HOW IT WORKS

CRACKING YOUR GENETIC CODE

HOW IT WORKS

THE MAGAZINE THAT FEEDS MINDS

DISCOVER

TECHNOLOGY
WORLD'S FIRST ROBOCOP

SPEED DEMONS

GET BEHIND THE WHEEL OF RECORD-BREAKING RACERS, HYPERCARS AND SUPERSONIC SPEEDERS

CUTTING-EDGE AERODYNAMICS

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TRAIN FOR A MARATHON... WITH SCIENCE

AMAZING ILLUSTRATIONS

Bloodhound's 1,600kph rocket

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Which hypercar is the fastest?

SPACE
HOW TO BUILD THE ULTIMATE ROCKET

+LEARN ABOUT

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ISSUE 111

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ISSUE 111

WELCOME

The magazine that feeds minds!

Last month was the 88th Geneva Motor Show and the start of the 2018 Formula 1 season, so what better time for us to celebrate all things fast on four wheels!

As hypercar manufacturers race to the title of world's fastest production car, F1 teams will be pushing engineering to the limits to achieve a podium finish. Meanwhile, the Bloodhound team are busy preparing for their land speed record attempt in their supersonic speeder, with the target of a whopping 1,600kph in their sights.

Also this edition, we find out what it takes to build the ultimate rocket; explore revolutionary genetic breakthroughs; discover what life was like in a Roman legion; investigate with the art detectives; and reveal the surprising secrets of seaweed. Enjoy the issue!

Jackie **Jackie Snowden**
Editor

"In the near future we'll have even more powerful megarockets that will put their predecessors to shame"

Building the ultimate rocket, page 52

Meet the team...

Charlie G
Production Editor
The foundations of the Roman Empire were built on the shoulders of its legions. Join the ranks on page 78 to find out how Rome made such fearsome warriors.

Baljeet
Research Editor
Given the recent success of SpaceX's Falcon Heavy rocket, what does it take to build a rocket? Find out more on NASA's and SpaceX's future plans on page 52.

Charlie E
Staff Writer
Algae is incredible. Not convinced? They help produce the air we breathe and are a sustainable superfood! Find out why algae are awesome organisms over on page 62.

Scott
Staff Writer
Ever wondered how the history of art is uncovered? Meet the art detectives on page 40, a team that use the latest tech to lift the mask from the masterpiece.

Duncan
Senior Art Editor
I loved the film *Robocop*, so I was interested to read about the real-life version pounding the streets of Dubai. Meet this futuristic crime-fighter on page 47.

Laurie
Studio Designer
This month I was heartbroken at learning that 90% of orangutans have disappeared in the last 20 years due to palm oil deforestation. Learn more about this travesty on page 68.

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+ PULL-OUT POSTER
Tutankhamun's tomb
PAGES 50–51

MEET THE EXPERTS...

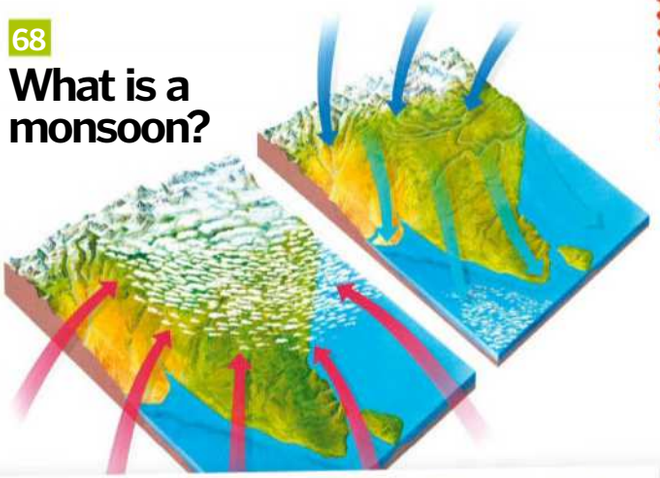
James Horton
In our cover feature, James explains the amazing engineering inside some of the world's fastest cars, from the latest tech on the F1 grid to the hypercar record contenders and the epic 1,600kph Bloodhound rocket car.

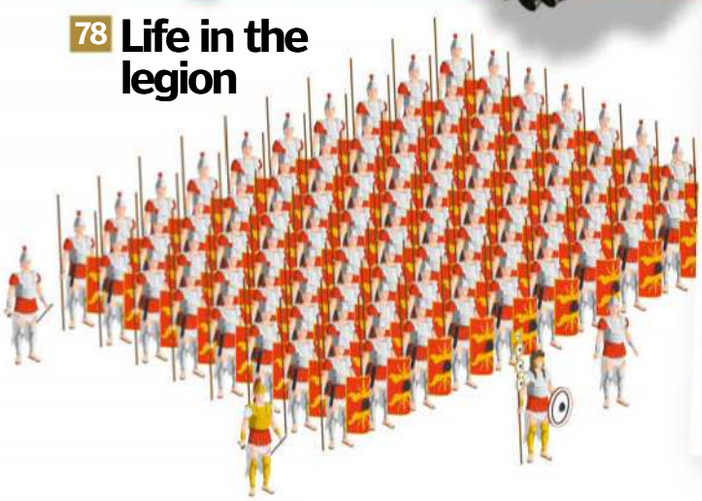
Jonny O'Callaghan
In this month's space feature Jonny reveals the tech and engineering behind the next generation of megarockets that could soon be ferrying us to Mars.

Steve Ashby
Editor of **Official Xbox Magazine**
Steve takes a trip down gaming memory lane for this issue's teardown. Find out what goes into Nintendo's relaunched NES console over on page 48.

Tim Williamson
In our history feature, **History of War** Editor Tim explains what life was like for soldiers serving in a Roman legion and how these structured units made up the world's most effective fighting force.

Laura Mears
Laura explains the past, present and future of DNA discoveries and revolutionary gene technologies. From deciphering our genome to cutting-edge CRISPR editing, we've come a long way in 200 years.





REGULARS

Remembering Stephen Hawking (1942–2018)

A look back on his groundbreaking work and inspirational life

Stephen William Hawking was born 8 January, 1942, in Oxford, England. He spent the next 76 years becoming one of the greatest minds in history.

After finishing his PhD at Cambridge, Hawking began working on a theory with mathematician Roger Penrose to investigate the supposed appearance of singularities in space-time based on Albert Einstein's 1915 theory of general relativity. This led him to show that space and time began with the Big Bang and end in black holes.

In his early 20s, the physicist was diagnosed with amyotrophic lateral sclerosis (ALS), the disease that would confine him to a wheelchair and severely restrict his movement in later life. This, however, didn't get in the way of his genius or prevent him from becoming a highly influential and respected figure in the science community.

Throughout his life Hawking became a household name for his courage, continued pioneering work and unwavering humour. He is quoted as saying, "The downside of my celebrity is that I cannot go anywhere in the world without being recognised. It is not enough for me to wear dark sunglasses and a wig. The wheelchair gives me away."

Hawking passed away at home in Cambridge on 14 March, 2018. The world may have lost one of its greatest minds, but Hawking's contributions to science and his inspiring life will continue to influence many generations to come.

"Hawking became a household name for his pioneering work"

1942
Stephen Hawking is born on 8 January in Oxford, England, exactly 300 years after the death of Italian astrophysicist Galileo Galilei.

1959
Hawking starts at University College, Oxford, where his father studied. As mathematics is not taught at the college, he studies physics.

1962
Awarded a first-class honours degree in natural science. Heads to Cambridge to study for a PhD in cosmology.

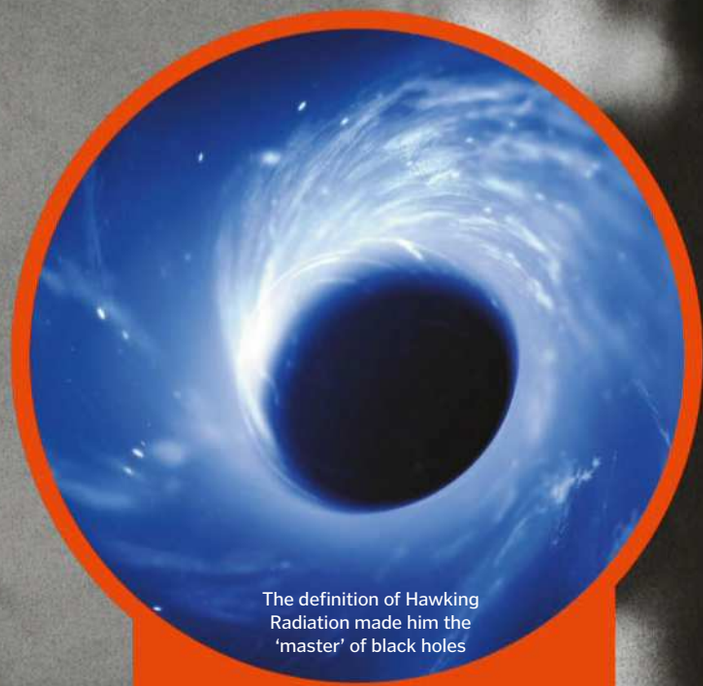
1963
Diagnosed with amyotrophic lateral sclerosis, a form of motor neurone disease.

1965
Marries Jane Wilde, with whom he has three children.

1973
Publishes his first book, *The Large Scale Structure of Space-Time*.

1974
His Hawking Radiation theory predicts black holes emit radiation and continue to do so until they evaporate and disappear. Named a fellow of the Royal Society.

1975
Honoured with the Pius XI Gold Medal by Pope Paul VI.



The definition of Hawking Radiation made him the 'master' of black holes

The theory of everything

In 1974, Stephen Hawking proposed the theory that black holes eject energy in the form of radiation, now known as Hawking Radiation. He also hypothesised that the universe began as a 'big bang' and will end with black holes; and his co-discovery of Hawking Radiation emitted by black holes is a consequence of his theory that cosmology and quantum theory are inherently linked. Hawking once said, "My goal is simple. It is a complete understanding of the universe, why it is as it is and why it exists at all."

1979
Becomes the 17th Lucasian Professor of Mathematics at Cambridge, a position he holds for 30 years.

1982
Receives a CBE from the queen of England.

1988
A Brief History of Time: From the Big Bang to Black Holes is published, one of Hawking's most famous and bestselling books.

1993
Publishes a popular collection of essays entitled *Black Holes and Baby Universes*.

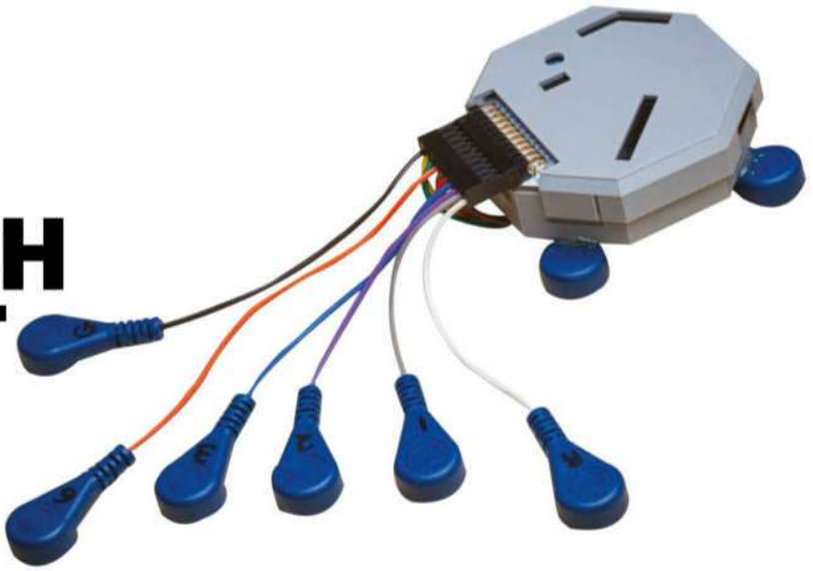
2001
Publishes *The Universe in a Nutshell*, a more accessible account of the universe as a whole than his previous books.

2006
Awarded the prestigious Copley medal for "his outstanding contribution to theoretical physics and theoretical cosmology."

2009
Awarded the Presidential Medal of Freedom, the highest civilian honour in the United States.

2013
Awarded the Special Fundamental Physics Breakthrough Prize for his discovery of Hawking Radiation.

WEARABLE TECH MONITORS GUT ACTIVITY



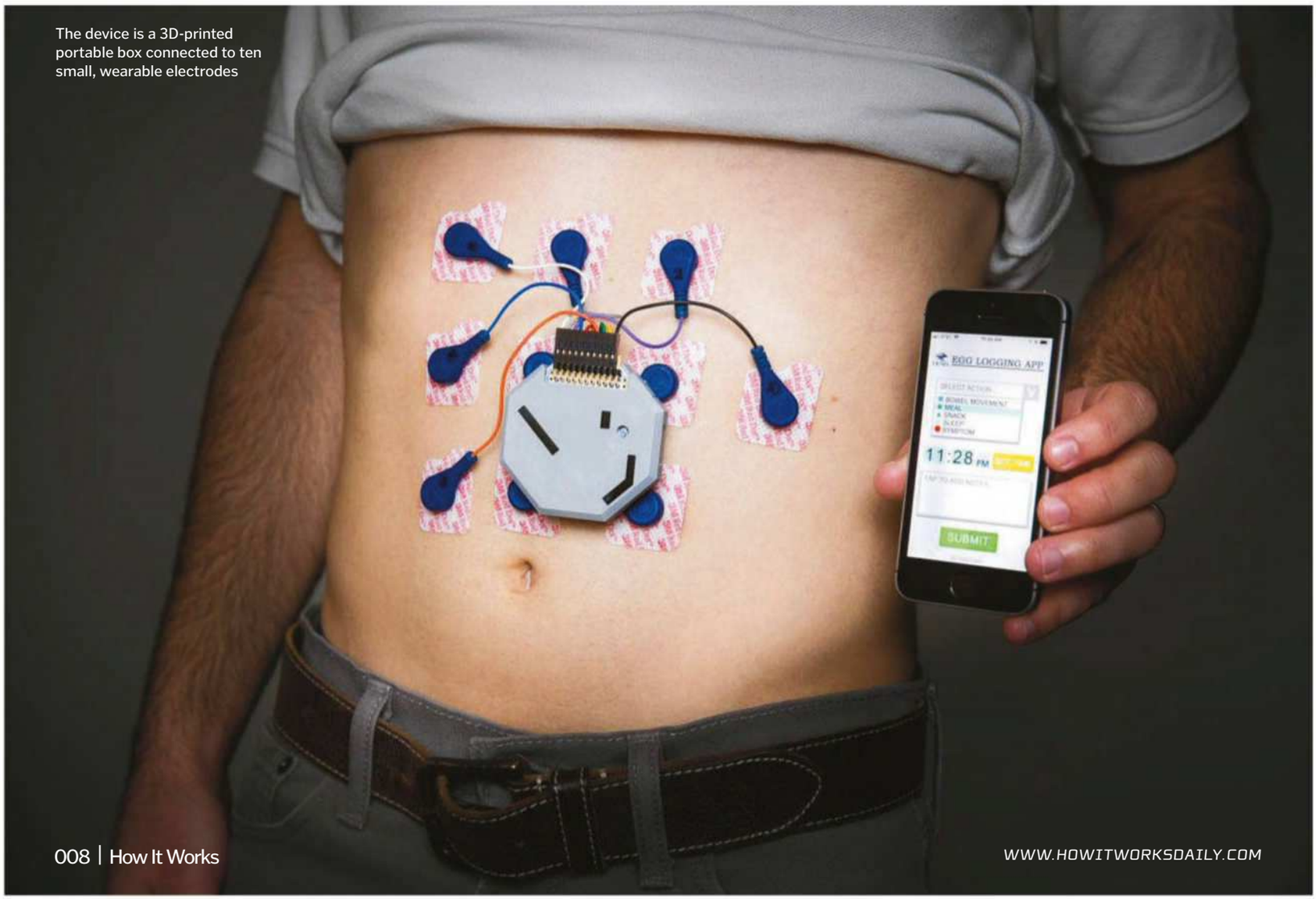
Researchers have developed a non-invasive way to detect abnormalities in the gastro-intestinal tract

Monitoring gastro-intestinal (GI) activity can currently be an invasive and time-consuming process. However, the development of a new, non-invasive device and partnering smartphone app could allow patients to be seen outside of hospital while still providing doctors with the real-time information they need.

"We think our system will spark a new kind of medicine, where a gastroenterologist can quickly see where and when a part of the GI tract is showing abnormal rhythms and as a result make more accurate, faster and personalised diagnoses," said the paper's first author Armen Gharibans, a bioengineering postdoctoral researcher at the University of California San Diego.

The device works using the same electrodes as those used in electrocardiograms, which are placed around the patient's abdomen. Readings from the electrodes are then monitored and stored on the smartphone app to record activity. This, alongside the patient's own inputs on meals and sleep, gives physicians a better understanding of their GI activity. After being tested on volunteers, the team compared the results of their device to the results of traditional methods and found them to be comparable.

"It provides the information without need for sedation and it offers the flexibility to monitor kids while they continue their daily activities. This procedure allows convenience without compromising accuracy," explained Dr Hayat Mousa, who worked alongside the research team. It is hoped this device will also help patients with diseases such as diabetes and Parkinson's, and it can also be used by athletes to track their digestion.



The device is a 3D-printed portable box connected to ten small, wearable electrodes

NEWS BY NUMBERS

2/3s

of British people feel unfulfilled in their lives according to a recent study

£7mn

The amount pledged by the coffee chain Starbucks to develop recyclable and compostable cups

2,000

The number of Sols (Mars days) the Curiosity rover has been on the Red Planet, as of 22 March, 2018

0

There are sadly no longer any male northern white rhinos left on Earth

Science fair goes off with a bang

The Big Bang Fair returns to Birmingham's NEC to showcase some stupendous science

School pupils from around the country came in their thousands to attend this four-day event, which involved science, technology, engineering and mathematics (STEM) companies and organisations gathering at the exhibition centre to inspire the next generation of scientists.

Each day visitors could explore the world of STEM, and from laparoscopy surgery to machine design, the exhibition hall was filled with all things science. Organisations such as the ambulance service and military were also on hand to explain the science behind their daily work. The spark of inspiration in the young visitors burned bright, maybe even more so than that of the pyrotechnics display.

"Visitors explored the world of STEM"

One of the exhibitors displayed a simple projection software that turned a sand pit into a changing topography demonstration

The documentary follows the Faroe Islands' leading medical expert and the families affected by mercury poisoning

The Islands and the Whales

New documentary highlights the dangers of pollution to isolated communities and their controversial traditions

The Faroe Islands are an archipelago in the middle of the North Atlantic between Scotland and Iceland. Often in the press for their controversial whale hunting practice, this documentary centres around the accumulation of mercury within whale blubber, which is poisoning the islands' residents.

Though beautiful in its cinematic prowess, the documentary reveals the ugly side of tradition. Graphic hunting scenes dominate the first part of the documentary, so be warned this isn't for the faint hearted. The film is showing in selected cinemas until 4 June. Visit **theislandsandthewhales.com** for more information.

Human and non-human primates' genomes were used to verify Ata's human ancestry

Mini mummy sheds light on genetic conditions

The mystery of this 15-centimetre mummified skeleton is finally solved with the help of DNA analysis

In 2003, scientists unearthed a surprising humanoid skeleton in the Atacama Region of Chile. The same size as a foetus, this mini mummy (known as Ata) was estimated to have been between six and eight years old when she died. Using DNA extracted from her bone marrow, a team of researchers sequenced the sample and found multiple mutations linked with conditions such as dwarfism and scoliosis. This discovery is hoped to further the understanding of genetic skeletal disorders.

GLOBAL EYE

10 COOL THINGS WE LEARNED THIS MONTH

1 There's a mysterious sea star illness

Researchers are investigating a disease that has devastated sea star populations along the US West Coast, killing off a record number of many starfish species. Scientists do not yet fully understand what causes the disease, known as sea star wasting syndrome (SSWS), but some predict it could be a viral infection. SSWS causes lesions and tissue decay, meaning the creatures lose limbs and die in a matter of days.

2 Bacteria may be increasing pancreatic cancer risk

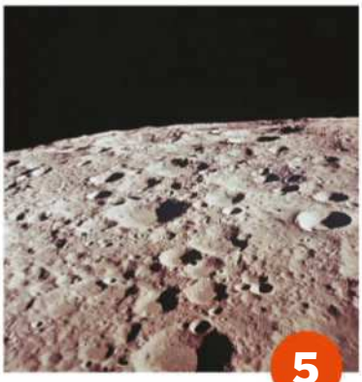
A study published in the journal *Cancer Discovery* has reported that bacteria move from the gut to the pancreas when a patient has pancreatic cancer. The study showed that human pancreatic tissue samples had an active microbiome, and in studies using mice, eliminating migrated 'bad' bacteria can slow the growth of pancreatic tumours and lower the tumour burden by approximately 50 per cent while also reversing immune suppression.

3 Could we slow glacial melting?

A group of international climate researchers have suggested the solution to preserve continental ice sheets is geoengineering. They argue in *Nature Comment* that the melting can be slowed by preventing warm ocean waters from reaching the glaciers' base; buttressing ice shelves by building structures in the sea; and draining the glacier beds or freezing the thin layer of water they slide upon.

4 Cassini's final data reveals more of Saturn's secrets

While it may have plunged into the atmosphere of Saturn seven months ago, we are still learning a lot from the last data Cassini sent to Earth. Scientists analysing the space probe's results have discovered that Saturn's swirling bands of clouds run further down towards the planet's core than expected and that tiny fragments of ice from the rings are eroding the innermost ring.



5

AI is better than humans at mapping the Moon's surface

A new algorithm attempting to mimic the way a brain processes information has been studying lunar images to learn what craters look like. The artificial neural network has discovered thousands of new pockmarks on the surface of the Moon, and it is hoped that it can be used in the future to catalogue impact scars on other moons or planets.

6

Comet tails may help to form Martian clouds

A new study of Mars' atmosphere suggests that magnesium ions forming in the cosmic dust trailing behind comets can cause the formation of tiny ice crystals that aid in cloud formation. As the dust vaporises in the atmosphere it leaves metals scattered throughout the air, and the new data suggests they clump together with carbon dioxide gas and form the clouds.

Obesity can cause loss of taste buds

A study published in *PLOS Biology* has compared one group of mice fed normal mouse food to another given high-fat meals. The results of the study have shown that mature taste bud cells died off faster and fewer new cells developed to take their place in the mice storing extra fat.

7

8

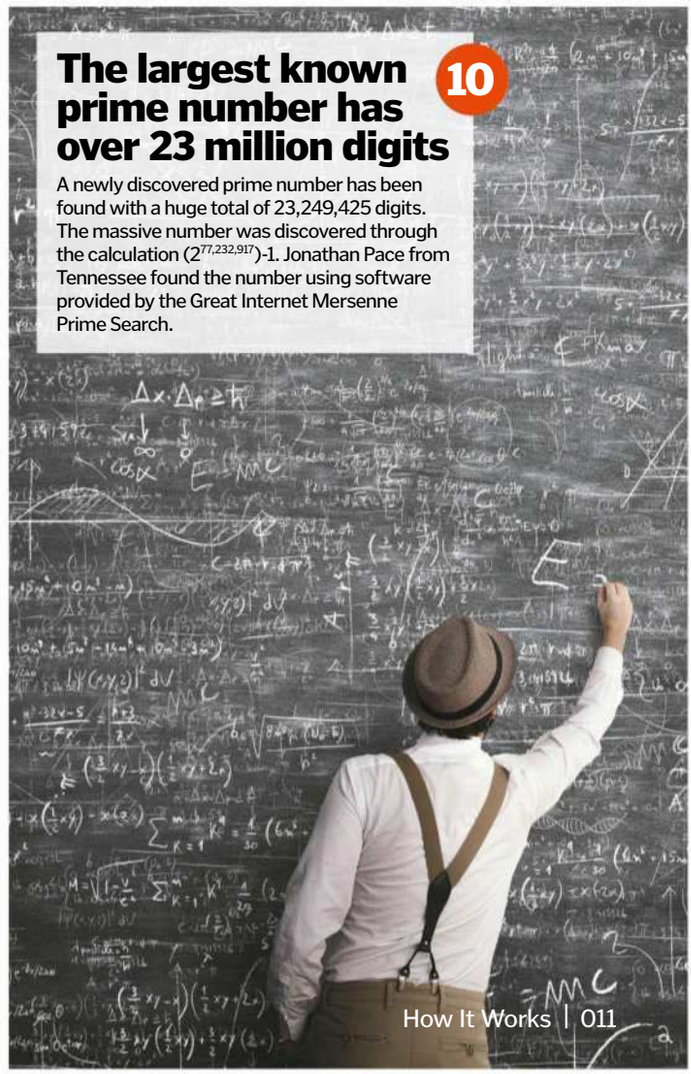
The Pacific garbage patch is bigger than originally predicted

Scientific Reports has published an article stating that the waste floating in the ocean between California and Hawaii contains at least 79,000 tons of plastic. This latest figure is four to 16 times larger than past estimates. It is thought that much of the plastic comes from the fishing and shipping industries.

Ceres may contain water

Scientists have used data from NASA's Dawn spacecraft – which has been orbiting Ceres since 2015 – to prove the planet is geologically active. It revealed there may be underground liquid escaping from the surface cracks.

9



10

The largest known prime number has over 23 million digits

A newly discovered prime number has been found with a huge total of 23,249,425 digits. The massive number was discovered through the calculation $(2^{77,232,917})$-1. Jonathan Pace from Tennessee found the number using software provided by the Great Internet Mersenne Prime Search.

WISHLIST

The latest must-have technology

Beoplay A1

■ Price: **£229 (approx. $320) / beoplay.com**

Good things come in small packages, and the Beoplay A1 is no exception. This compact wireless Bluetooth speaker is accompanied by the Beoplay app that allows you to personalise the mood of your music using touchtone. These circular speakers offer a crystal-clear sound without sparing any expense on battery life, which can last up to 24 hours. With an incorporated microphone, the Beoplay A1 can also act as a speakerphone and is supported by Apple Siri and Google Now voice. Impressively, these speakers can also pair with another to double the power and play the same music throughout your home.

UBTECH Jimu Robot AstroBot Kit

■ Price: **£179.95 / $199.99 / jimurobots.com**

With the UBTECH Jimu Robot AstroBot Kit, you can build not just one robot but three: AstroBot, Rover and Astron. Or, if you want to get really creative, you can build and program a robot of your own design using the app. Whether you want to make your robot a friendly humanoid or a wheeled vehicle, they're so much fun it is easy to forget that you're learning STEM skills as you build!

You can utilise the infrared sensors so your bot can pick up objects, install some treads to tackle tough terrain, or use the speaker to play music or sound effects – the possibilities are endless. The free Jimu app offers step-by-step 3D, 360-degree animated building instructions, and you can use Blockly coding to program AstroBot to do almost anything.

Stay Sixty

■ Price: **£29.95 (approx. $40) / staysixty.com**

With the UK alone using around 38.5 million plastic bottles every day, products like Stay Sixty offer consumers a reusable water bottle so they no longer have to rely on disposable ones. Stay Sixty is a sleek and stylish bottle made from a BPA-free stainless steel and finished with a rubberised matte. These bottles not only look good, but they are also excellent at keeping water, smoothies and fruit juices cool thanks to their double-walled, stainless steel interior.

What makes these bottles particularly useful is their removable base for quick cleaning. Bottles that only open at the top can be tricky to clean properly if they have narrow necks, but this innovative design means you can remove any drink debris with ease.

R2-D2™ App-Enabled Droid™

■ Price: **£129.99 / $179.99 / sphero.com**

This is the droid you've been looking for. Controlled using your smartphone or tablet, Artoo comes complete with front and rear LED lights and an integrated speaker for his bleeps and bloops. But he's more than just a robot – augmented reality means you can roam the galaxy and explore inside spaceships!

Sphero's Artoo brings the iconic droid's characteristic charms and quirks to life like never before. A few of the fun features of this little bot include Artoo's ability to interact with other *Star Wars* app-enabled droids by Sphero and his reactions if you watch *Star Wars* films with him by your side.

VN5 Harrier Drone

■ Price: **£29.99 (approx. $40) / hawkin.com**

This quadcopter is a perfect starter drone for beginners. It has an onboard camera for taking photos and video and is equipped with advanced gyro-stabilisation technology for super-smooth flight. After installing the remote's batteries, a micro SD card for the camera (not included) and attaching the drone's legs, you're ready to take off.

Considering its price, we were impressed with just how nimble and stable the VN5 is in the air. The controls are easy to pick up, and there is a choice of speed settings that you can try out once you get more confident. One of our favourite features is that this drone can perform somersaults at the touch of a button!

The VN5 Harrier will fly for about six minutes from a two-hour charge (via USB connection), with a range of about 30 metres. Overall, it's a great entry-level drone and excellent value for money. Just remember to check the Drone Code at **dronesafe.uk** before you fly!

Prynt Pocket

■ Price: **£149.99 (approx. $210) / prynt.co**

This compact device is bringing back the fun of printing instant pictures but with a modern twist. The Pyrnt Pocket is the second in the Prynt company line following the success of the Prynt Case. This pocket-sized printer turns your phone into a cool instant camera. Printing high-quality pictures without using any ink is just one of the many great features of this device.

However, by far the best features are its video capabilities. Using the accompanying app, you can embed augmented reality videos from your phone or social media platforms such as Snapchat into the printouts. The Prynt Pocket is currently only compatible with iOS products, but an Android version is said to be on its way.

APPS & GAMES

Discovery Tour - Assassin's Creed: Ancient Egypt

■ Developer: **Ubisoft**
■ Price: **£15.99 / $19.99 (standalone PC) or free update with Assassin's Creed: Origins (PC, PS4, Xbox One) / store.ubi.com**

The team behind the *Assassin's Creed* franchise don't skimp on their research. The latest title, *Origins*, is set in ancient Egypt, offering a highly detailed reconstruction of this region, its landmarks and people. The Discovery Tour provides a more peaceful way to explore this fascinating world by turning the game into a virtual museum, complete with 75 interactive tours curated by historians and Egyptologists.

Touch Surgery

■ Developer: **KINOSIS / Digital Surgery Limited**
■ Price: **Free / App Store / Google Play**

If you've ever wondered what it's like to be a surgeon, then this is the app for you. Touch Surgery is an interactive training programme that allows medical professionals to revise and simulate over 100 procedures. We're not the target audience (and it's obviously no substitute for years of medical school) but we enjoyed it all the same. Scalpel!

NASA Spinoff

■ Developer: **NASA**
■ Price: **Free / App Store (iOS iPad only)**

What have NASA ever done for us? Well an awful lot actually. This inspiring app includes all the articles from their online publication of the same name, highlighting how NASA's research is improving our lives. From making our cars safer to smart sensors that can catch cancer, there are plenty of innovations that the space agency have helped develop, and you can explore them here.

Meriel Jeater

We speak to the curator at the Museum of London about Roman Dead, an exciting new exhibition opening its doors this May

Armed with a BA in archaeology and ancient history and an MA in museology, Meriel Jeater joined the Museum of London in 2000 and has worked on a wealth of archaeological collections for the museum ever since. Her previous works include the permanent Medieval London gallery, the War, Plague and Fire gallery, and most recently she curated *Fire Fire!*, which explores the 1666 Great Fire of London. In a new exhibition titled *Roman Dead* (opening 25 May at Museum of London Docklands) Meriel and a team of curators will reveal the remarkable discovery of a Roman cemetery excavated from Harper Road in Southwark last year.

What first drew you to a career in archaeology?
When I was a child my father took us to see ancient ruins in Greece, which got me hooked on studying the past. A group of archaeologists visited my class at primary school and taught us how to dig mini excavations that they'd made especially for us using layers of soil in fish tanks. I loved it and decided to become an archaeologist! However, having actually been on a proper excavation when I was studying archaeology at university, I discovered I liked the objects and the history but not the mud and hard work, so I became a museum curator instead.

How did you feel when you first heard that a rare sarcophagus had been discovered on a building site, now a Roman cemetery, last year?
It was very exciting to learn about the discoveries at Harper Road. Roman sarcophagi are rare finds in London, plus there was the intriguing mystery about who might have been buried inside. The sarcophagus was moved – still with all the soil inside – to our store in Hackney so that archaeologists from Pre-Construct Archaeology (PCA) could excavate it carefully in a controlled environment. They are still analysing the contents and we look forward to finding out more shortly.

How do you approach curating an exhibition such as Roman Dead?
This is very much a collaborative effort – I'm

working with my colleagues Jackie Keily, who is senior curator for the prehistoric and Roman collections, and Dr Rebecca Redfern, who is a bioarchaeologist specialising in the study of ancient human remains. We also have help from many other colleagues both at the Museum of London and from external organisations such as PCA, who found the sarcophagus, and Museum of London Archaeology (MOLA). We really wanted to set our display of the sarcophagus in the context of Roman burials in London so that visitors could understand more about its significance and how it compares to other burials of the period. We also aim for visitors to be able to make connections with people who lived in London nearly 2,000 years ago by exploring some of the rituals and beliefs around burial.

What can the discovery of this cemetery add to the world's knowledge about Romans and their history?
Every time an archaeological excavation uncovers Roman remains in London we learn more about this period of British history, for which very few written records survive. Usually excavations can only take place before construction projects, so only pockets of London have been investigated in this way. Each excavation helps to create a bigger picture of what Roman London was like. The Harper Road excavations have found more of the cemetery that lay to the south of Londinium [the Roman name for London] and part of a Roman road, which helps us to understand how London was connected to the rest of the province.

In your opinion, what is the most interesting object on display at the exhibition?
It's hard to choose, as there are so many fascinating things. One of my personal highlights is the tombstone of a ten-year-old girl called Marciana. The inscription on the tombstone says it was set up by her father Aurelius in her 'everlasting memory'. The use of this phrase is usually found on tombstones from the Rhine and Danube regions of the Roman Empire, so it's likely that Marciana and her father came to London from abroad. The tombstone includes a portrait of a young girl who is meant to symbolise Marciana herself. It was found during excavations of the Roman city wall; [it had been] re-used as building rubble in a 4th-century tower. I find it amazing that a broken-up tombstone in a tower has been able to give us the name of a young girl who lived in Roman London.

"Every time an archaeological excavation uncovers Roman remains in London we learn more about this period of British history"

One of the artefacts displayed is the jet pendant of Medusa. What can this tell us about the beliefs of those buried?
Jet has electrostatic properties and is thought to have had magical associations for the Romans. Jet objects were used in daily life, but jet is frequently used as a material for burial goods, particularly jewellery and dress accessories. It may have been used to protect the dead, perhaps on their journey to the Underworld. The mythical figure of Medusa, with her snake hair and ability to turn onlookers to stone, was especially protective.

In the exhibition there are a series of human skulls with examples of blunt trauma. What can this tell us about the lives of the Romans found?
We will be showing a small number of skulls from a group of 40 that were found in waterlogged pits near London Wall. Most of the skulls were from men aged between 18 and 35 years old, and many showed signs of multiple blunt- and sharp-force traumas, showing that the men had been killed by being beaten and attacked with various weapons. Many also had healed injuries, which suggests that violence was a common feature of their lives. Why their skulls had been left in pits is uncertain. They could be the remains of executed criminals or gladiators or men who were killed for some other reason. It's one of the many mysteries from Roman London.

