REVEALED! REAL LIFE STAR WARS TECH

HOW IT WORKS

SCIENCE ENVIRONMENT TECHNOLOGY TRANSPORT HISTORY SPACE

PREHISTORIC MONSTERS

The deadly predators that ruled land, seas and skies

5 TIMES THE SPEED OF SOUND

HYPERSONIC FLIGHT

INSIDE THE PLANES THAT WILL SMASH SUPERSONIC RECORDS

SCRAMJET ENGINES

LIGHTWEIGHT BUILD

HEAT-RESISTANT MATERIALS

+ SELF-LACING SHOES
HAZMAT SUITS
MING VASES
BOWLING BALLS

SURVIVAL SCIENCE

The fascinating physics of the animal kingdom

LIFE ON THE SPACE SHUTTLE

Mike Massimino talks about his NASA career

SEE INSIDE OUR PLANET

What lies beneath the Earth's surface?

THE SCIENCE OF MUSIC

How it's made and why we enjoy it

+ LEARN ABOUT ■ SKIN SENSES ■ INSTANT CAMERAS ■ SOPWITH CAMEL ■ WATER WORLDS

Future
Digital Edition
GreatDigitalMags.com
ISSUE 093

Sega Toys Planetarium Homestar Original

Get 60,000 twinkling stars from the skies to your ceiling

Imagine enjoying the sky full of stars while sitting on your sofa. This dream can become reality with the Homestar Original from Sega Toys. The high definition planetarium with the ultra-bright 3 watt LED and its rotating movement projects the night sky throughout the year. Two interchangeable disks containing the fixed stars in the northern hemisphere will enable you to observe the night sky or the map of constellations. And with the integrated “shooting star” function you can help your dreams come true even quicker. Projection angle and focus are adjustable. The handy timer lets you fall asleep while gazing at the stars, turning off the planetarium automatically.

Buy online £99

www.segatoys.space

ISSUE 93

WELCOME

The magazine that feeds minds!

© Aerofex

"*New developments mean that some of the tech seen in Star Wars is becoming a reality*"

Real-life *Star Wars* tech, page 52

Meet the team...

Charlie
Production Editor
Could water be the clue to alien life? Head over to page 64 to discover the many water worlds that might hold the answer to this exciting question.

Katy
Research Editor
Ever wondered why you sound just like Beyoncé or Bublé in the shower? With this musical mystery solved on page 38, my time at **How It Works** comes to an end. Bye!

Jack
Senior Staff Writer
Planet Earth II is all well and good but prehistoric monsters are where it's at. Check out some gigantic ancient creatures on page 72!

James
Staff Writer
The newest hypersonic engine designs are truly breath-taking, and I mean that figuratively and literally. So speed over to page 14 to discover our future in the skies.

Duncan
Senior Art Editor
The force is strong with this issue. You want your very own speeder bike and real lightsaber, I hear you shout – well find out how on page 52!

Laurie
Assistant Designer
From agile pondskaters to hefty bumblebees, flick to page 26 to find out how animals use the nifty secrets of physics to survive life in the wild.

FOLLOW US... How It Works magazine @HowItWorksmag

Travel broadens the mind, but a large chunk of your holiday time is taken up by the journey itself. Over the next few decades, however, that could be set to change with the development of commercial hypersonic planes.

These next-gen jets will be able to take you to the other side of the world in just a couple of hours, travelling at mind-blowing speeds. So far, the only aircraft on our planet that have reached Mach 5 and above are experimental planes and Space Shuttles during re-entry. Advances in aeronautical engineering and smart materials means that we will soon see passenger jets reaching hypersonic velocities, reducing the flight times between London and Sydney from 22 hours to just two. Bonzer.

Also this issue, the humanoid robots like Pepper and Asimo in our *Star Wars* tech feature are very much the droids I'm looking for. Maybe we'll have real-life BB-8s loyally rolling alongside us soon enough. Enjoy the issue!

Jackie **Jackie Snowden**
Deputy Editor

CONTENTS

14 GOING HYPERSONIC

26 Amazing animal survival science

Meet the experts...

Jonathan O'Callaghan
Jonny takes us on a tour of the Solar System and beyond in a search for worlds with oceans. Check out the space feature on page 64 to discover where extraterrestrial water could be hiding.

Laura Mears
Why are some songs so catchy? And what makes the same note sound unique on the different instruments of an orchestra? Laura has the answers in the science of music on page 38.

Jo Stass
As a massive fan of the *Back To The Future* franchise, Jo jumped at the chance to write about the self-lacing Nike Mags, inspired by the shoes Michael J Fox wore in the second film.

Sarah Bankes
This month, Sarah investigates the mystery surrounding Devil's Kettle Falls in Minnesota, US, and also explains why the precious spice saffron is worth more than its weight in gold.

Gemma Lavender
Editor of our sister magazine **All About Space**, Gemma has a chat with ex-NASA astronaut Mike Massimino about his career and time in space.

72 **PREHISTORIC MONSTERS**

46 **The science of your Christmas dinner**

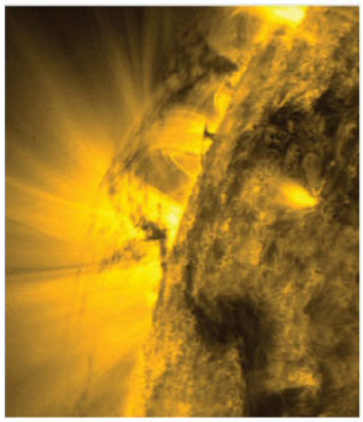
The science of music 38

25 **Future motorcycles**

52 **Real-life Star Wars tech**

64 **Water worlds**

REGULARS



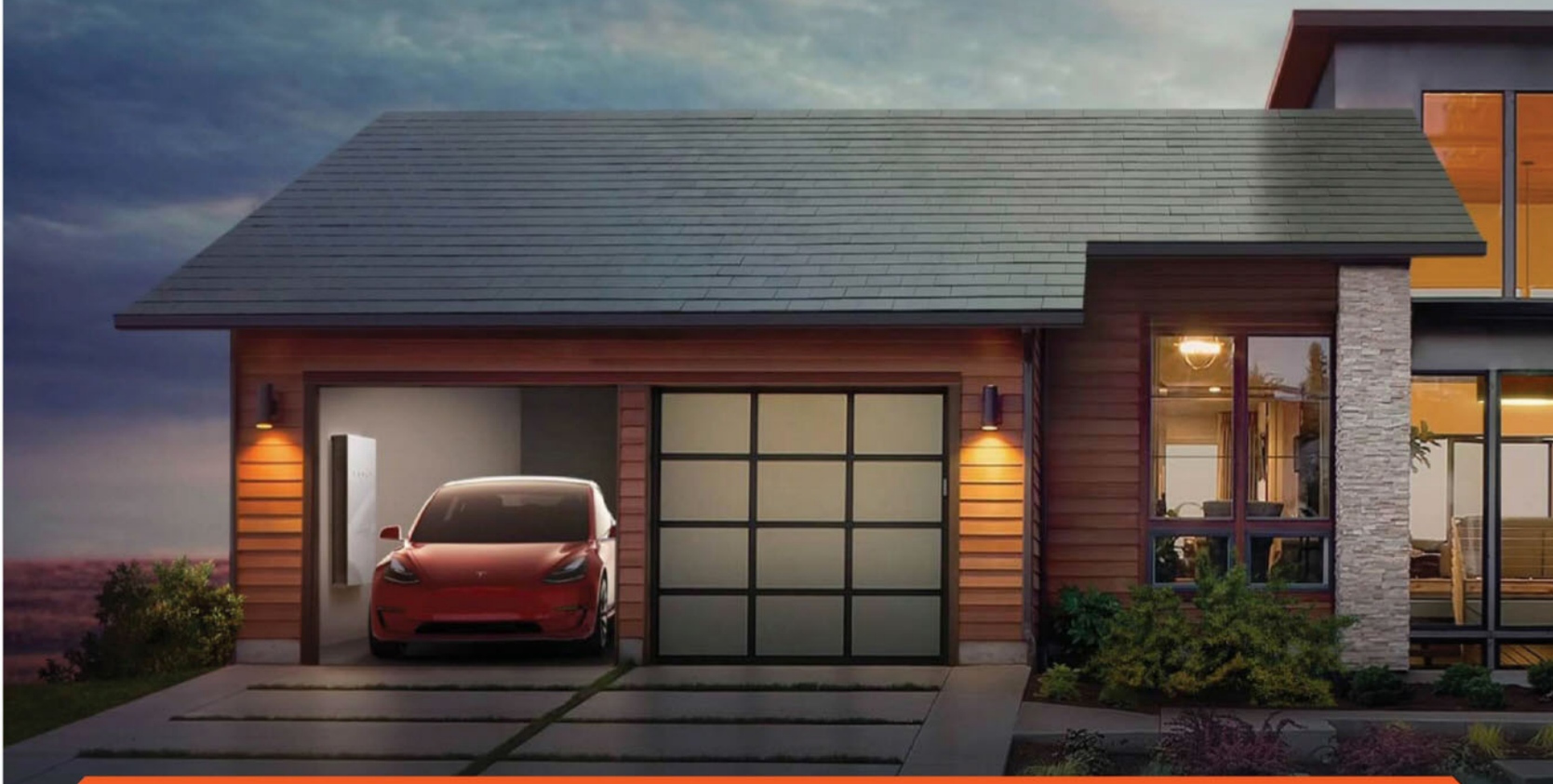
Tesla announces new solar panels

The solar roof that could revolutionise how we harness the Sun's energy

Solar panels are often criticised for being bulky and unattractive, but Tesla's latest development could be about to change that. The solar roof – comprising hundreds of small panels that look like regular roof tiles – is another foray into renewable power by the US motor company, and will produce enough energy to power an average-sized house.

Each tile contains a solar cell encased in tempered glass. The coating is engineered to be as durable as standard slate roofs, withstanding even the heaviest of hailstorms. Installing the roof is projected to cost approximately $6,500 (£5,200), but company CEO Elon Musk has promised it will be cost-effective, resulting in substantial savings on household energy bills.

To give the roof a sleek, high-end finish, the solar cells in the tiles can only be seen from above when exposed to sunlight; they are invisible from the street. And, while the efficiency of these more aesthetically pleasing tiles is reduced by around two per cent, they could convert millions of homes to renewable energy when released next year, alongside Tesla's Model 3.

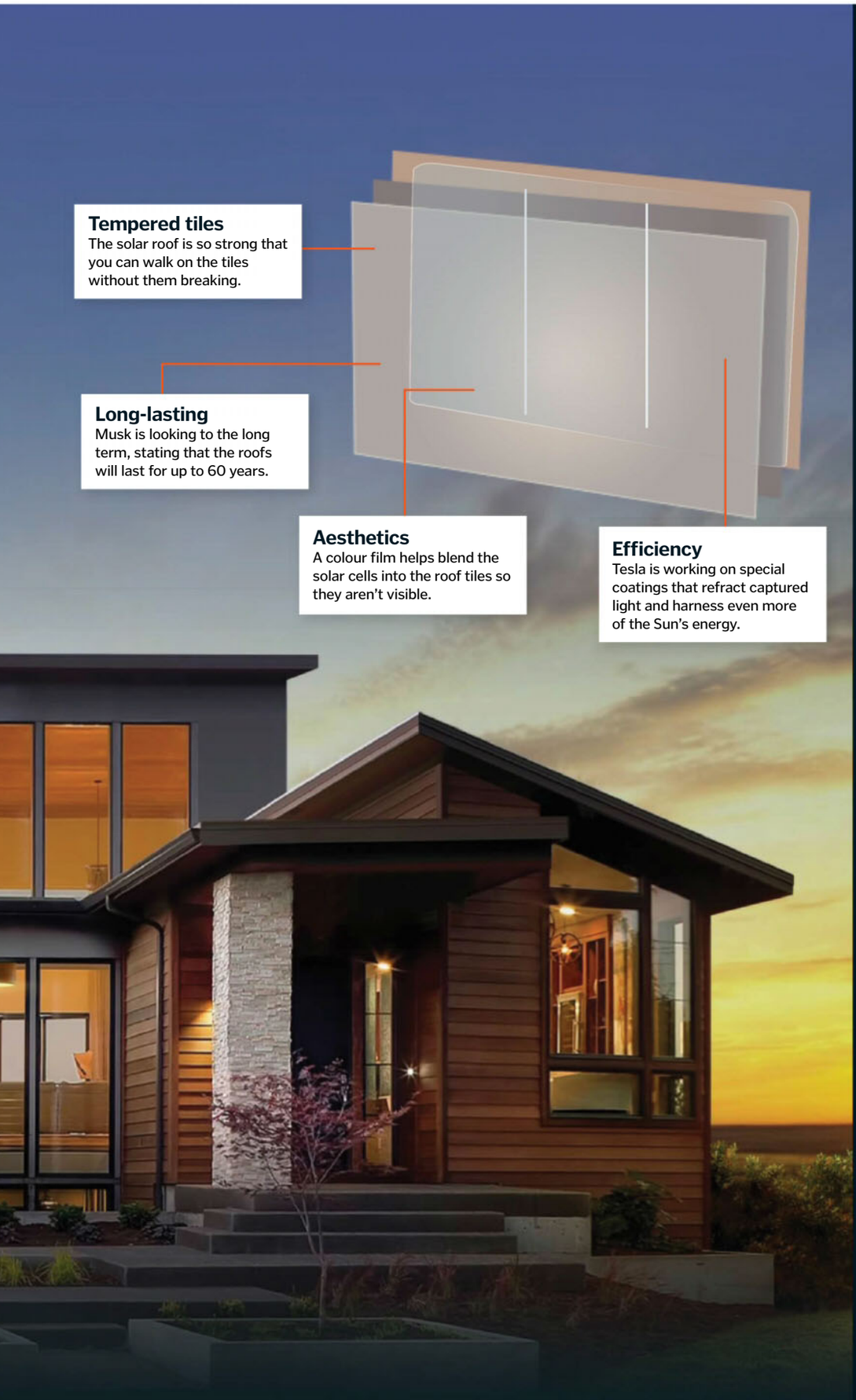


Powerwall 2

Another of Tesla's Energy products is the Powerwall 2. An update of the original Powerwall, this rechargeable lithium-ion home battery is installed on the wall of a house. When the Sun is shining, the solar roof will charge the Powerwall 2, which will store energy for use both day and night. The Powerwall 2 will also act as a back-up generator and will kick in if the tiles experience any power outages during extreme weather.

Musk is incredibly confident that these eco-friendly home batteries will become popular, so much so that the CEO has predicted that the Powerwall 2 will outsell Tesla's vehicle range after its release in 2017.

With double the energy of its predecessor, Powerwall 2 can power a two-bedroom house all day



Tempered tiles
The solar roof is so strong that you can walk on the tiles without them breaking.

Long-lasting
Musk is looking to the long term, stating that the roofs will last for up to 60 years.

Aesthetics
A colour film helps blend the solar cells into the roof tiles so they aren't visible.

Efficiency
Tesla is working on special coatings that refract captured light and harness even more of the Sun's energy.

"Tesla CEO Elon Musk has promised the solar roof will be cost-effective, resulting in substantial savings on energy bills"

Smooth glass tile
These futuristic tiles provide a sleek, even appearance.

Tuscan glass tile
This tile replicates those used on many Mediterranean-style homes.

Textured glass tile
These tiles offer a slightly more rugged look.

Slate glass tile
These 'slate' tiles would be difficult to distinguish from the real thing.

CHINA LAUNCHES ITS LARGEST EVER ROCKET

The Long March 5 is a giant leap towards the first Chinese space station

China has made a huge step forwards in its ambition to become a new space superpower. Lifting off from the Wenchang Space Launch Center on 3 November, thousands watched on as the 869-ton Long March 5 made its maiden flight. It is the biggest rocket ever launched by the nation, and the successful test demonstrates China's aspirations to rival NASA in space exploration.

Using fuel made from a mixture of kerosene and liquid hydrogen, the rocket is more environmentally friendly and has more thrust than its predecessors, Long March 2, 3 and 4. The rocket's greatest asset, however, is its ability to carry huge payloads of up to 14 tons into orbit. Long March 5 blasted off with the satellite Shijian-17 in tow, which will test the use of solar and battery-powered space propulsion for future greener missions.

The event is only the start for China's future space missions. Next year the unmanned robotic probe Chang'e 5 will be sent to the Moon to retrieve samples, the first lunar exploration mission to do this since the 1970s. This will be followed by an even bolder mission in the summer of 2020 when an orbiter, lander and rover is due to be sent to Mars. Two years on from that, China hopes to replace the temporary Tiangong-2 space station with a permanent version. Rockets like the Long March 5 will be essential in realising this ambitious vision.

Delta IV
US

Proton-M
Russia

Ariane 5
Europe

The Long March 5 lifted off from the Wenchang Space Launch Center on Hainan Island in southern China

NEWS BY NUMBERS

48

The number of new electric vehicle 'charging corridors' to be built in the US

57.9%

The estimated voter turnout in the US presidential election, 0.7% less than in 2012

26g

The weight of the world's heaviest earthworm, almost twice the weight of any other on record

40%

The predicted boost in grain yield in the UK from new genetically modified wheat

The LUTZ Pathfinder successfully completed a one-kilometre circuit around Milton Keynes' business district

Self-driving vehicles hit UK streets

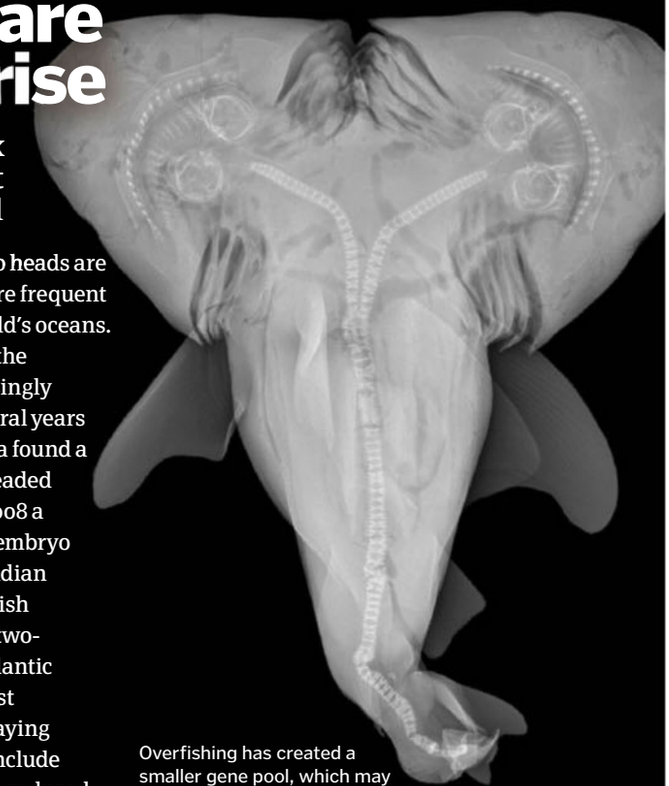
Scientists from the University of Oxford have successfully tested an autonomous car on public roads

On the streets of Milton Keynes, a self-driving vehicle has rolled into town. The LUTZ Pathfinder is the UK's first autonomous car to be tested in a public space, using cameras and LIDAR light sensors to navigate. The two-seater prototype runs using Selenium software that captures 20 high-definition images per second. The software was created by Oxbotica, a University of Oxford spin-out company, and the technology is the result of an 18-month project. Selenium is also set to be used in future public transport, with 40 more of these driverless cars to be released next year.

Two-headed sharks are on the rise

A mutated catshark embryo is the latest in a worrying trend

Sharks with two heads are becoming a more frequent sight in the world's oceans. Known as polycephaly, the condition is now surprisingly common in sharks. Several years ago, fishermen in Florida found a bull shark with a two-headed foetus in its uterus. In 2008 a two-headed blue shark embryo was discovered in the Indian Ocean. In October, Spanish researchers observed a two-headed embryo of an Atlantic sawtail catshark, the first documented in an egg-laying shark. Possible causes include pollution, infections or a reduced gene pool due to overfishing.



Overfishing has created a smaller gene pool, which may have led to a rise in these genetic abnormalities

Rare swordfish-like fossil unearthed

A 100-million-year old prehistoric predator has been unearthed in Australia

In the outback of northwest Queensland, the near-complete remains of a swordfish-like creature have been discovered. The extremely rare fossil was found by two families who were on holiday, and the bones are believed to be from a three-metre-long ray-finned fish called *Australopachycormus hurleyi*. The creature is similar in appearance to a swordfish (pictured), right down to the pointed snout. It swam the oceans while dinosaurs roamed the Earth and was a carnivore that preyed on other fish.

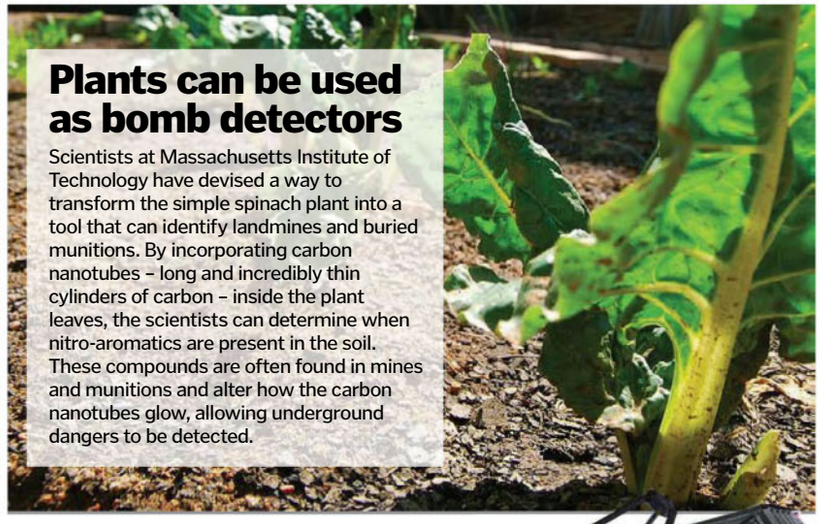
10 COOL THINGS WE LEARNED THIS MONTH

Heroic cells fight viruses with viruses

The marine microbe Cafeteria roenbergensis has an enemy – the giant CroV virus – which hijacks the organism's machinery to replicate itself, killing the microbe in the process. But the Cafeteria species has an ingenious defence mechanism; it releases a mavirus (a double-stranded DNA virus) stored inside its genome when infected. This doesn't save the microbe, but ensures that the virus can't destroy others. The tiny mavirus hijacks the CroV's replication mechanisms, which stops the infection from spreading to other cells.

Genes give chipmunks their stripes

A new study has shown that chipmunks' stripes are the result of a gene change. This mutation causes skin cells to stop producing melanin, a dark pigment, leaving white streaks through the dark patches on their backs. This is the same gene that gives many rodents their pale underbellies. These signature stripes are thought to help chipmunks hide from predators hunting from above, such as birds of prey.



Plants can be used as bomb detectors

Scientists at Massachusetts Institute of Technology have devised a way to transform the simple spinach plant into a tool that can identify landmines and buried munitions. By incorporating carbon nanotubes – long and incredibly thin cylinders of carbon – inside the plant leaves, the scientists can determine when nitro-aromatics are present in the soil. These compounds are often found in mines and munitions and alter how the carbon nanotubes glow, allowing underground dangers to be detected.

We'll soon be seeing outer space in 3D

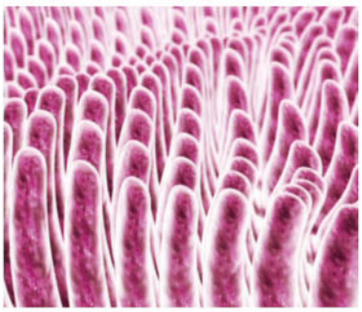
The James Webb Space Telescope will be joining Hubble in outer space in 2018, and together they will be able to paint a deeper picture of our Solar System than ever before. As the two will be separated by about 1.5 million kilometres, they'll be able to generate depth perception when pointed at the same object, providing us with a 3D view.

A volcano is ejecting heat from nowhere

The first 'cold-blooded' active volcano has been discovered. Unlike its volcanic neighbours, which are fuelled by magma rising from a tectonic plate subduction zone, researchers have been unable to find a heat source for the Mount St Helens volcano.

Roller-coasters can help dislodge kidney stones

Two researchers have found that riding roller-coasters may help with passing kidney stones. Their investigations, which involved repeatedly riding a roller-coaster with a 3D-printed kidney tucked beside them in a backpack, began after three separate patients told them how visiting the rides had helped them pass their stones. They found that around 64 per cent of their artificial stones cleared after a single spin.



Our intestines have inspired a new battery

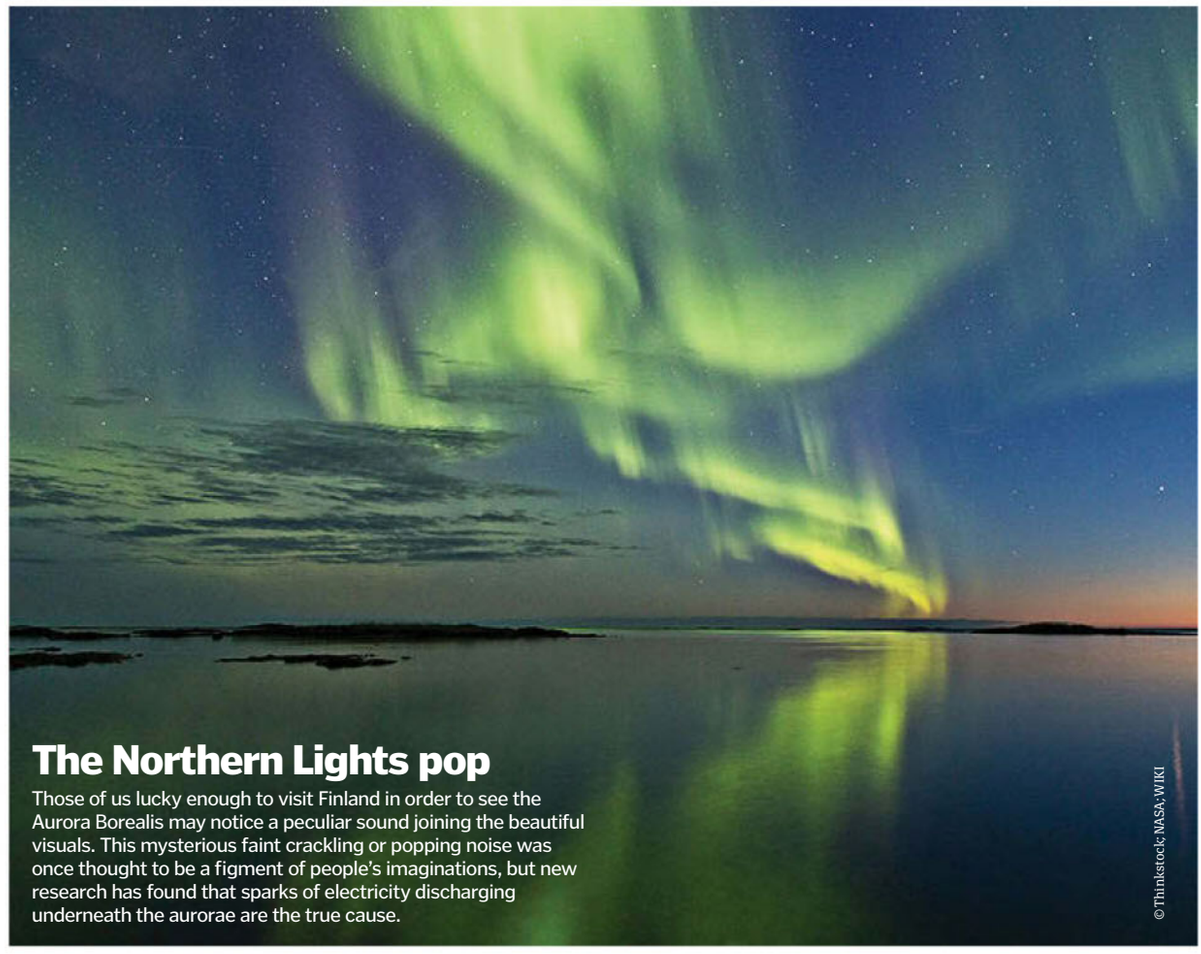
Lithium-sulphur batteries could theoretically hold far more energy than the lithium-ion ones used today. But realising their potential means clearing some hurdles, such as their rapid degradation. Scientists recently developed a nano-layer of protrusions – similar to the microscopic villi in our intestines – to prevent the loss of active material by trapping tiny fragments.

We're hunting for an alien megastructure

The Breakthrough Listen project, an initiative committed to spending $100 million (£80 million) in the search for alien life, has turned its attention to a curious anomaly in space known as 'Tabby's Star'. This star has peaked considerable interest thanks to its irregular dimming pattern, and some optimistic scientists believe this could be due to an alien megastructure that's blocking the flow of light. The Green Bank Telescope, a sophisticated radio telescope in West Virginia, US, will soon be investigating.

Parrots once inhabited Siberia

The very first parrot fossil has been discovered near Lake Baikal in Russia, the furthest north such a bone has ever been found. The fossil has been dated at between 16 and 18 million years old, and suggests that the birds may once have populated Eurasia as well as sub-tropical regions.



The Northern Lights pop

Those of us lucky enough to visit Finland in order to see the Aurora Borealis may notice a peculiar sound joining the beautiful visuals. This mysterious faint crackling or popping noise was once thought to be a figment of people's imaginations, but new research has found that sparks of electricity discharging underneath the aurorae are the true cause.

A mechanical design engineer

How to customise helicopters to meet the requirements of clients from across the globe

At the Airbus Helicopters headquarters in Oxford, UK, Gordon Bailey and his team prepare the design data for structural and mechanical components installed on aircraft. Using computer-based design software such as CATIA 3D, they take an idea on paper and develop it not just into a helicopter, but a sophisticated tool that will accomplish the customer's mission; whether that's for emergency, military, business or private services.

Today's project is to construct Human External Cargo baskets. These structures are suspended from helicopters and allow essential maintenance on live high-voltage power lines to be completed safely. We spoke to Gordon about his role in a design department that is recognised as an international centre of excellence.

Gordon and his team are involved in the design of helicopter components from concept to completion

SORTING THE SCHEDULE
8am

After a quick check of my emails, I review the planned activities for the day ahead. I have a team of people who work with me so my responsibility is for them to have clear objectives for the day. We are the first step in a chain of work so it's essential that we keep to scheduled completion dates.

DAILY MEETING
9am

Every morning we have a build review meeting on the hangar floor. We are all updated on task progress and if we have any issues, they are raised and then addressed. We have to investigate the root cause of any problems and develop a solution that can be incorporated into the design, and therefore the aircraft. With a platform as complex as a helicopter with more than 3,000 dynamic components, issue resolution is one of the key jobs.

After the parts are designed, the mechanical design engineers get hands on to approve safety standards

"One of our current projects is to design 'baskets' that suspend from a helicopter"

Airbus Helicopters is the world's leading manufacturer of helicopters, employing over 23,000 people

The designs are created using a 3D software package called CATIA

TESTING THE MATERIALS
10.30am

We organise a variety of tests to make sure the design is safe to use. If we are working on an interior fit, flammability tests are undertaken, as everything we produce must meet European Aviation Safety Agency requirements. We conduct burn tests on material samples, review the results and then certify materials for safe use on the helicopter.

WORKING ON THE BASKETS
11.30am

One of our current projects is to design 'baskets' that are suspended below a hovering helicopter, allowing operators to perform maintenance work on power lines. In the basket, workers will be protected from 400,000 volts by Faraday cage technology. We have to make sure that all the components within the basket are all connected to prevent any dangerous electrical hot spots building up.

LIAISING WITH MANUFACTURERS
1.30pm

We frequently liaise with the manufacturing areas of the company in order to support the build and completion of the designs. During the construction of the baskets, a number of minor amendments may be required to ease manufacture. For instance, the manufacturers could request that different materials are used to what we have suggested, due to the availability of certain supplies. A constant review process is required to ensure the successful completion of the basket build.

FURTHER TESTING
3.30pm

We often get involved in the testing and certification of our designs. This can range from ground-based vibration testing and environmental testing of new equipment, to supporting flight testing, which ensures the product works safely and meets the performance requirements.

END OF THE WORKING DAY
5.30pm

The day ends with a review of the progress made on all the tasks currently in work, with a look ahead to what will be undertaken the next day and in coming days. The job isn't for the faint-hearted, but the variety of work and the challenges it offers make it exciting and, once delivery is complete, rewarding!

5 TIMES THE SPEED OF SOUND

HYPERSONIC FLIGHT

Inside the planes that will smash supersonic records

Blink and you'll miss them, but you'll definitely hear them. Hypersonic aircraft may look similar to the jet planes we're familiar with, but these engineering marvels are completely different beasts. Able to attain speeds that would literally tear a conventional passenger jet apart, hypersonic aircraft possess unique engines, are built from advanced materials and are packed full of intelligent tech.

So just how fast are they? By definition, a supersonic vehicle can move faster than the speed of sound – or Mach 1 – which is 1,235 kilometres per hour, or 343 metres per second. But to be classed as hypersonic, planes must fly at least five times this speed – 6,175 kilometres per hour, or 1,715 metres per second. And their speed isn't limited to Mach 5; that's just the beginning. We've already created aircraft that can reach Mach 20 – that's nearly seven kilometres per second! As long as these vehicles can withstand the pressure in the atmosphere, they can keep moving faster and faster.

For over 30 years we were able to use Concorde to fly at supersonic speeds. It broke through the sound barrier and revolutionised air travel. But now the aim is to go faster than ever, with jets and commercial airliners capable of reaching even greater speeds. This is, of course, no simple task, but little over a century after the Wright brothers first took to the skies, we're still building new and innovative aircraft. This technology reveals new realms of possibility that would make air travel more efficient and convenient than ever before. Imagine travelling halfway around the world in just a few hours, or seeing a spacecraft climb into the upper atmosphere without a gigantic rocket.

The most exciting part is that this isn't the stuff of science fiction – we've already flown vehicles at hypersonic speeds, and researchers are now developing hypersonic planes suitable for public use. Read on for more of these incredible feats of engineering and the faster world that awaits us.

"Hypersonic aircraft attain speeds that would tear a conventional passenger jet apart"

Hypersonic vs supersonic

For many years experts believed it was simply impossible to fly faster than the speed of sound. But that all changed in the 1940s, when US test pilot Chuck Yeager flew faster than Mach 1 – the speed of sound – for the first time in human history.

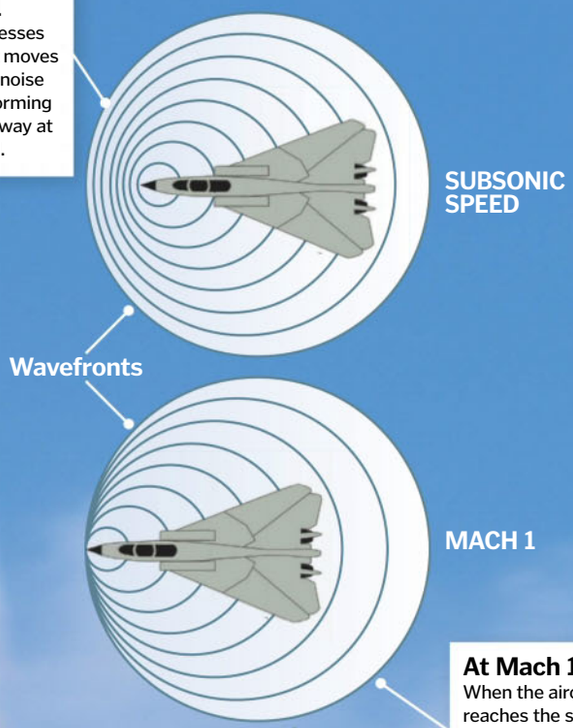
Onlookers below heard the sonic boom as the pressurised air gave way to the Bell X-1 rocket plane, and they realised that supersonic aircraft were dealing with new extremes.

But although supersonic aircraft have to overcome many obstacles to break the sound barrier, these factors are compounded when moving at hypersonic speeds. At Mach 5 and above, the air does more than just form shock waves. At such high speeds, the air heats the surface of the aircraft to very high temperatures – enough to melt steel – and the engines have to cope with huge pressures.

What causes a sonic boom?

Why breaking through the sound barrier is such a noisy affair

Below Mach 1
The aircraft compresses the air in front as it moves forward and emits noise from its engines, forming waves that move away at the speed of sound.



At Mach 1
When the aircraft reaches the speed of sound, the air being compressed cannot move away fast enough, so the waves accumulate at the nose of the plane.

Continuous boom
An aircraft travelling faster than Mach 1 is constantly producing shock waves, which merge to form a cone. In certain conditions, this is visible as a conical cloud of water vapour.

Around 75 passengers could be transported at Mach 10 inside the Skreemr

Above Mach 1
As the plane exceeds the speed of sound, it overtakes the waves. This causes a change in air pressure, or a shock wave, which is heard as a sonic boom.

BUILDING A HYPERSONIC VEHICLE

The challenges and successes in the engineering community's quest for hypersonic flight

Supersonic aircraft such as Concorde differed greatly from their subsonic counterparts. They had adapted wing designs and advanced engines. These changes allowed Concorde to smash through the sound barrier, which is something subsonic commercial jets were simply unable to do.

The difference between a supersonic and a hypersonic aircraft is even more striking, because at hypersonic speeds the rules change completely. The previously benign air starts to become a serious problem, as aircraft moving at hypersonic speed generate huge amounts of friction. This results in temperatures hot enough to melt the frame of a standard jet, so hypersonic aircraft must be built from robust heat-resistant materials such as ceramics. And they can't stop there, because even if they are able to withstand the heat, the pressure at low altitudes is simply too great to fly at hypersonic speeds. Hypersonic vehicles need to climb high up into the atmosphere, where the air is much thinner, in order to lessen the strain on the aircraft.

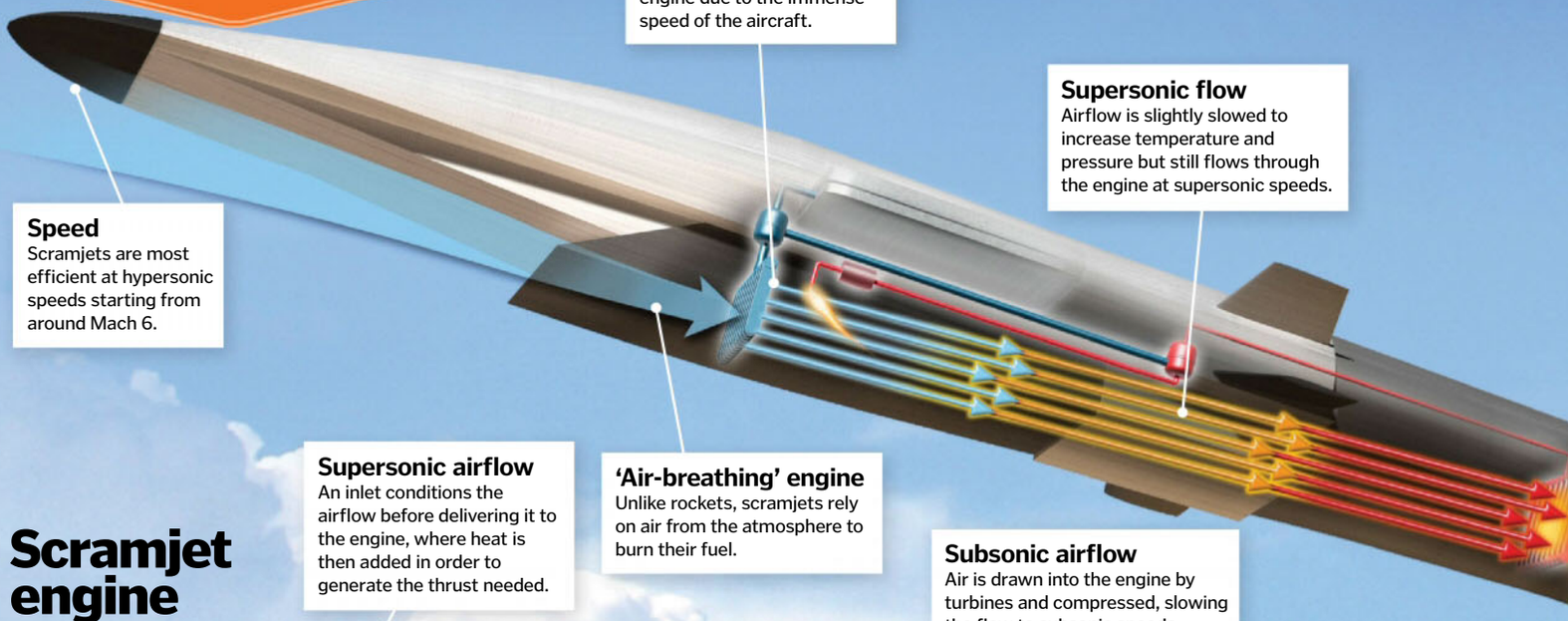
Perhaps the biggest consequence of the intense airflow is that hypersonic vehicles can't even use the same engines as subsonic aircraft. Air moving through supersonic plane engines does so at subsonic speeds (the supersonic airflow is slowed by an engine inlet), but if you tried using a similar setup when travelling at hypersonic speeds, it would melt or simply explode before your eyes. But rather than rely on rocket engines – the only proven systems to power hypersonic vehicles – engineers asked themselves a more ambitious question: could we take what we've learned about the jet engine and design an equivalent that works at high supersonic, and even hypersonic, speeds?

This led to the invention of the supersonic combustible ramjet, or scramjet. Taking the principles of a jet engine and stripping away all of the unnecessary components for hypersonic travel – such as a turbine and a compressor – allows air to move through much more quickly. With few moving parts, these simple-looking engines produce enough thrust for an aircraft to soar at incredible speeds; and in doing so, have started to bring the future of air travel to life.

The scramjet

Meet the supersonic combusting scramjet, an engine that thrives at hypersonic speeds

"At hypersonic speeds the rules change completely"



'Ramming'
Air is forcibly packed into the engine due to the immense speed of the aircraft.

Supersonic flow
Airflow is slightly slowed to increase temperature and pressure but still flows through the engine at supersonic speeds.

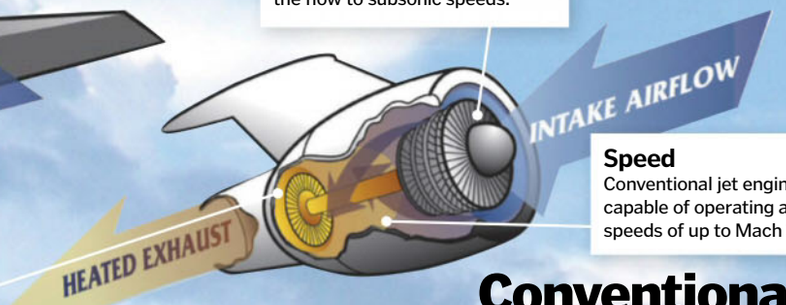
Speed
Scramjets are most efficient at hypersonic speeds starting from around Mach 6.

'Air-breathing' engine
Unlike rockets, scramjets rely on air from the atmosphere to burn their fuel.

Supersonic airflow
An inlet conditions the airflow before delivering it to the engine, where heat is then added in order to generate the thrust needed.

Subsonic airflow
Air is drawn into the engine by turbines and compressed, slowing the flow to subsonic speeds.

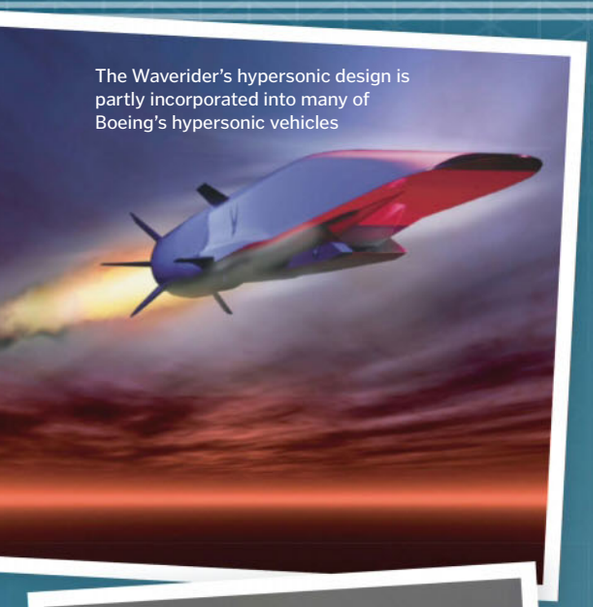
Scramjet engine



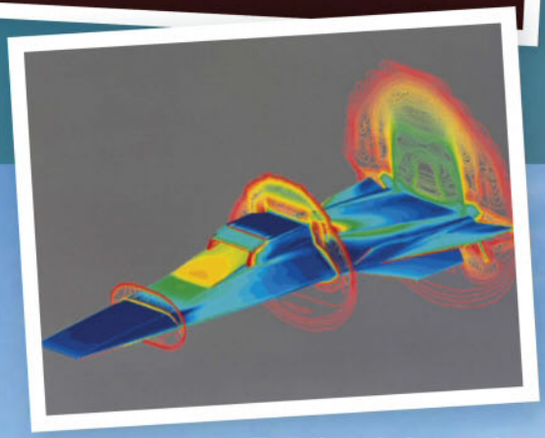
Speed
Conventional jet engines are capable of operating at speeds of up to Mach 3.5.

Combustion
Compressed air combusts the fuel source and leaves at a higher temperature and pressure through the exhaust, producing thrust.

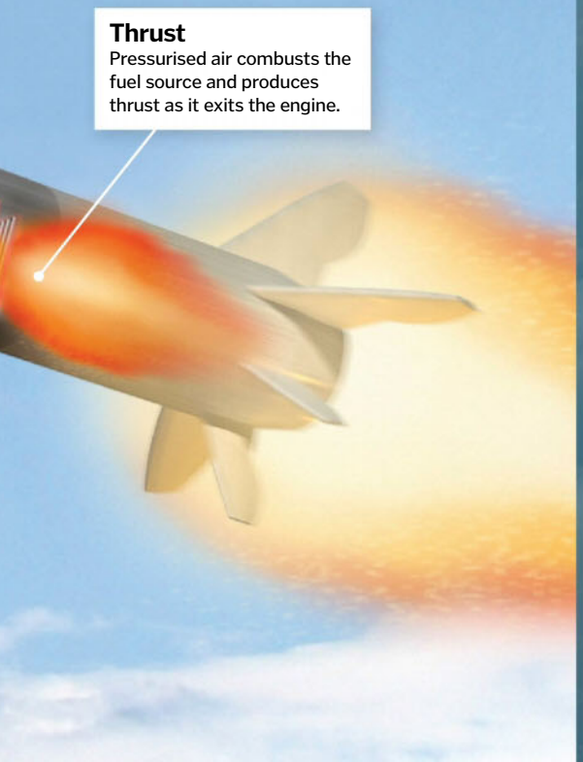
Conventional jet engine



The Waverider's hypersonic design is partly incorporated into many of Boeing's hypersonic vehicles



The X-43 was the first aircraft to travel at Mach 7, enduring 1,650 degrees Celsius in the process



MAKING HYPERSONIC FLIGHT A REALITY

We spoke with Boeing's chief scientist of hypersonics, Dr Kevin Bowcutt, about the future of high-speed travel

Dr Kevin Bowcutt is the senior technical fellow and chief scientist of hypersonics at Boeing. He is an AIAA Fellow, a Fellow of the Royal Aeronautical Society, and also a member of the National Academy of Engineering. He holds BS, MS and PhD degrees in aerospace engineering from the University of Maryland, US.

Why is Boeing so interested in hypersonic technology?
Boeing is interested in hypersonic technology for several reasons, including application to missiles, aircraft, and space planes. Hypersonic airplanes may someday whisk passengers and cargo across oceans in an hour or two, enabling international day trips. Perhaps most exciting of all, reusable hypersonic space planes may make transportation to Earth's orbit more like flying in an airplane than a rocket, and therefore much more affordable – up to 100-times cheaper.

What hypersonic technologies are you currently developing?
Key enablers to make hypersonic flight a reality include lighter and more durable high-temperature materials, increased hypersonic engine efficiency, and advanced sensing and data analysis technologies. On the technology front we are developing advanced high-temperature ceramic matrix composite materials, structures, and thermal protection systems. We are also developing, and have applied, advanced hypersonic vehicle design methods based on multidisciplinary design analysis and optimisation (MDAO). We have designed, and continue to study, hypersonic vehicle concepts such as missiles, reconnaissance aircraft, passenger airplanes, and reusable launch vehicles (space planes). We have built and successfully flown two scramjet-powered experimental vehicles, the NASA X-43A and the USAF/DARPA X-51A.

