MINUTES OF EXPOSURE TO SUNSHINE

1.4M THE MAXIMUM LENGTH OF A MALE IBEX HORN

28,700KG

THE TOTAL WEIGHT OF THE CARGO BEING TAKEN TO THE ISS ABOARD THE CYGNUS SPACECRAFT

50,000

THE NUMBER OF BUILDINGS DAMAGED IN COVENTRY DURING ONE NIGHT OF THE BLITZ

180-225

AVERAGE LITRES OF SAP NEEDED TO PRODUCE JUST 4.5 LITRES OF MAPLE SYRUP

FOUR

THE NUMBER OF CALORIES IN ONE GRAM OF CARBOHYDRATE

9,192,631,770

THE RADIATION CYCLES GENERATED BY THE WORLD'S FASTEST CAESIUM ATOMIC CLOCK IN ONE SECOND

427.2M

THE LONGEST RECORDED BOOMERANG THROW

18 MINS THE TIME IT TOOK RMS LUSITANIA TO SINK AFTER BEING TORPEDOED BY A GERMAN U-BOAT DURING WW1

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THE YEAR WHEN THE NEXT MARS ROVER WILL BE LAUNCHED

TOADS, SHEEP AND HORSES HAVE RECTANGULAR PUPILS TO WIDEN THEIR FIELD OF VISION

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