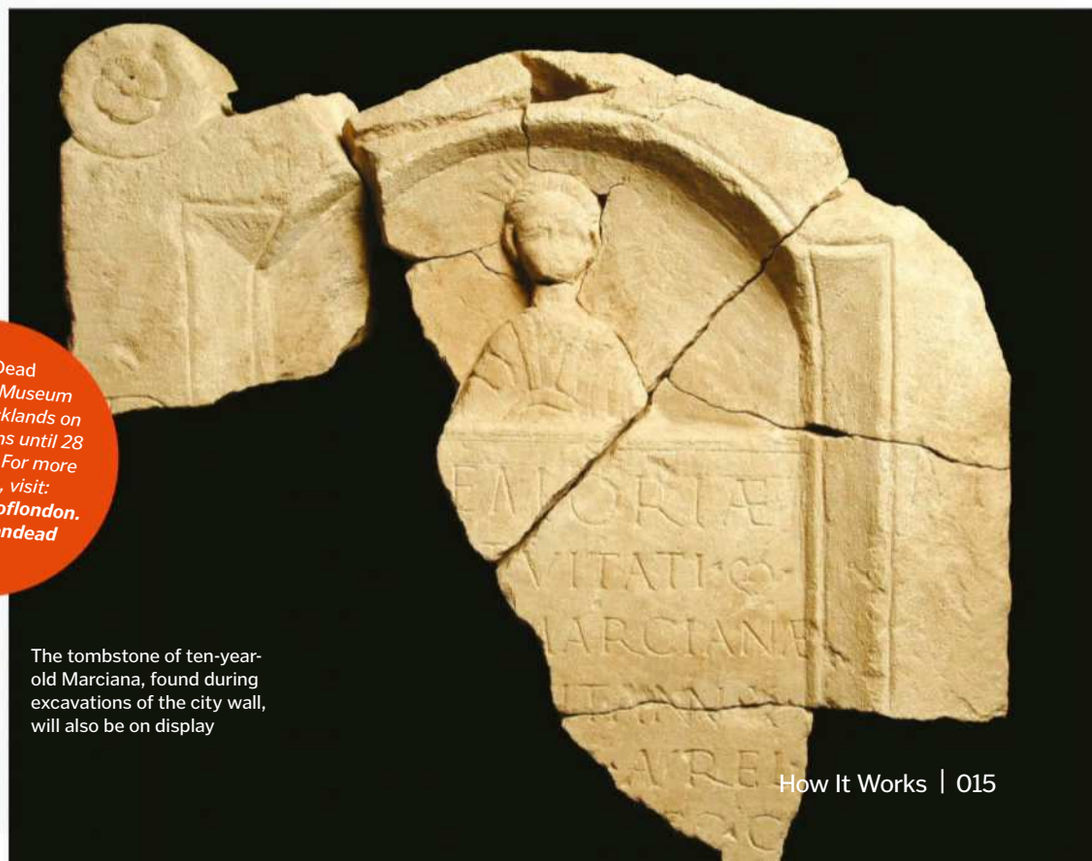
Are there any particular similarities between a Roman burial and a modern-day burial?
There were many different burial styles in Roman London. Particularly in the early Roman period, a lot of people were cremated and their burnt bones put into containers and buried. Today, many people have their ashes scattered – we don't know if this happened in the Roman period, as their remains would normally not survive. As time went on inhumation (the burial of a corpse) became more common. However, there were a wide variety of burial methods used, such as wood or lead coffins (and occasionally stone, as seen at Harper Road), or no coffin at all. The majority of people were buried on their backs, but some were found on their sides or even face down.

Roman Dead *opens at the Museum of London Docklands on 25 May and runs until 28 October 2018. For more information, visit:* ***www.museumoflondon.org.uk/romandead***

Four male skulls will be on display; many similar skulls that have been excavated show signs of multiple blunt- and sharp-force trauma

During excavations at Hooper Street, a jet Medusa pendant was found buried with the skeleton of a woman

Excavated last year, this Roman stone sarcophagus is the most recent to be found in London



The tombstone of ten-year-old Marciana, found during excavations of the city wall, will also be on display

SPEED DEMONS

The ultrafast cars that are smashing records and rewriting the rule books

Words by **James Horton**

Humans have an innate desire to go fast. Hundreds of years ago, when we were limited to galloping atop horses, we wouldn't have even dared to dream that we could move as quickly as we can today. But thanks to a surge in our understanding of engineering and mechanics over the past two centuries, we can now cross a kilometre in a matter of seconds. At the very front of today's pack of speed demons are the cars that we'll cover in this feature, all of which are the product of years of innovative ideas, imaginative designs and meticulous construction.

Perhaps the most exciting thing about these superfast cars is how tightly bound they are to our current technological prowess. As put so eloquently by Craig Glenday, editor-in-chief at Guinness World Records: "Speed records mirror our technological evolution. We are evolving all the time and becoming technologically more advanced. And that story is the story of speed."

This is a theme that's been embraced by the Bloodhound SSC team (who we'll learn more of a little later), as they are using their land speed record attempt to engage children in the practical applications of science and engineering. Throughout the world of car design we are seeing the newest technological endeavours being utilised. Machine learning, a powerful and popular methodology of artificial intelligence, for example, is set to make an impact during this season's F1 when it helps teams to decipher data collection during tests and races.

So let's take a look at the incredible vehicles that give us a glimpse into the wider world of our best current technology. But look quickly, because they're moving fast!

"These cars are the product of years of innovative ideas, imaginative designs and meticulous construction"

Many F1 teams use Zircotec ceramic coatings to protect their cars' composite materials from heat damage, even at temperatures of 1,400°C!

Need for speed

The factors that designers and engineers must consider when building a fast car

Shape

Aerodynamics is perhaps the most important factor behind any speed record attempt. The best designs minimise air resistance and control airflow to provide added stability at high speeds.

Powertrain

At the core of every car is a powertrain, which can encompass the engine, driveshaft and associated elements. Its primary role is to generate raw power and convert this into thrust.

Materials

Both strength and weight are dictated by the materials used to build a car. A combination of aluminium, titanium and carbon fibre – which is both light and strong – is very popular.

Electronics

No modern speed demon can function without able electronics. These orchestrate communications between different parts of the vehicle and can provide integral data when racing.

Wheels

As the points of contact with the ground, wheels and tyres are defining parts of any car. Grip must be carefully controlled, ensuring the correct amount of friction for maximum stability and speed.

Brakes

Slowing down may seem unimportant for a fast car, but without good brakes cornering becomes incredibly difficult. Disc brakes with cooling systems are used by most road and track cars.

Thanks to the Thrust SSC we now know that cars are capable of supersonic speeds

FORMULA 1

From ingenious designs to courageous drivers, uncover the pinnacle of modern speed racing

The 2018 season sees the introduction of the protective Halo cockpit structure

It may come as no surprise that speed is crucial in the world of Formula 1, but what may be less obvious is that for the teams who race, the clock starts ticking before the first concept sketch is even drawn. With every team constructing a new series of components and vehicles prior to every season, every department is crucial, and all must work incredibly quickly and efficiently to complete their cars before the new season begins.

For the organisers, the sport is a delicate balancing act. Teams are constantly striving for faster, smarter and more efficient vehicles, but the costs of achieving these ambitious goals must be kept in check to allow the smaller teams to remain competitive. The solution comes in the form of a detailed document spanning hundreds of pages, released prior to every season, that places restrictions on what teams are permitted to design and implement. Engine size, body dimensions and other major components are all tightly controlled. The regulation stretches even further than the car, shackling access to live testing and several elements of research and development. As a result, designers and engineers must readily adapt to a constantly changing technical landscape, and in doing so they are demanded to innovate. Fortunately, they have proven time and again that they can rise to the challenge, and the result is the creation of even more sophisticated machines with every iteration.

Today's Formula 1 team HQs are melting pots of materials science, engineering and technology. Wind tunnels and their virtually simulated equivalent, computational fluid dynamics, are at the forefront of the early stages of vehicle creation, where the aerodynamics of new components can be assessed. After selecting their preferred design, most teams will fully assemble the vehicles internally, creating the chassis with layers of precisely cast carbon-fibre sheets.

These are heated in an autoclave that compresses them together, sealing the layers into a material that's five-times lighter than steel and up to ten-times stronger. The final assembly can include over 16,000 parts, every single piece of which has been designed or ordered to exact specifications. This entire process takes less than six months, which makes the speed of building the cars just as impressive as their pace around the racetrack.

> *"Designers and engineers must readily adapt to a constantly changing technical landscape"*

Meet the next generation

Take a look inside a 2018 season Formula 1 racing car

Front wings
Designers can adjust the number and dimensions of flaps on their car's front wings to alter the airflow and downforce.

Driver fitness

Accelerating from a standing start to 100 kilometres per hour in less than two seconds, and returning to a stop in just over the same amount of time, puts a huge amount of pressure on the human body. As drivers shoot down straights and brake to take corners, they can be subjected to nearly 7Gs of force. That's more than the most extreme roller coaster and as much as the Apollo astronauts experienced during atmospheric re-entry!

Couple this with the intensive bouts of heat experienced by drivers from inside the cockpit, and it goes without saying that drivers must be extremely well conditioned to compete for a podium spot. As such, all drivers invest in cardiovascular training and must have particularly powerful neck and chest muscles in order to endure those punishing g-forces.

Halo
This new cockpit protection device will be introduced in the 2018 season to safeguard drivers against flying debris and during potential accidents.

Fins
The large 'shark fins' of 2017 have been banned for this season, but the rear of the vehicles will likely be adorned with a smaller fin that improves airflow.

Drag reduction system
Moveable rear wings, which can be controlled from within the cockpit to reduce drag, are used for overtaking at certain points.

Hybrid engine
A turbo-charged V6 combustion engine works in concert with electric motors, which collect energy from the exhaust and during breaking.

Slick tyres
Drivers will have the choice of seven tyre types this season. This includes the Hypersoft variant, which wears faster but allows for improved speeds.

Chassis
The chassis of Formula 1 cars are designed to funnel air over the body, pushing the vehicle downward onto the ground.

Ergonomic paddles
Finger grooves within the clutch paddle, combined with a soft spring, provide the driver with an optimal clutch control that can be quickly released.

Disc brakes
Rotating discs are squeezed between two brake pads to slow the vehicle. To aid cooling, approximately 1,400 venting holes can be incorporated into the disc's design.

Formula E

In recent years we have seen a cultural shift away from conventional combustion engines towards hybrid engines and electric motors, and this change has been reflected at the highest levels. Formula 1 has recently embraced electric motors to lower fuel expenditure and increase power, but Formula E has gone further, using vehicles with zero combustible material output.

Unlike Formula 1, E race cars compete with the same chassis and battery, meaning designers and engineers must focus their creativity on the powertrain. Major improvements in this area have pushed speeds above 225 kilometres per hour, which is still some way off F1's 375 kilometres per hour. But when we consider that Formula E only launched in 2014, it may be that electric vehicles soon compete with their hybrid cousins.

Formula E technologies have made considerable progress since the tournament's launch in 2014

The greatest production cars

All are masterfully crafted, all are fast, but which hypercar reigns supreme?

HYPERCARS

The road-legal cars that traverse our streets at eye-watering speeds

Hypercars represent the apex of road cars. They are to supercars what diamonds are to other jewels – the absolute best of a much sought-after group. And much like diamonds, they are exceedingly rare, with the most popular hypercars only numbering in the hundreds, and many have just a handful of units to their name. For their creators, these cars represent a challenge of creativity, an opportunity to push past expectations, break barriers and inspire us to think bigger on what can be achieved in a road-legal sports car. In recent years, companies such as Bugatti, Hennessey and Koenigsegg have joined Ferrari, Aston Martin, Lamborghini and co at the peak of this mechanical mountain.

The main curiosity on everyone's lips usually revolves around one question: which one is the fastest? But this question isn't as straightforward to answer as it may seem. In 2010, the Bugatti Veyron 16.4 Super Sport claimed the title of 'Fastest production car' from Guinness World Records, with a speed of 431.072 kilometres per hour. The award was nearly stripped from them in 2013 following complaints from rival companies that the record-setting vehicle had a component missing compared to the cars on general sale, but it was returned to Bugatti following an investigation.

Hennessey Performance, one of the chief Bugatti antagonists, would however beat this prestigious record the following year when their Venom GT model clocked a maximum speed of 435.3 kilometres per hour. There is some debate as to whether the Venom GT technically qualifies as a 'production car' due to the low number of units sold, but as a road-legal hypercar its speed was undeniable. Even so, this record would be shattered once more in 2017 by one of the new kids on the block – Koenigsegg. The Swedish company put their Agera RS model to the test on nearly 18 kilometres of Nevada highway and registered an average speed of 447.2 kilometres per hour.

So is the debate settled? Not entirely. Bugatti's latest model, the Chiron Sport, has shifted its focus towards better cornering to achieve faster lap times. The Porsche GT2 RS is also worthy of a mention as it holds the record for fastest lap time of the famous Nürburgring Nordschleife circuit in Germany.

Each fan will have their preferred model of hypercar, but all of these feats of engineering have the ability to both amaze and inspire us, and we can't wait to see where they go next.

Corbellati Missile

The Corbellati Missile is something of an oddity in the world of hypercars. Unveiled in its raw, unpolished prototype form at this year's Geneva Motor Show, the car's shape – with its rounded bumps and curves – harks back to the sports cars of decades past. Yet, contrastingly, what's inside the vehicle promises to define the future of the field.

Using a 9.0-litre Mercury Racing V8 engine, the Corbellati team believe that their prototype can create 1,800 horsepower and 2,350 Newton metres of torque. In terms of speed, this could allow their vehicle to reach speeds over 500 kilometres per hour. The current aim is to put their prototype to the test in 2019, and if these speeds are achieved and the Missile earns its name, expect to see a lot more of this hypercar over the next few years.

Hennessey Venom F5

A close rival of Bugatti's supercars, Hennessey's Venom series have become famous for their immense speed. The F5 looks set to take this reputation even further, with a touted top speed of 484 kilometres per hour and a reported acceleration from 0 to 300 kilometres per hour in less than ten seconds.

Bugatti Chiron

The Chiron is an era-defining machine, one that shook the car-loving world on its launch. Beautiful, powerful and practical, the Chiron combines a supercar's speed with a luxury car's comfort. It's also a firm contender for the fastest production car, clocking approximately 1,500 horsepower and a max speed of 420 kilometres per hour.

Koenigsegg Agera RS

This is another supercar that prides itself on being a functioning road car as well as a champion on the track. The Agera RS has a usable luggage compartment and a detachable hardtop, and its twin turbo V8 engine has been optimised for pump fuel, putting out a mammoth 1,160 brake horsepower on regular petrol.

ENGINEERING THE BLOODHOUND SSC

The ambitious project set to smash the land speed record

The Bloodhound SSC (supersonic car) is one impressive chimera. Affixed to this mammoth land vehicle's top half is a jet engine that's usually at home on a fighter jet, and tucked snugly beneath is a triple hybrid rocket that combusts at twice the temperature of a volcano. This much power may sound extreme, perhaps even excessive, but when we consider the vehicle's end goal of achieving 1,600 kilometres per hour, the reasoning behind these methods suddenly becomes clear. Climbing to such an incredible speed – equivalent to Mach 1.3 – is no simple feat, and this difficulty is compounded for a land vehicle.

In the air, pilots need not worry about the intense friction created by wheels spinning against the ground over 10,000 times every minute, or small debris such as stones that can transform into incredibly dangerous ballistic missiles. They don't even need to trouble themselves with punishing air resistance that occurs at ground level. But these are all hurdles that the Bloodhound engineers have worked hard to overcome.

Sturdy wheels assembled from a solid aluminium and zinc alloy will be able to tolerate the friction-generated heat, and a robust hybrid frame formed of steel, titanium and carbon fibre will provide strength and protection. The front portion of the frame, for example, is built to withstand a 20-millimetre projectile travelling at 980 metres per second! Plus, their no-nonsense jet and rocket engine combination design should prove capable of overcoming air resistance to blast them into the history books.

Aerodynamics also plays a pivotal role, a factor that former land speed champion Richard Noble eventually discovered driving Thrust 2. In 1983, the vehicle reached an average speed of 1019.468 kilometres per hour, but was capable of reaching a whopping 1047.49 kilometres per hour. He later discovered that had he driven just 11 kilometres per hour faster his car would have lifted off the ground. Such examples highlight both the danger and difficulty of achieving such speeds with a land vehicle, but fortunately the Bloodhound engineers have spent years perfecting the new SSC's shape with the assistance of computational fluid dynamics.

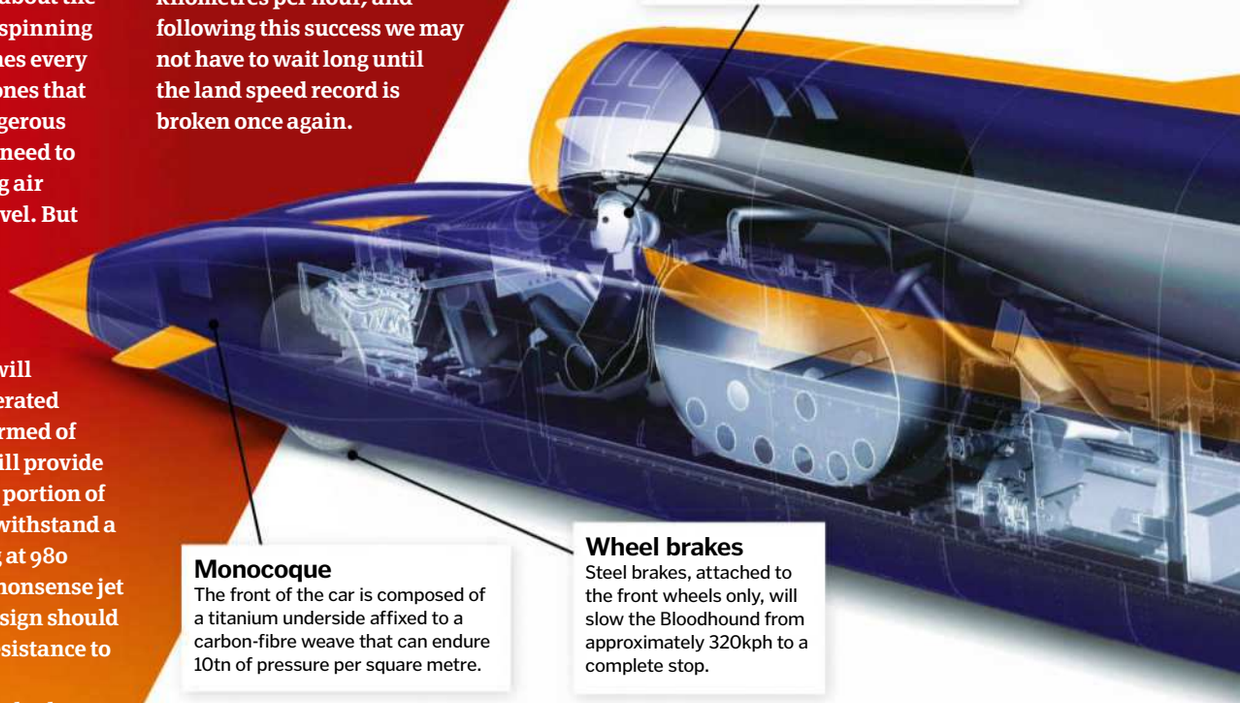
In 2018, the team will attempt the next milestone of their quest from South Africa's Hakskeen Pan, a dry lakebed composed of mud and salt. Their goal is to reach 804.7 kilometres per hour, and following this success we may not have to wait long until the land speed record is broken once again.

> *"Achieving Mach 1.3 in a land vehicle is no simple feat"*

The Thrust SSC has held the land speed record for over two decades

Building a beast

Unpack the components that will fire the Bloodhound SSC to 1,600kph



Cockpit
Commonly referred to as 'Andy's office', the Bloodhound's cockpit contains an air supply, a moulded seat, screens, pedals, a steering wheel and backup systems.

Monocoque
The front of the car is composed of a titanium underside affixed to a carbon-fibre weave that can endure 10tn of pressure per square metre.

Wheel brakes
Steel brakes, attached to the front wheels only, will slow the Bloodhound from approximately 320kph to a complete stop.

Elon Musk's Tesla Roadster became the fastest car in space following its launch inside a Falcon Heavy rocket

Dubai's police take to the streets in an array of supercars, with the coveted Bugatti Veyron in front

The current land speed record

On 15 October, 1997, Andy Green officially broke the sound barrier for the first time ever in a land vehicle. In Black Rock Desert, Nevada, the Thrust SSC that he was driving reached a staggering 1,227.985 kilometres per hour – equal to Mach 1.020 – using its twin Rolls-Royce Spey 202 jet engines, cementing a record that's now stood for over 20 years. With 222 kilonewtons (kN) of thrust, the loud sonic boom could be felt by the local townspeople who believed they were experiencing an earthquake. But Andy isn't done setting records; in fact, he's busily preparing to knock himself off his perch as the driver of the Bloodhound SSC.

FIVE FACTS ABOUT RECORD BREAKERS

1 Fastest electric car
A converted Genovation GXE achieved the fastest standing mile in 2016, reaching an amazing 304.94kph in the attempt.

2 Fastest police car
Police in Dubai splashed the cash on a Bugatti Veyron to join their fleet of law-enforcement sports cars. Their new addition can reach a top speed of 407kph.

3 Fastest-accelerating streetcar
In 2013, the Hennessey Venom GT supercar claimed top spot on the streets when it climbed from 0–300kph in just 13.63 seconds.

4 Fastest biogas-powered car
A team in Germany repurposed a used Audi A4 to run on biogas and achieved a maximum speed of 364.6kph.

5 Fastest car in space
SpaceX's Falcon Heavy rocket first launched into space this February, carrying a Tesla Roadster inside. The car reached a speed of 40,140kph relative to the Earth.

Fin
Rising 2m high and composed of around 100 aluminium parts, the cruciform-shaped fin will provide lateral stability even at supersonic speeds.

Jet engine
Originally engineered to power a fighter jet, the EJ200 engine will provide 90kN of thrust.

Parachute port
Once the vehicle has slowed to just over 1,000kph a parachute will be deployed, adding 9tn of drag.

Auxiliary power
In most cars, a Jaguar Supercharged V8 engine would be the primary source of power, but in the Bloodhound it's responsible for running the rocket oxidiser pump.

Airbrakes
Deployed after the throttle is closed to begin the braking process, the airbrakes will create an extra 6tn of drag.

Desert wheels
Solid aluminium alloy wheels, each weighing 95kg, will be used for the 1,600kph desert attempt.

Rocket engine
A cluster of three hybrid rockets will be fuelled by high-test hydrogen peroxide and synthetic rubber to create, in total, 212kN of thrust.

How does jump-starting a car work?

A dead battery doesn't have to be the end of the road

Your car's battery not only powers the vehicle's electrical systems – it also provides the energy to start the engine. The battery can be recharged by the engine once it's running, but accidentally leaving electronics on (like the headlights or the radio) while the engine is off can drain it. However, a dead battery can be revived with the help of another car with a fully-charged battery of a similar voltage, plus a set of jump leads. The difference in voltage between a charged and a dead battery will cause a current to flow to the dead battery, recharging it enough to get the car started.

Knowing how to jump-start a car is a helpful skill, but always make sure you do so safely and follow the instructions from a reputable source, such as your car's manufacturer or a roadside assistance company. If in any doubt, contact a professional breakdown service.

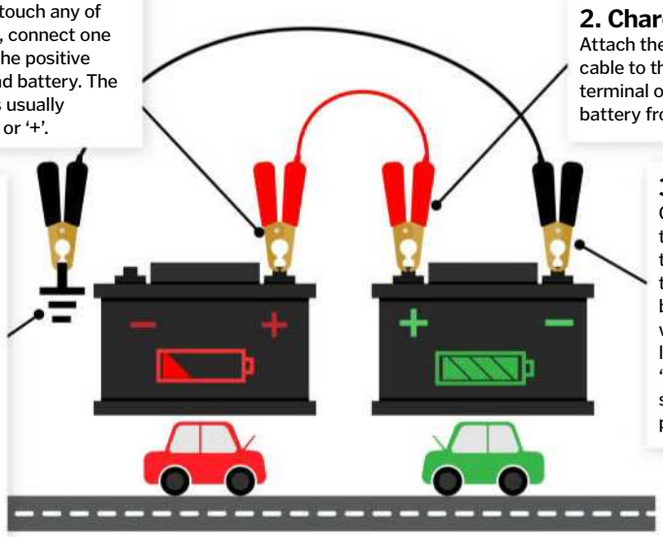
It's a good idea to keep jumper cables in your car, especially in the winter months

1. Positive terminal
Taking care not to touch any of the exposed metal, connect one of the red clips to the positive terminal of the dead battery. The positive terminal is usually labelled with 'POS' or '+'.

2. Charged battery
Attach the other end of the cable to the positive terminal of the booster battery from the other car.

3. Negative
Connect one of the black clips to the negative terminal on the booster battery, which is usually labelled with 'NEG' or '-' and is smaller than the positive terminal.

4. Car body
The last black clip must be attached to a metal part of the car – away from the battery – like a bolt. You can now start the engine of the helper car and leave it to run a few minutes before trying to start the other car again.



Battery-boosting basics

Before getting started, check the batteries are both the same voltage, turn off your ignition and put your handbrake on

Airplane altimeters

How this instrument enables pilots to determine a plane's altitude

When a plane you are flying in has reached altitude, your pilot will announce that you are cruising at 10,000 metres, but have you ever wondered how they know that? It isn't guesswork – they are using an altimeter.

Air molecules are pulled down to the Earth by gravity, so those closest to the ground are at a high pressure surrounded by lots of other air molecules, as the molecules above them are pushing them down. At higher altitude there are fewer air molecules and therefore lower air pressure. This means that the air pressure decreases as the plane's altitude increases. By precisely measuring the small changes in air pressure, an altimeter can determine how many metres above sea level the aircraft is flying.

It is important for a plane to have an accurate altimeter so it can avoid obstacles, like mountains or other planes

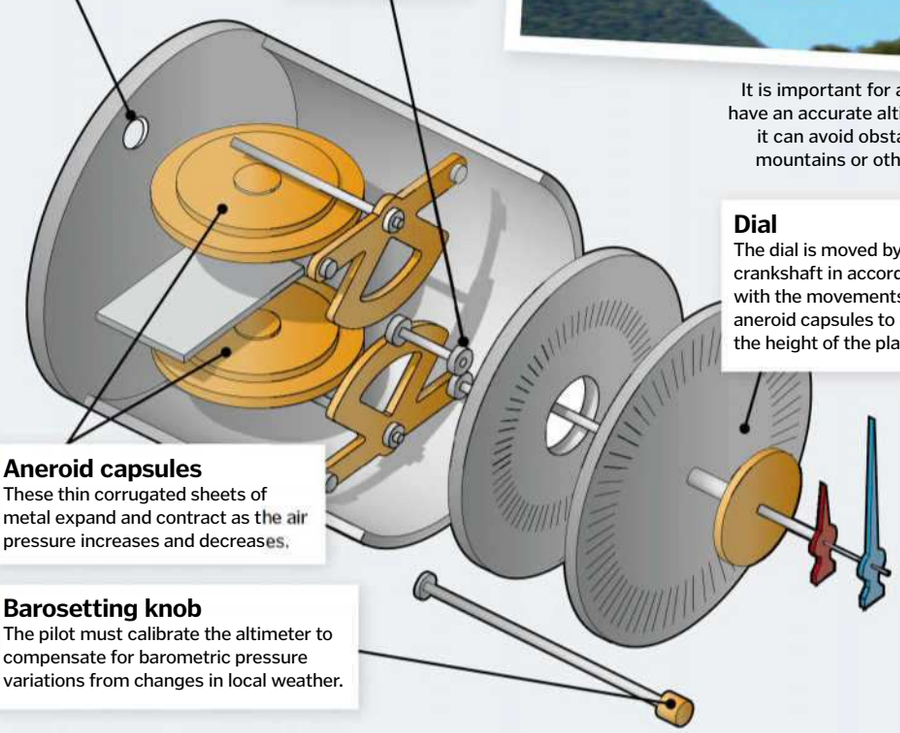
Air pressure inlet
An inlet to the outside of the plane allows the instrument to be filled with air.

Gears and cogs
A delicate system of gears and cogs amplifies the small air movements.

Dial
The dial is moved by the crankshaft in accordance with the movements of the aneroid capsules to display the height of the plane.

Aneroid capsules
These thin corrugated sheets of metal expand and contract as the air pressure increases and decreases.

Barosetting knob
The pilot must calibrate the altimeter to compensate for barometric pressure variations from changes in local weather.



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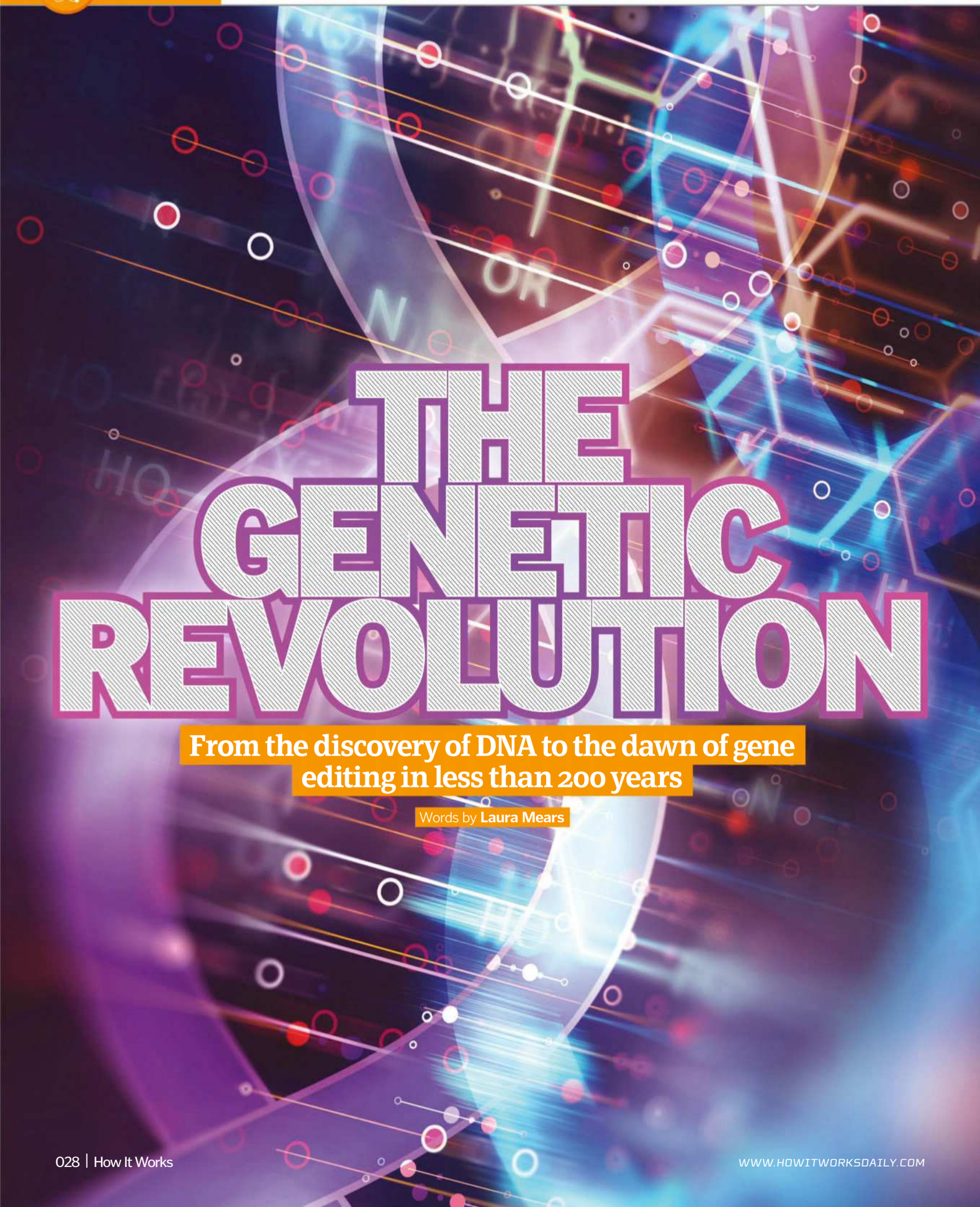


THE GENETIC REVOLUTION

From the discovery of DNA to the dawn of gene editing in less than 200 years

Words by **Laura Mears**

In the 1800s, Swiss biologist Friedrich Miescher discovered something strange. When he broke open the nuclei of white blood cells he found a substance rich in phosphorous unlike anything he'd seen before. He named it nuclein. We now know it as DNA.

DNA stands for deoxyribonucleic acid. Thanks to the work of Russian-born American scientist Phoebus Levene we know that it has three parts. The phosphorous that Miescher noticed connects to a pentagon-shaped sugar called deoxyribose. This, in turn, links to a nitrogen-containing structure known as a 'base'. Four different bases make up the chemical letters of the genetic code, and the sugars and phosphates join them together into long strings.

The four DNA letters are adenine, cytosine, guanine and thymine. We know them most commonly by their first letter abbreviations: A, C, G and T. In a piece of DNA, the amount of A matches T and the amount of C matches G, but it wasn't until James Watson and Francis Crick that we found out why. This Nobel Prize-winning pair revealed the structure of the molecule.

Rosalind Franklin and Maurice Wilkins had taken a picture of DNA using X-rays. Using their images, along with cardboard cutouts of each of the DNA bases, Watson and Crick played with possible configurations. In 1953, they finally revealed that DNA is a double helix.

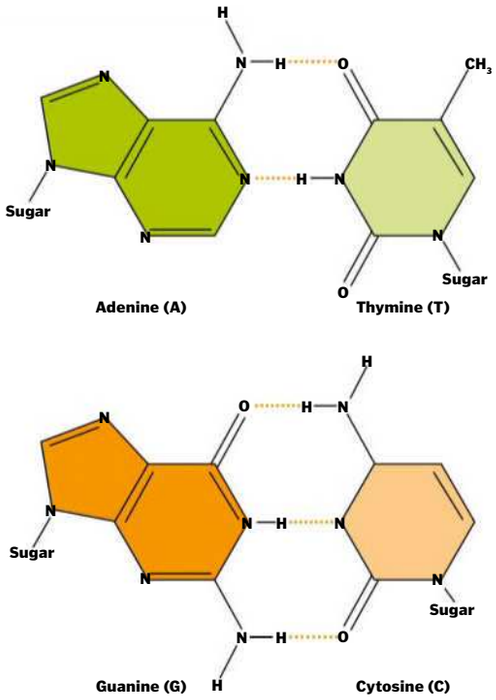
Two strands of code form a pair that wind around like a twisted ladder. The bases on one strand cling to the bases on another via interactions called hydrogen bonds, forming the ladder's rungs. The sugars and phosphates form the sides of the ladder, or the 'backbone'. Space between the rungs allows other molecules to read or copy the code.

DNA has a right-handed curl, and the strands store opposite sequences running in opposite directions. The As on one strip cling to the Ts on the other, while the Cs partner up with Gs. One strand stores the code running top to bottom and the other stores the inverted code running bottom to top. Each strand has an up and a down, known to scientists as the 5' (pronounced five prime) and 3' (three prime) ends. These work a bit like having a capital letter at the start of a sentence and a full stop at the end, telling the cell in which direction it should read the code.

Watson and Crick standing next to their famous model of the DNA double helix

The structure of DNA has become iconic, but the distinctive twist is a frequent chemical quirk of biological molecules. The collagen strands in your skin twist like ropes, and so does the keratin in your hair. The building blocks of DNA are asymmetrical, and they stagger when stacked end-to-end. Once Watson and Crick revealed the structure, the next step was to crack the code. The scientific cryptographer responsible was Marshall Nirenberg.

Proteins make up most of the molecular machinery of the body, and cells build them from blocks called amino acids. There are 20 different blocks to choose from, so Nirenberg put each in a different tube. To understand what different DNA sequences meant he made synthetic strings of code. Then he watched to see which amino acids would be strung together with different sequences. His work revealed that DNA stores information as three-letter 'words'. There is a word for 'start', signalling the beginning of a gene, there are three words for 'stop', signalling the end, and, between them there are 60 other three-letter 'codons' that correspond to amino acids.



Adenine always pairs with thymine and cytosine always pairs with guanine

With the cipher in hand, the next step was to decode the genome. To do this, Frederick Sanger invented DNA sequencing in 1977. His pioneering technique worked by breaking the code into overlapping chunks. He then copied each chunk in the presence of 'chain-terminating' nucleotides. These stop the copying process early, indicating which base just joined the end of the sequence. Bit by bit, the process reveals each letter of the code. Once he had the sequence for each chunk, Sanger could then stitch them back together like a jigsaw.

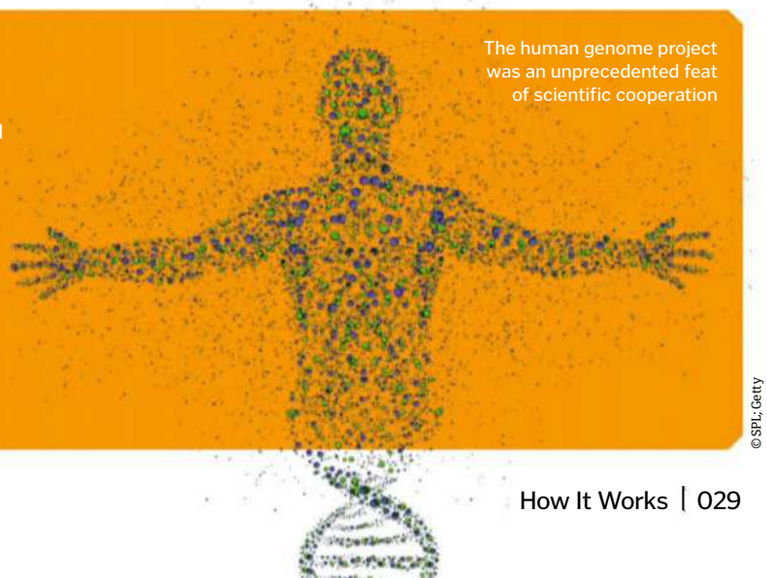
Armed with this new tool, scientists read the first full genome in 1995. It belonged to the bacterium *Haemophilus influenzae*. For the first time, scientists had the full instruction manual for making a living organism. In 2000, scientists

Reading the human genome

The Human Genome Project was one of the biggest scientific undertakings ever attempted. An international team of scientists worked together to read all 3.2 billion base pairs of human DNA. They mapped each human gene using a technique called bacterial artificial chromosome (BAC) sequencing.