What are the main challenges you currently face?
Finding materials that withstand very high temperature, and that are lightweight and durable, remains a challenge, although good progress is being made in their development. Scaling up scramjets to larger sizes (beyond small jet engine size in terms of air flow rate) and speeds above Mach 7 is another difficulty due to ground testing limitations. Integrating low-speed and high-speed propulsion systems into combined cycle engines is another area for further development; combined cycle engines are required to accelerate from zero to hypersonic speed. Additional challenges include vehicle thermal management and thermo-structural health monitoring, as well as designing highly integrated systems such as hypersonic vehicles, driving the need for MDAO. On top of this, adequate funding is a perennial problem, although the situation is improving.

What is the overall goal of your project?
While Boeing is not developing a hypersonic airliner, and does not see a near-term demand for the product, we continue to research many advanced hypersonic concepts and technologies, so that we are prepared if the market develops for such vehicles. The potential for hypersonic aircraft in the future will require further advances in several areas of technology, as well as market demand. Ultimately, we want to help create the future of flight: ultra-rapid global transportation and routine and affordable space access.

How do you picture the future of hypersonic flight?
Although it's likely to be a few decades away, I envision a future where Mach 5 airplanes fly people between international cities in a couple of hours, and space planes routinely fly people to a hub in Earth's orbit for connecting flights to the Moon or Mars. Eventually, these vehicles will be powered by clean, high-density energy, probably some form of safe nuclear power.

THE FUTURE OF HYPERSONIC FLIGHT

Exploring the concepts that could one day replace the jet plane

If there's one lesson that we've learned about hypersonic flight so far, it's that heat, weight and power are all major obstacles. Too much weight, and you can't reach the desired speed. Too much heat, and your aircraft will melt mid-flight. And then there's the question of how we can power our machine to hypersonic speeds and keep it there. Fortunately, solutions for each of these critical problems have been suggested – and some seriously cool aircraft have been designed in the process.

Innovative engineers such as Charles Bombardier have been at the forefront of these endeavours. His envisioned aircraft, called Skreemr, would take to the skies with the help of an electrical launch system such as a railgun – so we could be bidding farewell to runways one day. A railgun is an electromagnetic strip that uses electricity to launch projectiles at incredible speeds, and could be used to fire the Skreemr into the air. This would eliminate the need for tons of extra rocket fuel for take-off, reducing the aircraft's weight considerably.

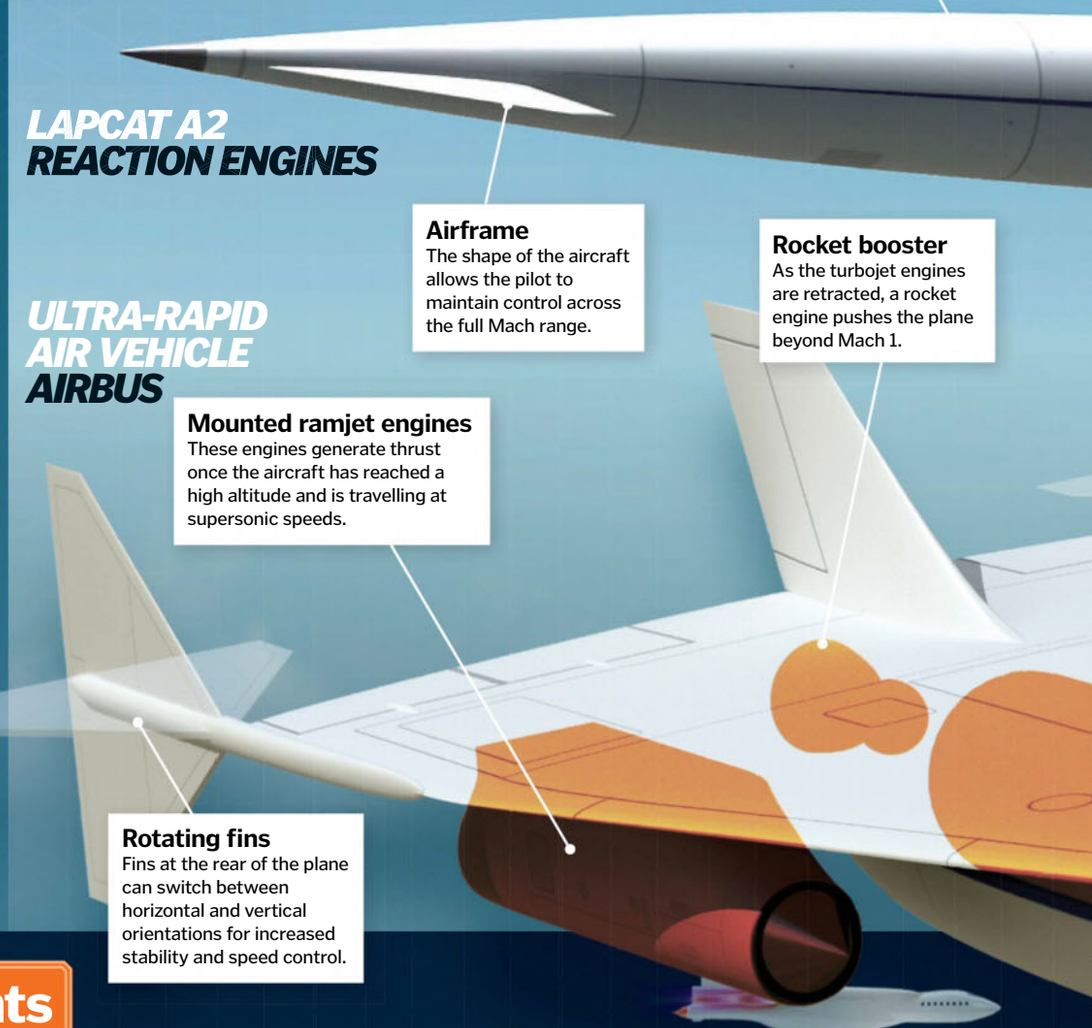
Another design by Bombardier, known as the Antipode, could tackle the heat problem as well as the menacing sonic boom. By using counter-flowing jets of air that move outwards in front of the aircraft, the temperature generated from aerodynamic friction and the sound produced by the sonic shock waves would be significantly reduced. And these features would help the Antipode fly up to Mach 24, equivalent to 29,500 kilometres per hour! These designs are still some time away from being realised, but Airbus and Reaction Engines have recently generated two concepts that could have us cruising at hypersonic speeds that much sooner.

Hypersonic hopefuls

Rival aerospace engineers are tackling the same mission in two very different ways

LAPCAT A2 REACTION ENGINES

ULTRA-RAPID AIR VEHICLE AIRBUS



Passengers
Up to 300 passengers plus baggage can be transported, ensuring ticket prices remain competitive with those of subsonic airliners.

Airframe
The shape of the aircraft allows the pilot to maintain control across the full Mach range.

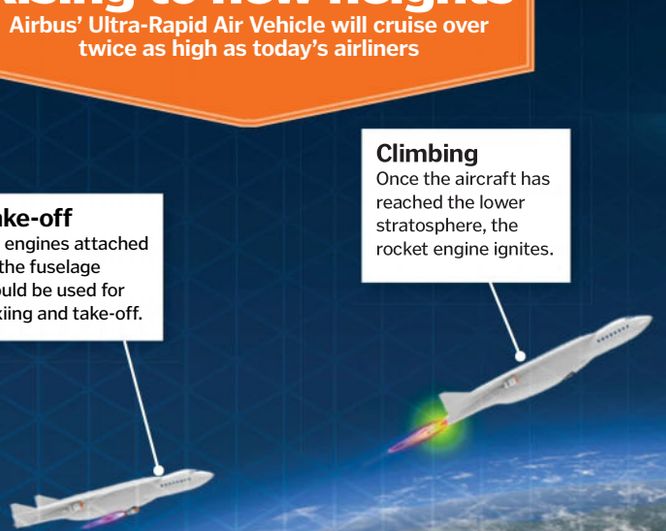
Rocket booster
As the turbojet engines are retracted, a rocket engine pushes the plane beyond Mach 1.

Mounted ramjet engines
These engines generate thrust once the aircraft has reached a high altitude and is travelling at supersonic speeds.

Rotating fins
Fins at the rear of the plane can switch between horizontal and vertical orientations for increased stability and speed control.

Rising to new heights

Airbus' Ultra-Rapid Air Vehicle will cruise over twice as high as today's airliners



Take-off
Jet engines attached to the fuselage would be used for taxiing and take-off.

Climbing
Once the aircraft has reached the lower stratosphere, the rocket engine ignites.

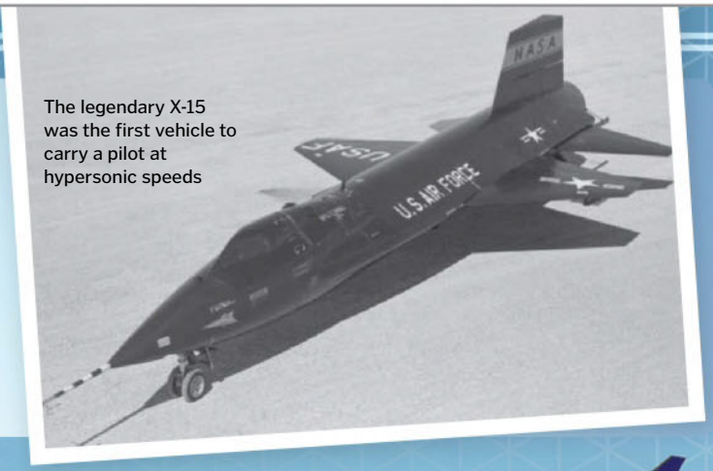
Accelerating
The aircraft breaks through the sound barrier while travelling vertically, causing the sonic boom to travel horizontally instead of towards the ground.

Cruising
Advanced ramjet engines are ignited when the aircraft reaches an altitude of 35km.

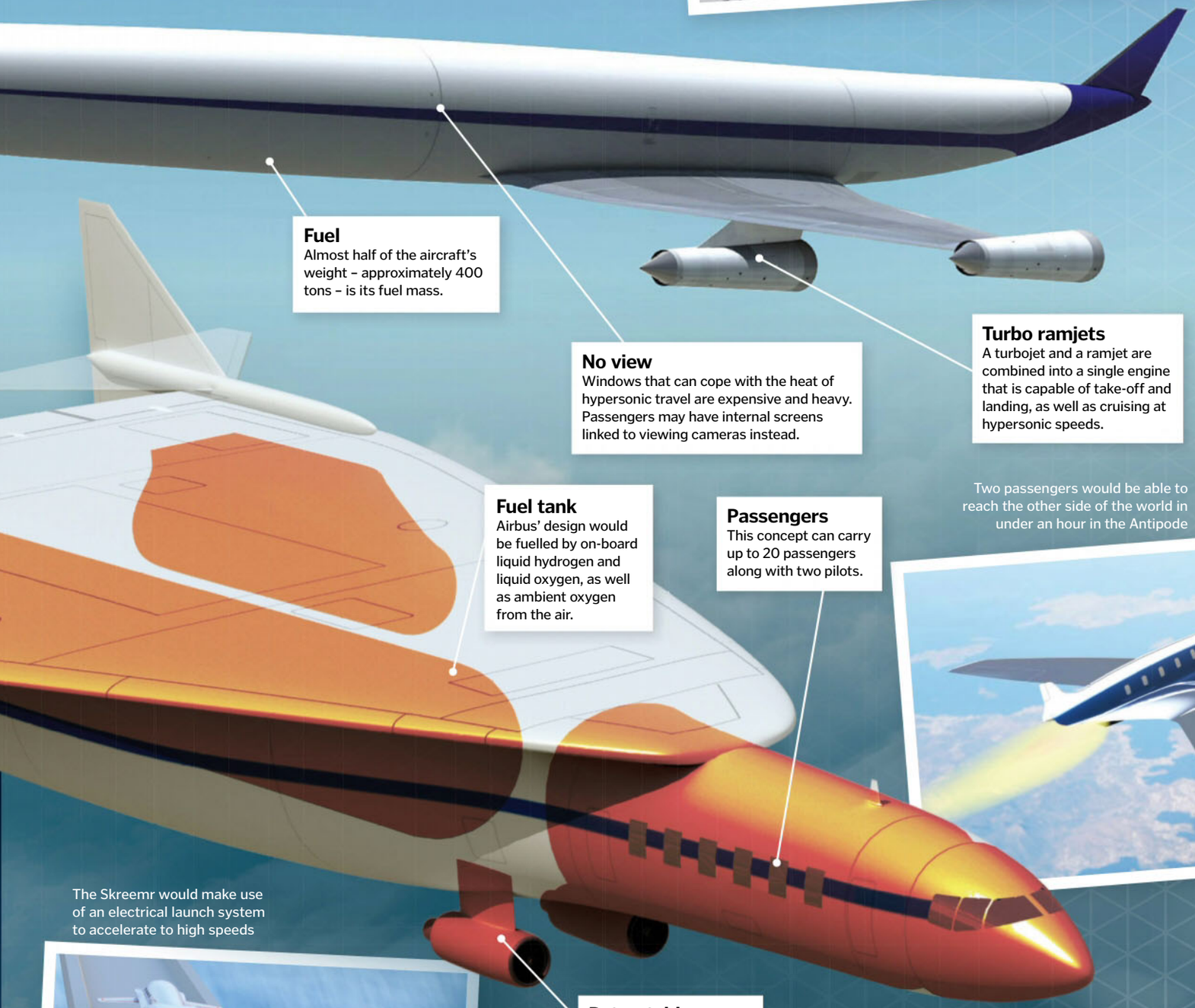
The history of hypersonic travel

It's been 60 years since a piloted vehicle first travelled faster than Mach 5, breaking the hypersonic barrier in a defining moment that showed the true possibility of space travel. The X-15 aircraft not only showed us that we could be carried at hypersonic speed, but taught us about how best to design, control and safely land a vehicle capable of achieving such a feat. The aircraft itself was essentially a rocket/plane hybrid, built to endure temperatures up to 700 degrees Celsius and fly at an altitude of over 100 kilometres, while being blasted through the air by a rocket engine at the rear.

Its achievements filled its creators with confidence that they could soon launch a vehicle into space at high speeds and bring it back into the atmosphere safely. Essentially, the X-15 played a role in putting humans on the Moon.



The legendary X-15 was the first vehicle to carry a pilot at hypersonic speeds



Fuel
Almost half of the aircraft's weight – approximately 400 tons – is its fuel mass.

No view
Windows that can cope with the heat of hypersonic travel are expensive and heavy. Passengers may have internal screens linked to viewing cameras instead.

Turbo ramjets
A turbojet and a ramjet are combined into a single engine that is capable of take-off and landing, as well as cruising at hypersonic speeds.

Fuel tank
Airbus' design would be fuelled by on-board liquid hydrogen and liquid oxygen, as well as ambient oxygen from the air.

Passengers
This concept can carry up to 20 passengers along with two pilots.

Two passengers would be able to reach the other side of the world in under an hour in the Antipode

The Skreemr would make use of an electrical launch system to accelerate to high speeds

Retractable turbojet engines
Conventional engines are used during take-off and are then withdrawn into the fuselage, making the vehicle more streamlined.

"We could be bidding farewell to runways one day"

HIGH-SPEED HOLIDAYS

It may soon be possible to watch the Sun rise in Paris and set in Tokyo

Most of us see travelling to the other side of the globe as the trip of a lifetime. Aside from the expense, these journeys take a very long time indeed. When we have to watch hours upon hours of in-flight entertainment on long-haul flights, it feels like we're lumbering through the air.

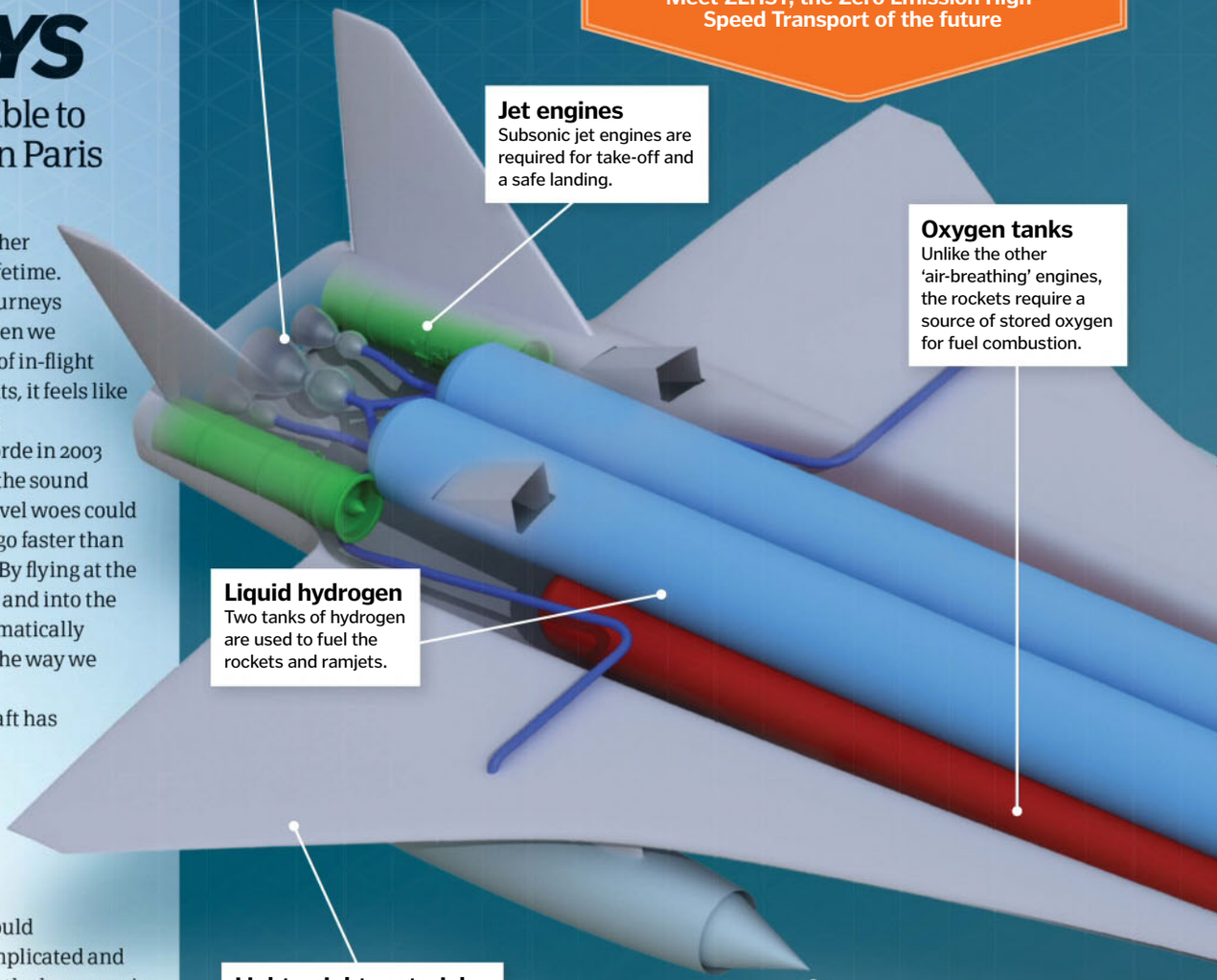
Ever since the world lost Concorde in 2003 we've been content to fly within the sound barrier. But the answer to our travel woes could be to punch right through it and go faster than any passenger plane has before. By flying at the upper limits of supersonic speed and into the hypersonic region, we could dramatically reduce travel times and change the way we explore the world.

The unique design of the aircraft has become the main challenge for revolutionising air travel. Most passengers probably wouldn't be comfortable strapping into a rocket and blasting across the planet. Using a rocket for international travel would also be infeasibly expensive, complicated and bad for the environment. Ideally, the hypersonic passenger carrier of the future will operate much like today's subsonic airliners. Passengers would be able to take their seats in a pressurised cabin, and the vehicle would be able to take-off and land unaided on a conventional runway.

Engineers have decided that using multiple engine types is the way to get this technology off the ground. Typical jet engines could be used for take-off and landing; a rocket engine could then propel us to great heights and speeds; and then the supersonic or hypersonic engine could take over. This would nevertheless be something of a thrill ride, as some designers believe their aircraft would have to take off near vertically! Those of us with a nervous disposition to flying may find it best to stick to the relatively sluggish speeds of a jumbo jet. However, for those holidaymakers and businesspeople who want to maximise the time spent at their destinations, and are willing to brave a vertical ascent into the atmosphere, hypersonic journeys will be the way forward.

Taking tourists to the upper stratosphere

Meet ZEHST, the Zero Emission High-Speed Transport of the future



Rocket power
Rockets take over from the jet engines after take-off to increase the aircraft's speed to at least Mach 2.5.

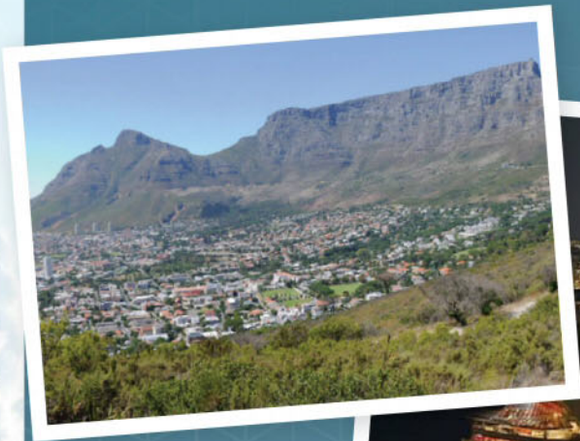
Jet engines
Subsonic jet engines are required for take-off and a safe landing.

Oxygen tanks
Unlike the other 'air-breathing' engines, the rockets require a source of stored oxygen for fuel combustion.

Liquid hydrogen
Two tanks of hydrogen are used to fuel the rockets and ramjets.

Lightweight materials
To compensate for the weight of multiple engines, the frame must be lightweight yet strong enough to endure high levels of aerodynamic drag.

Ramjets
When the aircraft's speed reaches 3,100km/h, air can be 'rammed' through the ramjets fast enough for the engines to produce thrust.



It would take a hypersonic vehicle only an hour and a half to travel from London to Cape Town

A hypersonic vehicle could get you from London to Sydney in less than three hours

Suppressing the sonic boom

Whether you're going supersonic or hypersonic, breaking the sound barrier is loud. As a vehicle accelerates, the waves of air pressure being pushed along by the frame begin to merge into one single shock wave. This air can travel at the speed of sound but as a vehicle surpasses this speed, a drastic change in pressure results in a deafening clap – a sonic boom.

The sonic boom is one major hurdle for aviation companies to overcome if hypersonic flight is going to be made available commercially. Concorde – the first and only public transport to break the sound barrier – was criticised for its volume and was only permitted to break the sound barrier over the ocean.

Like many aerospace issues, it could be NASA that comes to the rescue once again. The space agency and its partners at Lockheed Martin are in the process of designing an aircraft with many lifting surfaces to stop the airwaves from combining. The result would be a series of small booms rather than one big one – lowering the sound output to that of a normal conversation.

NASA and Lockheed Martin's Quiet Supersonic Technology (QueSST) X-plane design will be a step towards 'low-boom' supersonic travel

Helium tanks
Helium is used to pressurise the propellant tanks, allowing liquid hydrogen to be combusted in the rocket engines.

Passenger cabin
Up to 100 passengers can be carried in the pressurised cabin.

High altitude
To minimise air resistance the ZEHST would climb 32km above sea level for its journey – three-times higher than a Boeing 747!

Streamlined design
The pointed nose and narrow wingspan, reminiscent of Concorde, maximise the aerodynamics of the vehicle.

"Hypersonic travel would change the way we explore the world"

Goodbye long-haul flights

Domestic hypersonic travel promises to make the world feel a whole lot smaller

London to New York flight times

1hr	ZEHST	6,180km/h (Mach 5)
3.5hrs	Concorde	2,180km/h (Mach 2)
8hrs	Boeing 787	920km/h (Mach 0.85)


The pilot can also change the angle of the tail rotor to vary thrust

How a helicopter rotor works

Discover how helicopters take to the air and navigate the skies

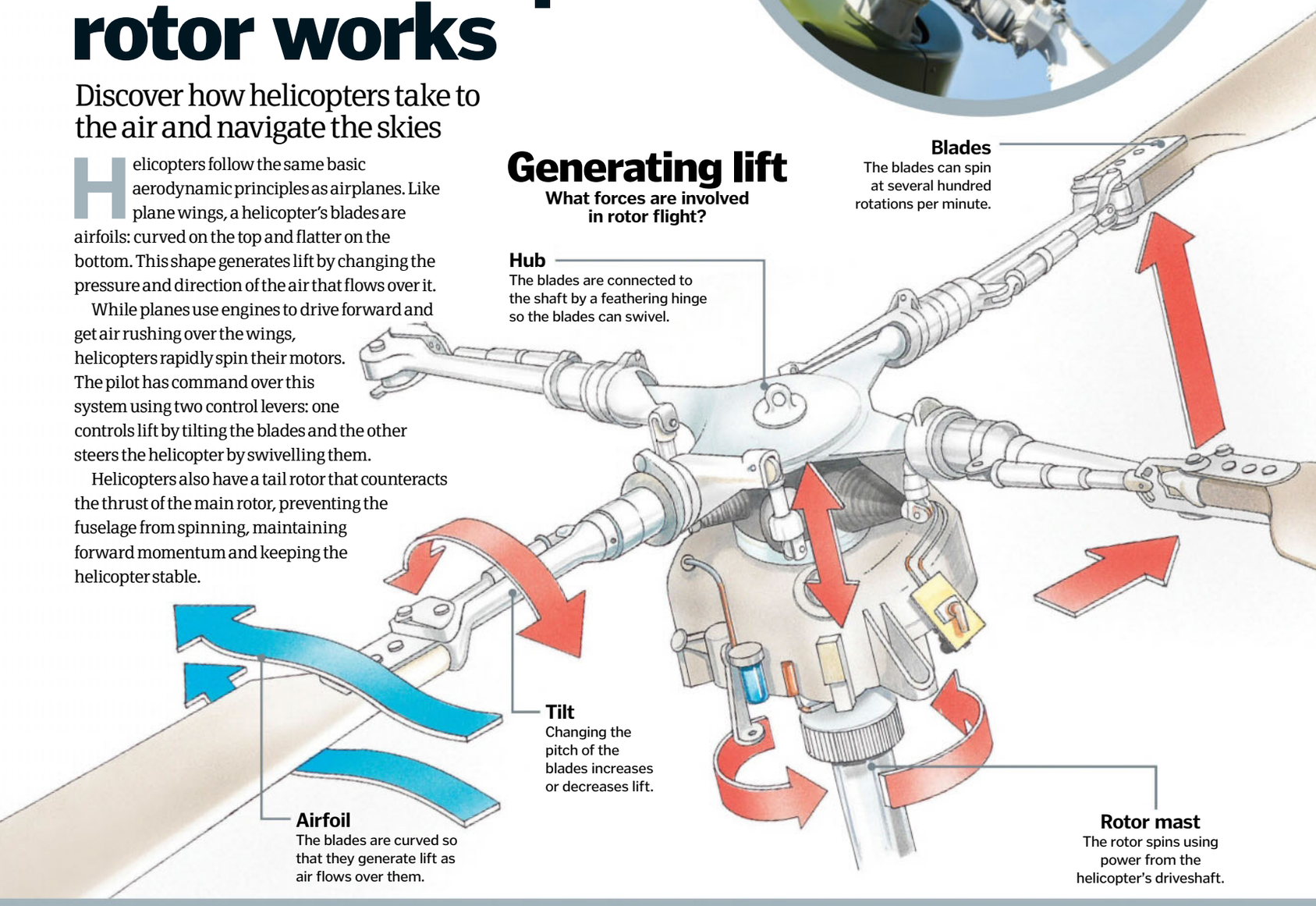
Helicopters follow the same basic aerodynamic principles as airplanes. Like plane wings, a helicopter's blades are airfoils: curved on the top and flatter on the bottom. This shape generates lift by changing the pressure and direction of the air that flows over it.

While planes use engines to drive forward and get air rushing over the wings, helicopters rapidly spin their motors. The pilot has command over this system using two control levers: one controls lift by tilting the blades and the other steers the helicopter by swivelling them.

Helicopters also have a tail rotor that counteracts the thrust of the main rotor, preventing the fuselage from spinning, maintaining forward momentum and keeping the helicopter stable.

Generating lift

What forces are involved in rotor flight?



Milk floats

Discover how milkmen made their rounds in the early inspiration for Tesla cars

It may seem that electric vehicles are a new phenomenon, but early models have actually been in use since the 1830s, pre-dating the petrol-powered car by approximately 40 years.

One of the most commonly used examples was the milk float, which began to replace the horse-drawn cart method of delivering milk during the 1940s. Thanks to its quiet battery-powered motor, it was ideal for making early morning deliveries in residential areas, and also proved to be a more economical option for the regular stopping and starting required on a milk round.

Although it could only reach speeds of 24 to 32 kilometres per hour, this was fast enough for going from street-to-street, and meant that drivers didn't have to constantly fasten and unfasten their seat belt. It also allowed the back of the van to be left open for easy access, with no danger of the milk being thrown across the road, although some featured sliding doors to keep the produce cold.

Today, due to an increase in the number of convenience stores selling milk, milk floats are not so common, but they've helped pave the way for other electric vehicles on the roads.

Hay balers

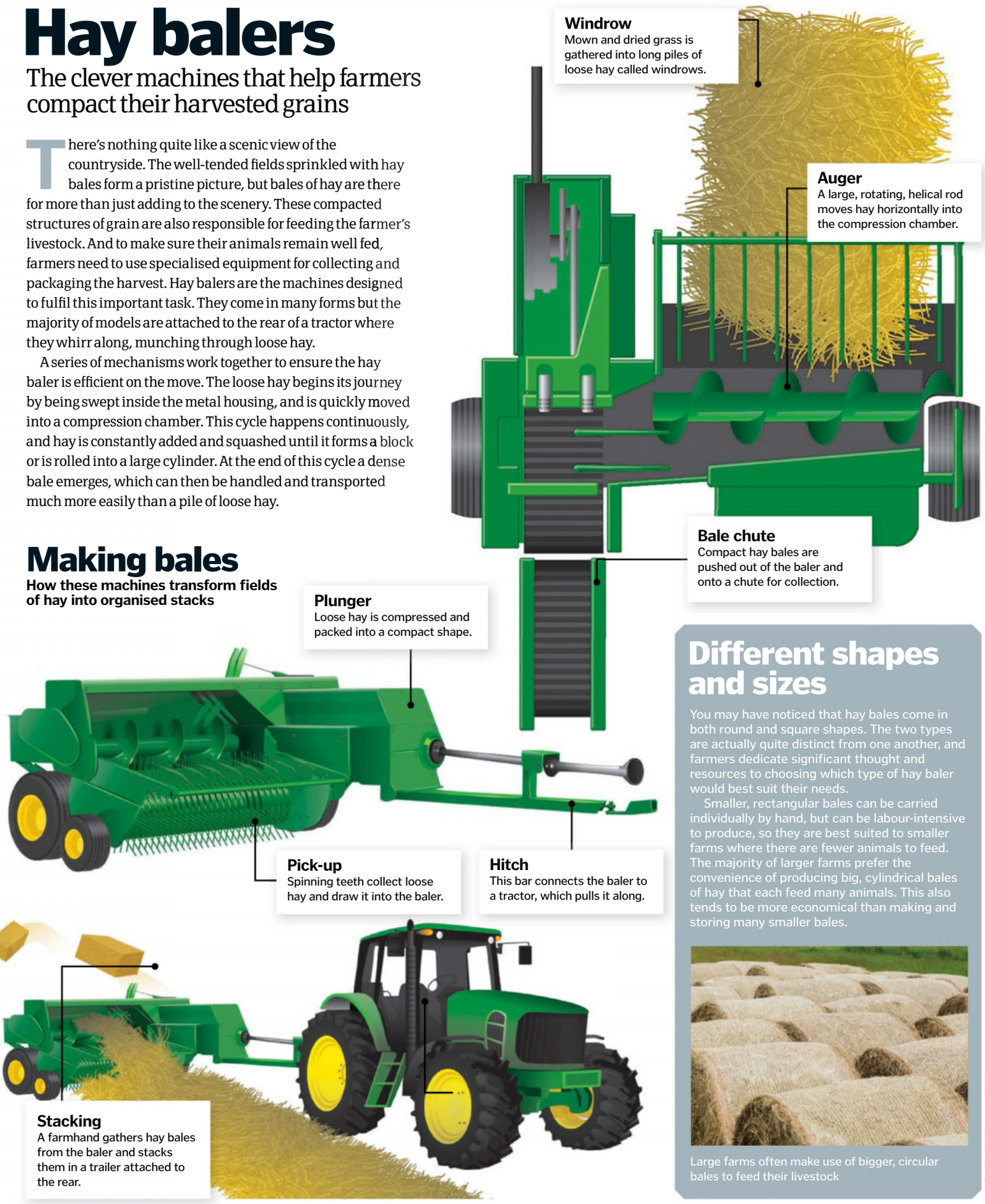
The clever machines that help farmers compact their harvested grains

There's nothing quite like a scenic view of the countryside. The well-tended fields sprinkled with hay bales form a pristine picture, but bales of hay are there for more than just adding to the scenery. These compacted structures of grain are also responsible for feeding the farmer's livestock. And to make sure their animals remain well fed, farmers need to use specialised equipment for collecting and packaging the harvest. Hay balers are the machines designed to fulfil this important task. They come in many forms but the majority of models are attached to the rear of a tractor where they whirr along, munching through loose hay.

A series of mechanisms work together to ensure the hay baler is efficient on the move. The loose hay begins its journey by being swept inside the metal housing, and is quickly moved into a compression chamber. This cycle happens continuously, and hay is constantly added and squashed until it forms a block or is rolled into a large cylinder. At the end of this cycle a dense bale emerges, which can then be handled and transported much more easily than a pile of loose hay.

Making bales

How these machines transform fields of hay into organised stacks



Different shapes and sizes

You may have noticed that hay bales come in both round and square shapes. The two types are actually quite distinct from one another, and farmers dedicate significant thought and resources to choosing which type of hay baler would best suit their needs.

Smaller, rectangular bales can be carried individually by hand, but can be labour-intensive to produce, so they are best suited to smaller farms where there are fewer animals to feed. The majority of larger farms prefer the convenience of producing big, cylindrical bales of hay that each feed many animals. This also tends to be more economical than making and storing many smaller bales.

Large farms often make use of bigger, circular bales to feed their livestock

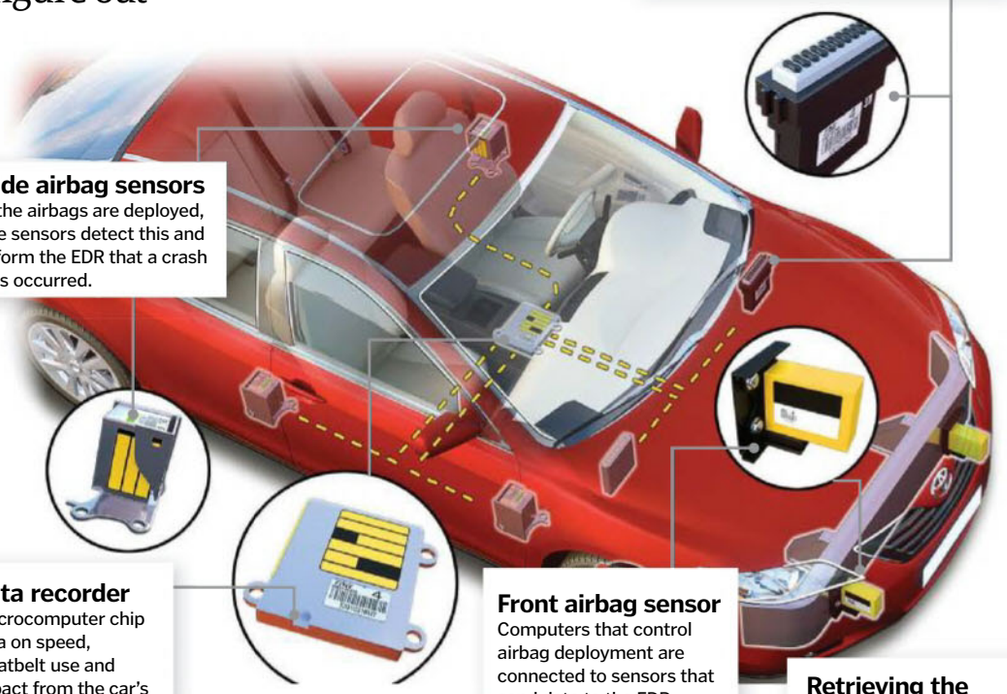
In-car data recorders

The black boxes that can help figure out the cause of a car crash

When you think of a black box, you probably think of the devices recovered from air crash sites, used by investigators to determine what went wrong. However, it's not just airplanes that have these clever computers on board. Most modern cars now come fitted with an event data recorder (EDR), more commonly known as a black box, which automatically activates in the event of a crash. The data it records can then be used by law enforcement agencies, insurance companies and car manufacturers to work out if the driver was at fault, or if the car malfunctioned prior to the accident.

Black box recording

Discover how these tiny devices can help to determine what happened during an accident



Anti-lock brake system computer
The braking system also sends data to the EDR, recording whether the driver braked or if there was a malfunction.

Side airbag sensors
If the airbags are deployed, the sensors detect this and inform the EDR that a crash has occurred.

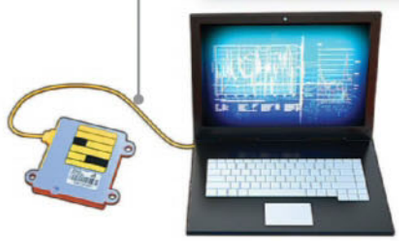
Event data recorder
This tiny microcomputer chip records data on speed, steering, seatbelt use and force of impact from the car's onboard computers.

Front airbag sensor
Computers that control airbag deployment are connected to sensors that send data to the EDR.

Retrieving the crash data
The EDR data is analysed to determine the driver's actions and the car's performance leading up to the crash.

Constant recording
The EDR continuously records data, storing five seconds' worth at a time before the next five seconds overwrite it.

In an accident
In the event of a crash, the EDR stores the data captured a few seconds before and after the airbags were deployed.



Tugboats

Discover how these small but mighty vessels guide megaships into port

As ships are getting bigger and harbours are becoming more crowded, the role of tugboats has never been more crucial. These sheepdogs of the sea are able to push, pull and turn ships a thousand times their size, herding them through narrow harbour entrances, helping them to parallel park, and then guiding them back out into the ocean. They can do this thanks to their immensely powerful diesel engines, which are capable of reaching up to 27,200 horsepower, and also the special way in which their hulls are designed.

A large portion of a tugboat lies under the water and it sinks even further as it accelerates. This increases its contact with the water, creating more friction and giving it more power. Tugboats are also very agile, thanks to two independently controlled propellers on the bottom of the hull. These can be turned 360 degrees, allowing the boat to move backwards, forwards and sideways to complete complex manoeuvres. They have an incredibly strong winch on board, allowing them to hook onto a ship and travel in the opposite direction, quickly and safely slowing it down.

They may be small in comparison, but without tugboats, megaships would never get into port

The future of motorcycles

BMW has unveiled a high-tech bike concept that is impossible to topple over

If the rider looks down while wearing the visor, a map of their route will appear

Predicting a future where most vehicles will be driverless, BMW hopes to still provide bikers with a thrilling, hands-on ride. To celebrate its centenary year, the company has unveiled the Motorrad VISION NEXT 100 concept, a high-tech bike designed for the digitally connected world of the future.

While it may look a bit like something from *Tron*, the motorcycle does in fact take inspiration from a classic, as the black triangle frame is a subtle reference to the R32, BMW's first ever motorcycle, released in 1923. However, this new upgrade has some rather more sophisticated features on board, including self-balancing technology. If the bike is about to tip over it will automatically right itself, even when stationary, meaning the rider won't fall off and can dismount without the need to flick out a stand.

Thanks to this safety feature, BMW doesn't foresee a need for riders to wear a helmet, instead equipping them with a special visor that acts as a digital companion. If they look straight ahead, symbols suggesting their ideal banking angle and warning of any upcoming hazards will appear in their field of view, while if they look up, a rear-view function will activate, allowing them to see what's going on behind. The accompanying suit is also designed to enhance the riding experience, with a neck section that inflates for support when accelerating.

The BMW Motorrad VISION NEXT 100

The bike BMW thinks you'll be riding three decades from now

1. Flexible frame
With no bearings or joints, the entire frame adjusts with a turn of the handlebars, changing the direction of the bike.

2. Zero emissions
Designed to look like a traditional BMW boxer engine, the fully electric power unit extends outwards when the bike is in motion.

3. Visor display
As well as providing wind protection, the visor also features an information display, which can be controlled by the rider's eye movements.

4. Comfortable suit
The suit monitors the rider's body temperature, adjusting the level of heat accordingly, and vibrates to give navigation instructions.

5. Adaptive tyres
The variable tread of the tyres automatically adjusts to grip onto any road surface, whatever the conditions.

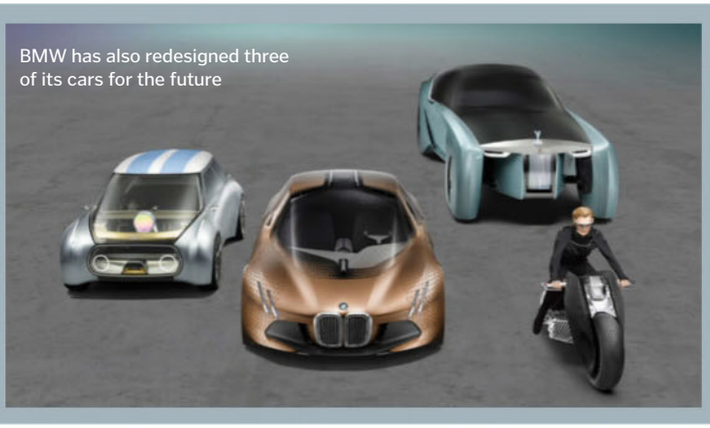
6. Modern materials
Under its matte-black fabric cover, the frame is made from carbon fibre, and so are the seat and wings.

More future vehicle concepts

The motorcycle isn't the only vehicle BMW has re-imagined for the future. As part of its VISION NEXT 100 exhibition, the company has also designed concepts for three of its car brands: MINI, Rolls Royce and BMW. The idea for the MINI is to have a network of cars available at all times, able to autonomously pick up drivers who can then adjust the car's appearance, driving characteristics and connectivity to suit their preferences.

The Rolls Royce, on the other hand, won't need a driver at all, as it will be controlled by a virtual personal assistant who can also fulfil your every wish throughout the journey. Customers will be able to create their own customised version of the car, which will be spacious enough for them to stand up inside.

The BMW combines the best of both worlds, allowing the driver to take the wheel themselves or hand over control if they want to sit back and relax.



BMW has also redesigned three of its cars for the future

AMAZING ANIMAL SURVIVAL SCIENCE

Animals have it tough, but using the laws of physics helps them to stay alive

We have it easy. Get hungry and our local shop will provide us with anything from an apple to a frosted cheesecake. If we're at home and thirsty we can walk several paces to a tap and access clean, fresh water. If we're chilly, we can turn up the heating or put on another jumper. All the while, nothing – on the whole – is trying to eat us.

Animals aren't so lucky – their world is far less comfortable. Fortunately they can exploit physics to survive. Mosquitoes in rainstorms, for example, play with Newton's laws, sticking to and travelling with raindrops that hit them to cut down the force of the impact and survive the collision. Bees, meanwhile, detect the electric fields given off by flowers to check whether the flower has enough nectar in stock. That way the bee saves time and energy while foraging for this sugary liquid. And the California spiny lobster uses the same friction technique as a violinist to make enough noise to scare away fish and other animals that want to eat it when it has moulted away its protective shell.

Like the bees that sense electric fields, other animals can also detect things that we can't. Turtles use the Earth's magnetic field to navigate, while ants, bees and many other species detect polarised light patterns in the sky to orient themselves. Many birds can see ultraviolet light, which has a frequency higher than our eyes can handle. These superhuman skills mean biologists must employ a physics kit to work out what these animals perceive.

Along the way, scientific discoveries, like that of polarised light, have helped us to fathom what animals are up to. Animals have helped us with scientific discoveries in turn – for instance, learning about electric eels was crucial in our development of the battery. Even today, in the field known as biomimicry, researchers copy animal designs to make tiny flying drones, 'shark-skin' swimming suits and more.

Meet the experts

Matin Durrani and Liz Kalaugher are science journalists at IOP Publishing in Bristol, UK. Matin heads up *Physics World* magazine and Liz edits **environmentalresearchweb**. Their first popular science book, *Furry Logic: The Physics of Animal Life*, is out now with Bloomsbury Sigma.

Liz Kalaugher

Matin Durrani

Japanese honeybees surround an attacking giant Japanese hornet in a buzzing ball that gets hot enough to kill it

Hot or not?

Temperature is crucial for animals; too warm or too cold and they could die

If you've ever gone swimming in the sea on a cold, windy day, you'll know how awful it can feel to immerse your entire body into cold water. And when you come out, how horrible it is to dash back to the beach, water dripping off your body whilst the droplets that remain on your skin evaporate to chill you further. We humans need to be within strict temperature limits – even a couple of degrees either side of 37 degrees Celsius and we can overheat or suffer from hypothermia. Fortunately, we're 'endotherms' and can generate our own heat by burning food and using our muscles to stay warm, though fluffy towels come in handy too.

Some animals, such as reptiles, butterflies and moths, can cope with a wider span of temperatures, but these 'ectotherms' can't generate their own heat and have to lie in the sun in order to get into their comfort zone. One snake is so desperate to get warm that it plays a rather cunning trick. Meet the red-sided garter snake, which lives in Manitoba in Canada, where winter temperatures fall to -40 degrees Celsius, forcing these animals to hunker down in underground hideouts for nine months of the year.

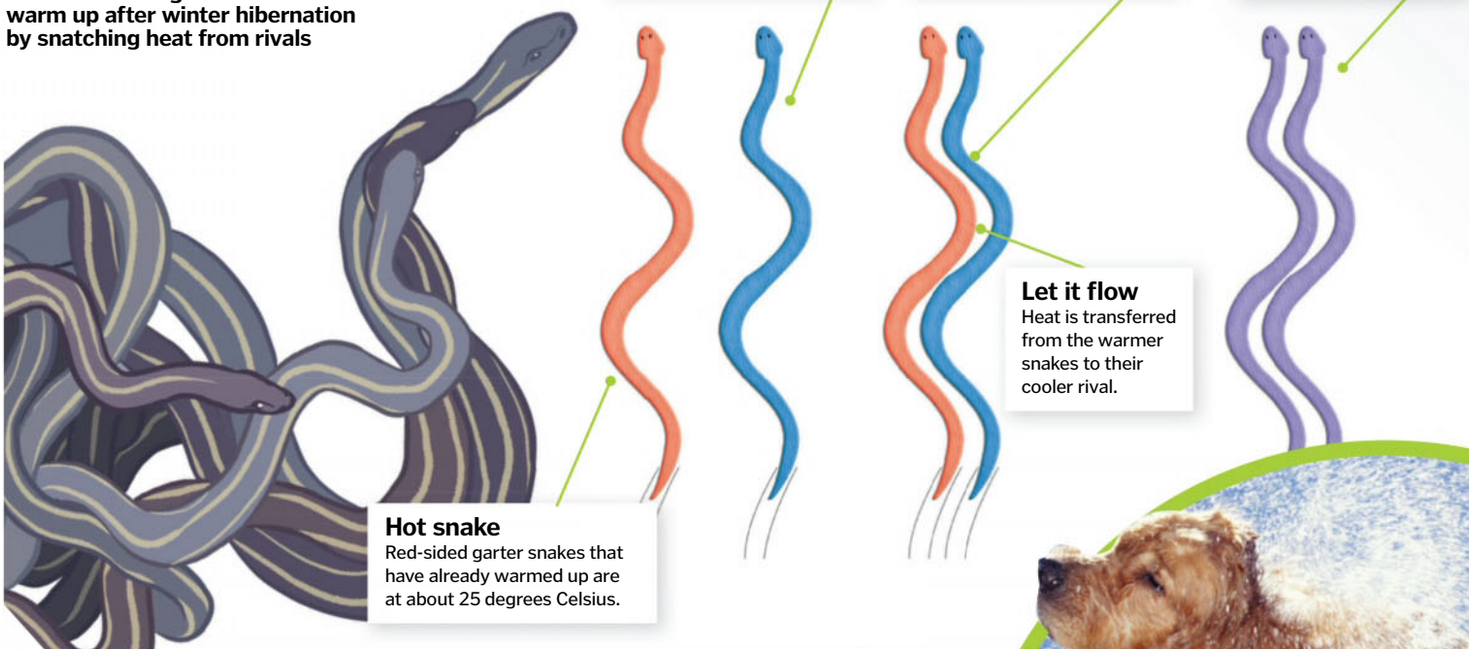
Once the male snakes emerge in spring, they lie in giant, heaving huddles, thousands strong – like a plate of squirming spaghetti – waiting for females to come out. But the females don't fancy being surrounded by gangs of amorous males and leg it, as far as that's possible for a snake. Spotting the mass of snakes, however, each new male emerging from its bunker covers itself in sex chemicals called pheromones that fool his rivals into thinking he's a female. The snake gets jumped on by the other guys, who believe he's a she – a 'she-male' in biologists' lingo.

The she-male isn't after sex; the snake simply wants to warm up, pronto. Stealing heat is known as kleptothermy, with all male red-sided garter snakes going through a she-male phase. It makes sense, as being cold and lethargic means the snake's a target for birds overhead that want a tasty snack. If survival means theft, then so be it.

"One snake is so desperate to get warm that it plays a rather cunning trick"

Kleptothermy: the art of stealing heat

Male red-sided garter snakes warm up after winter hibernation by snatching heat from rivals



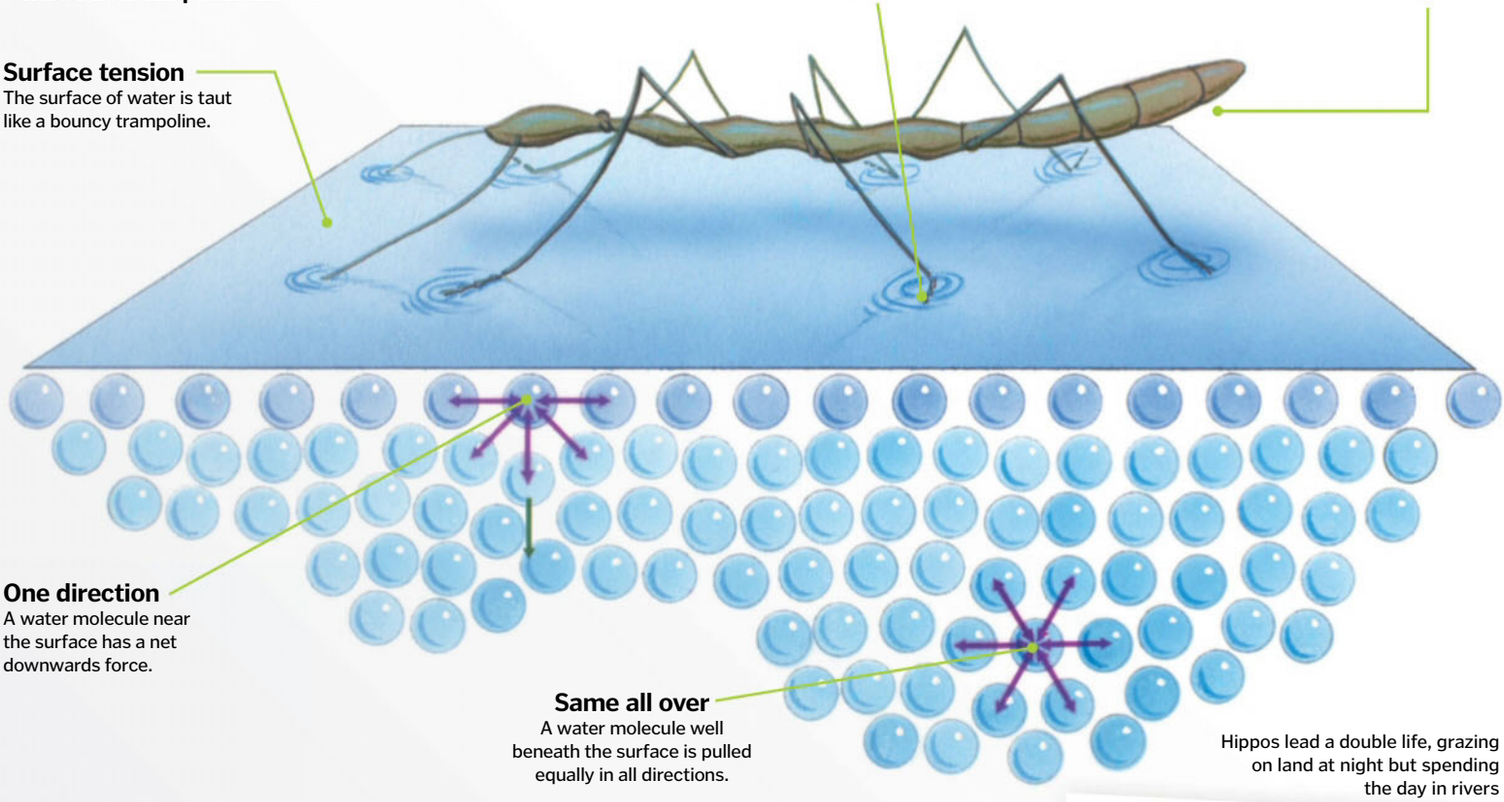
How dogs dry off

Throw a stick into the river, and your pet dog will probably jump straight in. The trouble is, dogs are furry, and those hairs trap roughly half a kilogram of water, chilling the soggy mutt fast when it bounds out. Rather than waiting for its body heat to evaporate the water off, a dog instead spins itself dry by rotating its backbone and twisting the layer of soft, spongy tissue between its outer skin and its muscles. A dog can rotate its fur through an angle of 180 degrees – a back-and-forth process known as 'simple harmonic motion' that's similar to how a pendulum or spring moves. Tests with Labrador retrievers show that they can spin off about 70 per cent of the water in this way, using around 5,000 times less energy than if they evaporated that amount off. This is handy for the dog, but less so for anyone standing nearby!

Wet dogs spin themselves dry by rotating back and forth about five times a second

A delicate balancing act

Just 0.1 per cent of insects can walk on water – here's how the pondskater does it



The physics of fluids

How pondskaters walk on water and hefty bumblebees fly

In science, liquids and gases are known as fluids: matter that can flow. The physics of how fluids behave can help to explain some seemingly miraculous feats performed by animals.

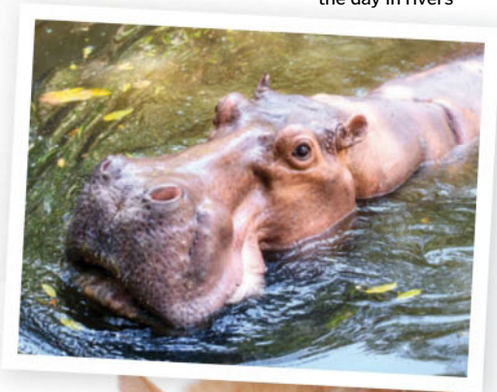
Crouch near the surface of a lake and you might – if you stare hard enough – see an insect walk on water. It's a pondskater, of which there are more than 1,700 species. With a thin, brown or black body, these small animals have six slender, stick-like legs splayed out, three on either side. If you look really closely, you'll see the ends of its legs lying flat and denting the surface of the water like a bowling ball on a mattress. Some people even call these insects 'Jesus bugs', but we don't need miracles to explain why they don't sink.

Basic physics tells us that the insect can sit on the surface of water only if its weight (the downward pull of gravity) is less than the force from the liquid pushing it upwards. To avoid sinking, the pondskater needs to make that upward force as big as possible. As the ancient Greek scientist Archimedes pointed out, the upward force on an object immersed in water equals the weight of water displaced. But for something on the surface of a liquid – not submerged in it – different rules apply.

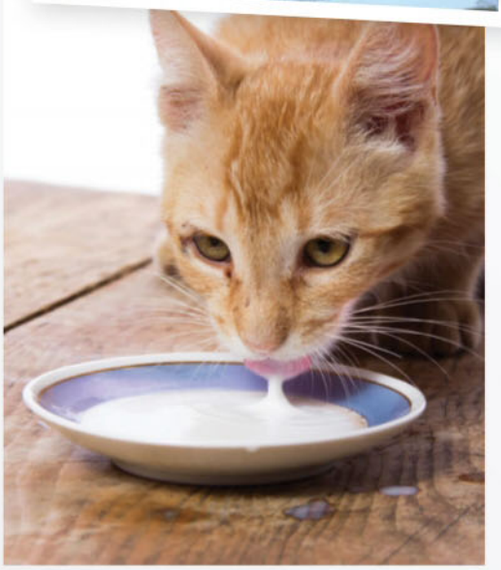
That's because the surface of a liquid is weird; it's taut and bouncy like a trampoline. The upward force on an object on a liquid surface depends on that bounciness – or surface tension – and the object's length. The pondskater can't adjust the surface tension, but it helps that this is stronger for water than for any other naturally occurring liquid. The secret lies in the insect's legs, the ends of which are typically about one centimetre long. They sit flat on the water, boosting the total upward force to well above the animal's weight. The result: no sinking.

Most pondskaters have a generous safety margin, but the largest species (Gigantometra gigas) is near the limit. With a mass of roughly three grams, its legs are over 20 centimetres long in order to generate enough upward force to stay above the water.

Out of the water, understanding the physics of fluids can also help to bust a popular myth: that bumblebees are too heavy and their wings too small for them to fly without defying the laws of aerodynamics. See 'Bumblebee flight' for more.



Hippos lead a double life, grazing on land at night but spending the day in rivers



A cat drinks elegantly by drawing up a column of liquid with the tip of it's tongue

Stealthy seahorses

The dwarf seahorse is just 2.5 centimetres long and holds the title of the slowest-moving fish in the world, travelling at barely 1.5 metres per hour. If there were an underwater 100-metre sprint for these pointy-headed, curly-tailed creatures, they'd reach the finishing line in nearly three days. But their slowly-slowly approach has physics behind it. Living in the warm waters of the Caribbean, the dwarf seahorse loves to dine on copepods – millimetre-sized transparent crustaceans that it eats by rotating its head, pointing its snout upwards and sucking the prey through its mouth. But the copepod has antennae covered with sensitive hairs that spot even the tiniest fluid flow, forcing the seahorse to creep up so slowly that it creates no turbulence in the water. It's skilled enough to catch 94 per cent of copepods that it sneaks up on.

The dwarf seahorse reduces turbulence by holding its head at an angle of 25 degrees to the vertical

"In an underwater 100m sprint, a dwarf seahorse would reach the finishing line in three days"

The Namibian desert beetle drinks by letting water droplets condense and roll down its back

Bumblebee flight

Contrary to popular belief, bumblebees aren't too heavy for flight; they gain enough lift to fly through fancy aerodynamics

Bees look at the sky's polarisation pattern to determine the direction in which they found food before

Unconventional flight

Early last century, scientists argued whether bumblebee flight should be impossible. Conventional aerodynamics assumes wings don't flap and have no ends.

In a flap

Bumblebees flap their relatively short wings at a rate of 150 times per second.

Boosting lift

A study showed that bees gain up to 70 per cent of their lift from spiral, leading-edge vortices.

Spiral, leading-edge vortex

Air is directed towards the tips of the wings, rather than flowing towards the insect's rear end.

Changing flow

Diverting air sideways keeps the vortex – a swirling, low-pressure region that creates lift – above the wing for longer.

Light work

Animal vision is different to ours – many species detect more than we can see

We humans can see colours from red to violet, but there's much more to light than meets our eye. Many birds, along with some insects, reptiles and fish, can detect higher-frequency ultraviolet light. Meanwhile, other animals distinguish between 'unpolarised' sunlight and sunlight that's become 'polarised' after striking molecules in the atmosphere. Some desert ants exploit polarised light to navigate home after finding food on their travels, while bees use it to tell fellow hive mates which direction to fly in to get nectar.

Like X-rays, microwaves or gamma rays, visible light is an electromagnetic wave made up of electric and magnetic fields at right angles to each other. The strength of the fields varies up and down with a frequency that gives the wave many of its properties. Unpolarised light is like a piece of string held between two people and waggled, first from side to side, then at an angle to the horizontal, then at a different angle, changing direction a hundred million times a second. If the two people move the string, which represents the electric field of the wave, in one direction only – say from side to side – the wave is polarised.

Some animals see through water, where light acts differently than in air; it travels more slowly, and water molecules tend to absorb lower-frequency light – the reds and yellows – more than the higher-frequency blues and greens. That's why you might see your diving companion's face turn pale green as you head deeper. What's more, water molecules and particles such as plankton scatter the light so that, for underwater animals, trying to see is often like peering through fog. Go deeper still, and even the blues and greens are absorbed – so it's pitch black in the ocean depths.

One remarkable animal is the archerfish, which lives near the surface of tropical rivers and lakes. It hunts insects that live in the air, and so has to deal with the bending – or refraction – of light as it moves from air into water and slows. The archerfish is a master at compensating for refraction, almost always spitting a jet of water on target and knocking its prey into its reaches.

The huge eyes of giant squid can detect the glow from plankton disturbed by sperm whales

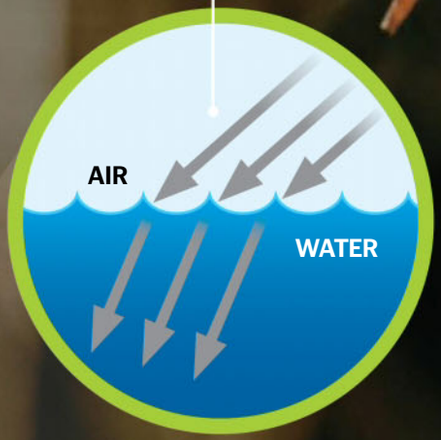
Sharp shooter

The archerfish is a master spitter, firing jets of water at insects above the surface

Perceived position
To the fish, refraction makes the insect appear in a different position than it really is.

Change of path
Light travels at a steeper angle as it passes from air to the denser water.

True path
Light from an insect that reaches the archerfish bends on its way to the animal's eye.



Time for snacking
Compensating for the refraction, the archerfish fires a jet of spit right on target, dislodging the insect.

Eyeing up its dinner
An archerfish just below the surface of the water spots a tasty insect on a leaf.

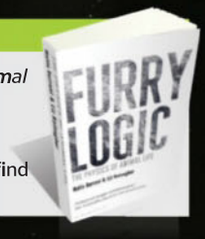
Tricky wings

Like many cuckoos, the Horsfield's hawk-cuckoo lays its eggs in other species' nests, leaving unwitting foster parents to rear its young. As soon as the imposter chick hatches, it disposes of its nest-mates and eats everything its new carers bring. The cuckoo chick needs more food than the chicks it displaced – it will grow up to be much bigger – so it tricks its red-flanked bluetail foster parents into thinking there are two extra chicks by having vivid yellow patches on the underside of its wings. Each patch looks like the orange-yellow gape of an open-mouthed red-flanked bluetail chick, so the parents are duped into bringing more food back to the nest.

A foster parent brings food to a Horsfield's hawk-cuckoo chick. Note its yellow wing patch on the left

Learn more

Furry Logic: The Physics of Animal Life by Matin Durrani and Liz Kalaugher is out now with Bloomsbury Sigma. Head to **www.furrylogicbook.com** to find out more and read an extract.



Animal physics extra

Animals exploit the physics of forces, sound, electricity and magnetism too

Forces

Komodo dragons, despite having a bite force about as strong as that of a pet cat, can kill animals the size of a water buffalo. To do this they use a 'can-opener' action with their sharp, serrated teeth while pulling backwards with their powerful body. Geckos, meanwhile, use tiny 'van der Waals' forces to hang on to the ceiling by having hairy, fleshy-folded feet that make a lot of contact with the surface.

Sound

Male peacocks attract female peahens by holding their beautiful feathers up high. But they also woo partners by rustling their feathers to emit 'infrasound' that's so low in frequency we can't hear it. Elephants sense sound waves travelling through the ground to detect distress calls from distant herd members. They absorb the sound waves through fleshy pads in their feet, which may either feel the vibrations directly or send them via the animals' front leg bones to their ears.

Electricity and magnetism

Electric eels, which use high-voltage electric pulses to navigate and find dinner, inspired early experiments on electricity back in the 18th century. The electric eel below, called Miguel Wattson, lives in the Tennessee Aquarium, and tweets every time its voltage discharge rises above a certain level (@EelectricMiguel). Loggerhead turtles from Florida use the Earth's magnetic field to navigate a ten-year, 14,500-kilometre trip around the Atlantic before heading back to the very beach where they hatched.

Bite force
Komodo dragons have a surprisingly weak bite force, but can still inflict fatal wounds thanks to their sharp teeth and strong neck muscles.

Randrops can be 50 times the mass of a mosquito, but these insects survive the impact by clinging to droplets as they fall

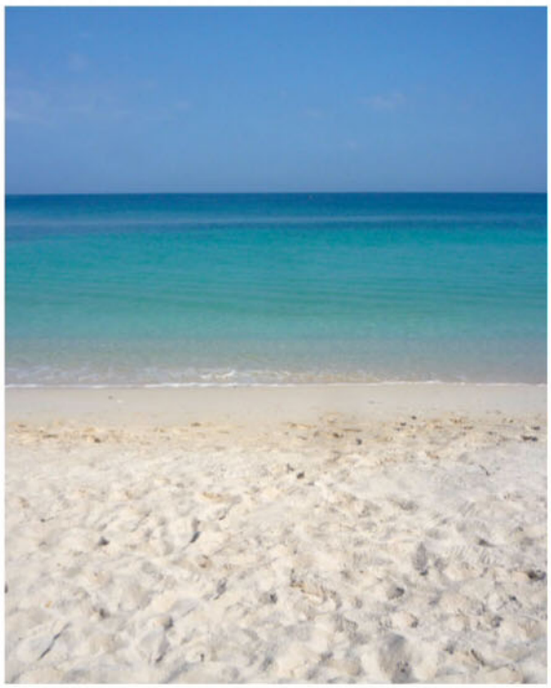
Infrasound
Elephants can recognise calls of individual members of the herd from up to 1.5 kilometres away.

Electric organs
An electric eel has thousands of tiny cells called electrocytes stacked together that, combined, produce shocks of up to 900 volts.

"Elephants sense sound waves through the ground to detect distress calls from distant herd members"

What is sand made of?

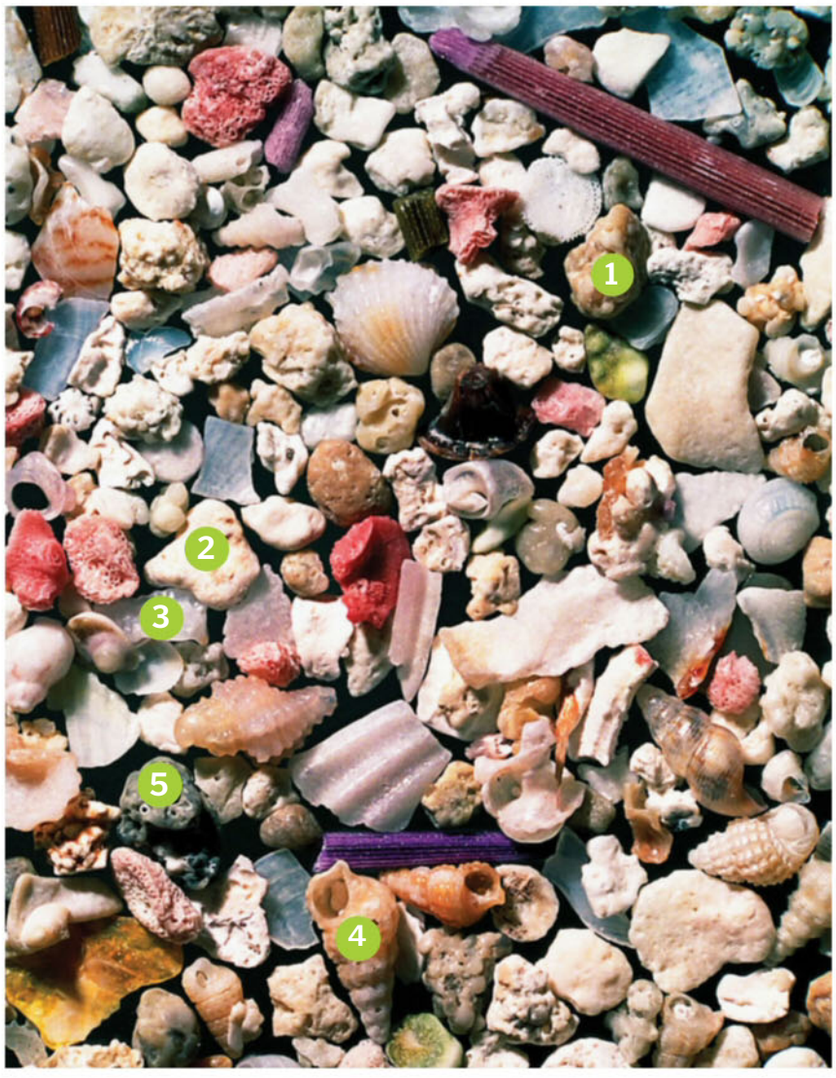
Discover the many minerals that determine the colour of our beaches and deserts



Whether it's between your toes or sculpted into a magnificent castle, sand is made up of lots of different components. The most common are minerals from rocks, which are broken up by a process called weathering. Wind, rain and the freezing and thawing of ice all chip away fragments of the rock and shape them into fine grains of sand. Therefore, the type of sand you find is often determined by the types of rock nearby. However, if you're on a tropical beach then the sand is likely to also contain the shells and skeletons of sea creatures, which have been eroded by the waves and washed up on the shore.

Sandy ingredients

What might you find when you put the beach under the microscope?



© Alamy; Science Photo Library

1. Quartz
The most common component of sand is made of silicon dioxide. It's a hard, light grey-coloured mineral, but can be stained yellow by iron impurities.

2. Feldspar
Feldspar is made of sodium, calcium or potassium combined with silica. Like quartz, it is eroded from igneous and metamorphic rocks in the Earth's crust.

3. Mica
On a sunny day, flakes of sheet silicate minerals can catch the light to create a shimmering effect, making the sand appear to sparkle.

4. Marine organisms
The shells and skeletons left behind by dead molluscs and coral are made of calcium carbonate, which is often white but can also be pink, red or orange.

5. Volcanic rock
Some sand features the black-coloured volcanic rock basalt, which also contains glassy green grains of the mineral olivine.

Earth's largest organism

The bizarre natural wonder that's over 3,000 metres bigger than a blue whale

In the Blue Mountains of Oregon, US, lives an organism that may not look very impressive, but is hiding a rather large secret underground. To those passing by, it will simply look like a few large clumps of yellow-brown mushrooms spread out across the ground, but beneath the soil is a vast network of matter joining them all together. Consisting of flat, bootlace-like structures called rhizomorphs, which search for food, and tubular filaments called hyphae, which form its asexual reproductive parts, the underground organism measures an incredible 3.8 kilometres across – over 126 times the size of a blue whale!

Known as honey fungus, it's a species that can kill a variety of trees and plants, and also tastes great in a risotto. This humongous fungus has been able to grow so large due to the way hyphae from two genetically identical honey fungi fuse together when they meet, forming one large individual. As this means it consists of genetically identical cells that can communicate and have a common purpose, it qualifies as a single, record-breaking organism.

David Walliams

GANGSTA GRANNY

'IT'S SO MUCH BETTER THAN THE BOOK!' DAVID WALLIAMS

WEST END PREMIERE

GARRICK THEATRE

26 JULY – 3 SEPTEMBER 2017

GangstaGrannyWestEnd.com 0330 333 4811

NIMAX THEATRES

amazon tickets

Journey to the centre of the Earth

What goes on inside this big lump of rock we call home?

Humans may have circumnavigated the globe, scaled Everest, and even reached the Moon, but we haven't travelled particularly far into our own planet. The deepest we've managed to dig is less than 0.2 per cent of the distance to the Earth's core – so we've barely scratched the surface. Despite this, we still know quite a lot about what's going on inside. For example, we know that, like an onion, Earth consists of several different layers, each with its own unique composition and characteristics.

We also know that, as you go deeper, the pressure and temperature in those layers increases dramatically. This information has made it possible for scientists to recreate the conditions inside the Earth, allowing them to find out what happens to chemistry and biology as you get closer to the core. By crushing samples between pieces of extremely hard material, such as diamond, they can deliver the same pressure experienced towards the centre of our planet, leading to some exciting discoveries.

Deepsea Challenger was the submersible used by film director, James Cameron, to reach the bottom of the Mariana Trench

Towards the core

How does pressure and temperature affect life and chemistry as you travel deeper?

Volcanoes form where ruptures in Earth's crust allow magma from the mantke to reach the surface

Key:
- Earth
- Chemistry
- Life

Bottom of the Mariana Trench
Depth: 11km
This trench at the bottom of the Pacific is the deepest point of the world's oceans and the deepest point humans have ever reached.

Deepest hole dug by humans
Depth: 12.3km

Deepest scuba dive
Depth: 0.3km

Proteins start to become unstable
Depth: 20km

Deepest suspected life
Depth: 19.3km
Rocks found deep beneath the Earth's surface contain high levels of carbon, which is associated with microbes that give off methane.

Average depth of oceanic crust
Depth: 7km

Complex life impossible
Depth: 30km
The immense pressure at this depth would cause the complex molecules used to make cells to disintegrate.

Deepest observed life
Depth: 11km
The bottom of the Mariana Trench is home to sea cucumbers and foraminifera – single-celled organisms that are thought to resemble some of the earliest lifeforms.

Diamonds form
Depth: 150km
Carbon dioxide is heated to 1,204 degrees Celsius and subjected to immense pressure, then pushed up towards the surface to cool into diamond.

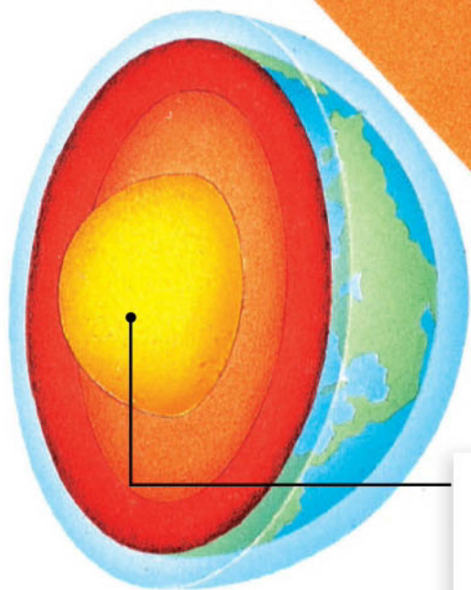
Mantle
Depth: 30km
Made of a rock called magma, this thick layer is solid at the top but becomes soft and molten as you get closer to the core.

Oxygen becomes solid metal
Depth: 2,500km

Outer core
Depth: 2,920km
In this liquid layer of iron and nickel, the atmospheric pressure is equivalent to 17,800 elephants balancing on your head.

Hydrogen may become a solid metal
Depth: 4,000km
Although not yet proven, it is believed that metallic hydrogen could become a superconductor at such high pressure, able to conduct electricity with zero resistance.

Inner core
Depth: 4,140km
The centre of the Earth is made of solid iron and nickel, and temperatures here can reach 6,000 degrees Celsius.

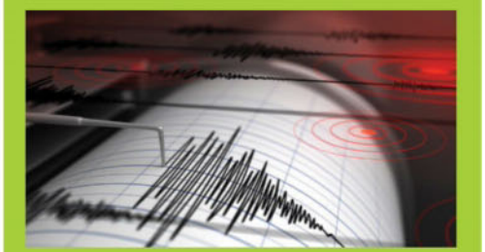


Centre of the Earth
Depth: 6,370km
With gravity pulling equally in all directions you would feel weightless, but the pressure – over 3 million times greater than it is at the surface – would crush you.

How do we know what's inside Earth?

With no physical samples from the Earth's core, the first step in figuring out what was down there was to work out the planet's mass. This was done by observing the effect the planet's gravity has on objects at the surface. Because the average density of the whole Earth is much higher than the density of material at the surface, it was determined that most of the planet's mass must be at the core. To work out what it is made of, scientists then looked to the universe.

Iron is one of the most common elements in our galaxy, yet it is not very common on Earth's surface, so they worked out that it must have slowly gravitated towards the core over time. To work out the size of the core, they then turned to earthquakes. These natural disasters send shock waves through the planet, and so by analysing how they pass from one side to the other, they were able to work out the core's size and consistency.



By studying earthquake shock waves, scientists discovered that the Earth's core is both solid and molten

DID YOU KNOW? More people have been to the Moon than have explored the deepest depths of the oceans on Earth

What is freezing rain?

Discover how these supercooled droplets are formed and why they can be so dangerous

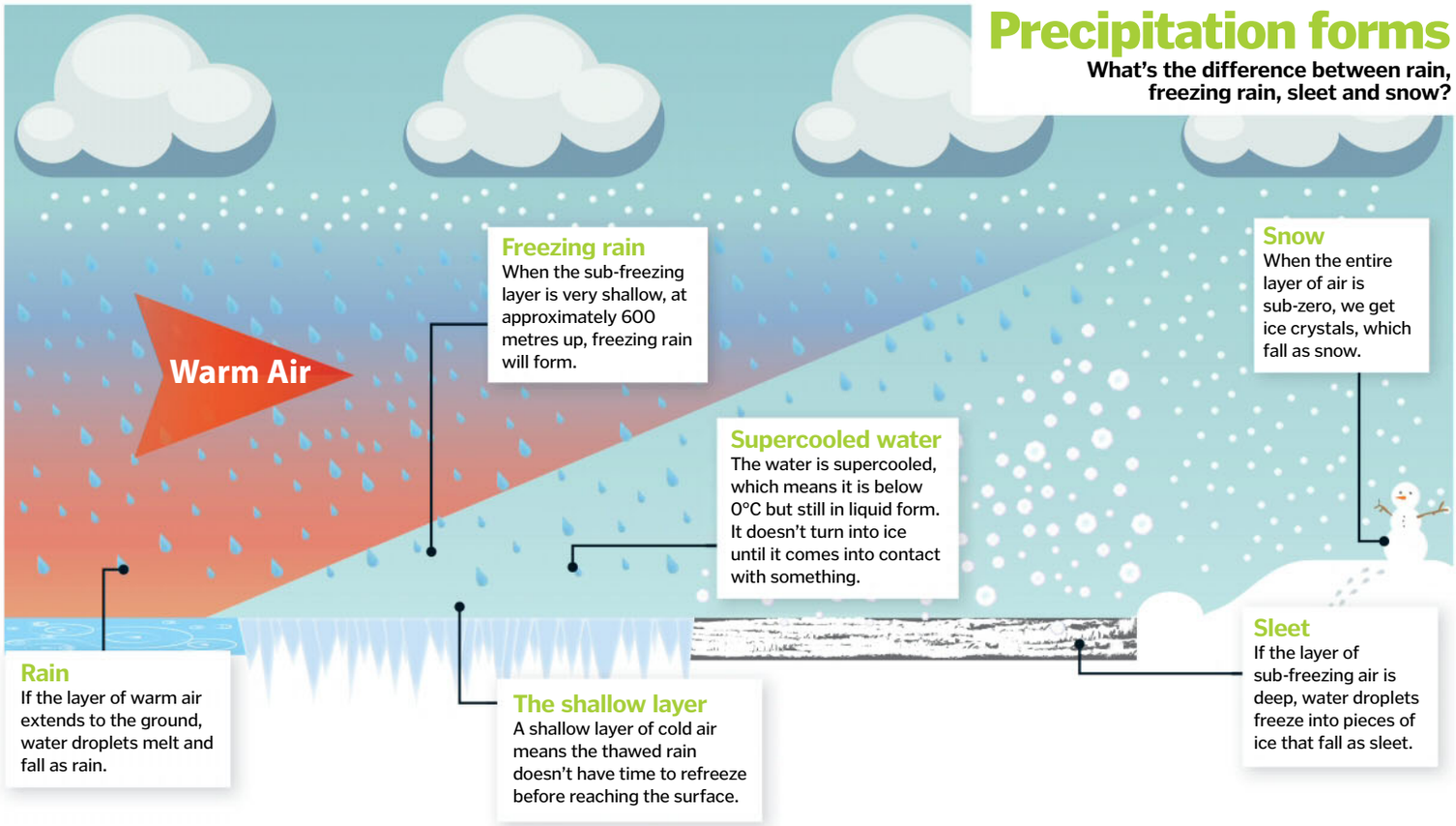
Freezing rain usually begins as snow, ice, sleet or hail. When it passes through a layer of warmer air, it melts and turns back into a liquid. However, if the rain travels through a shallow layer of cold air – with a temperature below freezing – as it continues to fall, this supercools the water droplets. When these droplets hit an object, such as a road, vehicle or tree, they freeze on impact, turning into ice. This can create dangerous driving conditions, and the weight of ice on power lines or trees can cause them to collapse.

Thankfully, freezing rain is a rare occurrence in the UK, because conditions have to be so precise. The sub-freezing layer must be relatively shallow, at 600 metres above the surface.

An accumulation of freezing rain can add weight to trees and power lines, causing serious damage

Precipitation forms

What's the difference between rain, freezing rain, sleet and snow?



Saffron

Why its harvesting process makes saffron the most expensive spice on the market

Originating in Greece but now native to southwest Asia, saffron comes from the saffron crocus bulb, a purple flower that grows to between 20 and 30 centimetres in length and produces three burnt-orange stigmas. It is these stigmas that are so valuable, as they produce the saffron spice used in cooking. As each flower only produces three stigmas, it takes approximately 150,000 flowers to produce just one kilogram of saffron. This labour-intensive process is what makes saffron so expensive.

The saffron crocus grows best in full sunlight. While it's relatively easy to grow in the right conditions, collecting the spice is tedious. Harvesting begins when the plant starts to bloom over a three-week period during the autumn. It needs to be a speedy process though, because the flowers blossom at dawn before wilting at night. Their fragile stigmas are plucked by hand and then dried. This lengthy process is the reason the price of saffron ranges from £180 to £1,800 ($225 to $2,250) per kilogram, depending on the quality.

The three stigmas from the saffron crocus flower are picked and then dried to create the saffron spice

Devil's Kettle Falls

Will anyone ever unearth the mystery surrounding this geological phenomenon?

A few kilometres south of the US-Canadian border flows the Brule River. Providing a picturesque setting for canoeing and fishing, its tranquil façade gives no clue as to what lies beneath: one of nature's biggest mysteries.

Meandering south through Minnesota's Judge C R Magney State Park, the Brule River descends 244 metres over 13 kilometres, forming multiple waterfalls as it flows towards the lake. Around 2.5 kilometres upstream of the lake, an outcropping of volcanic rhyolite rock splits the river in half, resulting in a double waterfall. As the eastern half plummets into a pond below and continues its journey along the river as normal, the western half drops three metres down a giant pothole, before vanishing into the unknown.

Marked logs and ping-pong balls have been thrown into the torrent, and dye poured into it too, but these things have never been recovered in the lake, discrediting any suggestion that an exit point exists. One theory proposes that the water must create a cave and an underground river, but the hard rhyolite rock would make this impossible. Likewise, even if evidence of a fault line existed, it would have to be enormous to allow such a mass of water to endlessly flow through it.

Another theory suggests that the water is flowing into lava tubes – caves formed when lava cools to become volcanic rock . However, rhyolite never forms lava tubes, and existing flood basalt came from fissures rather than a volcano. So although scientists have carried out experiments and geologists have investigated theories, a sufficient geological explanation is yet to be found.

The enigmatic pothole

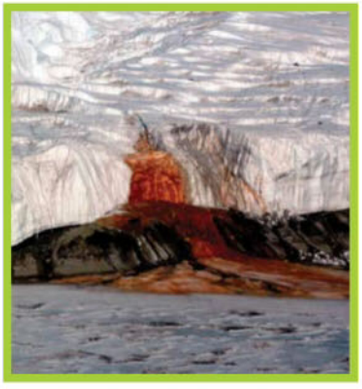
As scientists continue to study this geological conundrum, will Devil's Kettle Falls ever be understood?

Weird waterfalls

Check out these other unusual waterfalls from around the world

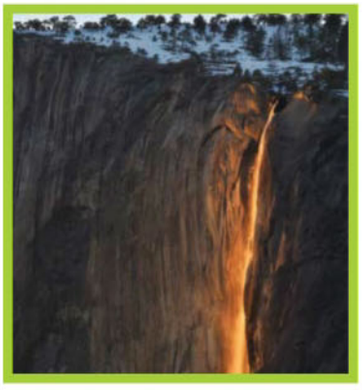
Bua Tong

Also known as the Sticky Waterfalls, you can actually climb up Thailand's Bua Tong due to the limestone deposits and the lack of algae or slime on the rocks.



Blood Falls

Rusty-red in colour, the saltwater of Blood Falls in Antarctica contains so much iron oxide that it takes the appearance of ghastly flowing blood.



Horsetail Falls

Located in California's Yosemite National Park, this seasonal waterfall reflects the winter sunset and glows orange and red, making it appear to be on fire.

Baatara Gorge

When melting snow turns to water in the Lebanon village of Balaa, it falls 255 metres down a spectacular pothole, past three natural bridges.

THE SCIENCE OF MUSIC

How do we make music, and what happens when it hits our ears?

Music is an ancient part of our culture, and has a powerful influence over our minds. Songs can make people laugh, cry, dance, or cover their ears in disgust, and everyone has their own favourites.

Sound is generated by vibrations. When the strings of an instrument vibrate, they push the air in front of them (compression) and the air behind them expands (rarefaction). These compressions and rarefactions create waves that move through the air.

When the sound waves reach your ears, they push on the air in your ear canals and set your ear drums moving. These vibrations then trigger the movement of three tiny bones, which send the vibrations on to a fluid-filled structure called the cochlea. The motion of the fluid in this coil is used to generate electrical signals that travel to the brain. But this is just a tiny part of the story.

These simple vibrations can cause a powerful emotional response, and there are layers of complexity in the notes themselves, and in the way that our brains perceive them.

The sound waves that reach your ears carry a huge amount of information. The basics of musical notes come down to volume, pitch and timbre (or tone); the bigger the vibrations are, the louder the sound is, and the more frequently the vibrations happen, the higher the pitch. And as for timbre, that is determined by the smoothness of the sound wave itself.

Standard waves drawn in physics textbooks are very smooth, but sounds produced by the human voice or by instruments aren't so even. It's the little imperfections that add up to produce the timbre, or tone, of the final notes. Then there is echo, reverberation, and resonance, and layer upon layer of instruments, voices and lyrics.

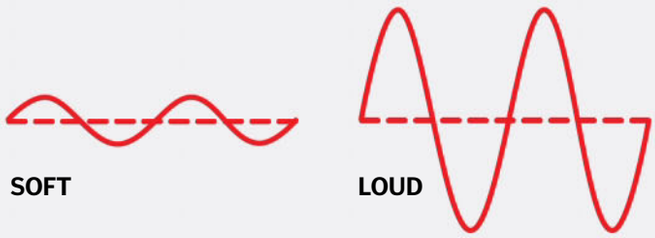
Your brain then has to handle these incoming sounds, and it doesn't just translate the notes into electricity. The processing of music links up with the parts of your brain that control pleasure, fear, movement, memory and emotion, and songs can trip unexpected circuits. We'll show you exactly what goes on in your brain when your favourite song is played.

Waveforms

Changes to the shape of a sound wave alter its properties

Volume

The loudness of a sound is dictated by the amplitude, or height, of the wave. The bigger the vibration, the louder the sound.



Pitch

Pitch is determined by the frequency of the wave: how often it vibrates in a given time. Low frequency waves produce low notes, while high frequency waves produce high notes.

Timbre

Timbre is the quality or tone of the sound; two instruments can produce the same note, but sound completely different. This property is determined by the sound wave's shape.

We can change the shape of our vocal cords to produce different tones

Sound resonates within the hollow body of string instruments such as guitars

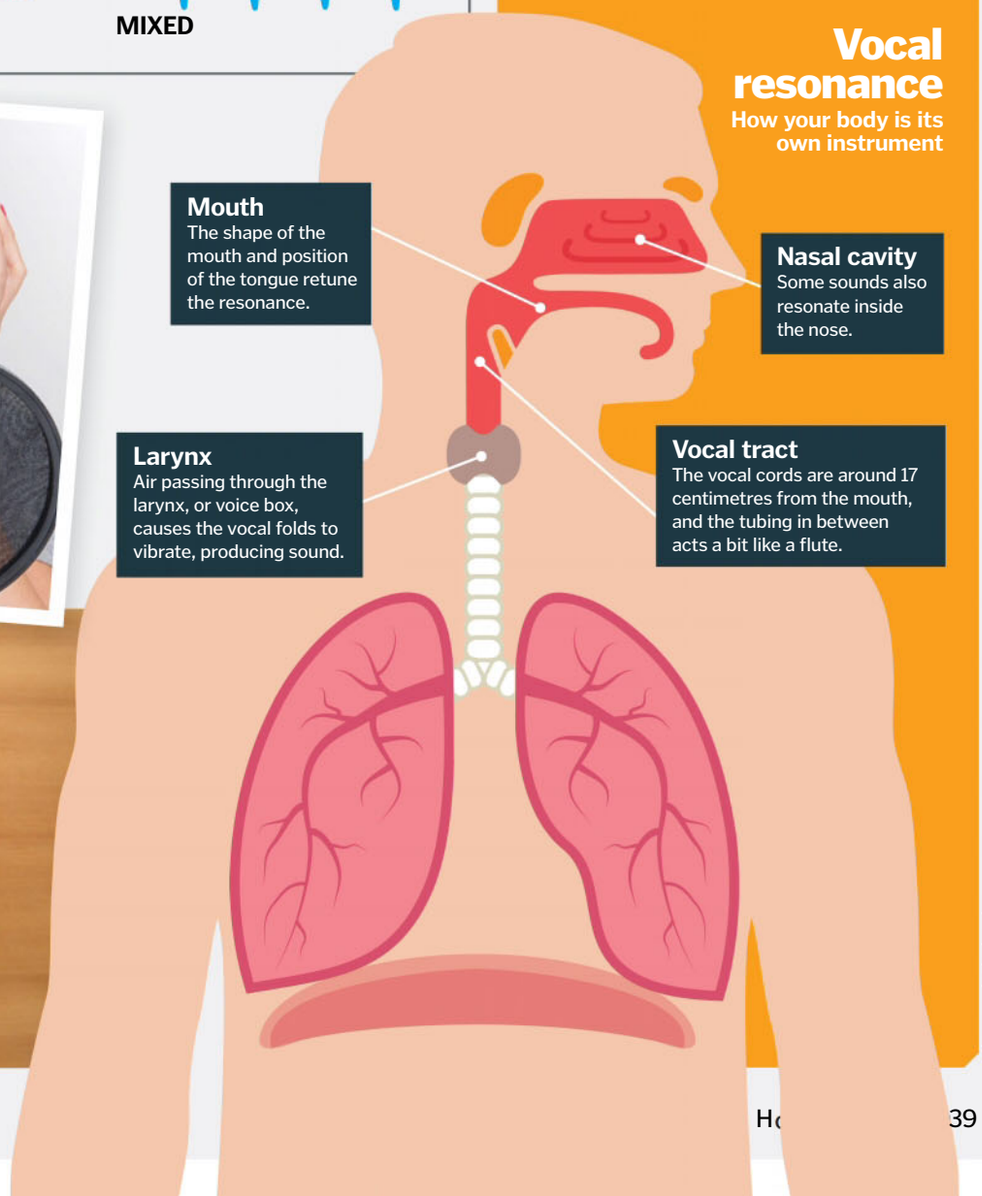
Acoustic resonance

Elastic bands stretched over margarine tubs don't sound the same as steel strings stretched over a guitar. The vibrations created by plucking the band, or the string, are transferred into the body of the instrument, and the shape and materials have a huge impact on the resulting notes. Different objects prefer to vibrate at certain frequencies, and some frequencies are amplified much more than others; this is known as resonance.

The resonant frequencies of a musical instrument are fixed, unless it can change shape – and this is what makes the human voice so special. The throat, mouth and nose act like the pipes of a musical instrument, amplifying the vibrations made by the vocal folds. Changing the shape of the mouth produces different vowel sounds, and opening the throat or singing through the nose produces completely different tones – this is because we are changing the resonating characteristics of our vocal sound system. Opera singers are experts in resonance, using it to fill a concert hall with their voices without the need for a microphone.

Vocal resonance

How your body is its own instrument



Mouth
The shape of the mouth and position of the tongue retune the resonance.

Nasal cavity
Some sounds also resonate inside the nose.

Larynx
Air passing through the larynx, or voice box, causes the vocal folds to vibrate, producing sound.

Vocal tract
The vocal cords are around 17 centimetres from the mouth, and the tubing in between acts a bit like a flute.

Instruments

The different orchestra sections explained

Brass

Brass players produce sound by buzzing their lips against a metal mouthpiece. The vibration that they produce determines the frequency of the note, and it can be altered by changing the shape of the mouth. The final sound is also influenced by the instruments, and they come in many different shapes and sizes, from a simple tube, all the way up to complex networks with holes, valves and slides. These change the path that the air takes through the pipes, altering the pitch – the further the air travels, the lower the note.

Mouthpiece
The larger the mouthpiece, the lower the sound.

Bell
The flared shape at the end helps to radiate the sound.

Valve
Slides and valves force the air to take different routes, altering the pitch.

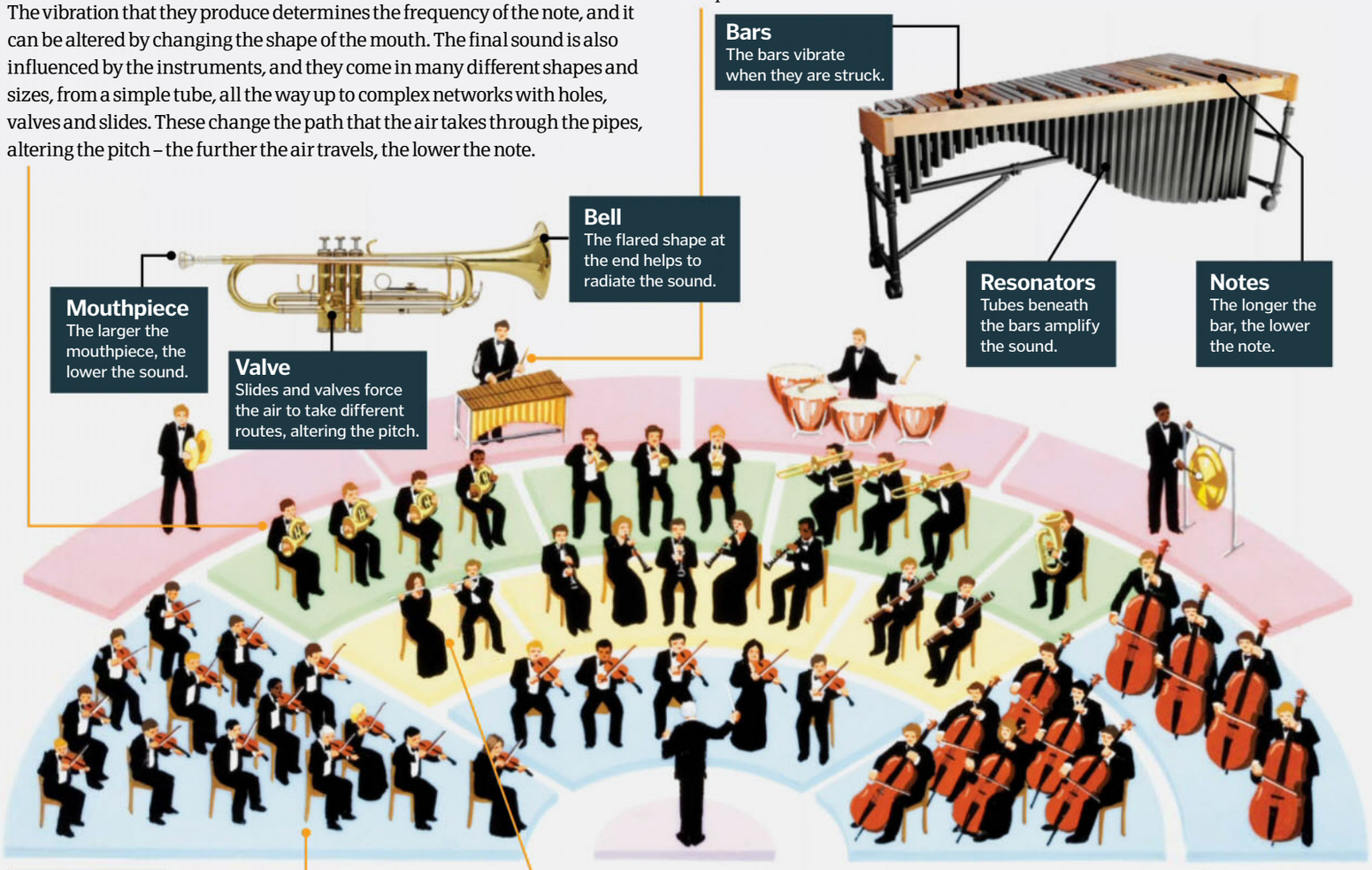
Percussion

These instruments make a sound when they are hit, and like their more complex siblings, they do this through vibration. With a drum, the vibrations are made when the stretched skin is struck, and the sound is amplified by the shell. With a bell, the clapper strikes the metal, causing the bell and the air inside to vibrate, and with a xylophone, the sound is amplified by tubes beneath the bars. Varying the size, shape and materials of the instruments can produce different notes and tones.