First, they broke each chromosome into pieces around 200,000 base pairs long. Then they slotted them into 20,000 loops of DNA. Bacteria then copied the loops, building a vast DNA library. Scientists then cut the cloned DNA into 2,000 base pair fragments. A sequencer read the fragments, and they pieced the code back together by looking for areas that overlapped.

Before the project started people thought a genome as complicated as ours might contain more than 100,000 genes. However, when the results emerged it became clear that there were fewer than 25,000. Armed with this knowledge, scientists continue to explore our genetic code to find out where we came from, how we work and why our bodies go wrong.



The human genome project was an unprecedented feat of scientific cooperation

finished the genetic code of the fruit fly. In 2002, they completed the mouse. And, a year later, the holy grail of sequencing emerged: the complete human genome.

With access to these manuals, scientists could start to understand how things worked and why they go wrong. By the early 2000s they had amassed a powerful kit of molecular tools to help with their investigations. Even so, it would be an invention from two decades prior that would prove to be a pivotal piece in the mission to fully decode human DNA.

In 1983 an American biochemist by the name of Kary Mullis invented a technique called polymerase chain reaction (PCR), an accomplishment for which he received the Nobel Prize in Chemistry in 1993. PCR is a DNA photocopier that can make millions of identical sequences from one DNA strand. First, the temperature rises, splitting the double helix apart. Then an enzyme called a polymerase runs along and copies the DNA. Finally, the temperature drops and the strands find a matching pair to form a double helix again. Scientists can choose where to start and stop the copying process by using short stretches of DNA called primers. With this tool at their disposal, it became even easier to study individual genes.

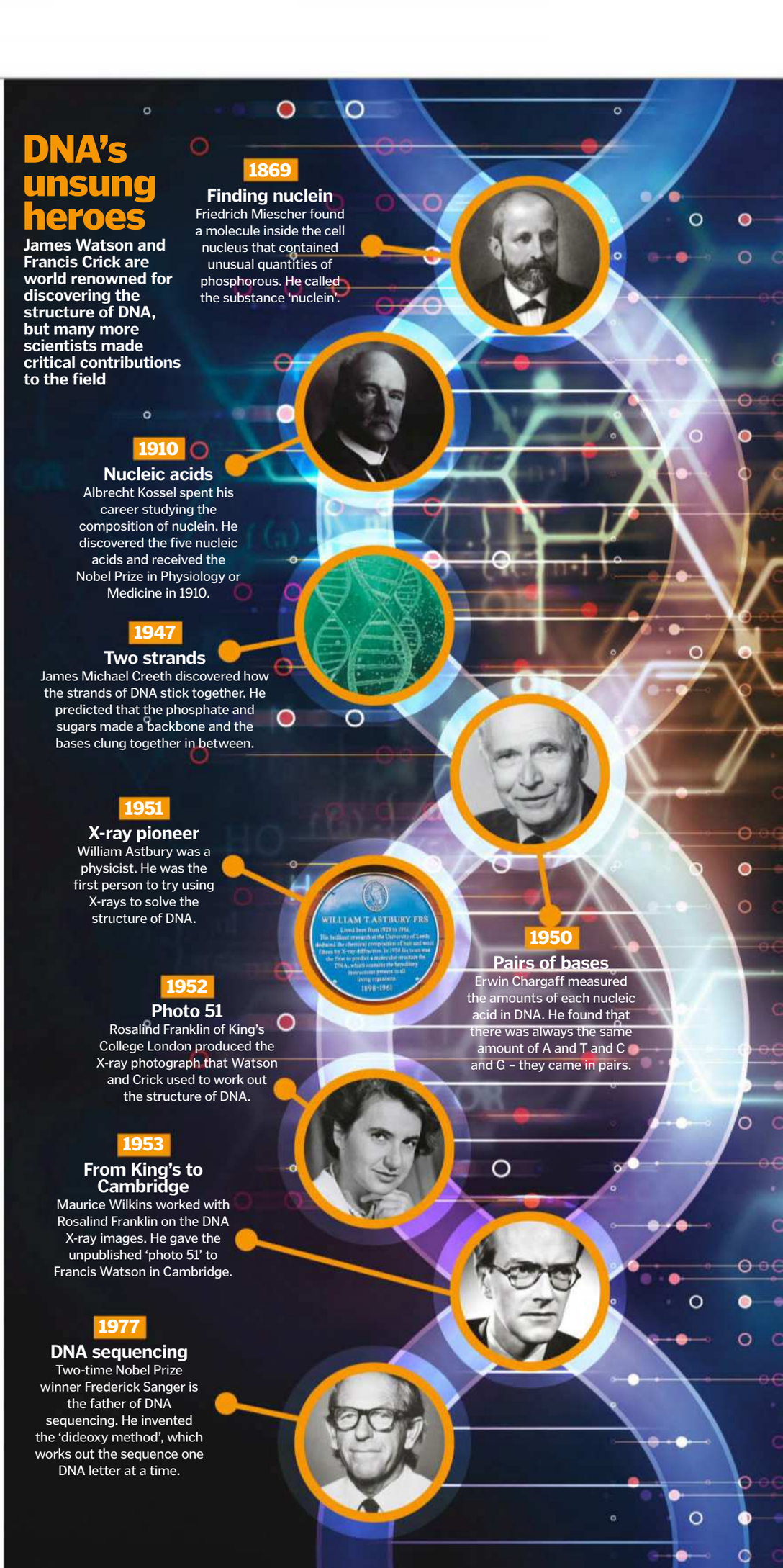
Scientists also had access to molecular scissors called restriction enzymes. These cut DNA in specific places, often leaving a little overhang. The 'sticky ends' let scientists glue different

> *"With access to these manuals, scientists could start to understand how things worked"*

Berkeley scientist Jennifer Doudna invented the CRISPR gene editing technique

DNA's unsung heroes

James Watson and Francis Crick are world renowned for discovering the structure of DNA, but many more scientists made critical contributions to the field



1869

Finding nuclein

Friedrich Miescher found a molecule inside the cell nucleus that contained unusual quantities of phosphorous. He called the substance 'nuclein'.

1910

Nucleic acids

Albrecht Kossel spent his career studying the composition of nuclein. He discovered the five nucleic acids and received the Nobel Prize in Physiology or Medicine in 1910.

1947

Two strands

James Michael Creeth discovered how the strands of DNA stick together. He predicted that the phosphate and sugars made a backbone and the bases clung together in between.

1951

X-ray pioneer

William Astbury was a physicist. He was the first person to try using X-rays to solve the structure of DNA.

1950

Pairs of bases

Erwin Chargaff measured the amounts of each nucleic acid in DNA. He found that there was always the same amount of A and T and C and G – they came in pairs.

1952

Photo 51

Rosalind Franklin of King's College London produced the X-ray photograph that Watson and Crick used to work out the structure of DNA.

1953

From King's to Cambridge

Maurice Wilkins worked with Rosalind Franklin on the DNA X-ray images. He gave the unpublished 'photo 51' to Francis Watson in Cambridge.

1977

DNA sequencing

Two-time Nobel Prize winner Frederick Sanger is the father of DNA sequencing. He invented the 'dideoxy method', which works out the sequence one DNA letter at a time.

A revolution in gene editing

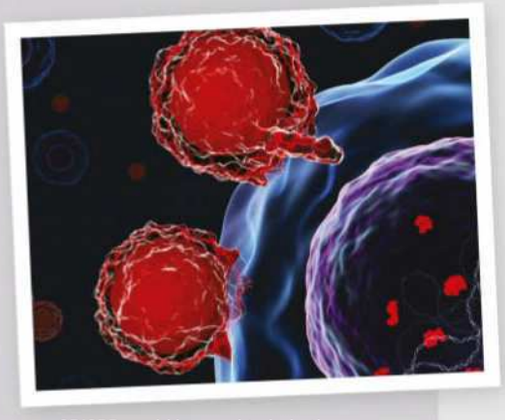
Precision gene editing with CRISPR-Cas9 could change the way we interact with our genome

CRISPR stands for 'Clustered Regularly Interspaced Short Palindromic Repeat'. The acronym describes sections of DNA that read the same forwards and backwards (palindromes). They occur in groups in some bacteria and archaea, forming part of their defence against viruses.

When a virus invades, the bacterium cuts out a piece of its genetic code and slots it between two CRISPR sequences. It then makes copies of the CRISPR DNA and the viral DNA sandwiched between. The copies, made from RNA, are like DNA but exist as single strands instead of double helixes. This means that the unpaired bases are free to stick to any matching code that they find inside the cell. If the same virus attacks again, the RNA sticks to its genetic code. This is where the second part of the system comes in.

CRISPR works together with molecules called Cas (which stands for CRISPR-associated). They are gene-snipping molecular scissors, and the RNA carries Cas to the matching viral genetic code, enabling Cas to cut it up. Scientists can hijack the system for genetic engineering by replacing the RNA with a sequence of their own. By designing the sequence to match part of a gene, they can guide the molecular scissors to make specific cuts in the genome.

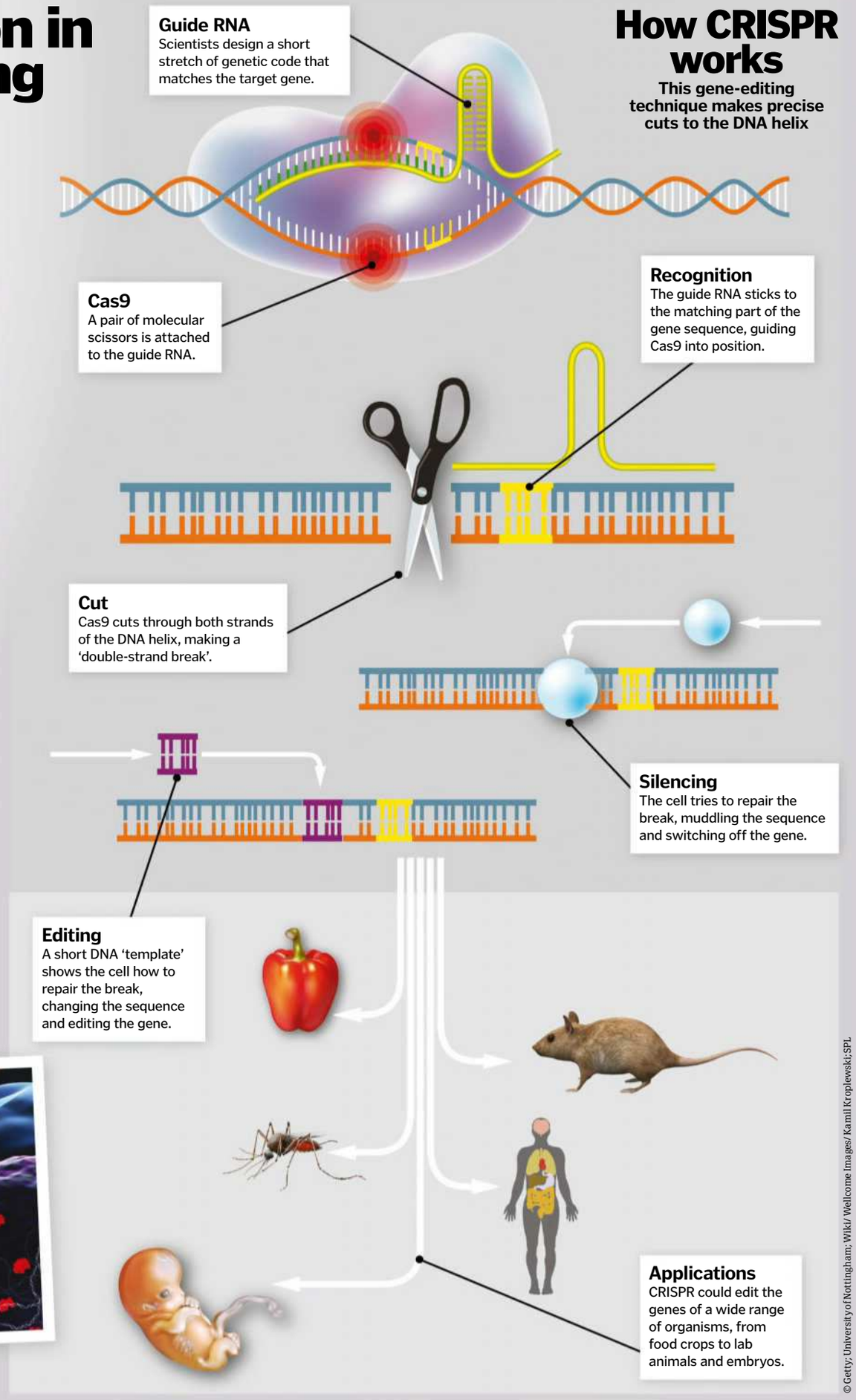
When the cell tries to repair the cut it often makes mistakes. This disrupts the gene, switching it off – a process known as silencing. If the scientists provide a DNA template, the cell can use it as a guide to repair the break, making edits to the gene.



CRISPR could be used to help the immune system fight cancer

How CRISPR works

This gene-editing technique makes precise cuts to the DNA helix



Unravelling DNA repair

In 2015, Tomas Lindahl, Paul Modrich and Aziz Sancar received the Nobel Prize in Chemistry for their work on DNA repair.

Throughout our lives, our DNA is continuously under assault from the environment. Ultraviolet light sticks DNA bases together and cigarette smoke can cause mutations. Every time a cell divides, it makes small copying errors. The separate work of these three scientists delved into the microscopic machinery that finds this damage and fixes it.

Lindahl discovered 'base excision repair', a process that cuts small errors from the genome and remakes them. Sancar found a similar system called 'nucleotide excision repair', which removes and fixes errors that make the DNA bulge. Modrich identified DNA 'mismatch repair', which fixes areas where bases on opposite strands don't match up. Understanding how these tools work is the vital first step in finding out how best to use them going forward.

DNA damage

DNA accumulates errors over time. Some occur when cells make copying mistakes. Others are the result of an environmental attack from carcinogens like UV light, radiation or cigarette smoke.

BASES A PAIRS WITH T C PAIRS WITH G

Base excision repair

Chemical changes can alter the structure of bases over time. Lindahl discovered base excision repair, which cuts out the damaged areas and replaces them.

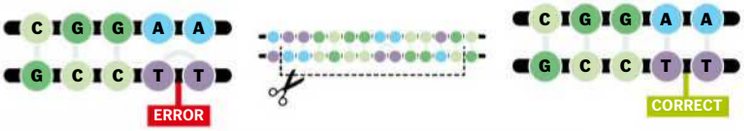
1 C loses an amino group to form U. U can't pair with G.

2 Enzymes remove U and its section of the DNA strand.

3 The correct base is inserted and the strand sealed.

Nucleotide excision repair

Environmental agents like UV light can stick adjacent bases together, forming bulges. Sancar discovered nucleotide excision repair, which recognises and repairs these errors.



1 UV radiation can cause two Ts to bind to each other.

2 An enzyme cuts a 12-nucleotide strand, removing damage.

3 The resulting gap in the DNA is filled and then sealed.

Mismatch repair

Cells make errors as they copy their genetic code. Modrich found the system that corrects these errors by cutting them out and replacing them with the correct bases.

1 Sometimes the nucleotides in copied DNA don't match.

2 Enzymes remove a section containing the faulty nucleotide.

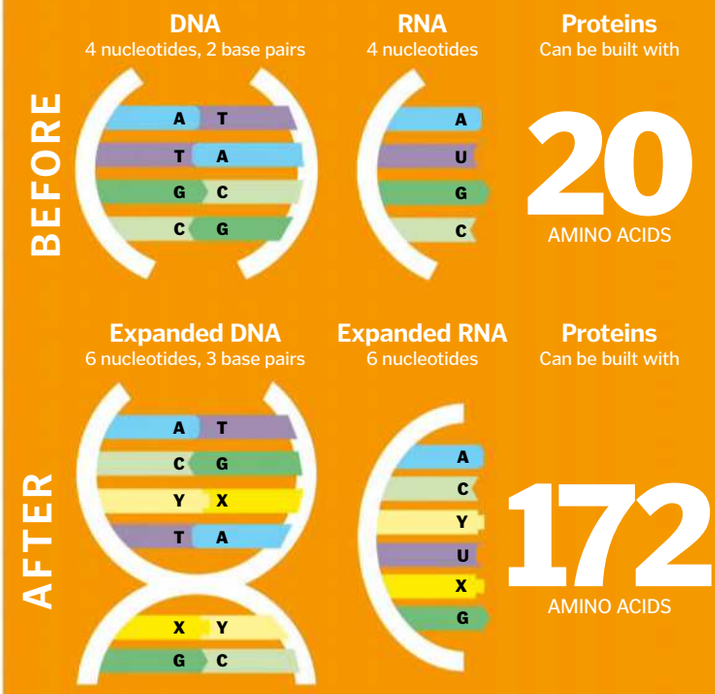
3 The resulting gap in the DNA is filled and then sealed.

The fluorescent bands on this gel are fragments of DNA

Expanding the genetic code

In 2017, a team of scientists from California increased the size of the DNA alphabet. In 2014, they had succeeded in getting E coli bacteria to put different chemical bases into their DNA. However, at the time the extra letters were silent – they stayed in the genetic code, but they didn't spell anything useful.

Now they've upgraded the cells so that they can use the code to make 'designer proteins'. In nature, cells work with a toolbox of 20 amino acids, but more exist artificially. Extra letters open up the possibility to write new genetic words that code for these amino acids. In the latest study, bacteria put unnatural bases into their DNA. They then used the new code to add unusual amino acids to their proteins.



Scientists are trying to make designer proteins using new genetic bases and synthetic amino acids

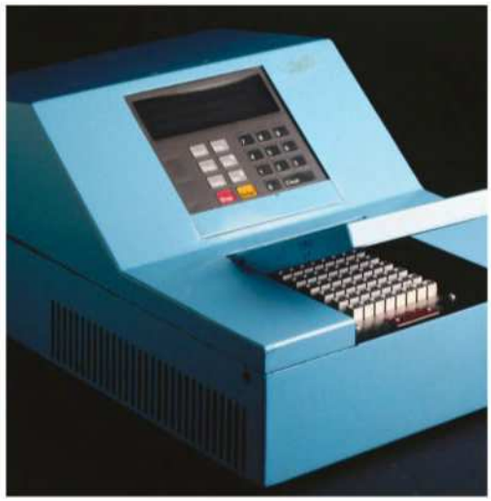
chunks of DNA together, opening the door to genetic engineering.

Using PCR, scientists can make copies of a gene they're interested in. Then they cut open a circle of bacterial DNA, called a plasmid. They stitch the gene into place and put the plasmid back into bacteria so that the microbes can read the code. The bacteria use the gene as if it were their own, decoding the three-letter words and stringing amino acids end-to-end to make protein. The pharmaceutical industry uses this technique to make human insulin to treat diabetes, and it's widely employed in labs to manufacture protein for research. But bacteria aren't the only organisms that will accept foreign DNA. Biologists can also put genes into animal or human cells in a process called transformation.

Human cells don't use plasmids in the same way as bacteria, but there's a small chance that genetic code carried into the cell will fuse with the genome. In the early days of genetic engineering, scientists boosted the chances by making breaks in the genetic code. As the cell repaired the strand the new DNA became a template. It worked, but it was hard to direct the genetic edits to the right place.

Then, in the 1990s, scientists discovered 'programmable nucleases'. These molecules have two parts: one sticks to specific sequences of DNA, and the other cuts through the strands. Scientists can design stretches of DNA to match specific parts of the genome, allowing them to direct the DNA scissors to precise parts of a gene.

The first programmable nucleases were 'zinc finger nucleases'. Zinc fingers are twists of protein that recognise three base pairs of DNA, and DNA scissors can be used to shorten the sequences of bases, but they aren't always accurate. They have so called 'off-target effects', often taking the scissors to more than one section of DNA by mistake.



This device is a prototype of one of the first DNA-photocopying PCR machines of the 1980s

The next step up was the transcription activator-like effector nucleases, or TALENs. These contain TAL effectors: proteins made by bacteria that recognise DNA. The repeats recognise one base at a time, making them more precise than zinc fingers. The latest and most exciting programmable nuclease is CRISPR, which promises precision never seen before.

> *"Genetic engineering is now commonplace in biomedical research"*

With these tools at our disposal, genetic engineering is now commonplace in biomedical research. Scientists use it to switch genes on and off to study their effects. They make edits to the genomes of cells and animals, and they manipulate genetic information to look for the changes that might cause disease. They put human genes into animals to see what they do; they hijack bacteria to make vast quantities of protein; and they transfer genes from one animal to another. Genes from fluorescent jellyfish proteins are used to make other animals glow, for example. Genetic engineering is also finding its way into everyday life. It gave us insulin to treat diabetes, vitamin A-rich golden rice, and soybeans resistant to weed-killers. It's now starting to make its way into medicine too.

In the early 2000s, 13 children underwent gene therapy to repair a faulty gene that was stopping their immune systems from working. The technique cured nine of the children, but it wasn't perfect. Two went on to develop leukaemia. The repaired gene had inserted into the wrong part of the genome, disrupting a gene involved in preventing cancer.

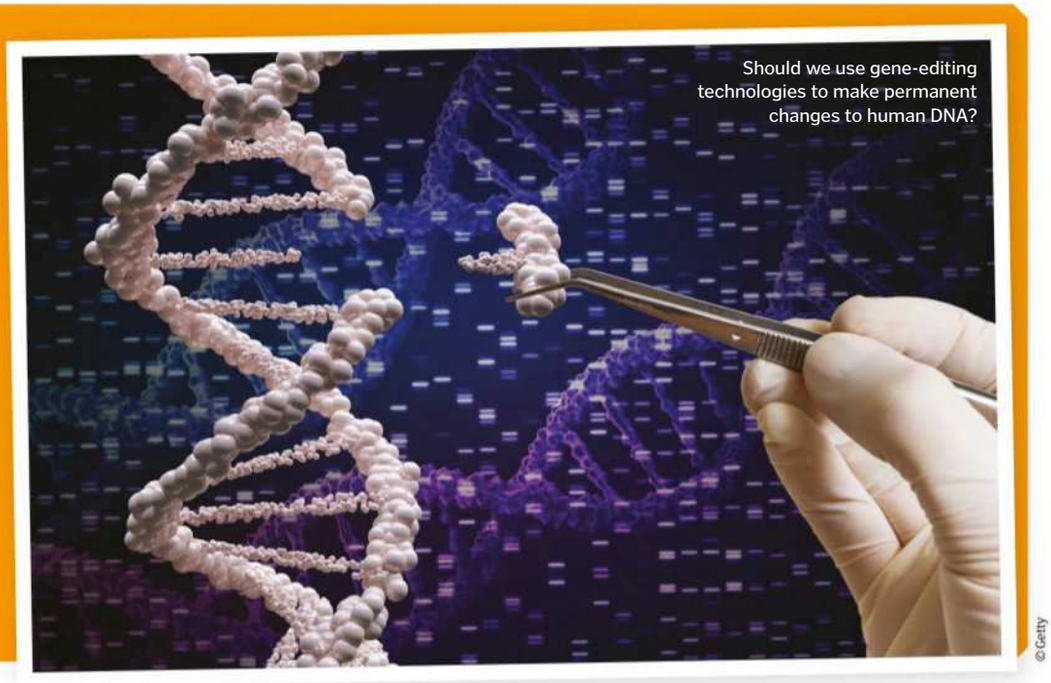
For genetic engineering to become a powerful clinical tool we need more control. CRISPR promises better precision, but research is ongoing. Being able to read the genome could point to the errors that cause human disease. Being able to edit it could help us to fix them.

In the future, genetic engineering could bring us new fuels, chemicals and drugs. It could help us to increase the size of plants and animals and boost their resistance to disease. It could help endangered species to cope with changing environments or resurrect extinct animals. It might even change what it means to be human.

Is it right to play with our genes?

Genetic engineering is amazing, but many people worry about the consequences. At the moment most gene editing takes place in research labs, but in the future it could find more and more uses in the real world. One goal is to use technologies like CRISPR to repair faulty genes in the cells of sick children and adults. This might treat their illness, but the genetic changes wouldn't pass on to their offspring.

Another option is to make changes to sperm and egg cells. The genetic repairs would then pass to the next generation and every generation afterwards. But making permanent changes to the human gene pool is risky. Some people worry that we don't yet understand the human genome, or the tools, well enough to ensure that the edits will be safe. Others worry that it's the start of a slippery slope to designer babies. At present many countries ban this type of 'germline' gene editing.

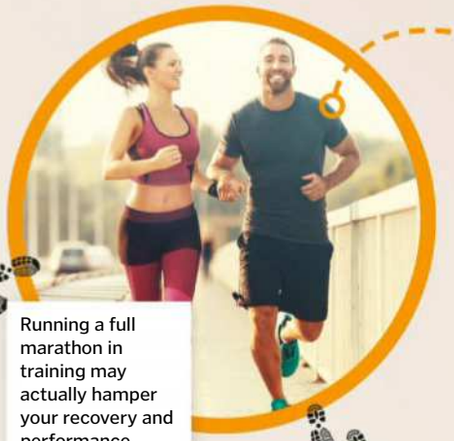


Should we use gene-editing technologies to make permanent changes to human DNA?

Marathon training

With the London Marathon this month, we asked the experts to explain the science behind surviving the gruelling 26.2-mile race

Over 40,000 people ran the 2017 London Marathon, collectively completing over 1.6 million kilometres



Running a full marathon in training may actually hamper your recovery and performance

Why don't you run the full marathon distance in training?

You'd expect it would be a good idea to run the full distance ahead of the big day at least once, but that isn't actually the case. Dr Andy Blannin, lecturer in exercise metabolism at the University of Birmingham, explains.

"You can get the training adaptations needed by running a variety of distances; typically the longest run will be 16–20 miles [25.7–32.2 kilometres]. These distances are sufficient to stress the energy stores, particularly glycogen, a natural carbohydrate polymer, in the muscles and liver. Going longer than this, or attempting 26 miles [41.8 kilometres], in training can induce unnecessary fatigue, both physical and mental."

So running a full marathon would essentially exhaust your body and deplete your energy stores. If you can run 20 miles [32.2 kilometres] comfortably, that should set you up nicely for the race.

Morning runs will burn fat, but evening runs are more likely to result in better performance

Why do short runs

Most marathon runners will have days when they only run a few miles, even if they're capable of much longer distances. The benefit of this is to prevent lactic acid build up on race day. Nairn Scobie, lecturer in sports science at the University of Glasgow, explains the science behind this method.

"Shorter runs, especially if they are performed at a higher intensity, can help improve your lactate threshold. Lactate threshold is the point at which lactate begins to accumulate in the muscle. Once it begins to build up the athlete will soon fatigue. By training at high intensity for short periods of time at an intensity above the athlete's lactate threshold, over time they will delay the point at which the lactate threshold occurs."

Delaying the onset of lactic acid build up will really help you in the latter stages of a marathon when your muscles are tiring.

High-intensity, short runs can help prevent the onset of lactic acid build up

What causes muscle cramps?

Lactic acid is the enemy of the short-distance runner, but it can also affect marathon runners. It's the cause of cramp and can be incredibly painful, as Nairn Scobie explains.

"Lactate builds up at the end of a process called glycolysis, which breaks down carbohydrates into pyruvate. In conditions where plenty of oxygen is available, this pyruvate enters a process that creates lots of energy. In conditions with little oxygen available (anaerobic respiration) this pyruvate is converted into lactate. In high-intensity exercise there is an increased release of lactate. Exercise at this level can only be tolerated for a short period."

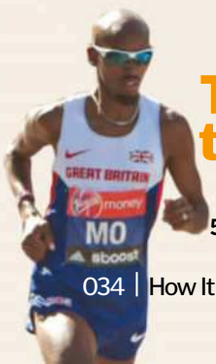
So if you're pushing hard in a race and feel fatigued, slow down and breathe deeply to re-oxygenate your blood.

Lactic acid build up during anaerobic respiration causes painful cramps

Is it better to train in the morning or the evening?

Dr Stephen Mears, lecturer in sport and exercise nutrition at Loughborough University, says you can get more out of different types of training at different times.

"Studies in the lab in normal conditions have shown no difference unless the exercise is in the heat, and then performance increases in the morning, possibly due to a lower starting core temperature. If you want to train in a fasted state and try to utilise fat stores during a run it is easier to run before breakfast. If you want to perform well at a high intensity, fuel is needed and this means training later in the morning or early on in the evening."



Training timeline

Ten steps to completing the 55,000-step race

17 WEEKS
Start your training out lightly, with a few 30- to 40-minute runs throughout the week.

15 WEEKS
You should be running at a steady pace for an hour. Be sure to set aside a stretching day too.

14 WEEKS
Introduce Fartlek running to your training, which entails alternating sprinting and slow jogging.

12 WEEKS
Aim for a ten-mile run with around four miles at marathon pace.

11 WEEKS
Use this time as an easier week to help your body recover from any training soreness or injuries.

Plenty of carbs provide you with the energy required to keep running

What is carb loading?

When you digest carbohydrates, the sugars inside them are stored as glycogen in the muscles and liver, providing a quick-release source of energy. Before a race, runners will load themselves up with foods rich in carbohydrates to help them 'stock up' their glycogen stores. Duane Mellor, senior lecturer in human nutrition at Coventry University, explains why.

"There are two types of carb loading: one where you taper your carbs to run them down and do the same with training and then eat carbohydrate to reload, while the other is just increasing carbohydrates to eight to ten grams per kilogram [of body weight]."

Filling your body with carbs the night before a race should provide you with enough glycogen fuel to sustain you for the majority of the race. Just make sure you don't eat too late, as a carb-rich meal can weigh heavily on your stomach.

Does listening to music help during a race?

Many runners listen to music while running. Rather than just force of habit, Nairn Scobie suggests there could be psychological benefits in jogging to your favourite tunes.

"We could feel motivated by certain songs or types of music. Listening to music during exercise can also help us dissociate from the activity. To put it simply, if we pay attention to the music then it can help us forget about the pain we may experience during the run."

So if you're struggling to motivate yourself, your favourite music could distract you enough to get in those crucial miles.

Listening to music could help your rhythm and sharpen focus

The best practice is to drink little and often before the race, and watch out for water stations along the route if you need to top up along the way

What happens when a runner 'hits the wall'?

'Hitting the wall' is a term used by runners to explain the moment they suddenly become physically and mentally fatigued while running long distances. Dr Blannin reveals why this happens.

"This phenomenon is multi-faceted, but one of the major factors is likely to be the severe depletion of the body's glycogen stores. Without glycogen in the muscle and no glucose coming from the glycogen stores in the liver, the muscle has limited metabolic pathways to produce energy for running."

The sensation of hitting the wall occurs when your body changes its major energy source from glycogen to fat. Burning fat is a more complicated (slower) metabolic process, but effective training helps prepare the body to use its fat stores more efficiently.

A good training and nutrition regime will help prepare your body and mind for overcoming 'the wall'

Why do we need to drink water during a race?

We drink water to rehydrate our bodies, something especially important during a run, as Dr Mears explains.

"When you exercise, you sweat. This is to dissipate heat through evaporation. When you lose fluid, blood volume decreases meaning your heart must work harder to pump the blood around the body and maintain cardiac output. Drinking fluid allows you to replace the fluid that has been lost and maintain blood volume. This will allow you to continue to sweat and will also allow blood to be directed to the skin to allow further heat loss. It is recommended not to lose more than two per cent of your body weight through sweat."

Losing more than this can lead to dehydration, affecting your physical and mental performance.

Have you read this before?

Discover the science of déjà vu and the technique used to trigger it

Déjà vu is more common in younger people, becoming less common as we age

Around 70 per cent of us experience it, in particular those of us aged 15–25, and it can be one of the most jarring feelings: déjà vu. French for 'already seen', it has previously been linked to the theory of false memories; the idea that we can view something once and when exposed to a scene or situation that is similar our brain will respond by creating a memory that didn't really happen. However, an experiment led by psychology researcher Akira O'Connor in 2016 revealed that this might not be the case. Rather than false memory, the brain is memory checking and sending an error message, signalling what we have actually experienced versus what we think we have experienced. Around 70 per cent of us experience...wait a minute...

O'Connor's experiment

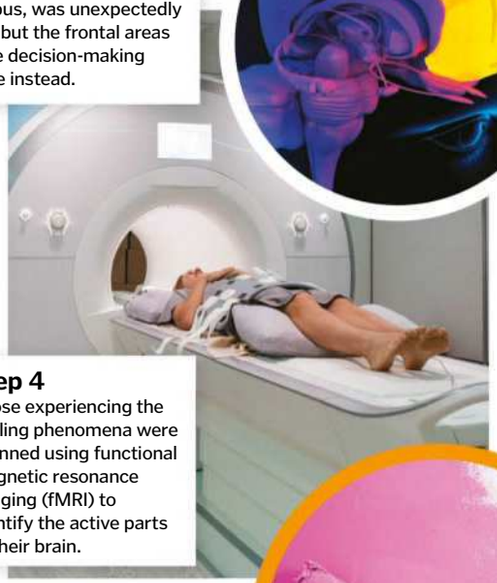
How did scientists artificially trigger déjà vu in the study's volunteers?

Step 1
Participants were given a list of words to remember including bed, pillow, dream and doze; all words that are connected, in this case, to the word 'sleep'.

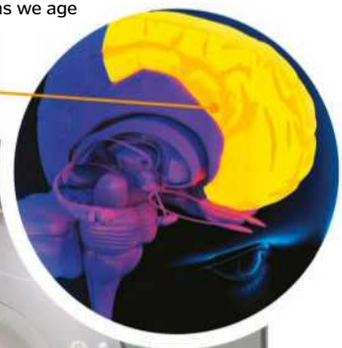
Step 2
They were then asked if any of the words in the list began with the letter 'S'. Each person correctly said no.

Step 3
Later on, the volunteers were asked if the word 'sleep' was included in the previous list of words. This prompted a feeling of déjà vu.

Step 4
Those experiencing the chilling phenomena were scanned using functional magnetic resonance imaging (fMRI) to identify the active parts of their brain.



Step 5
Scans revealed that the memory centre of the brain, the hippocampus, was unexpectedly not active, but the frontal areas that handle decision-making were active instead.



Adsorption versus absorption

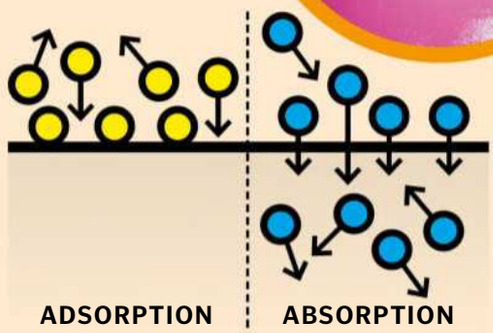
These almost identical words mean quite different things

Adsorption and absorption are both types of 'sorption'. This word describes one substance attaching to another. This can happen at the surface of a substance or through a substance, and that's where 'adsorption' and 'absorption' come in.

The more commonly used word, absorption, describes the process happening inside the volume of the substance. If one substance absorbs another, it soaks it up. An example is pumping carbon dioxide into cola to make it fizzy – the liquid absorbs the gas. Adsorption, on the other hand, occurs only at the surface. If a substance adsorbs another, it sticks to the outside but it doesn't move through, such as paint clinging to a wall.