Bars
The bars vibrate when they are struck.

Resonators
Tubes beneath the bars amplify the sound.

Notes
The longer the bar, the lower the note.



Strings
Pressing a finger on the string makes it shorter, and the note higher.

Pegs
The pegs tighten or loosen the strings, changing the pitch.

Fine tuners
Tuning can be precisely adjusted by stretching the string millimetres at a time.

Strings

The strings of a violin, guitar or piano produce different notes depending on their length and thickness. The longer and thicker the string, the lower the sound. The sound also varies depending on the way that the strings are played. A plucked string is tugged against its anchor points, which produces a sharp kink; as it vibrates back and forth, this bend lessens, and the quality of the sound becomes almost instantly smoother. As a bow passes along a string it is continuously vibrated, producing long, sustained notes. And with the hammers of a piano, the strings are struck and then dampened, ending the vibrations to create a crisp sound.

Woodwind

Wind instruments work by creating a column of air that can be lengthened or shortened by covering and uncovering holes in the tube; the longer the column, the more time it takes for vibrations to travel through, and the lower the pitch. There are two main families: flutes and reed instruments. Flutes work in the same way as blowing over the top of a bottle – using a jet of air to make the air inside the instrument vibrate. Reeds are flexible, and when the musician blows, they vibrate and change the flow of air through the instrument.

Up an octave
By adjusting their lip position and blowing harder, players can make the air travel faster, producing the same note an octave higher.

Embouchure hole
The jet of air is disturbed by the hole, creating vibrations in the instrument.

Changing notes
Pressing the keys down effectively makes the tube longer, lowering the pitch.

Concert hall acoustics

These specialised venues are engineered to envelop the audience in music

Dome
Domed ceilings can cause problems with echoes because they are so far above the audience.

"Music can be tweaked and perfected before it hits your ears"

Anti-echo panels
Panels in the ceiling help to deflect the sound away from the dome.

Acoustic panels
Specially designed structures equalise the sound, and bounce selected frequencies inwards.

Absorption
The seats and the audience themselves absorb sound, so the room must be designed to compensate for this.

Shoebox
This traditional concert hall shape has narrow walls, helping to reflect the sound back towards the audience.

The panels on the walls and ceilings of concert halls are crucial

Concert hall acoustics

Playing the right notes is only part of the battle

Concert halls have a big job to do. They need to immerse the audience in the sound of the loudest of orchestras without causing echoes, and they need to amplify the most delicate of soloists so that people at the back can hear clearly. There are three factors to consider to make sure the audience enjoys the experience: volume, equalisation and reverberation.

Volume is dictated by the direct sound of the orchestra, but it is also influenced by reflections from the walls and ceiling. For concert halls, it's important not to have too much reflected sound. Your ears expect sound to come from the orchestra, not from the walls behind you.

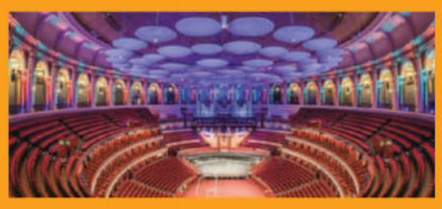
Equalisation ensures that all frequencies can be heard; different rooms amplify some frequencies more than others. The goal is to balance the sound somewhere in the middle, and to dampen the highest notes a little to avoid any screeching from the strings.

Reverberation is the result of sound bouncing around inside the hall. Surfaces don't reflect all sounds equally, so this can cause some distortion if it's not corrected.

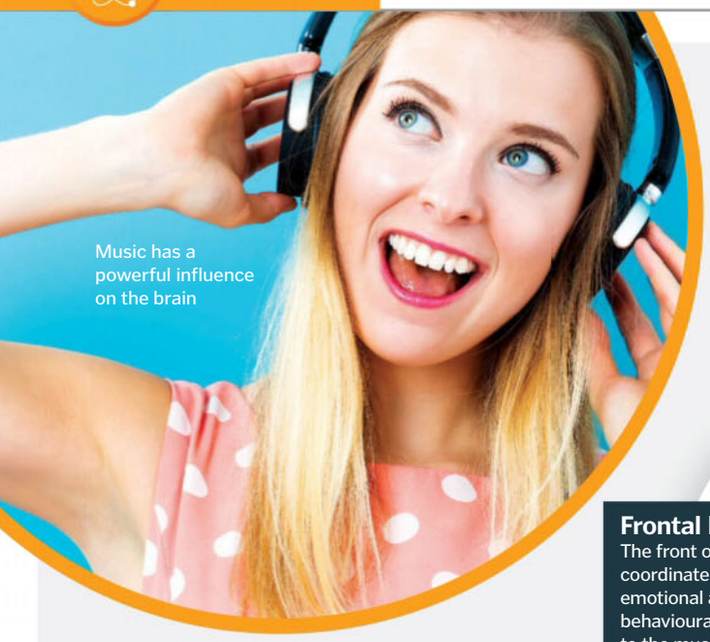
Concert halls balance all of these factors by using different shapes and materials to balance the sound and direct it at the audience. Flat, hard surfaces bounce the sound, soft surfaces absorb it, and rough surfaces scatter the incoming waves. By lining the walls and ceiling with specially designed panels, the music can be tweaked and perfected before it hits your ears.

Improving acoustics

The ceiling of the Royal Albert Hall in London is covered with dangling mushrooms, but it's not infested with damp. The strange structures are there to improve the acoustics. They were installed following tests conducted in the 1960s, and improved again in 2001, and today there are 85 of these fibreglass fungi. The Royal Albert Hall is huge, and the ceiling is domed, so without the mushrooms there would be a long, delayed echo following every note the orchestra played. Even with the mushrooms, a huge orchestra is required to fill the enormous hall with sound.



The Royal Albert Hall uses acoustic mushrooms to reduce the echoes caused by its domed ceiling



Music has a powerful influence on the brain

Your brain on music

What happens inside your head when you are listening to your favourite tunes?

Brains are complex, as is music, so teasing out the neurological response to melodies is something of a challenge, but researchers across the world have been working to demystify the baffling science behind it.

The first components of music to be processed by the brain are the basic sounds – pitch, length and volume. From this, the brain then teases out melody, and distinguishes between different instruments. This information is then compared to memories, establishing whether the incoming sound is familiar, and revealing any linked emotions. All together, the processing leads to a response, whether that's switching the song off, or starting to dance. And if you move, that feeds back into your brain again, affecting the experience even further.

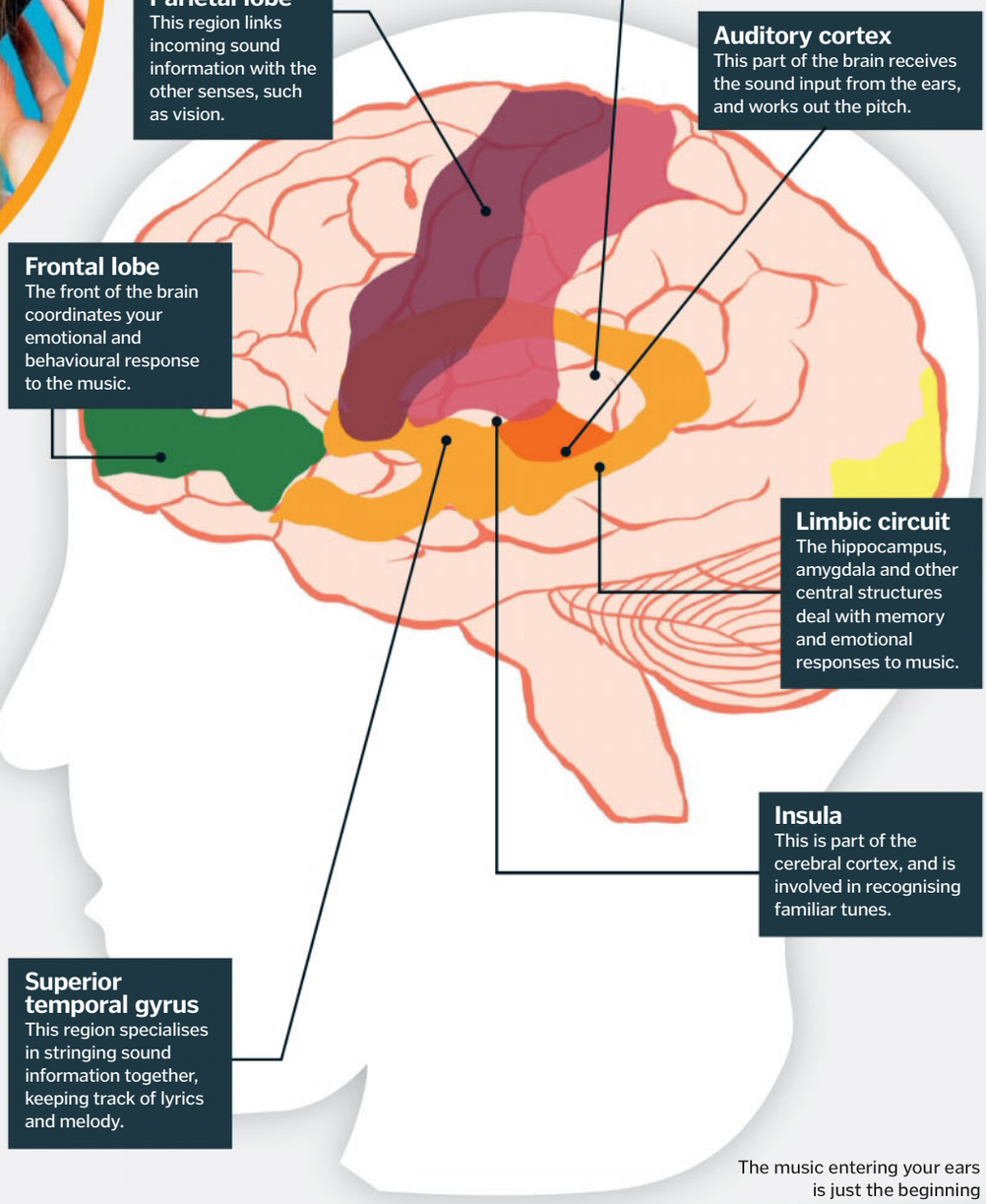
Some of the complexities of the brain's response to music can be revealed by people with damage or injury to their brains. By seeing what happens to the ability to process music after the brain is injured in a certain place, and by observing how that improves as the brain heals, scientists can start to piece together which parts of the brain are involved. This is aided by advanced imaging technology, such as functional MRI scanners, which can monitor the activity in different parts of the brain in response to music.

One major revelation from this kind of work is that music is separate from language. Aphasia is the medical term for a neurological disorder that results in difficulty speaking. It can happen as a result of a brain injury, like a stroke, and makes it challenging for people to find the words that they need to express themselves, but strangely it doesn't always interfere with their ability to sing. Similarly, people with a stammer may struggle with speech but can sometimes sing a song without hesitation.

Around one in 20 people is tone deaf, or 'amusical', and has trouble identifying the notes in a tune. Brain scans have revealed that the white matter in the area involved in processing sound is thinner in these individuals, indicating that it could be less well connected than the same pathways in their musical counterparts.

Processing music

Different areas of your brain come together to handle rhythm, melody, lyrics and emotion



Planum temporale
This area deciphers complex sounds, picking out rhythm, timbre and patterns.

Parietal lobe
This region links incoming sound information with the other senses, such as vision.

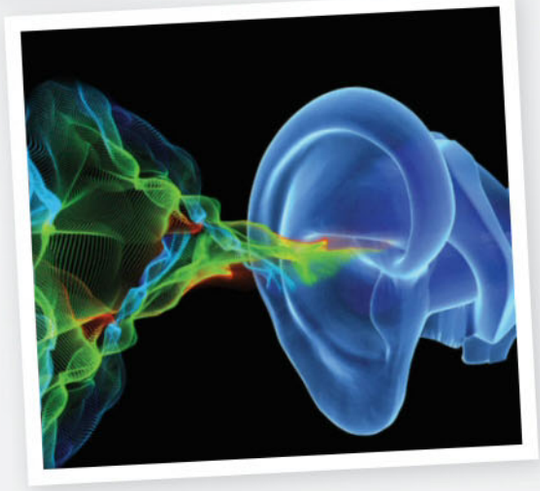
Auditory cortex
This part of the brain receives the sound input from the ears, and works out the pitch.

Frontal lobe
The front of the brain coordinates your emotional and behavioural response to the music.

Limbic circuit
The hippocampus, amygdala and other central structures deal with memory and emotional responses to music.

Insula
This is part of the cerebral cortex, and is involved in recognising familiar tunes.

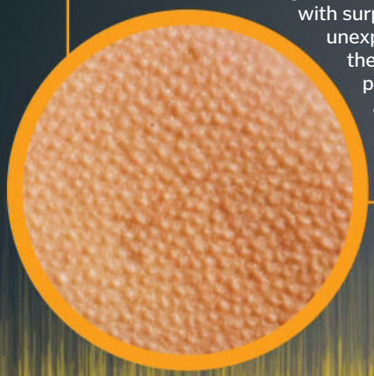
Superior temporal gyrus
This region specialises in stringing sound information together, keeping track of lyrics and melody.



The music entering your ears is just the beginning

Why does music give you 'chills'?

Good songs can make your hairs stand on end, and this is thought to be triggered by the way that our brains are wired. Music taps into the parts of the brain involved with emotion and reward, and listening to certain tunes can light up the same areas tickled by food, and even drugs. At the same time, music seems to decrease the activity in the areas of the brain involved in fear. Getting goose bumps is linked to arousal of your autonomic nervous system, which comes hand-in-hand with an increase in heart rate and deeper breathing. Researchers looking into exactly what triggers this think that it might have something to do with surprise; unexpected shifts in the music are particularly good at setting off this response.

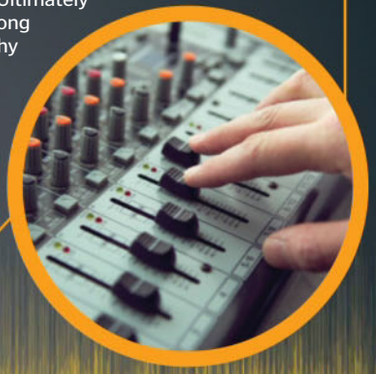


Why do we tap our feet to music?

The urge to tap your foot along to a strong beat is often irresistible. It was previously believed that our movements in response to music reflect how we perceive that it was created – a tapping foot imitates a drummer's pedal, for instance – or our mood upon hearing the music. However, more recent research suggests that tapping your foot may influence the way you perceive the music, helping your brain to process what you are hearing.

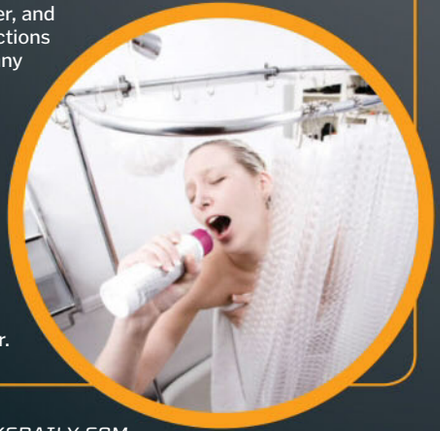
What makes songs so catchy?

Researchers have an interesting way to describe this phenomenon – they sometimes refer to it as a 'brain itch' or an 'earworm'. Some songs seem to get stuck in people's heads more often than others, but there is not a simple formula that determines catchiness. Researchers working in the field have noticed that catchy songs tend to have short, repetitive sections, and they also often have some connection to the listener. A similarity to a song that you already know, or a cultural connection – such as lyrics that you can relate to – both help to get a tune stuck in your head. Ultimately though, a song that is catchy to one person might not be for another.



Why does your singing sound better in the shower?

This is down to acoustics. If you sing in a big room with plastered walls, the sound travels a long way before it reaches an obstacle, and a lot of the vibration is absorbed. In a bathroom, the room is smaller, and the tiles or glass reflect the sound back at you in all directions. This creates reverberation. The result is that the sound is louder, and the multiple reflections help to even out any tiny mistakes in your voice. The size of the shower cubicle also has a part to play – lower frequencies tend to be amplified more than higher ones, making the voice sound richer.



"Around one in every 20 people is tone deaf"

What are the origins of music?

People have been making music for millennia, and the oldest known instruments date back 42,000 years. They are bone and ivory flutes, discovered in a cave in Germany alongside other early human art and ornaments. However, it's generally believed that music was around a long time before the first instruments, as people used their voices to make melodies. Being able to produce music could have helped with social bonding, an idea that is sometimes described as 'vocal grooming'. These kinds of cultural advances are thought to have given our species an edge over our human-like cousins, including Neanderthals.

Music has been a part of human culture for thousands of years

Sinuses explained

Explore the twisted network of cavities that lies behind your skull

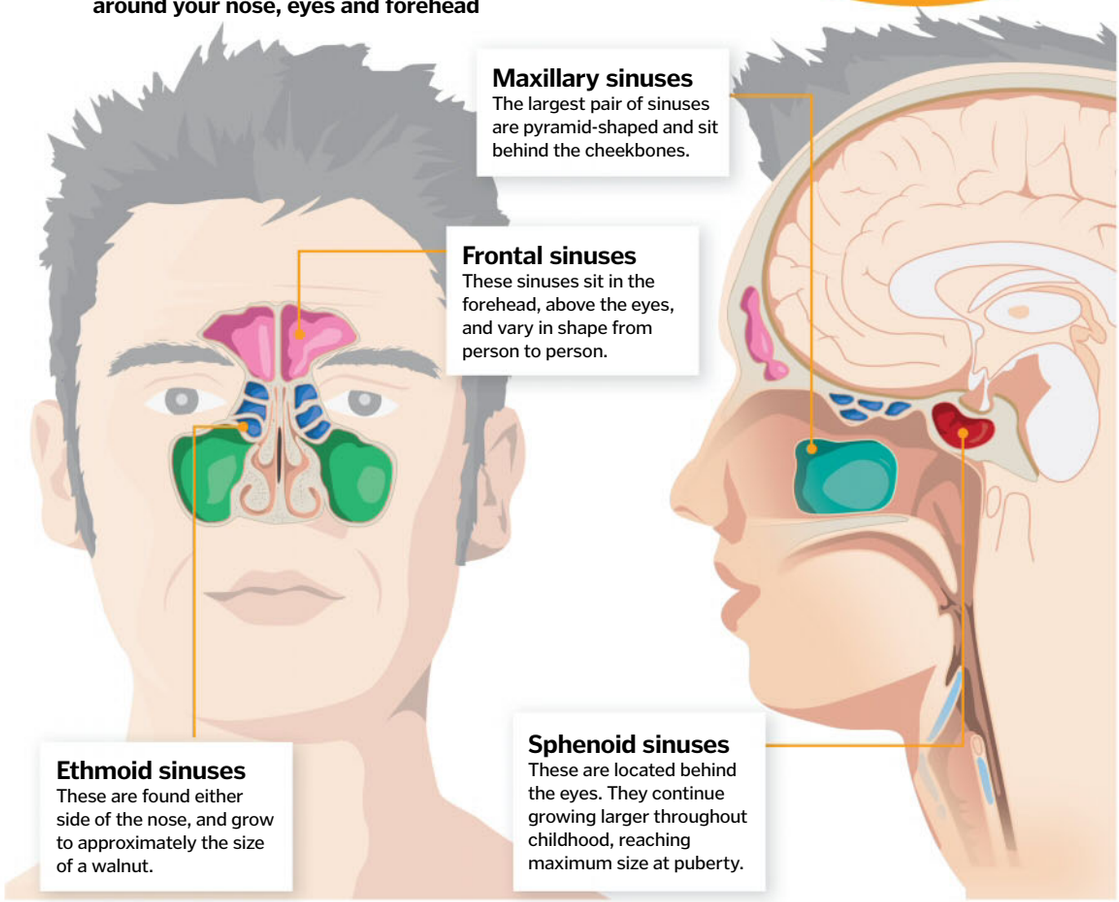
There are eight sinuses in total – four on each side of your head – and they sit around your eyes, nose and forehead. They are lined with specialised cells that form a mucous membrane, a damp layer of skin that produces sticky mucus to capture small particles that might be lurking in the air that you breathe.

The primary function of the sinuses is not known for sure, but they seem to have a few important roles: they warm and moisten air before it hits the lungs; they change the tone of your voice; and they make your skull a little lighter by taking up space that would otherwise be filled with bone.

When you become unwell, with a cold or the flu, your sinuses increase their mucus production. They can also become infected, causing the membranes to swell up. This leads to a blockage, known as sinusitis. The blockage is the reason for the feeling of pressure in your face when you aren't well, and it is also the cause of the distinctive change in your voice.

Sinus anatomy

There are four pairs of sinuses around your nose, eyes and forehead



Smoke points

Learn how to maximise the flavour in your meals with the right choice of oil

Most of us search for the healthiest option when we're choosing cooking oil, but not many of us consider the oil's smoke point. And if we want a tasty meal we should be paying close attention, because this determines the temperature at which the oil will begin to break down and produce smoke.

'Virgin' variants typically have the lowest smoke points. These unrefined oils are typically bottled straight after they've been extracted from their source (typically nuts, seeds or fruit) so a lot of compounds other than fats are also included. These constituents help to make the oil healthier, but some are heat-sensitive, and will cause the oil to start smoking when cooking under a high heat.

Refined oils – such as vegetable and grapeseed oil – undergo bleaching, filtering and heating steps to remove these extra compounds, which can raise the smoke point considerably. This makes these oils better suited for frying food at hot temperatures, such as in a stir-fry. So think carefully on your next choice of cooking oil, as those that go past their smoke point may break down to release harmful free radicals and acrolein – a chemical responsible for the flavour and aroma of burnt foods – which could really tarnish a meal.

The science of Christmas dinner

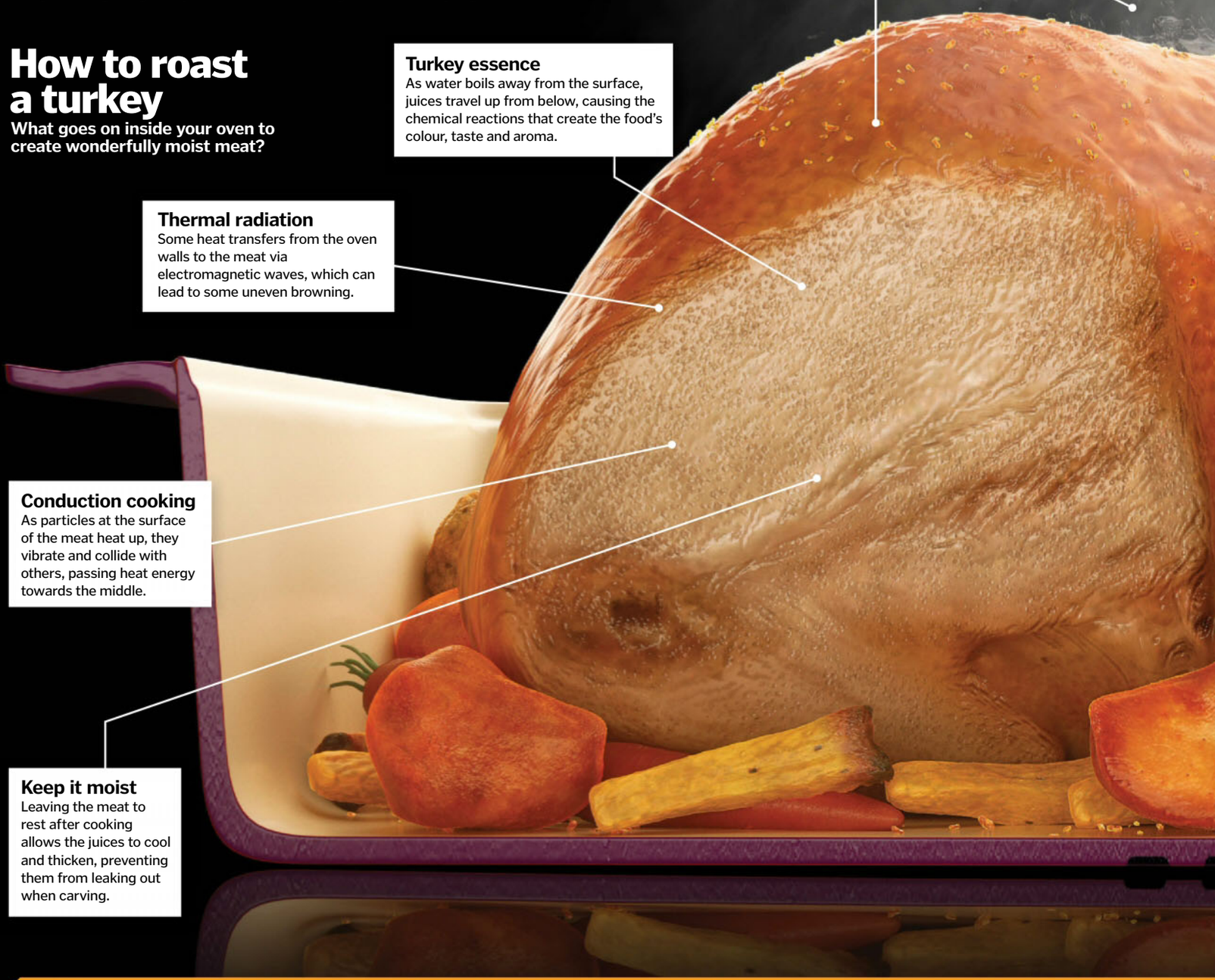
Learn the physics and chemistry that will help you cook the perfect festive feast

For most Brits, Christmas dinner would not be complete without a plump and juicy roast turkey to enjoy alongside the crispy potatoes and Brussels sprouts. However, preparing the perfect bird can be a challenge, as it's easy to misjudge cooking times and the temperature of your oven. Undercook the turkey and you risk giving everyone the unwelcome gift of food poisoning, yet overcook it and your guests will be left with a plate of dry meat.

Thankfully, understanding the science going on inside your oven can help you get it right. The physics of heat transfer and the chemistry of flavour development both play an important role in cooking the perfect roast turkey, but resting and drying the meat are vital too.

How to roast a turkey

What goes on inside your oven to create wonderfully moist meat?



Crispy skin
When the surface of the meat dries out, it heats to higher temperatures, creating a crispy skin.

Let it dry
Convection dries out the humid air just above the food, causing the surface of the meat to dry too.

Turkey essence
As water boils away from the surface, juices travel up from below, causing the chemical reactions that create the food's colour, taste and aroma.

Thermal radiation
Some heat transfers from the oven walls to the meat via electromagnetic waves, which can lead to some uneven browning.

Conduction cooking
As particles at the surface of the meat heat up, they vibrate and collide with others, passing heat energy towards the middle.

Keep it moist
Leaving the meat to rest after cooking allows the juices to cool and thicken, preventing them from leaking out when carving.

Christmas cooking science tips

1 Brine the turkey
Before roasting, soak the turkey in salty water for at least 12 hours. The salt will change the protein structure within the turkey's muscle fibres, helping it to retain more moisture while cooking.

2 Start upside down
The turkey breast should be cooked at a lower temperature than the rest of the bird, so place it upside down in the oven for the first hour to shield it from the hotter temperatures at the top.

3 Circulate the air
When cooking, place the turkey on a rack that sits inside the roasting tray. This will allow air to circulate evenly around the bird, giving it a crispy brown skin.

Humidity
Water just beneath the surface of the meat begins to boil, creating steam to increase the humidity of the oven.

Check the temperature of the turkey before you serve it to make sure it is cooked through

Convection cooking
Heat energy transferred from the air inside the oven heats the outside of the food.

Added flavour
Heat from the bones also generates chemical reactions in the surrounding meat, giving it more flavour.

Leave the bones in
The bones quickly reach the hottest temperature of any part of the bird and conduct heat into the meat, helping to cook the turkey's insides.

Soggy vegetables
The juices at the bottom of the roasting tray will only reach the boiling point of water – not hot enough to produce crispy potatoes.

Turkey traditions

No one in Britain had even seen a turkey, let alone eaten one, until the mid-15th century when they were first brought over from the Ottoman Empire, now known as Turkey. King Henry VIII was the first monarch to demand the bird for his Christmas feast, but goose, boar's head or pheasant were traditional Christmas feasts at the time. It wasn't until the 1950s, when turkey was more widely available, that it became a tradition. It was seen as a practical way of feeding a large family and meant that livestock such as cows and chickens could be used for their milk and eggs instead.

Up until the mid-20th century, Christmas dinner was more likely to involve pheasant or goose

4 Check the temperature
When you think the turkey's done, use a meat thermometer to check that the white meat in the breast is at 71 degrees Celsius and the dark meat in the legs and thighs is at 74 degrees Celsius.

5 Cook stuffing separately
Stuffing must be heated to 74 degrees Celsius due to its egg content, but at that temperature you risk overcooking the turkey. Therefore, it's best to cook it outside of the bird.

"Understanding the science going on inside your oven can help you get it right"

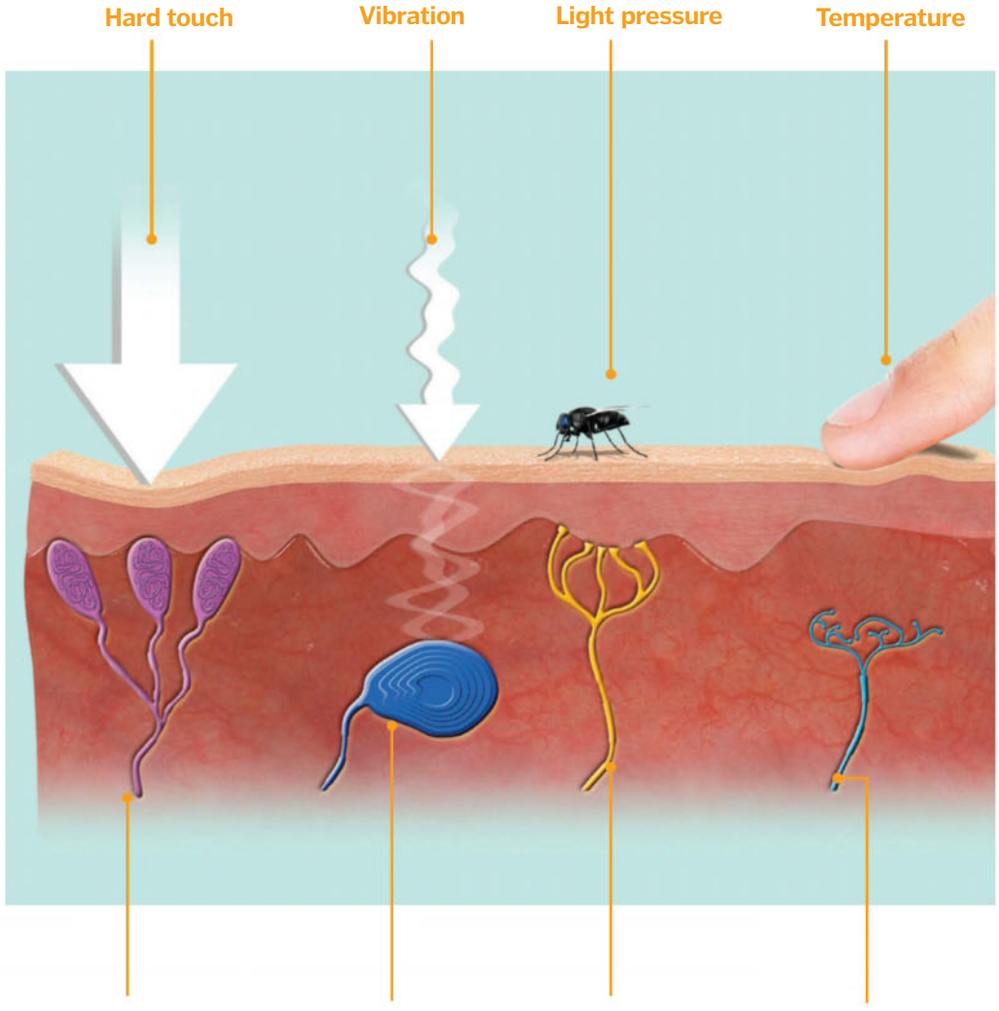
Skin senses

How does your skin pick up signals from the outside world?

The skin uses different detectors (called sensory receptors) to tell the difference between pressure and pain, hot and cold, and a light brush versus a hard poke. These receptors are specially adapted nerve endings, and many are wrapped in layers of tissue, helping them to function in various ways. They are located in different numbers across your body, with more in your hands, feet and lips than anywhere else. Some respond quickly before stopping, allowing you to grow accustomed to sensations that don't need constant monitoring, like the feeling of your clothes against your skin. Others are slow to stop signalling, so you remain aware of the sensation.

Under the skin

Different receptors take responsibility for detecting different aspects of touch



Meissner corpuscles

These sit in the bumps and ridges beneath the top layer of skin on the hands and the soles of the feet. They are sensitive to pressure and vibrations, which is useful for detecting texture.

Pacinian corpuscles

These are the largest of the sensory detectors in the skin. They sit deep below the surface, and are equipped to respond to fast vibration, deep pressure and tickles.

Merkel's discs

There are lots of these in the fingertips and lips, and they are good at sensing light pressure. They are particularly important for working out the shape and texture of objects.

Free nerve endings

Lots of the nerve endings under the skin aren't buried inside specific structures. These 'free' endings mainly detect pain, but some pick up on sensations such as pressure or temperature.

Hazmat suits

The clever pieces of kit that protect us from invisible dangers

For every weapon forged there is a piece of armour made to defend against it. For swords it was chainmail, for bullets it was Kevlar, and for chemical agents it's the hazmat suit. Short for hazardous materials suit, this piece of kit is built to defend us both on and off the battlefield by shielding us from harmful liquids and gases.

A barrier formed of plastic, fabric and rubber, along with an independent source of oxygen, hazmat suits protect workers by separating them from their hazardous environment. Simpler suits can be slipped on to protect against harmful liquids, but more advanced suits can become completely airtight to defend against airborne contaminants and toxic chemicals. This versatility has meant that hazmat suits can be used by the military, in industry and by healthcare workers.

Workers operating in waste disposal make daily use of hazmat suits, and they're used by staff in nuclear power stations to ensure they don't carry any radioactive contaminants home at the end of the day. Recently, nurses and carers treating patients infected with the Ebola virus in West Africa wore hazmat suits to protect themselves against airborne infection.

These examples are just a few of the many ways hazmat suits can keep us safe by protecting our skin, eyes and respiratory system.

Workers collecting recyclable material from landfills need to protect themselves

Biohazard protection

A hazmat suit can include several specialised parts to protect against biological agents

Respirator
Full or half face respirators protect against airborne mould, asbestos and pesticides. For chemical protection, self-contained breathing apparatus must be used.

Facial protection
Goggles, face shields, medical masks and surgical caps can all be used to keep hazards away from the head and face.

Overalls
These are made out of materials such as PVC, which biological agents are unable to penetrate.

Apron
This catches the majority of solid and liquid contaminants and can be easily removed.

Gloves
Nitrile or latex gloves are suitable for handling pathogens and are disposed of after use.

Rubber boots
Hazardous liquids, oils, chemicals and contaminated water are unable to seep through the protective footwear.

Levels of protection

The term 'hazmat suit' covers a wide spectrum of protective clothing. Anything capable of blocking hazardous materials may be labelled as a hazmat suit, but a brewer working with a liquid disinfectant would be dressed quite differently to a scientist handling toxic gases. So to ensure the appropriate amount of precaution is taken, hazmat suits are arranged into four different types.

Type A suits are fully concealed from the outside and are equipped with a self-contained breathing apparatus. By ably defending against biological and chemical hazards, they are the go-to choice when working in dangerous atmospheres. Type B suits are not airtight but retain breathing equipment, so can be used when handling gases that aren't harmful to the skin. Type C suits are used when working with general biohazards, and include a respirator. Finally, Type D suits would be worn by our brewer, and could simply include a protective apron, boots, glasses and long gloves.

Type A suits fully enclose the wearer and their breathing apparatus

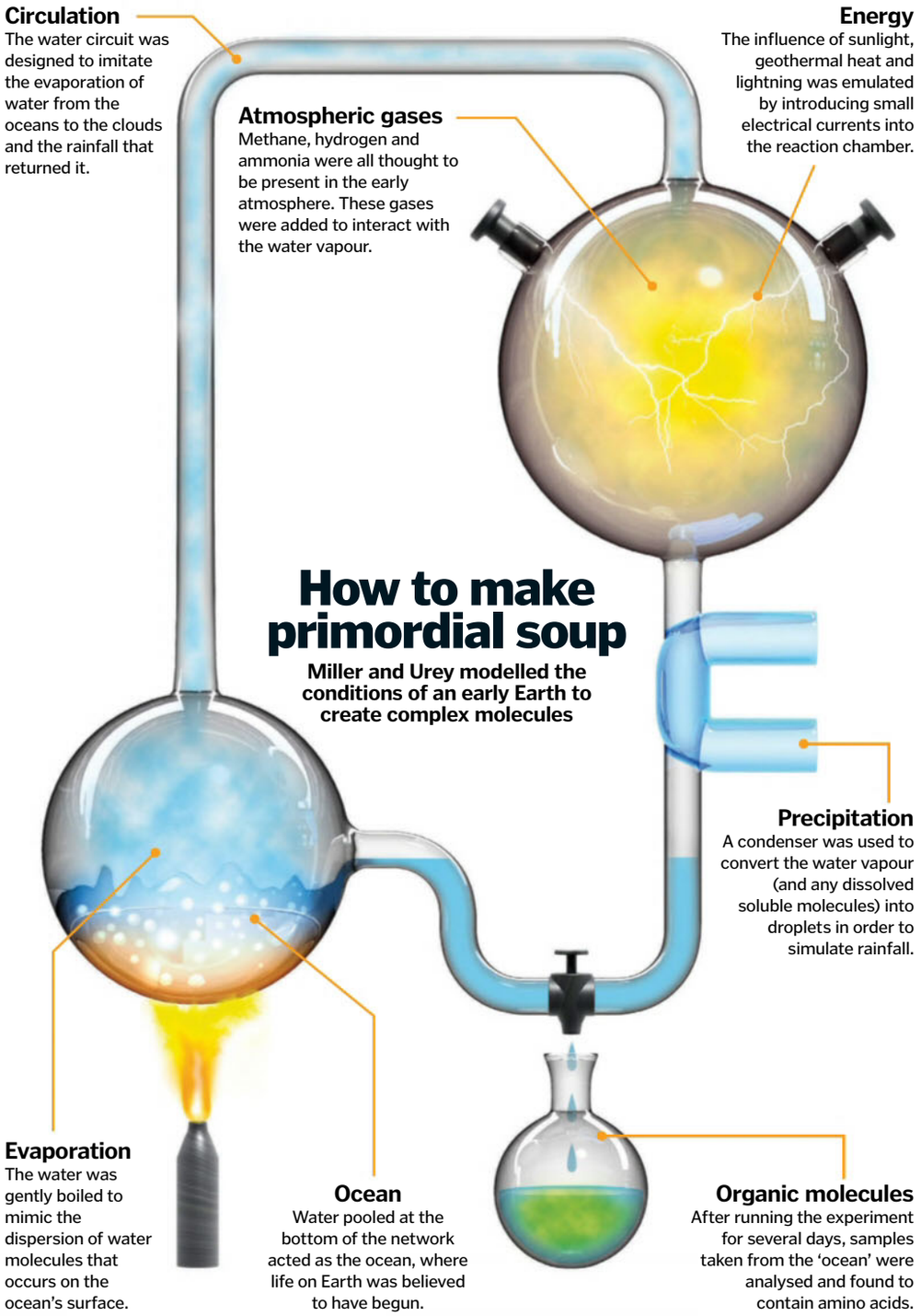
Life in the lab

Discover the experiment that set out to simulate the origins of life

After a series of experiments in the 1860s, Louis Pasteur described the law of biogenesis, which explains that all lifeforms come from other lifeforms. Not long before that, Charles Darwin had published his theory of evolution, explaining how complex life evolved from simple organisms over millions of years. Both theories answered a lot of questions, but one piece of the puzzle was still missing – how exactly had life started in the first place?

An answer was suggested in 1924 by Russian biochemist Alexander Oparin, who described the early oceans of Earth as a 'primordial soup'. He believed that the seas had been full of complex molecules. These included the building blocks of life such as amino acids and other organic compounds, which would later react and combine with other molecules to form the first cells. Scientists knew that these building blocks could be made inside living things, but Oparin believed that at first, they had been formed solely by chemical reactions.

In 1952, American chemists Stanley Miller and Harold Urey set out to show how these building blocks had found their way into the soupy seas. They set up a lab experiment that replicated the conditions of the oceans found on early Earth; using water, gases and electricity inside a network of flasks and tubes, the two scientists built a circuit that emulated the atmospheric composition, the water cycle and frequent lightning strikes. After a week of running this experiment the pair made an amazing discovery; the simple molecules had reacted to form many complex molecules, including amino acids, all by chemistry alone.



Inconclusive results

Since Miller and Urey conducted their ground-breaking experiment, we have a better understanding of the conditions of early Earth. Analysis of ancient rocks has revealed that atmospheric conditions were different to those modelled in the experiment. There, air was richer in carbon dioxide and nitrogen, with only trace amounts of other gases. Repeating the experiments with this more realistic mixture is unlikely to produce amino acids.

Other scientists have cast doubt on the likelihood that amino acids would directly lead to the building blocks of life. Nucleic acids that form RNA and DNA, molecules that can make copies of themselves, are much more difficult to create. Scientists estimate that the production of these kinds of molecules would require a lot of energy and catalysts, molecules that speed up reactions. Hydrothermal vents on the sea floor are now considered to be a more likely location for the origins of life. The chemicals and heat found at these deep-sea chimneys could potentially provide the necessary conditions for life to emerge.


The conditions on an early Earth are now thought to be rather different to Miller and Urey's initial predictions

60 SECOND SCIENCE

The conservation of energy

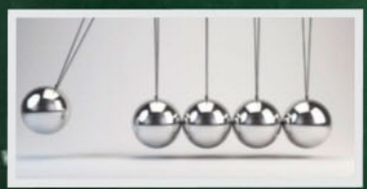
ENERGY CAN NEITHER BE CREATED NOR DESTROYED, BUT WHAT DOES THAT MEAN?

BACKGROUND

The conservation of energy is one of the most important concepts in physics. It states that in a system, the total amount of energy remains constant. Energy can be transformed from one form to another, from chemical to thermal for example, but it cannot be created or destroyed. This principle dictates much of our understanding of the world around us, and it forms one of the four laws of thermodynamics, the study of heat and energy.

IN BRIEF

In physics, energy describes the capacity for doing work. It comes in many different forms, which can be broadly divided into two groups: kinetic (movement) and potential (position). The example of a pendulum is often used to demonstrate conservation of energy in action. If you lift a ball on a string, it gains gravitational potential energy. When you let it go and it starts to swing down, its gravitational potential energy decreases, and its kinetic energy increases. As it passes the bottom of its arc and starts to swing upwards, it slows down; its kinetic energy decreases and its gravitational energy increases again. The energy isn't lost, it's just transferred from one type to another. With each swing a small amount of energy is also transferred as heat to the surrounding air, which is why the ball gradually slows down.

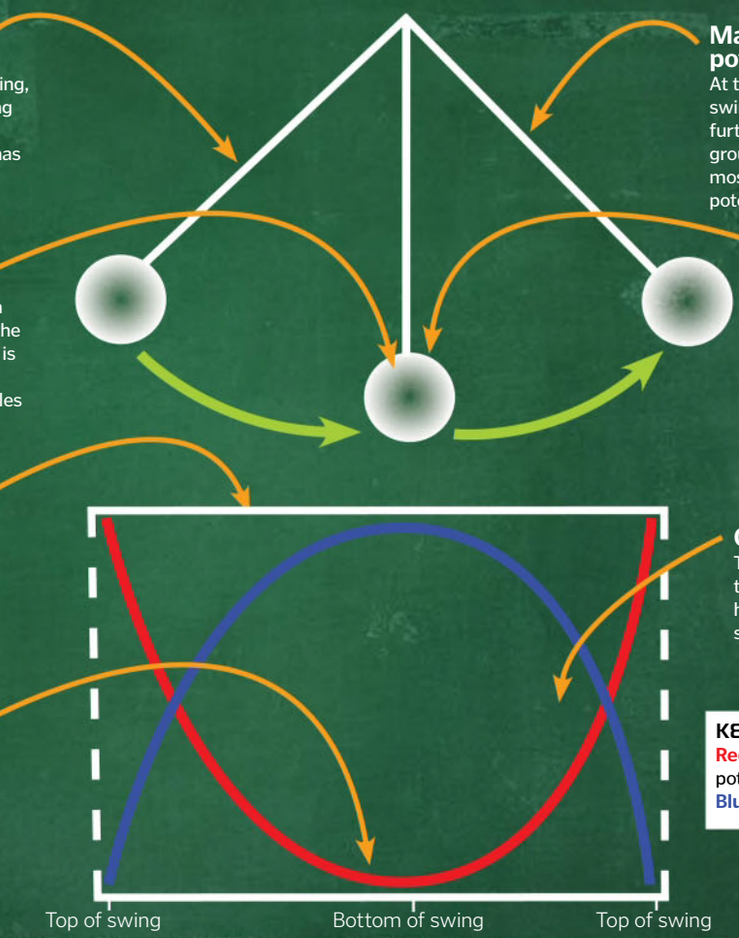


SUMMARY

The total amount of energy in a system remains constant. Therefore energy cannot be created or destroyed, but it can be transferred from one form to another.

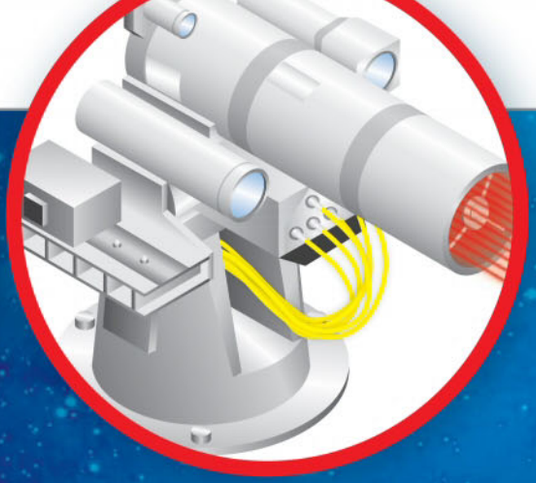
The law in action

Conservation of energy can be demonstrated by the swing of a pendulum



JULIUS MAYER

THE LAW OF CONSERVATION OF ENERGY WAS FIRST DESCRIBED IN THE 19TH CENTURY BY JULIUS MAYER, A MEDICAL DOCTOR FROM GERMANY. MAYER STARTED HIS EXPERIMENTS AS A CHILD; HE WANTED TO CREATE A MACHINE THAT COULD PUMP WATER AROUND A WATER WHEEL USING ONLY THE ENERGY CREATED BY THE WHEEL ITSELF – ESSENTIALLY, A SELF-POWERING MACHINE THAT GENERATES ENERGY FROM NOTHING. TRY AS HE MIGHT, HE COULD NOT FIND A SOLUTION. AS AN ADULT, HE TURNED HIS ATTENTION TO THE ENERGY PRODUCED BY THE HUMAN BODY. HE USED HIS OBSERVATIONS TO MAKE THE LINK BETWEEN HEAT ENERGY AND MECHANICAL ENERGY, CONCLUDING THAT LIVING THINGS ARE JUST MACHINES, AND THEY TOO CANNOT CREATE ENERGY FROM NOTHING.



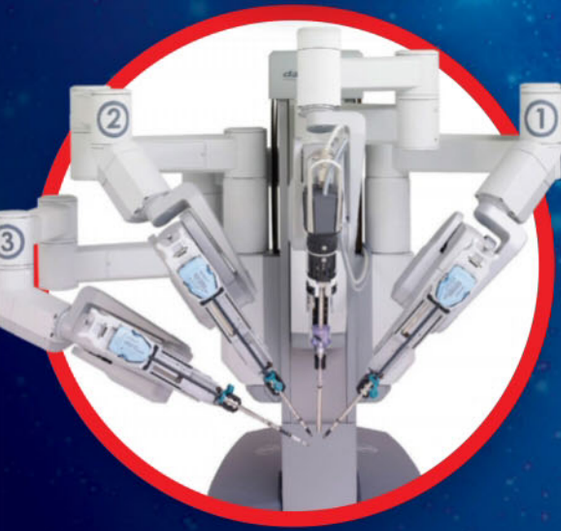
REAL-LIFE STAR WARS TECH

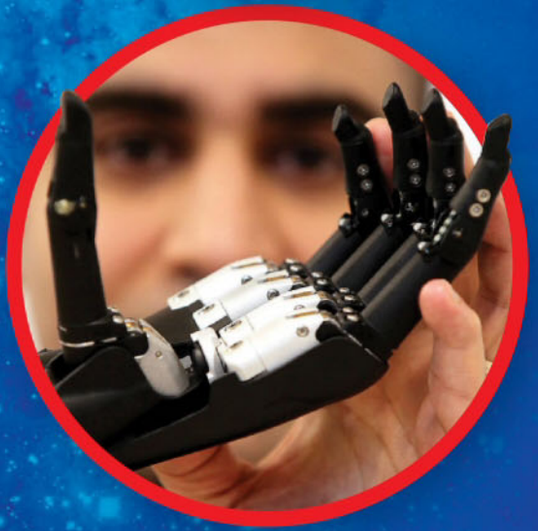
THE FUTURISTIC SCI-FI TECH THAT COULD CHANGE OUR LIVES

Even though *Star Wars* took place "a long time ago, in a galaxy far, far away", George Lucas' universe contains some of the most advanced technology ever seen on film. We'd all love our own BB-8, and the lightsaber remains the ultimate fantasy weapon.

Many companies have been working on new inventions that aren't too dissimilar from the droids, holograms and laser weapons in the saga. These exciting developments mean that much of the technology seen in the films is now becoming a reality.

Bionic limbs are rapidly improving prosthetics; laser weapons could alter warfare; and holograms could potentially revolutionise communication. But not all the new inventions resemble their *Star Wars* counterparts. Tractor beams, for example, would be smaller in real life and used to help surgeons rather than capture spaceships. Read on for more real-life tech that wouldn't be out of place in *Rogue One*.





HOLOGRAMS

Widespread holographic technology is near and could be the next step in communication

While we are yet to achieve the sophisticated holographic projections used in *Star Wars*, great progress has been made in recent years, and a holographic message from across the planet could soon become a reality.

A holographic image displays an object in three dimensions, without the viewer having to wear special glasses. To make a holographic image, light from a laser is split into two beams: a reference beam and an object beam. The reference beam travels uninterrupted to the holographic film, but the object beam is scattered by the irregular shape of the object. When the two beams combine again at the film, they interact to create a pattern of waves unique to that object. This pattern is recorded on the film, which can then be used to project a holographic version of the object.

The Microsoft HoloLens is taking this basic principle even further, with holographic projections that move in real time. The US company describes its invention as 'mixed reality', to distinguish it from both augmented and virtual reality. The user wears a headset and the HoloLens brings digital images to life on a suite of 3D cameras. The mechanism can also accurately capture and reconstruct every detail of the human body. In comparison, motion sensors like Microsoft's Kinect only concentrate on the skeleton. Microsoft is calling this 'holoportation', and it could revolutionise how we communicate over long distances.

Build your own hologram projector
PAGE 94

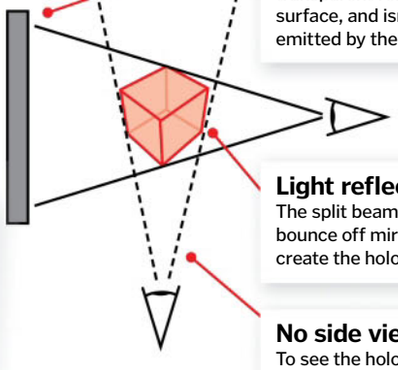
In the first *Star Wars* film, hologram chess was played with virtual pieces

People could pay each other virtual visits with new holographic technology

Sci-fi vs real-life holograms

The differences between the holograms in Star Wars and some of those available today

REAL

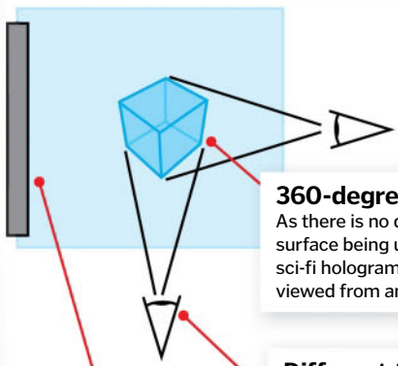


Display surface
The light bounces off a transparent reflective surface, and isn't emitted by the object.

Light reflection
The split beams bounce off mirrors to create the hologram.

No side view
To see the hologram your view must align with the display.

SCI-FI



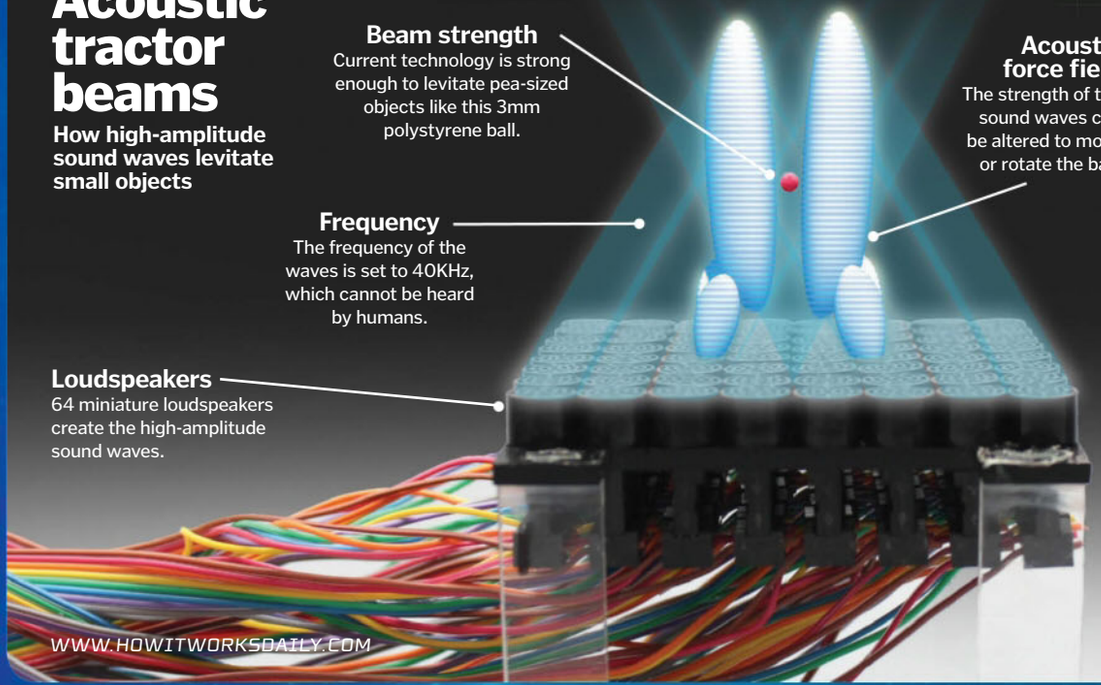
360-degree view
As there is no display surface being used, sci-fi holograms can be viewed from any angle.

Holographic projectors
In *Star Wars* the light is projected from the hologram itself rather than a display surface.

Different types of holograms
Holograms are more flexible in *Star Wars* as they don't have to follow optic rules and can alter the natural properties of light.

Acoustic tractor beams

How high-amplitude sound waves levitate small objects



Beam strength
Current technology is strong enough to levitate pea-sized objects like this 3mm polystyrene ball.

Acoustic force field
The strength of the sound waves can be altered to move or rotate the ball.

Frequency
The frequency of the waves is set to 40KHz, which cannot be heard by humans.

Loudspeakers
64 miniature loudspeakers create the high-amplitude sound waves.

TRACTOR BEAMS

The Death Star's tractor beam was used to capture enemy spacecraft. Recently, a real-life version has been created, albeit on a much smaller scale. Ultrasonic waves are fed through speakers to create acoustic holograms, and the density of the waves makes them powerful enough to move objects. However, this 'tractor beam' won't be used to move large objects like the Millennium Falcon; instead it's aiming at much smaller items, just a few millimetres in size. This ultrasound technology could become an important tool in medicine, manipulating microsurgical instruments without making incisions, or transporting drugs to a specific area of the body.

DROIDS

As intelligent robots develop, how far can we go with AI?

The droids in *Star Wars* come in all shapes and sizes, from battle droid foot soldiers to the lovable BB-8. Back on Earth, the robots that exist are less intelligently programmed, but developments have been made that are raising the bar for robotic artificial intelligence. There's the humanoid Asimo that can understand emotions and actions, and PIBOT, which is being taught to fly planes. Robots will be useful in space exploration too, with NASA's SPHERE and Robonaut2 designed to perform tasks in microgravity on the ISS. Robots are slowly taking on more responsibility and, with further tweaks, could become less reliant on humans, with AI to match droids like C-3PO and R2-D2.

How BB-8 works

The fan theories on this popular droid's inner workings

Head
The dome-shaped head has magnetic rollers that allow it to roll evenly over the body.

Body
The spherical body gives BB-8 a speed advantage compared to older astromech droids.

Electronic control system
Four motors connect to omni-directional wheels, controlling BB-8's movement a bit like a Segway.

Motorised arm
BB-8's interior contains a spherical joint that can move the droid in any direction.

Real-life droids

The highly advanced robots currently used for specialised tasks

1 AEODRS
Bomb disposal robot
This small, robust, unmanned robot will safely disarm and remove bomb threats. It can fit snugly inside a soldier's backpack and is deployed to help save lives.

2 DA VINCI SURGICAL SYSTEM
Robotic surgical assistant
With medical instruments more mobile than the human hand, this robot helps surgeons perform precise operations.

3 PEPPER
Emotion reader
One of the most advanced robots ever created, the humanoid Pepper is designed to be a companion. It can interact with humans in a natural way and is able to read our emotions.

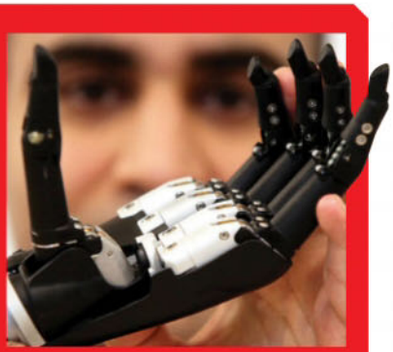
4 KUKA KR 1000 TITAN
Robotic arm
These devices are used prominently in the manufacture of cars and have the power, as well as the precision, to lift and load weights of up to 1,000kg.

5 NASA'S CURIOSITY MARS ROVER
Robotic explorer
Essential for exploring the Red Planet, this robot sends images back to Earth and can analyse Martian rock samples in its onboard laboratory.

ADVANCED BIONICS

In the *Star Wars* films, both Anakin and Luke are fitted with bionic limbs after losing their right forearms in lightsaber duels. In the real world, a new research project directed by Newcastle University is developing bionic hands to replace injured limbs. Current limb prosthetics are mostly 'plug and socket' designs, which the wearer learns to move by flexing certain muscles. However, the muscles in injured limbs are often too damaged for this to work. This new technology will allow artificial limbs to sense both pressure and temperature like a real hand.

Electronic devices connect to the remaining nerve endings in the forearm, recreating the natural movement of the hand. Fingertip sensors will allow the wearer to accurately differentiate between the sensations of hot and cold and rough and smooth, as well as comfortably grasp objects like glasses, balls or fruit without breaking or dropping them. The two-way communication between the brain and the hand is done in real-time, and the proprioception (the sense of your body's position) is as it would be in a natural limb.



A team led by Dr Kianoush Nazarpour created a more sensitive bionic hand

Star Wars droids

What are the droid classes of the Star Wars universe?

CLASS 1
Medical
These droids are used to cure ailments and injuries. Surgical droids saved Anakin's life, transforming him into Darth Vader.

CLASS 2
Technical
This class of droid is built to repair spaceships and their internal systems. The lovable astromech R2-D2 is one of them.

CLASS 3
Protocol
As C-3PO once said, these droids specialise in 'human-cyborg relations'. They are primarily employed as assistants.

CLASS 4
Fighters
Combat droids carry out the dirty work in the galaxy, and range from bounty hunters and soldiers to security robots.

CLASS 5
Labour
These basic workers are used for jobs like cleaning and maintenance, often in dangerous places like the lava-planet Mustafar.

LANDSPEEDERS

Travel Tatooine-style on vehicles that hover

The Aero-X is an exciting new invention that resembles Luke Skywalker's landspeeder. The two-person hover vehicle is controlled just like a motorbike, and is designed for search and rescue operations, as well as farming and ranching. A similar vehicle is the Malloy Aeronautics Hoverbike. A very ambitious project, it is predicted to be able to hover at heights of nearly 3,000 metres. The hoverbike will utilise a fly-by-wire system that uses electrical impulses to send instructions from the dashboard to the engine. Both these vehicles use propellers to achieve flight, but other designs instead change the infrastructure below them. Magnetic levitation, or maglev, is already used in rail tracks in a number of countries. Powerful electromagnets in the ground repel the vehicle, causing it to hover.

The Malloy Aeronautics Hoverbike is described as the world's first flying motorcycle and is currently in the testing stage

ASK THE EXPERTS

We spoke to Aerofex to find out more about the hoverbike

How does the Aero-X work?
The Aero-X uses two ducted fans arranged in tandem like the wheels on a motorbike, but parallel to the ground. This arrangement lifts and propels the vehicle, while allowing the pilot to balance and fly as if they were on a bike.

How will it be used?
It will be used mostly for low-altitude utility such as farming, pipeline and track inspection, and specialty services such as unexploded ordnance remediation. It will also be very popular for recreation and air-racing.

Why have you used rotor blades in the Aero-X design?
The vehicle uses rotor blades inside the ducts as they are very efficient for generating lift. Rotors are a reliable technology whose behaviour is well understood. Inside the ducts they are safe and their downwash can be tailored.

Are rotor blades the best type of hovering technology? Are you looking at any others?
Other hovering technologies were considered but have their drawbacks. Jet engines have been tried in the past, but their noise and downwash are intolerable at low altitude. Magnetic levitation is also effective, but it requires a lot of energy and a prepared surface – so it is difficult to employ for our purposes.

Can the technology be used in other vehicles or machines?
We are currently building a smaller robotic version for spraying crops. We have also been asked to develop a similar version to operate on water. As drones become larger, we believe they will use Aero-X technology to make them safer.

How is it different from the landspeeder in *Star Wars*?
The land speeder can hover even when it is turned off. The Aero-X needs the pilot on board before it can lift off. Otherwise they are very much the same.

What is the future for hover vehicles?
We will see a whole new class of vehicles that operate between the ground and 15 feet [4.6 metres] above. They will begin to resemble cars and offer an additional layer of near-surface transport. They will initially be used for emergency services and patrol, and then eventually for taxi services and transport. They will augment cars rather than replace them.

Aero-X

Step on board a low-altitude hoverbike that is controlled just like a motorcycle

Control
It only takes a week of training to learn how to operate the Aero-X. It is fitted with a roll bar and optional air bags for added safety.

Extras
A transport trailer can be attached to the hovercraft, and there's a USB port for charging phones and tablets.

Ground clearance
The Aero-X hovers 3m off the ground using rotating carbon-fibre fans, and can reach speeds of 72km/h.

Fan protection
For more efficient airflow and to protect from potentially damaging obstacles, the rotors are encased in ducts.

"The Aero-X will also be very popular for recreation and air-racing"

Structure
A carbon-fibre composite construction makes the vehicle light yet durable. Flotation pontoons can be included to allow the Aero-X to travel over water.

Vertical lift
The vehicle takes off vertically with no need for a runway, and can run on standard petrol for up to 75 minutes.

LASER WEAPONS

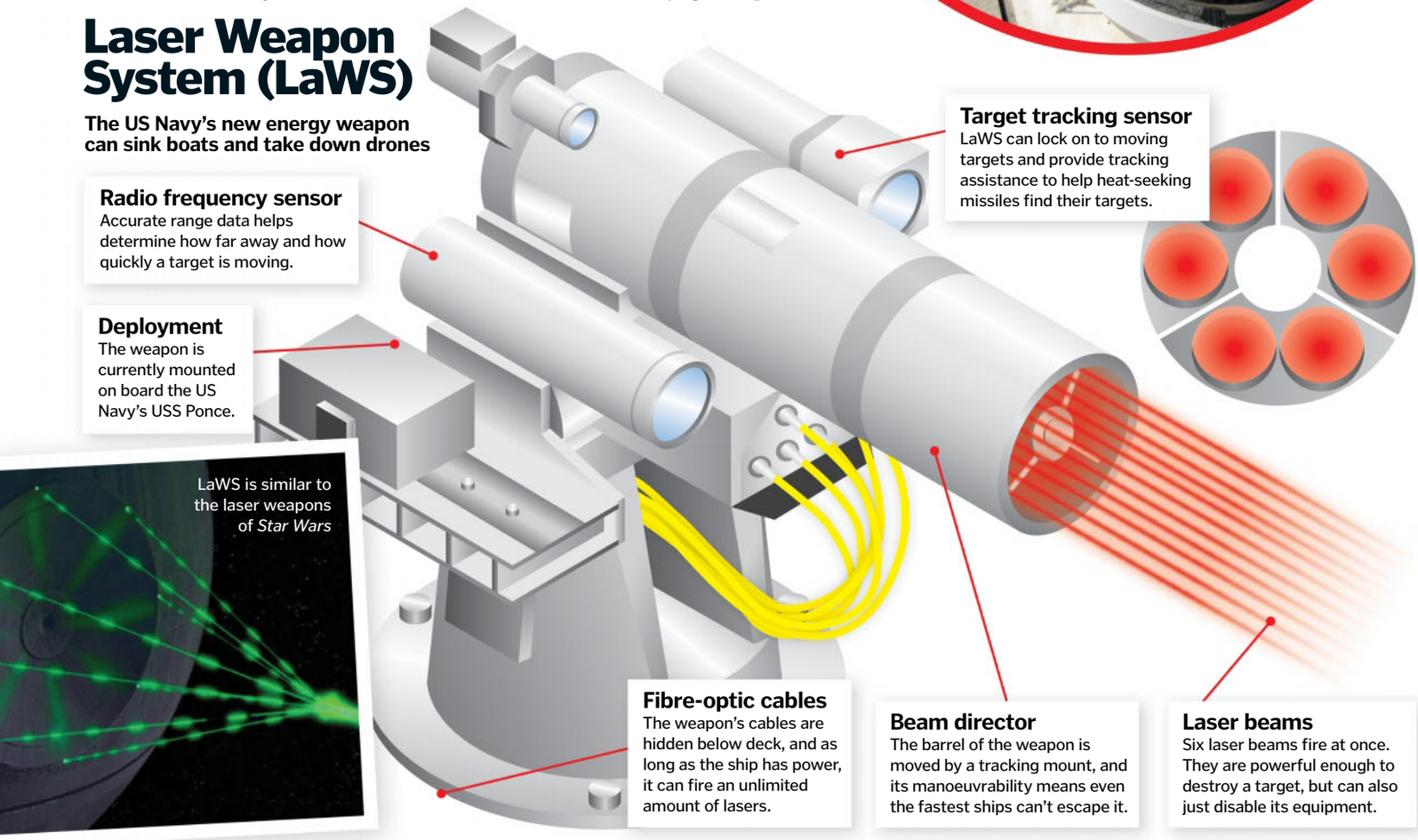
Blasters firing powerful rays of light could soon be used in combat

The US military demonstrated the use of laser weapons in 2010 when four drones were shot out of the sky by a directed-energy weapon aboard USS Ponce. Laser weapons could replace missiles in some capacities, and are also being tested on land in Stryker armoured vehicles, and in the air on AC-130 gunships.

A laser attack can be invisible – the target won't know they're under fire until the damage is done

Laser Weapon System (LaWS)

The US Navy's new energy weapon can sink boats and take down drones



Radio frequency sensor
Accurate range data helps determine how far away and how quickly a target is moving.

Deployment
The weapon is currently mounted on board the US Navy's USS Ponce.

Target tracking sensor
LaWS can lock on to moving targets and provide tracking assistance to help heat-seeking missiles find their targets.

Fibre-optic cables
The weapon's cables are hidden below deck, and as long as the ship has power, it can fire an unlimited amount of lasers.

Beam director
The barrel of the weapon is moved by a tracking mount, and its manoeuvrability means even the fastest ships can't escape it.

Laser beams
Six laser beams fire at once. They are powerful enough to destroy a target, but can also just disable its equipment.

LaWS is similar to the laser weapons of *Star Wars*

HOW WOULD AN X-WING WORK?

The unusual shape of the Rebel Alliance's starfighter has led many to wonder whether it would really make it off the ground in real life. It isn't very aerodynamic, and both the engines and the weapons on the wings are very heavy, which would cause lots of unwanted drag if it were to fly on Earth. That said, the wings are similar to a biplane, which is a design type that has been proven to work.

Ultimately, a real-life X-Wing could fly as long as it was computer-controlled. Without any computer assistance, it would be very tricky to pilot. As an X-Wing doesn't have a tail, it would be hard for the pilot to maintain stability in the air. In conventional aircraft, the centre of pressure is behind the centre of gravity, which helps keep the flight trajectory level, but this is not how the X-Wing is designed. The most similar design we currently have to Red Squadron is the Boeing X-48B with its blended-wing body style.

The blended-wing style of the Boeing X-48B wasn't too different from the X-Wing

"A real-life X-Wing could fly as long as it was computer-controlled"

LIGHTSABERS

Many fans of Star Wars have dreamt of having their very own Jedi weapon

Scientists have proposed a couple of ways to recreate the legendary lightsaber. One method is to harness the fourth state of matter, plasma, an ionised gas in which atoms are separated into negatively charged electrons and positively charged ions. In theory, this superheated substance could slice through metal, but it would require an enormous amount of energy to do so – and that would make it far too hot to hold in your hand.

Another idea is to use lasers. Scientists at Harvard and MIT have discovered that photons can be coaxed into interacting with each other. After being bound together with rubidium atoms in a vacuum chamber at temperatures of almost absolute zero, it was found that they combined to form molecules. This would allow the lasers to clash rather than simply passing through each other. One potential drawback is that lasers can easily be reflected, so all your opponent would need is a mirror and they could turn the lightsaber back against you!

The TEC Torch is a portable breaching tool that burns through material in a similar way to a lightsaber. Developed by Energetic Materials & Products Inc, it contains thermite cartridges that burn at 2,800 degrees Celsius, which is strong enough to cut through steel. It can slice through door hinges, locks and chains in a matter of seconds, and could be a valuable tool for the police and the military when conducting rescue missions.

The TEC Torch

This thermal cutting tool emits intense blasts of heat that melts steel in seconds

The Tec Torch erodes materials by heating them past their melting point

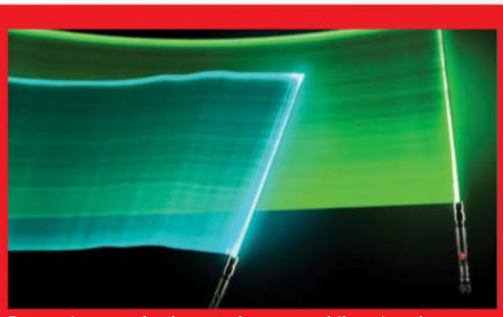
Heat blast
Each blast of metal vapour lasts for only two seconds, but this is long enough to burn through metal locks, chains and hinges.

Ignition
A push of a button ignites the thermite cartridges that contain a combustible mixture of metals and metal oxides.

Uses
The TEC Torch is useful in military operations and allows quick access to blocked-off areas during rescue missions. It can even work underwater.

THE LASERSABER

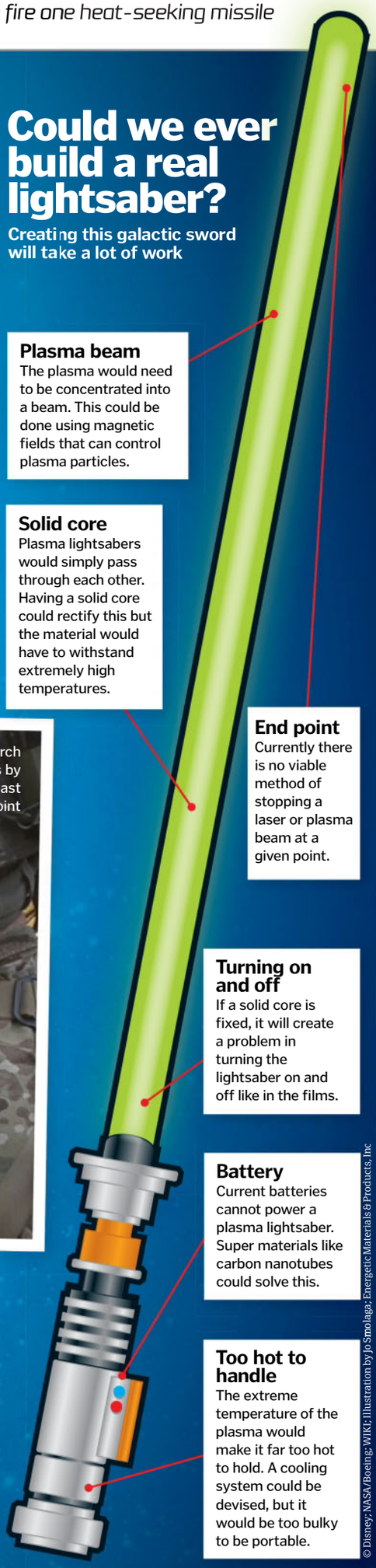
A gadget that looks very similar to a lightsaber is already available: the LaserSaber. It consists of an 80-centimetre polycarbonate blade and an aluminium alloy hilt. The laser's energy is distributed evenly along the blade, and it even appears to 'power up' and 'power down' like its fictional counterpart. This is achieved using a metal sphere suspended in the tube, which is held in place by magnetic forces. When the LaserSaber is switched on, the sphere is pushed along the tube and locks in place at a magnet at the tip, giving the blade a solid end point.



Protective goggles have to be worn while using the LaserSaber as the laser itself is very powerful

Could we ever build a real lightsaber?

Creating this galactic sword will take a lot of work



Plasma beam
The plasma would need to be concentrated into a beam. This could be done using magnetic fields that can control plasma particles.

Solid core
Plasma lightsabers would simply pass through each other. Having a solid core could rectify this but the material would have to withstand extremely high temperatures.

End point
Currently there is no viable method of stopping a laser or plasma beam at a given point.

Turning on and off
If a solid core is fixed, it will create a problem in turning the lightsaber on and off like in the films.

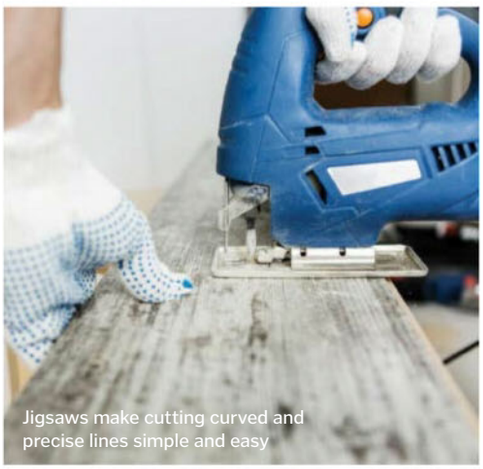
Battery
Current batteries cannot power a plasma lightsaber. Super materials like carbon nanotubes could solve this.

Too hot to handle
The extreme temperature of the plasma would make it far too hot to hold. A cooling system could be devised, but it would be too bulky to be portable.

Jigsaws

The power tools that help you cut your material into all kinds of amazing shapes

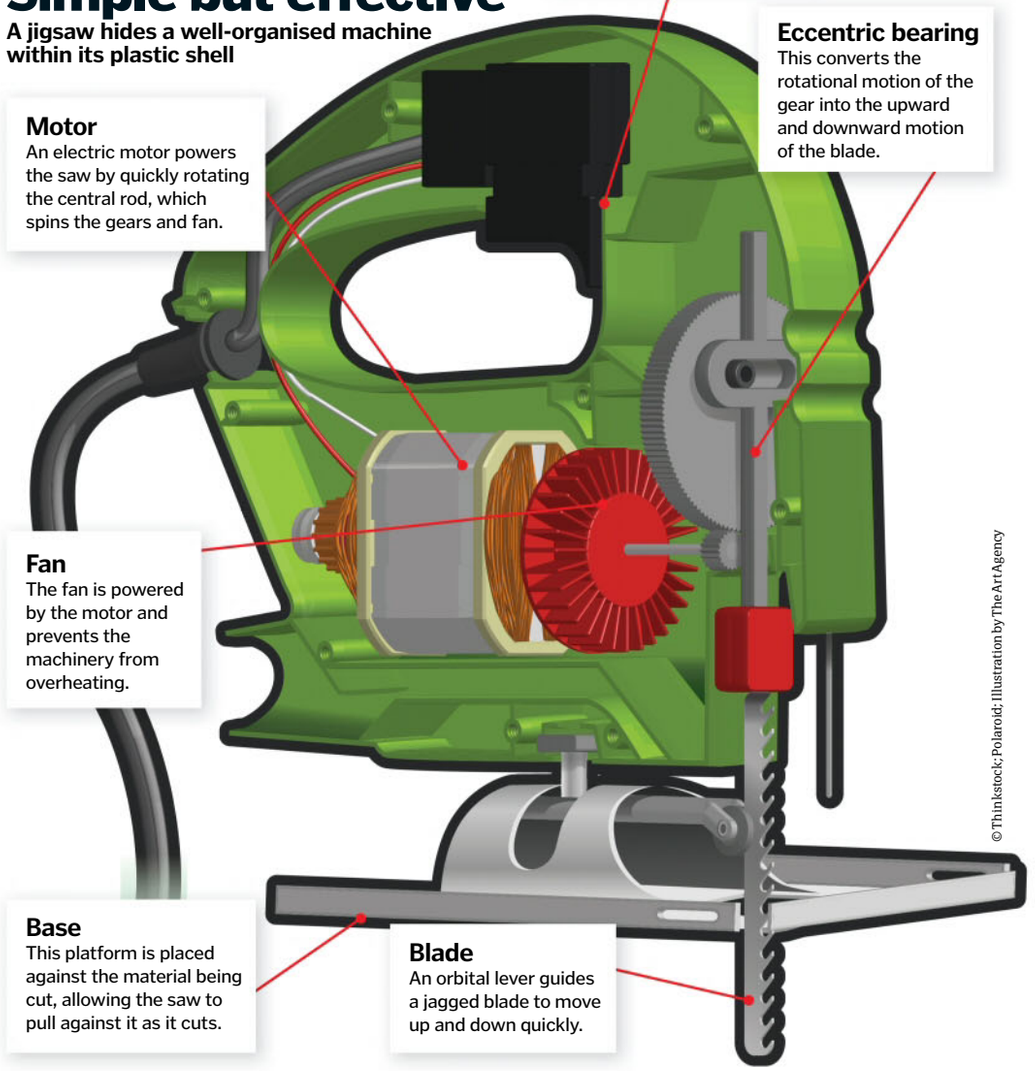
Jigsaws are a firm favourite in woodwork lessons. These hand-operated tools cut using a toothed blade that protrudes from the bottom of a plastic housing, and are ideal for cutting precise curved lines into materials. They're also adaptable, as most jigsaws have different speed settings and blade options to optimise the kit for plastic, wood or metal. Their versatility and ease of use make jigsaws a great choice for learning carpentry. If you ever want to change the shape of your boring rectangular desk, you know what tool to look for.



Jigsaws make cutting curved and precise lines simple and easy

Simple but effective

A jigsaw hides a well-organised machine within its plastic shell



Trigger
Holding this down activates the saw, connecting the circuit from the power source to start the motor.

Eccentric bearing
This converts the rotational motion of the gear into the upward and downward motion of the blade.

Motor
An electric motor powers the saw by quickly rotating the central rod, which spins the gears and fan.

Fan
The fan is powered by the motor and prevents the machinery from overheating.

Base
This platform is placed against the material being cut, allowing the saw to pull against it as it cuts.

Blade
An orbital lever guides a jagged blade to move up and down quickly.

Polaroid Snap Touch

Instant photography gets a digital upgrade

Taking a good photo on a Polaroid instant camera used to involve a great deal of luck, as you were unable to preview your snap before a print emerged. Now though, the days of disappointing shots are a thing of the past, all thanks to a digital upgrade. The new Polaroid Snap Touch combines the benefits of an instant photo print with the convenience of modern camera technology, as it features a 13-megapixel sensor, instead of analogue film, and an LCD touchscreen.

Once you've taken a photo, you can check that it is picture perfect on the screen, before you decide whether or not you want to print it. You can even edit your shot too, turning it black and white or sepia for a more vintage look. Then the photo prints on innovative Zink Zero Ink paper straight from the camera, ready to go into an album or be stuck on the fridge.

The Polaroid Snap Touch can produce a 2x3-inch print in less than a minute

Zero ink printing

How does the Snap Touch print without ink cartridges?

1. Load the paper
The Zink paper inside features colourless crystals that turn into coloured dye when heat is applied.

2. Crystal colours
There are three layers of dye crystals; one turns cyan, another magenta and another yellow.

3. Tap the screen
After you take a photo, you can preview, edit and print it via the LCD touchscreen.

4. Apply some heat
The level and duration of heat dictates which colour dyes activate.

5. Admire your print
Mixing these three colours together can create all the colours of your photo, producing a high quality print.

Christmas Gift Guide

If you've got some gaps on your Christmas list this year, or need to find someone the perfect present, look no further. Treat your family and friends (or yourself) to some of the coolest gifts around

Super Precision Gyroscope

This gyroscope has been designed and built to the highest precision. A solid brass disk, lightweight aluminium frame and stainless-steel ball bearings allow it to operate at over 12,000 rpm using the provided electric motor. It comes with attachments allowing numerous configurations to perform scientific, educational or simply mesmerising experiments.

www.gyroscope.com

Salomon Trail 20 Pack

The Trail 20 ensures a balanced load distribution and ease of use, with great access to the main compartment and convenient hip belt pockets. It is ideal for moderate runs or day hikes on any terrain.

www.salomon.com

Chris Hadfield Live in the UK

In January Chris Hadfield returns to the UK for a short series of innovative and inspirational shows which open up the world of space exploration for everyone. Featuring photos and videos from his own collection, Chris tells his own incredible story and reveals incredible stories about life on the International Space Station. *For further price information and to purchase tickets:*

www.uniquelives.com/chris-hadfield-uk

GoPro HERO Session

Never miss capturing the perfect picture during your most exciting moments. Small and light with easy one-button control and rugged waterproof design, this is the simplest grab and go capture experience.

www.ellis-brigham.com

Nite Watches - ALPHA-209S T100

Tell the time, all the time. The ALPHA-209S T100 from British watch brand Nite Watches combines the completely self-powered T100 rated Tritium illumination with sapphire crystal and a Swiss movement, providing 10 years battery life. A watch that can be depended upon, appreciated and desired at all times.

www.nitewatches.com

Universe2go

Universe2go is an augmented-reality star viewer and app, combining stargazing with history, mythology and lasting impressions, otherwise solely experienced in a planetarium. Using your smartphone, Universe2go superimposes a digital picture over the night sky, offering a revolutionary perspective of the universe and the chance to explore the cosmos with astounding precision and ease.

10% promo code: u2gohiw16. Valid until 31st January 2017.

www.universe2go.com

The next generation of programmers

Discover why children are learning to code through apps and games

Programming is set to become one of the fastest-growing professions over the next ten years, and there just aren't enough computer-science students to fill all of the jobs. Learning to code is now a fundamental part of mainstream education. Even for those who won't grow up to become programmers, coding teaches valuable lessons.

Learning to 'speak' to computers teaches children how to use logic to solve problems. They get to test out different ideas, and have the opportunity to produce something functional or fun using their own creativity. And getting started has never been easier. The latest toys, games and apps make coding accessible to pretty much anyone.

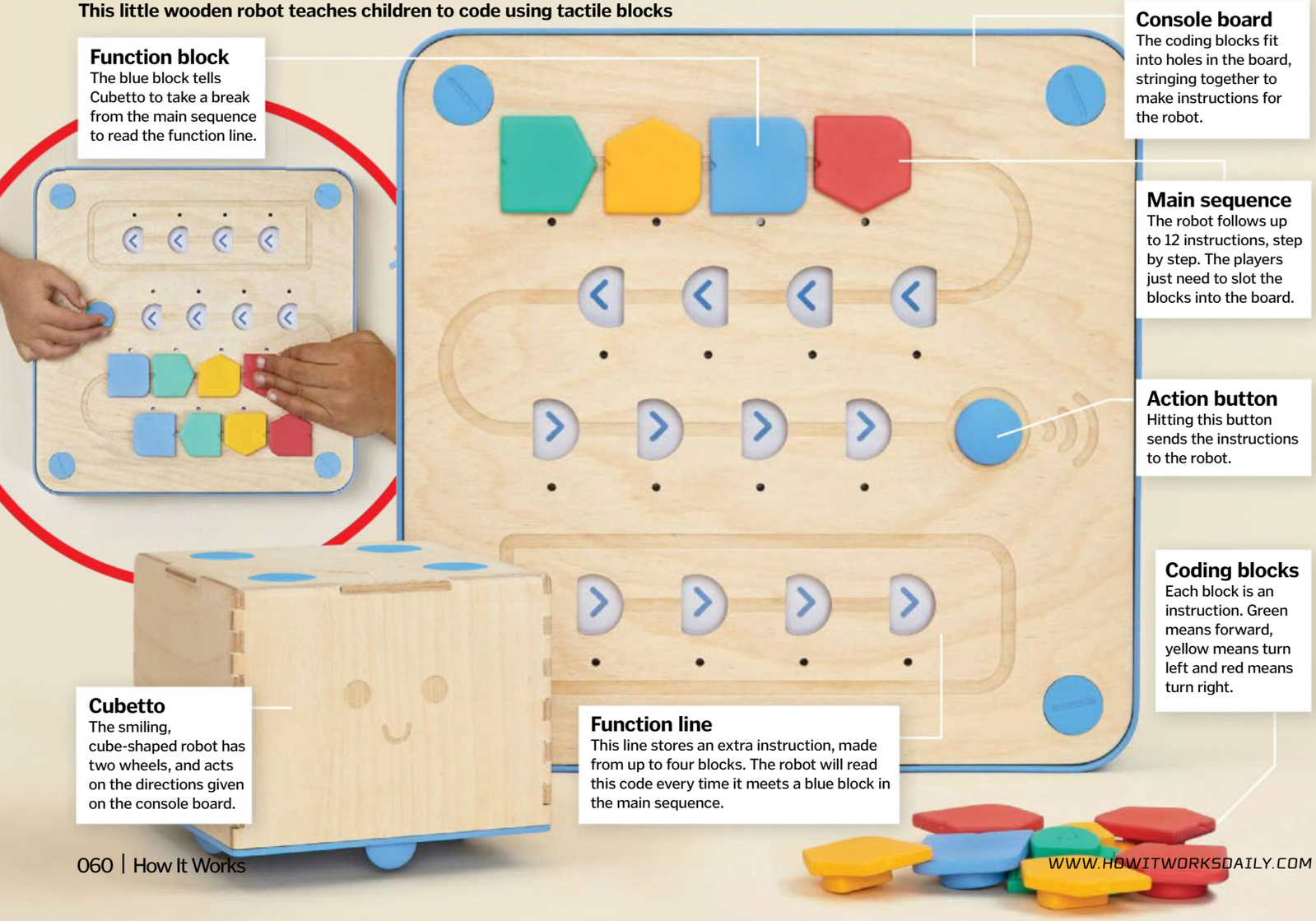
For those who want to dive right in at the deep end, there are plenty of websites available that teach the basics of popular programming languages through interactive lessons. This allows you to type code straight in to your web browser and immediately see the effects. Some even turn the process itself into a game to make it more engaging.

If that's all too much, there is now a wealth of apps and games that hide the language of programming, and instead go straight into teaching the concepts and structures that hold it all together. Instead of asking you to type out the code line by line, they provide ready-made blocks that can be slotted together to build programs without having to type a word.

The secret is learning by doing, through trial and error, and the latest tools and technology make that easier and more engaging than ever before. What are you waiting for? Get stuck in!

How Cubetto works

This little wooden robot teaches children to code using tactile blocks



Function block
The blue block tells Cubetto to take a break from the main sequence to read the function line.

Console board
The coding blocks fit into holes in the board, stringing together to make instructions for the robot.

Main sequence
The robot follows up to 12 instructions, step by step. The players just need to slot the blocks into the board.

Action button
Hitting this button sends the instructions to the robot.

Coding blocks
Each block is an instruction. Green means forward, yellow means turn left and red means turn right.

Cubetto
The smiling, cube-shaped robot has two wheels, and acts on the directions given on the console board.

Function line
This line stores an extra instruction, made from up to four blocks. The robot will read this code every time it meets a blue block in the main sequence.

Making Cubetto

We spoke to Filippo Yacob, CEO and co-founder of Primo, about the importance of teaching kids how to code

How did you first come up with the idea for Cubetto?
It was 2013. I was looking for the easiest way to teach my son coding starting at age three. I wanted to give him a head start in life. I wanted a toy that would be completely tangible, accessible to all cultures and genders, and worked without a screen. Today, Cubetto is a standard in early learning and coding in more than 90 countries. I was not alone.

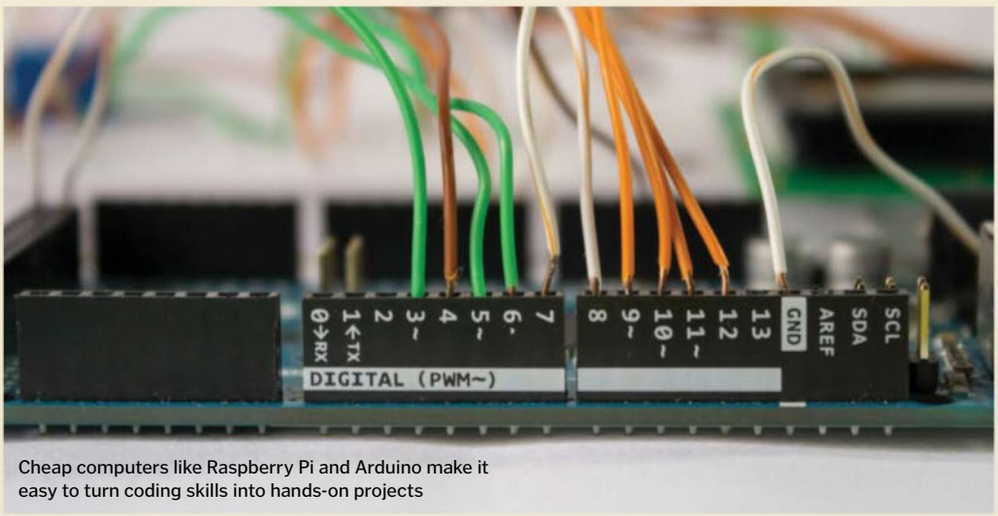
Why is it important for children to learn programming skills?
There will be nearly 900,000 job vacancies by 2020 for computer programmers. This deficit is growing. Teach your children programming and you increase their chances for success in the future. The second reason is that from art to music to science, coding gives us infinite capacity for creative expression, and a greater chance at a richer life.

Is there an advantage to learning to code at a really young age?
Learning to code is like learning a language. If you start early it becomes second nature. Learning to program also helps you to think logically, and solve problems better by developing critical thinking. These are transferable skills that will help a child in all aspects of his or her life.

Why do you think games are such a good way to get children learning?
Play mirrors real life. It gives children a safe place to learn their limits and discover themselves. The coding blocks children use to program Cubetto are a ground-breaking, tangible, procedural programming language. By making code look, feel and work like a toy, we made coding immediately accessible to young children by making it playful.

What would you say makes a good educational game?
A good educational toy makes children forget they're learning. When we see children play with Cubetto they talk about adventure, movement, places they want Cubetto to visit. The learning happens naturally.

What is the future for Cubetto and learning to code using games?
In April, Cubetto became the most crowd-funded educational invention in Kickstarter history. There are 2.5 million early-learning centres, primary schools and public libraries in the world. We would like to see a child play with a Cubetto in every one of them. The potential of a generation growing up with a tool like Cubetto is huge.



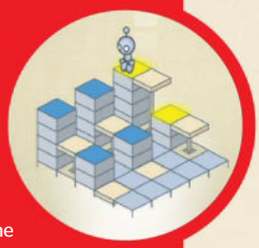
Cheap computers like Raspberry Pi and Arduino make it easy to turn coding skills into hands-on projects

Programming apps and games

CodeCombat
www.codecombat.com

This community project aims to teach code in the form of a role-playing game. Beginning in the Dungeons of Kithgard, the player is first asked to choose a hero, and is then given the choice of four programming languages: Python, JavaScript, CoffeeScript and Lua. They put on their boots and prepare to navigate through a maze of spikes to gather gems, not by using the arrow keys, but instead by typing out lines of code. As the player improves, so does their character, and the upgrades they unlock open up even more programming options.

Lightbot
www.lightbot.com



This mobile app has coding puzzles for children aged as young as four. The player must program Lightbot to help it navigate through each level. The code comes together by clicking on blocks to create a sequence. It starts simple, teaching the player to walk, before moving on to more complex concepts like loops.

Machineers
www.machineers.com

This beautiful construction puzzle game teaches the underlying structure of code by replacing programming languages with knobs, wires and switches. The player is tasked with helping a town to repair their machines, and will pick up fundamental coding skills along the way, without even realising.

Hopscotch
www.gethopscotch.com

This mobile app teaches the principles of coding using a simple drag-and-drop system. Assemble blocks of code to create games, websites, images, videos and more. Learn about variables and loops, then quickly publish your content and share it with the world. Video tutorials help people to jump straight in.

Online coding tutorials

Get to grips with programming basics on these interactive sites

Minecraft
https://minecraft.net
With thousands of children already playing Minecraft, the LearnToMod add-on gives players the chance to use their favourite game to learn coding. The result: the ability to make your own Minecraft 'mods' with altered game features.

Codecademy
www.codecademy.com
This online learning hub provides step-by-step interactive coding courses, right from the basics of making a website, all the way up to tapping into Twitter. Codecademy teaches 12 different programming languages.

Code School
www.codeschool.com
Here we have another online interactive tutorial site with a wealth of possibilities for the budding programmer. With video lessons, practice sessions and badges, tutorials cover everything from HTML to iOS app development.

Hour of Code
www.hourofcode.com
These bite-sized tutorials get people coding very quickly. It started as a one-hour introduction to coding, and now you can learn to make a maze, a Flappy Bird clone or a Minecraft adventure in just 60 minutes.

How are bowling balls made?