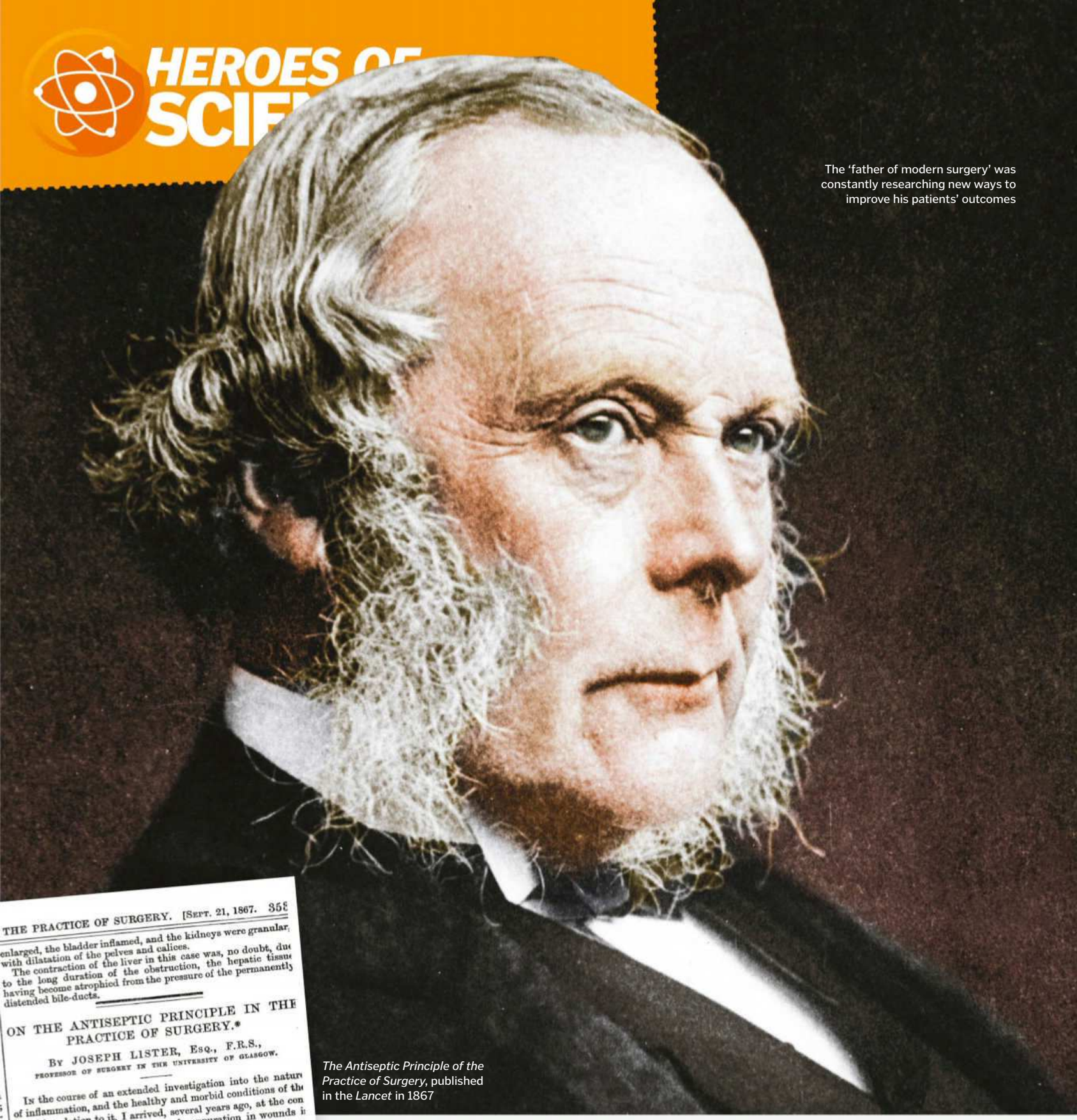
Both types of sorption can be physical or chemical. Weak electrostatic attractions called van der Waals forces can make one substance cling to another. The same forces help solutes dissolve. The molecules stay separate and the interaction is reversible.

Painting works by adsorption: it clings to the surface but doesn't soak into the wall



Sorption describes substances coming together. Adsorption happens only at the surface, while absorption occurs inside. Sometimes the interaction is just physical, and other times a reaction bonds the substances together.

The 'father of modern surgery' was constantly researching new ways to improve his patients' outcomes



THE PRACTICE OF SURGERY. [SEPT. 21, 1867. 358

enlarged, the bladder inflamed, and the kidneys were granular, with dilatation of the pelves and calices.

The contraction of the liver in this case was, no doubt, due to the long duration of the obstruction, the hepatic tissue having become atrophied from the pressure of the permanently distended bile-ducts.

ON THE ANTISEPTIC PRINCIPLE IN THE PRACTICE OF SURGERY.*

By JOSEPH LISTER, Esq., F.R.S.,

PROFESSOR OF SURGERY IN THE UNIVERSITY OF GLASGOW.

In the course of an extended investigation into the nature of inflammation, and the healthy and morbid conditions of the blood in relation to it, I arrived, several years ago, at the conclusion that the essential cause of suppuration in wounds is decomposition, brought about by the influence of the atmosphere upon blood or serum retained within them, and, in the case of contused wounds, upon portions of tissue destroyed by the violence of the injury.

To prevent the occurrence of suppuration, with all its attendant risks, was an object manifestly desirable; but till lately apparently unattainable, since it seemed hopeless to attempt to exclude the oxygen, which was universally regarded as the agent by which putrefaction was effected. But when it had been shown by the researches of Pasteur that the septic property of the atmosphere depended, not on the oxygen or any gaseous constituent, but on minute organisms suspended in it, which owed their energy to their vitality, it occurred to me that decomposition in the injured part might be avoided

The Antiseptic Principle of the Practice of Surgery, published in the *Lancet* in 1867

A life's work

How a studious boy became the father of modern surgery

1827
Joseph Lister is born in Upton, Essex, to Quaker parents Isabella Harris and Joseph Jackson Lister, the fourth of their seven children.

1847
Graduates with an arts degree from University College, London. His father encouraged him having a rounded education.

Teenage years
Lister knew he wanted to be a surgeon early on. He spent a lot of time drawing bodies and dissecting animals.

1852
Graduates with a bachelors in medicine and becomes a fellow of the Royal College of Surgeons.

Joseph Lister

The man who used antiseptics to revolutionise surgery

Lister's drawing shows blood vessels and muscles in the femoral region of the thigh

Joseph Lister was born into a Quaker family on 5 April 1827. Having spent his childhood dissecting specimens and looking at tissue samples using his father's microscope, the young Lister decided to become a surgeon. Despite his interest in comparative anatomy, he completed an arts degree at University College London (a secular alternative to Oxbridge). He eventually did go on to study medicine in 1848, graduating with several different honours and gold medals.

At this time surgery was developing as a speciality, with the introduction of proper training and the use of general anaesthetics. In December 1846, Lister witnessed the first use of ether anaesthetic in England. But, many patients still died after their operations from infection. People believed this was caused by poisonous air, or 'miasma'. Surgeons often arrived in theatre straight from dissecting dead bodies and didn't consider washing their hands between patients. They took pride in the 'good old surgical stink' of their unwashed operating gowns.

In 1853, Lister travelled to Edinburgh to learn from Professor James Syme, where he would transform the future of medicine. Three years later, Lister married Syme's daughter Agnes, who would help him with much of his research.

By the age of 33 Lister had become professor of surgery at the University of Glasgow. He was a popular lecturer, known for making students laugh and investing his own money in a lecture theatre more suited to learning.

However, he was still frustrated by the high levels of infection on his wards. Other surgeons were using various antiseptics to treat infected wounds with limited success. Building on the work of Louis Pasteur, Lister's revolutionary approach was to use diluted carbolic acid (now known as phenol) *before* infection set in.

He first tested it on patients with broken bones where the injuries were open to the air. He and his assistants washed their hands and instruments in carbolic acid before applying it to the site of the injury. Eight out of ten of his first patients fully recovered. Encouraged, he began using the system for operations.

When he published his first results in 1867 there was considerable opposition. He was seen by some as a dangerous charlatan, but Lister was undeterred. Gradually, his principles were adopted. In 1869, he left Glasgow to replace his father-in-law as professor of clinical surgery in Edinburgh. He would later develop a new method of fixing broken kneecaps with wire.

Towards the end of his life he was honoured with many awards, including a knighthood and elevation to the House of Lords as Lord Lister of Lyme Regis. He became Queen Victoria's personal surgeon as well as one of her privy counsellors. He was also elected president of the Royal Society, following in the footsteps of Sir Isaac Newton. In the midst of this, he helped found what is now the Lister Institute of Preventive Medicine in Hertfordshire, UK.

THE BIG IDEA

How Lister built on Louis Pasteur's work to revolutionise surgery

After reading Pasteur's work, Lister became convinced that infection was caused by germs, not the surrounding 'bad' air. He soon began searching for an ideal antiseptic.

He knew sewage plant engineers used carbolic acid to conquer the smell from rubbish and nearby fields irrigated with liquid waste. It was noted that the cows grazing there were no longer getting a disease known as 'cattle fever'.

Lister used these facts to develop a system where surgeons and assistants washed their hands and instruments and cleaned the wound with carbolic acid to prevent infection. This reduced the number of post-operative deaths from around 50 per cent to 15 per cent – a remarkable reduction at this time.

Lister was the first to use antiseptics during surgery to prevent infection before it developed

5 THINGS TO KNOW ABOUT... JOSEPH LISTER

1 Science ran in the Lister family
His father left school at the age of 14, but was later internationally recognised for his work improving the compound microscope with his achromatic lens design.

2 He designed surgical instruments
Lister's patents included a needle for stitching wounds, a hook to pull objects out of the ear and a tourniquet for the abdominal aorta – the largest artery in the body.

3 His system was internationally adopted
While there was still opposition to his antiseptic system in the UK, French and German doctors were successfully using it to treat casualties in the Franco-Prussian War.

4 He was a caring doctor
Lister referred to patients as 'this poor man' or 'this good woman' instead of 'cases'. He taught students to use technical words when discussing their care to avoid frightening them.

5 He almost became a preacher
At one point during his studies Lister decided to abandon surgery and become a preacher instead, but his father managed to persuade him against the idea.

1853
Moves to Edinburgh to learn from James Syme, one of the greatest surgical teachers at the time, in Europe.

1856
Marries Agnes Syme, Syme's bright daughter. Agnes assists him with his experiments.

1860
Becomes professor of surgery at the University of Glasgow and visiting surgeon at Glasgow Royal Infirmary in 1861.

1867
Having spent two years developing his methods, Lister publishes his revolutionary work on antiseptics.

1897
Elevated to the peerage as Lord Lister of Lyme Regis, one of many honours he receives following widespread acceptance of his ideas.

1912
Lister dies in Walmer, Kent, aged 84. His funeral service is held at Westminster Abbey and he is buried at West Hampstead Cemetery.

THE ART DETECTIVES

Meet the technology uncovering the history of the world's artwork

Words by **Scott Dutfield**

Last year, a painting by the legendary Leonardo da Vinci sold for the record-breaking price of $450.3 million (around £320 million). Entitled *Salvator Mundi* (*Saviour of the World*), for most of its life it was assumed this portrait of Christ was a copy. It wasn't until a team of researchers at New York University successfully analysed the piece in 2007 that the artwork's origins were revealed.

Technological advances in the art conservation and restoration industry allow academics to truly dig into the history of art and preserve it correctly. Restoration is vital in ensuring the longevity of artwork for future generations, but in order to save them, they must first be investigated.

Earlier this year we visited the University of Lincoln, which is home to the UK's largest centre for conservation and restoration studies. Deep in the heart of a building full of aspiring art students, extensive hallways lead to an unassuming series of high-tech laboratories. These purpose-built labs are full of ingenious technologies designed to sniff out the secrets of their subjects. Here, inquisitive minds are busy unravelling the histories and mysteries of paintings, sculptures, artefacts and more.

Dr Lynda Skipper (senior lecturer and programme leader from the school of history and heritage) and her colleagues shone some light on these pieces of technology in a tour of their impressive workspaces.

THE ELEMENT ANALYST

A key detective technique, especially when dealing with paint, is to look at chemical composition. To maintain or restore the original appearance of an item, knowing the composition of the paint used enables conservators to perform a composition and colour match for repair.

A handheld X-ray fluorescence (XRF) spectrometer is just the tool to get the job done. This handheld machine can identify the elemental composition of different materials. This is achieved by measuring the fluorescent X-rays emitted from a sample after it has been stimulated by X-rays emitted from the handheld gun.

Paints contain an array of different elements, such as zinc, iron and titanium. Each of the elements has its own unique signature, which is like its own fingerprint. These spectrometers are used to calculate the unique peak X-ray energy released from the atoms of each element after being blasted by X-rays from the gun. These levels are then recorded as a kind of element line-up, allowing researchers to point out which ones (and how much) are present in any given sample.

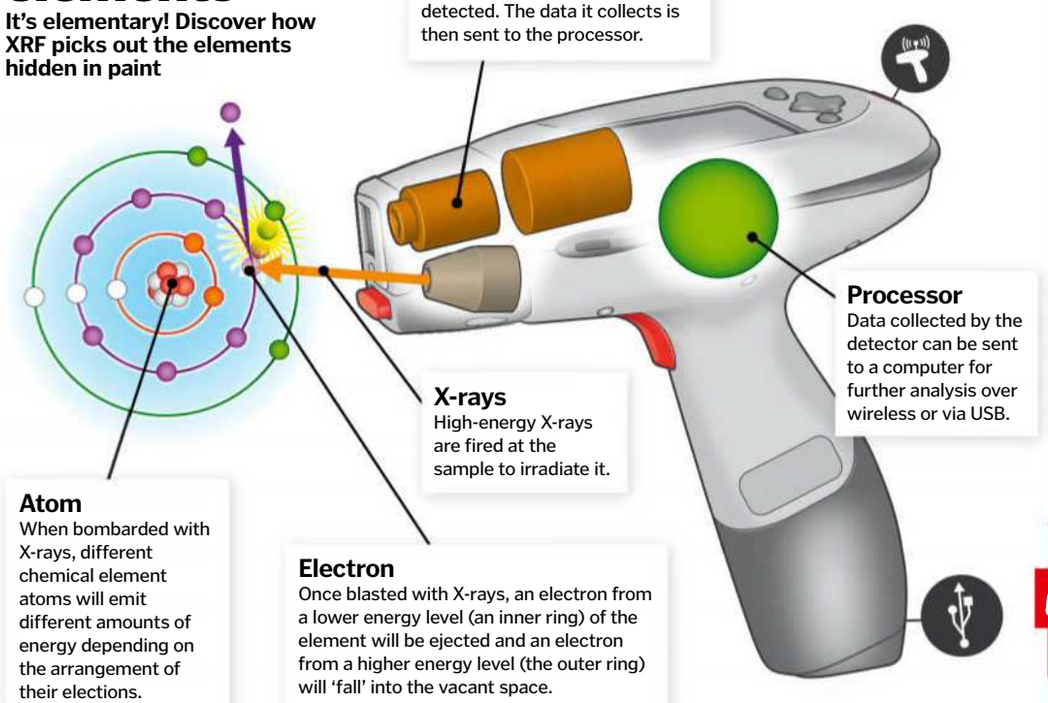
This technology isn't only used to uncover the composition of paints in a frame but also those coating historical machinery. Paul Croft, research fellow at the University of Lincoln, used the XRF spectrometer to colour match the camouflage paint covering a 1943 army tank. While studying a piece of the tank, Croft discovered a high quantity of one element in particular.

"When you understand the make up of paints you can begin to understand the pigments that were used. They were using a zinc-based paint and zinc-based primers presumably for its corrosion-preventative properties."

A macro-X-ray fluorescence scanner was recently used to analyse Vermeer's *Girl with a Pearl Earring* (circa 1665)

Uncovering elements

It's elementary! Discover how XRF picks out the elements hidden in paint



THE DISSECTOR

You should never judge a book by its cover – equally, you should never judge paint by its colour. Hidden beneath the top layer of paint can lie several layers of previous paints, representing a timeline for each piece. With the use of optical microscopes, these art detective technologies can reveal the different pigments, dyes and layers of a single sample of paint.

Samples from paint covering a gilded frame, for example, can be taken and manipulated to sit up at a right angle to expose its layering and then held in a block of transparent resin, which is similar to the way in which prehistoric insects are found encased in amber. Placed under a microscope, these samples can reveal the different coatings the object being investigated could have been covered in.

Paul Croft uses this technique to highlight the contrasting layers of traditional oils and modern paints within some paintings. The different layers glow when viewed under ultraviolet light. "All of those early layers that fluoresce, those are the traditional oil paints, and those that don't are the modern synthetic paints," explains Croft.

Different paints will have been applied at different times, so by comparing the paints to those in historical records, these layers can uncover the story of the artwork's journey over time.

Zinc layers in a paint cross-section will glow under UV light

"You should never judge a book by its cover – equally, you should never judge paint by its colour"

THE SIMULATOR

In order to crack the code of aging artwork, looking to the future can be useful. In lieu of a time machine to hop into the future and see how a piece of art is going to age, artificial aging chambers can provide a glimpse into the future. By exposing materials such as paper and fabric to varying temperatures or levels of humidity, these chambers can replicate the effects natural and artificial environments can have on artwork. This process can be used to explore aspects such as discolouration or degradation. Therefore, conservators can manage the materials, especially the adhesives used to repair different pieces.

"You can look at actual historical materials and see how they age, or you can look at materials you would like to use for a repair and see how they are going to age and if they are going to age similarly to the material that you are trying to repair," says Dr Skipper.

Discolouration in particular can also be experimented with and quantified using a spectrophotometer. Exposing fabric to natural sunshine can lighten delicate fabrics in paintings or tapestries; these light detectors can graphically represent the level of discolouration to an object, revealing how light may affect original works.

Above: After light damaged the clothed areas of this doll figure, researchers simulated the effects the environment could have on the material used for repair

THE INSPECTOR

In the case of *Salvator Mundi*, infrared reflectography (IRR) allowed the experts analysing the painting to identify markings made by hand on the canvas. The IRR scans picked up areas where the edge of the painter's palm had been pressed into wet paint to create softness, which matched a technique known to be used by da Vinci. This advanced technology can essentially dust for prints digitally, and in this instance it picked up prints that were over 500 years old.

In most cases IRR is used to reveal work that has been previously hidden by another layer of paint. This piece of technology uses infrared light to look beneath the surface. Visible light is absorbed and reflected from the surface of objects, while infrared can penetrate past the top layer of paint before being reflected, reaching the ground work of a painting. The reflected infrared can then be recorded and images of drafts, mistakes, a change in scenery or hidden figures can be brought to light.

"The source of these art saboteurs can be tricky to find"

Hidden art
Infrared reflectography revealed a hidden ominous figure in the forefront of this piece by Jheronimus Bosch (circa 1450–1516).

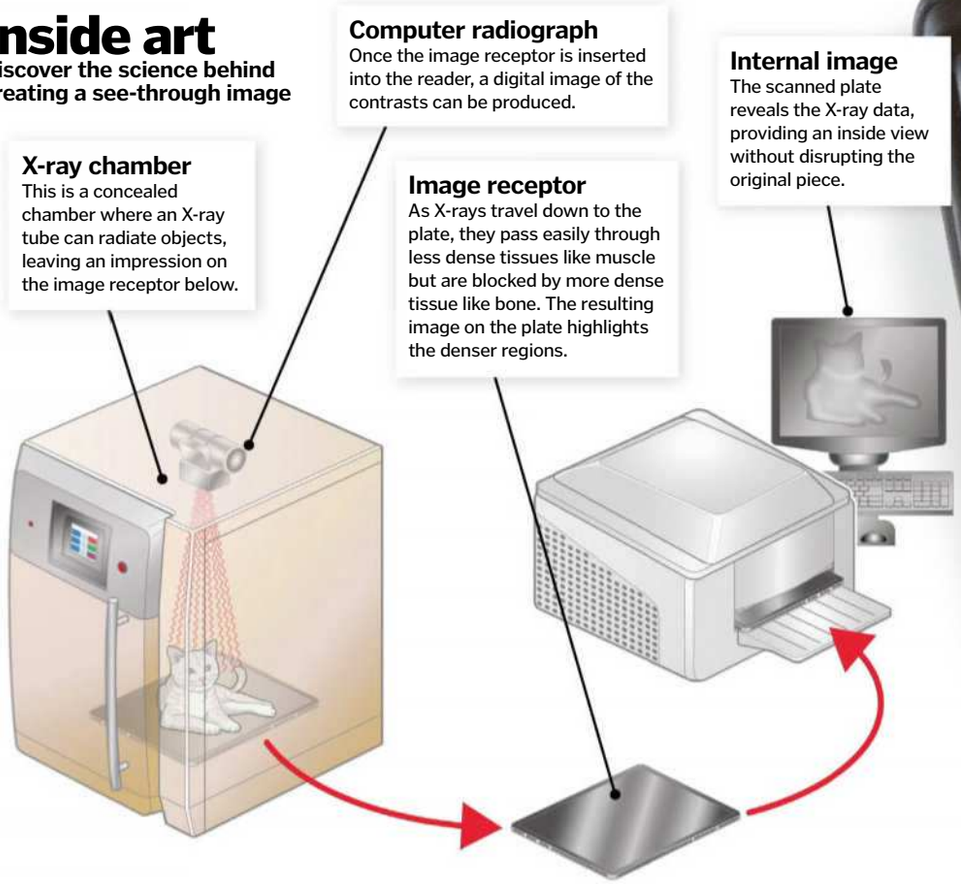
X-ray scans can be useful for analysing and restoring taxidermy specimens

THE RADIOLOGIST

In order to create a full picture of an artwork's past, sometimes you literally have to take a look inside. Taxidermy, for example, is an art form commonly under this type of investigation. Without slicing into animals again, computer radiology uses X-rays to establish the way the specimen was prepared and therefore how best to fix damaged items. In exactly the same way as a person may have to get an X-ray for a broken bone, radiographs emit X-ray radiation to penetrate the skin and produce a contrast image of the inside of the body. This can then be used to create a digital image, rather than developing a film. The approach allows for the identification of any metal armature or bones. The technique can also be used on ceramics and to identify hairline fractures, for example, which may remain undetected until X-rayed.

Inside art

Discover the science behind creating a see-through image



THE HEAT SEEKER

When exploring the damage caused to material, such as the canvas of a painting, the scene of the crime has to be investigated. A key factor that can cause damage to artwork is heat and moisture. However, the source of these art saboteurs can be tricky to find.

Using a handheld thermal imaging camera can expose areas of these damaging factors. Invisible to the naked eye, infrared radiation can be detected as heat. Every object emits infrared, whether it is hot or cold, and thermal imaging cameras monitor this radiation to create a visual representation of different temperatures. This information can then help conservators locate areas in galleries or storage facilities where temperature or moisture fluctuates.

THE RE-CREATORS

Once the subject has been scanned it is shaped to form a print sculpture

During their lifetimes, sculptures can experience different breaks and bruises. The famous Venus de Milo, for example, lost her arms sometime before her rediscovery in 1820. With the introduction of 3D scanning and printing technology, art conservators are able to visualise and restore sculptures without damaging the originals. The restoration of these pieces of art can be a tricky and time-consuming process, unless you can print out a copy to practise on. By applying different restoration materials and techniques to a plastic doppelganger, conservators can assess the best way to approach the genuine article.

The first stage for a digital recreation is to scan the original. Using a 3D scanner, a laser is shone over the subject and bounced back to the scanner. Equipped with a sensor, these scanners can collect data on the size and shape of a sculpture. The geometry is then imported into computer-assisted design software, where the data can be manipulated and act as a print template. Once formulated, the digital copy of a sculpture can be sent to the printers.

Michael Poole, business development manager and art conservator for the University of Lincoln, has worked on a wealth of projects while at the institution. Poole has used this technique on several projects, including a set of terracotta warrior statues.

"We were given three bodies and there was one head missing. We scanned the two good heads and digitally morphed a new one, which is difficult. It sometimes can be easier to actually physically sculpt and scan, which we did with the Roman bull."

After the torso of a Roman bull sculpture was found in a garden, Poole's team printed out a replica torso and used a sculpture to recreate the missing head, legs and partial tail. This could then be scanned a second time to create a complete digital image.

3D printers enable art conservationists to recreate original pieces, such as this bust

"Art conservators are able to visualise and restore sculptures without damaging the originals"

Printing a portrait

Discover the technology producing art without the use of a paintbrush

CAD
Computer-assisted design (CAD) software uses a scanned image of a sculpture to create a digital three-dimensional image.

Extruder
The extruder releases the plastic filament onto the heated plate in precise amounts to form the shape of the sculpture.

Printing
Printers use the information from the CAD program to layer tiny slices of plastic on top of one another to start to form a plastic replica.

Plastic copy
Once formed, the newly created masterpiece can be subject to different techniques, the most successful of which will be used on the original sculpture.

WHEN RESTORATION GOES WRONG

Botched beard

In 2014, the 3,300-year-old golden burial mask of Tutankhamun was damaged at the Egyptian Museum, Cairo, causing his beard to break off. The beard was originally glued back with epoxy superglue at the wrong angle, damaging the chin. A team of experts have since restored the mask correctly.

Fresco fail

In 2012, at a church in Borja, Spain, an amateur painter tried her hand at restoring a fresco of Jesus, which was around a century old.

Complete cover up

Rather than repair the damage to the nearly 300-year-old fresco on the wall in Chaoyang's Yunjie Temple, Beijing, the piece was covered with cartoon-like paintings, outraging visitors.

Head of horrors

After a Canadian statue of the Virgin Mary and baby Jesus was vandalised, an artist sculpted a new terracotta head. Thankfully, the head was returned so the statue could be properly restored.

Ruined wall

The reconstruction of the Castle Matrera, Spain, left people confused by its modern style. The aim of this 'restoration' was to highlight the ancient ruins.

Bulletproof glass

How layers of plastic make this glass resistant to bullets

In the early 20th century, French chemist Édouard Bénédictus sandwiched celluloid between sheets of glass to create an early form of laminated safety glass. Bulletproof glass is based on an extension of the same principle: using multiple layers of glass and plastic to absorb the impact of bullets.

These protective panes are typically made with a plastic called polyvinyl butyral (PVB). Sheets of PVB, just a few millimetres thick, are sandwiched between each layer of glass. The layers are heated to melt the plastic layers so that they bond to the glass and strengthen it. Some panes may be as much as ten centimetres thick, but the number of layers used will vary depending on the glass' intended purpose.

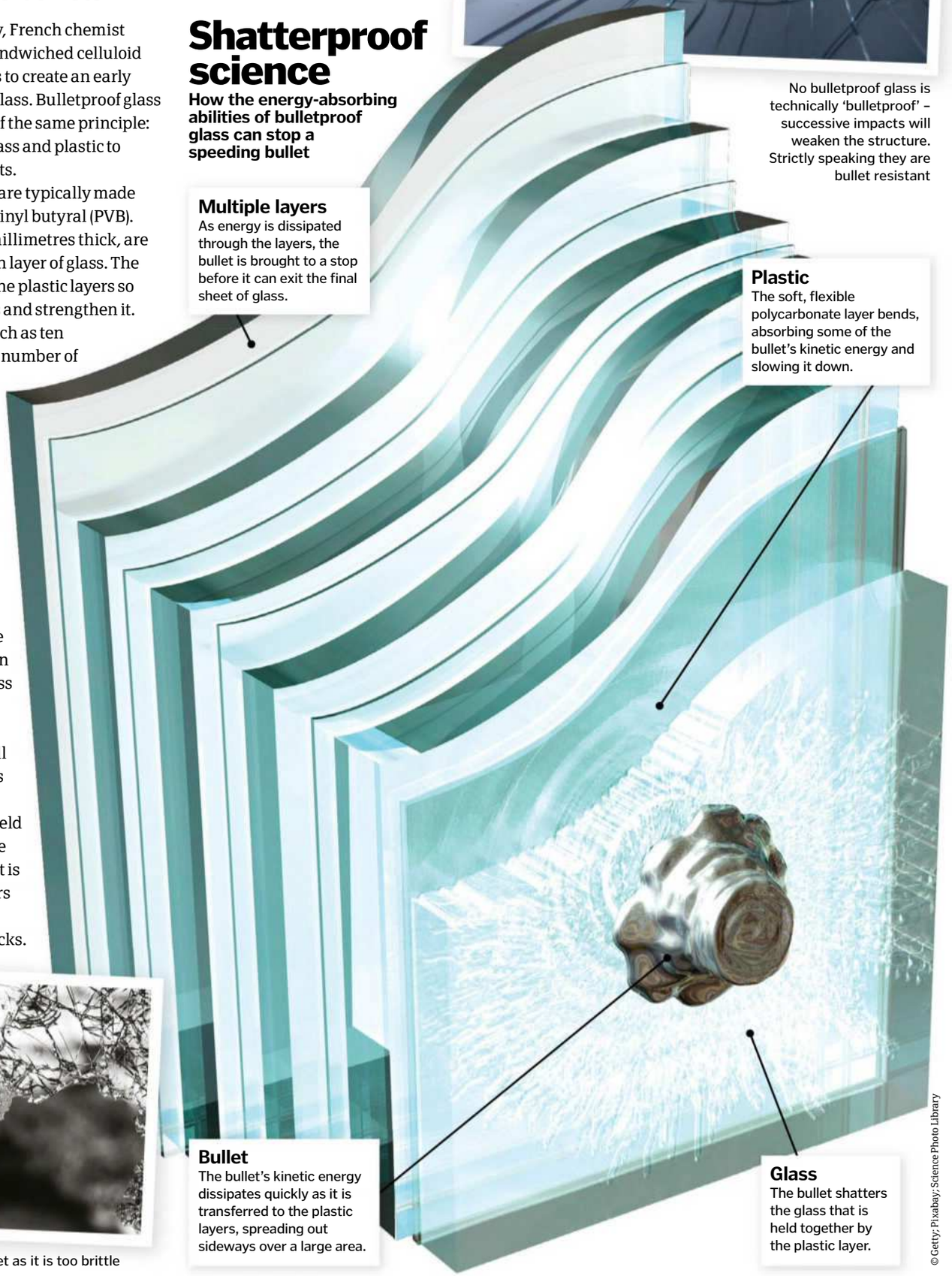
Normal glass shatters on impact as it is unable to bend in order to absorb a bullet's energy, so the ammo continues hurtling along the line of fire without much loss of momentum. But if you have seen a cartoon where bullets are being fired at an indestructible piece of glass and bullets are bouncing back – that's not how it works. The bullets will still fracture the glass and pass into it, but as each layer of glass shatters it remains held together by the plastic. The kinetic energy of the bullet is spread out across the layers and quickly absorbed, stopping the shot in its tracks.

Normal glass can't slow a bullet as it is too brittle

No bulletproof glass is technically 'bulletproof' – successive impacts will weaken the structure. Strictly speaking they are bullet resistant

Shatterproof science

How the energy-absorbing abilities of bulletproof glass can stop a speeding bullet

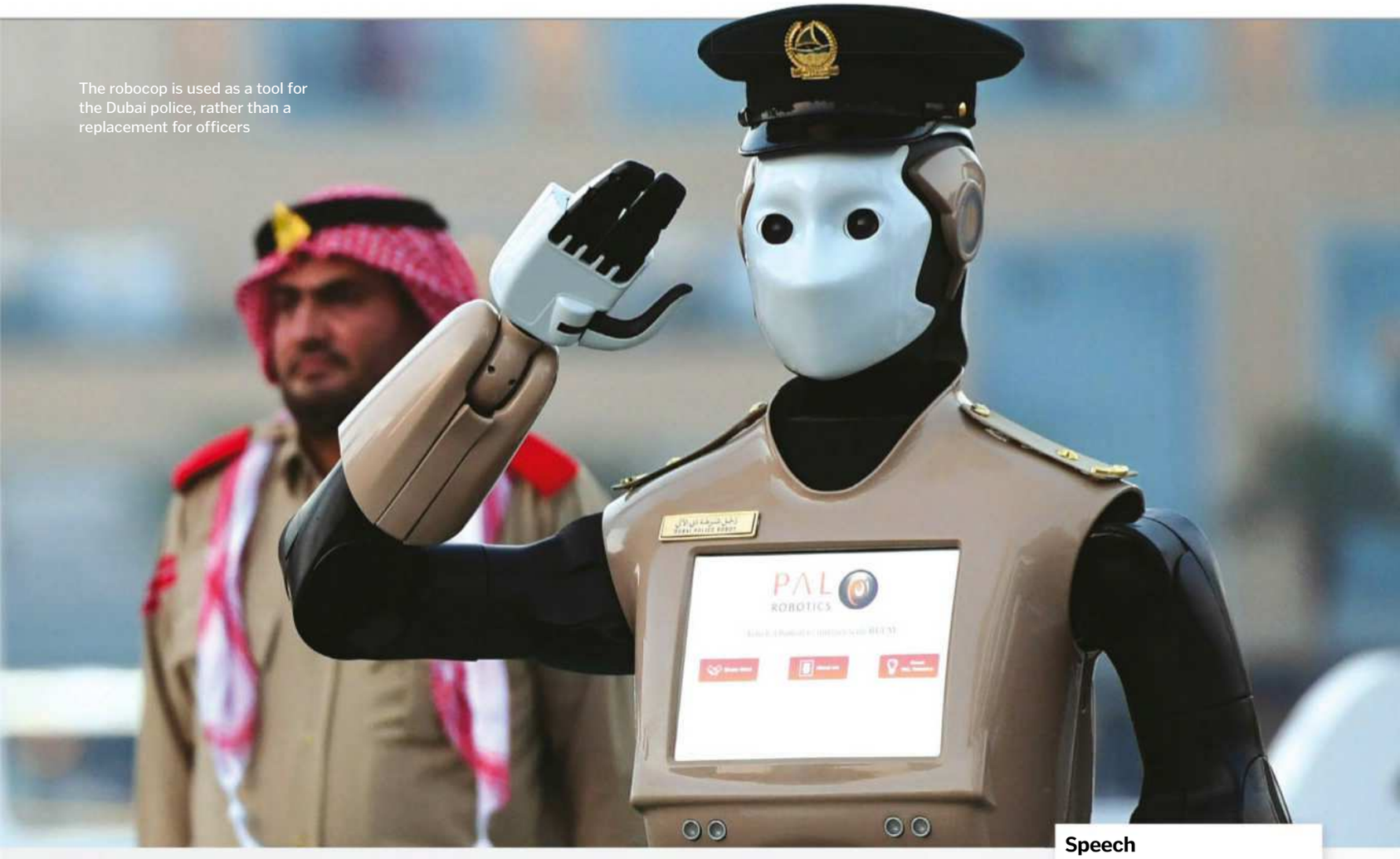


Multiple layers
As energy is dissipated through the layers, the bullet is brought to a stop before it can exit the final sheet of glass.

Plastic
The soft, flexible polycarbonate layer bends, absorbing some of the bullet's kinetic energy and slowing it down.

Bullet
The bullet's kinetic energy dissipates quickly as it is transferred to the plastic layers, spreading out sideways over a large area.

Glass
The bullet shatters the glass that is held together by the plastic layer.



The robocop is used as a tool for the Dubai police, rather than a replacement for officers

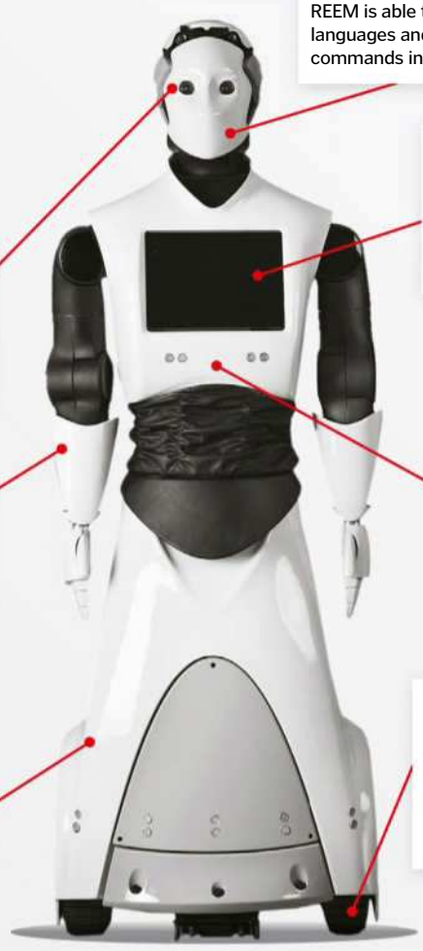
The first Robocop

Patrolling the streets of Dubai, meet the first automated police officer of the Middle East

Autonomous machines and robots are being introduced into the workforce of many industries, from manufacturing to retail. Moving with this trend, the Dubai Government introduced its first humanoid robot into their police ranks last year. Designed and built by PAL Robotics and programmed by the Dubai police, this fully autonomous humanoid is able to assist the public in cases of emergency and general enquiry.

Beneath its official uniform is the REEM robot, which has integrated AI enabling it to patrol through busy areas such as shopping centres and communicate with the public. Equipped with facial-recognition software and a live camera feed, REEM can keep an eye out for anyone of interest to the police, or investigate suspicious packages. Its software can detect the faces of wanted criminals or number plates of cars by automatically comparing images to those in a police database.

REEM has an iPad-style interface embedded in its chest for the public to report crimes on or hit the SOS button for immediate help 24 hours a day. Though it's hard to imagine REEM tackling any wrong-doers, the Dubai Government has faith that this style of 'robocop' could account for 25 per cent of the country's police force by 2030.



Speech
REEM is able to speak nine languages and understands voice commands in English and Russian.

Interface
A touchscreen chest allows the public to choose from several options to report a range of crimes.

Sight
Law enforcement officials can access the live camera feed from lenses in REEM's eyes.

Size
Built on a human scale, REEM is 1.7m tall and weighs 100kg.

Power
Robocop can stay on duty for eight hours before needing to be recharged.

Movement
Autonomous navigation allows REEM to avoid obstacles and even manoeuvre through crowds.

Hard exterior
The REEM robot is made from long-lasting material, protecting it from damage.

Inside the NES Classic Mini

Discover how Nintendo have revived their popular NES console for a new generation

Videogames have changed a lot over the last 35 years – graphics have improved, technology has become more powerful and the worlds that you can explore are bigger than ever. However, that doesn't mean that the games from all those years ago aren't still fun!

Thousands of fans of classic games are still desperate for a taste of nostalgia, and Nintendo have provided it with the Classic Mini NES. This tiny console is a miniature version of the Nintendo Entertainment System first released in Japan in 1983, and it comes with some classic games pre-installed so you can play right away.