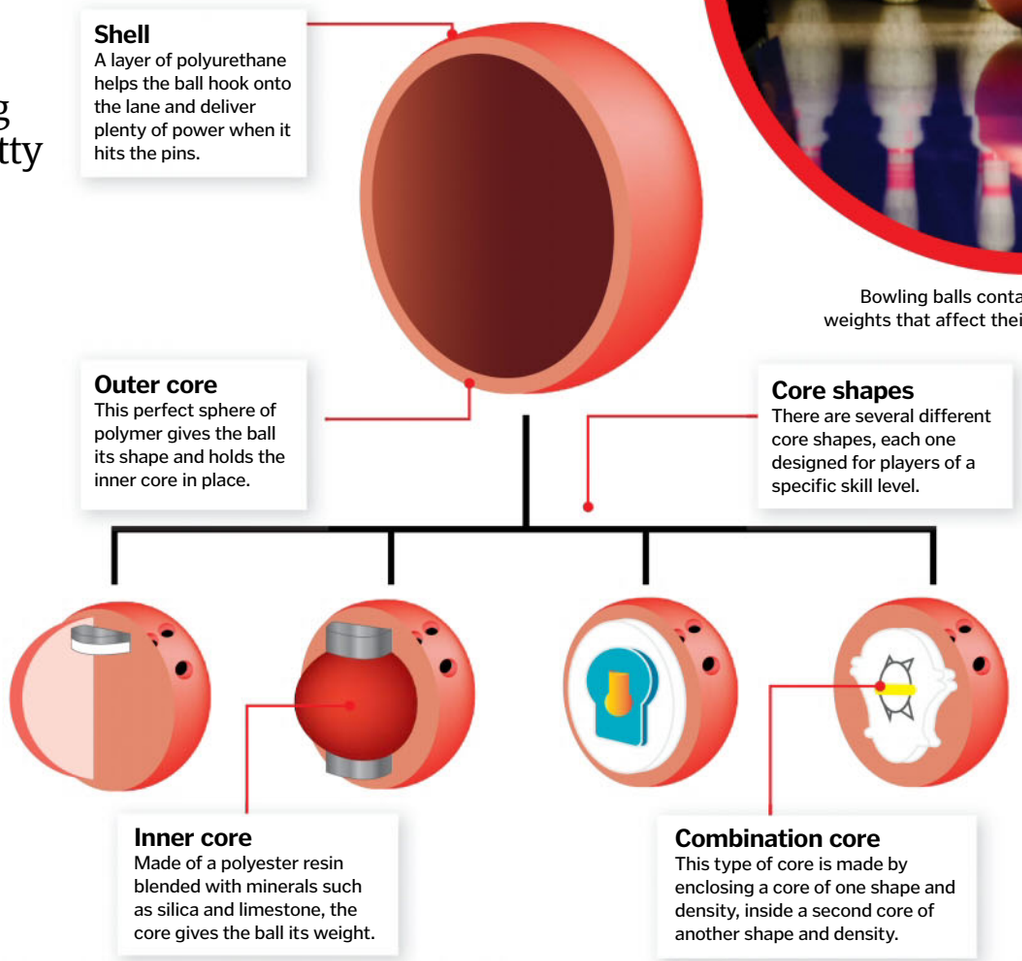
If you cut open a bowling ball, you'd be in for a pretty big surprise

They may look like simple spheres of coloured plastic, but bowling balls are carefully engineered for optimal sporting performance. Inside are several different layers, with a heavy asymmetrical core designed to curve the ball towards the pins. The core is made from polyester resins blended with minerals. A catalyst is added to trigger a chemical reaction that heats up the plastic mixture. It can then be poured into a mould, where it quickly solidifies. Next, the core is placed within a larger mould and another layer of plastic is poured in. An outer layer of veneer is added to help the ball grip the lane. Finally, the three finger holes are drilled into the side.

Bowling balls contain hidden weights that affect their rotation

Inside a bowling ball

Discover the many layers of plastic that help you topple those pins



Shell
A layer of polyurethane helps the ball hook onto the lane and deliver plenty of power when it hits the pins.

Outer core
This perfect sphere of polymer gives the ball its shape and holds the inner core in place.

Core shapes
There are several different core shapes, each one designed for players of a specific skill level.

Inner core
Made of a polyester resin blended with minerals such as silica and limestone, the core gives the ball its weight.

Combination core
This type of core is made by enclosing a core of one shape and density, inside a second core of another shape and density.

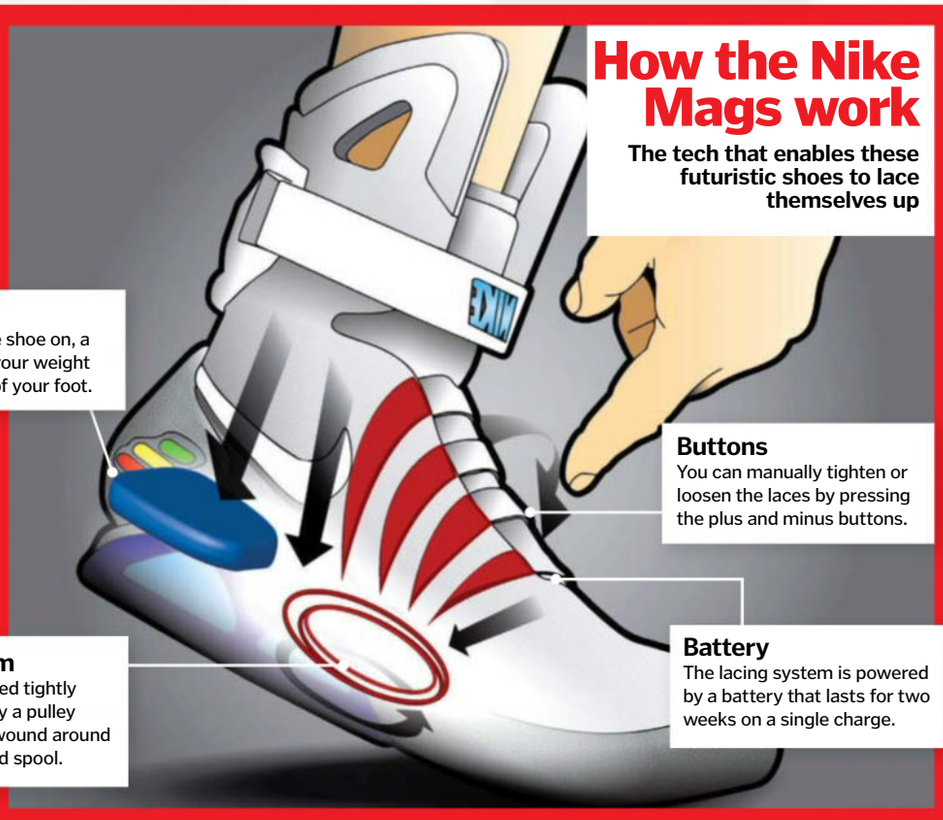
Self-lacing shoes

Where we're going, we don't need to tie our shoelaces

While we may not have flying cars, proper hoverboards, or many of the other inventions predicted in *Back To The Future II*, one exciting innovation has become reality. Nearly 30 years after the film's release, Nike has unveiled a working version of the self-lacing shoes Marty McFly wore when he travelled to 2015. They may be a year late, but the 2016 Nike Mags look just like their movie inspiration, and feature laces that automatically tighten to fit your feet. Only 89 pairs have been made, and Nike distributed them all via an online draw to raise money for The Michael J Fox Foundation's fight against Parkinson's disease.

How the Nike Mags work

The tech that enables these futuristic shoes to lace themselves up



Sensor
When you slip the shoe on, a sensor registers your weight and the position of your foot.

Buttons
You can manually tighten or loosen the laces by pressing the plus and minus buttons.

Pulley system
The laces are pulled tightly around the foot by a pulley system, and are wound around a battery-powered spool.

Battery
The lacing system is powered by a battery that lasts for two weeks on a single charge.

Glasses for the colour blind

EnChroma glasses help people with CVD distinguish between colours

Discover the optical tech that can restore normal colour vision

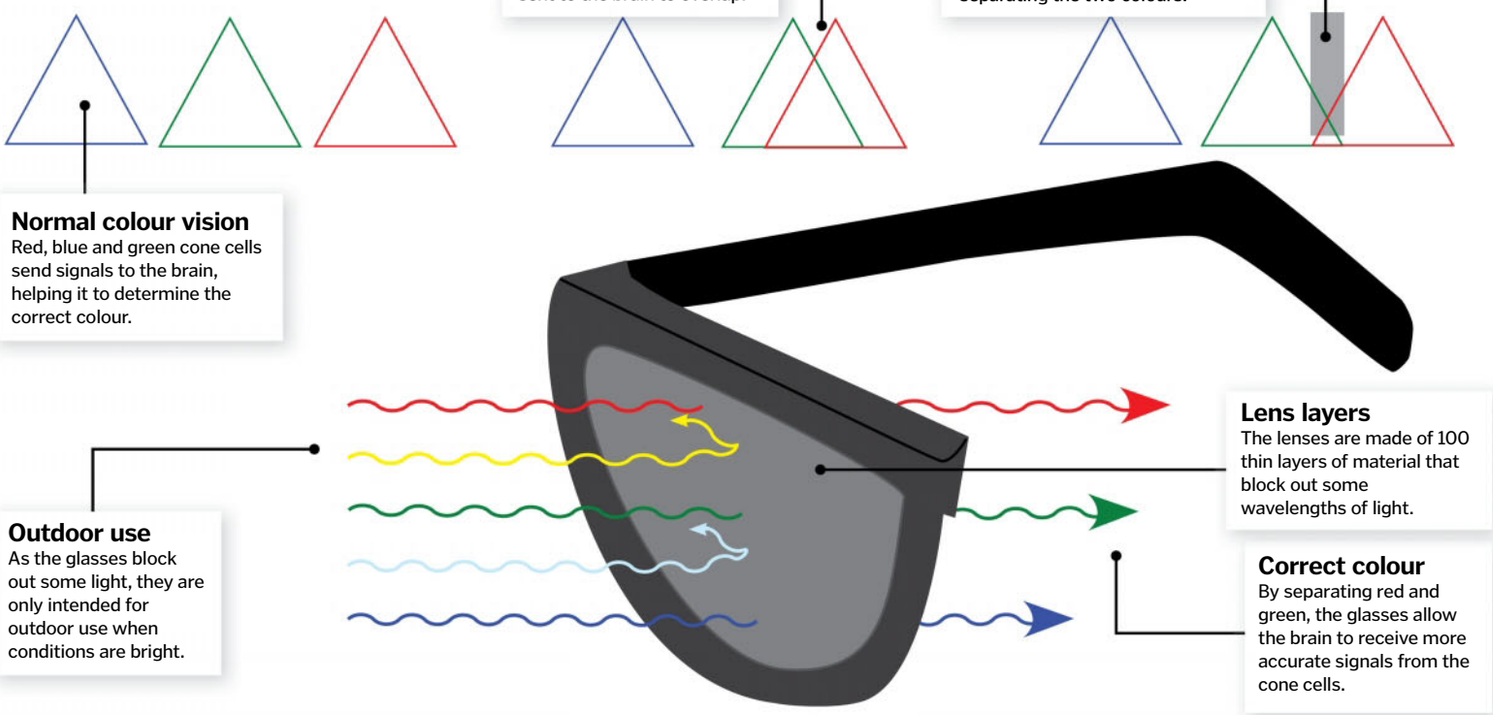
Millions of people around the world experience colour blindness, with one in 12 men, and one in 200 women affected by the condition. Men are more susceptible because most cases are inherited through the X chromosome, of which men have one and women have two. Therefore, men have a decreased chance of inheriting one normal copy of the gene.

Although commonly referred to as colour blindness, those affected are not actually blind to colour. The more accurate term is colour vision deficiency (CVD), as those with the condition have difficulty distinguishing between certain shades. This is caused when one type of cone cell at the back of the eye is missing or mutated, affecting the signals received by the brain that help it determine colour. The most common form of the condition is known as red-green CVD, which occurs when the red and green cone cells overlap more than normal. This alters the strength of the signals sent to the brain, causing green to appear more brown, and red to appear more yellow.

While there is no cure for CVD, EnChroma has developed a pair of glasses that can improve colour vision. They were originally used as safety glasses by surgeons performing laser eye surgery, but when a person with red-green CVD put them on, they noticed that they could see more colours than they were able to before.

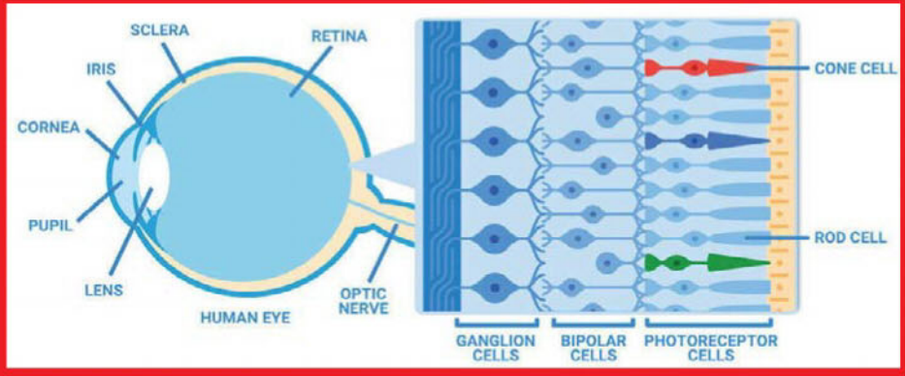
Seeing the rainbow

How do EnChroma glasses solve red-green colour vision deficiency?



How we see colour

When light reaches our eyes, it is detected by photoreceptor cells in the retina called rods and cones. Rods detect the brightness of the light, while cones detect the colour. Humans have three different types of cone cell, each able to detect all of the visible wavelengths, or colours, of light. However, some respond more strongly to certain wavelengths than others. Red cone cells respond more strongly to long wavelengths, blue cone cells to short wavelengths and green cone cells to the wavelengths in the middle of the spectrum. To determine the colour of the object you are seeing, your brain compares the strength of the signal coming from each cone cell, and mixes them together to create the right shade.



WATER WORLDS

In our search for life, water may lead the way

As we continue our search for life elsewhere in the universe, one thing is becoming clear. There are many worlds like Earth, and some may also play host to water – a key ingredient for life as we know it.

In our own Solar System, there is a rapidly growing list of worlds that have water in one form or another. Some, like Ceres in the asteroid belt, are likely to merely have the frozen remains of a once liquid ocean. But others hint at a surprising level of activity.

We are yet to actually see any of these oceans, as they are buried deep beneath the surfaces of various moons, away from prying eyes. But we do have indirect evidence for their existence, in the form of shifting surface features, fluctuating magnetic fields, or plumes of water vapour ejected into space. The latter, seen on Saturn's moon Enceladus, has been studied in detail by NASA's Cassini spacecraft.

It is not just our own Solar System that is enticing though. We now know of thousands of exoplanets – worlds beyond the Solar System – many of which could play host to fascinating reservoirs of water. Evidence is already mounting for some planets that could be covered in a global ocean, while we now know of a handful that are located in the revered 'habitable zone' of their star, where the temperature is right for liquid water to exist on their surface.

No other world is known to have bodies of liquid water on its surface; only Saturn's moon Titan has any large amount of liquid, composed of liquid hydrocarbons. But we know how vital water is to life, and further studies of any one of these worlds could reveal some exciting findings.

Ocean world status definitions

ACTIVE
A dynamic ocean that could support life.

LOCKED
A trapped ocean that is unlikely to support life.

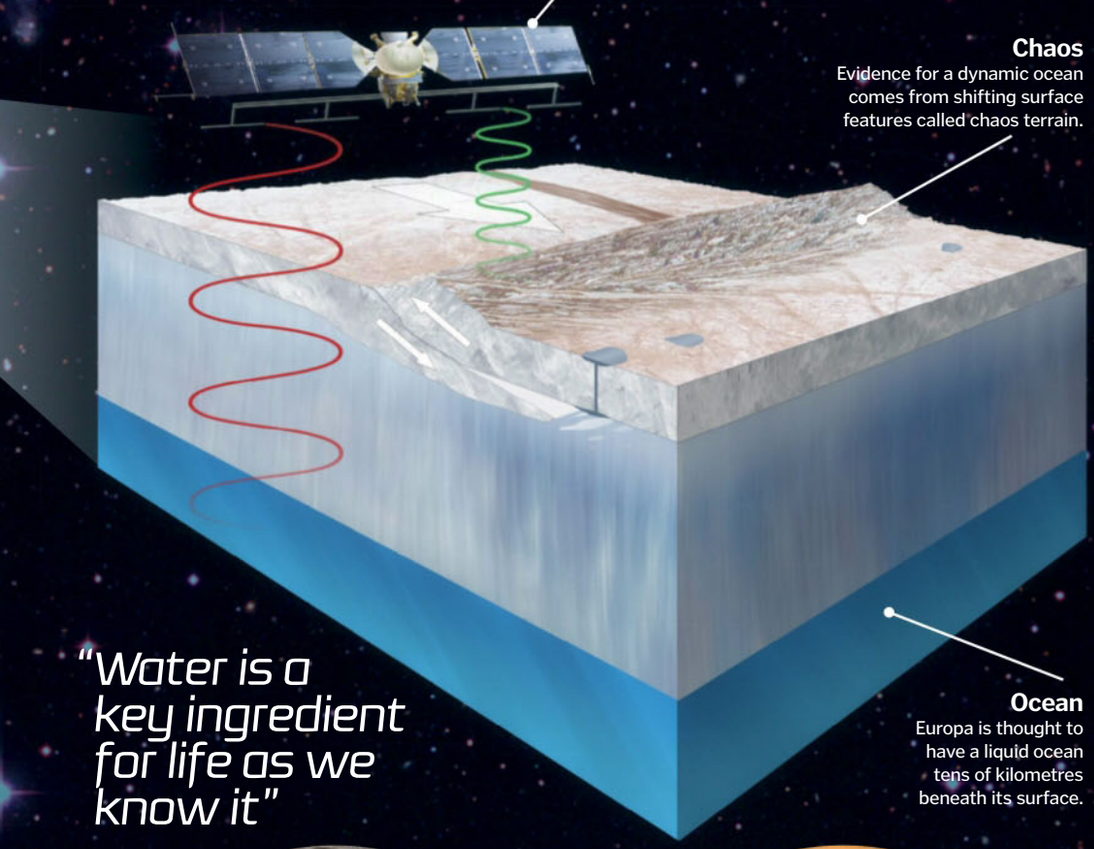
POSSIBLE
Evidence for an ocean, but not confirmed.

JUPITER AND SATURN'S MOONS

These gas giants are orbited by a number of ocean worlds

Inside Europa

What secrets might this icy moon be hiding under its surface?



"Water is a key ingredient for life as we know it"

Ganymede

Parent planet: **Jupiter** Ocean world status: **Locked**

Jupiter's moon Ganymede, one of the few moons thought to have a magnetic field, may have multiple layers of liquid water beneath its surface. This subsurface salty ocean may explain Ganymede's magnetic field, and could also be the cause of aurorae on the moon.

Titan

Parent planet: **Saturn** Ocean world status: **Locked**

Titan is the only world other than Earth known to have bodies of liquid on its surface, in the form of liquid hydrocarbons. But it may also have a subsurface ocean, trapped about 50 kilometres below the surface. It's unlikely Titan could support life as we know it though.

Enceladus

Parent planet: **Saturn** Ocean world status: **Active**

Saturn's icy moon has been observed spouting water from a suspected underground ocean. NASA used its Cassini spacecraft to fly through these plumes and sample them.

Mimas

Parent planet: **Saturn** Ocean world status: **Possible**

Yes, it looks like the Death Star, but based on its wobble while orbiting Saturn, researchers think it could contain a liquid water ocean. The surface, though, shows no geological activity.

Callisto

Parent planet: **Jupiter** Ocean world status: **Locked**

Evidence for a subsurface ocean on Callisto comes from its magnetic field's interaction with Jupiter's magnetic field. This implies there are electric currents within the moon, which are thought to be conducted by a salty ocean.

DWARF PLANETS

Some of these worlds in our Solar System may play host to oceans

Pluto

It turns out this ex-planet is full of surprises

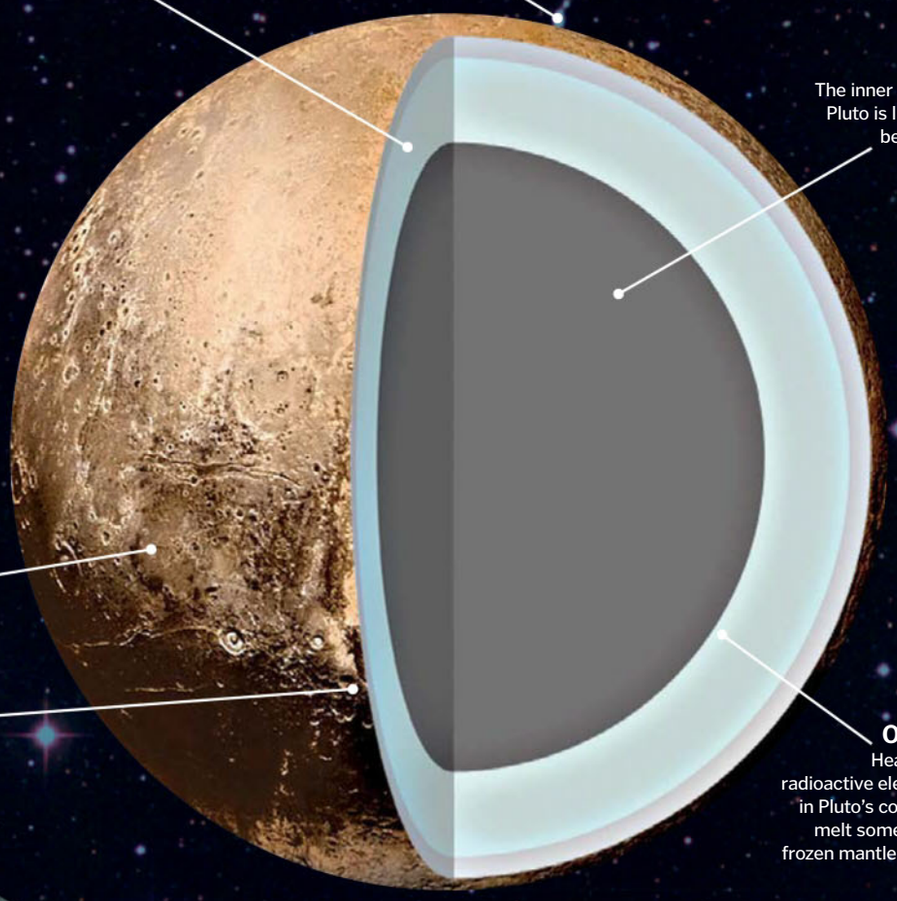
When NASA's New Horizons spacecraft flew past Pluto at the edge of the Solar System in July 2015, no one could have expected what it would find. Aside from a seemingly active surface, Pluto also shows signs of a subsurface ocean. Evidence for this comes from a massive crater on the surface, called Sputnik Planum.

You might better know this as the heart-shaped feature on the surface of Pluto. It is 900 kilometres across, and was likely caused by an impact from a huge object. Despite being a large crater, the crust at Sputnik Planum has more mass than the rest of Pluto. The reason for this could be that the impact caused material to shift in Pluto's interior, a scenario that requires a subsurface ocean about 100 kilometres deep.

PLUTO
Parent star:
THE SUN
Ocean world status:
POSSIBLE

Inside Pluto

What we think this dwarf planet might look like



Mantle
Unlike Earth's hot mantle, Pluto's may be a frozen ocean.

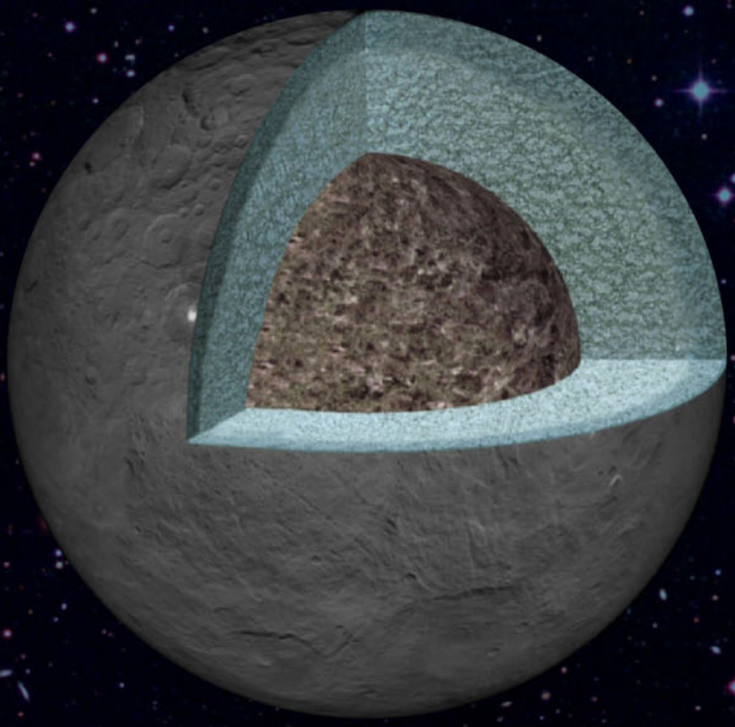
Atmosphere
Pluto has a very thin atmosphere that changes depending on its distance from the Sun.

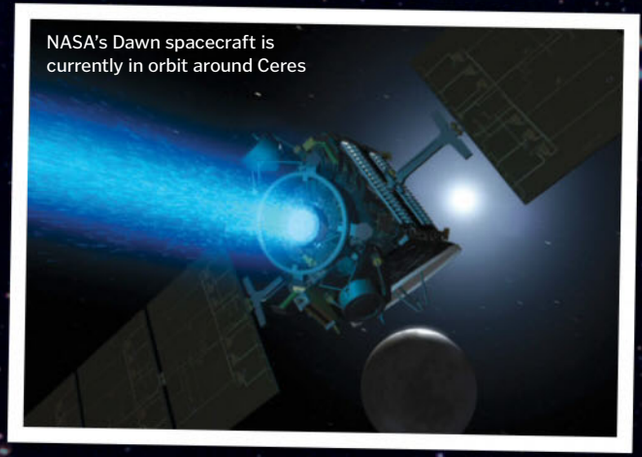
Core
The inner core of Pluto is likely to be rocky.

Surface
Pluto's surface is covered in methane and nitrogen frost.

Sputnik Planum
Evidence for the ocean comes from Pluto's heart-shaped region (not visible here).

Ocean
Heat from radioactive elements in Pluto's core may melt some of the frozen mantle above.





NASA's Dawn spacecraft is currently in orbit around Ceres

Ceres

Parent star: **The Sun** Ocean world status: **Possible**

Ceres is located in the asteroid belt between Mars and Jupiter, but one thing that has puzzled scientists is the lack of large craters on its surface. The answer may be that the upper layers of Ceres' interior contain ice. This would allow the surface to flow, wiping out evidence of large craters. This ice could even be the remains of an ancient ocean, now frozen beneath the surface. A fraction of this may be in a liquid state.

EXOPLANETS

The worlds beyond our Solar System that may have water

Kepler-62 system

Could this far-off celestial body harbour life?

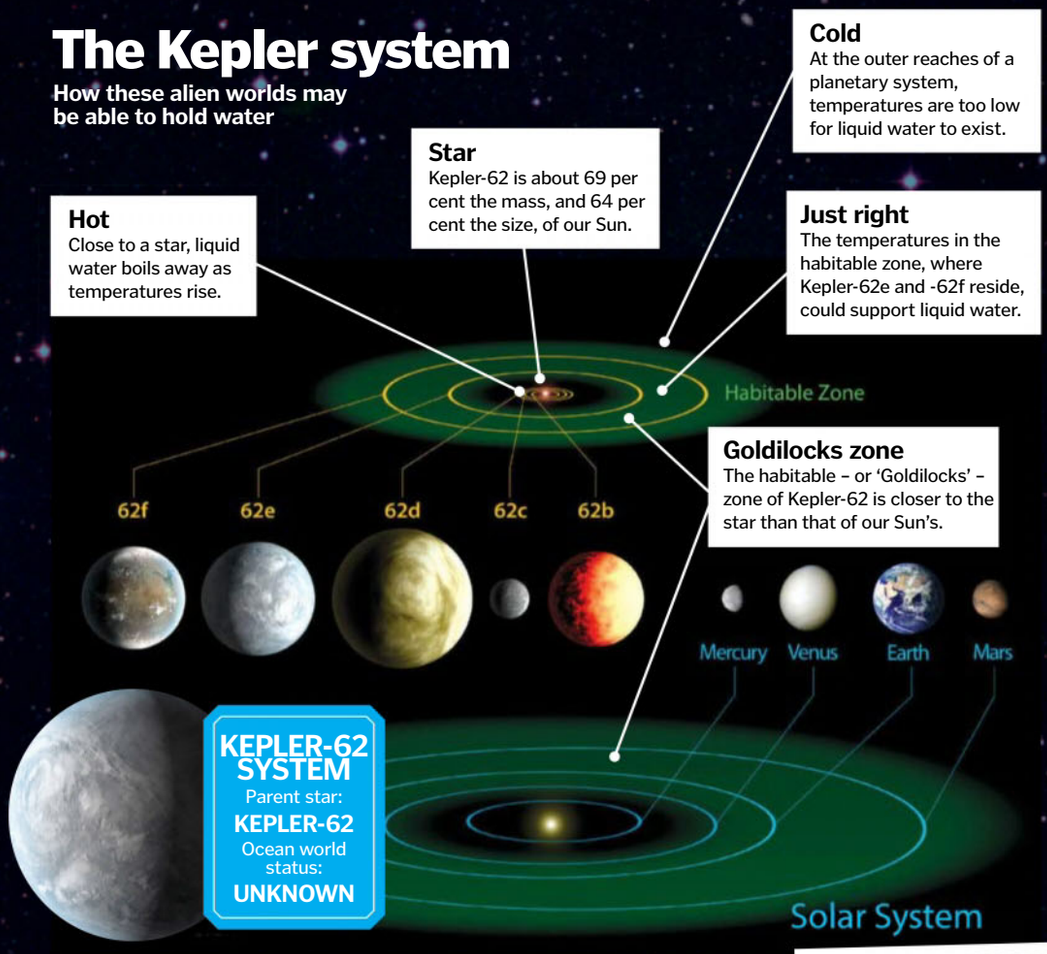
The mysterious red dwarf star system known as Kepler-62 is located 1,200 light years from Earth, and two of its orbiting planets show signs of having large amounts of water.

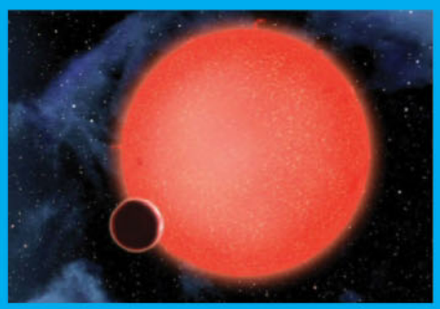
The first is Kepler-62e, which orbits its star at the equivalent distance of Mercury from the Sun in our Solar System. Owing to its size and distance, scientists think it may have a cloudy sky and water on the surface, possibly even encased in a global ocean – a water world.

The same may also be true of Kepler-62f, which is also 1.6-times the size of Earth. Both worlds are thought to be in the habitable region (also known as the Goldilocks zone) of their star, where liquid water can exist due to the fact that the temperatures are neither too hot nor too cold.

The Kepler system

How these alien worlds may be able to hold water





Gliese 1214b

Parent star: **Gliese 1214**
Ocean world status: **Unknown**

This world, located 42 light years away from us, is 2.7-times the size of Earth. A huge fraction of its mass is thought to be water, but being so close to its star, where the temperature and pressure are both extremely high, its water may be in an exotic form.

Proxima b

Parent star: **Proxima Centauri**
Ocean world status: **Unknown**

Proxima b is the closest Earth-like planet to us, located just 4.2 light years away around Proxima Centauri. It orbits in the habitable zone, and some models say it has a good chance of having a significant amount of water.

"Proxima b is the closest Earth-like planet to us"

Salty oceans

Depending on how salty the ocean on a world is, it could have a major effect on its climate – and therefore its ability to host life. On Earth, the salinity levels cause warm water to move to the poles, where it is cooled. But for a world with a saltier ocean, water from the poles could flow to the equator, creating a circulation pattern that dramatically warms the polar regions, possibly increasing the planet's habitability. A low salinity – close to that of fresh water – could have the same effect. So salt may be key in the hunt for life outside the Solar System.

The salinity of an ocean may play a key role in a planet's habitability

Cosmic chemistry

Could molecules recently discovered outside of our own galaxy support life?

For the first time, a hot molecular core – the hot and dense mass of complex molecules surrounding a newborn massive star – has been discovered outside of our galaxy. Similar objects found within the Milky Way contain organic molecules, such as methanol and ethanol, which are connected to the origins of life, meaning this new discovery could potentially prove the possibility of extragalactic beings. However, while some familiar molecules were found, the core's chemical composition features a lack of organic compounds, suggesting that if there is life outside of our galaxy, it develops in a very different way.

Core characteristics

Get the lowdown on this ground-breaking extragalactic discovery

Small and hot
The core measures just under half a light year across and has a temperature of over -173 degrees Celsius (80 degrees warmer than a standard molecular cloud).

Galactic neighbour
It is located around the newborn star ST11 in the Large Magellanic Cloud, our neighbouring dwarf galaxy.

High-tech discovery
The discovery was made using the ALMA telescope, which can detect wavelengths of light between radio and infrared. These wavelengths provide clues about cosmic chemicals.

Complex molecules
The core contains lots of sulphur dioxide, nitric oxide, formaldehyde and dust, but only low levels of methanol.

Rover twins

Meet the Earth-bound counterparts of the robots exploring the Red Planet

While the Curiosity rover crawls around on the surface of Mars, its twins are down here on Earth, helping to ensure its mission runs smoothly. Instead of navigating real Martian terrain, they roam around the Mars Yard, a sandy outdoor arena scattered with boulders and dunes, that can be found outside the NASA's Jet Propulsion Laboratory in California. Here, scientists use them every day to practise for situations on Mars, before programming Curiosity to carry out the tasks for real. The first twin, called Maggie, is an exact replica of the Red Planet rover, used to test its software and scientific equipment. The second is Scarecrow, so called because it doesn't have an onboard computer 'brain', and is used solely for driving practice. It's lighter than Curiosity to simulate the effects of the lower gravity on Mars, and can be controlled via an iPhone app. Using 3D images captured by Curiosity, NASA's scientists recreate its surrounding terrain in the Mars Yard. They then carefully choreograph Scarecrow's manoeuvres, before sending the same commands to its twin 200 million kilometres away.

Before Curiosity even reached Mars, engineers were practicing with Scarecrow on California's desert sand dunes

DISCOVER THE UNIVERSE

www.spaceanswers.com

All About Space

Available from all good newsagents and supermarkets

ON SALE NOW

Contacting alien life › The fate of the universe › Groundbreaking space images › SpaceX

BUY YOUR ISSUE TODAY

Print edition available at www.imagineshop.co.uk

Digital edition available at www.greatdigitalmags.com

Available on the following platforms

Print Tablet Phone Desktop

facebook.com/AllAboutSpaceMagazine twitter.com/spaceanswers

Astronaut Mike Massimino

With the release of his memoir *Spaceman*, we caught up with Mike to talk about his 18-year NASA career

Massimino is a veteran of two Space Shuttle missions that serviced the Hubble Space Telescope

Credited as the man who fixed the Hubble Space Telescope, the veteran of two Space Shuttle missions explains what is involved in training to go into space and how you can become an astronaut.

At what point in your life did you realise that you wanted to become an astronaut?
Well for me, the dream started when Neil Armstrong took those first steps on the Moon. I was six years old when that happened. And so that was when [my interest] formed. I just thought [landing on the Moon] was the most important thing going on and the most exciting thing I'd ever seen. And even though I was six, I knew that I wouldn't see anything quite like it in my life. My life was changed forever.

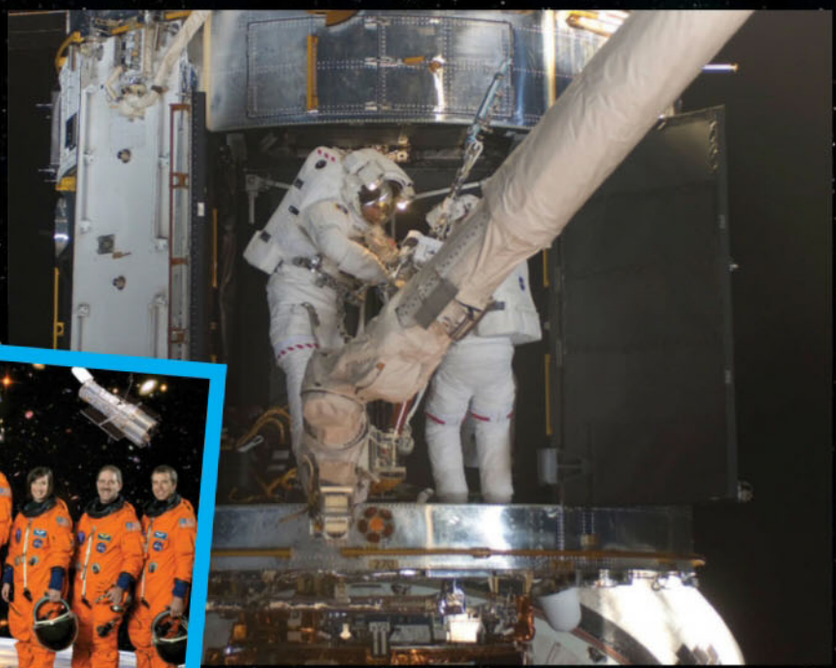
But then that dream kind of went away. I thought that it was absolutely impossible to become an astronaut. I thought: there is no way, how could this happen? But my dream was rekindled when I was finishing up college and after that, after I was working, I realised that I really needed to do something in the space program in order to be happy.

You're a veteran of two Space Shuttle missions, could you tell us what's involved in training to go into space?
As an astronaut you get trained to do all kinds of things: you learn to fly in a high performance airplane, learn the systems of the Space Shuttle and the Space Station, learn how to work as a team in simulations. You're practising, practising and practising. My primary job on my missions was that I worked the [Canadarm] robot arms a little bit. However, my number one job in space ended up being the spacewalker. And so, to do that, you piece together different experiences – including stuff in virtual reality, we had lessons where we had to learn about the spacesuit and the techniques [we'd be employing in space] and so on. It all seemed to come together in our big pool – the Neutral Buoyancy Laboratory. It's the largest pool in the world and you can fit an entire Space Shuttle inside it, or even a Hubble Space Telescope in there, to work on as well as an International Space Station. You can practice what you're going to do in space in the water. You're floating in a water column like you'd be floating in space.

For me, those were the big events. It was a wonderful experience training for a spacewalk.

Could you describe what it was like to fly in the Space Shuttle?
During the launch, you're lying on your back for a few hours, getting ready to go and then the Space Shuttle wakes up. It felt like it was alive when I looked at it from the outside, it looked like a beast. You get inside and you count down and then [the Shuttle] gets active at six seconds left. The main

"I don't like heights, I don't like going fast. I'm more of an academic"



Massimino and fellow astronaut Michael Good (left) refurbish and upgrade Hubble. During the eight-hour repair they improve the space telescope's spectrograph

Massimino (far left) was on the final Space Shuttle mission to the Hubble Space Telescope alongside (from left to right) Michael Good, Gregory Johnson, Scott Altman, Megan McArthur, John Grunsfeld and Andrew Feustel

engines start and you feel it lurch forward and then it comes back at zero. And at zero, the solid rockets light and then you start moving at 100 miles [161 kilometres] per hour. We got to 117,000 miles [188,293 kilometres] per hour in eight and a half minutes so it was a huge amount of acceleration that took place. When we launched, I had this sensation, part of the way up, that I was leaving the planet for the first time. I was leaving home.

Massimino was an STS-125 mission specialist

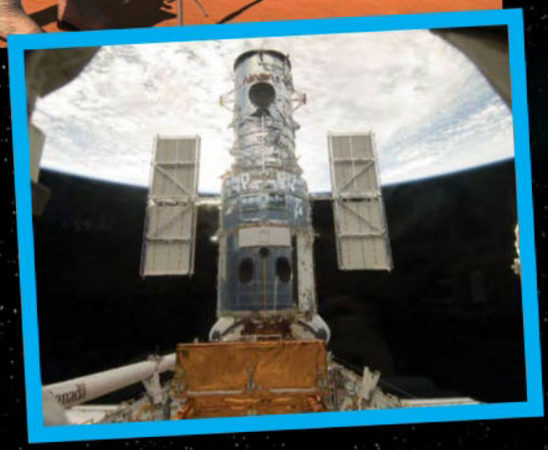
You were the first astronaut to use Twitter in space. Is this something you intended to do before you launched for space?

Yes, I was! I didn't know anything about Twitter, it became popular around 2008 or 2009. My second spaceflight was around May 2009. And NASA public affairs had this idea that they would have an astronaut that would start using Twitter. It just so happened that my spaceflight timing was when they wanted to start doing this. So, NASA approached me with this idea that I would start using Twitter about a month's time before I launched into space. They rigged my phone up as well as my computer and showed me how to do it. I really liked sharing the experiences of going into space more than any other astronaut I know. I really enjoy talking about [the experience] so much – not just flying, but the people I got to work with: the astronauts, the people who helped us to get ready to go, as well as the camaraderie and the teamwork and even the exciting things we got to do on the ground was just wonderful. Imagine, I was just a civilian academic egghead before I became an astronaut. I dreamt about it, but I didn't really know what it was like and so, to get to do these things – fly high performance aircraft, train to do spacewalks and do simulations, get ready to fly in space and then actually fly in space, was so out of the ordinary for me. I liked sharing it with other people because it was such a unique, extraordinary experience.

You helped fix the Hubble Space Telescope. What was it like to be involved in such a historic event in spaceflight?

It was really extraordinary. Most of the flights we had at that time during my career were Space Station-related flights – Space Station assembly, missions on the Shuttle… and they were all great missions. But Hubble to me, it was the best flight to be on. Hubble was truly great because the spacewalks we did, they didn't involve a standard spacewalkers routine – far from it. It involved something different – the altitude of Hubble was higher, about 100 miles [161 kilometres] higher than the Space Station, you got a different view, you got to see more of the planet, such as the curvature of it. We set records for both of my missions for spacewalking time. We set the record for one of my flights and broke that record on my second flight – five spacewalks in five days in a row. So it was a great opportunity to work on this magnificent instrument. One thing that I didn't realise on my first flight but did on my second, was that I wanted to fly to the Hubble again. The Hubble team – both on the ground and in space – was a great team to be a part of. There's a lot of great dedication.

Massimino is interested in going on a trip to Mars, provided he can return to Earth!



The Hubble Space Telescope in the cargo bay of Space Shuttle Atlantis after capture and lock-down

What was it like to go on a spacewalk? What does space actually feel like?

When you go on a spacewalk, you're kind of like a scuba diver, interacting with the [space] environment. You truly feel like a spaceman. It wasn't like I was in the spaceship with other people, I was the only guy in the spacesuit. I was out there in space, all by myself, with my own life support system there and I could look anywhere I wanted. I could look and see the planet from where Hubble is. Getting to see the planet and the stars on a spacewalk was truly an incredible experience. The greatest thing someone can do is go into space.

If you could go on a one-way trip to Mars, would you?

No [laughs]. I wouldn't go on a one-way trip, I'm coming back! I don't think it's a good idea to go on a one-way trip anywhere. If I could come back, then yes, I would definitely go to Mars. I've been on Earth for too long, it's time for me to go back into space. With all of these private companies [aiming for Mars], one of them has got to be successful. I'm no longer a NASA astronaut, so I need to somehow get back into space again. Mars would be great. I'd really love to go.

For anyone who wants to become an astronaut, do you have any advice for them?

Yes! I think it's a great job, if you're interested you should pursue it. Tim Peake is a great example – he's a wonderful guy and he's a great example for young people. I thought it was [going to be] impossible for me to become an astronaut – I don't like heights, I don't like going fast. I'm more of an academic. But if it's something that you really want to do, you should do it. There are many paths to get there, you can be a military test pilot or an academic. I flew into space with a veterinarian, which is quite unusual, you might think, as well as an oceanographer and a geologist, astrophysicists and so on. Anything you like doing – science, maths, computing, whatever you like doing – you should go for it. And that puts you in a good position to become an astronaut.

Learn more

Read the interview with Mike Massimino in full at **www.howitworksdaily.com**. If you'd like to find out more about his career and time in space, Massimino's memoir, *Spaceman: An Astronaut's Unlikely Journey to Unlock the Secrets of the Universe*, is out now from Crown Archetype.

Prehistoric monsters

Meet the enormous ancient predators that stalked the land, dominated the oceans and terrorised the skies

Sharp teeth
Needle-like teeth meant the dinosaur could secure slippery prey, such as fish, with ease.

Sail
A flexible spine with ball-and-socket joints enabled the Spinosaurus to arch its back, perhaps to impress mates or intimidate rivals.

Flexible neck
A long and mobile neck allowed the Spinosaurus to strike quickly to snatch up its prey.

Colossus
According to estimates, a Spinosaurus could reach lengths of over 15 metres – if it did have any predators, they would have thought twice about tackling such a big beast.

Swimming
The Spinosaurus was adapted to a semi-aquatic life, having flat feet with broad claws to help propel itself through water.

Colossal cretaceous carnivore

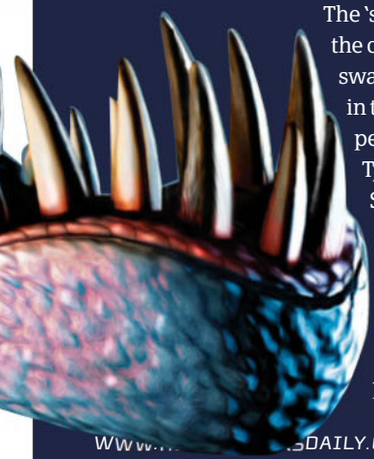
SIZE COMPARISON

SPINOSAURUS ▶ 112-97 MYA

Move over T rex: the spine lizard was the true king

Nearly three storeys high and longer than a bus, the Spinosaurus was the largest carnivorous dinosaur to walk the Earth. The 'spine lizard' roamed the coastal plains and swamps of North Africa in the mid-Cretaceous period. Unlike the Tyrannosaurus rex, Spinosaurus' teeth were not serrated, so they were not used for tearing through flesh; its conical teeth, powerful jaws and long snout were better suited to snapping up large fish. It's thought that Spinosaurus was the first dinosaur to swim, and that it spent a lot of time in the water where it could snatch aquatic creatures with its razor-sharp claws. There is evidence to suggest Spinosaurus' snout openings and skull cavities were part of a pressure-detection system, so it could sense the movements of fish even in murky waters.

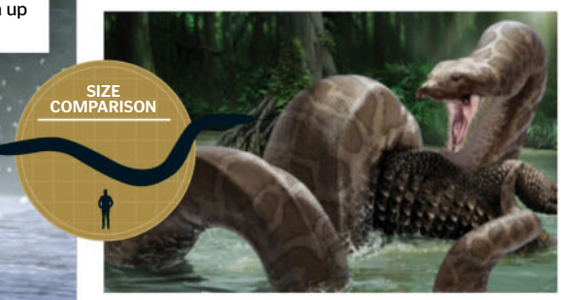
The giant carnivore's defining feature was the 1.5-metre-high 'sail' on its back, formed by tall vertebral spines. This may have been a display to attract mates or intimidate rivals, help regulate temperature, or possibly support a camel-like hump of stored fat that Spinosaurus could build up when food was plentiful.



Mega monitor lizard

VARANUS PRISCUS ▶ 1.8 MYA-40,000 YA

Also known as Megalania, these giant goannas of eastern Australia were the largest land lizards of all time. They could grow to lengths of over five metres and weigh as much as 600 kilograms. Megalania had razor-sharp teeth and claws, perfect for tearing into its prey. These large lizards compensated for their lack of speed by lying in wait to ambush victims, and sought out carrion using their excellent sense of smell.



Super-sized serpent

TITANOBOA ▶ 60-58 MYA

Reaching lengths of up to 15 metres, Titanoboa was one of the largest land animals on Earth following the extinction of the dinosaurs. These colossal serpents lived in the jungles of South America, devouring turtles and crocodiles in single mouthfuls. Titanoboa could hunt on land and in water, slithering or swimming up to its prey undetected, then suddenly leaping up to clamp its powerful jaws over the victim's windpipe.

Terror birds

PHORUSRHACIDAE ▶ 62-2 MYA

These terrifying predators of prehistoric South America were members of the Phorusrhacidae family, known as 'terror birds', and some could reach heights of three metres. Their main weapon was a sharp, hooked beak that could strike victims from above like a pickaxe. The birds' legs were also incredibly strong, and they may have used their feet to kill by repeatedly kicking, or thrown their prey violently to tenderise the meat.

Marine monsters

Lurking in the depths of prehistoric seas were a whole host of deadly aquatic giants

Sense of smell
Water was funnelled through the reptile's nostrils so it could smell its prey even in dark or murky water.

Vice-like bite
Liopleurodon's large, powerful jaw muscles helped it keep hold of prey that tried to struggle free.

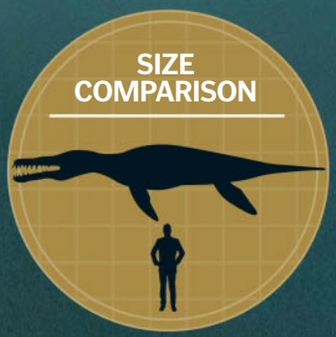
Terrifying teeth
Liopleurodon's needle-like teeth were each about ten centimetres long, ideal for piercing the flesh of prey.

A powerful pliosaur

What made Liopleurodon such a formidable Jurassic carnivore?

Intimidating size
Liopleurodon's length is hard to estimate accurately due to incomplete fossil records, but some pliosaurs may have reached 15 to 18 metres in size.

Strong swimmer
Long, paddle-like flippers helped the pliosaur push itself through the water and accelerate in short bursts to ambush prey.



Mighty ocean predator

LIOPLEURODON ▶ 160-155 MYA

A fierce killer with a bone-crunching bite

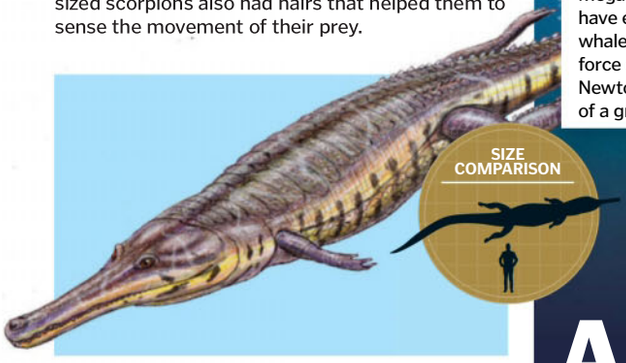
Liopleurodon was among the most powerful predators ever known on Earth, with a bite possibly even stronger than that of the mighty T rex. It belonged to a group of marine reptiles called pliosaurs, which were large with short necks. Liopleurodon's diet primarily consisted of fish and squid, but it would occasionally seek out much larger prey. Huge bite marks that were found in plesiosaur fossils suggest that they were victims of the Liopleurodon's massive jaws, which were packed with sharp teeth. Scientists even estimate that these colossal carnivores would have been strong enough to bite a car in half, if they had existed at the same time!

Liopleurodon may have also had a pale underside to help keep it camouflaged from prey below, allowing it to make ambush attacks despite its enormous size.

Giant sea scorpion

PENTECOPTERUS ▶ 467 MYA

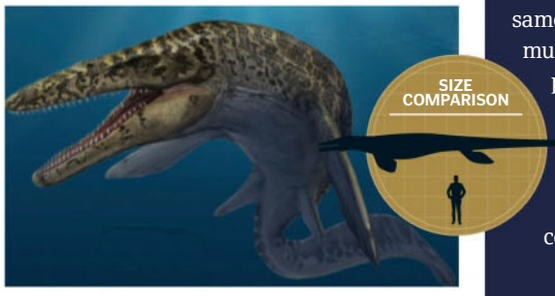
Over 200 million years before the first dinosaurs emerged, this nightmarish Pentecopterus was an important Palaeozoic predator. These arthropods grew to lengths of around 1.8 metres, and used their large limbs to grab prey. Young lived on the seabed while adults mainly resided in shallow waters to avoid larger predators. These super-sized scorpions also had hairs that helped them to sense the movement of their prey.



King-sized croc

MACHIMOSAURUS ▶ 130 MYA

Lurking in Cretaceous seas, Machimosaurus was a colossal crocodile at nearly ten metres long, almost twice the size of its biggest modern relatives. Its teeth were best suited for crushing shells and crunching bones rather than slicing through flesh. Machimosaurus' main tactic was to hide in shallow water and, without warning, clamp its mouth shut on a turtle or fish. Once its prey was caught in the jaws, there would be no escape.



Apex ocean reptile

MOSASAURUS ▶ 80-66 MYA

The massive Mosasaurus was a giant aquatic lizard and dominant predator in Cretaceous-era oceans. Some grew to 15 metres or more, and had long, powerful tails to propel themselves through water. They preyed on reptiles, fish, sharks and shellfish, snapping their tough shells with its powerful jaws. As an air-breather, Mosasaurus was unable to dive for prolonged periods, so it was limited to hunting near the ocean surface.

Megalodon vs Livyatan

Who would emerge victorious between the two prehistoric goliaths?

Shielding
Thick blubber may have offered Livyatan some protection from Megalodon bites.

Powerful muscles
A strong, streamlined body helped Megalodon ambush its prey.

Size isn't everything
Livyatan was slightly smaller than Megalodon, but it was still a formidable foe with gigantic jaws full of huge teeth.

Similarities
From fossils, Livyatan seems to be anatomically similar to modern sperm whales, so may have used echolocation to find prey.

Big bite
Megalodon's jaws could have easily crushed a whale's skull, with a bite force of over 182,200 Newtons, ten times that of a great white shark.

Cold-blooded killer
Megalodon could only survive in warm waters and would have struggled with a drop in temperature.

A real-life leviathan

LIVYATAN ▶ 13-12 MYA

A killer sperm whale with one of history's biggest bites

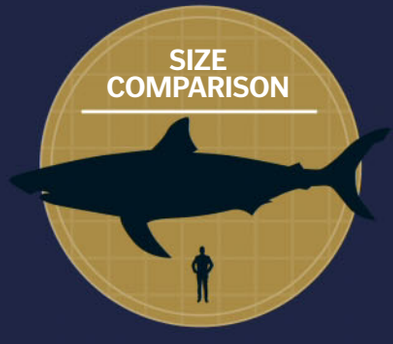
Hebrew for 'leviathan', Livyatan was roughly the same size as a modern sperm whale, but it was a much more formidable hunter. The 50-ton beasts probably competed with Megalodon for food, preying on smaller whales, cetaceans like dolphins, and large fish. Livyatan teeth are possibly the largest of any animal at over 30 centimetres long, and its bite force could rival that of the Megalodon.

Super-sized shark

MEGALODON ▶ 28-1.6 MYA

Meet the colossal sharks that dwarfed great whites

These gigantic 75-ton sharks were so big that they could hunt whales with ease. Up to 20 metres long and equipped with a mouth full of teeth as large as a human hand, these mega-sharks made short work of dolphins, whales, seals, squid and other sharks. When faced with a turtle shell, they snapped it in two. It is estimated that Megalodon had one of the strongest bite forces of any animal that's ever lived, capable of crushing a small car.



Sky giants

The huge aerial predators that brought death from above

Deadly impact
Gathering momentum on a swoop, a 13-kilogram eagle could take down prey even bigger than itself, such as a moa.

Dive bomb
Haast's eagles could strike from above at an estimated speed of 80 kilometres per hour.

Talons
These eagles would use one foot to secure prey while the other crushed the neck or head.

Haast's eagles were eventually driven to extinction as they competed with humans for moas, their preferred prey

Jumbo raptor

HAAST'S EAGLE ▶ 1.8 MYA-1400 CE

With talons the size of tigers' claws, these monstrous eagles preyed on helpless herbivores of New Zealand's South Island. Swooping at speeds of up to 80 kilometres per hour, they could knock victims off their feet with the sheer force of impact. Their favourite prey were giant flightless birds called moas, which could weigh up to 250 kilograms. Compared to the size of its body, Haast's eagles' three-metre wingspan was relatively short. This meant that they would have killed moas on the ground rather than carry them away. Their terrifying, razor-sharp talons could quickly incapacitate victims by delivering crushing blows to their head or neck.

Plane-sized pterosaur

QUETZALCOATLUS NORTHROPI ▶ 70-65 MYA

Quetzalcoatlus was the largest-known species of pterosaur, the group of flying reptiles that lived alongside dinosaurs. With a wingspan of ten metres or more, it was roughly the size of a small jet plane. Its toothless beak suggests that it hunted small prey that didn't require chewing, such as baby dinosaurs, and possibly also scavenged for carrion. Quetzalcoatlus is also thought to have roamed on land, because it had small, cushioned feet that were suited to moving over firm terrain. If this is true, it may have hunted like a modern-day stork, snatching small prey up in its beak.

Land and air
Quetzalcoatlus' wide wings helped it to soar, while its compact feet helped it move quickly across the ground.

Sharp beak
Using its pointed beak, Quetzalcoatlus could snap up small dinosaurs.

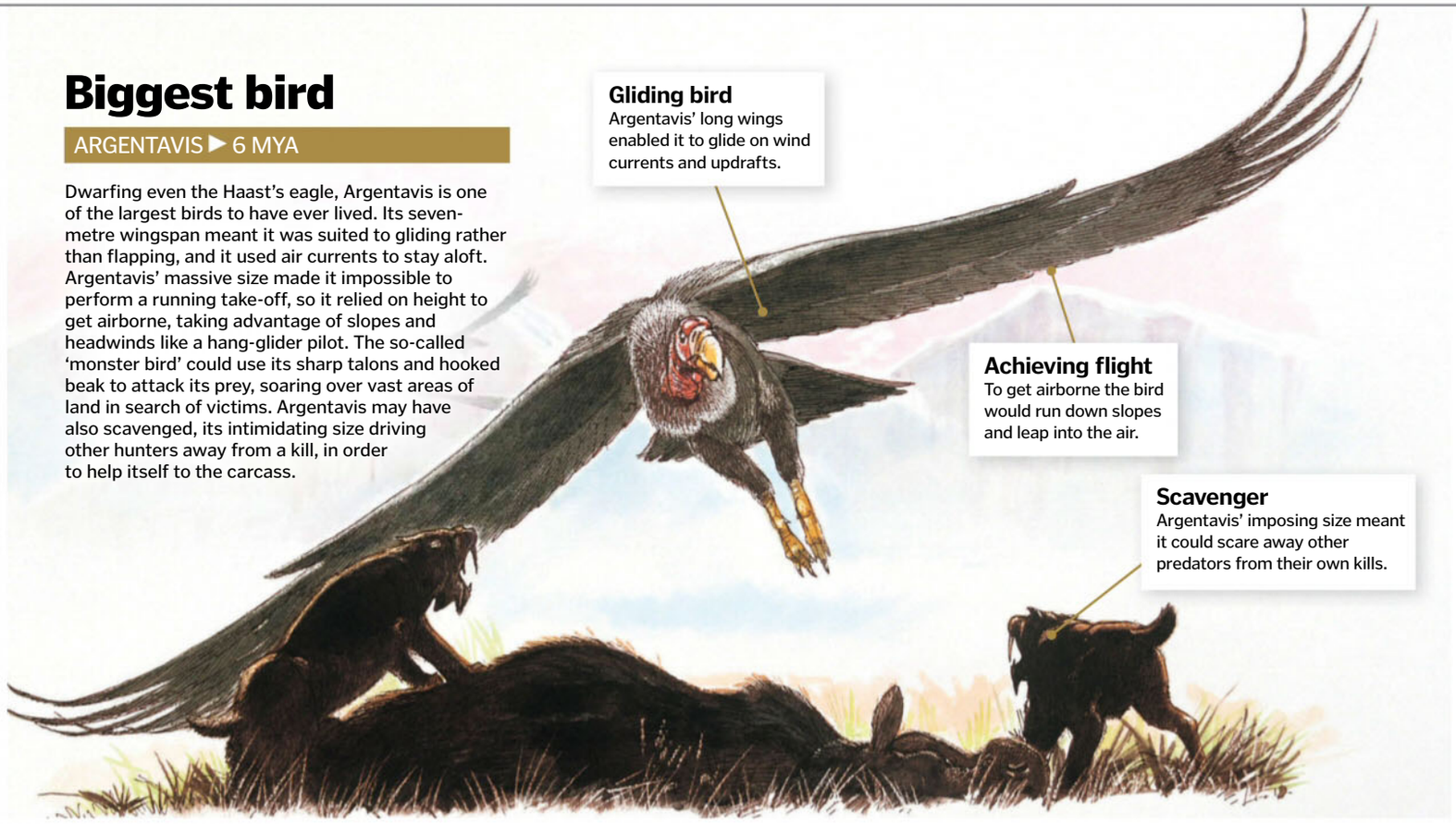
Wing tips
Quetzalcoatlus' wings stretched from its elongated fourth fingers to the top of its legs.

Quetzalcoatlus had a crest on top of its head, possibly brightly coloured to attract mates

Biggest bird

ARGENTAVIS ▶ 6 MYA

Dwarfing even the Haast's eagle, Argentavis is one of the largest birds to have ever lived. Its seven-metre wingspan meant it was suited to gliding rather than flapping, and it used air currents to stay aloft. Argentavis' massive size made it impossible to perform a running take-off, so it relied on height to get airborne, taking advantage of slopes and headwinds like a hang-glider pilot. The so-called 'monster bird' could use its sharp talons and hooked beak to attack its prey, soaring over vast areas of land in search of victims. Argentavis may have also scavenged, its intimidating size driving other hunters away from a kill, in order to help itself to the carcass.



Gigantic fly

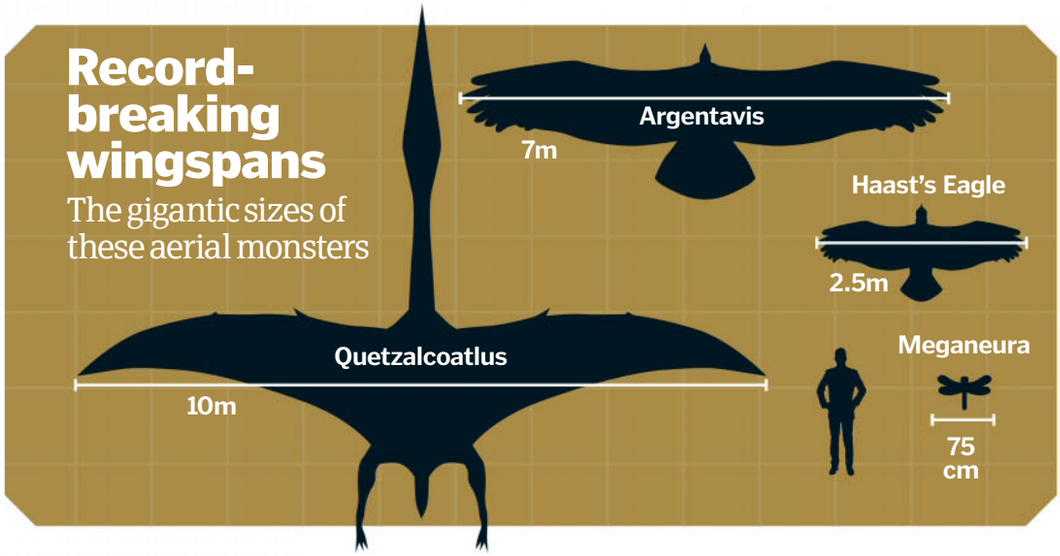
MEGANEURA ▶ 300 MYA

One of the biggest insects to ever exist, the Meganeura was a member of the griffinflies, which are closely related to dragonflies. This prehistoric insect benefited from a higher percentage of oxygen in the atmosphere in the period in which it lived. This allowed it to grow to and maintain its huge size. It used its large eyes to spot prey such as small amphibians and other insects, which it grabbed with its legs while in midair.


The Meganeura's 75-centimetre wingspan was larger than that of a magpie

Record-breaking wingspans

The gigantic sizes of these aerial monsters



Why were prehistoric animals so big?

It had previously been accepted that prehistoric animal size was a result of Cope's Rule. Named after American palaeontologist Edward Drinker Cope, the theory suggested that dinosaur gigantism was down to the notion that animals naturally evolve to be bigger. When mass extinctions occur, new smaller animals replace the larger extinct ones, and the process begins anew. As it has 'only' been 66 million years since the Cretaceous mass extinction, and 12,000 years since the last ice age, animals on Earth are now smaller because they haven't yet had enough time to evolve to reach such large sizes once again.

Another theory suggested that environmental factors, such as higher oxygen levels and warmer temperatures, could have played a significant role in gigantism. Cold-blooded reptiles benefited from the toasty climate as it allowed for efficient digestion, circulation and respiration, as well as an abundance of vegetation to consume.

More recent research and fossil discoveries have cast doubt on both these theories, though. Some creatures seemed to evolve to be smaller rather than larger over time, and many different-sized animals existed at the time. One explanation for why dinosaurs in particular were typically large is because they where physiologically similar to birds. Their bones had air pockets in them, making even large species relatively light, so they wouldn't collapse under the weight of their own bodies.

Not all of the biggest beasts were prehistoric, though. In fact, the heaviest animal ever to exist on planet Earth is still alive today: the blue whale. Marine animals can grow to epic proportions because the buoyancy from water helps to balance the force due to gravity. This supports their considerable masses, and allows for far larger body sizes than on land.

WWII gas masks

The headgear produced en masse to protect Britons during the Blitz

At the beginning of World War II there was a huge gas panic in Britain. After witnessing the horrors of mustard gas on the Western Front during World War I, the British Government was worried that chemical warfare could be unleashed on its citizens. In response, 38 million gas masks were handed out.

Covering the entire face, they blocked the intake of harmful substances by filtering the air before it entered the mouth. To prepare for air raids, mock attacks were carried out in the streets. Hand rattles were sounded to signal that 'gas' was incoming and bells were rung when it was safe to take off your mask. Despite these preparations, not a single poison gas bomb was dropped on Britain during the entire war.

Special full-body masks were made in order to protect babies

Anatomy of a WWII gas mask

How did the mask prevent the wearer from being poisoned?

Colour
Adult masks were black but young children's 'Mickey Mouse' masks were coloured red and blue to encourage kids to wear them.

Full coverage
Mustard gas damaged the eyes and exposed skin, so the rubber mask covered the whole face to shield as much of the head as possible.

Tin canister
Covering the mouth, the filter allowed the user to breathe while preventing dangerous gases from entering.

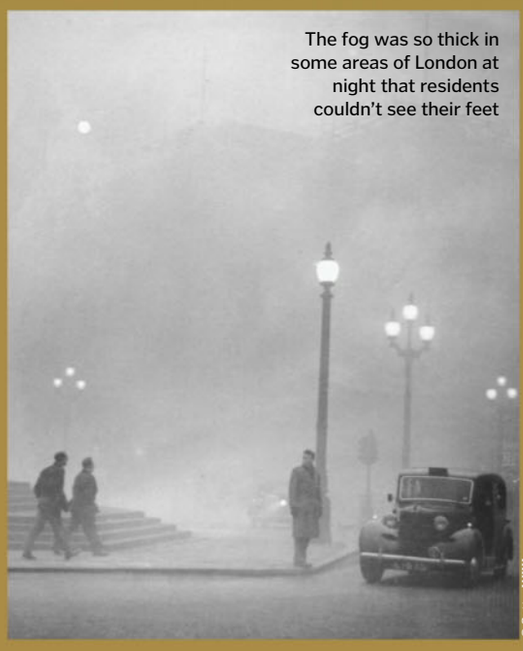
Respirator
The filters of many civilian gas masks actually contained asbestos, which was later discovered to be harmful.

The Great Smog of 1952

This dense and polluted fog choked livestock and claimed the lives of thousands of Londoners

After the boom of the Industrial Revolution, Londoners had grown quite accustomed to smog forming in their city. But none were prepared for what was to come on 5 December 1952, when a poisonous cloud fell on London, so thick that its residents couldn't see across the street. The smog wreaked havoc on the city for four long days before eventually clearing, leaving 4,000 dead in its wake. But how did this tragedy occur? As it turns out, the victims themselves were partly to blame, as were unfortunate weather conditions.

The city had experienced some very cold weather in the weeks prior to The Great Smog, so Londoners were burning coal in abundance to keep warm. The densely packed houses churned out smoke relentlessly from their chimneys; but rather than dispersing into the atmosphere, the particles were trapped by an anticyclone hanging overhead, which forced the air downwards. The smoke then began to stick to water vapour. All it took was a light breeze to stir the air and it was transformed into thick smog 100 metres deep!



The fog was so thick in some areas of London at night that residents couldn't see their feet

Special overseas offer

All titles just £49.99

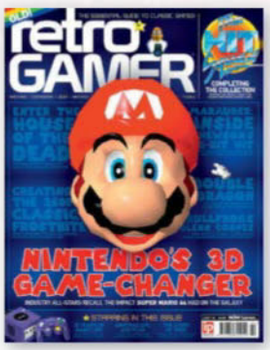
The ideal Christmas gift, that lasts all year

Give a Gift Subscription

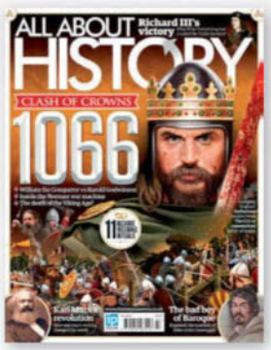
this Christmas and save up to 17%

With free delivery Direct to their doorstep, every month

13 issue subscription
Save 10%



12 issue subscription
Save 17%



13 issue subscription
Save 15%

12 issue subscription
Save 17%

12 issue subscription
Save 17%

13 issue subscription
Save 4%

12 issue subscription
Save 17%

13 issue subscription
Save 4%

12 issue subscription
Save 17%

12 issue subscription
Save 17%

Order securely online **www.imaginesubs.co.uk/xmas161**

Unlimited offer: Grab as many subscriptions as you want!

Call **+44 1795 592 869**

IMAGINE PUBLISHING

These offers will expire on
Saturday 31 December 2016

Please quote code **xmas161**

Canadian fighter ace, William George Barker, received the Victoria Cross for his heroics

The Sopwith Camel

Climb inside the cockpit of an iconic dogfighter, 100 years since its first flight

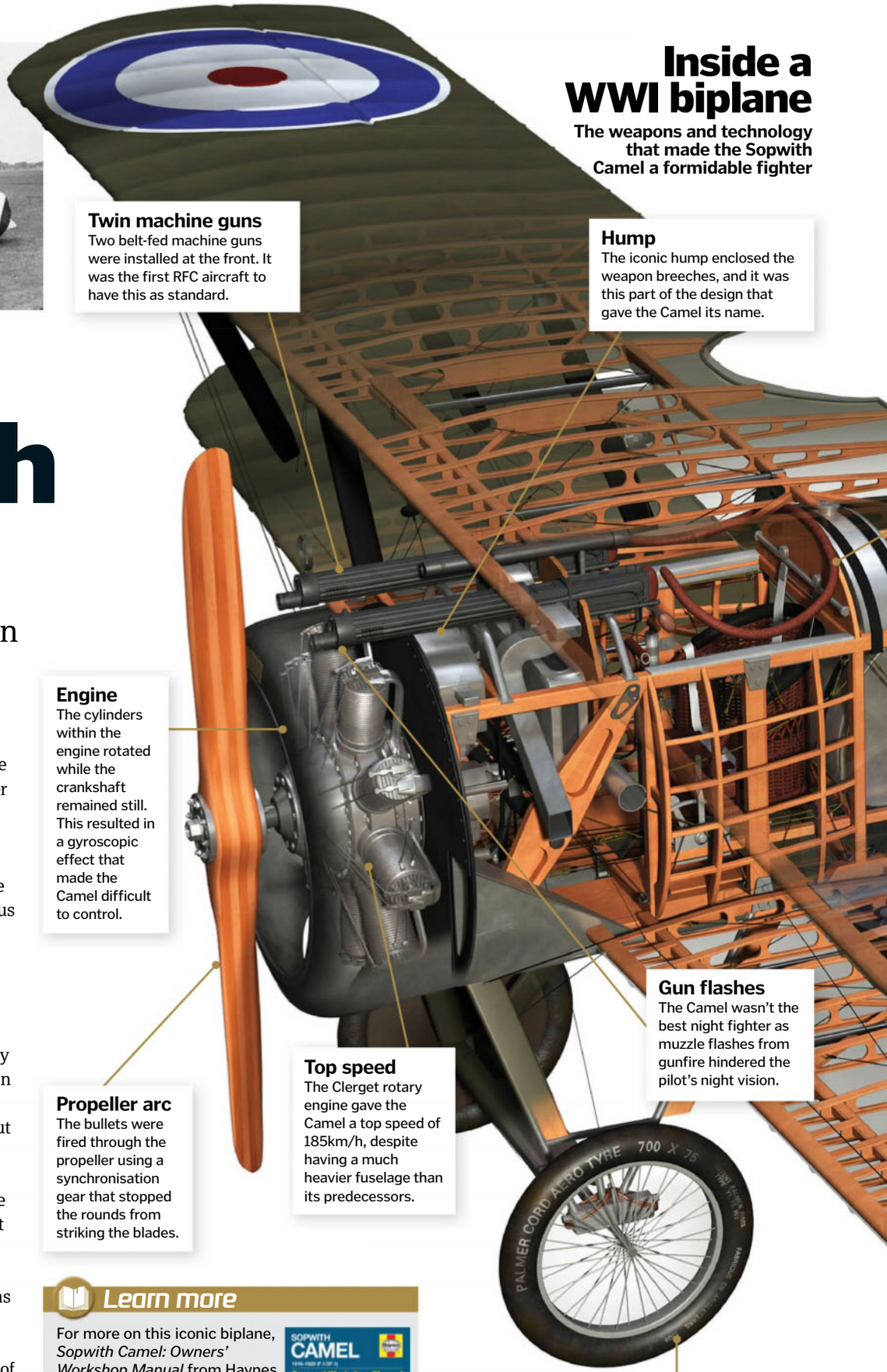
The Sopwith Camel was one of the best fighter planes of World War I. A prototype single-seat aircraft first flew in December 1916, and was constructed with the aim of replacing its aging predecessors in the Royal Flying Corps (RFC). Prior to the Camel, German Fokker and Albatros aircraft had dominated the skies over the Western Front. After the disastrous 'Bloody April' of 1917, when the RFC suffered devastatingly high losses, a new weapon was badly needed.

The new aircraft was an upgrade on both the Sopwith Pup and Sopwith Triplane. The fighter was notoriously tricky to handle, but its mobility helped it evade and then strike down its German rivals during dogfights. Its twin machine guns tore through enemy fuselages, blasting them out of the air. In response, the Germans put the Fokker Dr.I Triplane into production. While technologically superior, it simply couldn't cope with the sheer number of Camel squadrons that were in service above Western Europe. Along with the French SPAD S.XIII, the Camel helped turn the tide of the war in the air. The design was so popular that it was also flown by US, Belgian and Greek squadrons.

The aircraft soldiered on until the latter days of the war and, although it was slowly superseded by more advanced aircraft, it still held its own. Camels downed more enemy planes than any other fighter during the war and it holds the same iconic status as the Spitfire of World War II.

Inside a WWI biplane

The weapons and technology that made the Sopwith Camel a formidable fighter



Twin machine guns
Two belt-fed machine guns were installed at the front. It was the first RFC aircraft to have this as standard.

Hump
The iconic hump enclosed the weapon breeches, and it was this part of the design that gave the Camel its name.

Engine
The cylinders within the engine rotated while the crankshaft remained still. This resulted in a gyroscopic effect that made the Camel difficult to control.

Gun flashes
The Camel wasn't the best night fighter as muzzle flashes from gunfire hindered the pilot's night vision.

Top speed
The Clerget rotary engine gave the Camel a top speed of 185km/h, despite having a much heavier fuselage than its predecessors.

Propeller arc
The bullets were fired through the propeller using a synchronisation gear that stopped the rounds from striking the blades.

Landing gear
Large wheels allowed the biplane to land safely as it descended at high speed.

Learn more

For more on this iconic biplane, *Sopwith Camel: Owners' Workshop Manual* from Haynes Publishing has 160 pages of rare photography of the Sopwith Camel from WWI. The winner of Letter of the Month next issue will receive a copy; head to page 96 for details!

Control and handling issues

Sopwith built six prototypes of the Camel and all of them had a reputation for being tricky to handle. Inexperienced pilots struggled with the plane's outstanding manoeuvrability, and a staggering 385 died after losing control in non-combat situations.

The design was both the plane's greatest asset and its biggest drawback. The heaviest parts of the aircraft, the engine, fuel tank and guns, were all at the front of the plane, making it nose-heavy. Fuel was also a problem; the Camel required a very precise mixture and its engines could stall mid-flight.

The plane also had a tendency to spin wildly, a movement that many novice pilots couldn't correct. Once it was mastered however, the Camel was an incredibly rewarding fighter. Its flexibility meant it could outmanoeuvre almost any of its German rivals in a dogfight, and many a Fokker found itself in the Camel's crosshairs before being shot out of the sky.

The engine's rotary mechanism made the Camel poor at turning left but twice as fast as any other fighter when turning right

Bomb release

Some Camels carried a payload of four 11kg bombs, which were dropped using a release toggle activated by the pilot.

Fuselage

The majority of the aircraft was wooden. Aluminium cowling protected the engine and fabric covered the airplane's body.

Frame

The Camel was fitted with wire bracing that gave its structure the strength to climb to heights of 6,000m.

The Sopwith Camel in numbers

The key stats of the aircraft's 17 months of service

46
William George Barker's total aerial victories

90%
of the aircraft's weight was in the front two metres of the fuselage

5,490
Number of Camels made

76
Average number of German planes shot down per month

10 minutes
Time taken to climb 3,000 metres

1,294
Total kills by Camel pilots

2.5hrs
Range on a full tank

The Camel's tricky handling meant that many trainees fatally crashed the aircraft

Ming vases

The beautiful Chinese ceramics that embodied an empire

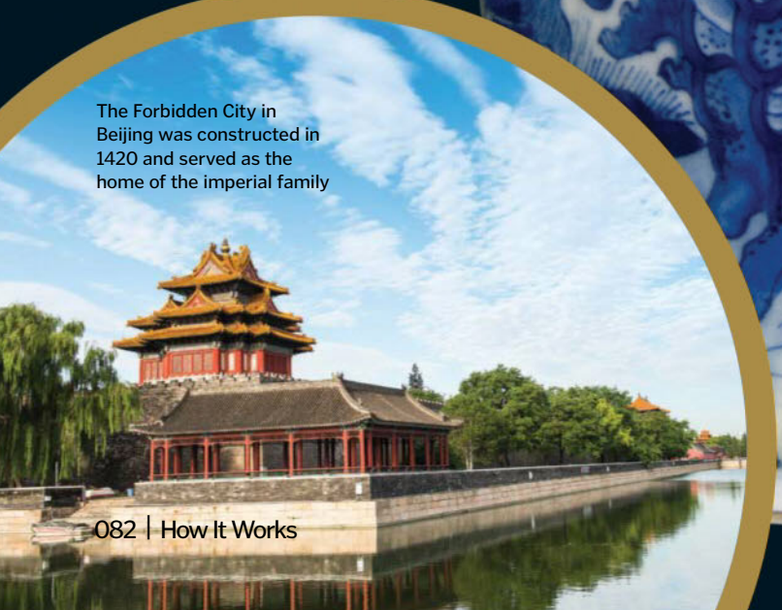
Intricately decorated with an array of designs, Ming vases were the pride of the dynasty

A Ming vase is one of the most iconic examples of pottery ever created. Popularised during the Chinese dynasty of the same name, this prized porcelain embodied the prosperity of the 276-year-long era (1368-1644). The industry's epicentre was in the city of Jingdezhen in southeast China. This area was ideal for porcelain manufacture as it was rich in kaolin clay and petuntse rock. The petuntse was ground down into a powder and added to the clay to create porcelain, which was then sculpted into a vase shape. It was then baked in a kiln at temperatures of 1,450 degrees Celsius. With the vase now fully formed, it was decorated. The preferred style in the Ming dynasty was to paint dragons or floral patterns directly onto the ceramics in cobalt blue or copper red. A glaze was applied and then, in some cases, further designs were added on top, known as an overglaze.

The vases were mass-produced by the Ming government, who established a Bureau of Design to ensure all porcelain ceramics were made to a high standard. The iconic blue-and-white designs were influenced by those from the Islamic world, which had close ties with China at the time.

Ming vases were exported around the world as trade with Europe and the Middle East boomed. By the 16th century, Chinese potters were producing porcelain specifically for international export, complete with designs such as coats of arms or scenes from battles, in order to suit their customers' preferences.

"Vases were exported around the world as trade boomed"



The Forbidden City in Beijing was constructed in 1420 and served as the home of the imperial family

The Ming dynasty

After almost a century of foreign rule, the Chinese wrestled control of their homeland back from the Mongols in 1368. Ming dynasty China became a major centre of military power, economic prosperity and cultural identity. The ceramics trade became big business as Chinese artists learnt new ways of working from the many merchants who travelled far and wide across the region. The dynasty based its hierarchy on the best-educated people in Chinese society, the literati, who dominated state affairs. Along with pottery, many other creative arts flourished during this period, including opera, drama and literature.

The Great Wall of China was significantly extended during the Ming Dynasty

History like you've never seen it before

ALL ABOUT HISTORY

BUY YOUR COPY TODAY

Print edition available at www.imagineshop.co.uk

Digital edition available at www.greatdigitalmags.com

Available on the following platforms

Print Tablet Phone Desktop

facebook.com/ImagineBookazines twitter.com/Books_Imagine

BRAIN DUMP

Because enquiring minds need to know...

Want answers?

Send your questions to...

How It Works magazine @HowItWorksmag

howitworks@imagine-publishing.co.uk

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*.

Shanna Freeman

Shanna describes herself as somebody who knows a little bit about a lot of different things. That's what comes of writing about everything from space travel to how cheese is made. She finds that her job comes in very handy for taking part in quizzes!

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.

BMX cycling started in the 1970s, and became an Olympic sport in 2008

Why are BMX bikes so small?

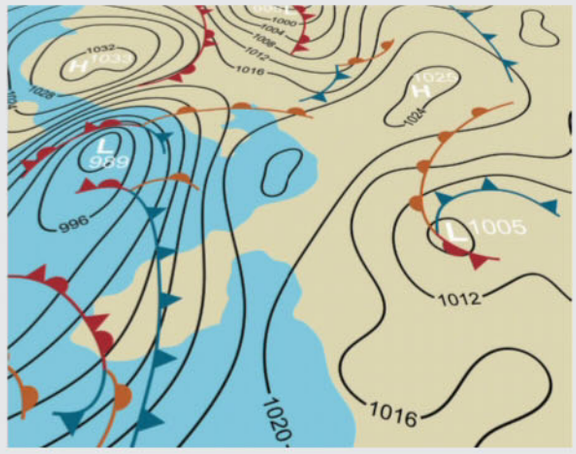
Kieran MacLean

The tiny proportions of BMX bikes make them lighter and more manoeuvrable when it comes to sprinting, doing stunts and negotiating jumps. BMX cycling involves a combination of racing and jumping, so riders need a bike that is lightweight and agile but also tough enough to withstand landing repeatedly from jumps. The small size of the bikes also allows BMX riders to swing the bike around 360 degrees or perform backflips, with the low seat position providing extra clearance. High-end bikes are often made of chrome, providing maximum strength for minimum weight. BMX bikes typically have 51-centimetre wheels, enabling them to accelerate rapidly; when approaching jumps, riders often need to pick up speeds of up to 60 kilometres per hour in just a few seconds. Finally, the rider's hunched position over a BMX's small frame allows them to absorb shocks and rapidly shift their bodyweight and centre of gravity to perfect gravity-defying stunts. **AC**

Why is the weather forecast so often wrong?

Katie Bryce

Weather forecasting is based on observations of Earth's atmosphere, the planet's surface and the oceans. Every day, the UK's Met Office takes over 500,000 measurements from around the world at various altitudes. Supercomputers use these to make models of what the atmosphere is currently doing, and predict what it might do next, but it's not an exact science. Improvements in tech mean that the four-day forecasts produced today are as accurate as the one-day forecasts of 30 years ago. And temperature predictions for the next day are right to within two degrees Celsius 87 per cent of the time. **LM**



Weather predictions are made using vast quantities of data from across the world

FASCINATING FACTS

Why did dial-up internet make such strange sounds?

Lucinda Clark

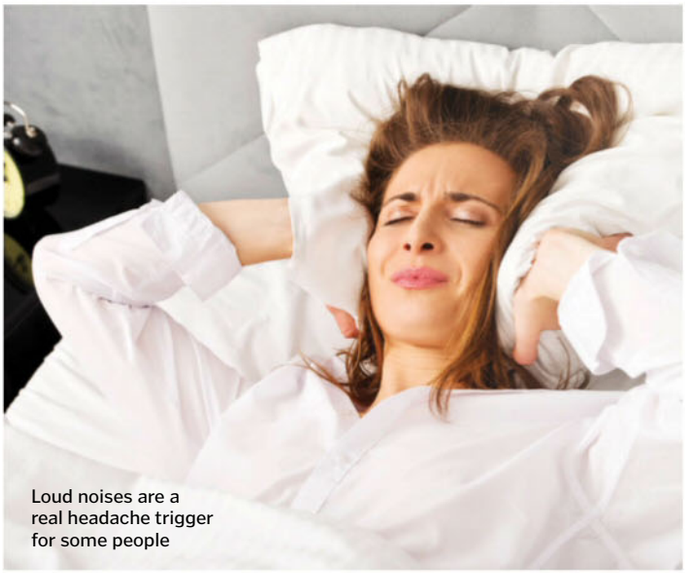
Those beeps and hisses were your modem dialling your internet service provider's telephone number. Communication between the two then negotiated how fast the connection would be and other technical issues. **TL**

Some scientists believe that our Milky Way galaxy has already died

Can a galaxy die?

Jules Barnes

Not exactly. When a galaxy is still forming stars, we might think of it as being 'alive'. Some galaxies are no longer capable of star formation, and are called 'dead'. We have come up with two theories as to why this happens: either strangulation or a sudden removal of gas. Dead galaxies have much higher amounts of metals than live galaxies. Stars are mostly hydrogen and helium, and form these metals through fusion. In the strangulation theory, as the gas supply slowly decreases, even heavier metals form. The other theory is that the gas is suddenly pulled from the galaxy, possibly through gravity from a nearby galaxy. **SF**



Loud noises are a real headache trigger for some people

Can loud noises give you a headache?

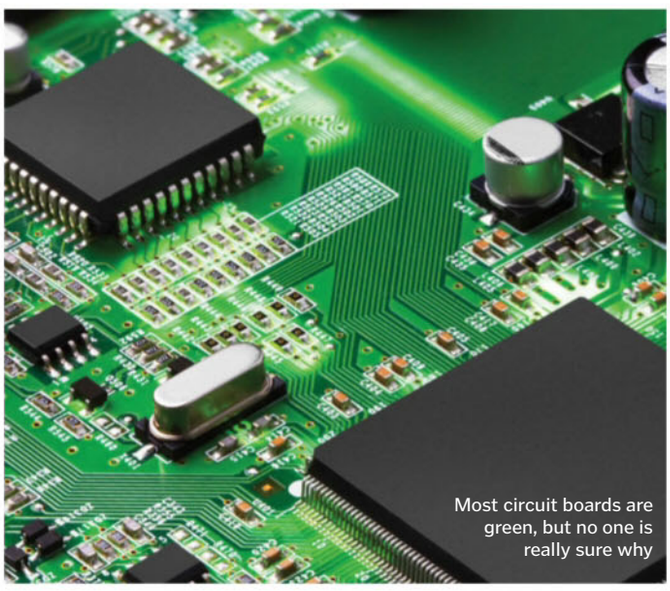
James O'Neill

Noise has been shown to cause headaches. Research indicates that listening to loud music for a few hours a day is a good way to give yourself a sore head. For some, loud noises can cause headaches even if they don't usually get them. Noise is also a possible trigger for sufferers of migraines or tension headaches. However, we're not entirely sure why loud noises are a trigger. It might be that they cause blood vessels in the face to dilate in people who are sensitive to it. Noise-induced headache sufferers could also have problems in the ear canal or in the way that their brains suppress sound. **SF**

Why are circuit boards usually green?

Katie Rees

No one seems entirely sure why circuit boards are usually green, but there are lots of theories. Some claim it's because the materials they are made out of are naturally greenish. However, the plastics used in early circuit boards were actually an ugly brown, and may have been coloured green to make them more appealing. Others suggest green was a military requirement, because components are easy to see on a green background. Although circuit boards are sometimes made in other colours, it seems it became industry standard practice for them to be green, and the tradition continues to this day. **TL**



Most circuit boards are green, but no one is really sure why

BRAIN DUMP

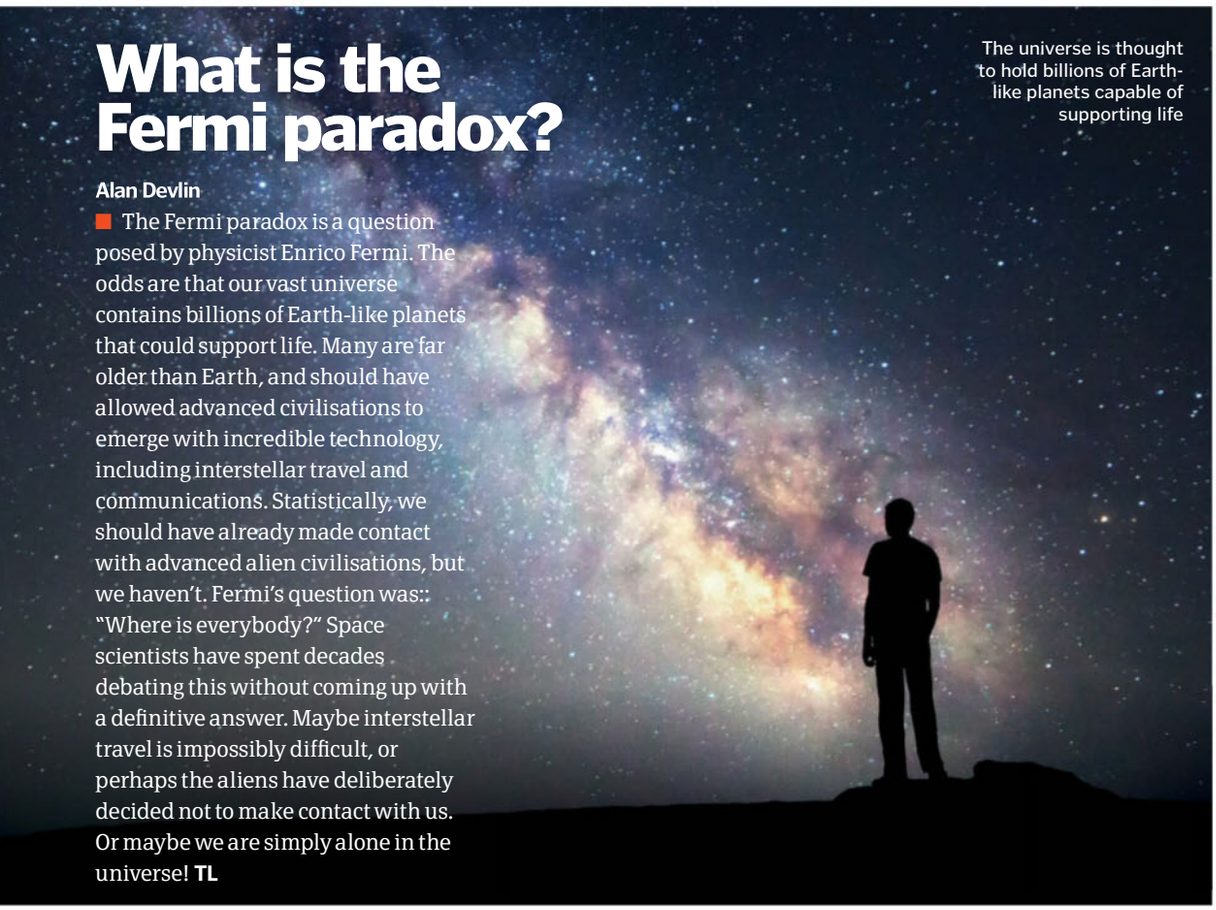
Cacao beans are extracted from the pods of the Theobroma cacao tree

What's the difference between cocoa and cacao?

Selina Mahew

Both come from the same source, cacao beans, which are the seeds of the Theobroma cacao tree. But they differ in the way they are processed. Once the beans have been harvested, they're left to ferment in a low heat. This causes cacao butter, the white fatty substance coating the beans, to melt away. The beans are dried and the shells removed, leaving raw cacao nibs, which can be ground into cacao powder. Cacao nibs can also be roasted at high temperatures and ground into a liquid called cocoa mass. This is compressed to extract cocoa butter and then either pulverised into cocoa powder or used with the cocoa butter to make chocolate bars. Roasting cacao brings out the sweetness and characteristic chocolate flavour of cocoa, but it can also reduce its nutritional value. **JS**

What is the Fermi paradox?



The universe is thought to hold billions of Earth-like planets capable of supporting life

Alan Devlin

The Fermi paradox is a question posed by physicist Enrico Fermi. The odds are that our vast universe contains billions of Earth-like planets that could support life. Many are far older than Earth, and should have allowed advanced civilisations to emerge with incredible technology, including interstellar travel and communications. Statistically, we should have already made contact with advanced alien civilisations, but we haven't. Fermi's question was:: "Where is everybody?" Space scientists have spent decades debating this without coming up with a definitive answer. Maybe interstellar travel is impossibly difficult, or perhaps the aliens have deliberately decided not to make contact with us. Or maybe we are simply alone in the universe! **TL**

FASCINATING FACTS

What was the biggest iceberg ever to have been discovered?

Iceberg B15 was the largest iceberg ever recorded. When it broke away from Antarctica's Ross Ice Shelf in 2000, it had an area of 11,000 square kilometres, which is about the size of Jamaica. **JS**

Iceberg B15 still exists today, but has broken up into smaller parts

How long would it take our fastest spacecraft to travel a light year?

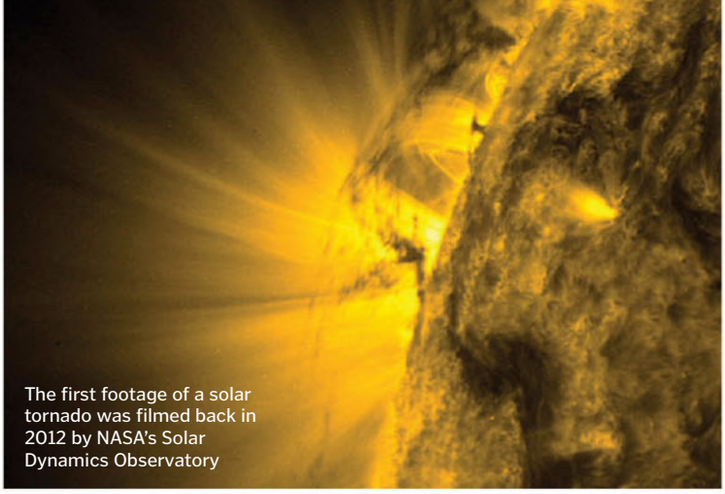
The Helios space probes reached peak speeds of around 70 kilometres per second. At this pace, travelling a light year (9.46×10^{12}km) would take over 4,200 years. **AC**

The Helios probes hold the record for the fastest man-made objects

How do they make plastic banknotes?

Plastic banknotes start as rolls of clear plastic, a bit like cling film. These are cut into sheets and painted white, except for a clear window where lasers etch a security image. The design is printed and then they are sliced into notes. **TL**

The new £5 note is Britain's first plastic banknote



The first footage of a solar tornado was filmed back in 2012 by NASA's Solar Dynamics Observatory

What are solar tornadoes?