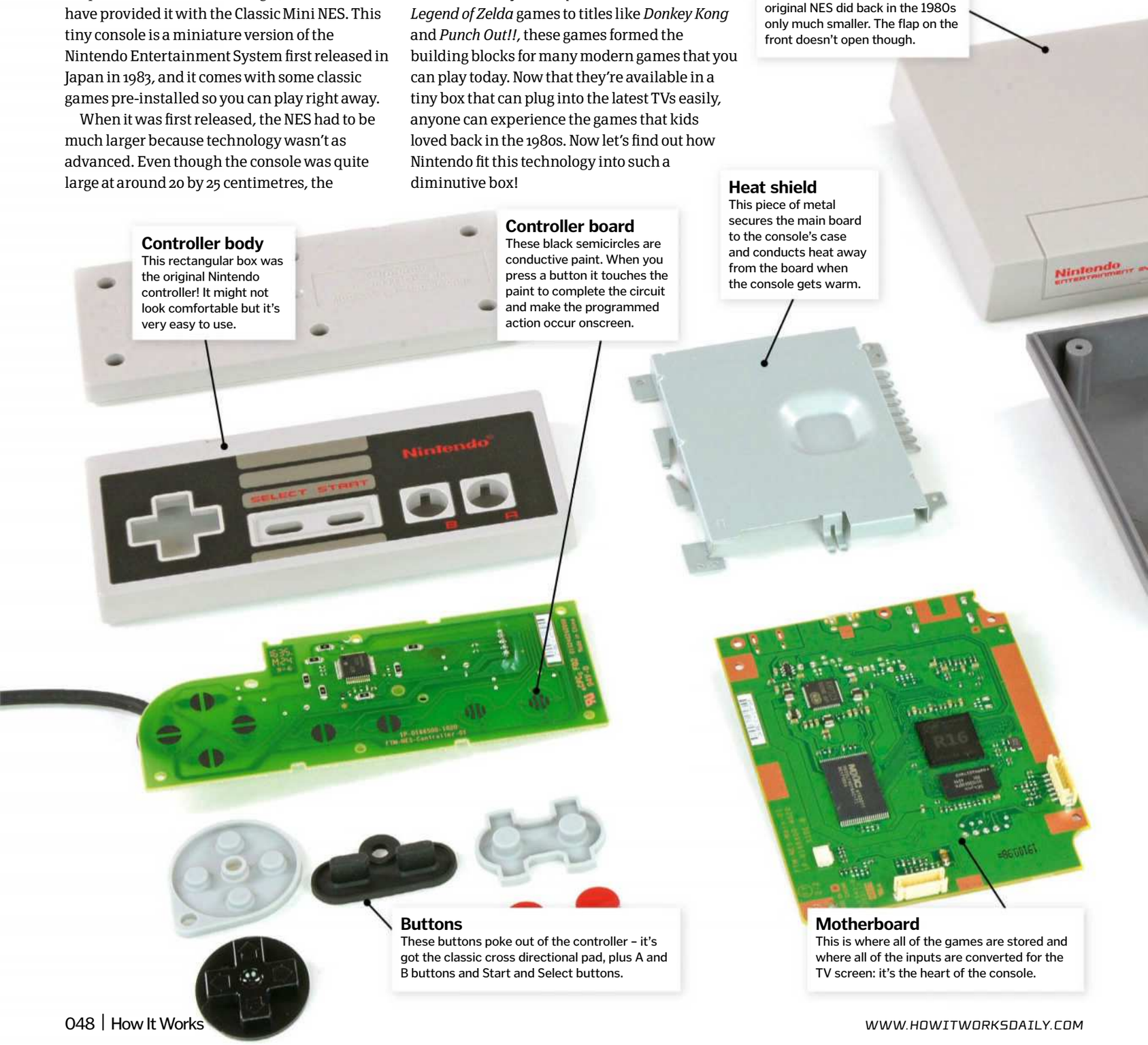
When it was first released, the NES had to be much larger because technology wasn't as advanced. Even though the console was quite large at around 20 by 25 centimetres, the graphics it could produce back then were very simple compared to today's games. Still, at the time people were really impressed.

Now, the same technology can fit into a much smaller box, and it can also store 30 classic games – including some of the most famous and well-loved heroes ever!

From the very first *Super Mario Bros* and *Legend of Zelda* games to titles like *Donkey Kong* and *Punch Out!!*, these games formed the building blocks for many modern games that you can play today. Now that they're available in a tiny box that can plug into the latest TVs easily, anyone can experience the games that kids loved back in the 1980s. Now let's find out how Nintendo fit this technology into such a diminutive box!

Next-gen NES

Good things come in small packages: what's inside this tiny classic console?



Console case

The console looks just like the original NES did back in the 1980s only much smaller. The flap on the front doesn't open though.

Heat shield

This piece of metal secures the main board to the console's case and conducts heat away from the board when the console gets warm.

Controller body

This rectangular box was the original Nintendo controller! It might not look comfortable but it's very easy to use.

Controller board

These black semicircles are conductive paint. When you press a button it touches the paint to complete the circuit and make the programmed action occur onscreen.

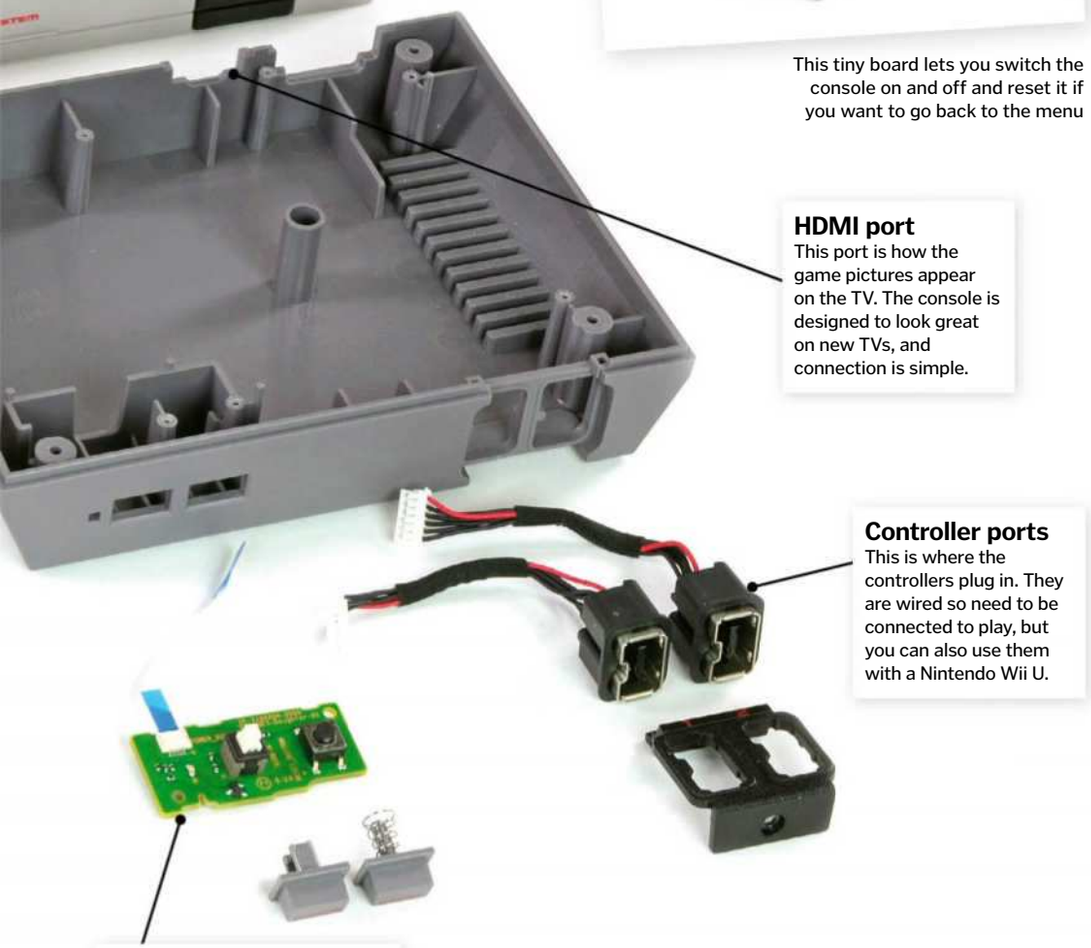
Buttons

These buttons poke out of the controller – it's got the classic cross directional pad, plus A and B buttons and Start and Select buttons.

Motherboard

This is where all of the games are stored and where all of the inputs are converted for the TV screen: it's the heart of the console.

On the left is an original NES game cartridge – the new console is almost the same size!



This tiny board lets you switch the console on and off and reset it if you want to go back to the menu

HDMI port
This port is how the game pictures appear on the TV. The console is designed to look great on new TVs, and connection is simple.

Controller ports
This is where the controllers plug in. They are wired so need to be connected to play, but you can also use them with a Nintendo Wii U.

Daughter board
This smaller board controls the Power and Reset buttons and also has a small LED to show when the console is switched on.

"The console features some of the most famous and well-loved heroes ever"

The best classic NES games

Donkey Kong
Mario makes his first ever appearance here, but in this game he's called Jumpman and must save Pauline from the evil Donkey Kong by jumping over barrels and climbing ladders to reach the angry ape. It was an arcade game before it appeared on the NES.

Metroid
Take control of intergalactic bounty hunter Samus Aran and explore a mysterious planet in this side-scrolling shooter. Samus was one of the first female protagonists in a video game – her identity was not revealed until the end of the game when she is seen without an exosuit.

Super Mario Bros
Mario's first proper adventure is a stone-cold classic. Jump onto Goombas to take them out, leap into blocks for coins and power-ups, and ultimately defeat the evil Bowser to save the Princess. If you have never played this, you're missing out.

HOW IT WORKS

THE TOMB OF TUTANKHAMUN

Discovered in 1922 after lying sealed for thousands of years, step inside the final resting place of Egypt's boy king

ANNEX

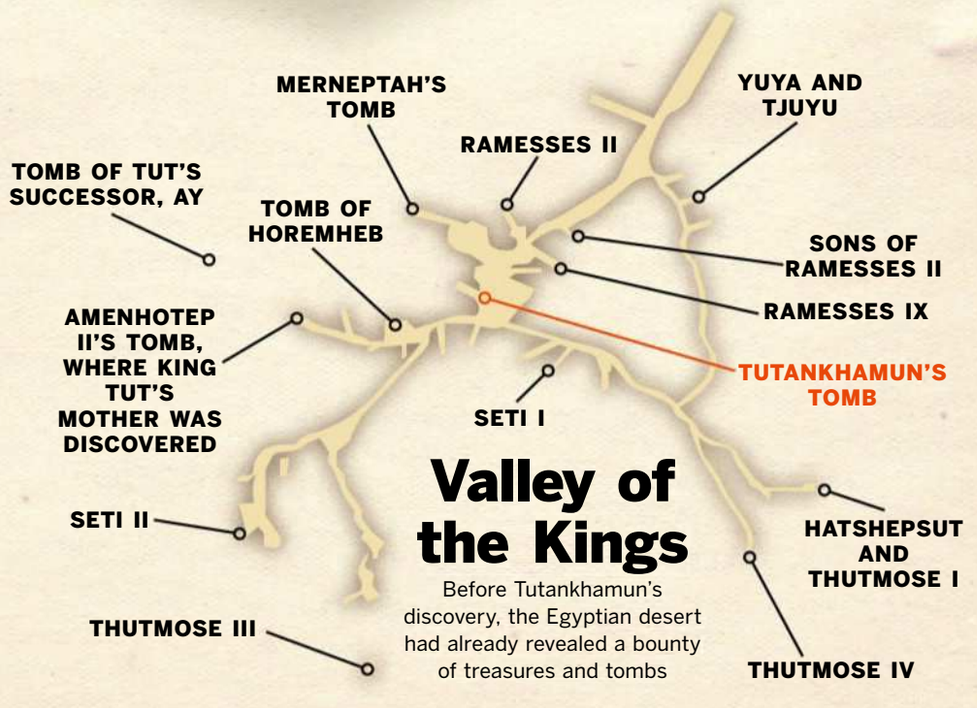
Named by Howard Carter (who discovered the tomb), this is the smallest room in the tomb and contained many valuable objects, including oils, wines, pottery and even board games.

ENTRANCE CORRIDOR

This corridor has a steady descent and was originally filled with limestone chips and rubble to prevent graverobbers digging. There is a second plaster door at the end, stamped with King Tutankhamun's royal seal. This door also shows signs of having been opened.

STAIRCASE

16 steps descend through bedrock toward a doorway. This doorway was sealed and plastered but showed signs that it had been penetrated by ancient graverobbers at least twice.



Valley of the Kings

Before Tutankhamun's discovery, the Egyptian desert had already revealed a bounty of treasures and tombs

ANTECHAMBER

This chamber was found in a state of organised chaos, packed full of an array of precious items including King Tut's throne, two life-sized statues of the king and a selection of chariots. The walls are unusually rough and undecorated, adding to the idea that this was a speedy, unexpected burial.

Crowned in 1332 BCE, King Tutankhamun only ruled for nine years before his death

BURIAL CHAMBER

This is the only chamber in the tomb that is decorated, with the walls painted bright yellow and showing scenes of Tutankhamun with various deities. The unusual size and lack of detail of these paintings contribute to the idea that it was a hasty burial. The room is filled by four wooden shrines that surround the golden sarcophagus, which contained three coffins, the last of which housed the mummified remains of the boy king.

TREASURE TROVE

A total of 5,398 artefacts were found in the tomb, including archery bows, trumpets and a dagger made from a meteorite.

TREASURY

Accessed by an unblocked doorway, this room was packed full of over 5,000 objects, most of them associated with the funeral or rituals surrounding death. This room also contained two mummified foetuses that many believe were the stillborn children of the pharaoh.

How to build the ULTIMATE ROCKET

The megarockets that could launch missions to the Moon, Mars and beyond

Words by **Jonathan O'Callaghan**

NASA tests a model of its SLS rocket in a wind tunnel

The SLS's liquid hydrogen tank (right) is nearly 40m tall

Rockets come in a variety of sizes, from the relatively small to the monstrously big. It's those bigger rockets, however, known as heavy-lift rockets, that really stir up some major excitement. Just recently we were treated to the launch of SpaceX's huge new Falcon Heavy rocket, the most powerful rocket in operation today. But we've had bigger rockets before, and in the near future we'll have even more powerful megarockets that will put their predecessors to shame.

Building a rocket is no mean feat. Essentially, you've got one or more powerful jet engines strapped to a tall, narrow structure. That engine has to get your rocket moving fast enough to escape the pull of Earth's gravity. While some rockets are more powerful than others, they all work under the same basic principles. In order to send something into space, you not only need to fight against Earth's gravity, but you also need to be going fast enough to enter orbit.

Consider throwing a ball forwards – the faster you throw it, the further it will go, but it'll always come back to Earth. If you were some sort of superhuman, however, and could throw it hard enough, then you could theoretically make it go all the way around Earth and hit you in the back of the head.

It's the same idea with rockets. On the smaller scale you've got sounding rockets, which can take cargo weighing up to a few hundred kilograms on short 'hops' into space. They have small engines capable of thrust of more than 450 kilograms of force, which is not enough to reach orbit. Even so, they can send their cargo beyond the Karman Line – the official line of space 100 kilometres up – for minutes or hours. As you move up the rocket sizes, you move up in thrust as well as size. The more thrust a rocket has, the further it can go. If your rocket is powerful enough, you'll be able to send cargo, or even people, into Earth orbit. From there, you can use a smaller engine to then leave Earth's orbit. This is how we've sent spacecraft to the Moon and beyond.

At the upper end of the scale you'll find SpaceX's heavy-lift rocket, the Falcon Heavy, which has 2.3 million kilograms-force of thrust. It launched for the first time on

"SpaceX's Falcon Heavy is the most powerful rocket in operation today"

NASA's Saturn V rocket consumed around 20tn of fuel per second

Saturn V

NASA's Saturn V rocket was developed in response to the Soviet Union placing the first human in space, Yuri Gagarin, in 1961. The rocket's purpose was to launch astronauts to the Moon, which it did successfully on six occasions. But to do that, the rocket needed to be big, and it needed to be powerful. So NASA went about building the biggest rocket the world had ever seen, towering 110.6 metres high. With a thrust of over 3.4 million kilograms-force, it was capable of launching all the components of the Apollo mission in a single launch. This made it the world's first ultimate rocket. So far it remains unbeaten and the holder of the accolade of most powerful rocket ever.

6 February 2018 to global acclaim, and it's capable of taking 63,800 kilograms of cargo into low-Earth orbit. It's not the most powerful rocket ever launched though. That honour belongs to NASA's Saturn V rocket, which was launched 13 times in the 1960s and 1970s. With an incredible 3.4 million kilograms-force of thrust and towering some 111 metres tall, it was capable of taking 140,000 kilograms into orbit. NASA is also developing a new heavy-lift rocket called the Space Launch System (SLS), which will have 4.2 million kilograms-force of thrust. It's expected to fly in 2020 at the earliest.

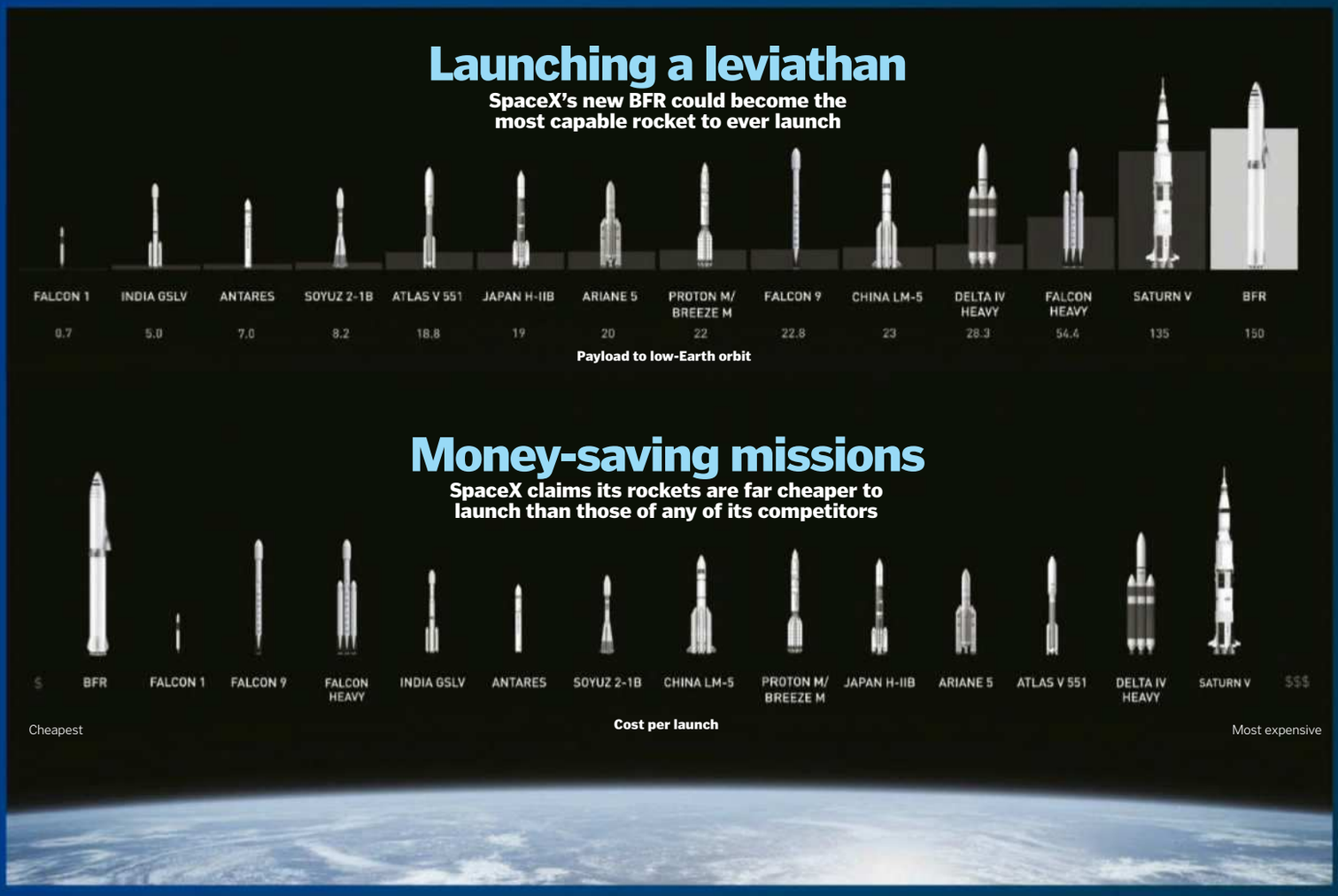
Heavy-lift rockets are important as they enable the launch of bigger and better spacecraft to a greater distance. The more thrust there is, the more fuel that can be taken into orbit, and thus the further and faster the rocket can go. While smaller rockets have been used to travel to destinations like Mars, Saturn and even as far out as the dwarf planet Pluto, these bigger rockets mean a reduction in the time taken to travel there and an increase in the amount of equipment that can be transport. NASA's Saturn V rocket, for example, enabled a whole spacecraft, lunar lander and lunar ascent vehicle to be taken with humans to the Moon in a single flight.

All rockets rely on using either liquid fuel or solid fuel. The former uses fuel like kerosene, along with an oxidiser – normally liquid oxygen. Using this set up you can control the flow of fuel to the engine, allowing you to turn the engine off and on. This is particularly useful if, say, you want to try and land your rocket boosters on the ground – as SpaceX has been doing for the last few years. Solid fuel, meanwhile, uses fuel and an oxidiser that is pre-mixed. Like a firework, once it's ignited you can't turn it off, but it's useful because it's simpler, safer and cheaper. Solid rocket boosters were used alongside a liquid-fuel rocket on the Space Shuttle to give it an extra kick to reach orbit, and they'll be used on the SLS.

"Heavy-lift rockets enable the launch of bigger and better spacecraft"

The SLS will have two solid rocket boosters on the side and will not be reusable

SpaceX's Falcon Heavy, on the other hand, uses three liquid-fuelled rocket boosters. The reason is so that SpaceX can restart the rockets on their way back to Earth, allowing them to touch down back on the ground or a drone ship, as they have done with their Falcon 9 rockets. On their maiden Falcon Heavy launch, two of these boosters touched down simultaneously in a stunning event, while the third unfortunately just missed its landing on a ship. By reusing these boosters, SpaceX hopes to dramatically undercut its competitors on price. The Falcon Heavy costs just $90 million to launch, while its nearest competitor, the Delta IV Heavy, is at least four times that – and half as powerful.



SpaceX had originally planned to use its Falcon Heavy rocket to launch humans, but they're now already working on their next project – the bigger and better Big Falcon Rocket (BFR). First teased by CEO Elon Musk in 2016, this huge rocket is intended to one day enable us to colonise Mars by launching about 100 people at a time. Towering 106 metres tall, it will be capable of taking 150,000 kilograms into orbit (more than the Saturn V), with a reusable spaceship on top of a large booster below. The company wants to start launching it in 2020, although some are sceptical of SpaceX's bold claims.

NASA's SLS, in comparison, is intended to launch smaller spacecraft with crews of six people or so. NASA wants to use this rocket to build a new space station in lunar orbit, send humans to the Moon and possibly one day send humans to Mars. With an upper limit of just 130,000 kilograms to orbit, however, and with no plans to make the rocket reusable, many are questioning why NASA is building it – at a cost of $2.6 billion (around £1.9 billion) a year – when SpaceX appears to be making such great strides. Whether the SLS actually sees the light of day remains to be seen. But with a first launch touted for 2020, if it does get built, it might look rather paltry compared to the BFR.

One thing that's for sure though is we're likely to see some new rocket tests in the near future. Typically, when a rocket is tested for the first time, it includes some sort of test mass – like a block of concrete – although it often includes something of scientific value as well, like a student-led experiment. Elon Musk chose not to follow this tradition on the inaugural launch of the Falcon Heavy rocket, instead sending his own Tesla Roadster car into space on a journey that will take it out to the orbital path of Mars and back again. It will likely remain on this path for millions of years until it eventually hits another body.

The first flight of the SLS will send an unmanned NASA spacecraft, the Orion vehicle, on a journey around the Moon. We're also expecting to see another heavy-lift rocket, Jeff Bezos' Blue Origin's New Glenn rocket, launch in the next few years.

These new megarockets provide us with a range of new capabilities. Able to take bigger objects into orbit in larger quantities, they could enable some rather grandiose missions. Already the Falcon Heavy has sent waves through the launch industry with its low cost. Whether SpaceX can continue making headway, and what impact NASA's SLS will have, will be revealed in due course, but the next few years will certainly be exciting.

A brief history of SpaceX

How Elon Musk's company went from start-up to stardom in less than two decades

2002

SpaceX is founded and, despite some initial hurdles, it completes construction of its first rocket – the Falcon 1 – in 2006.

2008

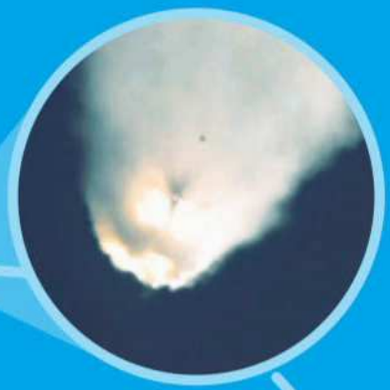
After three failures, and on the brink of financial ruin, SpaceX successfully launches its Falcon 1 rocket from Kwajalein Atoll, an island in the Pacific Ocean.

2012

Following a huge injection of funds from NASA, SpaceX's Dragon spacecraft successfully berths with the International Space Station (ISS), the first private spacecraft ever to do so.

2015

A Falcon 9 rocket explodes on its way to orbit less than three minutes after launch – a major setback for the company.



2016

A Falcon 9 rocket explodes during pre-launch testing. The cause of the failure is later found to be a tank of helium rupturing.

2017

SpaceX reuses one of its orbital rocket boosters, the first time this has ever been done, ushering in a new age of low-cost rocket flight.

2017

Elon Musk outlines plans to build a huge new rocket, the Big Falcon Rocket (BFR), to take humans to Mars in a decade.

2018

SpaceX successfully launches its Falcon Heavy rocket for the first time, the world's most powerful operational rocket.

The launch of the Falcon Heavy took Musk's own Tesla Roadster car into space

The Falcon Heavy's inaugural launch saw two boosters land simultaneously

FALCON HEAVY

Inside the SpaceX behemoth that wowed audiences in February 2018

Second stage
The second stage of the rocket has a single Merlin 1D engine to take the spacecraft on the rest of its journey after detaching from the boosters.

Size
The Falcon Heavy is 70m, 12.2m wide and has a mass of over 1.4mn kg.

Reusable
All three of the main boosters on the Falcon Heavy are reusable, capable of landing on the ground or on floating drone ships.

27 engines
The Falcon Heavy uses 27 Merlin 1D engines at its base to achieve its immense thrust, using a mix of kerosene and liquid oxygen as fuel.

31 engines
The BFR will have 31 of SpaceX's new Raptor engines to produce enough thrust to lift 150,000kg into orbit, more than the Saturn V.

"The Falcon Heavy has sent waves through the launch industry"

DID YOU KNOW? *Musk says the BFR will eventually replace both of SpaceX's existing rockets, the Falcon 9 and the Falcon Heavy*

Spaceship
The second part of the rocket is the reusable spaceship, which will apparently be capable of launching 100 people. It's 48m tall and 9m wide.

Payload fairing
The case around the nose cone, known as the payload fairing, detaches in space. SpaceX have been attempting to reuse this too in efforts to further bring down the cost of a launch.

Deep space destinations
The entire system is designed to be reusable, and Elon Musk envisages the BFR being used for trips to Mars and beyond. Ultimately, he wants to colonise Mars using the BFR.

Fuel
The BFR will use supercooled liquid methane and oxygen to power its engines. It will have a thrust of 5.4mn kg of force.

Booster
The huge single main bottom booster of the BFR, called the BRB, measures 58m tall. The whole thing will be reusable.

PROS AND CONS OF REUSABLE ROCKETS

1 They're really cheap
Being able to reuse a rocket means the cost of launching can be greatly reduced by ten times or more, as the only costs are fuel.

2 Refurbishment is a pain
Reusable rockets must be refurbished after each launch, although the costs of doing so are still much less than building a new rocket.

3 More launches
If the turnaround time on each rocket can be lessened, then the number of rockets that can be launched can be increased substantially.

4 Testing, testing, testing
As the rockets are used over and over again, they can be tested repeatedly and modified to sort out any minor problems, rather than engineers having to start from scratch with a whole new rocket.

5 Less waste
Discarding rockets in the oceans or on land, as is often done on expendable launches, has been likened to throwing away an aircraft after every single flight.

6 Wear and tear
Reusable rockets must be thoroughly checked and tested after each landing to make sure they are still safe to fly again.

The BFR could be used for satellite launches, ISS missions, journeys to the Moon and beyond

The BFR plays a major role in Musk's Mars colony plans

How SpaceX's huge proposed rocket will take humans to Mars

BIG FALCON ROCKET (BFR)

Born from chaos

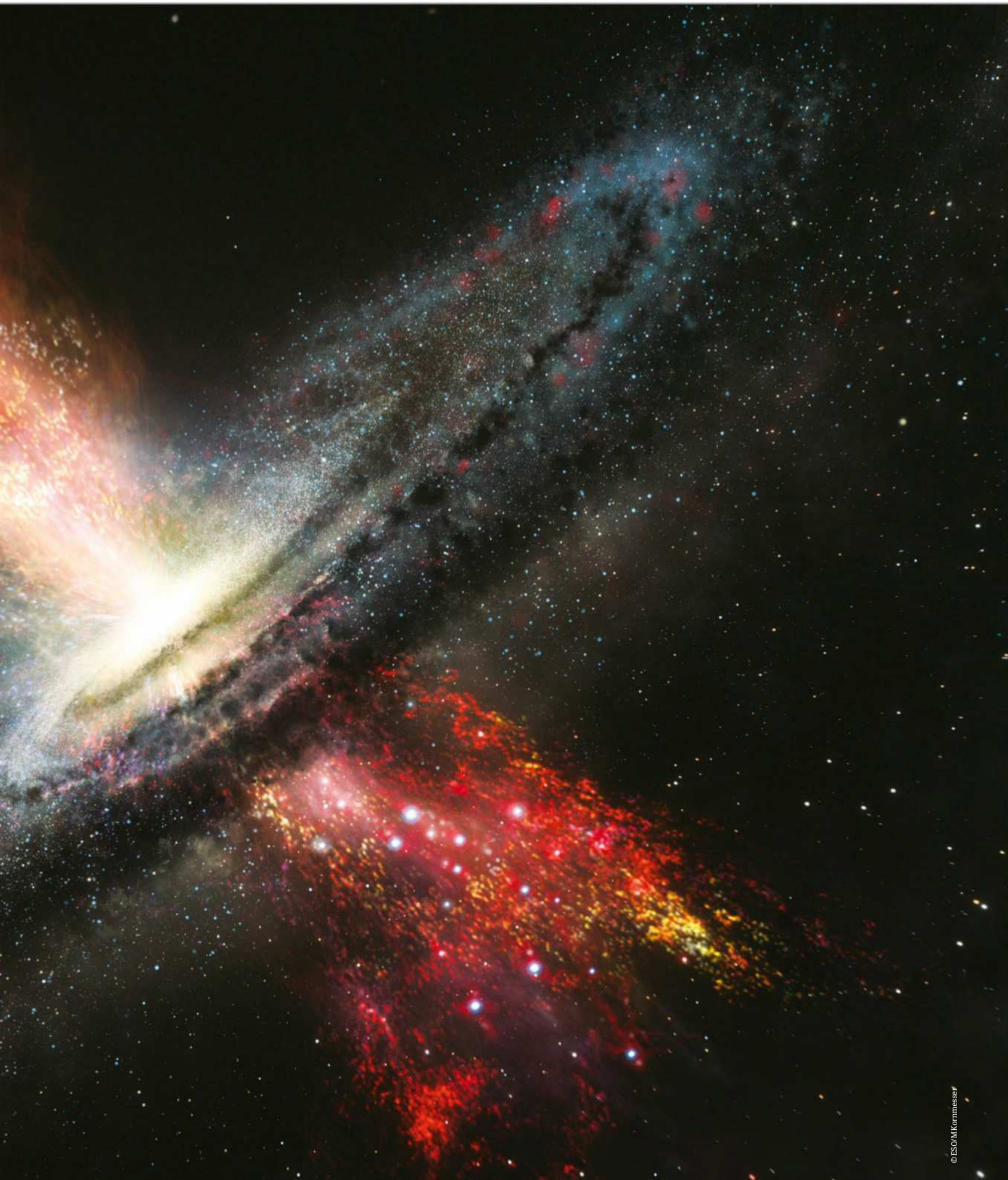
Stars can form even in some of the universe's most extreme environments

This artist's impression depicts the process of star formation that occurs within the outflows of a supermassive black hole. Outflows are huge winds of material that are ejected from around an active galactic core, powered by immense amounts of energy from the supermassive black hole lurking at its centre.

This type of star formation was only discovered by astronomers last year using observations from the European Southern Observatory's (ESO) Very Large Telescope. While watching an ongoing galactic collision 600 million lightyears away, the team found evidence of new stars forming in the cosmic winds blasting out from one galaxy's core.

The stars born in the outflow are estimated to be less than a few tens of millions of years old and are much hotter and brighter than those that form under less extreme conditions. The new stars were also forming very rapidly – astronomers estimate that the stars that form each year would be equivalent to 30 times the mass of our Sun in total.

The stars born in the outflows that astronomers observed account for over 25 per cent of all star formation in the merging galaxy system



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Ghost galaxy

The cosmic case of the missing dark matter

Most galaxies that astronomers observe form distinct shapes, like our own spiral Milky Way. However, Hubble has recently imaged an incredibly faint and tenuous galaxy, which seems to have very few stars for its size. It has no distinct central region, is not spiral or elliptical in shape and there is also no evidence that it has a central black hole.

Observations suggest that this galaxy, named NGC 1052-DF2, has less than 1/400th of the dark matter that we would expect a galaxy of this size to contain. Dark matter is believed to act like an invisible 'glue' that holds normal matter together, and astronomers don't yet understand how a galaxy can form with so little of it. One theory is that the nearby giant elliptical galaxy NGC 1052 could have influenced the development of nearby galaxies, affecting their dark matter levels.

Scientists are now searching for more of these ultra-diffuse galaxies to discover more about the role of dark matter (or the lack of it) in galaxy formation and evolution.

NGC 1052-DF2 is about the same size as the Milky Way but contains 0.5% as many stars

RemoveDebris

How this small satellite will test space-cleaning tech

Earlier this month, the RemoveDebris mission launched to the ISS ready to demonstrate space junk clearing techniques. Once released into orbit, the prototype platform will release two tiny cubesats to play the role of some target trash. RemoveDebris will track the cubesats, testing out lidar and camera technologies to help analyse the space junk.

The mission will also be demonstrating a couple of recapture methods. RemoveDebris will attempt to catch one of the cubesats in a net, and it will also fire a small harpoon at a target to see how effective this technique would be in microgravity.

At the end of the mission RemoveDebris will deploy a large space sail to increase the drag from air molecules in the upper atmosphere. This will slow the craft's orbit, bringing the satellite back towards Earth where it can burn up in the atmosphere.

The RemoveDebris platform was built at the Surrey Space Centre, UK

Dragsail
RemoveDebris will deploy the dragsail to speed up the de-orbiting process, ensuring the craft and any collected space junk burn up in the atmosphere more quickly.

Harpoon capture
During the mission, RemoveDebris will test whether or not harpoons are an effective way to catch orbiting space junk.