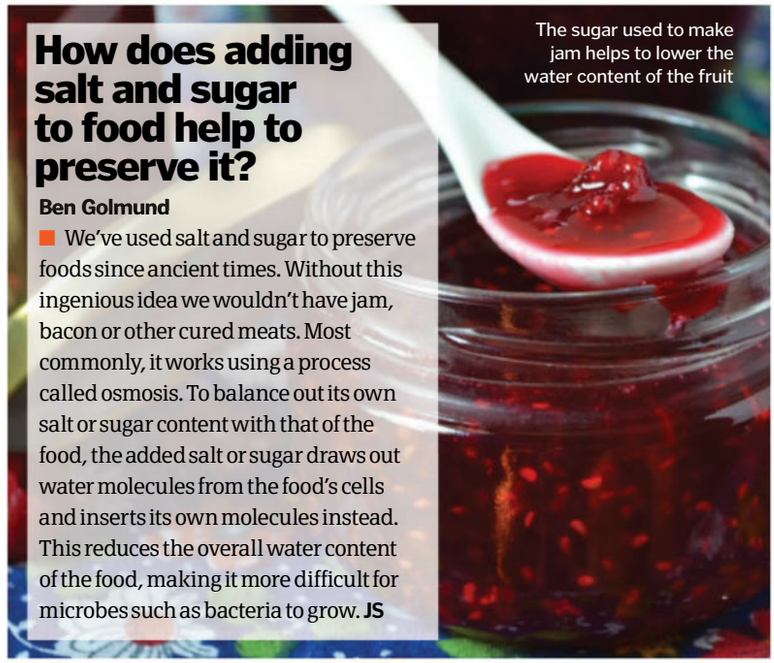
Jason O'Sullivan

Solar tornadoes are rotating swirls of magnetised plasma, which occur just above the Sun's surface. These gigantic twisters can reach speeds of up to 300,000 kilometres per hour, with temperatures of around 2.8 million degrees Celsius. Plasma is a state of matter that occurs only under extremely high pressure and temperature conditions, breaking down atoms into a soup of charged ions. Above the Sun's surface, the star's powerful magnetic field sets plasma into motion, leading to spectacular plumes up to 3,000 metres high. These tornadoes are often formed before events known as coronal mass ejections – huge eruptions of hot, charged particles that are flung out of the Sun's surface. **AC**

How does adding salt and sugar to food help to preserve it?

Ben Golmund

We've used salt and sugar to preserve foods since ancient times. Without this ingenious idea we wouldn't have jam, bacon or other cured meats. Most commonly, it works using a process called osmosis. To balance out its own salt or sugar content with that of the food, the added salt or sugar draws out water molecules from the food's cells and inserts its own molecules instead. This reduces the overall water content of the food, making it more difficult for microbes such as bacteria to grow. **JS**

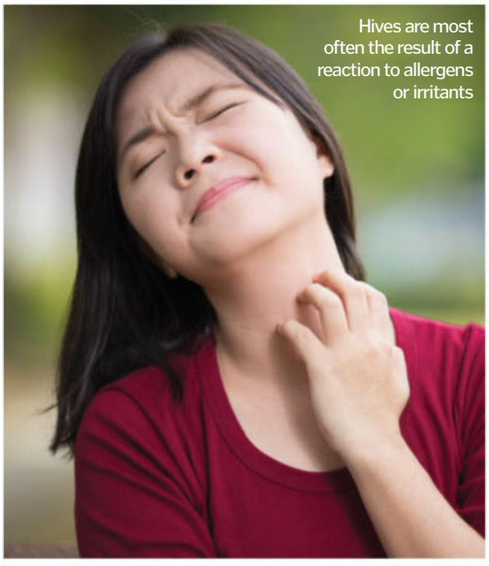


The sugar used to make jam helps to lower the water content of the fruit

Can you get hives from stress?

Sheryl Richards

Hives is a type of skin rash that is also known as nettle rash, weals, welts or urticaria. It is red, raised and itchy, and usually triggered by chemical messengers, like histamine. These signals are released in the skin in response to irritants and allergens, and work to increase the blood flow to the area. They make the blood vessels leaky, helping the immune system to get in and clear out whatever is causing the irritation. However, not all cases of hives have an obvious cause, and emotional stress can sometimes be a trigger. Alcohol, caffeine and warm temperatures can also make the skin react in this way. **LM**



Hives are most often the result of a reaction to allergens or irritants

It's incredibly rare for a comet to hit Earth, and scientists are unsure when it's happened

What was the last comet to hit Earth?

Jordan Sykes

It's rare for comets and asteroids to hit Earth intact, but small pieces of debris sometimes fall to the ground as meteorites, or burn up in the atmosphere as meteors; the Perseid meteor shower visible each summer is caused by the passage of the Comet Swift–Tuttle. Asteroids are mostly rock and very occasionally hit Earth, such as the impact in Chelyabinsk in 2013, but comet hits are incredibly rare. As comets are mostly ice and dust, there is little left to show where comet hits happened in the past. However, scientists have recently found evidence that a comet may have exploded over the Sahara desert some 28 million years ago. **TL**

What was the first country in the world to have a democratic election?

Ben Pinter

The word democracy, meaning 'rule by the people', originated in Ancient Athens, but women and slaves could not vote. There's evidence that democratic societies existed in India prior to the Athenians. Some would argue that the first true national democratic election was in Finland in 1906, when citizens of both genders could vote and hold positions in government. Women could vote in some countries prior to this, but not hold office. Many countries still prohibit certain groups of citizens from voting, like incarcerated criminals. **SF**

A democratic society must hold free and fair elections

BRAIN DUMP

Have scientists discovered how dinosaurs evolved?

Nick Lyes

Life started in water, and it wasn't until the Devonian Period (410-360 million years ago) that animals started to make first steps on to the land. These early pioneers were likely lobe-finned fish, which developed limb bones in their fins. During the Carboniferous Period (360-290 million years ago), reptiles split off from amphibians, and both evolved down separate branches of the evolutionary tree. During the Permian Period (290-250 million years ago), the land was dominated by therapsids, the ancestors of mammals, but a mass-extinction event killed most of them off. This cleared the way for the dinosaurs to rise to dominance, and during the Triassic Period (250-210 million years ago), their immediate ancestors, the archosaurs, finally emerged. This lineage split in two to form dinosaurs (and later birds), and crocodiles and alligators. **LM**

Does it make a difference if I listen to the 'left' and 'right' headphones in the wrong ears?

Bernard Thrump

It all depends on what you're listening to. If a recording has true left and right stereo channels, you'll probably notice a difference. With music, you may not get the intended experience because the instruments and voices won't be coming through as designed. Watch a movie with your earphones switched and it'll really stand out – you might hear a voice coming from the left, but see a person entering the scene from the right. If you're using a headset when playing a first-person shooter video game, you'll get frustrated because the enemy will come from one side and you'll think they're coming from the other. Some research indicates that we don't hear the same in both of our ears, so that may make a difference too. Most of the time, though, you probably wouldn't notice if you switched your headphones. **SF**

Wearing your earphones on or in the correct ears can make a difference

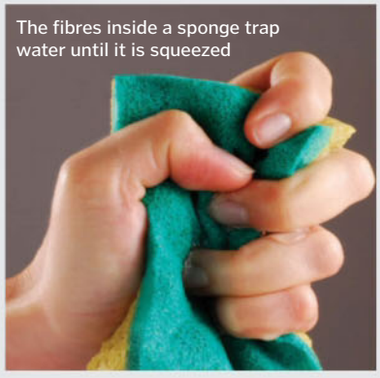
Squirrels and rats are linked by their teeth, which are specially designed to gnaw food

How are squirrels related to rats?

Leanne Groves

They are both rodents, and all rodents have one thing in common: their teeth. The pair of sharp incisors on each jaw grows continuously, wearing away as the animal eats. The front of the incisors has an enamel covering, but the back doesn't, so it wears away quicker. This helps to maintain the teeth's chisel-like shape. However, that's where the similarity ends, as squirrels and rats belong to different rodent families. **JS**

How do sponges hold so much water?



The fibres inside a sponge trap water until it is squeezed

Cosmo McClellan

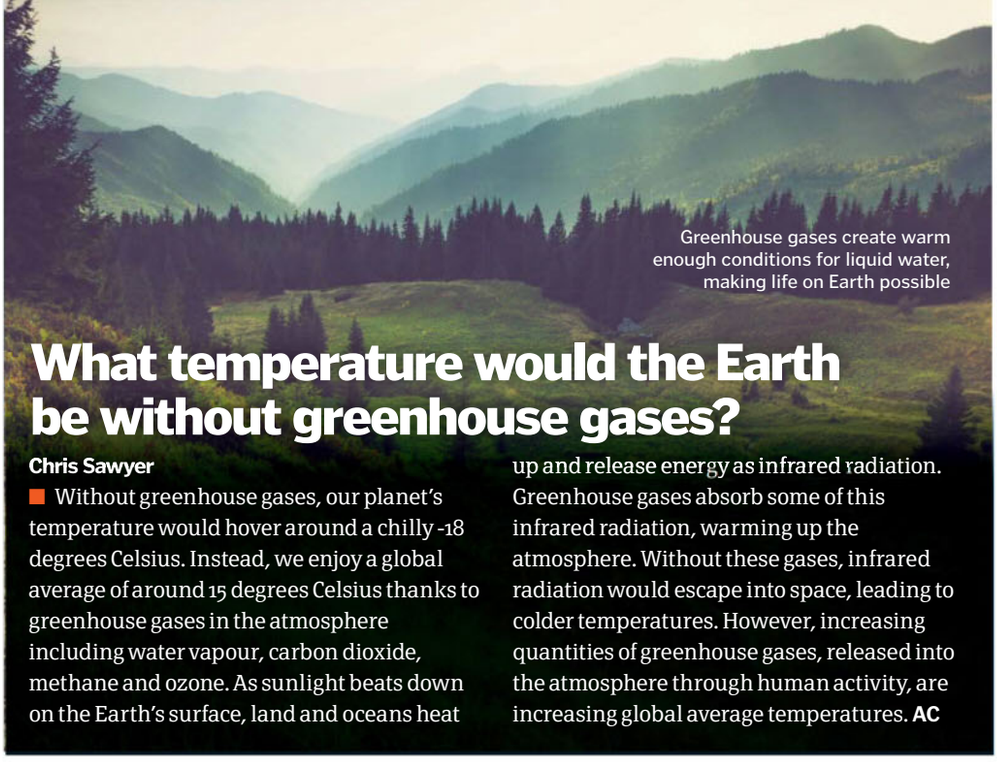
The sponge you have on your kitchen sink is likely to be man-made, but it is a copy of a sea creature of the same name. These living sponges are also filled with tiny holes, and their strange anatomy holds some clues about how our man-made sponges manage to cling on to so much liquid. The fibres inside a sponge are made from a substance called spongin, which swells in contact with water. This blocks off the holes, preventing the liquid from escaping. Manmade sponges simulate this, using cellulose, hemp and other absorbent fibres to hold on to the water until the sponge is squeezed. **LM**

FASCINATING FACTS

Can you sneeze underwater?

Greg Foot

You can, but it's unlikely to happen. Sneezes are usually triggered by particles irritating the nose, or by sunlight, and underwater your body is powerfully programmed not to breathe. **LM**



Greenhouse gases create warm enough conditions for liquid water, making life on Earth possible

What temperature would the Earth be without greenhouse gases?

Chris Sawyer

Without greenhouse gases, our planet's temperature would hover around a chilly -18 degrees Celsius. Instead, we enjoy a global average of around 15 degrees Celsius thanks to greenhouse gases in the atmosphere including water vapour, carbon dioxide, methane and ozone. As sunlight beats down on the Earth's surface, land and oceans heat up and release energy as infrared radiation. Greenhouse gases absorb some of this infrared radiation, warming up the atmosphere. Without these gases, infrared radiation would escape into space, leading to colder temperatures. However, increasing quantities of greenhouse gases, released into the atmosphere through human activity, are increasing global average temperatures. **AC**

How does jewellery cleaner work?

Flora Bolland

Most jewellery cleaners use similar solvents to those found in household detergents, such as ammonia, to dissolve grease and lift oil and dirt from gemstones and metals. Silver cleaners work a little differently. Silver appears tarnished when a thin layer on the surface combines with sulphur to make silver sulphide, which is black. Silver sulphide can be converted back to silver using a solution that contains aluminium ions; the sulphur transfers from the silver to the aluminium, restoring your silver jewellery to its former glory. Another method is ultrasonic cleaning, which uses high-frequency sound waves to create tiny bubbles in a liquid. As these bubbles burst they generate heat and pressure, knocking dirt off the jewellery. **AC**

Jewellery cleaners restore sparkle and shine by removing the build-up of oils and dirt

What exactly is Chaos Theory?

Jason Thompson

Chaos theory is a branch of mathematics that deals with non-linear, complex phenomena. Some examples of these complex systems include weather patterns, evolution and the behaviour of animals. Scientists once believed that everything in the universe had a cause and an effect, and that everything occurred according to unchangeable laws. Now we know that it's impossible to predict the outcome of complex systems because of constant change and interactions. The 'butterfly effect' is one principle of chaos theory, and it's often used to help explain the concept. It states that a tiny action, such as the flapping of a butterfly's wings, can ultimately lead to a large event, like a hurricane, on the other side of the world. Fractal mathematics visually shows how chaotic, complex systems can have self-similarity – the whole has the same shape as the parts, and the pattern repeats infinitely. **SF**

Fractals are found everywhere in nature, such as in this Romanesco broccoli

Why are trains so often delayed?

Liam Grantham

There are many reasons, but the most common cause is usually a knock-on effect from another delay. In an effort to accommodate as many passengers as possible, train timetabling is often quite tight, leaving little room for error if something goes wrong on the line. The cause of the initial delay though, is most likely to be a problem with the railway infrastructure. Trains, tracks, signals, tunnels and overhead lines can all become worn out or malfunction unexpectedly, and the engineering work needed to fix them often causes yet more disruption. **JS**

Even if one train is delayed by a few seconds, it can throw the whole schedule into chaos

Get in touch

Facebook: How It Works magazine
Twitter: @HowItWorksmag
Email: howitworks@imagine-publishing.co.uk

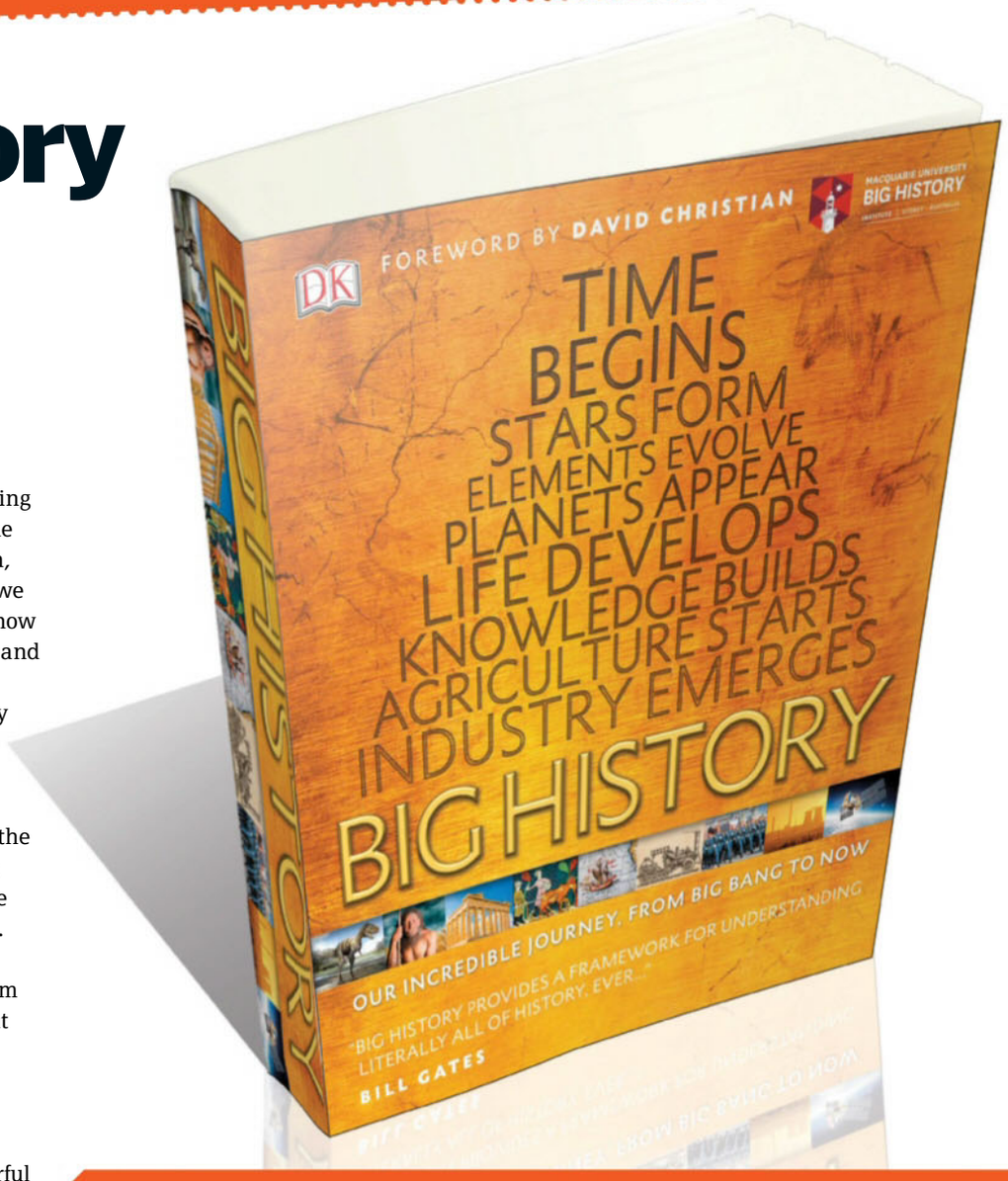
BOOK REVIEWS

The latest releases for curious minds

Big History

An incredible journey from the Big Bang to now

- Author: **Dorling Kindersley**
- Publisher: **Dorling Kindersley**
- Price: **£25 / $50**
- Release date: **Out now**



How often do you consider that every atom in your body – and every atom around you – was formed inside a dying star? *Big History* lives up to its title within the first few pages as it opens with this question, and it really is a big question. How often do we think about how the Earth was formed? Or how the plants and animals diverged into males and females? Or even how many other possible outcomes an event like the Big Bang actually could have had?

As you might expect, the book doesn't shy away from questions like these, revelling in the knowledge it shares. It literally starts at the beginning of the universe, exploring the Big Bang, what may have caused it, and possible explanations of how our cosmos came to be. From here it weaves its way through to the modern day, covering all kinds of topics, from ancient hunting tools to the information that can be gained from studying pollen grains.

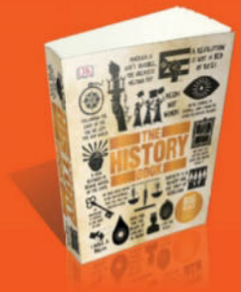
Big History is illustrated with stunning imagery, which appears simple at first but reveals a hidden complexity when you look closer. The 'Story of Life' pages are a wonderful example, stuffing four billion years into a line that snakes across a single spread and still explaining – in detail – facts like when mitochondria first formed, and why it was such an important development.

Where there aren't graphical representations explaining a subject, you'll instead find pages draped in beautiful photography. Whether it's a shot of an ancient device made of copper and gold to help Bronze Age people document astronomy, or a stunning macro photo of an animated peacock spider during a courtship display, these images illustrate and introduce each topic brilliantly.

Yes, it's expensive, but *Big History* is well-edited, packed full of information, and – importantly – encourages you to ask questions. The best part of all is that this book almost always has the answer.

★★★★★

YOU MAY ALSO LIKE...



The History Book

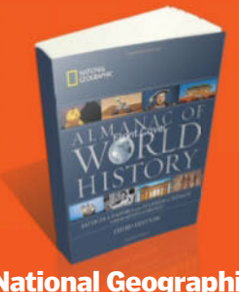
Author: **Dorling Kindersley**
Publisher: **Dorling Kindersley**
Price: **£16.99 / $25**
Release date: **Out now**

It's a slightly heavier read than *Big History*, and is perhaps aimed at an older audience, but *The History Book* is still packed with tons of information and infographics.

What's Where In The World?

Author: **Dorling Kindersley**
Publisher: **Dorling Kindersley**
Price: **£12.99 (approx. $16)**
Release date: **Out now**

If studying geography is your thing, this provides a great basis. Each double-page spread is a map, covering different topics, from shipwrecks to skyscrapers.



National Geographic Almanac of World History

Author: **Patricia Daniels and Stephen Hyslop**
Publisher: **National Geographic**
Price: **£25 / $40**
Release date: **Out now**

This epic almanac covers all of human history, exploring each of the different ages and cultures.

Bring Back The King: The Science Of De-extinction

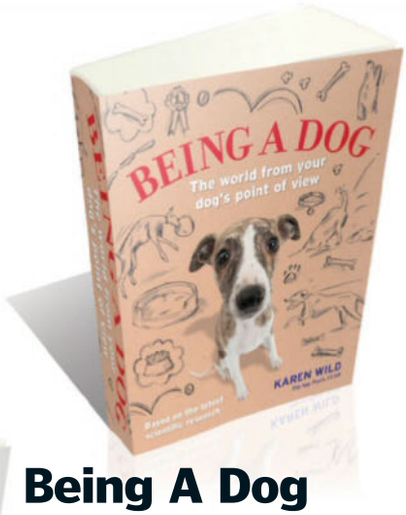
Could we make a real-life Jurassic Park?

- Author: **Helen Pilcher**
- Publisher: **Bloomsbury**
- Price: **£16.99 / $27**
- Release date: **Out now**

If you could resurrect one extinct animal, which would it be? This intriguing book seeks to answer whether we really could bring the likes of the T-rex, woolly mammoths, or even Elvis Presley, back from the dead.

Written by comedian and professional science writer, Helen Pilcher, it explains the science of de-extinction in an informative and accessible style for a fascinating read. There's a humorous, quirky tone to the writing, which makes the science engaging. *Bring Back The King* also examines the consequences of bringing extinct creatures back to life, and is likely to make you think and chuckle in equal measure.

★★★★★



Being A Dog

A scientific look at the life of your pet pooch

- Author: **Karen Wild**
- Publisher: **Octopus**
- Price: **£14.99 / $19.95**
- Release date: **Out now**

This unique title is based on the latest scientific research about our canine companions, explained in a very novel way. Told from a dog's perspective, the book is packed full of interesting information, from why their sense of smell is so good to what different types of tail wags mean.

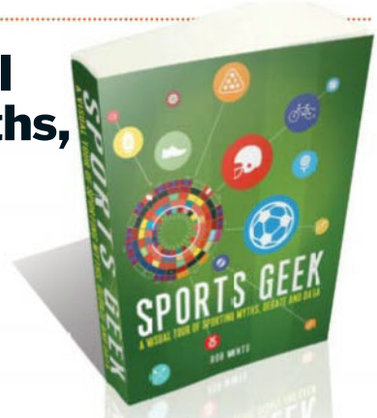
Both a science book and a pet guide, the pages are littered with little fascinating facts to teach you more about how your dog sees the world. If you're looking for a stocking filler for a dog-loving friend this Christmas, *Being A Dog* would be a great choice.

★★★★☆

Sports Geek: A Visual Tour Of Sporting Myths, Debate And Data

A guide to sport through the medium of statistics

- Author: **Rob Minto**
- Publisher: **Bloomsbury**
- Price: **£12.99 / $20**
- Release date: **Out now**



Sports fans love a good stat, so what better than an entire book full of them? *Sports Geek* covers 21 major sports from football to swimming to golf. Naturally, a book of sports graphs isn't for everyone and it's a shame there aren't any images of the sports themselves. Critically though, this isn't just a collection of random stats.

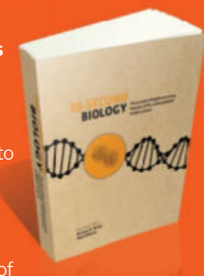
Big questions like "Is the Tour de France getting easier?" and "Just how important is home advantage?" are tackled, emphasising the issues in modern sport. Rather than being a simple pub quiz aid, this revealing read raises a lot of key points to consider in the world of sport.

★★★☆☆

30-Second Biology

50 thought-provoking theories of life

- Author: **Nick Battey & Mark Fellowes**
- Publisher: **Ivy Press**
- Price: **£14.99 (approx. $18)**
- Release date: **Out now**



30-Second Biology is a great introduction to the wonderful world of living organisms, providing just the right level of scientific depth to be informative while remaining understandable to a non-expert reader. It attempts to tackle this mammoth branch of science with one-page summaries of key areas in biology, from the origins of life to extinction, throwing in the profiles of some notable scientists for good measure. The breadth of the book is its greatest strength and its biggest weakness, as readers wanting to explore further will need to look elsewhere. Even so, it's a fine addition to the *30-Second* series.

★★★★☆

How Super Cool Stuff Works

Exploring high-tech modern and future inventions

- Author: **Dorling Kindersley**
- Publisher: **Dorling Kindersley**
- Price: **£19.99 (approx. $25)**
- Release date: **Out now**

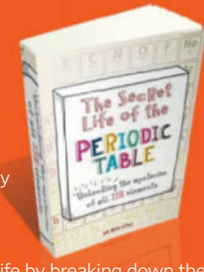
We love to learn about the inner workings of technology here at **How It Works**, so we were particularly pleased to have a chance to read this book. Arranged into six main sections – Play, Move, Construct, Power, Live and Future – all kinds of inventions are neatly displayed and explained with the help of cool imagery and annotations. The Construct chapter is particularly impressive, as some of the world's most beautiful buildings have had their architecture dissected and explained, but some of the other categories feel a little muddled. Even so, this makes a great shelf addition for dipping in and out of.

★★★★☆

The Secret Life Of The Periodic Table

Discover the hidden stories of the elements

- Author: **Dr Ben Still**
- Publisher: **Octopus**
- Price: **£12.99 / $24.95**
- Release date: **Out now**



We may all have come across the periodic table during our school years, but not many of us know the fascinating tale behind its inception or the stories of each of its members. Dr Ben Still has done an admirable job of bringing the elements to life by breaking down the chemistry into highly enjoyable and digestible chunks. The book opens with a brief history and overview of the periodic table, before dedicating space to each element in turn, using attractive illustrations and photos to describe the pivotal role each plays in our world.

★★★★★

Get in touch

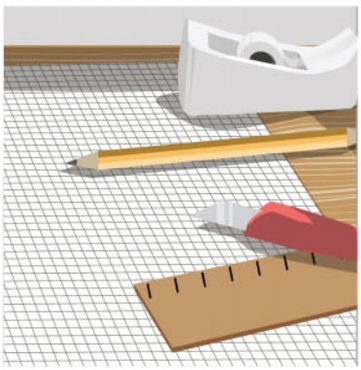
Want to see your ideas on this page? Send them to...

How It Works magazine @HowItWorksmag

howitworks@imagine-publishing.co.uk

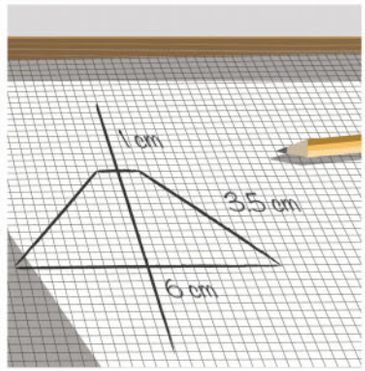
Build a hologram projector

Transform the 2D videos on your smartphone into dancing 3D holograms, using a projector made from simple household objects



1 Prepare your kit

First, gather your tools. You will need a clear CD case, a pen or pencil, a ruler, sticky tape, a craft knife, scissors, a smartphone and some graph paper. Make sure you choose a CD case no one will be wanting again, because it'll soon be transformed into the frame of our projector! If you don't have access to a CD case, you can use another clear, thin piece of plastic.



2 Make your template

You will need to create a template for your projector panels. On the graph paper, use your pencil and ruler to draw a straight line about ten centimetres long down the page. Then draw the trapezoid shape with dimensions 1 x 3.5 x 6 centimetres, using the line as a centre point. Carefully cut the paper template free with a pair of scissors when you're done.

3 Cut the panels

Take your CD case cover and carefully snap off the raised sides so only the flat square sheet of plastic is left. Now with the help of an adult, place your paper template on the plastic and use the crafting knife to cut around the shape. Once you've cut your first piece, you can then use the plastic trapezoid panel as a template for the remaining three pieces.

4 Assemble the projector

Now it's time to bind your panels together with thin strips of sticky tape. Cut at least four strips of sticky tape, roughly two centimetres long and one centimetre wide. Hold two panels at an angle so that the connecting sides run parallel, and use the tape to attach them, then attach the remaining two panels one at a time.

DON'T DO IT ALONE
IF YOU'RE UNDER 18, MAKE SURE YOU HAVE AN ADULT WITH YOU

5 Use your hologram

With your projector assembled, you just need to pick what you'd like your hologram to be. Find a specialist hologram video on YouTube – you could choose fireworks, jellyfish or even a Pikachu! Then lay your smartphone on a flat surface and place your projector in the centre of the screen. Now all you need to do is turn down the lights and enjoy your dancing hologram, which appears to be floating inside the projector!

In summary...

The projector panels take advantage of light refractions to form holograms. Specialist holographic videos will have four copies of the same moving image each facing the panels at the same orientation. When the light sources are refracted through the panels at a 45-degree angle, they combine to form an illusion of a 3D object inside the glass.

NEXT ISSUE
- BUILD A ROCKET
- MAKE A COMPASS

Make colour-changing flowers

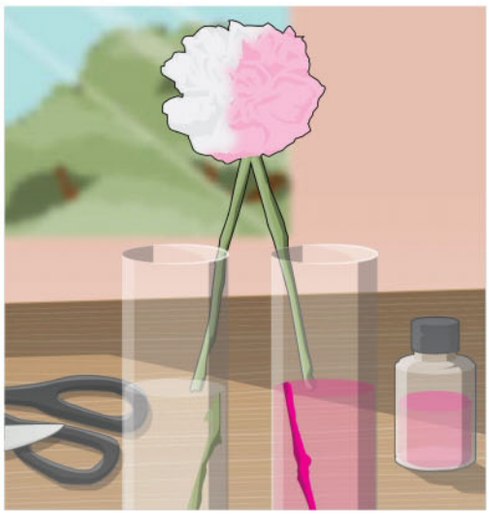
Use the power of capillary action to create your own custom-coloured carnations!

1 Pick your tools

For this experiment you'll need water, two vases or large glasses, one or two food colourings, scissors and a fresh white carnation with a long stem. A sharp knife will also be needed at the next step, so make sure you've got an adult nearby who can help you. Although the flower has no roots, the stem can still suck up water, and we can use this experiment to show us just how far the water travels!

2 Divide the stem

First, carefully remove the last few centimetres of the flower's stem using a pair of scissors. If you have a kitchen sink full of water nearby, you can ask an adult to cut the stem underwater for you, which will make sure no air gets trapped in the stem to block the flow of water. Next, ask an adult to use the sharp knife and cut the stem down the middle, leaving two separate stem 'legs' attached to the flower head.



3 Add to coloured water

Fill your two glasses with water and add your food colouring. Either add a different colour to each glass or leave one with just water. Place the glasses close to each other and add one part of the divided stem to each, then leave the flower for a few days. Which petals turned a different colour? If you used two different food colourings, did one change the colour of the petals quicker than the other?

In summary...

Plants absorb water through their roots, and it travels upwards through the stem by a process known as capillary action. We can see this natural process happen before our eyes by adding food colouring to the flower's water source and watching it climb all the way into the petals.

WIN!

A robotic dog worth £199.99

Meet CHiP – the Canine Home Intelligence Pet – your new robotic companion. CHiP features voice recognition to understand its master's voice, and will obey commands like 'sit', 'stay' and 'lay down'. If you say 'yoga', he'll even do a handstand!

What is the title of the latest Star Wars film?

a) **Rogue One**
b) **Vogue One**
c) **Brogue One**

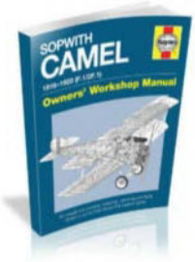
Enter online at **www.howitworksdaily.com** and one lucky reader will win!

INBOX
Speak your mind...

Get in touch
Want to see your letters on this page? Send them to...

How It Works magazine @HowItWorksmag

howitworks@imagine-publishing.co.uk



WIN!
AMAZING PRIZE FOR LETTER OF THE MONTH!
HAYNES SOPWITH CAMEL MANUAL
Packed with cutaways and rare colour photos, discover everything there is to know about this legendary WW1 fighter plane.

Letter of the Month

Why do we laugh?

Dear **HIW**,

I am always excited when I get my latest copy of **How It Works** magazine through my letterbox. It is always jam packed full of wonderful facts, articles, information and brilliant pictures of the latest technology, science, wildlife and history. I would like to ask two questions: How and why do we laugh? And how and why do swifts make such amazing patterns in the sky during flight?
Clara Benwell

Laughing involves several different regions of the brain, but mainly those associated with emotional responses, such as the frontal lobe and amygdala. The brain sends signals to various parts of the body, including our cheek muscles, lungs and vocal cords, in order to produce a laugh. The 'why' is slightly trickier to answer, but we can suggest a popular theory. Most experts agree that laughter is fundamentally a social tool. It overcomes language barriers, and babies start giggling and smiling after only a few months so that they can interact with their parents. Ultimately, laughter is for bonding, and we use it subconsciously. For example, have you noticed that you laugh more when watching a comedy with your friends than you do when you're alone?

To answer your second question, the flight patterns of swifts are also thought to be a social behaviour, and are sometimes used by the birds to court a mate. They can weave around the sky, thanks in part to large wingtip bones, which are able to adjust the shape and area of their wings for quick changes in direction.


Babies use laughter and crying as basic ways to communicate with their parents

What's happening on... Twitter?

Make sure you follow us **@HowItWorksmag** for amazing facts, competitions and the latest in science & tech!

@HarrietLovesMJ
@HowItWorksMag – Yet another great issue! Found the article about Fabergé Eggs really interesting!

@c_stimp
I think it is fair to say I quite like @HowItWorksmag

@speedimpexusa
Hey #TWTR. Ever wonder "WOW, how does that work?" Well @HowItWorksmag has just the answer

@kristawelz
Interesting article on the future of teaching. Via @HowItWorksmag

@dhesi_mia
10 accidental discoveries that changed the world. Who would've imagined? This is why I love this mag! @HowItWorksmag

@MoreUtterPiffle
We've just sorted a subscription to @HowItWorksmag!

A salty situation

Dear **HIW**,

My dad and I have different opinions of how long seawater will take to dissolve a piece of fabric, such as cotton. Personally, I think it will probably take years, but I'm unable to convince my dad who believes it will take weeks. What is your take on this?
Jean

Fabrics such as cotton are made from plant fibres, so 90 per cent of their composition is cellulose. Cellulose isn't broken apart as it binds to water, which is why cotton towels are good at mopping up spills and don't disintegrate in the washing machine. The salt in seawater would have little effect on the cellulose – it's more likely to be degraded by microbes in the water. The size of the fabric would also affect the time it would take to disintegrate. It would probably take months, more likely towards a year, until a piece of cotton fabric would be broken down in seawater.


Our seas dissolve most compounds that form bonds with water molecules


Bubbles grow on tiny ridges in the glass, and float up when they get too big

A carbon conundrum

Dear **HIW**,

I love your magazines and have been reading them since issue 1 and subscribed at about 20! I was wondering: Why do bubbles always go to the outside of the glass or cup?
Nick Richards

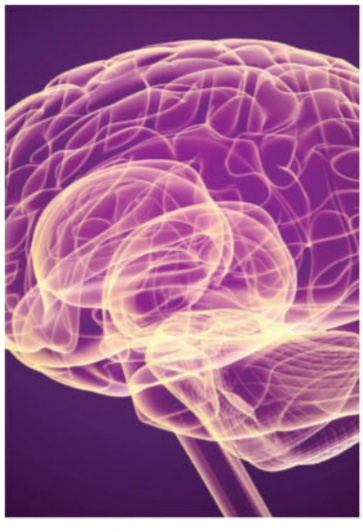
That's great to hear, Nick! And we can answer your question by considering how bubbles behave in liquids. All liquids contain at least some gases, and fizzy drinks have had extra gas added by carbonation. However, these gases will usually only form into bubbles on tiny crevices or bumps. Glasses and cups have microscopic flaws like these in their surfaces, which is why the bubbles tend to cling to them.

Big brains

Dear **HIW**,

Is it true that we can only access 10 per cent of our brains? And if so, do more intelligent people therefore access more of their brain?
Sarah Corbin

In reality there's no evidence to suggest that this statement is anything more than a myth. Our brains are actually formed from many distinct sections that are responsible for different tasks – such as the regulation of breathing, emotions and planning – and we use them all regularly. Intelligent people don't seem to use any more or less of their brain, but there is evidence to suggest that clever people have better connections between different parts of their brains.


Our brain is divided into many regions that perform different tasks

HOW IT WORKS

Future Publishing Ltd
Richmond House, 33 Richmond Hill
Bournemouth, Dorset, BH2 6EZ
☎ +44 (0) 1202 586200
Web: **www.howitworksdaily.com**
www.greatdigitalmags.com
www.futureplc.com

Editorial
Deputy Editor **Jackie Snowden**
jacqueline.snowden@futurenet.com
☎ 01202 586264
Senior Art Editor **Duncan Crook**
Research Editor **Katy Sheen**
Production Editor **Charlie Ginger**
Senior Staff Writer **Jack Griffiths**
Staff Writer **James Horton**
Assistant Designer **Laurie Newman**
Editor in Chief **Dave Harfield**
Photographer **James Sheppard**
Picture Editor **Tim Hunt**

Contributors
Stephen Ashby, Sarah Bankes, Alexandra Cheung, Ed Crooks, Matin Durrani, Nicholas Forder, Shanna Freeman, Rebekka Hearl, Amelia Jones, Liz Kalaugher, Gemma Lavender, Tom Lean, Adrian Mann, Laura Mears, Philip Morris, Jonny O'Callaghan, Alexander Phoenix, Jo Smolaga, Joanna Stass, The Art Agency

Cover images
Alamy, NASA, Thinkstock, Oscar Viñals

Photography
Alamy, Corbis, DK Images, Getty, NASA, Science Photo Library, Shutterstock, Thinkstock, Wikimedia. All copyrights and trademarks are recognised and respected.

Advertising
Digital or printed media packs are available on request.
Head of Sales **Hang Deretz**
☎ 01202 586442
hang.deretz@futurenet.com
Account Manager **Lee Mussell**
lee.mussell@futurenet.com

International
How It Works is available for licensing. Contact the International department to discuss partnership opportunities.
Head of International Licensing **Cathy Blackman**
☎ +44 (0) 1202 586401
cathy.blackman@futurenet.com

Subscriptions
For all subscription enquiries:
howitworks@servicehelpline.co.uk
☎ 0844 815 5944
☎ Overseas +44 (0)1795 418680
www.imaginesubs.co.uk
Head of subscriptions **Sharon Todd**

Circulation
Circulation Director **Darren Pearce**
☎ 01202 586200

Production
Production Director **Jane Hawkins**
☎ 01202 586200

Management
Finance & Operations Director **Marco Peroni**
Creative Director **Aaron Asadi**
Editorial Director **Ross Andrews**

Printing & Distribution
Wyndeham Peterborough, Storey's Bar Road, Peterborough, Cambridgeshire, PE1 5YS

Distributed in the UK, Eire & the Rest of the World by
Marketforce, 5 Churchill Place, Canary Wharf, London, E14 5HU
☎ 0203 787 9060 www.marketforce.co.uk

Distributed in Australia by Gordon & Gotch Australia Pty Ltd, 26 Rodborough Road, Frenchs Forest, New South Wales 2086
☎ + 61 2 9972 8800 www.gordongotch.com.au

ISSN 2041-7322

NEXT ISSUE

Issue 94 on sale 29 December 2016

Including
- At-risk species
- Shark sanctuaries
- Killer anatomy
- Surviving in the deep

SHARK ATTACK

The deadly predators with only one thing to fear: us

Why we'll leave Earth and where we'll go next

Extreme science: death-defying research

Behind the scenes: special effects explained

+LEARN ABOUT

■ LOST CITIES ■ SAIL SHIPS ■ HONEYPOT ANTS ■ ANCIENT STARS
■ COMPUTER HACKING ■ LAND ROVER ■ INSIDE THE SUN ■ PIANOLAS

FAST FACTS

Amazing trivia to blow your mind

3.8BN YEARS

THE LENGTH OF TIME LIFE HAS EXISTED ON OUR PLANET

9.65km²

THE SIZE OF A HONEY FUNGUS LIVING IN THE BLUE MOUNTAINS OF OREGON

899KG

WEIGHT OF THE CAR-SIZED CURIOSITY MARS ROVER

104 DECIBELS

THE VOLUME OF CONCORDE'S SONIC BOOM

Sopwith Camel planes shot down more enemy aircraft than any other Allied fighter during WWI

70% THE AMOUNT OF WATER A WET DOG CAN SHAKE FROM ITS FUR IN FOUR SECONDS

$4.05 BILLION

THE PRICE DISNEY PAID FOR STAR WARS CREATORS LUCASFILM LIMITED

5

THE NUMBER OF MASS EXTINCTIONS DURING EARTH'S HISTORY

IN THE MIDDLE AGES, THE PUNISHMENT FOR SELLING IMPURE SAFFRON WAS BEING BURIED ALIVE

96.5%

OF THE WATER ON EARTH IS SALT WATER

10 MILLION

The number of times the average person blinks every year

1 LITRE

THE AMOUNT OF MUCUS YOU PRODUCE AND SWALLOW EACH DAY

A UK POLL REVEALED THE PROCLAIMERS' SONG *I'M GONNA BE (500 MILES)* IS THE MOST COMMON 'EARWORM'

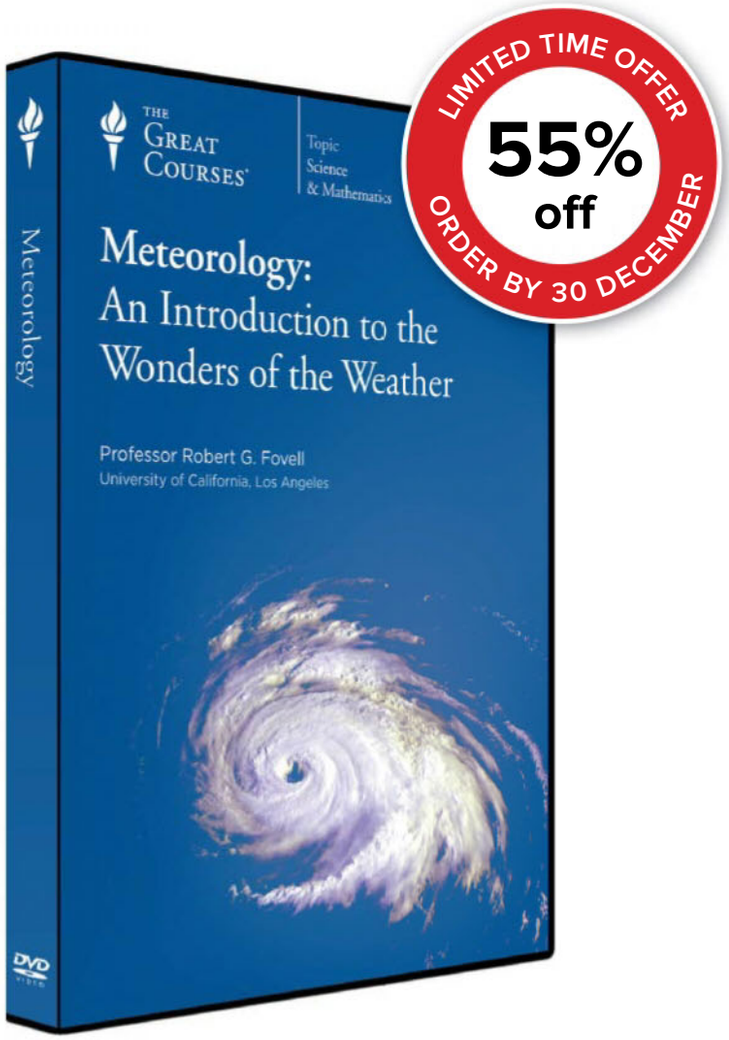
3.5 HRS

THE AVERAGE TIME IT TAKES TO COOK A CHRISTMAS DINNER

92 MINS

THE TIME IT TAKES FOR THE INTERNATIONAL SPACE STATION TO ORBIT EARTH

THE GREAT COURSES®



Explore the Mystery and Intrigue behind the Weather

Weather affects your life every day. From the transformation of water vapor into clouds to the swirling winds of a tornado, meteorological events are the result of intricate interactions between powerful forces around you. To grasp the mystery of these phenomena is to understand a remarkably complex system that continues to captivate scientists.

Meteorology: An Introduction to the Wonders of the Weather is a fascinating foray into an enthralling field of study. In 24 engaging lectures, you'll explore the often surprising, always intriguing workings of the weather, guided by expert atmospheric scientist and professor Robert G. Fovell. Combining geography, chemistry, physics, and other disciplines, he offers insights into lightning, cyclones, thunderstorms, and other wondrous aspects of one of nature's most compelling mysteries.

Offer expires 30/12/16

THEGREATCOURSES.CO.UK/4HIW

0800 298 9796

Meteorology: An Introduction to the Wonders of the Weather

Taught by Professor Robert G. Fovell
UNIVERSITY OF CALIFORNIA, LOS ANGELES

LECTURE TITLES

1. Nature Abhors Extremes
2. Temperature, Pressure, and Density
3. Atmosphere—Composition and Origin
4. Radiation and the Greenhouse Effect
5. Sphericity, Conduction, and Convection
6. Sea Breezes and Santa Anas
7. An Introduction to Atmospheric Moisture
8. Bringing Air to Saturation
9. Clouds, Stability, and Buoyancy, Part 1
10. Clouds, Stability, and Buoyancy, Part 2
11. Whence and Whither the Wind, Part 1
12. Whence and Whither the Wind, Part 2
13. The Global Atmospheric Circulation
14. Fronts and Extratropical Cyclones
15. Middle Troposphere—Troughs and Ridges
16. Wind Shear—Horizontal and Vertical
17. Mountain Influences on the Atmosphere
18. Thunderstorms, Squall Lines, and Radar
19. Supercells, Tornadoes, and Dry Lines
20. Ocean Influences on Weather and Climate
21. Tropical Cyclones
22. Light and Lightning
23. Prediction and Predictability
24. The Imperfect Forecast

Meteorology: An Introduction to the Wonders of the Weather
Course no. 1796 | 24 lectures (30 minutes/lecture)

SAVE £30

DVD ~~£54.99~~ NOW £24.99
+£2.99 Postage and Packing
Priority Code: 138547

For over 25 years, The Great Courses has brought the world's foremost educators to millions who want to go deeper into the subjects that matter most. No exams. No homework. Just a world of knowledge available anytime, anywhere. Download or stream to your laptop or PC, or use our free mobile apps for iPad, iPhone, or Android. Over 550 courses available at www.TheGreatCourses.co.uk.

MEADE INSTRUMENTS

MAKE SOMEONE'S CHRISTMAS

HIGH QUALITY OPTICS

THE UNIVERSE AWAITS

Everything you Need in One Box

Get set up and started with astronomy in minutes.

Stable Mounts, Finderscopes and Slow Motion Controls

Allow smooth, easy tracking of objects for more enjoyable exploration of the night sky.

Sky and Land-Based Viewing

Stars, planets, lunar surface, deep space or land. Infinite possibilities are at your fingertips.

Argos www.argos.co.uk	**Binoculars UK** www.binoculars-uk.co.uk	**Black & Lizars** www.blackandlizars.com	**Crooked Imaging** www.crookedimaging.co.uk
Currys www.currys.co.uk	**Express Processing** www.exprodirect.com	**Fotosound** www.fotosound.je	**Ideal World** www.idealworld.tv
J & A Cameras www.jandacameras.co.uk	**JD Williams** www.jdwilliams.co.uk	**JRS Photo** www.jrsphoto.co.uk	**LCE** www.lcegroup.co.uk
Merchant City Cameras www.merchantcitycameras.com	**Mifsuds** www.mifsuds.com	**PicStop** www.picstop.co.uk	**Sherwoods** www.sherwoods-photo.com

@HamaUK
HamaUKLtd

MEADE INSTRUMENTS
www.meade.com

Hama UK
Hama UK