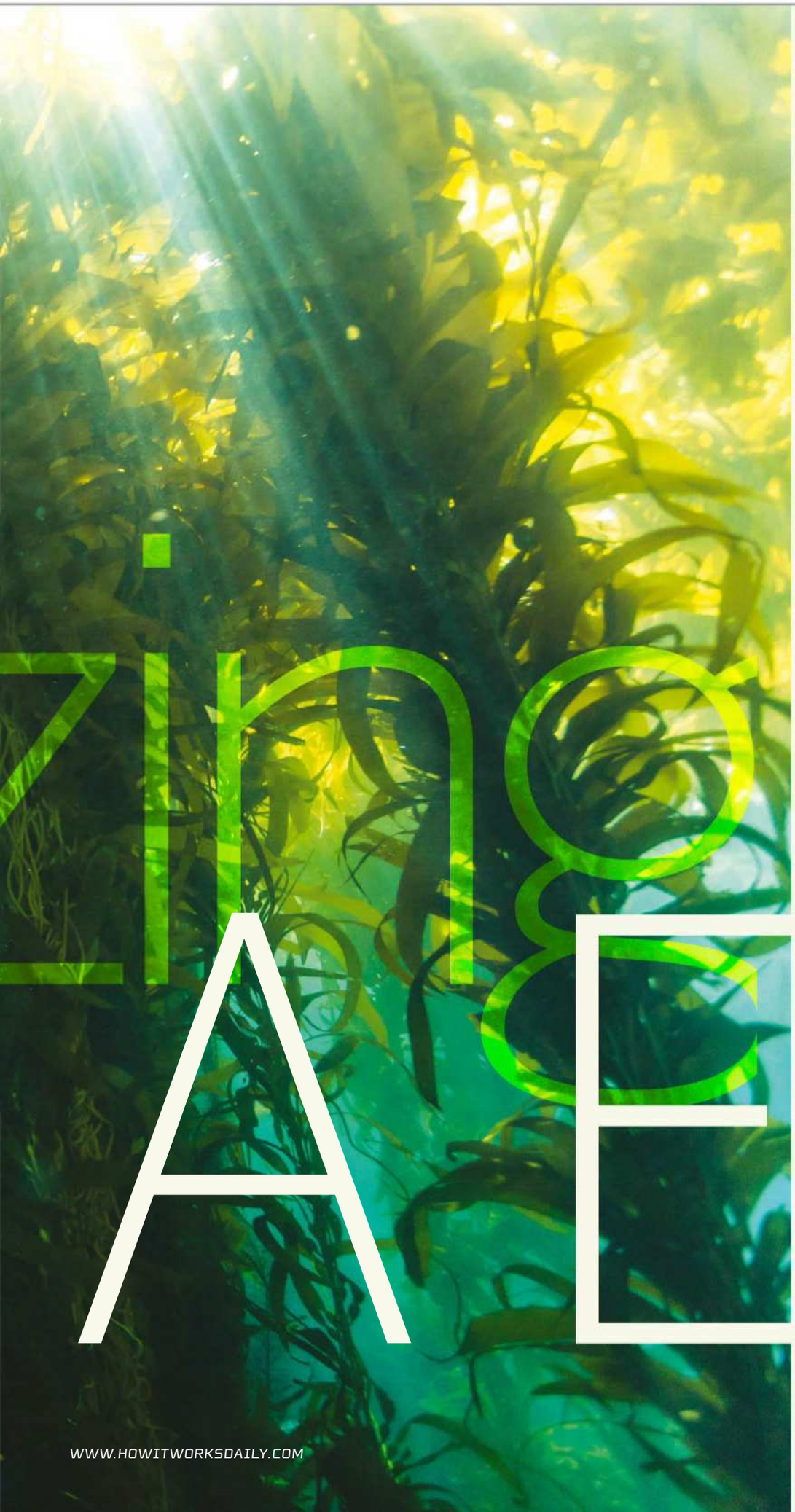
Vision-Based Navigation experiment
The main section of the RemoveDebris craft includes a camera and lidar to monitor and analyse the debris it's tracking.

Net capture
One of the released cubesats will be the target for a net capture demonstration, snaring the satellite before de-orbiting.

ALGAE

These organisms are more than just green slime - they have shaped human history and will go on to protect our future

Words by **Charlie Evans**



zing ALGAE

You can find algae almost anywhere you can find water, from magnificent giant kelp forests rising from the ocean floor to the thin green film resting on a shallow pond. Over millions of years they have evolved to survive in the most extreme environments: deep within the ice of the Arctic, around acidic ocean vents and in lava flows. Even in puddles, within the bark of trees, and inside droplets of dew on grass in the morning, microscopic algae diatoms will be thriving – they are masters of survival.

Algae have shaped life on our planet, and without them many of the species alive today wouldn't exist. Entire ocean ecosystems rely on them as a source of food, and over half of the oxygen we breathe comes from these remarkable organisms. Algae even play a role in the formation of clouds.

Throughout human history they have sustained us through famines and provided our species with medicine and nutrition. Today, having harnessed the power of algae, we use them in everything from food and pharmaceuticals to cosmetics and fuel. They are arguably the most important organisms in the world, but could they offer us even more in the future? Around the world people are looking towards algae to provide solutions to some of our planet's greatest challenges.

WHAT ARE ALGAE?

Algae are a genetically diverse group of over 48,000 different species. They come from a wide range of different evolutionary lineages that can't be truly classified as animals or plants. As a result they are lumped into a group known as protists – a category for predominantly single-celled living organisms that don't fit into any other. They are also ancient – fossil records indicate that red algae date back at least 1.6 billion years.

These simple organisms contain chlorophyll, which gives them the ability to photosynthesise, and they inhabit almost every body of water in the world. For freshwater and marine life, algae are the ultimate food source. Whether they eat algae directly, or eat an animal that does, every other organism in the water relies on them to obtain energy – they are the very foundations of the food chain, and some research suggests they might well be the foundations of all life.

The types of algae alive today are numerous, but they can be divided into two large groups – macroalgae and microalgae. You're probably familiar with macroalgae, or seaweed. Microalgae are their microscopic relatives.

Seaweeds are plant-like organisms that live in the ocean or coastal areas by attaching themselves to rocks. They don't have roots or leaves, instead absorbing all the nutrients they

need directly from the surrounding water. Their root-like structures are called holdfasts and these attach the seaweed to a hard surface, such as rocks or the seafloor. However, they don't have the ability to move (translocate) fluid or minerals like plants' roots do.

The largest of the macroalgae is giant kelp, which grows in expansive underwater forests that can rise taller than a 20-storey building from the ocean floor. Just like a forest on land, these aquatic jungles support ecosystems. From tiny critters living among the holdfasts to larger animals like seals and otters that use them as feeding grounds, many creatures rely on these places for shelter, food, play and sleep.

At the other end of the seaweed spectrum are the microalgae, single-celled organisms that are invisible to the naked eye. Many microalgae belong to a group called diatoms, which come in a kaleidoscope of colours and a variety of jewel-like shapes. Their unique silica shells, which form almost completely symmetrical patterns, are perforated to allow materials to diffuse across them. It's thought that they first evolved around the Jurassic period, and they can be found today in almost any body of water.

When these organisms die, they fall to the bottom of the sea or lake they inhabit and get mixed up with organic matter and clay to form a type of sediment known as diatomite. We use diatomite for many purposes, including water filters, cat litter, paints and facial scrubs. But the most valuable use of diatoms is within forensics – particularly in cases where a person may have drowned. In a victim who has inhaled water, diatoms can enter their bloodstream and spread around the body. By examining a cadaver, scientists can determine if the victim was alive when they entered the water if they find diatoms in the bone marrow. Investigators can even determine if a body was moved based on the particular species of diatom present.

SEAWEED SUPERPOWERS

We know that humans have eaten algae since prehistoric times. Edible seaweed is still a common ingredient in many countries, such as the nori that surrounds many Japanese sushi dishes. Algae are far less common in Western diets, but there are growing efforts to change this. Consuming algae is a delicious way of introducing more vitamins and minerals into your diet. They are particularly rich sources of beta-carotene (provitamin A) and iodine, which we need to make hormones that keep our metabolism healthy. Studies suggest that iodine deficiency is rather common in the UK (which ranks seventh in the ten most iodine-deficient nations in the world); increasing our seaweed consumption could help reduce this problem.

Entire ecosystems rely on the large kelp forests in our oceans

Perhaps the most valuable algal product is as a source of fatty acid supplementation in food products, as it contains huge amounts of both mono- and polyunsaturated fats. If you want to try edible seaweed, it is easy to introduce into your diet and can be eaten raw or dried.

However, algae can do more than just fuel our bodies – they can fuel our vehicles too. As our

"Increasing seaweed consumption in the UK could help reduce levels of iodine deficiency"

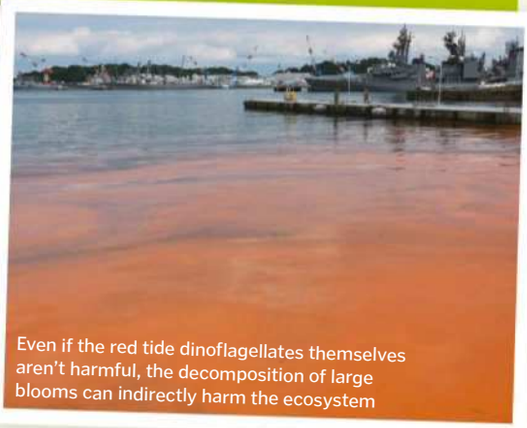
Dinoflagellates: dazzling and dangerous

Dinoflagellates are a curious group of organisms that are similar to diatoms: they are microscopic, single-celled and many species can photosynthesise. While they are sometimes classed as algae, scientists regularly debate this taxonomic placement because dinoflagellates' genomes are much larger than those of other algae.

One of the best-known properties of dinoflagellates is that some species can bioluminesce. If they are disturbed, they emit a flash of bright blue light, causing the surface of the water to sparkle. The secret to their stunning light display is within the cytoplasmic bodies called scintillons that involves a luciferase-catalysed reaction of luciferin. To us it looks beautiful, but the dinoflagellates use the light as a defence mechanism to scare away potential predators.

A more sinister property of these tiny organisms is that some species can form 'red tides'. These huge blooms of dinoflagellates occur when their populations rapidly increase, forming a visible discolouration across the water. Some species even release toxins that are harmful to marine wildlife. The decomposition of these large blooms can also result in a depletion of oxygen in the water.

More than 18 dinoflagellates are bioluminescent; the majority of them emit a blue-green light



Even if the red tide dinoflagellates themselves aren't harmful, the decomposition of large blooms can indirectly harm the ecosystem

Algae cultivators have to be inventive to find ways to keep the organisms exposed to the sunlight they need to thrive

planet starts to move away from fossil fuels, we have started to make biofuels from crops, but scientists are now investigating algal fuel as an even better alternative. The industry has even spawned a new word to describe it – algaculture. Some species of algae can produce more than 60 per cent of their dry weight in the form of oil, which is perfect for powering our vehicles. Even better, algae isn't a fussy grower. Unlike soy or corn, cultivators wouldn't need to drain the Earth's freshwater, because algae can thrive in salt water or even sewage. It would also give humanity the opportunity to utilise land that is unsuitable for traditional agriculture.

There are benefits for the environment too – devastating oil spills would be a catastrophe of the past, as algal biofuel is almost completely harmless. Two possible species that are being investigated as a new fuel source include sargassum and chlorella, which have a harvesting cycle of less than ten days, meaning fuel could be produced much faster than the annual cultivation of current biofuel crops.

ALGAE IN THE FUTURE

Algae has shaped human history and every ecosystem on our planet, and it plays a part in controlling our climate, but what will these protists be helping us with in the future? Companies around the world are using these organisms as architectural cladding, lampshades, yarn and textile dye. It could even help us tackle climate change and plastic pollution. Every plastic straw you ever used still

Foraging for your own seaweed snacks

- **Check the law in your country to make sure you have permission to be harvesting seaweed in the area, and check that the water is clean.**
- **Select the species you would like to harvest and cut it carefully with scissors rather than pulling up the seaweed.**
- **Harvest the seaweed across a wide area, taking a little from each space to ensure that you don't do any damage to the growth of the species in the area.**
- **When you get home, clean the seaweed by washing it in a bowl of water at least three times, changing the water between each wash. Make sure all of the sand is removed and there are no little critters still attached.**
- **Almost all seaweed tastes great baked in the oven for half an hour, but to make the most out of your well-earned snack, check the best way to prepare it.**

Seaweed on toast can make a delicious and nutritious snack

Q&A

Tim van Berkel

Conservationist Tim van Berkel cofounded the Cornish Seaweed Company, which harvests quality edible seaweed from the southwest coast of the UK. The company is the first in England to trial seaweed cultivation, and it's the largest seaweed company in the country.

Which seaweeds are you harvesting?
We harvest a lot, including kelp, sea spaghetti, bladderwrack, dulse, gutweed and sea lettuce. We have also just started a small cultivation trial using sugar kelp. At the moment we only harvest from the wild in Cornwall, but the trial we have started is on lines in the sea.

Is there any impact on the environment to harvesting or cultivating seaweed?
We only work with local plants and we make sure we do it in an area where we don't impact on other species that are already there. The cultivation itself is beneficial for the environment. You don't need fertiliser or pesticides, and it soaks up carbon dioxide, nitrates and phosphates. It also forms a safe zone where fish and other animals can spawn.

How do you harvest seaweed from the wild?
We go down to the beach at low tide and walk around with scissors and give them a bit of a haircut. Then we wash it and dry it in specific drying kilns we developed ourselves. We also harvest by free-diving for some species, because it's easier than slipping over the rocks. We use a snorkel, mask, wetsuit, weight belts, and we go up and down 50 to 100 times to get the seaweed. It's fun. If the weather is good, it's great!

Are there any threats to the seaweeds' agriculture, such as disease or grazing marine life?
The biggest danger we have is climate change, especially the kelp and sea spaghetti – they are disappearing. We see species of kelp that shouldn't be here, but it's making its way up – that could take over our native species.

Why is seaweed so important to us?
It's the most nutritious food source in the world; it has more vitamins and more minerals than anything else you can think of [sic]. It's incredible. We are now learning they contain substances that are antiviral, antibacterial and may help fight a range of diseases – it's phenomenal. And it does more. Bioplastics [made from seaweed] is going to be the next thing – it's going to save the world.

Which seaweed is your favourite to eat? Do you recommend any for our readers to try?
Try sea spaghetti; that is definitely the nicest you can eat straight from raw. Dulse is probably my other favourite. It's bacony, quite salty – I like to eat it raw as a snack or add it to a curry.

exists – and it will probably still exist when your great grandchildren are born. This is because plastic doesn't degrade, it just breaks down into smaller and smaller toxic pieces. It's become a massive problem for our oceans, but scientists and designers have started to look at algae for a solution. Both new and established companies are investigating ways of using seaweed-based bioplastics to replace conventional plastics in their products, from bottles to car bodies.

Algopack, based in Saint-Malo, France, is one of these pioneering companies. They've developed a bioplastic that uses a naturally occurring polymer from algae to produce fully biodegradable granules that completely decompose within 12 weeks in soil and just five hours in water. And they're not the only ones who want to start a bioplastic revolution.

Dutch designers Erin Klarenbeek and Maartje Dros have spent years perfecting a bioplastic polymer that can be used to print 3D objects. The entrepreneurs cultivate algae before drying and processing it, and they can make everything from tableware to shampoo bottles.

Even larger companies are now getting involved. In 2009, the car manufacturer Toyota announced that it is looking to develop a kelp-based bioplastic to be used for car bodies. "[Carbon-fibre-reinforced plastic] is made from oil. In the future, I'm sure we will have access to new and better materials... In fact, I want to create such a vehicle from seaweed because Japan is surrounded by the sea," said the project manager, Tetsuya Kaida.

Can you imagine yourself sipping from an algae water bottle before preparing yourself a seaweed snack, then getting into your algae bioplastic car? One day this may be a reality.

Seaweed distribution

These global species live on the shoreline, each thriving in a different spot

Channelled wrack
This deep-green-coloured brown algae is found high on the shoreline attached to a hard substrate.

Fucus spiralis
This variety displays a characteristic ridge along the edge of its receptacles.

Ulva lactuca
Sporting crumpled, transclucent fronds, this species is found along all but the most exposed shorelines.

Gutweed
This bright green algae is found in rock pools and can attach itself to sand, mud and hard substrates.

Bladderwrack
This mid-shore algae has distinctive paired air bladders that keep its fronds afloat.

Indonesian seaweed farms are an important food source for many local people

Seaweed dishes around the world

JAPAN
Nori *(Pyropia yezoensis/tenera)*
This dried red algae is used to wrap sushi and to garnish/flavour noodles and soups. It is farmed in the ocean and made into sheets in a process similar to papermaking.

PHILIPPINES
Sea grapes
(Caulerpa lentillifera)
This is a soft and succulent seaweed eaten raw with vinegar, usually in a salad dressed with fish sauce and accompanied by chopped raw shallots and tomatoes.

ICELAND
Dulse *(Palmaria palmata)*
This bacon-flavoured seaweed is eaten in Iceland, historically by boiling it with milk or eating it alone with butter. Today it is used to flavour soups and casseroles or garnish dishes.

WALES
Laverbread *(Porphyra umbilicalis)*
A puree is made from boiling laver seaweed and mixing it with lemon juice, olive oil, salt and pepper. It is served with shellfish, hot buttered toast or as part of a fried breakfast.

NEW ZEALAND
Karengo *(Pyropia columbina)*
Karengo is eaten by the Maori of New Zealand, who pick and Sun-dry it. It is then steamed or simmered before being used in dishes that include soups, rice and omelettes.

The longest giant kelp on record reached a height of

65m

– equivalent to a 21-storey building!

50–85%

The estimated proportion of Earth's oxygen produced by algae

Around **1,000km²**

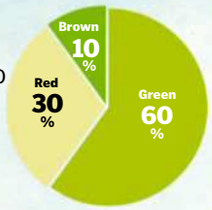
of shallow coastlines are farmed for nori in Japan

Algal blooms can contain up to

20 MILLION

dinoflagellate cells per litre

There are approximately 16,500–19,500 species of the edible brown, red and green seaweeds, of which...



Just **1g**

of seaweed can provide between 11–1,989% of your daily recommended iodine, depending on the species

Fucus serratus
This olive-brown seaweed displays serrated edges, and its fronds have an orange peel-like texture.

Dulse
Similar only in name to the pepper dulse, this species has tough, red, blade-shaped fronds.

Dumonts
This small red algae has irregular dark red-brown tubular fronds and flourishes in winter.

Nori porphyra
This seaweed consists of delicate, thin purple-brown fronds and is able to bore into calcium carbonate substrates.

Forest kelp
This tough kelp grows in flat, broad blades with large branched holdfasts.

Pepper dulse
This small, red, cartilaginous algae features flattened fronds and is found in the tidal zone.

Sea spaghetti
As the name suggests, this brown seaweed resembles spaghetti. It grows from small, button-shaped thalli (roots).

Sugar kelp
This large brown kelp displays individual fronds with an undulating margin that resembles a frill.

India experiences the most dramatic monsoons in the world – many farmers there rely on the rains to sustain their agriculture

Monsoons explained

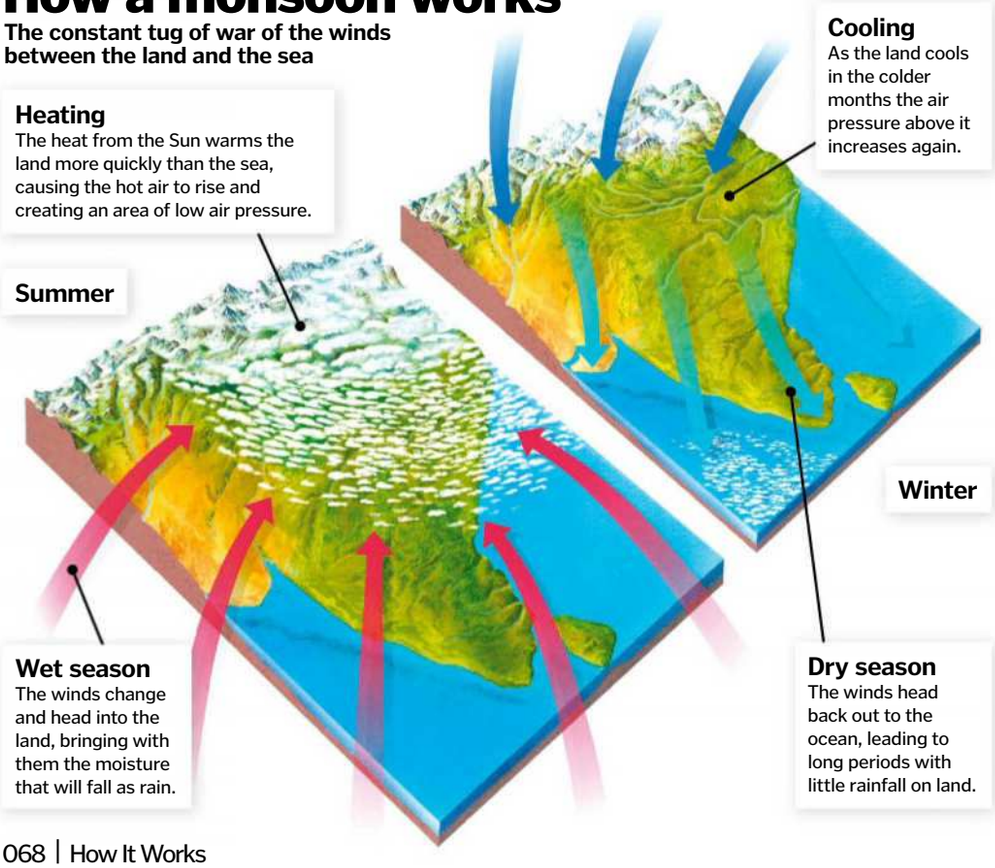
During these seasonal shifts, when it rains, it pours

When you think of a monsoon, you probably think of torrential rains causing flooding, but there is more to these downpours than a single storm. A monsoon is actually a reversal of wind direction. These weather events cause heavy rain in summer and dry spells in winter as the prevailing winds shift as land heats and cools.

There are only specific areas of the world that are susceptible to this extreme weather, known as monsoon zones, and these are typically found in subtropical regions. Countries that suffer from regular monsoons include Bangladesh, India, Thailand and Sri Lanka, and they can experience anything from violent thunder and lightning to harsh dust storms.

How a monsoon works

The constant tug of war of the winds between the land and the sea



The problem with palm oil

Discover the stats behind one of the most ecologically devastating industries

~34,520,000 tons
The amount of palm oil produced in Indonesia: that's 58 per cent of global production

26 million
Hectares of rainforest are estimated to be lost by 2025

6,000 tons CO_2
of carbon dioxide is released from every hectare of rainforest converted into palm oil plantation

~90%
of orangutans have disappeared over the last 20 years due to palm oil deforestation

Only 19%
of global palm oil **production is sustainable**

Around 300 football fields worth of rainforest are destroyed every hour for palm oil plantations

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Gemstones

Discover the chemistry that determines the captivating colours of these crystals

PEARL

Formula: $CaCO_3$
Hardness: 2.5–4.5 Mohs

Crystalline iridescent calcium carbonate forms in concentric layers produced inside shelled molluscs as a protective mechanism against trapped grains of sand. Although they are not formed through geological processes, pearls are still considered to be gemstones.

TURQUOISE

Formula: $CuAl_6(PO_4)_4(OH)_8.4H_2O$
Hardness: 5.0–6.0

Turquoise is an opaque blue-to-green mineral composed of hydrated phosphate of copper and aluminium. Turquoise stones may also have splotches or spider web-like patterns.

OPAL

Formula: $SiO_2.nH_2O$
Hardness: 5.0–6.5

Opal is a form of amorphous hydrated silica featuring small points of shifting colour caused by light being interfered with, refracted or diffracted.

JADEITE

Formula: $NaAlSi_2O_6$
Hardness: 6.5–7.0

Formed in metamorphic rocks under high pressure and relatively low temperature conditions, jadeite's green colour is caused by the presence of chromium, although some iron impurities may also be present.

PERIDOT

Formula: $(Mg,Fe)_2SiO_4$
Hardness: 6.5–7.0

The rich yellow-green colour of peridot is due to presence of iron 2+ ions replacing magnesium ions in some locations within the crystal's structure. The more iron it contains, the deeper the green will be.

GARNET

Formula: $A_3B_2Si_3O_{12}$
Hardness: 6.5–7.5

The deep red colour of garnet gems is caused by presence of iron 2+ ions. These gems form in distinct dodecahedral and trapezohedral vitreous (glass-like) crystals.

AMETHYST

Formula: SiO_2
Hardness: 7.0

The violet-colour of this quartz is caused by irradiation of iron 3+ ions. When heated, it loses its violet colour and often turns yellow, resembling citrine. Amethyst forms in naturally pyramidal crystals or inside of rocks as geodes.

CITRINE

Formula: SiO_2
Hardness: 7.0

Citrine is a yellow- or orange-coloured quartz. Its pale amber shades come from the presence of iron or aluminium impurities.

TOURMALINE

Formula: $(Na,Ca)(Mg,Li,Al,Fe^{2+})_3Al_6(BO_3)_3Si_6O_{18}(OH)_4$
Hardness: 7.0–7.5

Tourmaline crystals can occur in a wide range of colours from colourless to black. In the pictured form, the pink colour arises due to the presence of trace amounts of manganese ions.

The most valuable crystals form within the Earth's crust under great amounts of pressure and heat and are brought to the surface by volcanic or seismic activity. Each gemstone has a unique chemical composition that affects the way they absorb and reflect light. Our eyes can only see colours between 380–750 nanometres, so gemstones that absorb all of these wavelengths will appear black, while the ones that all light wavelengths can pass right through appear completely colourless. But when a crystal only absorbs some wavelengths as others pass through it, a captivating display of colour is created.

ZIRCON

Formula: $ZrSiO_4$
Hardness: 6.0–7.5

Zircon belongs to the nesosilicates group, and can display various colours due to impurities, including red, green and blue. It is thought to be the oldest known mineral found on Earth.

AQUAMARINE

Formula: $Be_3Al_2Si_6O_{18}$
Hardness: 7.5–8.0

Aquamarine crystals appear blue because iron 2+ / 3+ ions replace aluminium ions in some locations in the crystal structure. They are usually found as individual six-sided prismatic crystals.

EMERALD

Formula: $Be_3Al_2Si_6O_{18}$
Hardness: 7.5–8.0

Emeralds are a cyclosilicate variety of the mineral beryl that appear rich green due to the presence of chromium ions. Crystals contain numerous inclusions and surface breaking fissures.

SPINEL

Formula: $MgAl_2O_4$
Hardness: 8.0

Spinel comes in a variety of colours, include red and rose. These intense reds are caused by traces of chromium while orange and purple gems contain a mixture of iron and chromium.

TOPAZ

Formula: $Al_2SiO_4(F,OH)_2$
Hardness: 8.0

Pure topaz is in fact colourless, but varieties of blue or brown shades of topaz are caused by atomic-level imperfections.

ALEXANDRITE

Formula: $BeAl_2O_4$
Hardness: 8.5

The green hues of alexandrite are caused by chromium ions, although the gem's colour appears to change under different lights and different directions.

RUBY

Formula: Al_2O_3
Hardness: 9.0

Rubies can be pink to blood-red in colour, a tone caused by the presence of chromium ions which replace some aluminium ions at locations throughout the structure.

SAPPHIRE

Formula: Al_2O_3
Hardness: 9.0

Blue shades of this variety of corundum are caused by titanium and iron ions. Trace elements of chromium, vanadium or magnesium can create other colours, including pink, purple and green.

DIAMOND

Formula: C
Hardness: 10

Pure diamonds are colourless, but trapped nitrogen or boron atoms within the crystal structure can create a faint colour.

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A giant lily pad leaf is large and strong enough to support the weight of a child

Giant water lilies

The floating plants known for their enormous leaves and short-lived flowers

The *Victoria amazonica* is the largest species of water lily in the world and is native to South America. An individual plant can produce up to 50 leaves in a single season, and it's these leaves that make it so well known and prized as an ornamental plant.

The huge, circular leaves start off as spiny heads but then rapidly grow at a rate of half a square metre per day until eventually reaching more than 2.5 metres in diameter. The leaf is anchored by a long, submerged stalk, the stem of which is buried in the muddy waterbed below.

Not only are the leaves enormous, but they also have distinctive features that make them unique. The surface of the leaf has upturned rims and a layer of wax that repels water, while the underside of the leaf is purple-red in colour and consists of ribs covered in sharp spines.

It is the air that becomes trapped inside the spaces between the ribs that enable the leaf to float and even support heavy items – a mature leaf can hold 45 kilograms of weight. It's also quite likely that the spines function as protection against any creatures that swim below.

The submerged stalks of the *Victoria amazonica* can reach up to eight metres in length

© Getty: Wiki/Bilby

Lily flowers

The *Victoria amazonica* produces incredible flowers, with each plant producing one flower at a time, each one lasting just 48 hours or so. On the first evening that it opens the flower is female, appearing white in colour and smelling of sweet pineapple. A thermochemical reaction then occurs in the flower, which gives off heat. This scent and the heat attract beetles, which dispose of pollen that they've collected from other plants. While fertilisation takes place the beetles find themselves trapped inside the flower as it closes until the following evening.

The next day, the flower changes to male and, as the anthers mature, it starts producing its own pollen. By the time it opens up again that evening it has lost its scent and heat and appears purple-red in colour. No longer finding it attractive, the beetles escape and head towards white flowers on the other plants. Equipped with fresh pollen, the whole process starts again. Meanwhile, the flower left behind closes and sinks below the water.

The giant lily's flowers bloom at night, opening at dusk and closing at dawn

STRANGE SOUNDS

Discover some of Earth's most mysterious noises and the science behind their surreal sound waves

Skyquakes

Strange booms in the upper atmosphere can make it seem like an extraterrestrial life form is about to descend upon humankind. However, these weird noises aren't the result of little green aliens – they are in fact 'skyquakes', and they have been heard for centuries. Multiple explanations have been suggested for this phenomenon, from military action to meteorites, the release of natural gas to mini avalanches. There is, however, no definitive explanation, meaning the cannon sounds of a skyquake are still a mystery.

It has been suggested that skyquakes could be the result of gas escaping from underwater vents

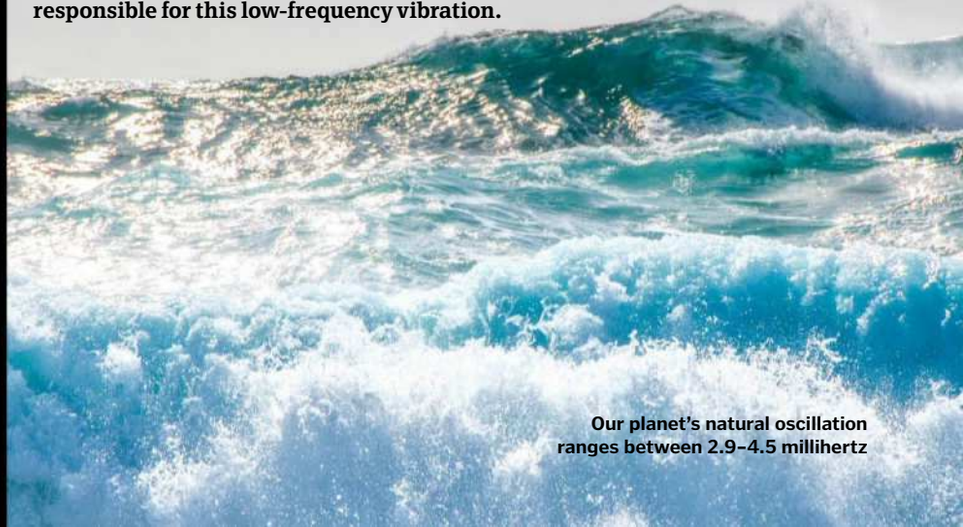
Batfish are just one of many fish species that make sounds underwater

Dawn chorus

At the breaking of dawn it's common to hear the chirping and tweeting of songbirds, but what about the bass and pops of fish? The songs of marine life are often reserved for marine mammal solo singers, but over an 18-month study at Port Hedland in Western Australia it was revealed that several fish choruses are harmonising at dust and dawn. From the foghorn sounds of black jewfish to the buzzing tones of terapontidae, at sunrise and sundown the sea is awash with marine melodies.

Earth's hum

Many machines come with that expectant humming sound, which is often proof they are working. The Earth is no different, but with a lack of a motor to investigate, scientists have been searching for the sound's origins. Last year, a study published by researchers from the Paris Institute of Global Physics recorded the relentless planetary hum deep below the motion of the ocean using seismometers. Undetectable to the human ear, it has been hypothesised that it's the global pounding of the ocean waves that could be responsible for this low-frequency vibration.



Our planet's natural oscillation ranges between 2.9–4.5 millihertz

The bloop

Lurking deep in the ocean is a sea monster so big it makes the blue whale look tiny, or at least that is what people thought back in 1997 when an almighty 'bloop' sound rose from the depths. The sound was picked up by hydrophones across the Pacific and emulated that of a blue whale. However, in order for it to have come from a marine mammal, the owner of the sound would have had to be about the size of the Eiffel Tower! It was later revealed that rather than a sea monster, the bloop was simply the very audible cracking of an ice shelf in Antarctica. Because the original recording was sped up to 16 times its usual speed, the cracking sounded like a big bubble popping, but when reduced to normal speed it sounded like one of the many examples of an ice shelf fracturing.

The bloop was recorded on hydrophones in 1997, rapidly increasing in frequency for one minute before completely disappearing

The aurora borealis creates cracking sounds under the right weather conditions

An acoustic aurora

Beneath the flowing light of the vibrant aurora borealis, popping, crackles and an almost static sound can be heard. The explanation for this subtle buzz is not one of spiritual communication, as previously believed, but an electrical discharge from the aurora. These bands of light are the result of solar flares interacting with the magnetic field of the Earth. Combined with a layer of trapped cold air and a build up of electrical charge, this results in the aurora's static song.

The bio-duck

Imagine being hundreds of feet below the ocean and through the sonar you hear the sound of what appears to be a duck. As odd of an idea as that is, that was the puzzling reality for a submarine crew in the 1960s. It wasn't until 2014 that the sound's origins were identified, and surprise, surprise, it wasn't a new species of marine duck but the singing of Antarctic minke whales. After 50 or so years of wondering what was quacking, a team of researchers tagged two whales to study their behaviour and movements, but they inadvertently uncovered the truth behind the mysterious sound.

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Lifecycle of the kangaroo

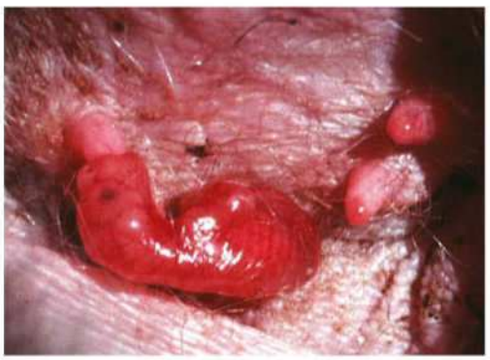
These big-footed marsupials have evolved an amazing lifecycle that is fully geared for the species' survival

A national symbol of the land down under, kangaroos not only look incredible bounding their way over the sun-scorched Australian outback, but they also have one of the most interesting and extraordinary lifecycles in the entire animal kingdom.

Mating happens all year round, and mother kangaroos are pregnant for around one month. When the baby (joey) kangaroo is born it is the size of a jellybean – the newborn is blind, hairless and so small that its mother can't even touch it yet. She licks a pathway through her fur and the joey uses this (guided by its sense of smell), along with its sharp claws, to make its way up her body. It reaches the safety of the pouch – virtually unaided – where it will continue its development.

Within the pouch are the mother's teats. These provide the young 'roo with a rich milk full of essential nutrients. The joey spends about eight more months growing in its mother's pouch before taking its first tentative hops outside.

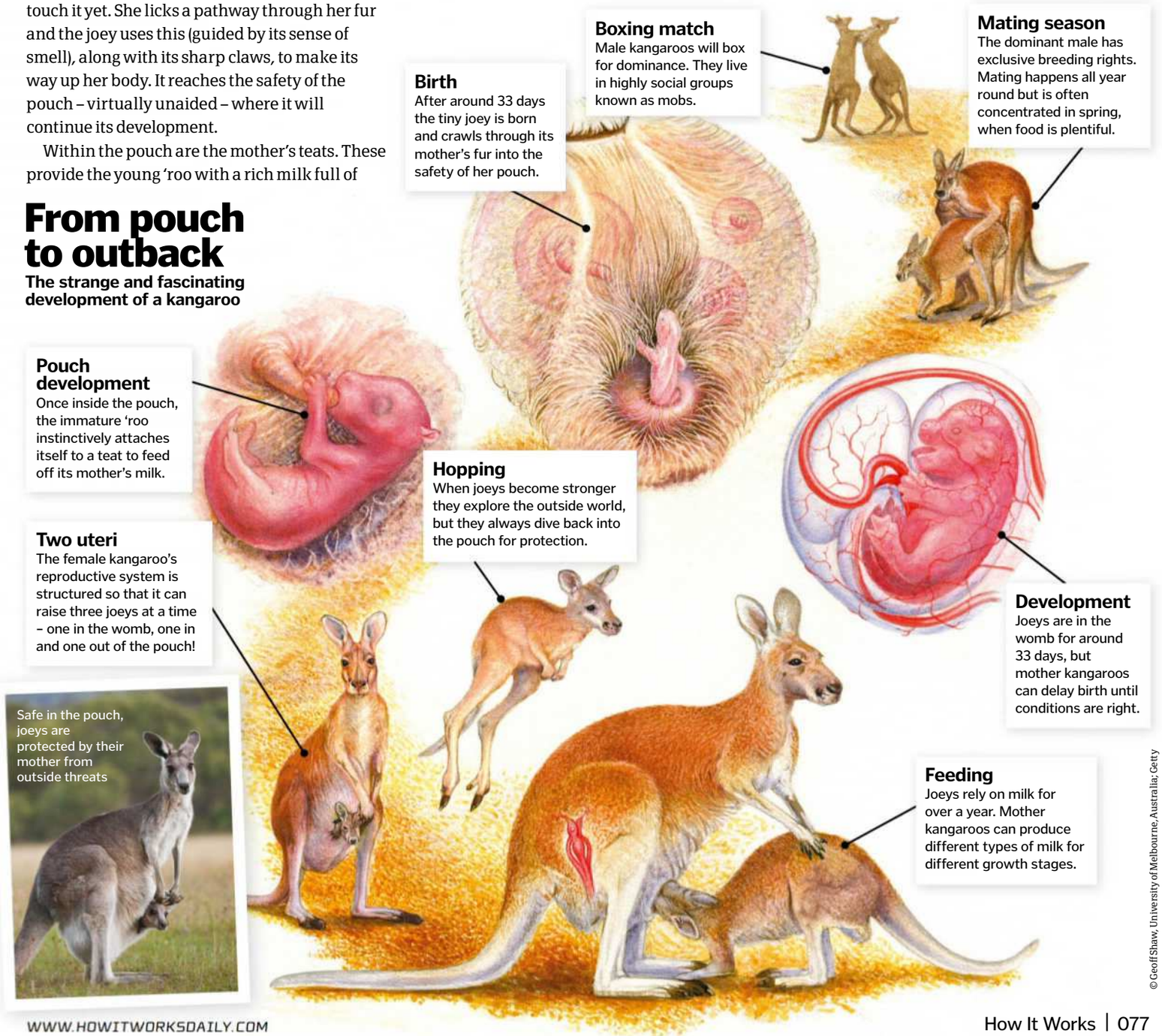
Joeys will suckle on their mother's milk until they are around 12–18 months old, when they will begin to adopt the usual kangaroo diet of grasses, leaves and ferns. The pouch is still very much a safe haven from the outside world, and joeys will still be carried in this comfortable papoose until they are kicked out to make room for younger brothers and sisters.



A newborn joey is about 2.5 centimetres long and weighs less than one gram! It latches onto its mother's teat to continue development in her pouch

From pouch to outback

The strange and fascinating development of a kangaroo



Boxing match
Male kangaroos will box for dominance. They live in highly social groups known as mobs.

Mating season
The dominant male has exclusive breeding rights. Mating happens all year round but is often concentrated in spring, when food is plentiful.

Birth
After around 33 days the tiny joey is born and crawls through its mother's fur into the safety of her pouch.

Pouch development
Once inside the pouch, the immature 'roo instinctively attaches itself to a teat to feed off its mother's milk.

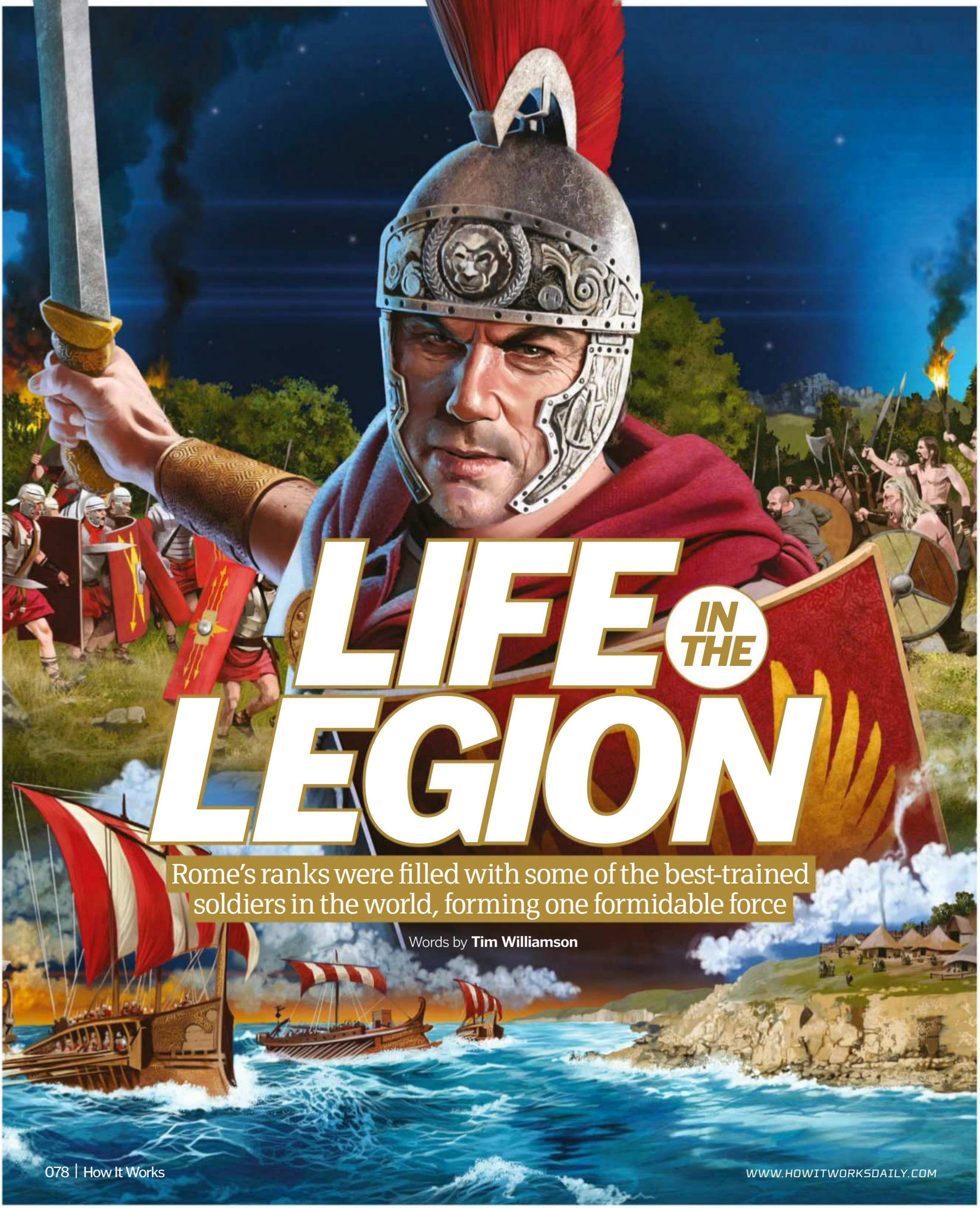
Hopping
When joeys become stronger they explore the outside world, but they always dive back into the pouch for protection.

Two uteri
The female kangaroo's reproductive system is structured so that it can raise three joeys at a time – one in the womb, one in and one out of the pouch!

Development
Joeys are in the womb for around 33 days, but mother kangaroos can delay birth until conditions are right.

Feeding
Joeys rely on milk for over a year. Mother kangaroos can produce different types of milk for different growth stages.

Safe in the pouch, joeys are protected by their mother from outside threats



LIFE IN THE LEGION

Rome's ranks were filled with some of the best-trained soldiers in the world, forming one formidable force

Words by **Tim Williamson**

Roman armies were highly organised and supremely disciplined entities of war. Each legion numbered around 5,000 men, all trained and armed to defeat enemies from all across the vast Roman territories. The backbone of a legion was its legionaries, heavy infantry with sworn allegiance to the Senate and the people of Rome (Senatus Populusque Romanus) and later to the emperor. However, the daily lives of these men weren't filled with glorious adventures fighting Rome's enemies but were instead governed by strict routine, endless hours of marching and yet more hours spent training.

These reenactors are playing the role of auxiliary cavalry, armed with spears and longer swords for cutting down the enemy

As a legionary, you would march, work, eat, fight and rest alongside the men of your contubernium, or squad. Each contubernium contained eight soldiers, with ten contubernia making up one centuria. At the end of each day's march, after constructing the legion's fortifications for the night, each squad would set up its own tent, then enjoy some precious down time. One servant was assigned to each squad, who would repair kit, cook, clean and carry out any general chores for the soldiers. At least one member of each squad would be assigned to guard duty throughout the night, before the camp rose at the crack of dawn and prepared to march once more.

> *"Officers trained their men using gladiatorial techniques and combat styles"*

TRAINING AND DRILLS

Officers trained their men mercilessly, using techniques and combat styles developed by gladiators. Experience of the competitive and bloody contests in the arenas had made gladiator trainers experts in teaching fighters how to best their opponents. New recruits practised with wooden swords and shields, which were heavier than the equipment they would be armed with in a battle. This was intended to build up strength and stamina for the real fight. Practising on wooden stakes, recruits repeated drills to strike at the head, legs and torso areas, all while dodging and blocking as if their lives depended on it.

New recruits would have to master the pilum (javelin) and the gladius (sword), as well as battlefield formations

The next stage of training was the armatura, a sparring exercise that pitched two soldiers head-to-head. Wielding blunted or covered blades to avoid injury, soldiers attacked and parried one another using the same techniques learned fighting the wooden stakes. Legionaries trained in this way throughout their careers so as to maintain their skills. In fact, it was so important to the legions that buildings were constructed especially for this purpose, so practice could continue regardless of the weather. Those who underperformed during training were punished with a reduction in their rations, heavy fines or even a rough beating from an officer.

Weakness or dissent in the ranks could mean the difference between victory and defeat on the battlefield, so strict discipline was often enforced through harsh punishments. Depending on the circumstances, crimes such as theft, desertion or even falling asleep on duty could be met with a whipping, demotion or even public execution – usually by being clubbed to death. In very rare circumstances where entire units ran away in the face of the enemy, the sentence of decimation was carried out – one in every ten of the accused would be executed. The fear of such a fate was usually enough to bolster the courage of any wavering squad or centuria.

BLOOD AND COIN

A regular wage was one of the key attractions for Roman recruits, and legionaries were the highest-paid units in the army. Through promotion and time served, soldiers could hope to receive pay-and-a-half (sesquiplicarius), and veteran troops eventually could get double pay (duplicarius). While auxiliary recruits were generally paid a little less than legionaries, they

A DAY IN ROME'S RANKS

Backbreaking work, relentless training and routine marches were just a few of the daily tasks facing legionaries

Washing

Soldiers were expected to maintain their own equipment but also their own personal hygiene during their limited free time each day. While barracks often had comfortable adjoining bathhouses, when on campaign troops would wash with whatever resources they could find.

Training

Soldiers were expected to train daily, practising for real combat with wooden swords, slings, bows and javelins. Repeating tough battlefield drills prepared soldiers mentally and physically to face the enemy for real.

Martial punishment

Discipline was essential in the army, and breaking any rules could earn a severe sentence. Theft, desertion, disobeying orders and other crimes were often punishable by demotion, beatings, flogging or even public execution by clubbing.

Building fortifications

All soldiers would help construct a new temporary fortification at the end of each day's march, building trenches and wooden walls around the camp. This meant that no matter where the army travelled, it could ensure some level of protection from enemy attacks at night.

Marching

An army would be regularly ordered to march up to nine hours per day, with each soldier carrying their equipment and rations, which could weigh up to 40 kilograms. Disciplined marching was often the first thing taught to new recruits.

had the additional lure of being granted full Roman citizenship on completion of 25 years' military service.

Anyone looking to earn a little more could seek out both wealth and glory in war. In the aftermath of a battle, generals were known to reward particularly brave actions, or those who had received grisly wounds in the line of duty. After the Battle of Dyrrhachium (48 BCE), for example, Julius Caesar was presented with a shield that had been pierced by over a hundred arrows – he rewarded its owner, a centurion, with riches and honourable promotion.

However, during campaigns men often found less honourable ways to gain wealth. After a successful conquest, generals would often allow their men to pillage and loot, enabling legionaries to fill their pockets with the spoils of war. In many extreme cases, generals used this as a way to secure the loyalty of the army and prevent possible mutinies in the ranks. Legionaries lucky to live long enough could receive a bonus of 12,000 sesterces (praemia) upon retiring or even be granted land to settle down, often within the same region in which they served.

DECLINE OF THE LEGIONS

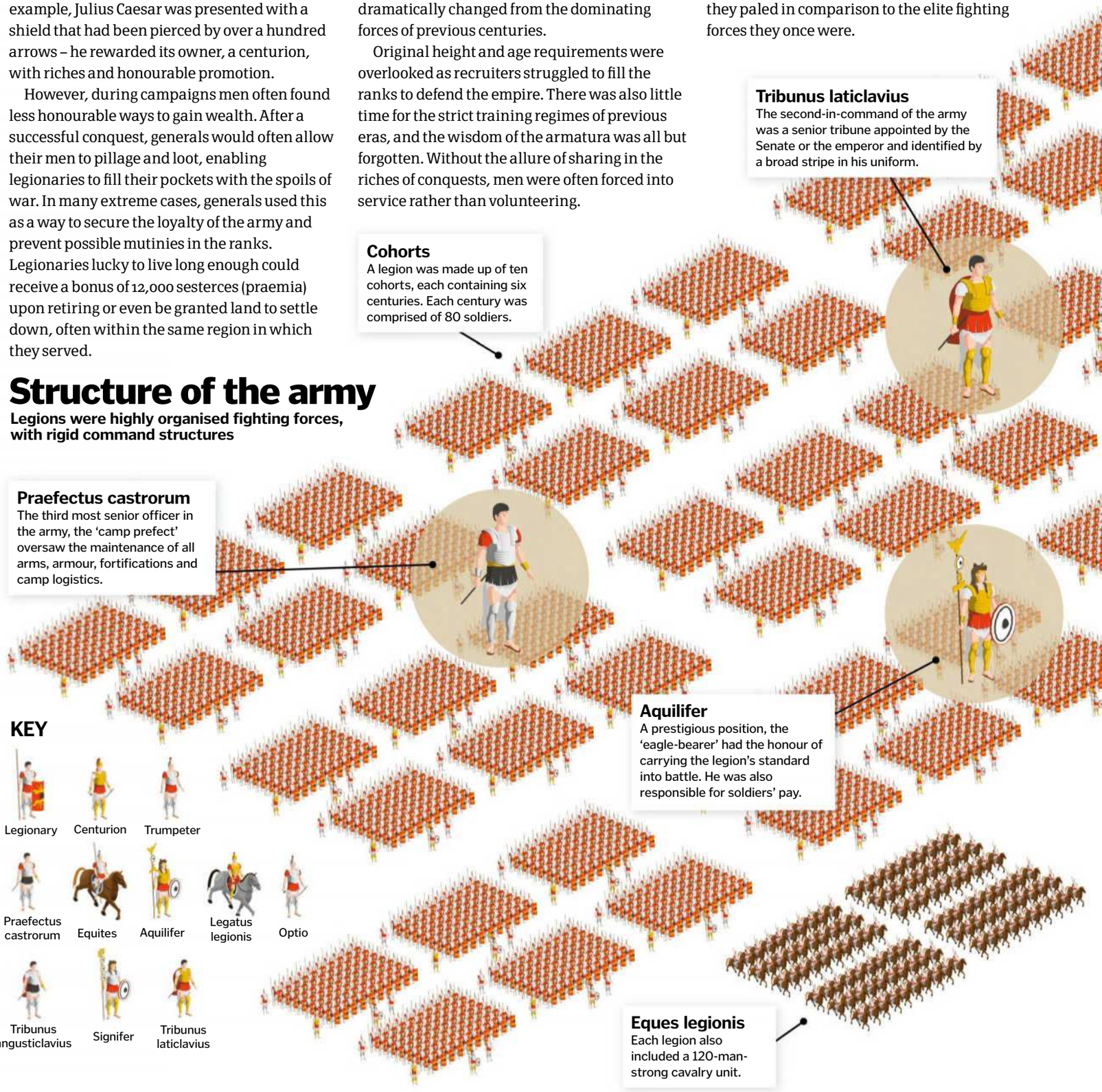
Towards the middle of the 4th century CE, the Roman Empire was past the height of its power, and several fearsome tribes – Goths, Vandals, Huns and others – began threatening its borders. Armies garrisoned at the furthest edges of imperial territory, such as in Britain, were marched back down the roads to defend Roman heartlands. By this period the legions had dramatically changed from the dominating forces of previous centuries.

Original height and age requirements were overlooked as recruiters struggled to fill the ranks to defend the empire. There was also little time for the strict training regimes of previous eras, and the wisdom of the armatura was all but forgotten. Without the allure of sharing in the riches of conquests, men were often forced into service rather than volunteering.

By this time, non-citizens were no longer prevented from becoming legionaries, while Roman citizens were also as likely to join auxiliary units. This meant that Rome's armies were no longer filled with men from the regions close to Rome itself but from among so-called 'barbarian' territories conquered by the empire, some even from beyond its borders. Although these new legions did achieve some victories, they paled in comparison to the elite fighting forces they once were.

Structure of the army

Legions were highly organised fighting forces, with rigid command structures

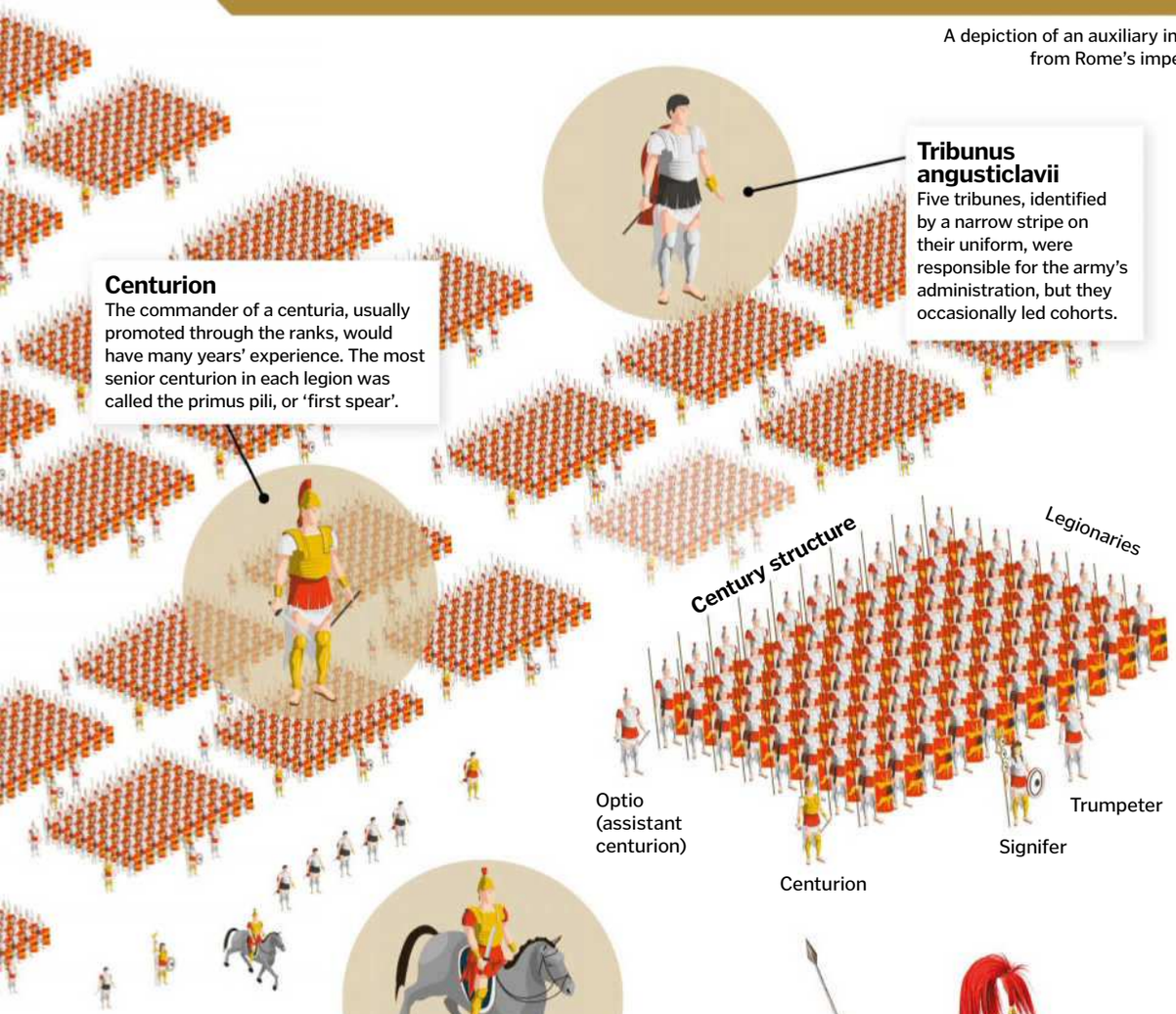


Auxiliaries

Although heavy infantry formed the backbone of Roman armies, specialist troops such as archers, slingers and cavalrymen were also crucial on the battlefield. These units were largely recruited from conquered territories, such as Gaul, Greece, Germania and Britain. Archers from Crete, for instance, were renowned for their skill with the bow, while German cavalrymen proved instrumental during Caesar's conquest of the Gauls in 58–50 BCE.

While auxiliary units were often raised and disbanded to meet the needs of a legion, the Romans became increasingly reliant on them. Unlike their legionary comrades, these men were not considered Roman citizens, but citizenship could be earned through lengthy service. As the empire began to decline, auxiliary and legionary units became almost indistinguishable. Eventually, non-citizens were widely recruited to help defend Roman territory.

A depiction of an auxiliary infantryman from Rome's imperial period



Tribunus angusticlavii
Five tribunes, identified by a narrow stripe on their uniform, were responsible for the army's administration, but they occasionally led cohorts.

Centurion
The commander of a centuria, usually promoted through the ranks, would have many years' experience. The most senior centurion in each legion was called the primus pili, or 'first spear'.

Legatus legionis
The overall commander of the legion, the legionary legate was usually a former politician, appointed directly by the emperor or Senate.

Galea
Usually made of bronze, the helmet protected against attacks to the wearer's head, neck and face.

Pilum
Measuring up to 2m long, the metal barb of these javelins was designed to bend upon impact.

Gladius
These short iron blades were the primary weapon for Rome's infantry, designed for thrusting and stabbing.

Scutum
These large, rectangular shields protected much of the body from the neck down.

Below: a reenactment shows a centuria on the march, led by a centurion, signifiers and a trumpeter

ROMAN LEGION RECRUITMENT REQUIREMENTS

1 Citizenship
Only a citizen of Rome could become a legionary. Freed or current slaves were not permitted to join, although this rule was relaxed as the needs of the army changed.

2 Height
Recruits were expected to be a minimum height of 1.72 metres, though for some roles even taller men were required. Even so, it is thought that this rule was not always strictly followed by recruiters.

3 Age
Boys as young as 17 could join the ranks, and men generally aged anywhere up to their mid-20s would be accepted. In desperate times, this maximum age was extended to 35.

4 Education
Although the ordinary soldier did not need any education, those wishing to gain officer posts needed basic numeracy and literacy skills.

5 Strength
Most important was the recruit's health, stamina, eyesight and strength. Soldiers incapable of carrying out the highly physical tasks demanded of them were often discharged from the army.

Arms and armour

Roman soldiers were equipped with the best weapons and protection of the period

The Alhambra of Granada

As a beautiful example of Islamic architecture, the Alhambra is one of the last reminders of a powerful dynasty

Sitting on a hilltop in southern Spain is a fortress fit for an Islamic king. From 711 CE, Islamic Moors migrated across the Strait of Gibraltar from northern Africa and settled across the Iberian Peninsula. By 720 CE, most of Spain and Portugal was under Moorish control, ruled from the southern region known as Al-Andalus (from which the modern region of Andalucia takes its name). The Alhambra of Granada became that territory's capital and housed royalty for centuries.

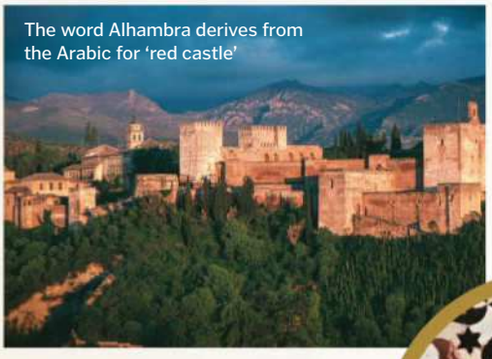
It was originally constructed from the remains of a fort built by the first kings of Granada, but during the 13th and 14th centuries the founder of the Nasrid dynasty, Muhammad Al-Ahmar (and his successors), began transforming the Alhambra into a grand fortification. The site contained three main palaces: the Comares Palace, the Palace of the Lions and the Partal Palace. The Comares Palace, surrounding the Court of the Myrtles, was the main residence for the sultan and enjoyed views of the Darro river valley. All of the palaces and royal gardens are surrounded by a grand 1,730-metre-long wall, headed by a formidable military base known as the Alcazaba.

The Iberian kingdom that the Moors had built fell during the Reconquista (Christian reconquest) in 1492. The Alhambra was taken by the Christian forces of the Holy Roman Emperor Charles V. Following his victory, Charles ordered the destruction of part of the fortress to make room for the construction of his own palace at the site, which incorporated Renaissance and Roman decoration.

The Alhambra was abandoned during the 18th century, and much of it was destroyed during the French occupation of Granada during the Peninsular War of 1808–1814 . It wasn't until the 19th century that efforts were made to repair and restore the fortress.

Today, the Alhambra is one of the most visited tourist spots in Spain, with over 2.4 million people walking through its fortress gates in 2014.

Alcazaba
This was the military base for the fortress, offering defensive support during sieges.



The word Alhambra derives from the Arabic for 'red castle'

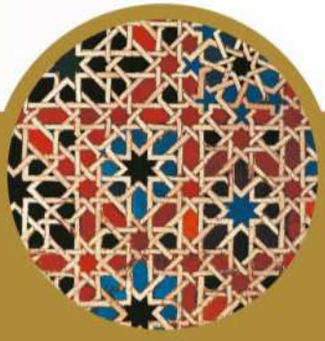
A Moorish architectual marvel

The Alhambra combines Medieval majesty with intricate design to create a fortress fit for a king

Painting with numbers

As with any royal palace, the interior decoration is something to take your breath away. However, the decoration in the Alhambra is not only stunning but mathematically inspired. Along with scripture from the Quran, tessellations and infinite geometric patterns are the main design themes featured in the palaces and surrounding buildings.

In order to create these intricate tile designs, artists used the endless possibilities that can come from tessellations – patterns that when designed individually can connect with a copy perfectly.



This colourful geometric design is almost an optical illusion. These patterns are intricately woven, making it very difficult to discern where one single line begins and ends.

As part of the Islamic faith, it is forbidden to decorate with figures of animals or faces. Instead, scripture is used as decoration throughout the palaces.

Court of the Myrtles
Named after the dense shrubbery myrtle, this courtyard houses a length of water, which contrasts against the adjacent structures.

The Golden Room
This grand room was decorated in painted woodwork and was where the sultan of the palace would meet with subordinates.

Court of the Lions
As a symbol of wealth and functionality, a fountain sits at the centre surrounded by statues of lions.

Palace of Yusuf III
After the conquest of Granada, this palace was home to the Count of Tendilla before being demolished by order of Philip V around 1718.

Palace of Charles V
After taking control of the Alhambra, Charles V commissioned his own Roman-style palace in 1526.

St. Mary Church
Completed in the 17th century, this church was built where the previous mosque had once stood.

Gate of Justice
This is the largest of the four gates in the Alhambra walls and originally displayed hand-carved Islamic symbols and scripture.

The Generalife

After dealing with the daily demands of being royalty, kings of Granada throughout their reign would retreat to the lush gardens of the Generalife. The neighbouring palace was also built in the 13th century, however, after Christian crusaders evicted the Moors from the area, this palace has faced many Roman-inspired alterations. The Patio de la Acequia (Patio of the Irrigation Ditch) connects the two modest buildings that make up the palace. Water from the irrigation ditch at Alhambra flows into the canal that splits the courtyard. It is said that the king who created the gardens did so in the image of what he believed paradise to look like.

A plan of the Alhambra fortress, circa 1770

The phonetic alphabet

Decoding the ingenious communication system from Alfa to Zulu

A phonetic alphabet ensures military messages are understood

When communicating a message in a warzone, one mistake can be the difference between life and death. To ensure accuracy, letters of the alphabet were substituted for a standard set of words. None of them sounded alike, eliminating the risk of mixed messages. The only problem was agreeing on which words to use.

In the 1920s, the International Telegraph Union developed the first phonetic alphabet to be recognised around the world, using the names of cities. But the US military had its own version, the Able Baker, which featured words like King and Queen and was swiftly adopted by the British Royal Air Force. The International Civil Aviation Organization (IACO) had yet another system.

In need of a universal alphabet, the US and UK, both members of the North Atlantic Treaty Organization (NATO), conducted a review. They proposed to change a few words of IACO's system, and eventually, after a squabble over Nectar versus November was settled, the NATO Alphabet came into force in 1956. Adopted globally, it is now the official system for military, civilian and radio communications.

A	B	C	D	E	F	G
Alfa	**B**ravo	**C**harlie	**D**elta	**E**cho	**F**oxtrot	**G**olf
H	I	J	K	L	M	N
Hotel	**I**ndia	**J**uliett	**K**ilo	**L**ima	**M**ike	**N**ovember
O	P	Q	R	S	T	U
Oscar	**P**apa	**Q**uebec	**R**omeo	**S**ierra	**T**ango	**U**niform
	V	W	X	Y	Z	
	Victor	**W**hiskey	**X**-ray	**Y**ankee	**Z**ulu	

Daylight Saving Time

Why clocks spring forward and fall back depending on the season

It was early one summer morning in 1905 when a British builder by the name of William Willett was horseback riding. To his dismay, every house he passed had the curtains drawn. Aghast at such a waste of time, he published a pamphlet proposing that clocks be set ahead of standard time during the summer. However, he wasn't the first to come to this conclusion. In 1895, New Zealander George Hunter suggested a similar practice, and ancient civilisations were time-shifting even longer before that.

A year after Willett's death, Daylight Saving Time (DST) came into effect. During World War I, Germany turned its clocks ahead by one hour on 30 April 1916 to maximise natural light and conserve fuel. Shortly after, the UK, France, the US and other countries followed suit, but when the war was over DST fell in and out of favour as the arguments for and against it were never definitive. More than 140 countries have introduced it at some point, but only around 70 use a form of DST today.

The main purpose of Daylight Saving Time is to make better use of natural light

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BRAIN DUMP

Because enquiring minds need to know...

MEET THE EXPERTS

Who's answering your questions this month?

Laura Mears

Laura studied biomedical science at King's College London and has a research master's from Cambridge. She escaped the lab to write about science, and is now working towards a PhD in computational evolution.

Alexandra Franklin-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 published his first book, *Electronic Dreams: How 1980s Britain Learned To Love The Home Computer,* in 2016.

Katy Sheen

Katy studied genetics at university and is a former **How It Works** team member. She now works for a biomedical journal, where she enjoys learning about the brilliant and bizarre science of the human body.

Joanna Stass

Having been a writer and editor for a number of years, **How It Works** alumnus Jo has picked up plenty of fascinating facts. She is particularly interested in natural world wonders, innovations in technology and adorable animals.

The internet of things will connect many everyday devices to make life more convenient

What is the 'internet of things'?

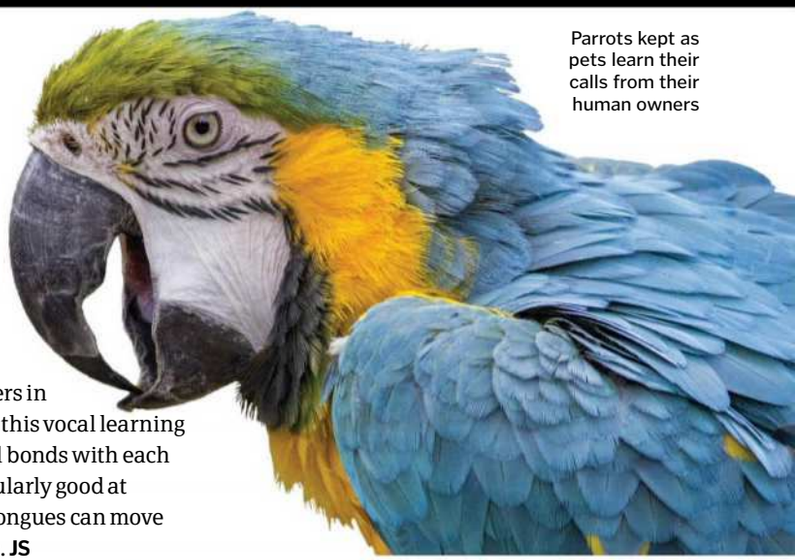
Jenny Aldridge

The internet of things (IOT) is the networking of different sorts of electronic devices through the internet, allowing them to collect data and communicate. For example, at home, Wi-Fi light bulbs can be controlled by a smart phone; in factories, faulty machines can automatically request an engineer; sensors in farmland can alert farmers to when more fertiliser is needed. However, while the IOT can make life more convenient and efficient, many worry about its negative implications. For example, electronic ID badges can let companies monitor their employees, enabling them to order them to work harder and spy on how long they take for coffee breaks. **TL**

Why can parrots talk?

Moira Jones

The noises made by most birds are hard-wired into their brains, but three types of birds – hummingbirds, songbirds and parrots – are capable of learning new vocalisations. Scientists believe that clusters in the birds' brains called song nuclei enable this vocal learning and that it helps them to form strong social bonds with each other and their owners. Parrots are particularly good at mimicking human speech because their tongues can move around to make human-like vowel sounds. **JS**



Parrots kept as pets learn their calls from their human owners

Want answers? Send your questions to...

How It Works magazine | @HowItWorksmag | howitworks@futurenet.com

Google Glass is becoming a useful tool for displaying vital information to workers

Whatever happened to Google Glass?

Tracey Kendall

The first version of Google Glass was withdrawn in 2015, but Google didn't scrap the project. Smart-glasses hadn't caught on with the public, but many organisations had found uses for them. Google secretly worked with these partners to find new ways of using the technology in workplaces, such as factories, warehouses and hospitals. This turned smart-glasses from a novelty into a useful tool, and they were relaunched for businesses in 2017 as the Google Glass Enterprise Edition. **TL**

Swirling gas makes up the colours and patterns of Jupiter's distinctive bands

Why does Jupiter have bands of colour?

Michael Sherman

Earth is mainly rock with just a thin film of atmosphere, but Jupiter is a gas giant. The layers that we can see are mainly hydrogen and helium gas, which become liquid deep below the clouds. Parts of the gas are different temperatures, contain different chemicals and move in different directions. This creates the bands. Known as zones and belts, the stripes represent areas where the gas is moving up and down respectively. **LM**

Who invented the bagpipes?

Virginia Burns

Bagpipes are generally thought to have originated in the Middle East thousands of years ago. While no one knows for sure who invented the bagpipes, they almost certainly weren't Scottish. TL

What's the origin of the legend of King Arthur?

Andy Zachs

It's unknown whether King Arthur really existed, but some historians think he was a British general from the 6th century, not a king. As people retold stories about him over the centuries they mixed in other events, creating the Arthurian legend. TL

Could a nuclear weapon destroy an asteroid?

Chris Lockwood

Researchers are looking into it. Detonating a weapon nearby could vaporise the surface, giving off gas that would deflect the asteroid. But there's a risk it might blow into chunks, showering the Earth in debris. LM

Why do kangaroos box?

Ian Smith

Boxing is a way for male kangaroos to decide who should be in charge. They live in large groups called mobs with a single male leader. He's known as the 'boomer'. Boxing also secures the leader exclusive access to the females of the mob. LM

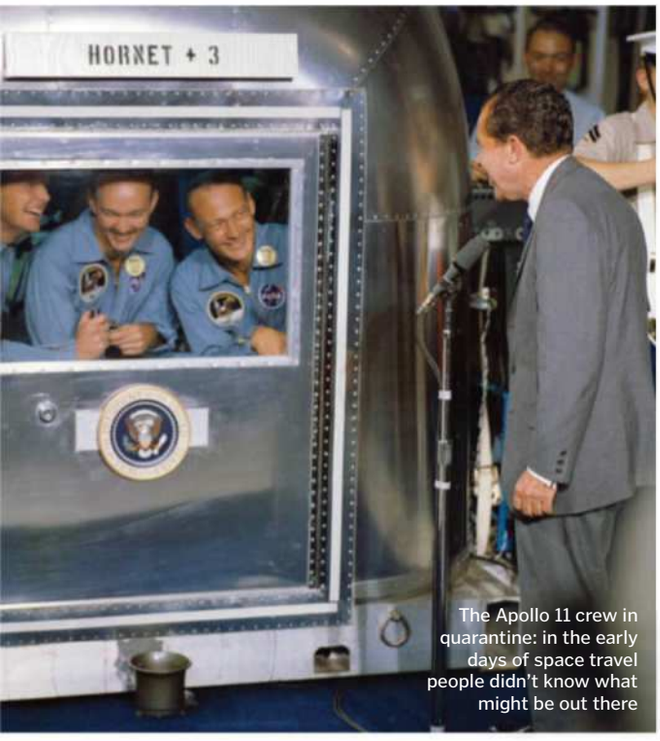
BRAIN DUMP

Why do prisms split light?

Amanda Alexander

■ Prisms refract different wavelengths of light at slightly different angles, causing white light to separate out into its constituent colours. As light enters a glass prism at an angle its speed and direction change because light travels more slowly through glass than air. This bending of light is known as refraction. Each wavelength (or colour) of light is refracted differently, with violet light bending the most and red light the least, producing a rainbow. **AFC**

Newton was the first to explain why prisms disperse white light into its constituent colours



The Apollo 11 crew in quarantine: in the early days of space travel people didn't know what might be out there

Do astronauts still have to be quarantined when they return to Earth?

Debbie Swanson

■ No one knew what to expect when humans first visited the Moon. People thought that astronauts might return to Earth with new diseases. So when the astronauts from Apollo 11, 12 and 14 came home they went into isolation for three weeks. This gave doctors and scientists time to check them for signs of infection. It soon became clear that there weren't any microbes living on the Moon, so there was no need to quarantine astronauts when they arrived home. However, today they still go through a period of quarantine *before* they travel. This helps to make sure they are free from infection so that they don't become sick during their mission. **LM**

Why did New Amsterdam change its name to New York?

Vincent Evans

The Dutch settlement of New Amsterdam was captured by an English naval squadron in 1664 and renamed New York in honour of the Duke of York (later James II of England), who organised the mission. JS

Why do fizzy drinks go flat?

Flynn Cogburn

Fizzy drinks are made by dissolving carbon dioxide into liquid at high pressure. When you open the can or bottle you cause that pressure to decrease, which then causes the carbon dioxide to escape in bubbles that float to the top and burst. JS

What is the difference between hair and fur?

Jacky Perez

Hair and fur are both made of keratin, and there is no chemical difference between them – we just tend to use the term 'hair' for humans and 'fur' for animals. KS

Why do we get chapped lips?

Marianna Spinelli

Lips get dry and chapped when they lose moisture by evaporation, which can happen in hot, windy or cold weather. The skin covering the lips gets tight and starts to split. Licking your lips can make this worse as you remove the thin layer of natural grease that locks in moisture. KS

Dark chocolate contains more cocoa solids to create its bitter taste

What is the difference between milk, plain and dark chocolate?

Kelly Olson

Dark and milk chocolate both contain cocoa solids, cocoa butter and sugar, but as its name suggests, milk chocolate also contains milk in the form of milk powder, liquid milk or condensed milk. In the US, chocolate must be at least 15 per cent cocoa solids to be labelled dark, while milk chocolate must be at least ten per cent cocoa solids and 12 per cent milk. In the UK, dark chocolate must be at least 35 per cent cocoa solids and milk chocolate must be at least 20 per cent cocoa solids and 3.5 per cent milk. Plain chocolate is just another name for dark chocolate: they have the same ingredients. **JS**

How do freezers stay so cold?

Shawn Fox

Inside a freezer, a liquid known as a coolant is pumped around in a closed loop and made to expand, causing the temperature to drop. As a liquid or gas' volume increases the kinetic energy carried by its molecules is spread over a larger space and its temperature therefore falls. As the coolant enters the freezer cabinet it passes through an expansion valve, causing it to cool and absorb heat from inside the freezer. Upon exiting it travels through thin pipes, allowing it to release heat to the outside and condense before the process is repeated. **AFC**

How do memory foam mattresses 'remember' their shape?

Ben Thomson

Memory foam is a viscoelastic foam: its viscosity means it deforms when pressure is applied before slowly returning to its shape thanks to its elastic properties. Memory foam can take up to ten seconds to spring back, giving it a brief 'memory' of your shape after you lie on it. **AFC**

Why are so many pubs called The King's Head or The King's Arms?

Kate Gale

In 1393, King Richard II ordered pubs in England to hang signs outside their premises to make them easier to identify. As literacy levels were low, most signs included pictures, which would end up giving the pubs their names. In order to pledge their allegiance to their king, many pubs displayed the royal emblem, or 'arms', on the sign, thus becoming known as The King's Arms. Others showed a portrait of the monarch himself and were therefore named The King's Head. **KS**

Why are crows attracted to shiny things?

Ryan Fernandez

It is actually a myth that crows or magpies collect shiny objects like keys or pieces of jewellery. Wild adult crows will never collect, hide or store anything other than items of food. Young crows are investigative and curious, so they like to handle objects, peck at them and sometimes hide them. In captivity, this would include any small objects, and shiny ones may catch their eye more than dull ones. This is probably how stories of crows stashing shiny objects came about. However, in the wild, young crows play with natural objects like acorn caps or stones. **KS**

Crows have an unfair reputation for stealing shiny objects

BOOK REVIEWS

The latest releases for curious minds

Destination: Planet Earth

A voyage of discovery around the world in which we live

- Author: **Jo Nelson & Tom Clohosy Cole**
- Publisher: **Wide Eyed Editions**
- Price: **£12.99 / $19.99**
- Release date: **Out now**

The most striking part of this worldwide tour is without doubt Tom Clohosy Cole's stunning illustrations, which greet you as you turn every page. The wonderful images will certainly grab the attention and interest of younger readers, giving them plenty to look at as they learn about the world they live in. The well-considered use of colours and charming characters will also keep them reading just to see where the adventure goes next. To be honest, the book is worth a look for the illustrations alone. But they aren't alone – not by any means.

Jo Nelson brings accessible and interesting science to this book as we zoom around the world, fly up into the atmosphere and dig down into the earth under our feet. Starting with an explanation about what the continents are and how they were formed, we learn how different maps can show different information and how the world is changing so slowly we can't see it. We then move on to latitude and longitude, then the poles, the equator, mountains, seas and far beyond.

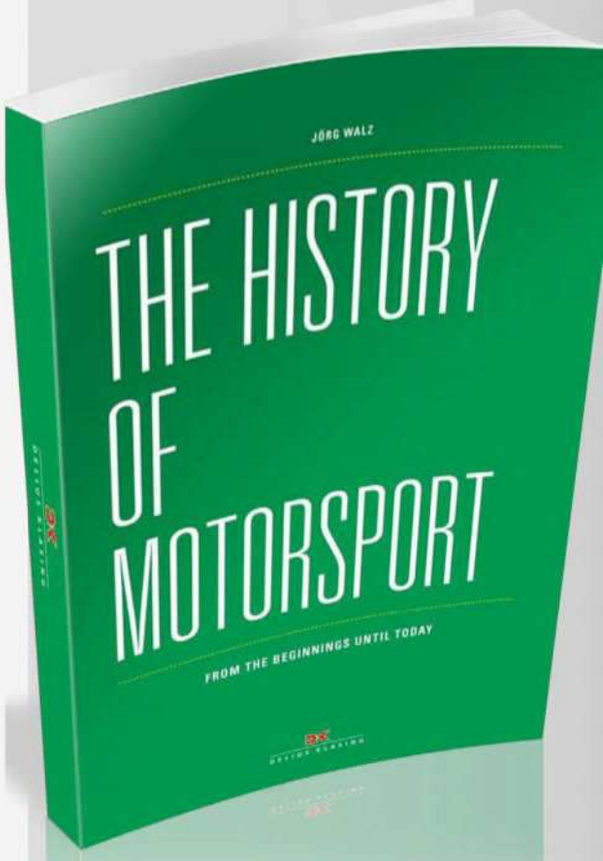
Along the way each topic is explained – often rather briefly but with useful details. It's likely that older readers will want more knowledge – the information provided here is kept relatively brief, which will be great for younger kids with shorter attention spans but may frustrate those looking for more comprehensive detail. Still, this means that the pace of this book remains quick throughout and those beautiful images have more room to breathe.

Topics like earthquakes and volcanoes will undoubtedly be popular, but the book also makes a point of covering important subjects such as the impact humans are having on the planet and how global warming is affecting the world. While the end of the book covers issues like deforestation and pollution, it also includes a positive note explaining how we can save the Earth in small ways, like walking instead of driving, or putting on jumpers rather than turning up the heating.

It's an apt end to a book that brilliantly shows the importance and beauty of the world around us. Some readers may want more information on certain topics, but if the worst it does is inspire further learning then it's a clear success.

★★★★★

"The end of the book includes a note on how to save Earth"



The History of Motorsport

In pole position

- Author: **Jörg Walz**
- Publisher: **Delius Klasing Verlag**
- Price: **£30 / $45**
- Release date: **Out now**

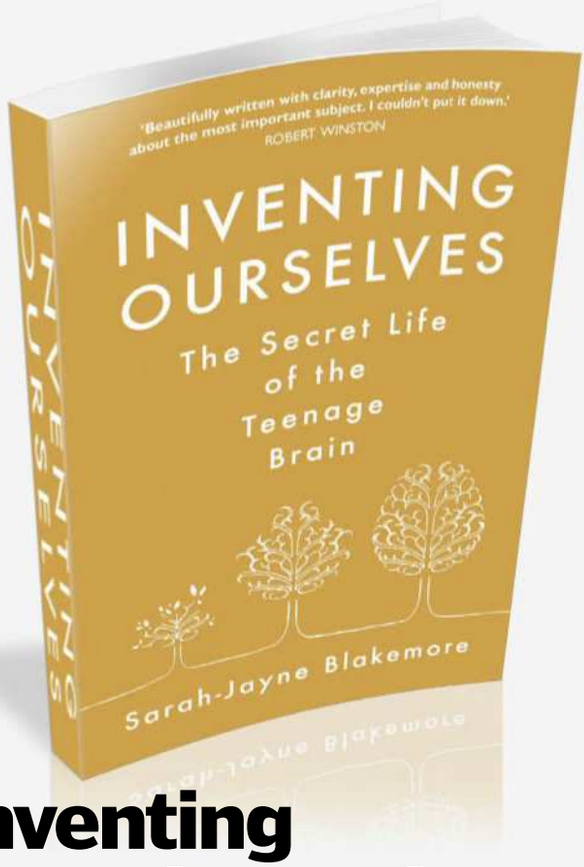
The magnitude of the task taken on by author Jörg Walz cannot be understated. The history of motorsport? In all of its many forms? Now that is a very tricky proposition by any measure.

Understandably, therefore, he hasn't gone for a full chronology. Rather, Walz generally devotes a page or two to each year, usually focusing on a particular theme or event, beginning in 1894 with the first ever international automobile race (the 126-kilometre Paris–Rouen) before encompassing the German Grand Prix of 1935, Ferrari's renaissance in 1976 and Williams-Renault's F1 dominance of 1992.

Walz then moves on to the more recent introduction of the Formula E season for electric cars. Fittingly, progress in motorsport is anything but slow.

This book may not be the trivia-infused speed-freak bible that some might have been after, but it doesn't pretend to be. Instead, it's pitched as a coffee table read to delve into, one momentous year at a time, and you can't argue with the results.

★★★★☆



Inventing Ourselves: The Secret Life of the Teenage Brain

Teenage kicks

- Author: **Sarah-Jayne Blakemore**
- Publisher: **Doubleday**
- Price: **£20 / $27**
- Release date: **Out now (UK) / 15 May (US)**

You'll often hear parents complain about how they can't understand their teenagers, which comes across as hugely patronising if you're a teenager yourself. Even so, it can't be denied that the adolescent years are ones of turmoil, with hormones and rites of passages colliding in one chaotic mash of growing pains.

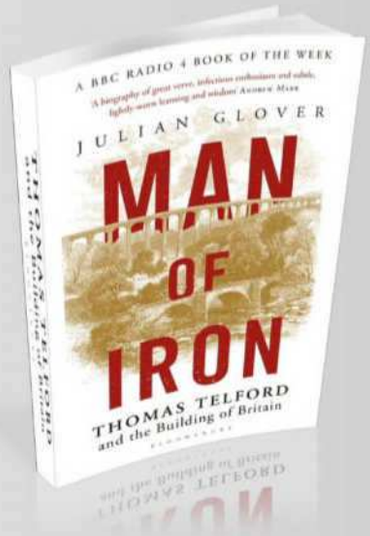
Aimed arguably more at adults than kids themselves, Sarah-Jayne Blakemore's *Inventing Ourselves* attempts to delve deep into the adolescent psyche, looking at exactly why this is often such a tumultuous time in our lives, using both anecdotal and research-focused data to provide a background.

As a professor in cognitive neuroscience at UCL, Blakemore's credentials are on show here, and she channels them into understanding a demographic that many adults have lamented as impossible to fathom.

This is probably more of note to academics looking at wider material, but it's still recommended for people looking to gain a deeper understanding of others – or even of themselves.

★★★★☆

"As a professor of cognitive neuroscience, Blakemore's credentials are on show"



Man of Iron: Thomas Telford and the Building of Britain

The master builder

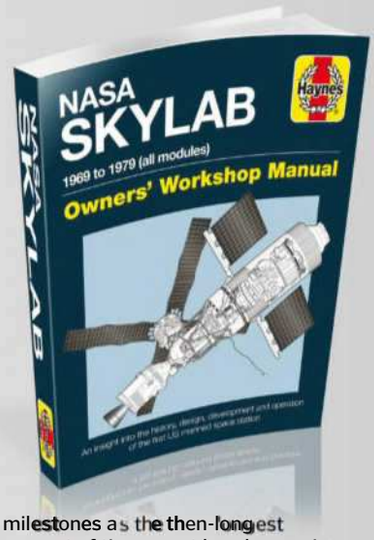
- Author: **Julian Glover**
- Publisher: **Bloomsbury**
- Price: **£10.99 / $30**
- Release date: **Out now**

Thomas Telford may well be the most influential man you've probably never heard of. Over his 77 years he helped to shape the nation via his design and construction of numerous roads, bridges, canals, harbours and more besides, many of which have stood the test of time, as does the story of his intriguing life.

The urge to uncover the man behind the legend is consistently irresistible, and again this proves to be the case here. From his poverty-stricken upbringing in Dumfriesshire in southern Scotland to fascinating accounts of the go-getting nature that would facilitate his meteoric rise to greatness, the case for regarding Telford as one of the greatest Britons in history is firmly established once more in this book.

For proof of his brilliance (as if it were required), why not visit the likes of his Lothian Bridge, the Menai Suspension Bridge or one of his 'Telford churches' – or indeed the town itself? It's but a taster of this man's impact; for more, you'll have to read this book.

★★★★★



NASA Skylab Owners' Workshop Manual

Space, as we now know it

- Author: **David Baker**
- Publisher: **Haynes**
- Price: **£22.99 / $36.95**
- Release date: **Out now**

NASA Skylab, we hardly knew thee. Luckily, those purveyors of lovingly compiled and intricately detailed mini tomes at Haynes are on hand to change that – should you need assistance – with their latest handbook, which tells in detail the story of the relatively short life of the United States' first, and to date, only space station.

Having launched in 1973 before coming crashing down to Earth (literally) in 1979, its life may have been brief but its significance and relevance remains. Discovering such milestones as the then-longest amount of time spent by a human in space (84 days) and the largest-scale repair job ever completed outside Earth (the deployment of a replacement heat shield), you'll likely gain a new appreciation for it.

We may sound like a broken record at this point, but when Haynes decide to tackle something with such a rich and evocative subject matter the results are always a sight to behold, and so it has proved yet again with this latest offering.

★★★★★

BRAIN GYM

GIVE YOUR BRAIN A PUZZLE WORKOUT

Wordsearch

B	M	V	T	M	K	N	O	I	G	E	L	O	F	T
Y	O	S	Q	J	A	H	F	Z	L	T	P	N	A	D
S	N	R	E	O	C	R	I	S	P	R	Q	F	L	Z
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P	X	E	P	L	T	O	K	O	L	L	K	R	P	O
I	S	J	O	O	R	A	G	N	A	K	B	S	H	M

FIND THE FOLLOWING WORDS...

ARTIST
CHIRON
CRISPR
FALCON
GEMS
GENES
JUMPSTART
KANGAROO
LEGION
LILYPAD
MARATHON
MONSOON
NATO
PALMOIL
ROBOCOP
ROCKETS
SEAWEED
SPEED

Quickfire questions

Q1 When and where was the first Women's Day celebrated?

- 1909, New York
- 1990, Moscow
- 1991, Berlin
- 1999, London

Q2 Seaweeds are types of _____

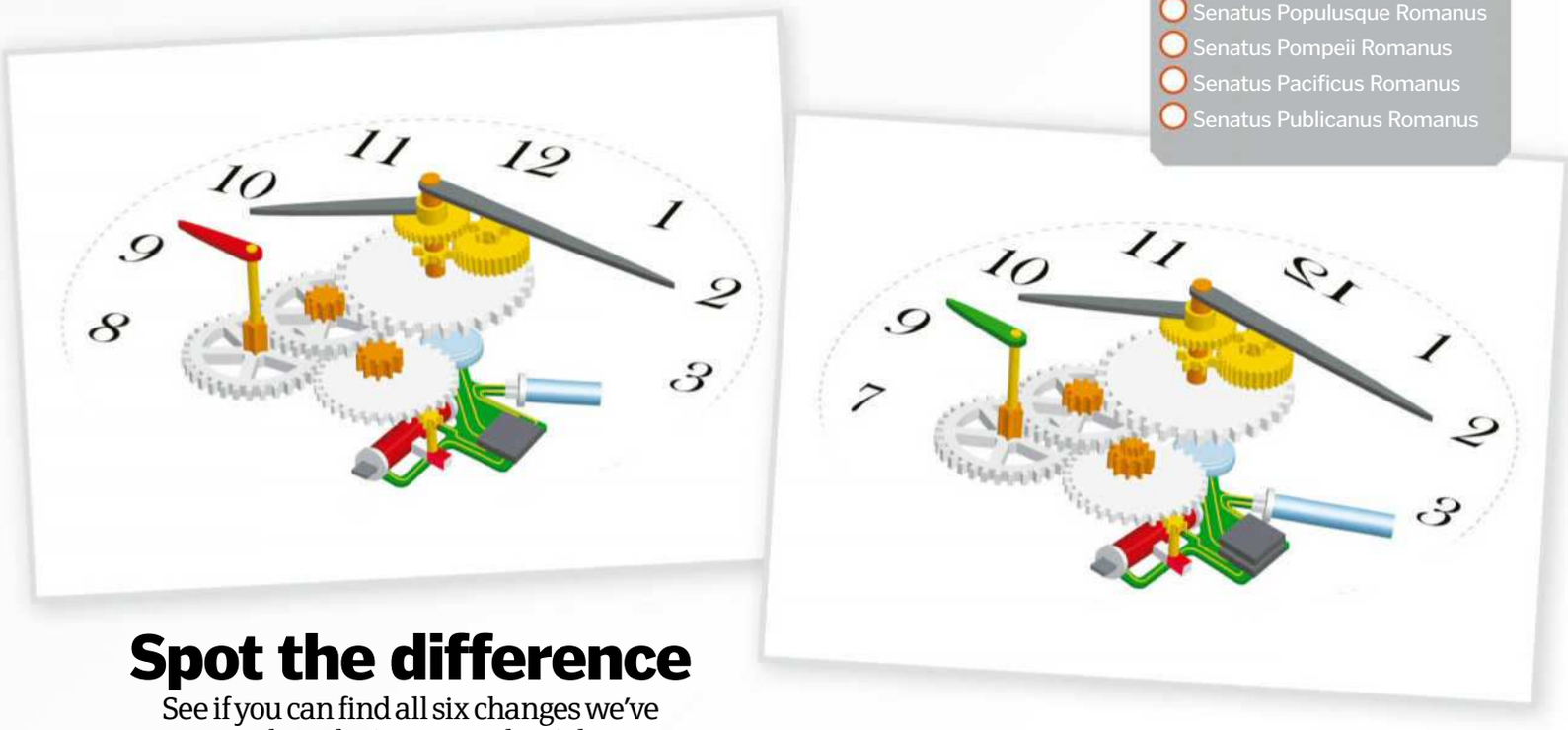
- Phytoplankton
- Algae
- Cabbages
- Lettuces

Q3 CRISPR stands for: Clustered Regularly Interspaced Short Palindromic _____?

- Receipts
- Reliefs
- Retreats
- Repeats

Q4 SPQR is short for what Roman phrase?

- Senatus Populusque Romanus
- Senatus Pompeii Romanus
- Senatus Pacificus Romanus
- Senatus Publicanus Romanus



Spot the difference

See if you can find all six changes we've made to the image on the right

Sudoku

Complete the grid so that each row, column and 3x3 box contains the numbers 1 to 9. See if you can beat the team!

EASY

5		9	1	2				
	3		4	8	7		9	5
8		6	3	5				
6	8		2			9		1
	5	2		3	1	7		
	1	7			8	3	2	4
	2		8	9	5			
	9		6			5	4	
				4		8		

DIFFICULT

7			3					9
					1	2	4	
6		2				7	5	
	1	7		3	5	6		
4			6				9	
	2							8
								7
		5			4	9		
			5					6

What is it?

A .....

▶ Visit our website at **www.howitworksdaily.com** to check your answers!

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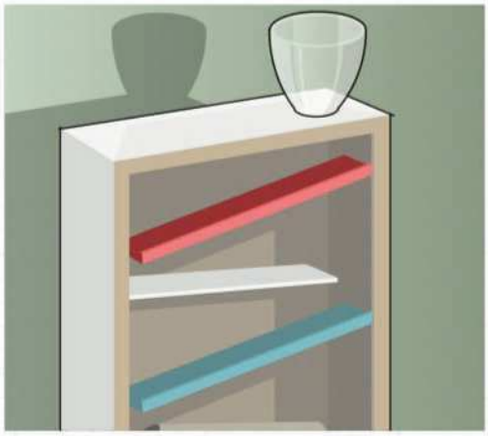
DON'T DO IT ALONE
IF YOU'RE UNDER 18, MAKE SURE YOU HAVE AN ADULT WITH YOU

Make a marble run

Beat our timed challenge by building the ultimate marble run!



1 Create the box

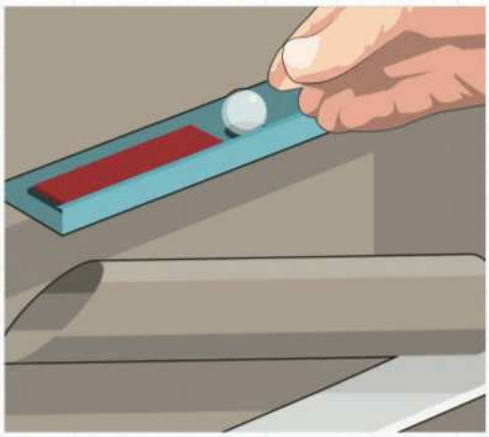
First you will need to find a cereal box no more than 60 centimetres high and 40 centimetres wide. Close the top of the box and seal it tightly with tape, then carefully cut the front off the box to create what will look like a tray. If you don't have a cereal box the right size you could alternatively cut pieces of corrugated card to the right size and glue them together.

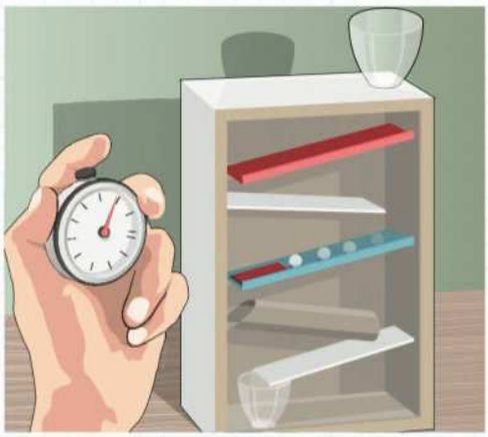
2 Add a funnel

Next you will need to make a stand for the back of your box in order to hold it at a slight angle – this will ensure that your marble keeps rolling down your run. Now carefully cut the top off a plastic bottle and cut a circular hole in the top of your box so that the top part of the bottle can slot into it, like a funnel. This is where you will place the marble.

3 Form the run

Now the challenge is to get the marble to travel from the top of the box to the bottom in as close to ten seconds as possible. To do this you will need to make a track down the box for the marvel to follow. Cut strips of card, kitchen rolls and more funnels to create a run, then try out each section by taping it with masking tape before glueing it on.





4 Adjust your run

If the marble is travelling too fast down certain sections, try using different surfaces on the strips within your run to see if they slow it down at all. You can stick sandpaper in, for example, or add some small bumps of card to slow it a little. You could also try adjusting the angle of some of your strips of card too – does that make any difference?

5 Time your run

To complete your run, carefully cut off the bottom of a plastic bottle and place it at the bottom of the box to make a marble catcher. Now get a stopwatch and time how long it takes for the marble to get from the top of the box to the bottom. How close were you to ten seconds? If it's too fast, or too slow, try adjusting your run again to see if this improves the time.

"Get a stopwatch and time how long it takes the marble to get to the bottom"

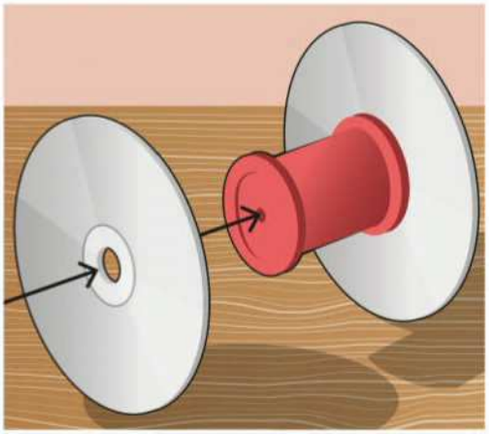
In summary...

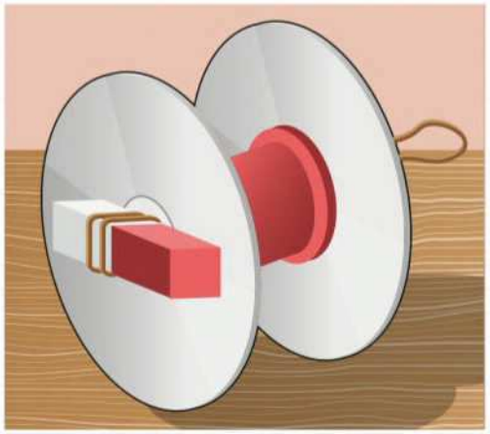
Gravity pulls the marble down the run. If you let it fall freely, it would take less than a second to hit the bottom. By adding strips of card you are making it travel further, stop and change direction, therefore slowing it down. Rough or bumpy materials will make it even slower.

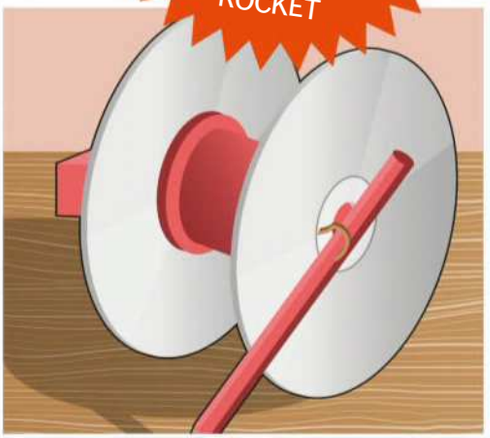
Create a CD racer

Use kinetic energy to power a racer with some simple materials

NEXT ISSUE
CREATE BALANCING GYMNASTS
MAKE A STOMP ROCKET







1 Make your wheels
First you need to create your wheels. For this you'll need two CDs and a cotton reel. Remove any paper from the ends of the reel, and use some sandpaper to roughen up the middle of the two CDs – this will help the glue to stick. Place some glue on one end of the cotton reel and stick it onto the middle of the CD. Make sure the holes in the middle are lined up and aren't blocked by glue. Do the same with the other CD at the other end.

2 Make a loop
Once the glue is dry you need to feed a rubber band through the hole in the centre of the CDs and the reel. You can poke it through with a thin wooden skewer, or you can unfold a paper clip, bend one end carefully into a hook and pull the band through using that hook. Once it's through, hold onto one end of the band and loop the other end around an eraser. Pull the band through from the other side so that it's tight around the eraser.

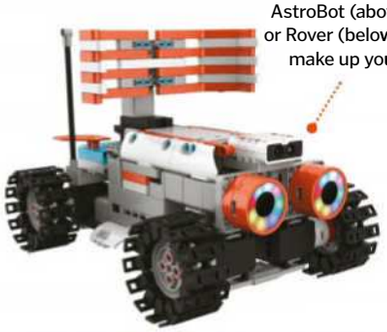
3 Add some speed!
Place a plastic or metal washer over the other end of the rubber band so that the loop pokes through, then put a pencil through the loop. Adjust the pencil so the pointed end sticks out a lot more than the other end. Now twist the pencil around to wind up your racer – make sure you hold the eraser with your other hand. Feel the increasing resistance as you turn, then put it down on a smooth surface and watch the racer go!

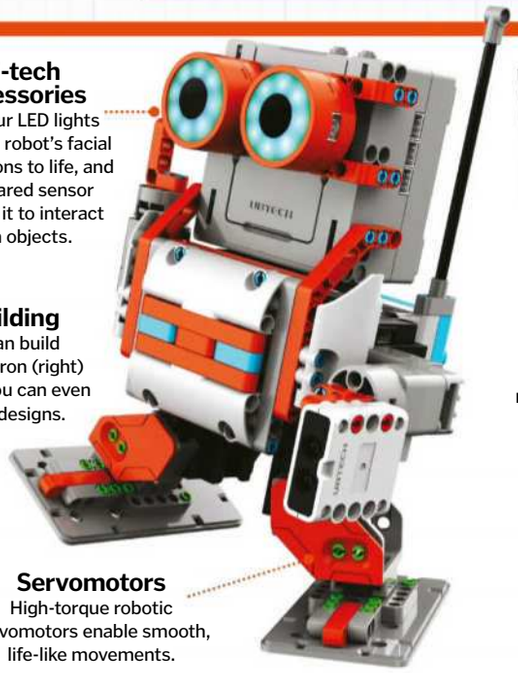
"Put it down on a smooth surface and watch the racer go!"

In summary...
When you twist the rubber band around you generate potential energy. This is converted into kinetic energy as the band unwinds, turning the eraser. This grips onto the CDs and makes them turn too, and the friction between the CDs and the floor is enough to make them move.

Hi-tech accessories
16 colour LED lights bring the robot's facial expressions to life, and an infrared sensor enables it to interact with objects.

Character building
From the kit you can build AstroBot (above), Astron (right) or Rover (below), or you can even make up your own designs.





Servomotors
High-torque robotic servomotors enable smooth, life-like movements.

WIN!

An ASTROBOT kit worth £179.95

Build and programme your very own robot with the JIMU Kit from UBTECH Robotics! This educational kit contains everything you need to construct one of three characters (or invent your own) and programme them to perform different actions via the accompanying app.

Which city introduced the world's first robot police officer in 2017?

a) **Dubai, UAE**
b) **Sydney, Australia**
c) **Buenos Aires, Argentina**

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AMAZING PRIZE FOR LETTER OF THE MONTH!
GRAPHENE
Discover the incredible properties and wide-ranging potential of graphene in this brilliant book by Les Johnson & Joseph E Meany

Letter of the Month

Bubbles in water

Hello **HIW**,
I always have water on the table by my bed overnight, but when I wake up in the morning there are always small air bubbles suspended in the water. Why is this?
Thank you,
Max Cozza

When you pour a glass of water from your tap and leave it in a glass overnight, the tiny bubbles that are formed are nitrogen and oxygen. It happens because air has been dissolved into the water, and as it warms (and the air pressure falls) it is less able to hold onto the gas, so it starts to come out as bubbles. It is a very slow version of the bubbles that form in a fizzy drink like cola.

Bubbles form where there are tiny imperfections on the glass

"It is a very slow version of the bubbles that form in a fizzy drink like cola"

Land and sea

Hi **HIW**,
We were wondering how did the sea come to Earth (Elis), and what came first: land or sea? (Boyd).
Thanks,
Elis and Boyd

Scientists aren't 100 per cent sure how the sea formed on our planet, but some think it might have arrived when huge asteroids containing vast quantities of ice hit the Earth, and that ice melted to form the oceans. As for which came first, Earth was born when bits of dust and debris clumped together about 4.54 billion years ago. This process eventually formed our planet, but young Earth was originally too hot for liquid water to survive on its surface. Once it had cooled and enough water had accumulated, the seas began to form.

There are lots of theories around the formation of land and sea, but most scientists agree that land formed first

Ear infections

Hi **HIW**,
Do you know why some children get more ear infections than others?
Ida

Bacteria are usually responsible for causing ear infections. They cause the middle ear to inflame as your body tries to kill the invading germ. Ear infections are really common in children, with about 80 per cent of under-threes having had one. Some children are more likely than others to suffer from these painful infections, and scientists think this is just a case of genetics.

Some risk factors for ear infections include being exposed to cigarette smoke or going swimming

What's happening on... social media?

To celebrate International Women's Day, we asked you which female scientists have inspired you the most and why?

"Mary Anning. Despite her gender and class, she made amazing geological/paleontology discoveries that helped develop these fields. She was the expert others came to. She helped inspire my own [v amateur!] interest in not just geology, but other scientific fields"

@GwenfarsGarden

"Cecilia Payne because she made a fantastic discovery although society was against her. She wanted to know and no matter where, she went"

@needlithium

"Austrian physicist Lise Meitner who led the team that discovered nuclear fission but was excluded from the Nobel Prize for the discovery She didn't give up even when discriminated against"

@2018Rachael

"Rosalind Franklin. Despite Crick and Watson getting all the glory for discovering DNA, their work was based on Franklin's studies #IWD2018"

@chiprocky

HOW IT WORKS

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Issue 112 on sale 17 May 2018

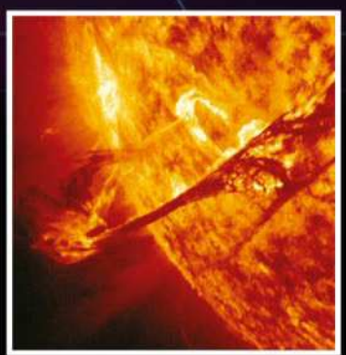
LIFE IN 2050

Discover the technological wonders that will change the world in the next few decades

+

Behind the scenes of *One Strange Rock*

The world's greatest science experiments



The dangers of space weather explained

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FAST FACTS

Amazing trivia to blow your mind

THE WORLD'S MOST ABSORBENT MATERIAL IS UPSALITE: JUST 1G HAS A SURFACE AREA OF 800M^2

LOW CANCER RATES IN JAPAN MAY BE ATTRIBUTED TO DIETARY SEAWEED, WHICH CONTAINS CANCER-FIGHTING SUBSTANCES

$450,312,500

THE AMOUNT PAID FOR *SALVATOR MUNDI* BY LEONARDO DA VINCI, THE MOST EXPENSIVE SINGLE PAINTING EVER SOLD AT AUCTION

61.9mn

NINTENDO ENTERTAINMENT SYSTEM CONSOLES WERE SOLD AFTER IT WAS RELEASED IN THE US IN 1985

OVER 52MN TONS

OF PALM OIL WAS PRODUCED BETWEEN 2016–2017

THE EDGE OF SPACE IS 118km ABOVE EARTH'S SURFACE

AT ITS PEAK, THE ROMAN ARMY HAD AROUND **500,000** SOLDIERS IN ITS RANKS

~2%

OF PEOPLE IN THE AFFECTED AREAS SEEM TO BE ABLE TO HEAR 'THE HUM' PHENOMENON

'PH' IS NOT PRONOUNCED AS 'F' IN MANY LANGUAGES, SO THE INTERNATIONAL PHONETIC ALPHABET WORD FOR 'A' IS SPELLED ALFA

THE HUMAN GENOME CONTAINS AROUND 3.2bn DNA BASES

FORMULA 1 HALO PROTECTION SYSTEMS MUST BE STRONG ENOUGH TO WITHSTAND THE WEIGHT OF A DOUBLE-DECKER BUS

A RED KANGAROO CAN LEAP UP TO **7.6M** IN A SINGLE BOUND

2hr 03m 05s THE CURRENT WORLD-RECORD TIME FOR RUNNING THE LONDON MARATHON, SET BY ELIUD KIPCHOGE OF KENYA IN 2016

TWO GREAT SHOWS TOURING THE COUNTRY!

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

David Walliams

GANGSTA GRANNY

★★★★

'TOTALLY GRANTASTIC!'
MAIL ON SUNDAY

David Walliams

AWFUL AUNTIE

LIVE ON STAGE!

★★★★

'ANOTHER HUGE DRAMATIC HIT!'
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See birminghamstage.com for tour dates!

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ENGINEERING ADVENTURE

TY86663 Bloodhound SSC Super Hauler (Length 245mm)
To accompany the new Corgi BLOODHOUND Supersonic Car we're launching this distinctive BLOODHOUND branded Super Hauler truck. The sturdy 1:64 scale truck features a detachable trailer and opening doors, and is suitable for children aged 3 and over (or older BLOODHOUND fans!).

TY81002 Bloodhound SSC UK Display Version (Length 144mm)
The BLOODHOUND Project is an international education initiative focused around a 1,000mph World Land Speed Record attempt. The jet and rocket powered BLOODHOUND Supersonic Car will streak down the 12 mile desert racetrack on the Hakskeen Pan, South Africa. The team will visit the desert twice, the first to reach 800mph and break the exciting record, the second to travel at 1000mph and inspire a generation of young people to study Science, Technology, Engineering and Mathematics (STEM).
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